RESEARCH PAPER

Effectiveness of Blood Flow Restriction Training on Pain, Physical Function, and Muscle Strength in Patients with Tendinopathy: A Systematic Review and Meta-Analysis

Heba Alkazaleh[1*], Omer M. Alsmear[2], Sarah Medhat Kamel[3,4], Ali Mohammed Hassan[5,2]

[1*]Department of Basic Health Sciences, Faculty of Allied Medical Sciences, Al-Balqa Applied University (BAU), Al-Salt, Jordan | ORCID: https://orcid.org/0009-0007-5122-1523 | Email: heba.khazaleh@bau.edu.jo

[2]Department of Physical Therapy, Faculty of Allied Medical Sciences, Zarqa University, Zarqa, Jordan | ORCID: https://orcid.org/0009-0009-8484-9792 | Email: omer.alsmear@gmail.com

[3]Department of Physical Therapy, Faculty of Allied Medical Sciences, Al-Ahliyya Amman University, Amman, Jordan

[4]Department of Physical Therapy, National Heart Institute, Imbaba, Giza, Egypt

[5]Department of Physical Therapy for Internal Medicine, Faculty of Physical Therapy, Qena University, Qena, Egypt

[2]Department of Physical Therapy, Faculty of Allied Medical Sciences, Zarqa University, Zarqa, Jordan (Ali Mohammed Hassan)

[3,4]ORCID: https://orcid.org/0009-0006-2945-4243 | Email: drsarahmedhatpt@gmail.com

[5,2]ORCID: https://orcid.org/0000-0003-0025-3457 | Email: ali311pt@svu.edu.eg

***Corresponding Author:** Heba Alkazaleh, Department of Basic Health Sciences, Faculty of Allied Medical Sciences, Al-Balqa Applied University (BAU), Al-Salt, Jordan | ORCID: https://orcid.org/0009-0007-5122-1523 | Email: heba.khazaleh@bau.edu.jo

Abstract

Background: Blood flow restriction (BFR) training enables resistance exercise at low external loads and may benefit individuals with painful tendons that cannot tolerate conventional heavy-load exercise.

Objective: To synthesize the effects of BFR-assisted exercise on pain, physical function, and muscle strength in adults with tendinopathy.

Methods: Comparative and uncontrolled clinical studies evaluating BFR for clinically diagnosed tendinopathy were synthesized according to PRISMA 2020 principles. Random-effects meta-analyses using restricted maximum likelihood were performed when outcomes, measurement scales, and follow-up periods were sufficiently comparable.

Results: Ten studies were included in the qualitative synthesis; six were comparative, and five contributed to the quantitative synthesis. Three short-term studies (102 participants) showed no significant pooled effect on pain (0–10 scale; mean difference [MD] = −0.44, 95% confidence interval [CI] −1.27 to 0.40; I^2 = 46%). Two studies of lateral elbow tendinopathy (66 participants) demonstrated improved short-term physical function on the Patient-Rated Tennis Elbow Evaluation (MD = −10.78, 95% CI −16.88 to −4.67; I^2 = 52%), although sensitivity analysis was imprecise. Strength outcomes were inconsistent because of heterogeneous measures and follow-up periods and were not pooled. Overall, BFR produced outcomes comparable to heavy-load resistance training and showed selective advantages over sham or non-BFR low-load exercise.

Conclusion: BFR-assisted low-load exercise may improve short-term diagnosis-specific function and selected strength outcomes but does not consistently reduce pain or outperform well-designed heavy-load rehabilitation. Larger, high-quality trials with standardized BFR protocols and core outcome measures are needed.

Keywords: blood flow restriction; tendinopathy; rehabilitation; pain; physical function; muscle strength; meta-analysis

How to cite this article: Alkazaleh H, Alsmear OM, Kamel SM, Hassan AM. Effectiveness of Blood Flow Restriction Training on Pain, Physical Function, and Muscle Strength in Patients with Tendinopathy: A Systematic Review and Meta-Analysis. Int J Drug Deliv Technol. 2026;16(70s): 1358. DOI: 10.25258/ijddt.16.70s.146

1. Introduction

Tendinopathy is a load related disorder that is characterised by pain, decreased function, and decreased tolerance to sport, work and daily activity. It exhibits changes in tendon matrix, vascular and nerve characteristics, pain mechanisms and neuromuscular function, and imaging changes are not necessarily related to the severity of the symptoms (Millar et al., 2021). Chronic tendinopathy is a problem that plagues not only athletes, but the general population as well and can have a significant personal and socioeconomic impact (Hopkins et al., 2016). Rehabilitation therefore must be geared toward decreasing the signs and symptoms and restoring the muscle-tendon unit's ability to withstand an increasing mechanical load.

Progressive resistance exercise is a mainstay of conservative treatment. Eccentric, combined eccentric-concentric and heavy slow resistance programmes have been shown to have beneficial effects on pain and patient-reported function; however, no one type of programme has been consistently shown to be superior across tendon sites (Irby et al., 2020; Lim & Wong, 2018; Malliaras et al., 2013). With this in mind, the size and duration of loading will affect the adaptation of the tendon, and hence relatively high resistances will be beneficial as long as they are tolerated (Bohm et al., 2015). But, with painful or irritable phases, patients with significant weakness or the inability to participate due to joint stress, high-load exercise may be challenging. Thus, an intervention with a lower load that still provides a significant muscle stimulus may have clinical potential.

Blood flow restriction (BFR) training is a form of exercise that involves low-load exercise (typically 20-40% of 1RM) and applying external cuff pressure to partially restrict blood flow to the muscles while maintaining a certain level of blood flow. This can lead to a metabolic stress and fatigue which can enhance motor-unit recruitment and strength and hypertrophy adaptations at lower external loads (Hughes et al., 2017; Patterson et al., 2019). This mechanism is attractive and renders BFR appealing in the rehabilitation of tendinopathy, but gains in muscle structure and mechanics may not be the products of tendon structure and mechanics being restored. There are gaps in adverse events reporting, and the pressure, contraindication screening and monitoring should be tailored to each individual in order to be safe.

