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Review

The effect of pressotherapy on performance and recovery in the management of delayed onset muscle soreness: A Systematic Review and Meta-Analysis

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Abstract: Background: It has been demonstrated that pressotherapy used post-exercise (Po-E) can influence training performance, recovery, and physiological properties. This study examined the effectiveness of pressotherapy on these parameters. Methods: The systematic review and meta-analysis were performed according to PRISMA guidelines. A literature search of MEDLINE, PubMed, EBSCO, Web of Science, SPORTDiscus and ClinicalTrials has been done up to March 2021. Inclusion criteria were: randomized control trials (RCTs) or cross-over studies, mean participant age between 18-65 yrs., ≥ 1 exercise mechanical pressotherapy intervention. The risk of bias was assessed by the Cochrane risk-of-bias tool for RCT (RoB 2.0). Results: 12 studies comprised of 322 participants have been selected. The mean sample size was n = 25. Pressotherapy significantly reduce muscle soreness(Standard Mean Difference;SMD= -0.33; CI = -0.49, -0.18; $p < 0.0001$; $I^2 = 7\%$). Pressotherapy did not significantly affect jump height (SMD = -0.04; CI =-0.36, -0.29; p = 0.82). Pressotherapy did not significantly affect creatine kinase level 24-96h after DOMS induction (SMD = 0.41; CI = -0.07, 0.89; p = 0.09; $I^2 = 63\%$). Conclusions: Only moderate benefits of using pressotherapy as a recovery intervention have been observed. Results varied between the type of exercise and used protocol. Pressotherapy should only be applied as an additional component of a more comprehensive recovery strategy. **Study PROSPERO registration number- CRD42020189382.**

Keywords: pressotherapy; compression; regeneration; DOMS

1. Introduction

Physical activity, especially at the competitive level, causes a lot of negative changes in the human body [2][3]. Inflammation occurs as a result of damage to muscle cells [4] from which creatine kinase (CK), lactate dehydrogenase, and metabolites are released [2][3]. In such cases, we observe decreased efficiency, faster muscle fatigue, a decrease in the range of motion (ROM), and the appearance of pain in places where they are overloaded [5][6]. This phenomenon is exacerbated especially with eccentric exercises (ECC) [7], in which intense exercise may cause Delayed Onset Muscle Soreness (DOMS) [8].

To increase exercise capacity as well as reduce the risk of injury, the key element is the use of training measures related to biological recovery to reduce metabolites to minimum values and to ensure the right amount of energy substrates, including ATP and phosphocreatine [9].

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The most commonly used methods of biological recovery include treatments in the field of physical therapy (cold therapy, heat therapy, electrotherapy, compression therapy), manual therapy, massage (myofascial release and self-myofascial release), and pharmacology [10][11]. Of the above methods, in recent years much attention has been paid to compression therapy [12]), in which the most frequent mention is External Pneumatic Compression (EPC) [13] as well as Intermittent Pneumatic Compression (IPC) [13].

Among the studies that used EPCs, a positive effect was found to increase flexibility and reduce muscle soreness (MS) [14][15], as well as reducing lymphoedema [16] and reduction of lactate [17]. The research conducted by Martin et al. [2015] showed that EPC did not statistically significantly affect the reduction of lactate after the 30-second Wingate test compared to the control group. Similar relationships were found by Haun et al. [2017], in which they did not notice a statistical difference in muscle strength between the control group and the experimental group after resistance training in the form of back squats.

Using IPC has been reported to be effective in regeneration with short-term ECC efforts, reduction of fatigue [18], reduction of edema [19], improvement of local blood supply [20] and improve the ROM [13]. In subsequent studies, IPC was more effective at reducing high lactate levels than passive rest after exercise [21], and also statistically significantly reduced soft tissue stiffness after ECC training [19] and slightly reduced delayed post–exercise (Po-E) pain after short-term intense exercise [22].

Other studies have shown mitigating the effects of reducing muscle strength immediately after training [18] and improving the speed of a 400-meter run [13].

This systematic review and meta-analysis aimed to examine the effectiveness of the above forms of compression therapy to reduce DOMS. The primary endpoint is to assess pressotherapy the changes in MS and sports performance. The secondary endpoint is to establish the specific benefits on the selected outcomes of muscle functional capacities (e. g. strength, power), muscle damage markers (e. g. serum CK levels), joint ROM and pain sensation

2. Materials and Methods

The present review and meta-analysis were reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and follow the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions [23]. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Systematic Reviews [1].

2.1. Search Strategy and Screening Procedures

Searches were carried out on the following electronic databases: MEDLINE (PubMed and EBSCO), Web of Science, SPORT Discus, we didn't have any limits and we searched all articles to March 2021 for studies aimed at determining the effect of pressotherapy on the magnitude and time course of Po-E muscle soreness and sports performance and recovery following exercise-induced muscle damage. We also searched current information about registers and reports in ClinicalTrials.gov. We head the same keywords as in databases. There were no associated publications, reports, or registers.

The search algorithm was conducted using PICO's strategy [23] (type of studies, participants, interventions, comparators, and outcome assessment) and combined Medical Subject Headings, free-terms and matching synonyms of the following related words: (1) population: healthy adults, "middle-aged", "young adults"; (2) intervention: external assisted mechanical therapy, „external counterpulsation", "lymphatic drainage", "pressotherapy", "intermittent pneumatic compression", "pneumatic compression", "pneumatic therapy", "intermittent compression", "compression therapy", "compression massage", "pneumatic massage")"; (3) outcome: "Soreness", "DOMS", "inflammation", "muscle fatigue", "recovery", "Delayed Onset Muscle Soreness", "EIMD",

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"hyperalgesia", "allodynia", "myalgia"; and (4) comparator: control conditions; RCT's studies and cross-over. In addition, we searched the citations included in the identified publications deemed eligible for our study.

2.2. Inclusion Criteria

Those studies in which the title and abstract were related to the aim of the present review were included for full-text request. We included studies that (1) were conducted as randomized control trials (RCT) and cross–over designs; (2) included a mean participant age between 18 and 65 y.o. (3) Healthy adults with exercise-induced muscle damage regardless of their level of sports activity and performance (4) were based on at least one exercise intervention described as "External assisted mechanical therapy" (machines).

2.3. Exclusion Criteria

Studies were excluded if (1) outcome measurements were not reported as DOMS max values, or (2) they were not written in English. A third reviewer (SW) resolved cases of initial reviewer disagreement. Nonrandomized experiments, observational studies, secondary studies (any types of evidence syntheses), and opinion pieces (e. g. narrative reviews, editorials) were excluded too.

2.4. Selection process, data collection, data extraction, and management

Two initial reviewers (MJ and MC) independently examined the titles and abstracts of retrieved articles to identify suitable studies and extracted the following information from the included studies: First author's name and year of publication; study design; characteristics of the participants included; mean age; sample size and percentage of female subjects; weekly frequency, period and modality of External assisted mechanical therapy intervention; the reported measurement of Muscle functional capacities (e. g. strength, power), Muscle damage markers (e.g. serum CK levels), Joint ROM and pain sensation. A third reviewer (SW) resolved cases of author disagreement.

