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Blood Flow Restriction Training for Tendinopathy Rehabilitation: An Exploratory Review of Tendon Morphology and Functional Outcomes

REVIEWS

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ABSTRACT

Tendinopathy is a prevalent degenerative condition characterized by collagen disorganization, pain, and impaired function. High-load resistance training (HL-RT) is the current standard for promoting tendon adaptation; however, it may not be feasible for all patients. Low-load blood flow restriction training (LL-BFRT) has emerged as a potential alternative that may allow exercise to be performed with lower mechanical loads. The objective was to explore the effects of LL-BFRT on tendon morphology and functional outcomes in individuals with tendinopathy and to identify common training parameters and limitations in the current literature. An exploratory review was conducted, with the study selection process reported using the PRISMA 2020 framework. Databases were searched (Jan 2020–May 2025) for studies assessing LL-BFRT in adult patients. Eligible study designs included randomized controlled trials, feasibility studies, case reports, and case series. Nine studies met the inclusion criteria: 4 randomized controlled trials (RCTs), 1 feasibility study, 1 case series, and 3 case reports. Improvements in pain, muscle strength, and patient-reported functional outcomes were reported across several tendinopathy types, including patellar, lateral elbow, rotator cuff, and gluteal tendinopathy. Ultrasound findings showed inconsistent changes in tendon morphology, with some studies reporting changes in tendon thickness or vascularity. Functional gains were observed even in the absence of morphological changes. Protocols commonly used low-load exercise performed 2–4 sessions per week, although occlusion pressure, exercise volume, and intervention duration varied across studies. No serious adverse events were reported. Heterogeneity in training parameters, small sample sizes, and lack of long-term follow-up limit generalizability. LL-BFRT may have potential for improving functional outcomes in tendinopathy rehabilitation, although the limited and heterogeneous evidence precludes firm conclusions regarding its clinical effectiveness and safety. Further high-quality RCTs with standardized protocols are needed to establish its clinical efficacy and characterize tendon-specific adaptations.

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KEYWORDS:
blood flow restriction training; tendinopathy; low-load resistance training; tendon morphology; functional outcomes; rehabilitation

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HIGHLIGHTS

1. Low-load blood flow restriction training (LL-BFRT) was associated with improvements in pain and functional outcomes across several studies in individuals with tendinopathy.
2. Tendon morphological responses to LL-BFRT remain unclear, with limited and heterogeneous evidence across the included studies.
3. LL-BFRT may represent a useful low-load rehabilitation approach when high mechanical loads are not well tolerated, although further high-quality research is required.

INTRODUCTION

Tendinopathy is a degenerative condition induced by repetitive overload, impairing quality of life and physical function (Hopkins et al., 2016). It causes pain, functional deficits, and structural disorganization, such as disrupted collagen architecture (Millar et al., 2021). Accounting for up to 30% of musculoskeletal disorders (Canosa-Carro et al., 2022), Tendinopathies are particularly prevalent in athletes, with patellar tendinopathy affecting elite athletes (Lian, Engebretsen and Bahr, 2005; Nutarelli et al., 2023). In Achilles and patellar tendinopathy rehabilitation, high-load resistance training (HL-RT) is considered the standard for promoting tendon adaptation (Nakamichi and Asahara, 2024).

Resistance training enhances tendon stiffness and thickness via mechanotransduction, which stimulates fibroblastic collagen synthesis and reorganization (Magnusson, Hansen and Kjær, 2003; Nakamichi and Asahara, 2024). These HL-RT–induced adaptations improve tendon strength, reduce pain, enhance motor function, and protect against overuse injuries (Pringels et al., 2025). However, high-load resistance training may not be well tolerated by all individuals, particularly those recovering from injuries or with conditions that limit their ability to tolerate high mechanical loads (Abe et al., 2012). Therefore, alternative resistance training modalities are needed for individuals contraindicated for HL-RT, to provide similar benefits without exacerbating symptoms or joint stress (Centner et al., 2019).

Blood Flow Restriction Training (BFRT) is a promising strategy in musculoskeletal rehabilitation (Hughes et al., 2017; Nitzsche et al., 2021). It involves performing low-load resistance training [20–30% one-repetition maximum (1RM)] while applying pneumatic or elastic cuffs to restrict arterial inflow and occlude venous return (Lorenz et al., 2021). This induces local hypoxia, promoting metabolic stress, angiogenesis, motor unit recruitment, and anabolic hormone release (Patterson et al., 2019). Notably, low-load blood flow restriction (LL-BFR) at 20%–30% 1RM elicits adaptations comparable to HL-RT at 70–85% 1RM without BFR (Ferlito et al., 2020; Grantham, Korakakis and O'Sullivan, 2021).