The results from clinical trials are inconclusive. All three RCTs, on lateral elbow tendinopathy, rotator cuff tendinopathy, and patellar tendinopathy, reported positive results with BFR, with some trials reporting greater improvements in pain and disability (Karanasios et al., 2022) and others reporting similar results as either non-BFR or heavy-load rehabilitation (Hjortshoej et al., 2025; Kara et al., 2024). However, other studies have demonstrated minimal or inconsistent, acute hypoalgesic effects and no long-term superiority (Karanasios et al., 2026; Lear et al., 2025; Park et al., 2026). Small samples and the variability in tendon site, comparator, cuff pressure, dose of exercise, outcome instrument and follow-up makes interpretation difficult.

Whilst previous reviews have reported BFR in healthy tendon and tendon rupture and tendinopathy, these reviews have not offered a focused pooled estimate reporting BFR in clinically diagnosed tendinopathy (Burton & McCormack, 2022; Öberg et al., 2025). The main aim of this review was to assess if BFR exercise improves pain, diagnosis specific physical function and muscle strength in adults with tendinopathy when compared to sham BFR, exercise without BFR, conventional rehabilitation or heavy-load resistance exercise. The hypothesis was that BFR would result in better outcomes than low load or conventional rehabilitation without BFR, and generate effects similar to heavy-load training in cases of poor tolerance of high external loads.

2. Literature Review

2.1 Tendinopathy as a Disorder of Load Tolerance

More recent models of tendinopathy have suggested that they are a spectrum of responses in tissues following loading, rather than being a single inflammatory lesion. The reactive change, tendon dysrepair and degenerative pathology can occur simultaneously and symptoms are influenced by irritability, loading history, functional demands and individual risk factors (Cook & Purdam, 2009; Cook et al., 2016). This framework is for progressive, symptom guided loading and not prolonged rest as both underloading and overloading of a tendon can disrupt the balance of tendon homeostasis and decrease the ability to tolerate mechanical loading (Magnusson et al., 2010).

Clinical outcomes to be judged on individual domains. Although these are all interconnected, pain, patient-reported disability, muscle performance and imaging findings are not interchangeable and patients may achieve a satisfactory clinical outcome despite imaging findings of structural changes (Malliaras et al., 2013; Millar et al., 2021). Therefore, changes in thickness/vascularity of the tendons cannot be presumed to be recoveries. In this review, information from pain during a tendon-loading task, region-specific questionnaires that have been validated and objective strength measures was prioritised. This is important for BFR, as some improvement in muscle performance can occur prior to tendon adaptation.

2.2 Exercise-Based Rehabilitation and the High-Load Challenge

Although eccentric loading has been a staple of exercise programmes, a combination of eccentric-concentric exercise and heavy slow resistance have been shown to benefit pain and function. Outcomes appear more dependent on progressive exposure to enough, tolerable load than on a single contraction style and significant variability exists in intensity, frequency, guidelines for pain monitoring, and time (Irby et al., 2020; Lim & Wong, 2018; Malliaras et al., 2013). Heavy slow resistance and eccentric exercise have proven to be equally effective in the long term in Achilles tendinopathy, albeit with varying degrees of adherence and satisfaction (Beyer et al., 2015). These results suggest individualised loading instead of using a single loading protocol.

Not all patients, however, or at all stages of rehabilitation are able to withstand heavy resistance. The load may not be possible due to pain related inhibition, high irritability, joint symptoms, fear of movement or marked weakness. If symptoms persist, they can become worse and that can also affect adherence. Low-load BFR may thus serve as an initial approach, a supplementation or a transitional method prior to moving onto higher load velocities and energy storage loading. It should NOT be thought of as a complete replacement for later tendon specific loading because when high-demand work or sport is required, the rapid production of force and the ability to store elastic energy is dependent on the tendon (Cook et al., 2016; Malliaras et al., 2013).

2.3 Physiological Rationale for Blood Flow Restriction Training

BFR alters the physiological requirements of low load exercise by causing venous pooling, relative hypoxia, metabolite build up and increased fatigue. These factors contribute to higher recruitment of high threshold motor units, and activation of pathways related to muscle protein synthesis, which may explain why low load BFR has been shown to result in greater strength and hypertrophy gains than load matched exercise without restriction (Hughes et al., 2017; Patterson et al., 2019). The suggested clinical benefit for tendinopathy is to increase the strength of the muscles around the tendon, decrease the resistance to movement and, potentially, peak tendon and/or joint stress. There may be added benefits of exercise-induced hypoalgesia and confidence with loading, but these mechanisms are still poorly understood in populations of symptomatic tendons.

The effectiveness is likely to be influenced by protocol characteristics. The absolute cuff pressure produces different restriction in different people due to variations in blood pressure, tissue makeup, cuff width and limb circumference. Consequently, pressure is recommended to be based on individual arterial occlusion pressure (IOAP), and it must be clearly reported: the load of the exercise; the number of repetitions; the time of rest between each repetition; continuous or intermittent inflation; and the number of times it is used per week (Patterson et al., 2019). There is insufficient standardisation to allow for across trials comparison and this may be a source of heterogeneity. While musculoskeletal rehabilitation seems to be safe, discomfort, bruising, numbness, cardiovascular intolerance, and rare complications do occur and should be screened for contraindications, monitored for symptoms and supervised by trained health care professionals (Minniti et al., 2020).

2.4 Evidence for Tendon and Clinical Adaptation

Biological plausibility can be derived from evidence from healthy tendons, but cannot be used to determine clinical effectiveness. Low-load BFR with prolonged duration was able to elicit morphological and mechanical changes that were similar to high-load training in healthy Achilles tendon (Centner et al., 2019). A later systematic review also indicated BFR can lead to an increase in tendon cross sectional area, and that BFR can have longer-term effects similar to high load exercise, however with limited evidence, dose dependent, and in asymptomatic participants (Bechan Vergara et al., 2024). The results of this study show that this decrease in external load does not necessarily mean that there is a decrease in tendon stimulus, and that the improvements in healthy tendons are not necessarily directly transferred to tendons that cause persistent pain, impaired function, and altered load tolerance.