2.5. Risk of Bias Assessment

The risk of bias of RCTs was assessed using the Cochrane risk-of-bias tool for randomized trials (RoB 2.0) [24], in which five domains were evaluated: Randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each domain was assessed for risk of bias. Studies were graded as (1) "low risk of bias" when a low risk of bias was determined for all domains; (2) "some concerns" if at least one domain was assessed as raising some concerns but not to be at high risk of bias for any single domain; or (3) "high risk of bias" when a high risk of bias was reached for at least one domain or the studied judgment included some concerns in multiple domains [1]. For pre-post studies and non-RCTs we used the Quality Assessment Tool for Quantitative Studies [24], in which seven domains were evaluated: Selection bias, study design, confounders, blinding, data collection methods, withdrawals, and dropouts. Each domain was considered strong, moderate, or weak. Studies were classified as "low risk of bias" if they presented no weak ratings; "moderate risk of bias" when there was at least one weak rating; or "high risk of bias" if there were two or more weak ratings [24]. The risk of bias was independently assessed by two reviewers (MJ and PW). A third reviewer (SW) was consulted in case of disagreement.

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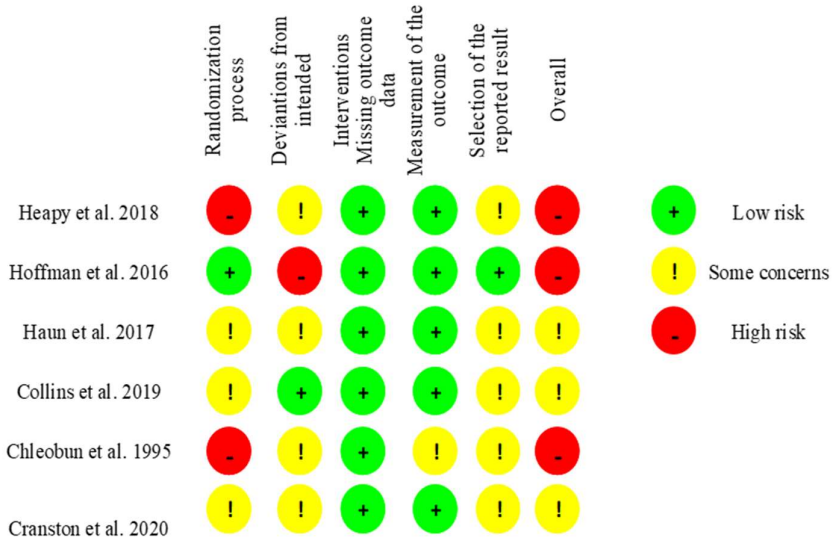

Figure 1. Risk of bias 2 tool. Assessment for individual randomized, parallel-group trials.

Author	Randomization process	Deviations from intended interventions	Mising outcome data	Measurement of the outcome	Selection of the reported result	Overall bias
Cochrane et al. 2013	High	Some concerns	Low	Low	Some concerns	Some concerns
Draper et al. 2020	High	Some concerns	Low	Low	Some concerns	High
Northey et al. 2016	High	Some concerns	Low	Some concerns	Some concerns	Some concerns
Velanzuela et al. 2018	High	Some concerns	Low	Low	Some concerns	High
Oliver et al. 2021	High	High	Low	Low	Some concerns	High

Figure 2. Risk of bias 2 tool. Individually randomized, cross-over trials.

2.6. Outcome measures.

Objective results of interest for meta-analyses from included baseline to last available follow-up. Data were typically collected immediately and 24h, 48h, 72h, up to 96h after the intervention.

2.7. Primary outcomes

The primary endpoint is to assess the effect changes in MS and sports performance.

2.8. Secondary outcomes

The secondary endpoint is to muscle functional capacities (e. g. strength, power), muscle damage markers (e. g. serum CK levels), and joint ROM and pain sensation.

3. Results

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3.1. Results of the Search

A total of 693 articles related to the topic were retrieved through a comprehensive database and other sources search, of which, 169 articles were duplicates. After removing all ineligible articles a total of 12 RCTs were included in the analysis. The detailed screening process is shown in (Figure 3).

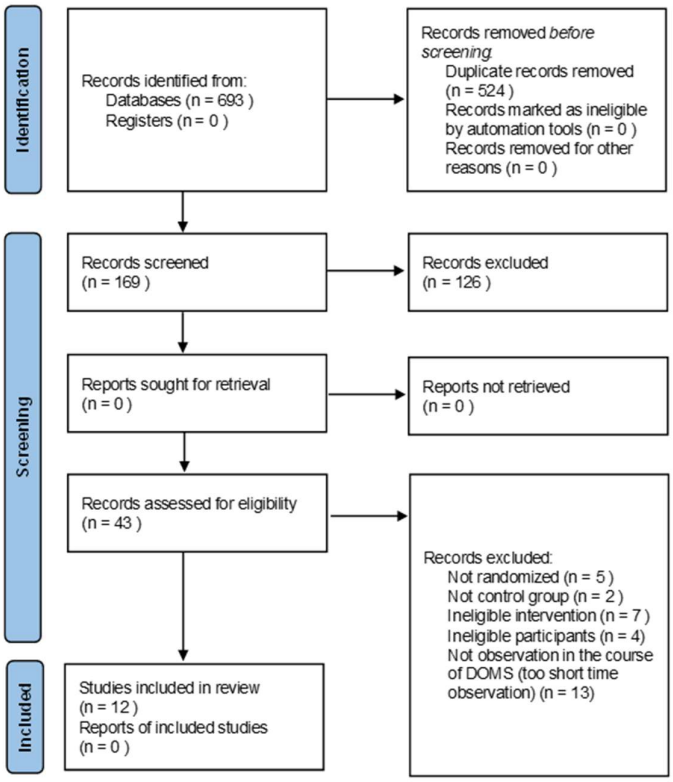

Figure 3. PRISMA flow diagram of included/excluded studies.

3.2. Details of the intervention groups in the included studies.

Characteristics of the included studies are summarized in Table 1.

Table 1. The key characteristic of selected studies (n = 12).

There were 5 randomized controlled trials [18][25][26][27][28] and 7 randomized crossover trials [29][13][12][30][31][19][32]. Overally, studies included patients from five countries: USA (n = 5), New Zealand (n = 3), Ireland (n = 1), Australia (n = 2), and Spain (n = 1).

The total study population of all selected articles comprised of 322 healthy volunteers with an unequal distribution of sex (n_{male}=274; n_{female}=48). Throughout all the studies, mean sample size ranged from 10 to 72 volunteers).

The average sample size of the pressotherapy group was 14.33 and the control group 13.25. The mean age of the study population was 28.1 yrs. In two studies the mean age was above 40 yrs. [2,3].