LL-BFRT has been proposed to influence tendon-related adaptations through mechanisms involving growth factor signaling, collagen synthesis, and responses to mechanical loading; however, evidence for tendon-specific healing effects remains limited (Boesen et al., 2013; Hughes et al., 2017). Studies in healthy tendons have reported structural and mechanical adaptations following BFR-based resistance training; however, the extent to which these findings translate to individuals with tendinopathy remains uncertain (Burton and McCormack, 2022). Additionally, LL-BFRT exerts analgesic effects via opioid and endocannabinoid systems, aiding early rehabilitation (Hughes and Patterson, 2020). It also promotes muscle hypertrophy and modest strength gains, albeit less than HL-RT (Loenneke et al., 2012; Lixandrão et al., 2018). Neovascularization may contribute to tendinopathy-related pain and dysfunction, and emerging evidence suggests that BFRT could modulate this process. A case series in patellar tendinopathy showed reduced vascularization and pain, despite unchanged tendon thickness (Skovlund et al., 2020). This aligns with systematic reviews linking neovascularization to symptom severity (Drew et al., 2014). Although most supporting studies lack control groups, these preliminary findings suggest a potential mechanism underlying BFRT's therapeutic effects in tendon rehabilitation.

This exploratory review explores the potential role of low-intensity BFRT on tendon morphology and functional outcomes in tendinopathy rehabilitation. Due to the limited available evidence and ongoing debate regarding its effectiveness, this exploratory review aimed to explore the therapeutic potential of LL-BFRT as a promising alternative for enhancing tendon recovery in patients with tendinopathy. This exploratory review differs from previous reviews by focusing on clinically diagnosed tendinopathy and incorporating the most recent evidence available as of May 2025, with particular emphasis on tendon morphology, functional outcomes, and training characteristics.

The review has established the following research question: What is the influence of blood flow restriction on functional outcomes and tendon morphology, specifically changes in tendon thickness in individuals with tendinopathy?

METHODS

An exploratory review was conducted to synthesize the available evidence on the use of blood flow restriction training (BFRT) in tendinopathy rehabilitation, with a focus on tendon morphology and functional outcomes. The review aimed to explore the potential role of BFRT in tendinopathy rehabilitation and to identify gaps in the available evidence. The study selection process was reported using the PRISMA 2020 framework (Page et al., 2021).

ELIGIBILITY CRITERIA

The review followed the PICO framework to establish eligibility criteria (see Table 1). Studies were included if they focused on BFRT for tendinopathy and were published in peer-reviewed journals. Randomized controlled trials, feasibility studies, case reports, and case series were eligible for inclusion. Adult human participants (≥18 years) of any sex with tendinopathy were considered.

Table 1 Inclusion criteria.

CRITERION	INCLUSION
Population	Adult patients (≥18 years) with a clinical diagnosis of tendinopathy.
Intervention	Low-load resistance training with blood flow restriction (LL-BFRT).
Comparison	Conventional resistance training, sham-BFR, or no comparator, depending on study design.
Outcome	Tendon morphology outcomes (e.g., thickness and vascularization) and/or clinical and functional outcomes (e.g., pain, strength, and patient-reported functional measures).

Exclusion criteria included non-human or in vitro studies, reviews, editorials, and conference abstracts without full texts, as well as interventions not involving BFR-based rehabilitation. To maintain a focus on tendinopathy populations, studies were excluded if they involved healthy tendons, non-tendinopathy conditions (e.g., tendon ruptures), participants under 18 years, the absence of a clinical diagnosis of tendinopathy.

SEARCH STRATEGY

The literature search was originally conducted in May 2025 and was rerun in August 2026 using the revised search strategy. The prespecified publication window (1 January 2020 to 1 May 2025) was retained. PubMed, Scopus, and Web of Science were searched. Keywords included combinations of terms related to blood flow restriction training (e.g., "blood flow restriction," "blood-flow restriction," BFR, BFRT, KAATSU, "occlusion training," "occlusive training," "ischem* training," "ischem* exercise," and "ischemic preconditioning") and tendon disorders (e.g., tendinopath*, tendinos*, and tendon*) using Boolean operators (AND/OR). The search syntax was adapted to the requirements of each database. Google Scholar was additionally searched as a supplementary source to identify potentially eligible studies not retrieved through the primary database searches. The supplementary search did not identify any additional studies meeting the predefined eligibility criteria. During the initial development of the search strategy, the search was first restricted to randomized controlled trials (RCTs). This restriction was subsequently removed to include other eligible study designs, including feasibility studies, case

reports, and case series. The complete database-specific search strategies and the number of records retrieved from each database are provided in Supplementary File 1.