Scoping reviews of the evidence that focus upon the tendon have noted that clinical evidence is encouraging and varied. Various cuff systems, pressures, exercise doses, and outcomes have been used in various studies, and various types of tendon rehabilitation have been synthesized together, such as healthy tendons, tendinopathy, and tendon rupture rehabilitation (Burton & McCormack, 2022; Öberg et al., 2025). There are a number of uncontrolled studies and case reports which report improvement in pain, function or strength, but the design of these cannot distinguish the effects of the intervention from natural recovery, co-intervention, expectation or regression to the mean. Controlled comparisons are thus needed to ascertain if BFR is beneficial in addition to exercise.

Comparative trials exhibit pattern of outcome- and comparator-dependency. Active BFR was more effective than sham BFR in lateral elbow tendinopathy for disability, selected pain outcomes, pain-free grip strength and perceived recovery (Karanasios et al., 2022). But, there was no superior pressure-pain-threshold response to a single-session crossover trial and longer-term or pragmatic trials did not consistently show an additional benefit over conventional or heavy-load therapy (Karanasios et al., 2026; Lear et al., 2025; Park et al., 2026). BFR led to better results in muscle-thickness and internal-rotation strength outcomes, but not pain or overall function, in rotator cuff tendinopathy (Kara et al., 2024). Similarly, low-load BFR and heavy slow resistance resulted in similar short- and long-term effects on pain and VISA-P (Hjortshoej et al., 2025) in chronic patellar tendinopathy. Therefore, BFR might be a suitable alternative or addition for lower load exercise, however, there is no consistent superiority of BFR by tendon location or outcome.

2.5 Knowledge Gap and Rationale for Quantitative Synthesis

There is still a lack of clarity to the evidence base as trials are still small and vary in terms of tendon location, length of symptoms, pressure of the BFR, dose of exercise, comparator, outcome instrument, and follow-up. The aggregation of all the studies in one estimate would thus lead to a loss of clinically relevant information. The previous reviews were also a mix of symptomatic tendinopathy and healthy tendon as well as tendinous rupture, which also limited the direct clinical inferences (Burton & McCormack, 2022; Öberg et al., 2025). To assess if BFR influences pain, physical function and muscle strength differently or not, a tendinopathy specific review with outcome- and time-specific pooling should be performed, and explicitly account for heterogeneity, risk of bias and imprecision.

3. Methods

3.1 Design and Reporting Framework

This systematic review and meta-analysis follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and methodological guidance in the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2024; Page et al., 2021). The review question was formulated according to four aspects: population, intervention, comparator, outcome and study-design. An analytical dataset was used for data extraction. For this reason, the PRISMA flow diagram, certainty assessment and some portions of study selection presented in this review were interpreted cautiously, and will need to be updated prior to journal submission, given that database-specific search yields and completed duplicate-review fields and domain-level risk-of-bias judgments were not fully available.

3.2 Eligibility Criteria

Eligible participants were adults with a clinical diagnosis of tendinopathy (involving any anatomical region). Studies of healthy tendons, acute tendon rupture, postoperative tendon repair or nonspecific regional pain without the diagnosis of tendinopathy were not included in the primary synthesis. The intervention was active blood flow restricted exercise/rehabilitation. Comparators were sham BFR, same exercise without BFR, physical therapy, eccentric exercise, and heavy slow resistance training, all of which were eligible. Primary outcomes were pain, physical function/disability for diagnosis, and muscle strength. Randomized and controlled comparative clinical studies could be included in quantitative synthesis. For narrative context and safety, uncontrolled feasibility studies, case series and case reports were kept.

3.3 Information Sources and Search Strategy

The search window was limited to 15 years, from 21 July 2011 to 21 July 2026 and the searches were planned on MEDLINE/PubMed, Embase, CINAHL, SPORTDiscus, Scopus, Web of Science, CENTRAL, PEDro, and trial registries with backward and forward citation chasing. Search concepts were the terms blood flow restriction (BFRT, KAATSU, occlusion training) and tendinopathy, along with the terms for tendon regions. At the initial search stage no language restriction was planned. But, the database-specific results, and the final search dates, were not fully available. Thus, the available evidence identified is a description of that evidence, and not necessarily a complete, reproducible search. The complete search record, deduplication report and the counts of each database are still necessary.

3.4 Study Selection and Data Extraction

Records were compiled in a systematic screening log that contained the decisions for inclusion in the title/abstract and full text and reasons for exclusion, as well as study identifiers. To minimize double counting, one effect for each study, outcome domain and prespecified time window was selected. Short term outcomes were those that had a time range of 12 weeks or less, medium term outcomes were those that had a time range of more than 12 to 26 weeks, and long term outcomes more than 26 weeks. Details on design, sample size, tendon region, intervention and comparator characteristics, follow-up, outcome instrument, group means and standard deviations, adjusted effects, standard errors, confidence intervals and reporting limitations were taken from each study. If both an adjusted effect and 95% confidence interval (CI) were provided, the standard error (SE) was computed as the width of the CI/3.92. Change-score mean differences were computed from the group change scores and the standard error was estimated as the square root of the sum of the two group standard errors divided by the sum of the two group sample sizes.

3.5 Risk of Bias and Certainty of Evidence

The planned tool for randomized parallel and cross over trials was the updated Cochrane risk of bias tool (RoB 2) which included assessment of randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting (Sterne et al., 2019). The GRADE domains of risk of bias, inconsistency, indirectness, imprecision and publication bias were planned for assessing certainty (Schünemann et al., 2024). No formal ratings were produced as completed RoB 2 assessments were unavailable and no supporting information was available. The results thus provide information on reporting concerns without offering an unsubstantiated traffic light plot or certainty grade.