Two studies involved well-trained volunteers [12][28]. Three studies included runners [29][13][25]. One study included strength-trained males [26]. Two studies included physically active volunteers [30][18] and athletes [31][32], another two studies chose healthy participants [19][27]. Detailed information about the training status is presented in the Table 1.

3.3. Characteristics of the Exercise Protocols, Therapy & Outcomes

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To induce muscle damage exercise protocols encompassed run and other activities. Five used run [29][13][12][31][25]. One of these types of exercise was sprint [31], another one middle-6km [12] and three while the remaining five were long-distance run 62,7 [29]; 87,4 [29]; 102,8 [29]; 2x20 mile [25]; 161 km [13]. Two studies used back squats, 10 sets x10 rep [26], and 10 sets of 5 repetition [30]. Another way to induction DOMS intervention was ECC exercise on Biodex system [18], eccentric exercise performed with weight [19], plyometric exercise bout [27], countermovement jump (CMJ) [31], and wheelchair court sprints [28]. One study used specific training: Reverse grip battle rope waves, Farmers carry, Chin-ups, Bar hangs, Handgrip crushers [32]. Table 1 gives a detailed overview of the conducted exercise protocols.

Table 1. The key characteristic of selected studies (n = 12)

Author/country	Design / Publication year	Participant cohort (training status, sex, age)	Sample Size (n)	Experimental vs. control condition	DOMS induction intervention	Outcome variables and time of measurement post-exercise (hrs)	Main effects [* p<0,05: pre-post (x time)]	Total exposition time	Therapy parameters
Hoffman et. al. / USA	RCT / 2016	participants in the 2015 161-km Western States Endurance Run, men (IPC:43 ± 8 yrs., Massage: 46 ± 10 yrs., con.:45 ± 9 yrs)	n = 72 n = 24 exp. (IPC) n= 25 exp. (Massage) n= 23 con.	45min post exercises IPC (20 min), 45min post-exercise Massage (20min) vs. Placebo therapy (20 min)	161km ultramarathon race	400-m run times, Muscle Pain and Soreness, Overall Fatigue (prerace, postrace, posttreatment, 24h-168h post-race day)	400-m run time's (pre↔, post 72h↑, 120h↓) Lower-Body Muscle Pain and Soreness (pre↔, postrace↑*, posttreatment↑*#, post 24h-96h↑*, post-120h-168 h↑ Time and interaction effect* (no group effect) Muscular Fatigue (pre↔, postrace↑, post-treatment↑*#, postrace 24h-168h↑) Time and interaction effect* (no group effect)	20 min ISPC 20 min Massage 20 min Con.	ISPC - 80mmHg Massage - (the 30s - calf and hamstring, 1 min - quadriceps), compression (2 min - calf and quadriceps, 3 min hamstring), tapotement (30s leg and quadriceps)
Haun et. al / USA	RCT / 2017	endurance-trained male, participating in ≥72h per week of endurance exercise for at least 3 months. (EPC:21±0.4 yrs, con: 21.1±0.6 yrs)	n = 18 n = 9 exp. (EPC) n= 9 con.	24h, 48h, 72h post exercises EPC (1h) vs. Placebo therapy (1h) 96h, 120h treatments only EPC (1h) vs. placebo therapy (1h)	6 km run on the treadmill at an incline of 1% (pre and 16h)	CK, Muscle Pain, and Soreness (pre-exercises, 72h to 168h), Flexibility (pre-exercises, 72h to 168h), 6-km run times (pre-exercises, 168h)	CK (pre, 72h↑, 96h↑*, 120h↑, 144h↑, 168h↔) Time effect* (No group or group x interaction effect) Muscle Soreness (pre, 72h↓*, 96h↓, 120h↓*, 144h↓, 168h↔) Time effect* (No group or time - group effect) Flexibility (pre, 72h↑, 96h↔, 120h↔, 144h↔,168h↓) 6km run time (pre, 168h↓)	300 min EPC 300 min EPC Con	EPC -70mmHg (inflation - 30s / deflation - 30s)
Cochrane et. al / NZ	RCO / 2013	10 healthy males, involved in physical activity (21.0 ± 1.7 yrs)	n=10 n=10 exp. (IPC) n=10 con.	immediately post exercises, 24h post-exercise, 48h post IPC (30 min) vs. Placebo therapy (30 min)	3 sets x 100 rep. strenuous bout of eccentric exercise on BIODEX	CK, VJ, Muscle Dynamometry ISO 75° - CON 30°/sec; 180°/sec - ECC 30°/sec; 180°/sec) (Pre, 24h, 48h, post 72h)	CK (pre, 24h↑*, 48h↑, 72h↑) VJ height (pre, 24h↓, 48h↑, 72h↑) VJ peak power (pre, 24h↓, 48h↓, 72h↓) Peak ISO (pre, 24h↓*, 48h↑*, 72h↑*) Peak CON 30° (pre, 24h↓*, 48h↓, 72h↓) Peak CON 180° (pre, 24h↓, 48h↓, 72h↓) Peak ECC 30° (pre, 24h↓, 48h↑, 72h↑) Peak ECC 180° (pre, 24h↓, 48h↑, 72h↑) Ave ISO 75° (pre, 24h↓, 48h↑, 72h↑) Ave CON 30° (pre, 24h↓*, 48h↓, 72h↓) Ave CON 180° (pre, 24h↓, 48h↓,	90min IPC 90min Con	IPC - cell 1 (distal) - 70mmHg, cells 2–4 80mmHg, cell 5 (proximal) 60mmHg / deflation - 30 s.