STUDY SELECTION PROCESS AND DATA EXTRACTION

All search results were imported into Excel, where duplicates were removed. Titles and abstracts of the unique records were independently screened by two reviewers against the predefined eligibility criteria. Discrepancies were resolved through discussion, and if consensus was not reached, a third reviewer was consulted. Full texts were assessed for eligibility based on predefined criteria. No formal critical appraisal or risk-of-bias assessment was conducted as part of this review. This methodological limitation was considered when interpreting the findings and drawing conclusions from the available evidence.

The study selection process was reported in accordance with the PRISMA 2020 guidelines (Page et al., 2021). Extracted data included author, study design, population, intervention, exercise type, duration, training parameters, outcome measures, and results.

The updated database search identified 155 records: 42 from PubMed, 63 from Scopus, and 50 from Web of Science. After removing 72 duplicate records, 83 unique records underwent title and abstract screening, and 72 were excluded. Eleven full-text reports were retrieved and assessed for eligibility based on the predefined criteria. Two reports were excluded at the full-text stage: one ongoing trial/study presentation with no original outcome data and one ineligible study design in which BFR was not evaluated as an intervention in patients with tendinopathy. Nine studies were included in the final review. The supplementary Google Scholar search did not identify any additional eligible studies. The study selection process is summarized in the PRISMA flow diagram (Figure 1).