3.6 Effect Measures and Statistical Analysis

Harmonization of effects was performed in order to make a negative mean difference represent benefit from BFR for pain and disability outcomes while a positive effect represent benefit for strength. Pain on a numerical 0–10 scale was combined as a mean difference. As the same instrument was used, the patient-rated tennis elbow evaluation (PRTEE) outcomes were pooled as a mean difference. Generic inverse variance (REvl) restricted maximum likelihood estimation was used to fit random-effects models. Cochran's Q, tau-squared and I-squared were used to summarise statistical heterogeneity. The primary forest plots had 95% Wald intervals plotted; a small-sample sensitivity analysis was performed using Hartung-Knapp intervals. When the timing, the study design or the unit of measure for acute pressure-pain threshold, long-term, or muscle-strength outcomes was clinically incompatible, the data were not pooled. Funnel plots, Egger tests and meta-regression were not performed due to the number of studies included in each analysis being less than 10.

4. Results

4.1 Study Selection

Twenty-one records were found by searching the database, trial registers, citation searching, and other additional search techniques. There were no duplicate records found. After title and abstract screening, two records were excluded, resulting in 19 reports being retrieved. There was one report that was not retrievable or verifiable and 18 full-text reports were evaluated for eligibility. Full-text screening excluded eight reports - four were of an ineligible population, three were registry and protocol reports with no peer-reviewed results, and one had unresolved publication/reporting concerns. Ten studies fulfilled the eligibility criteria and were included in the qualitative synthesis, of which six were comparative studies, and four uncontrolled or case-based studies. Five comparative studies provided data for the quantitative synthesis while one comparative study was included in the narrative synthesis only because it did not have enough numerical outcome data to analyze quantitatively. The steps taken to select the studies are illustrated in Figure 1.

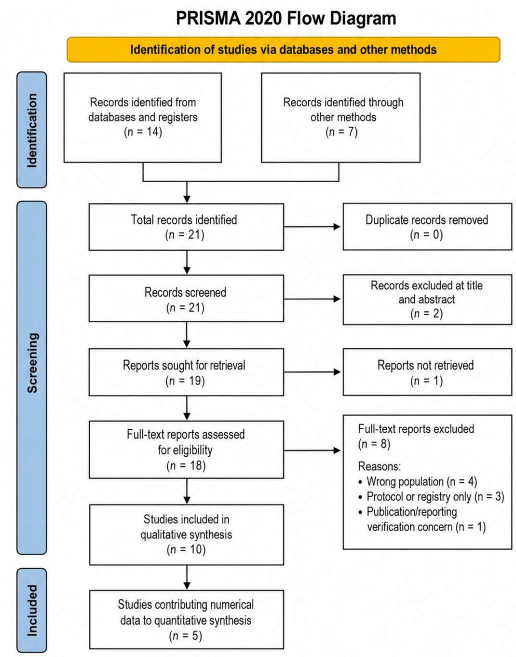

Figure 1. PRISMA 2020 flow diagram for study identification, screening, eligibility assessment, and inclusion.

4.2 Study Characteristics

A total of 10 studies were included, with 5 lateral elbow, 3 patellar tendon, 1 rotator cuff and 1 gluteal tendinopathy studies being clinically diagnosed. Six were comparative randomized designs, with four being feasibility, case-series, or case-report designs. Sample sizes were as small as 1 participant (case report) and as large as 46 participants (larger randomized trial). BFR programmes varied by duration, from one exercise session to 12 weeks, and either compared to sham restriction, matched exercise without BFR, conventional therapy, heavy slow resistance training, or standard heavy-load physical therapy. Table 1 provides an overview of the design, population, intervention, comparator group, follow-up and synthesis role of each of the included studies. Figure 2 displays the number of the included evidence by tendon area.

Table 1

Characteristics of studies included in the qualitative synthesis

Study	Tendon/region	Design (N)	BFR intervention	Comparator	Follow-up / role
Karanasios et al. (2022)	Lateral elbow	Sham-controlled RCT (46)	Low-load wrist-extensor exerci	Matched exercise plus	6 and 12 weeks; quant

Study	Tendon/region	Design (N)	BFR intervention	Comparator	Follow-up / role
			se plus active BFR	sham BFR	itative
Kara et al. (2024)	Rotator cuff	Assessor-blinded RCT (28)	Eight-week shoulder rehabilitation plus BFR	Same rehabilitation without BFR	8 weeks; narrative
Karanasios et al. (2026)	Lateral elbow	Cross-over RCT (20)	Single wrist-extensor session plus BFR	Identical exercise without BFR	Immediate; mechanistic
Hjortshoej et al. (2025)	Patellar tendon	RCT (36)	Twelve-week low-load BFR programme	Heavy slow resistance training	12 and 52 weeks; quantitative
Park et al. (2026)	Lateral elbow	Pilot RCT (22)	Conventional therapy plus BFR	Conventional therapy	6 weeks; quantitative
Lear et al. (2025)	Lateral elbow	Open-label RCT (41)	Low-load BFR physical therapy	Standard heavy-load physical therapy	End of therapy and 12 months; quantitative
Høgsholt et al. (2022)	Gluteal tendon	Feasibility study (16)	Low-load BFR exercise plus education	No comparator	8 weeks; narrative
Skovlund et al. (2020)	Patellar tendon	Case series (7)	Low-load BFR resistance training	No comparator	3 weeks; narrative
Cuddeford and Brumitt (2020)	Patellar tendon	Case report (2)	BFR-based in-season rehabilitation	No comparator	12 weeks; narrative
Karanasios et al. (2023)	Lateral elbow	Case report (1)	Wrist-extensor BFR within multimodal therapy	No comparator	3, 6, and 12 weeks; narrative

Note. BFR = blood flow restriction; RCT = randomized controlled trial. Only comparative studies with sufficiently compatible numerical outcomes contributed to meta-analysis.