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							72h↓) Ave ECC 30° (pre, 24h↓, 48h↑, 72h↑) Ave ECC 180° (pre, 24h↓, 48h↑, 72h↑)		
Collins et. al / IE	RCT / 2019	21 male team sport athletes (21.6 ± 3.4 yrs)	n = 21 n=11 exp. n = 10 con.	pre, post, 24h post exercises ECP (20 min) vs. Placebo therapy (20 min)	Max CMJ, 2 x 20 sprint, and second max CMJ	CK, C, T, IgA, sAA, VAS, CMJ height (Pre, post, 24h post)	CK (pre, post↑*, 24h↑*) Main effect for time* Cortisol (pre, post↑, 24h↓) Testosterone (pre, post↑*, 24h↓*) Main effect for time Alpha-Amylase (pre, post↑*#, 24h↑*#) Main effect for time, and group Immunoglobulin - A (pre, post↑,24h↓) VAS (pre, post↑, 24h↑*) Main effect for time CMJ (pre, post↓*#, 24h↑*#)	60min ECP 60min Con	ECP - 235.3 ± 26.9mmHg
Draper et. al / USA	RCO / 2020	10 runners, endurance-trained males (38.7 ± 11.2 yrs)	n = 10 n = 10 exp. n = 10 con.	1h, 24h, 48h, 72h, 96h, 120h post IPC (1h) vs. 1h, 24h, 48h, 72h, 96h, 120h post Placebo therapy (1h)	2 x 20 mile runs at 70% VO2 max separated by 3 or 4 weeks	CRP, VAS (pre, post, and 24h, 48h, 72h, 96h, 120h post)	CRP (pre, post-run ↔, 24h↑*, 48h↑, 72h↑,96h↔120) Main effect of time VAS (pre, post-run↑*, 24h↑*, 48h↑*, 72h↑,96h↑, 120h↔ pre-run)	6h IPC 6h Con	IPC - 90mmHg for cell 1 (distal) and cell 5 (proximal) and 100 mmHg for cells 2-4 (compression 30s)
Northey et. al / AU	RCO / 2016	12 strength-trained male (24.0 ± 6.3 yrs)	n = 12 n = 12 exp. n = 12 con.	1h post exercises SIPC (45min) vs. Placebo therapy (45 min)	10 sets x 10 rep. of back squats at 70% 1 repetition maximum	VAS, CON (peak of quadriceps), SJ, CMJ (Pre, post, 1h, 24h)	CON peak (pre, post↓*, 1h↓*, 24h↔) SJ (pre, post↓*, 1h↓*, 24h↓*) CMJ (pre, post↓*, 1h↓*, 24h↓) VAS (pre, post↑*, 1h↑*, 24h↑*)	12min OCC - 2 sets x 3min (per leg) 45min SIPC 45min Con	SIPC - 80mmHg (deflation - 15s) OCC 220mmHg (inflation 3min)
Heapy et. al / NZ	RCT / 2018	56 ultramarathoners (con. = 19; 42 ± 9 yrs),(IPC = 18; 41 ± 8 yrs), (Massage = 19; 43 ± 9 yrs), men	n=56 n=18 exp. (IPC) n=19 exp. (Massage) n=19 con.	Post-race, 24h, 48h, 72h post-race IPC (20min) post-race, 24h, 48h, 72h post-race Massage (25min) vs. Placebo therapy (20 min)	Run race - 3 distance options of 62.7 km, 87.4 km, and 102.8 km	400 m run times (pre-race 1, pre-race 2, post-race at 72h, 120h, 168h, and 336h), VAS, Fatigue Scores (pre, post, day 24h-168h post and 336h post)	400 m run times (pre race 1, pre race 2↔, 72h↑, 120h↑, 168h↔, 336h↔) Time effect* (No group, or interaction effect) VAS (pre race, post race↑*, 24h↑*, 48h↑, 72h↑,96h↑, 120h↑, 144h↔, 168h↔, 336h↔) Time effect* (No group or interaction effect) Muscle Fatigue (pre-race, post-race↑*, 24h↑*, 48h↑*, 72h↑*#, 96h↑#, 120h↑#, 144h↔, 168h↔, 336h↔) Time and interaction effect* (No group effect)	80min IPC 100min Massage 80min Con.	IPC - 80mmHg
Chleboun et. al / USA	RCT / 1995	22 college women students (21.7 ± 0.7 yrs)	n=22 n=22 exp. (IPC) n=10 con. (passive rest)	Post-exercise, 24h, 48h, 72h, 96h, 120h post IPC (20min) vs. Placebo therapy (20min)	3 sets of ECC exercise performed with weights equal to 90%, 80%, and 70% of the ISO MVC	Pain (five-point pain rating scale), Swelling (post, day 1 to 5), Stiffness, and Isometric Strength (pre-exercise, pre, post IPC days 1 to 5)	Pain (post, 24h↑, 48h↑, 72h↑, 96h↑, 120h↑) Swelling (post, pre IPC (post IPC), 24h↑ (24h↑*), 48h↑ (48h↑*), 72h↑ (72h↑*), 96h↑ (96h↑), 120h↑ (120h↑*)) Stiffness (post, pre IPC, (post IPC), 24h↑ (24h↑), 48h↑ (48h↓*), 72h↓ (72↓*), 96h↓ (96h↓), 120h↓ (120h↓) Strength (post, pre IPC (post IPC) 24h↓ (24h↓), 48h↓ (48h↓), 72h↓ (72h↓), 96h↑ (96h↑), 120h↑ (120h↑))	120min IPC	IPC - 60mmHg (inflation 40s / deflation 20s)
Velanzuela et. al / ES	RCO / 2018	10 healthy participants (27 ± 4 yrs), 7	n= 10 n = 10 exp.	post exercises, 24h post-EECP	Plyometric exercise bout (10 sets of 10 jumps)	Muscle Soreness (VAS), CK, CMJ, RSI	Muscle Soreness (pre, 24h post↑, 48h post↑) CK (pre, 24h post↑, 48h post↑) CMJ (pre, 24h post↓, 48h	60min EECP 60min Con.	EECP - 80mmHg

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		men, 3 females	n = 10 con.	(30min) vs. Placebo therapy (30 min)		(pre and 24 and 48 h post)	post↔) RSI (pre, 24h post↓, 48h post↔)		
Haun C.T. et. al / USA	RCT / 2017	20 resistance-trained male (21.6 ± 2.4 yrs)	n= 10 n = 10 exp. (EPC) n = 10 con.	48h, 72h, 96h, 120h, 144h post EPC (1h) vs. Placebo therapy (1h)	10 sets of 5 rep. at 80% of back squat 1RM	CK, Flexibility (pre, 48h-168h post) CRP (pre, 8h-168h post)	CK (pre, 72h↑*, 96h↑*, 120h↑*, 144h↑, 168h↑) Flexibility (pre, 72h↑*#, 96h↑, 120h↑*, 144h↑, 168h↓) CRP (pre, 48h↑, 72h↑, 96h↑, 120h↑, 144h↑, 168h↑)	5h EPC 5h Con.	EPC ~ 70mmHg (inflation - 30s / deflation - 30s)
Oliver et. al / NZ	RCO / 2021	11 well-trained wheelchair basketball and rugby athletes (33 ± 10 yrs), men	n= 11 n = 11 exp. n = 11 con.	post exercises ISPC (20min) vs. Placebo therapy (30min)	10 wheelchair court sprints (28m). 10 times figure of 8 agility drill (the 30s). 10 sprints (28m) immediately followed by 3 medicine ball chest throws	Medicine Ball Throw (m), Wheelchair Sprint, 5, 10, 15 (m) (pre-ex, post-ex, post-rec) Muscle Soreness 0–10 scale and Muscle Fatigue 0–10 scale (pre-ex, post-ex, post-rec, 24h post-rec) Blood Lactate (post-ex, post-rec)	Medicine Ball Throw (pre-ex, post-ex↓, post-rec↑), Wheelchair Sprint: (5m) (pre-ex, post-ex↑, post-rec↑) (10M) (pre-ex, post-ex↑, post-rec↑) (15m) (pre-ex, post-ex↑, pot-rec↑) Muscle Soreness (pre-ex, post-ex↑, post-rec↑, 24h post↑) Muscle Fatigue (pre-ex, post-ex↑, post-rec↑, 24h post↑) Blood Lactate (post-ex, post-rec↓)	20min ISPC 30min Con.	ISPC - 80mmHg (inflation 30s / deflation 15s)
Cranston et. al	RCT / 2020	50 resistance-trained athletes (27 ± 4 yrs), 37 men, 13 females	n= 50 n = 25 exp. n = 25 con.	post exercises ISPC (30min) vs. Placebo therapy (30min)	Fatiguing Exercise Circuit (consisted of 5 different exercises): 1. Reverse grip battle rope waves (the 60s) 2. 20 m Farmers carry (20 kg for women and 30 kg for men) 3. Chin-ups (maximum number of repetitions) 4. Chin-up bar hangs (long as possible with their hands in a pronated grip) 5. Handgrip crushers (as many times as possible)	Grip Strength Dynamometer (kg), Single-Arm Medicine Ball Throw (m), Preacher Bench Bicep Curls- max repetitions (pre-ex, post-ex, post-rec)	Grip Strength Dynamometer (pre-ex, post-ex↓, post-rec↓) Single-Arm Medicine Ball Throw (pre-ex, post-ex↓, post-rec↑) Max. Rep. Single-Arm Preacher Bench Bicep Curls (pre-ex, post-ex↓, post-rec↓) Triceps Brachii Long Head Soreness (pre-ex, post-ex↑, post-rec↑#, 24h post-rec↑#) Biceps Brachii Soreness (pre-ex, post-ex↑, post-rec↓#, 24h post-rec↑#) Extensor Digitorum Soreness (pre-ex, post-ex↑, post-rec↓#, 24h post-rec↑#) Flexor Carpi Radialis Soreness (pre-ex, post-ex↑, post-rec↓#, 24h post-rec↑#)	30min ISPC 30min Con.	ISPC - 80mmHg (inflation - 26s / deflation - 15s)