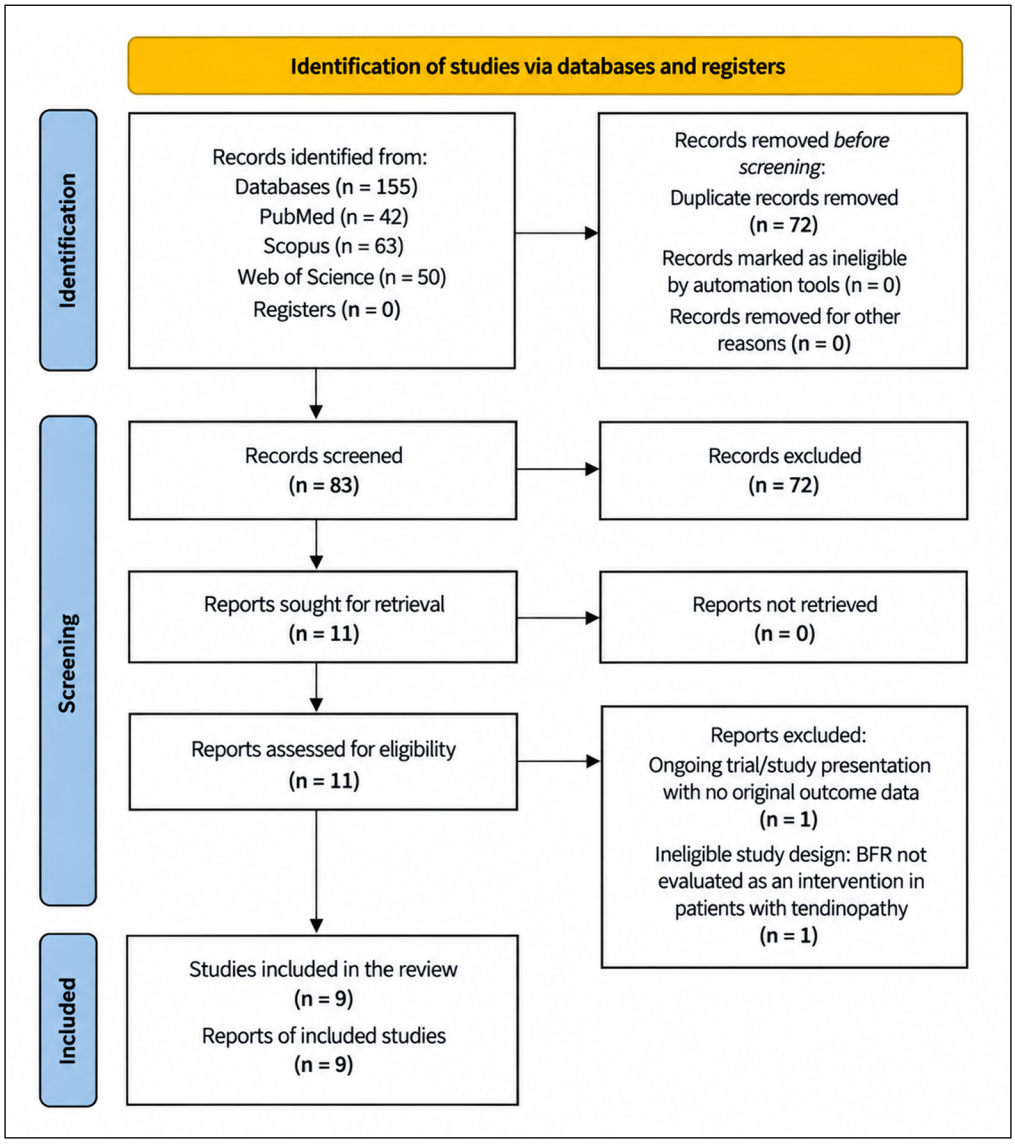


Figure 1 Flow Diagram.

RESULTS

STUDY CHARACTERISTICS

Nine studies published between 2020 and 2025 examined the effects of BFRT on tendinopathy: 4 RCTs, 1 feasibility study, 1 case series, and 3 case reports (Tables 2–3). Pathologies included patellar (2 studies: 1 case report (Cuddeford and Brumitt, 2020), 1 case series (Skovlund et al., 2020)), lateral elbow (4 studies: 3 RCTs (Karanasios et al., 2022, 2025; Kinandana et al., 2023), 1 case report (Karanasios, Lignos and Gioftsos, 2023), gluteal (1 study: 1 feasibility study (Høgsholt et al., 2022)), and rotator cuff (2 studies: 1 RCT (Kara et al., 2024), 1 case report (Begi et al., 2023)). Sample sizes ranged from 1 to 46 participants, totaling 149. Intervention durations varied from a single session to 12 weeks. A summary of study characteristics and outcomes is presented in Tables 2–3.

AUTHOR, STUDY DESIGN, POPULATION	INTERVENTION, EXERCISES, DURATION	TRAINING PARAMETERS	OUTCOMES	MAIN RESULTS
Karanasios et al. 2025 (Karanasios et al., 2025); ***RCT;*** *n* = 20, Lateral elbow tendinopathy	Low-load BFRT: Wrist extensor training, stretches. Single session	***Sets:*** 4***; Reps:*** 30-15-15-15; ***Freq:*** Single-session (cross-over), ***Int:*** Self-selected; ***SL***: 30 minutes; ***Rest:*** 3 min per exercise; ***LOP***: 40%	***PPTs:*** Algometer PFGS; ***Function:*** Dynamometer; ***Cardiovascular response***: Blood Pressure Monitor; ***Perceived exertion:*** Borg Rating of Perceived Exertion Scale	One session of BFR did not show immediate pain relief compared to exercise without BFR. Also, it may have a positive effect on strength, but it depends on patient characteristics
Karanasios et al. 2022 (Karanasios et al., 2022); ***RCT;*** *n* = 46, Lateral elbow tendinopathy	Low-load BFRT: Elbow flexion and extension; pain-monitored exercises (wrist movements in all directions), wall push-ups, ball grips, and wrist stretching exercises, 6 weeks	***Sets:*** 4; ***Reps:*** 30-15-15-15 with elbow extension, and *3 sets* × 10 reps with wrist extension, ***Freq:*** 2 in week; ***Int:*** 30% of 1RM with BFR applied; ***Rest***: 1 min per exercise; ***LOP***: 40–50%	***Pain:*** NRS-P; ***Functional Recovery:*** PRTEQ; ***Function:*** Jamar hand dynamometer, Isometric elbow strength; ***Tendon Thickness:*** US, Global	LLRT-BFR was more effective than sham-BFR in reducing pain and improving function and grip strength in patients with LET. No significant differences in tendon thickness.
Kara et al. 2024 (Kara et al., 2024); ***RCT*** (assessor-blinded); n = 28, Rotator cuff tendinopathy	Low-load BFRT: Biceps curls, scapular retractions, full-can raises, and side-lying external rotations, 8 weeks	***Sets:*** 4; ***Reps:*** 30-15-15-15; ***Int:*** 30% of 1RM with BFR applied; ***Freq:*** 2 sessions/ week, ***LOP***: 50%; ***Rest:*** 30 s per set, 1 min per exercise	***Pain:*** VAS ***Function:*** SPADI, Muscle; Isokinetic dynamometer. ***Muscle Thickness:*** ultrasound Strength Assessment:	No significant difference between BFRT and traditional training in improved shoulder muscle thickness, external rotation strength, pain relief, and Shoulder function.
Kinandana et al. 2023 (Kinandana et al., 2023); ***RCT;*** n = 28, Lateral elbow tendinopathy	Low-load BFR training compared with high-intensity resistance exercise, wrist dorsiflexion and palmar-flexion exercises, 4 weeks	***Sets:*** 4; ***Reps:*** 12 per set; ***Int:*** 20–40% of 1RM (BFR), 70–80% of 1RM (control); ***Freq:*** 3 sessions per week; ***Rest:*** 60 s per set; ***Cuff pressure:*** 1.2 × systolic blood pressure.	***Grip strength***: handgrip dynamometer; ***Functional ability/ disability***: PrTEEQ	Both groups improved grip strength and PrTEEQ scores. Improvements were significantly greater in the BFR group than in the resistance-exercise group ($p < 0.001$).