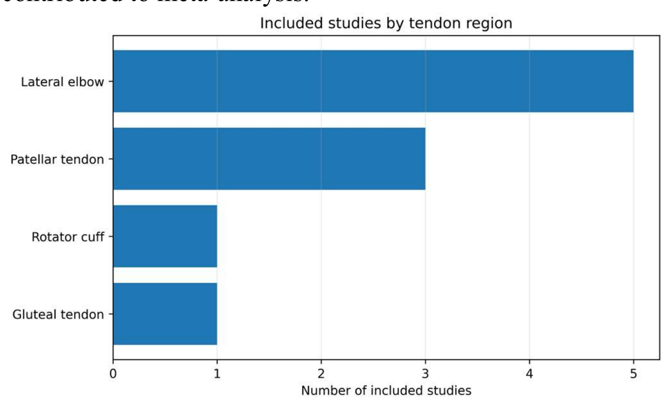

Figure 2. Distribution of studies retained in the qualitative synthesis by tendon region.

4.3 Risk-of-Bias and Reporting Considerations

Although all six confirmative studies were randomized, there were significant reporting issues. Several exercise comparisons were blinding was incomplete or couldn't be done, the pilot trial obtained paired variance data for optimal synthesis, incomplete or no group descriptive data provided with the open-label trial, and the cross-over trial provided two withdrawals requiring per-protocol analysis. Complete outcome data were not fully available for the following prespecified clinical outcomes in the rotator cuff and patellar trials: Complete numerical information was not available for all of these prespecified clinical outcomes from the available reports in the rotator cuff and patellar trials. No overall risk of bias ratings are provided, as completed RoB 2 domain judgments and supporting information was unavailable. The evidence should then be interpreted cautiously, pending completion of duplicate RoB 2 assessment.

4.4 Pain

A numerical pain scale (0-10) was used for pain outcomes in three short-term studies including 102 analysed participants. However, the random-effects pooled mean difference was -0.44 points (95% CI -1.27 to 0.40), so that there does not appear to be any clear short term benefit of BFR over the combined comparators. Heterogeneity was moderate (I^2 = 46%, tau² = 0.25; Q = 3.70, p = .157). Effect ranged from clinically relevant benefit in the sham-controlled lateral elbow trial, to no between group difference in the patellar and pilot lateral elbow trials. The Hartung-Knapp sensitivity interval was significantly more liberal (-2.39 to 1.52), reflecting the lack of precision of only three studies. The study-specific estimates and the pooled effect are shown in figure 3.

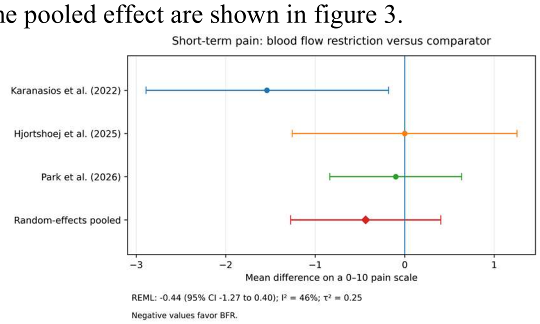

Figure 3. Random-effects meta-analysis of short-term pain measured on a 0–10 scale. Negative values favour BFR.

The long-term effects were also unknown. The between-group mean difference of the patellar tendinopathy trial was around 0.70 points at 52 weeks (95% CI -0.69 to 2.09), while the open-label lateral elbow trial reported a pain difference at 12 months of 0.23 points (95% CI -2.10 to 2.56). Both estimates failed to show superiority of BFR. The acute cross-over trial did not show any significant differences between local or remote pressure-pain thresholds following one BFR session and these mechanistic outcomes were not correlated with clinical pain scales.

4.5 Physical Function

Sixty-six subjects were analysed from two short-term lateral elbow trials that reported outcomes that were suitable for pooling with PRTEE. The REML random-effects mean difference was -10.78 points (95% CI -16.88 to -4.67) in favour of BFR, with moderate heterogeneity (I^2 = 52%, tau² = 11.44; Q = 2.09, p = .149). The point estimate was close to the 11-point threshold that was deemed clinically relevant in the sham-controlled study. However, only 2 studies provided data and Hartung-Knapp sensitivity interval was very large (-50.34 to 28.78), and one of the studies was a small pilot study. The apparent benefit is demonstrated in Figure 4 along with the study-level estimates and the pooled result, so should be viewed in the context of it being a potentially good signal, but not definitive evidence.

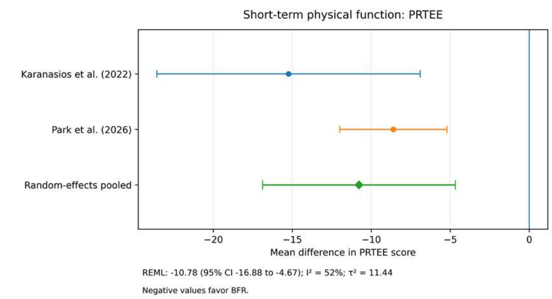

Figure 4. Random-effects meta-analysis of short-term PRTEE physical-function scores. Negative values favour BFR.

On the open label lateral elbow trial, there was no clear difference in function at 12 months (PRTEE mean difference -4.32, 95% CI -17.81 to 9.17). In both the patellar tendinopathy trial and the rotator cuff trial, clinically relevant improvement in VISA-P and shoulder symptoms and function, respectively, were reported in both the BFR and heavy slow resistance groups but there was no reported between group advantage. Therefore, the short-term apparent PRTEE benefit was not found to be reproducible throughout tendon regions, comparator types or more extended follow-up.