Abbreviations: PCD (pneumatic compression device), CS (compression sleeve), PC (pneumatic compression), EPC (external pneumatic compression), ECP (External counterpulsation), EECP (Enhanced external counterpulsation), IPC (intermittent pneumatic compression), ISPC (intermittent sequential pneumatic compression), OCC (evaluate vascular occlusion), SIPC (sequential intermittent pneumatic compression), VJ (vertical jump), SJ (squat jump), CK (creatine kinase), LDH (lactate dehydrogenase), ISO (isometric), CON (concentric), ECC (eccentric), HIIT (high intensity interval training), HIE (high-intensity exercise), CMJ (countermovement jump), DEC (deceleration), AMRAP (as much repetitions as possible), ALAP (as long as possible), WAnT (wingate anaerobic test), THB (total hemoglobin), O2HB (oxyhemoglobin), HHB (deoxyhemoglobin), ROM (range of motion), C (cortisol), T (testosterone), IgA (immunoglobulin-A), sAA (salivary alpha-amylase), CRP (C-reactive protein), PkP (peak power), AP (average power), FI (fatigue index), BLa (blood lactate concentration), NRS (numeric rating scale), CWI (cold water immersion), MuscleMechFx (muscle mechanical function), RPE (rate of perceived exertion), DM (Muscle radial deformation), TC (time of contraction), BF (biceps femoris), RF (rectus femoris), RSI (reactive strength index). #-significant difference between groups, $p<0.05$ ↑*- significant increase, $p<0.05$ ↓*- significant decrease, $p<0.05$ ↔ - no significant change.

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Considerable variation was observed in therapy parameters among the studies. Intermittent sequential pneumatic compression (ISPC) was used in three studies [13][28][32].Time of therapy was 2 min. [3], 30s/15s [28] or 26s/15s [32]. External pneumatic compression (EPC) was used in three studies [12][30][31], two authors used the same parameters 70 mmHg inflation – 30s, deflation -30s [12][30] and one study 235 mmHg pressure [31]. The most popular therapy was IPC [29][18][25][19].

There was a different time of experimental and control condition, the majority did therapy post and after 24h. The average therapy session was 30min. The shortest time was 6 min. [26] and the maximum of 1h [12][30][25]. Total therapeutic exposition time varied from 20 - 30 min. [13][28][32] to longer time from 80 min. to 6h[29][18][19][29].

Outcome variables and time of measurement varied depending on the study. The period of measurement keeps on from Po-E [13][31][25][26][19][28][32] to 336h after exercise [29]. The average time of access outcomes was 48h. Muscle pain soreness and (CK) were the most often measured. Six studies investigated CK [12][30][18][31][27], five MS [12][13][27][28][32] and eight pain Visual analogue scale (VAS) [29][13][12][31][25][19][26][27]. Other authors access Over Fatigue [13], Flexibility [12], Muscle Dynamometry and vertical jump (VJ) [18][19] C-reactive protein (CRP) [25] [30], countermovement jump (CMJ), reactive strength index (RSI) [31][26][27], cortisol, testosterone, alpha-amylase and immunoglobulin [31]. Detailed information about the measured parameters can be observed in Table 1.

Main effects were measured Po-E through 336h after. CK increasing Po-E to 24h [31], 72h [18] and 168h [30]. Haun (2017) concluded that after 168h there was no significant change. Significant effect was observed after 24h [18][31] and 96h [12][30] and 120h [30].

Muscle Pain increased Po-E to 24h [31][26], 96h [25], 120h [29][19] and 168h [13]. Significant effect was observed after one hour [26], 24h [29][31][26], 48h [25], 96h [13]. In one study a increasing was observed Po-E to 144h but with no significant changes [19].

Muscle soreness had a heterogeneous direction of changes. Some authors observed decreasing after exercise from 72h to 144h and significant changes were measured after 72h and 120h [12] [29]. The majority observed significantly increasing MS Po-E and after 24h to 96h [13]. Velanzuela (2018) observed increasing MS after 24 and 48h but without any significant changes. Oliver (2021) observed increasing MS Po-E, post-recovery, and after 24h and also without any significant changes. Cranston (2020) observed increasing Po-E in all four muscles group, post- recover decreasing in three groups with significant differences between groups, and after 24h increasing in all four muscle groups, with significant differences between groups.

Hoffman (2016) observed that muscle fatigue increases postrace, posttreatment – significantly and reached significant difference between groups and postrace 24-168h. Two other authors analyzed change of these parameters [29][28] and Heapy (2018) observed changes post-race, 24-168h, and 336h after exercise and post-race, 24 -72h increase was significant, furthermore, 72h, 96h and 120h was a significant difference between groups. In Oliver et.al (2021) muscle fatigue Po-E, post-recovery, and 24h Po-E remained unchanged.

Two studies assess muscle flexibility parameters [12][30]. Both observed increasing after 72h and decreasing after 168h. Swelling and stiffness were observed by Chleboun et.al (1995) after 24- 96h and 120h. The stiffness increased after 24 and 48h and then decreased to 120h.

Two studies measured isometric strength [18][19]. Cochrane (2013) observed decreased peak isometric strength after 24h and increased after 48 and 72h– all changes were significant. Chleboun (1995) observed a decrease after 24- 72h and an increase after 96 and 120h.