Table 2 Descriptive data of the included RCTs studies.

Note: **RCT:** Randomized Controlled Trial; **BFRT:** Blood Flow Restriction Training; **Reps:** repetitions; **Freq:** Frequency; **Int:** Intensity; **SL:** Session Length; **1RM:** 1 repetition maximum; **LOP:** Limb Occlusion Pressure; **PPTs:** Pressure pain thresholds; **PFGS:** Pain-free grip strength; **PRTEQ:** Patient-Rated Forearm Evaluation Questionnaire; **VAS:** Visual Analogue Scale; **SPADI:** Shoulder Pain and Disability Index.

Among the included studies, four examined BFRT in isolation (Cuddeford and Brumitt, 2020; Skovlund et al., 2020; Høgsholt et al., 2022; Begi et al., 2023), two compared it with low-load resistance training without BFR (Kara et al., 2024; Karanasios et al., 2025), one compared low-load BFRT with high-intensity resistance exercise (Kinandana et al., 2023), one compared it with sham-BFR (Karanasios et al., 2022), and one incorporated BFRT as an adjunct to a multimodal physiotherapy program (Karanasios, Lignos and Gioftsos, 2023). For upper-limb tendinopathies, BFRT protocols commonly include rotator cuff strengthening (Begi et al., 2023; Kara et al., 2024) or wrist exercises (Karanasios et al., 2022, 2025; Karanasios, Lignos and Gioftsos, 2023; Kinandana et al., 2023). In patellar tendinopathy, the single-leg leg press was the primary exercise (Cuddeford and Brumitt, 2020; Skovlund et al., 2020), while the gluteal protocol involved hip abduction, sidestepping, glute bridging, and squats (Høgsholt et al., 2022).

FUNCTIONAL OUTCOMES

Outcomes included both subjective and objective variables. Pain was evaluated using the Visual Analogue Scale (VAS) (Cuddeford and Brumitt, 2020; Karanasios, Lignos and Gioftsos,

2023; Kara et al., 2024) or the Numeric Pain Rating Scale (NPRS) in four studies (Skovlund et al., 2020; Høgsholt et al., 2022; Karanasios et al., 2022; Begi et al., 2023).