4.6 Muscle Strength

Strength outcomes were not pooled as the studies available used pain-free grip-strength ratios, kilograms of grip force, shoulder isokinetic and knee-extensor torque at various time points. No sham-controlled lateral elbow trial was identified that compared the pain-free grip-strength ratio at 6 weeks, and BFR was favoured (mean difference 0.20, 95% CI 0.06 to 0.34). In the acute cross-over trial, an adjusted post hoc contrast showed a favour towards BFR in the affected-side pain-free grip strength (4.4 kg, 95% CI 1.9 to 6.9), however, the overall interaction was not significant and the authors gave caution that the result was dependent on baseline characteristics. The pilot lateral elbow trial had a Hedges g of 0.74 (95% CI -0.17 to 1.65) indicating benefit or no effect. Both the open-label and patellar trials showed no significant difference in pain-free or maximum grip strength, respectively, and the patellar trial showed similar strength gains between low-load BFR and heavy slow resistance. The rotator cuff trial concluded that BFR led to a higher increase in one measure of internal-rotation strength but not in other shoulder-strength measures. The direction and availability of comparative evidence is represented in Figure 5 for the domains of pain, physical function and muscle strength.

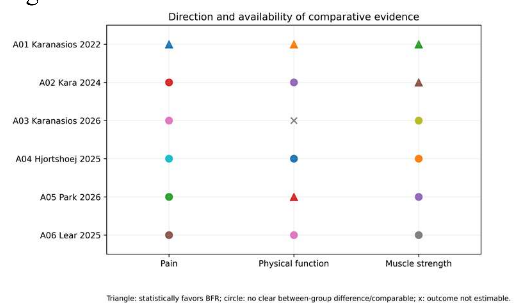

Figure 5. Direction and availability of comparative evidence for pain, physical function, and muscle strength.

4.7 Sensitivity, Small-Study Effects, and Interpretation

In the main synthesis, an unverified patellar tendinopathy trial with full numerical results was excluded due to the need for independent verification of the processes of trial registration, attrition handling, and results reporting. Only sensitivity analysis using verified data should be included to be appropriate with the data. Formal evaluation of small study effects was not conducted as there were less than 10 pooled studies. Overall, there is some evidence that BFR may benefit the short-term diagnosis-specific functional outcomes and some selected strength outcomes, but not that BFR consistently reduces pain or is superior to heavy-load rehabilitation. Due to the small sample sizes, the heterogeneous comparators, incomplete reporting, and the incomplete search and risk-of-bias processes, the conclusions are limited.

5. Discussion

5.1 Principal Findings

The current systematic review suggests that BFR exercise could be potentially useful in the rehabilitation of tendinopathy depending on the outcomes. There was no definite reduction in pain in the short-term in the pooled analysis when compared to sham BFR, conventional therapy and heavy slow resistance training. However, short-term PRTEE scores were in favour of BFR in lateral elbow tendinopathy with a pooled effect towards the clinically meaningful threshold reported in the largest sham-controlled trial. Other strength outcomes (selected) also showed a preference for BFR, but for these outcomes data could not be pooled due to the significant differences in assessment schedules, muscle groups and instruments used. This evidence indicates that it is not a simple case of either BFR is effective or not: BFR may be more beneficial compared to low-load exercise and/or sham restriction and appear to be similar to heavy-load resistance exercise if both can be performed.

Clinically important is the fact that there is no consistent pooled pain effect. Despite the potentially vascular origin of pain in tendinopathy, it is likely that pain will not be homogenous as it is influenced by load tolerance of the tissues, nociceptive processing, expectations and contextual features of rehabilitation. The sham controlled lateral elbow trial revealed a significant effect, while the patellar trial revealed comparable results between BFR and heavy slow resistance with progressive exercise being the common denominator, and BFR changing the load needed to provide progressive exercise. Immediately after the cross-over trial, it was also not found that there was an improvement in hypoalgesia after one session. To this end, BFR should not be considered first and foremost an analgesic method, but as a tool to allow for a muscular loading at a lower external load where it is painful or temporarily not possible to do heavy exercise.

5.2 Interpretation and Clinical Implications

The current results are consistent with previous reviews on tendons focusing on the clinical results which showed promising clinical outcomes but varying structural and mechanical responses of tendons (Burton & McCormack, 2022; Öberg et al., 2025). It is possible that BFR can induce a greater metabolic stress and motor-unit recruitment at loads typically employed in conventional strength training that may account for the muscle-performance adaptations at loads that do not involve high joint or tendon stresses (Patterson et al., 2019). But tendon adaptation is still load-, dose- and time-dependent and muscular changes are not necessarily correlated with normalized tendon structure and restored energy storage capacity (Bohm et al., 2015). Thus, BFR can more accurately be thought of as a loading strategy in the context of a staged rehabilitation pathway, rather than an alternative to tendon specific loading.

In the clinical setting, BFR could be most useful in early rehab, an irritable stage of rehab, if a patient is significantly weak, and/or if high load exercise is exacerbating symptoms. The similar results found between the low-load and heavy slow resistance training in patellar tendinopathy allow clinicians to customize the external load while still providing an adequate training stimulus. If the patient's goals call for high level or high rate tendon function, progress toward the higher levels of resistance, functional loading, and sport-specific energy storage exercises are still required. Implementation should be accompanied by individualized occlusion pressure, proper cuff size, an assessment of vascular and medical contraindications and a monitoring for symptoms and adverse events (Minniti et al., 2020; Patterson et al., 2019).

5.3 Strengths and Limitations

A strength of this review was the separation of the outcomes of pain and physically related function and muscle strength, rather than lumping clinically different outcomes together to give one estimate. Harmonization was by direction, analyses were conducted by scale of outcomes and by follow-up, and sensitivity intervals by small samples were added to random-effects models. The synthesis also excluded comparative trials that were uncontrolled feasibility studies, or case reports, and minimized the chance of uncontrolled improvement within a group being mistaken as comparative efficacy.