Cochrane et.al (2013) measured a few dynamometry parameters: Peak concentric 30°– decreased after 24, 48, and 72h; peak concentric 180° decreased like previously parameters; peak ECC 30° and 180°- decreased after 24h and increased after 48 and 72h. Other parameters average concentric 30°, 180° decreased after 24- 72h; average ECC 30°,

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180° decreased after 24h and increased after 48-72h. Northey et al. (2016) also measured concentric peak and he observed decreased post and after 1h and then no significant changes.

Collins et al. (2019) assessed blood test results: cortisol, testosterone, immunoglobulin– were increased Po-E and decreased after 24h; Alpha-amylase – significant changes post and 24h and between groups.. Oliver et al. (2021) measured blood lactate – post-recovery it decreased. C-reactive protein was measured in two studies [30][25] and remained unchanged after 24-144h and 168h.

Some authors used exercises to measure the main effect. Hoffman et al. (2016) and Heapy et al. (2018) used 400 m runs with increased time after 72h [13] and 120h [29], and decreased time after 120h [13]. Another activity to measure effects was 6 km run after 168h Po-E. In a countermovement jump (CM) [31][26][27] heterogenous results were observed: decreased post and increased after 24h - significant changes between groups [31]. Decreased post, 1 and 24h -post and 1h significant changes [26]. After 24h decreased and 48h no significant changes [27]. Valenzuela et al. (2018) also measured reactive strength index and had the same results as in the CMJ case. Cochrane et.al (2013) observed changes in vertical jump height – it decreased after 24h and increased after 48h and 72h; vertical jump peak power –decreased after 24- 72h. Northey et al. (2016) used squat jump (SJ) to measure the main effect and noted only decreased post and after 1 and 24h. Oliver et al. (2021) used a medicine ball throw test and wheelchair sprint on 5, 10, 15 meters and observed decrease with post-recovery increase [28]. Sprint on every distance was increased. Cranston et al. (2020) used exercises: Grip strength dynamometer -decreased Po-E and post-recovery; Single-arm medicine ball throw – Po-E it decreased and then post-recovery increased; Max repetition single-arm preacher biceps curls – Po-E and recovery it decreased.

3.4. Subgroup analysis

Muscle soreness.

There was moderate and statistically significant reduction in MS in overall effect from 24-96h after DOMS induction in pressotherapy intervention (Standard Mean Difference (SMD) = -0.33, 95% CI -0.49, -0.18; $p < 0.0001$; $I^2 = 7\%$). In the Subgroup 24h Po-E (participants = 311; studies = 9) there was moderate but NS reduction in MS (SMD = -0.28, 95% CI -0.60, 0.04; $p = 0.09$; $I^2 = 43\%$), 48h Po-E (participants = 144; studies = 5) there was moderate and significant reduction in MS (SMD = -0.40, 95% CI -0.73, 0.07; $p = 0.02$; $I^2 = 0\%$), 72h Po-E (participants = 124; studies = 4) there was moderate but NS reduction in MS (SMD = -0.37, 95% CI -0.79, 0.05; $p = 0.08$; $I^2 = 24\%$) and 96h Po-E (participants = 124; studies = 4) there was moderate but NS reduction in MS. In overall effect from 24-96h heterogeneity was small ($I^2 = 7\%$; $\chi^2 = 22.6$, df = 21; $p = 0.96$). Only in the subgroup 24h Po-E we detected NS heterogeneity ($I^2 = 43\%$; $\chi^2 = 14.16$, df = 8; $p = 0.08$). 48h-96h heterogeneity was low. Subgroup analysis from 24h to 96h didn't reveal statistically significant difference ($p = 0.96$) (figure 4).

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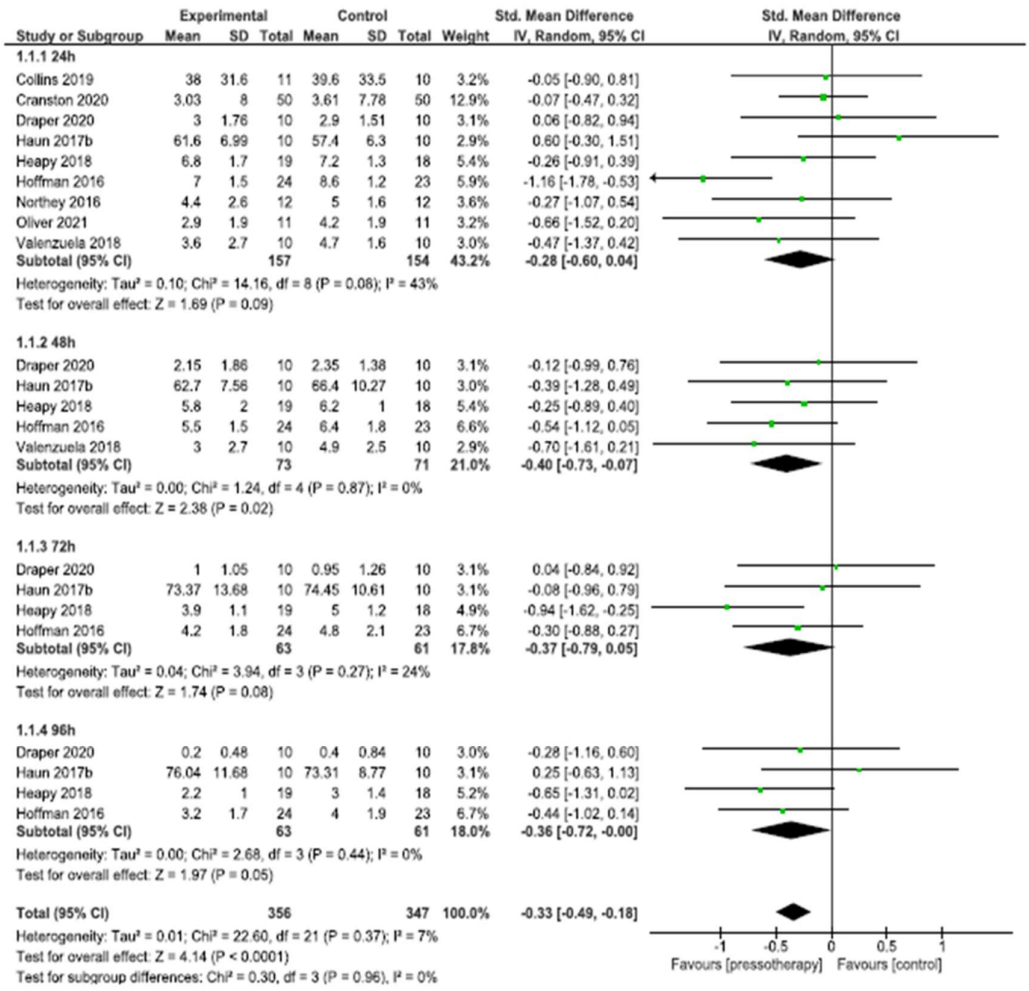

Figure 4. Effects of pressotherapy on muscle soreness from 24h to 96h after exercise.