AUTHOR, STUDY DESIGN, POPULATION	INTERVENTION, EXERCISES, DURATION	TRAINING PARAMETERS	OUTCOMES	MAIN RESULTS
Skovlund et al. 2020 (Skovlund et al., 2020) ***Case series;*** *n* = 7 Patellar tendinopathy	Low-load BFRT: Single-leg leg press, knee extension, 3 weeks	***Sets:*** 6; ***Reps:***30-25-20-15-10-5; ***Freq:*** 3 sessions per week; ***Int:*** 30% of 1RM; ***Rest:*** 30 s per set, 1 min per exercise; ***LOP:*** 120 mmHg	***Pain:*** NPRS-P; ***Function:*** VISA-P; Knee extensor strength (MVC- static dynamometry), SLDS ***Tendon vascularity and thickness:*** ultrasound	Intervention was effective for improving clinical outcomes and strength. Pain with SLDS reduced by 50%. Tendon vascularity diminished by 31%. No changes in tendon thickness.
Begi et al. 2023 (Begi et al., 2023) ***Case report;*** *n* = 1 Chronic supraspinatus tendinopathy	Low-load BFRT: Scapular stabilization exercises, rotator cuff strengthening, lower limb aerobic exercise, 4 weeks	***Sets:*** 4; ***Reps:*** 30-15-15-15; ***Freq:*** 3 sessions per week; ***Int:*** weeks 1–2: 15–20% of 1RM, ***Int***: weeks 3–4: 30–40% of 1RM; ***LOP:*** 50% of limb occlusion pressure; ***Rest:*** 30 s–60 s per set	***Pain:*** NPRS; ***PPTs:*** algometer; ***Function:*** Supraspinatus/ scapular stabilizer strength: dynamometer, ***Image:*** Supraspinatus thickness: ultrasound	LL-BFR improved strength, endurance, and pain in supraspinatus tendinopathy. Structural changes as increased tendon thickness (2.73%).
Cuddeford & Brumitt 2020 (Cuddeford and Brumitt, 2020); ***Case report;*** *n* =2 Patellar tendinopathy	Low-load BFRT: Single-leg leg press, unilateral squat on a 25° decline board, 12 weeks	***Sets:*** 4; ***Reps:*** 30-15-15-15; ***Freq:*** 2 sessions/week; ***Prog:*** Increase resistance (10 lbs increments as tolerated); ***Int:*** 30% 1RM; ***LOP***:80%; ***Rest:*** 30 s per set	***Pain:*** VAS; ***Function:*** VISA-P; knee strength: handheld dynamometry ***Tendon morphology:*** ultrasound, hip	BFRT showed significant improvement in pain, function, and muscle strength, with positive changes in tendon structure, enabling the athlete to return to sporting activity.
Høgsholt et al. (2022) (Høgsholt et al., 2022); ***Feasibility study;*** *n* = 16 Gluteal tendinopathy	Low-load BFRT: Static abduction, sidestepping, glute bridging, and squats, 8 weeks	***Sets:*** 3; ***Reps:*** 20,10,10; ***Freq:*** 3–4 sessions with BFR/weeks 3–8; ***Prog:*** gradual increase in repetitions and session duration (15–25 min); ***Int:*** Bodyweight, ***LOP***: 60%	***Pain:*** NRS; ***Strength:*** Dynamometer ***Function***: Sit-to-stand and stair-climb; ***Patient-reported outcome measures:*** VISA-G, EQ5D, VAS, OHS, and most HAGOS subscales.	The LL-BFR intervention combined with patient education was feasible, with improvements reported in pain, function, and strength.
Karanasios et al. 2023 (Karanasios, Lignos and Gioftsos, 2023); ***Case report;*** *n* = 1; Lateral elbow tendinopathy	Low-load BFRT: wrist extension exercises, soft tissue massage, wall push-ups, rubber bar exercises, grip strengthening, 6 weeks	***Sets:*** 4; ***Reps:*** 30,15,15,15; ***Freq:*** 2 days/week; ***Int:*** progression 0.5–1 kg/week (if pain <2/10, NPRS); ***LOP:***40%; ***Rest***: 30 s per set	***Pain***: VAS; ***Pain-free grip strength:*** Jamar Hand Dynamometer; ***PPTs:*** Digital algometer	LLBFR effectively reduced pain and improved strength and function in a patient with Lateral elbow tendinopathy.

Table 3 Descriptive data of the included non-RCTs studies.

Note: **BFRT:** Blood Flow Restriction Training; **Reps:** repetitions; **Freq:** Frequency; **Int:** Intensity; **SL:** Session Length; **1RM:** 1 repetition maximum; **LOP:** Limb Occlusion Pressure; **mmHg:** millimeters of mercury; **NPRS:** Numeric Rating Scale; **VISA-P:** Victorian Institute of Sport Assessment-Patella; **MVC:** Maximal voluntary contraction; **SLDS:** single leg decline squat; **PPTs:** Pressure pain thresholds; **PFGS:** Pain-free grip strength; **PRTEQ:** Patient-Rated Forearm Evaluation Questionnaire; **VAS:** Visual Analogue Scale; **SPADI:** Shoulder Pain and Disability Index; **EQ-5D:** EuroQol-5D questionnaire; **OHS:** Oxford Hip Score; **HAGOS:** Copenhagen Hip and Groin Outcome Score.