There are a number of limitations that significantly lower levels of confidence in the estimates. The evidence base was limited in size, anatomically heterogeneous and consisted mainly of lateral elbow studies. Comparators varied from sham restriction to heavy-load rehabilitation and there was a lack of uniformity in BFR pressure, the dose, frequency and length of the interventions. Some outcomes had a degree of missing numerical data and only two or three studies contributed to each meta-analysis; the very wide Hartung-Knapp intervals show the extent to which the apparent effects vary from study to study. Formal RoB 2 and GRADE judgments were not possible due to incomplete available information and counts in PRISMA require verification and verified using complete database records and duplicate screening. We were unable to make a statistical assessment of publication bias. The limitations of these means that the favourable function estimate should not be treated as definitive, but rather as hypothesis-confirming.

5.4 Research Implications

Future trials need to be prospectively registered, sufficiently powered and trial designs need to be focused on standardised core outcomes for tendons. They should provide individualised data on arterial occlusion pressure, cuff properties, intensity of exercise, total volume of exercise, adherence, co-interventions and adverse events to the extent that they would be adequate for replication. Direct comparisons should help to elucidate if BFR provides an advantage over an identical low load programme and whether or not BFR is non-inferior to heavy slow resistance in patients that are unable to tolerate high loads. The durability should be confirmed and clinically relevant effect modifiers should be identified by longer follow-up and prespecified subgroup analyses.

6. Conclusion

BFE are a novel form of LLE and could be a useful tool for the rehabilitation of tendinopathy patients, especially when high external loads are poorly tolerated. While there is some evidence that this may be beneficial in the short term for diagnosis-specific function and selected strength outcomes, heavy-load resistance training does not appear to have any clear advantage over this intervention in reducing pain, and there is no consistent pooled advantage. In the absence of any clear evidence from the limited number of small, methodologically varied trials, BFR should be considered as an individualized strategy, and an alternative technique to conventional loading, as part of a tendon rehabilitation program using progressive loading. Well designed and standardized comparative trials are required prior to solid clinical recommendations.

References

Bechan Vergara, I., Puig-Diví, A., Amestoy Alonso, B., & Milà-Villarroel, R. (2024). Effects of low-load blood flow restriction training in healthy adult tendons: A systematic review and meta-analysis. Journal of Bodywork and Movement Therapies, 39, 13–23. https://doi.org/10.1016/j.jbmt.2023.11.048

Beyer, R., Kongsgaard, M., Hougs Kjær, B., Øhlenschlæger, T., Kjær, M., & Magnusson, S. P. (2015). Heavy slow resistance versus eccentric training as treatment for Achilles tendinopathy: A randomized controlled trial. The American Journal of Sports Medicine, 43(7), 1704–1711. https://doi.org/10.1177/0363546515584760

Bohm, S., Mersmann, F., & Arampatzis, A. (2015). Human tendon adaptation in response to mechanical loading: A systematic review and meta-analysis of exercise intervention studies on healthy adults. Sports Medicine - Open, 1, Article 7. https://doi.org/10.1186/s40798-015-0009-9

Burton, I., & McCormack, A. (2022). Blood flow restriction resistance training in tendon rehabilitation: A scoping review on intervention parameters, physiological effects, and outcomes. Frontiers in Sports and Active Living, 4, Article 879860. https://doi.org/10.3389/fspor.2022.879860

Centner, C., Lauber, B., Seynnes, O. R., Jerger, S., Sohnius, T., Gollhofer, A., & König, D. (2019). Low-load blood flow restriction training induces similar morphological and mechanical Achilles tendon adaptations compared with high-load resistance training. Journal of Applied Physiology, 127(6), 1660–1667. https://doi.org/10.1152/japplphysiol.00602.2019

Cook, J. L., & Purdam, C. R. (2009). Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. British Journal of Sports Medicine, 43(6), 409–416. https://doi.org/10.1136/bjsm.2008.051193

Cook, J. L., Rio, E., Purdam, C. R., & Docking, S. I. (2016). Revisiting the continuum model of tendon pathology: What is its merit in clinical practice and research? British Journal of Sports Medicine, 50(19), 1187–1191. https://doi.org/10.1136/bjsports-2015-095422

Cuddeford, T., & Brumitt, J. (2020). In-season rehabilitation program using blood flow restriction therapy for two decathletes with patellar tendinopathy: A case report. International Journal of Sports Physical Therapy, 15(6), 1184–1195. https://doi.org/10.26603/ijspt20201184

Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2024). Cochrane handbook for systematic reviews of interventions (Version 6.5, updated August 2024). Cochrane.

Hjortshoej, M. H., Juneja, H., Svensson, R. B., Herzog, R. B., Lundgaard-Nielsen, M., Nielsen, F. K., Wulff, M. W., Olsen, A. E., Nybing, J. D., Hansen, P., Petersen, J., Kjaer, M., Aagaard, P., Magnusson, S. P., & Couppé, C. (2025). Effect of low-load blood-flow restricted training versus heavy slow resistance training in unilateral patellar tendinopathy: A randomized clinical trial. Scandinavian Journal of Medicine & Science in Sports, 35(12), Article e70186. https://doi.org/10.1111/sms.70186

Høgsholt, M., Jørgensen, S. L., Rolving, N., Mechlenburg, I., Tønning, L. U., & Bohn, M. B. (2022). Exercise with low-loads and concurrent partial blood flow restriction combined with patient education in females suffering from gluteal tendinopathy: A feasibility study. Frontiers in Sports and Active Living, 4, Article 881054. https://doi.org/10.3389/fspor.2022.881054

Hopkins, C., Fu, S.-C., Chua, E., Hu, X., Rolf, C., Mattila, V. M., Qin, L., Yung, P. S.-H., & Chan, K.-M. (2016). Critical review on the socio-economic impact of tendinopathy. Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology, 4, 9–20. https://doi.org/10.1016/j.asmart.2016.01.002

Hughes, L., Paton, B., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2017). Blood flow restriction training in clinical musculoskeletal rehabilitation: A systematic review and meta-analysis. British Journal of Sports Medicine, 51(13), 1003–1011. https://doi.org/10.1136/bjsports-2016-097071