Jump performance

24h Po-E (participants = 84; studies = 4; SMD = -0.05, 95% CI -0.47, -0.38; p = 0.99; I^2 = 0%), 48h Po-E (participants = 40; studies = 2; SMD = -0.01, 95% CI -0.61, 0.63; p = 0.77; I^2 = 0%) and 72h Po-E (participants = 20; studies = 1; SMD = -0.10, 95% CI -0.98, 0.78; p = 0.82; I^2 = not applicable) there was a small statistically NS effect of pressotherapy on jump height. In overall effect from 24-72 h (SMD = -0.04, 95% CI -0.36, -0.29; p = 0.82) heterogeneity was small (I^2 = 0%; χ^2 = 0.25, df = 21; p = 1.00).

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Subgroup analysis from 24h to 96h didn't reveal a statistically significant difference (p = 0.98).

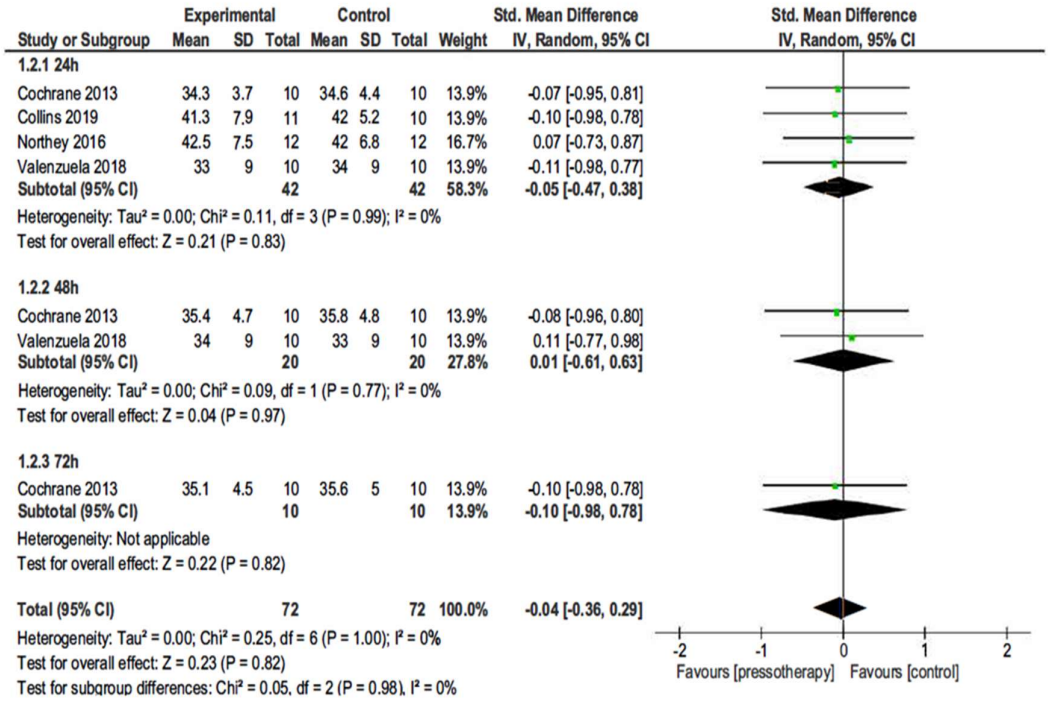

Figure 5. Effects of pressotherapy on jump performance from 24h to 96h after exercise. SMDs are calculated from CMJ, VJ, etc.

Creatine kinase

There was NS increase in serum CK activity in overall effect from 24-96h after DOMS induction in pressotherapy intervention (SMD = 0.41, 95% CI -0.07, 0.89; p = 0.09; I^2 = 63%). In the subgroup 24h Po-E (participants = 81; studies = 4; SMD = 0.14, 95% CI -0.30, 0.58; p = 0.54; I^2 = 0%), 48h Po-E (participants = 60; studies = 3; SMD = 0.52, 95% CI -0.77, 1.81; p = 0.43; I^2 = 82%), 72h Po-E (participants = 40; studies = 2; SMD = 0.49, 95% CI -1.25, 2.23; p = 0.58; I^2 = 85%) there was small (24h) and moderate (48-72h) but NS increase in serum CK activity. 96h Po-E (participants = 20; studies =1) there was large and significant increase in CK activity for the pressotherapy group (SMD = 1.26, 95% CI 0.28, 2.23; p = 0.01; I^2 = not applicable)

In overall effect from 24-96h heterogeneity was moderate (I^2 = 63%; χ^2 = 24.47, df = 9; p = 0.004). Only in the subgroup 24h Po-E we detected homogeneity (I^2 = 0%; χ^2 = 2.44, df = 3; p = 0.49). 48h (I^2 = 82%; χ^2 = 11.05, df = 2; p = 0.004) and 72h (I^2 = 85%; χ^2 = 6.78, df = 1; p = 0.009) heterogeneity was large. Subgroup analysis from 24h to 96h didn't reveal statistically significant difference (p = 0.23).

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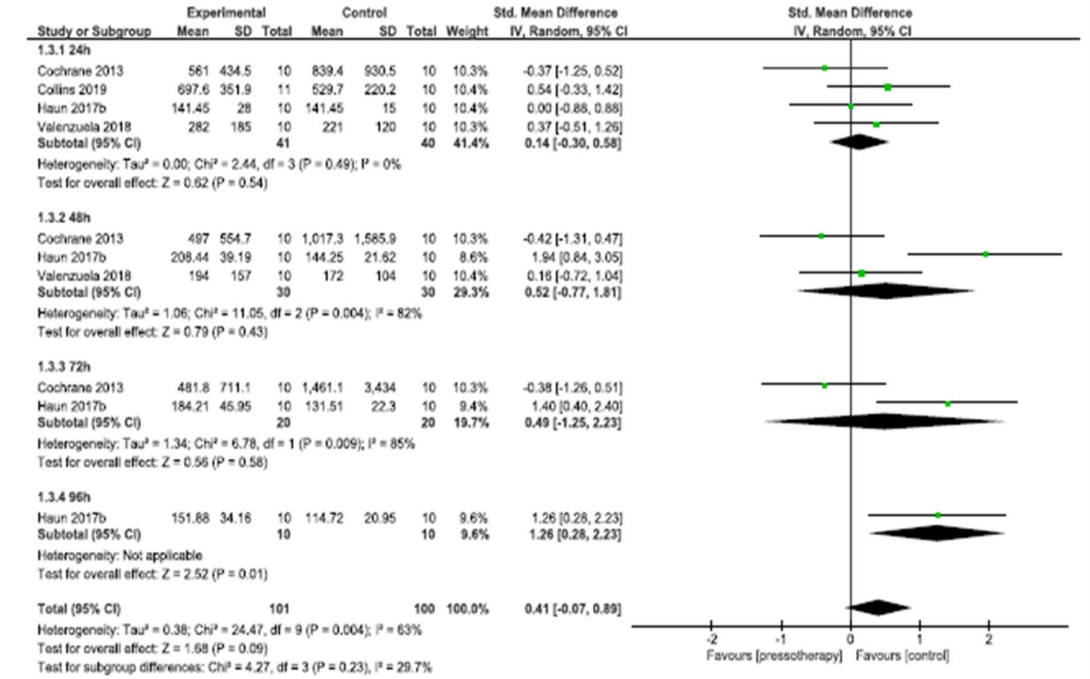

Figure 6. Effects of pressotherapy on serum CK activity from 24h to 96h after exercise.