Patient-reported function was assessed in six studies. Two used the Victorian Institute of Sport Assessment-Patellar (VISA-P) (Cuddeford and Brumitt, 2020; Skovlund et al., 2020), and two applied the Patient-Rated Tennis Elbow Evaluation (PRTEE) for lateral elbow tendinopathy (Karanasios et al., 2022; Kinandana et al., 2023). For rotator cuff tendinopathy, the Shoulder Pain and Disability Index (SPADI) was used (Kara et al., 2024). In gluteal tendinopathy, multiple scales were employed, including the Victorian Institute of Sport Assessment-Gluteal (VISA-G), European Quality of Life–5 Dimensions Visual Analogue Score (EQ-5D-VAS), Oxford Hip Score (OHS), and Copenhagen Hip and Groin Outcome Score (HAGOS) (Høgsholt et al., 2022).

Muscle strength and function were evaluated across the included studies. Strength was measured using dynamometry (Cuddeford and Brumitt, 2020; Høgsholt et al., 2022; Begi et al., 2023; Kara et al., 2024; Karanasios et al., 2025), maximal isometric voluntary contraction (MIVC) (Skovlund et al., 2020), and grip strength via Jamar dynamometer (Karanasios et al., 2022; Karanasios, Lignos and Gioftsos, 2023; Kinandana et al., 2023). Functional performance was assessed using single-leg decline squats (SLDS) (Skovlund et al., 2020), a Likert scale for global improvement (Karanasios et al., 2025), sit-to-stand, and stair-climb tests (Høgsholt et al., 2022). Additionally, three studies measured pain pressure threshold (PPT) using an algometer (Begi et al., 2023; Karanasios, Lignos and Gioftsos, 2023; Karanasios et al., 2025).

Overall, improvements in pain, strength, and patient-reported outcomes were reported across several included studies, although the magnitude and consistency of these changes varied

according to the intervention and outcome assessed (Cuddeford and Brumitt, 2020; Skovlund et al., 2020; Høgsholt et al., 2022; Karanasios et al., 2022, 2025; Begi et al., 2023; Karanasios, Lignos and Gioftsos, 2023). Kinandana et al. (2023) reported significant improvements in grip strength and PrTEEQ scores following low-load BFRT compared with high-intensity resistance exercise (Kinandana et al., 2023). No serious LL-BFRT–related adverse events were reported in the included studies. However, small sample sizes, heterogeneity of study designs, and variability in BFRT protocols limit generalizability.

TENDON MORPHOLOGY

Tendon morphology was assessed using ultrasound in four studies evaluating tendon thickness (Cuddeford and Brumitt, 2020; Skovlund et al., 2020; Karanasios et al., 2022; Begi et al., 2023). One study examined vascularity (Skovlund et al., 2020), and another examined echogenicity (Cuddeford and Brumitt, 2020). This exploratory review explored the available evidence, with a particular focus on tendon morphology and functional outcomes following LL-BFRT in tendinopathy rehabilitation. Functional improvements were frequently reported at low exercise intensities; however, findings regarding tendon morphology were inconsistent, with limited studies demonstrating measurable changes in tendon thickness or vascularity. Only three studies reported quantitative tendon thickness values (see Table 4).

Table 4 Changes in tendon thickness following blood flow restriction interventions.

Note: **mm**: millimeters; **BFR**: Blood Flow Restriction; **Δ**: Delta; **RCT**: Randomized Controlled Trial; ***** Data are reported as median (95% Confidence Interval).

AUTHOR (YEAR)	TYPE OF STUDY	TENDON SITE	BASELINE THICKNESS (MM)	POST BFR THICKNESS (MM)	Δ (%)
Begi et al. 2023 (Begi et al., 2023)	Case Study	Supraspinous	8.41	8.64	+ 2.73
		Trapezius	2.94	3.34	+ 13.78
Cuddeford & Brumitt 2020 (Cuddeford and Brumitt, 2020)	Case report: Athlete 1	Left Patellar tendon	0.39	0.28	–28.39
	Case report: Athlete 2	Left Patellar tendon	0.35	0.38	+6.98
Skovlund et al. 2020 (Skovlund et al., 2020)*	A case series: *n* = 7	Patellar tendon apex	6.5 (6.1;7.3)	6.3 (6.2;6.9)	–1%
		Patellar tendon max	6.7 (6.2;7.7)	6.6 (6.2;7.7)	–1%