Irby, A., Gutierrez, J., Chamberlin, C., Thomas, S. J., & Rosen, A. B. (2020). Clinical management of tendinopathy: A systematic review of systematic reviews evaluating the effectiveness of tendinopathy treatments. Scandinavian Journal of Medicine & Science in Sports, 30(10), 1810–1826. https://doi.org/10.1111/sms.13734

Kara, D., Ozcakar, L., Demirci, S., Huri, G., & Duzgun, I. (2024). Blood flow restriction training in patients with rotator cuff tendinopathy: A randomized, assessor-blinded, controlled trial. Clinical Journal of Sport Medicine, 34(1), 10–16. https://doi.org/10.1097/JSM.0000000000001191

Karanasios, S., Korakakis, V., Moutzouri, M., Xergia, S. A., Tsepis, E., & Gioftsos, G. (2022). Low-load resistance training with blood flow restriction is effective for managing lateral elbow tendinopathy: A randomized, sham-controlled trial. Journal of Orthopaedic & Sports Physical Therapy, 52(12), 803–825. https://doi.org/10.2519/jospt.2022.11211

Karanasios, S., Lignos, I., & Gioftsos, G. (2023). Wrist extensor training with blood flow restriction for the management of lateral elbow tendinopathy: A case report. Cureus, 15(2), e35468. https://doi.org/10.7759/cureus.35468

Karanasios, S., Sampsonis, T., Lignos, I., & Gioftsos, G. (2026). The immediate effects of wrist extensor training with blood flow restriction on pain perception in middle-aged patients with lateral elbow tendinopathy: A cross-over randomized controlled trial. Sports Medicine and Health Science, 8(4), 449–456. https://doi.org/10.1016/j.smhs.2025.03.003

Lear, A., Toal, P., Hass, D., McCreary, A., Xiao, H., & Mullen, C. (2025). An open label randomized controlled trial comparing physical therapy with low load blood flow restriction vs. standard physical therapy in treatment of lateral epicondylitis. Physiotherapy Theory and Practice. Advance online publication.

https://doi.org/10.1080/09593985.2025.2562909

Lim, H. Y., & Wong, S. H. (2018). Effects of isometric, eccentric, or heavy slow resistance exercises on pain and function in individuals with patellar tendinopathy: A systematic review. Physiotherapy Research International, 23(4), Article e1721. https://doi.org/10.1002/pri.1721

Magnusson, S. P., Langberg, H., & Kjaer, M. (2010). The pathogenesis of tendinopathy: Balancing the response to loading. Nature Reviews Rheumatology, 6(5), 262–268. https://doi.org/10.1038/nrrheum.2010.43

Malliaras, P., Barton, C. J., Reeves, N. D., & Langberg, H. (2013). Achilles and patellar tendinopathy loading programmes: A systematic review comparing clinical outcomes and identifying potential mechanisms for effectiveness. Sports Medicine, 43(4), 267–286. https://doi.org/10.1007/s40279-013-0019-z

Millar, N. L., Silbernagel, K. G., Thorborg, K., Kirwan, P. D., Galatz, L. M., Abrams, G. D., Murrell, G. A. C., McInnes, I. B., & Rodeo, S. A. (2021). Tendinopathy. Nature Reviews Disease Primers, 7, Article 1. https://doi.org/10.1038/s41572-020-00234-1

Minniti, M. C., Statkevich, A. P., Kelly, R. L., Rigsby, V. P., Exline, M. M., Rhon, D. I., & Clewley, D. (2020). The safety of blood flow restriction training as a therapeutic intervention for patients with musculoskeletal disorders: A systematic review. The American Journal of Sports Medicine, 48(7), 1773–1785. https://doi.org/10.1177/0363546519882652

Öberg, S., von Schewelov, L., & Tengman, E. (2025). The impact of blood flow restriction training on tendon adaptation and tendon rehabilitation: A scoping review. BMC Musculoskeletal Disorders, 26, Article 503. https://doi.org/10.1186/s12891-025-08734-5

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

Park, J.-H., Kim, H., & Lee, M.-M. (2026). Effects of blood flow restriction training combined with conventional physical therapy on pain, muscle architecture, strength, function, and psychosocial outcomes in chronic lateral epicondylitis: A pilot randomized controlled trial. Medical Science Monitor, 32, Article e951969. https://doi.org/10.12659/MSM.951969

Patterson, S. D., Hughes, L., Warmington, S., Burr, J., Scott, B. R., Owens, J., Abe, T., Nielsen, J. L., Libardi, C. A., Laurentino, G., Neto, G. R., Brandner, C., Martin-Hernandez, J., & Loenneke, J. (2019). Blood flow restriction exercise: Considerations of methodology, application, and safety. Frontiers in Physiology, 10, Article 533. https://doi.org/10.3389/fphys.2019.00533

Schünemann, H. J., Higgins, J. P. T., Vist, G. E., Glasziou, P., Akl, E. A., Skoetz, N., & Guyatt, G. H. (2024). Chapter 14: Completing Summary of Findings tables and grading the certainty of the evidence. In J. P. T. Higgins, J. Thomas, J. Chandler, M. Cumpston, T. Li, M. J. Page, & V. A. Welch (Eds.), Cochrane handbook for systematic reviews of interventions (Version 6.5). Cochrane.

Skovlund, S. V., Aagaard, P., Larsen, P., Svensson, R. B., Kjaer, M., Magnusson, S. P., & Couppé, C. (2020). The effect of low-load resistance training with blood flow restriction on chronic patellar tendinopathy—A case series. Translational Sports Medicine, 3(4), 342–352. https://doi.org/10.1002/tsm2.151

Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C. J., Cheng, H.-Y., Corbett, M. S., Eldridge, S. M., Emberson, J. R., Hernán, M. A., Hopewell, S., Hróbjartsson, A., Junqueira, D. R., Jüni, P., Kirkham, J. J., Lasserson, T., Li, T., ... Higgins, J. P. T. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. Cochrane.