4. Discussion

Most of the studies used a one-time protocol to assess the time of post-workout regeneration. The most reliable method would be to use it multiple times under different conditions to maximize results accuracy[33].

The best methods of post-workout recovery are sleep and a proper diet[34][35]. Additional methods can only be supplementary. For the assessment of the credibility of the studies, we recommend that the information on whether pressotherapy was the primary method or an addition to the more comprehensive scheme should be included in the methodology section.

Maximizing the efficiency of post-workout adaptation is crucial for athletes to maintain an appropriate performance level throughout the season and during the pre-competition preparation periods [36][37]. This is especially important in sports with a high frequency of competitions (i.e. team sports like soccer and basketball), as well as in disciplines where the athlete prepares for a long time for one event in which their organism achieves peak performance (i.e. individual disciplines such as sprinting or swimming).

We stipulate that pressotherapy does NS affect post-workout regeneration and can only supplement a complex protocol.

Serum CK level

The blood level of CK is an indicator of the status of muscle damage and change in both pathological and normal conditions [38]. An increase in this enzyme may predict a state of microscopic tissue impairment after acute and prolonged injuries. Variables in CK level are also observed under physiological conditions in athletes after demanding training. The highest CK growth is observed after prolonged exercise, i.e. triathlon events and demanding strength exercises, or activities that include eccentric muscle contraction phase, i.e downhill running [39][40]. In our study, we saw an improvement in this

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parameter, which suggests that pressotherapy improves regeneration. However, its impact was not statistically significant in any case except the 96h Po-E group, which had the lowest number of participants. In addition, a significant result was observed in the longest period after the training was performed, which leaves some ambiguity as CK activity decreases with time and it is a natural process [41]. Not without relevance is also the fact that a significant result was observed by Haun et. al., who investigated CK levels on a group of trained high-volume endurance athletes, who underwent over 70h of exertion per week for 3 months. Although significant results have been observed, previous studies suggest that CK levels naturally decline between days 4 and 10 after exercise [42]. The characteristics of the test group (endurance athletes) and testing protocol could also affect the results, as resting CK levels are higher in the trained population [43][44] and everyday strenuous workouts may cause persistent blood rise of CK [45]. Therefore, the potential outcome of pressotherapy on a different group of people would not be so important. To summarize, in the current state of knowledge, pressotherapy should not be recommended as the basic method of recovery after exercise, because there is a large heterogeneity of previous research results.

DOMS

DOMS is a regular experience for advanced or beginner athletes. Its manifestations can range from muscle stiffness to severe excruciating pain [46]. DOMS is most prevalent at the beginning of the sporting season when athletes are returning to training following a period of reduced activity[47]. DOMS is also common when athletes are first introduced to certain types of activities regardless of the time of year. DOMS can negatively attenuate athletic performance [48]. Possible mechanisms include a reduction in joint ROM, peak torque, and feeling of pain [46]. Compensation methods may raise the probability of further injury [49][50] when participants try to return to activity too early without completing the full recovery process. Therefore, it is of high importance to search for new methods of the most effective regeneration and reduction of MS. Commonly described in the literature are pressotherapy, [46] stretching [51], cryotherapy [52], and massage, mainly considered as self-foam rolling. It has been the most often assessed parameter in selected studies. Although pressotherapy is one of the methods of DOMS reduction, our results indicate that its use for this purpose remains questionable. Only when MS was measured after 48h a significant effect of pressotherapy was observed. This method does also significantly alleviates DOMS when considering the whole population and all protocols. On the other hand, no significant reduction in MS was found in the remaining groups. Taking into account the previously mentioned methods of therapy, which are easily available (stretching or foam-rolling), as well as low-cost (cryotherapy and water immersion) or self-applicable and physiologic (i.e. rest), there are few arguments in favor of the wide use of pressotherapy in the current state of knowledge. High prices and limited availability suggest other forms as a method of choice and first-line treatment strategy. However, pressotherapy has shown some positive effects, mainly limited to the 48h Po-E period, so while the above-mentioned factors are not a barrier, it can be used in some circumstances [53] (e.g. in professional athletes as a supplemental method).

Jump performance

The level of muscle power in the lower limbs is a vital factor in numerous disciplines, such as sprinting [54][55] or in decisive moments of team sports [56][57]. In a widespread view, the research has demonstrated that jump heigh is an applicable index to characterize power output, mainly described by the association found between them [58]. It is meaningful that upright jump may be easily evaluated and hereafter used by team staff and physical trainers to categorize the level of athletes' muscle power within a wider group of participants.[59][60] Due to the great practical importance of jump performance in the overall assessment of an athlete's fitness and the development of motor skills, it is crucial

to properly place this type of activity in the training plan and the microcycle.[61][62] Effective recovery after jumping efforts would be of key importance, hence the influence of pressotherapy on jump performance was also assessed in this meta-analysis. In our review, we did not observe any significant effect of pressotherapy on jump ability performed at various intervals from the previous exercise. Further investigation is needed to specify whether and in what population this method will be an effective approach for improving jump performance and overall power generation.

Limitations

Although, this paper has a few limitations. Firstly, we performed a comprehensive literature investigation whereas did exclude articles that were not published in English. However, from an actual point of view, we suppose this will have a minor effect on our outcomes.[63] Nevertheless, we conducted a reasonable attitude to overwhelm these barriers and attempted to stick to principles of open science. Secondly, the protocols used and the study groups differed between the selected articles. Third, the time of outcome evaluation from the preliminary endpoint was not identical in all trials. Fourth, the particular subgroup analyses were conceivably underpowered due to their small participant number and should be interpreted carefully. To enhance the validity of results in similar research, future randomized studies have to concentrate on better conducting and reporting of applied protocol and methodology, intention-to-treat examination, assessor blinding, random sequence generation, control group observation, and reporting of adverse events or the possible other influencing factors.

5. Conclusions

The conducted systematic review and meta-analysis assessed 12 randomized controlled studies investigating the outcome of pressotherapy on the recovery of absolute (i.e. physiological), and subjective (i.e. perceptual) outcomes. The findings indicate only moderate benefits of using pressotherapy as a recovery intervention, dependent on the type of exercise and used protocol. A reduction in DOMS, changes in CK level, and improvements in perceived recovery were observed after pressotherapy, although they were usually not significant. Dose-response relationships emerged for several variables indicating that different duration protocols may improve the efficacy of pressotherapy if applied after exercise. We recommend further continuing research on various populations and broadening tested protocols to obtain the highest possible homogeneity of results and to facilitate the creation of a consensus statement on whether pressotherapy seems to be an effective method in minimizing exercise-induced negative effects.

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