TRAINING PARAMETERS

Despite methodological heterogeneity, common trends in LL-BFRT application for tendon rehabilitation are evident. Most protocols employed low loads (15–40% 1RM) (Cuddeford and Brumitt, 2020; Skovlund et al., 2020; Karanasios et al., 2022; Begi et al., 2023; Kara et al., 2024). One study used bodyweight (Høgsholt et al., 2022), another adjusted load weekly based on pain (Karanasios, Lignos and Gioftsos, 2023), and one progressed from 15–20% to 30–40% (Begi et al., 2023). One study used low-load resistance exercise at 20–40% 1RM in the BFR group, compared with 70–80% 1RM in the high-intensity resistance exercise group (Kinandana et al., 2023).

Occlusion pressures ranged from 40% to 80% of limb occlusion pressure (LOP). Three studies applied 40–50% LOP for wrist extensors, commonly used in lateral elbow tendinopathy (Karanasios et al., 2022, 2025; Karanasios, Lignos and Gioftsos, 2023). One study prescribed cuff pressure at 1.2 times the participant's systolic blood pressure rather than as a percentage of LOP (Kinandana et al., 2023). Two studies used 50% LOP for rotator cuff tendinopathies (Begi et al., 2023; Kara et al., 2024). In patellar tendinopathy, occlusion pressure ranged from 120 mmHg (Skovlund et al., 2020) to 80% LOP (Cuddeford and Brumitt, 2020), whereas the gluteal tendinopathy protocol used 60% LOP (Høgsholt et al., 2022).

BFR frequency ranged from 2 to 4 sessions per week in most studies (Cuddeford and Brumitt, 2020; Skovlund et al., 2020; Høgsholt et al., 2022; Karanasios et al., 2022; Begi et al., 2023; Karanasios, Lignos and Gioftsos, 2023; Kinandana et al., 2023; Kara et al., 2024), with one applying a single session (Karanasios et al., 2025). The 30-15-15-15 repetition protocol was

employed in six studies (Cuddeford and Brumitt, 2020; Karanasios et al., 2022, 2025; Begi et al., 2023; Karanasios, Lignos and Gioftsos, 2023; Kara et al., 2024). The number of sets and repetitions varied across the remaining protocols (Cuddeford and Brumitt, 2020; Skovlund et al., 2020; Høgsholt et al., 2022; Karanasios et al., 2022, 2025; Begi et al., 2023; Karanasios, Lignos and Gioftsos, 2023; Kara et al., 2024). One study used four sets of 12 repetitions, with 60-s rest intervals between sets (Kinandana et al., 2023). Exercise types varied (isometric, dynamic, functional), as did cuff application (continuous or intermittent). Rest intervals were generally 30 s per set (Cuddeford and Brumitt, 2020; Skovlund et al., 2020; Høgsholt et al., 2022; Begi et al., 2023; Karanasios, Lignos and Gioftsos, 2023; Kara et al., 2024), and 1–3 min between exercises (Skovlund et al., 2020; Karanasios et al., 2022, 2025; Kara et al., 2024). Intervention duration ranged from a single session to 12 weeks.

DISCUSSION

This exploratory review explored the available evidence regarding LL-BFRT in tendinopathy rehabilitation, focusing on tendon morphology and functional outcomes. Structural adaptations such as changes in thickness, hypoechoic regions, and neovascularization may reflect structural changes associated with tendon adaptation, although these findings cannot be interpreted as definitive evidence of tendon healing (Cook and Purdam, 2009; Cuddeford and Brumitt, 2020; Skovlund et al., 2020). These structural changes may accompany clinical and functional improvements; however, their clinical significance remains uncertain.

Across the included studies, structural tendon adaptations were variable, suggesting that morphological recovery may differ depending on the tendon site, intervention protocol, and follow-up duration. For example, the case report by Begi et al. (Begi et al., 2023) reported increased supraspinatus tendon thickness after BFRT; however, the biological and clinical significance of this change remains uncertain. This may be consistent with proposed mechanisms associated with mechanical loading under hypoxic conditions, including pathways involving HIF-1α, VEGF, GH, and IGF-1, which have been suggested to influence collagen synthesis and tenocyte activity (Miescher et al., 2023; Zulkifli et al., 2023; Moschini, 2024). However, tendon thickening is not a definitive marker of healing, as it may also reflect edema, fluid retention, or degenerative changes (Cook and Purdam, 2009). Despite clinical improvements, studies by Skovlund et al. (Skovlund et al., 2020) and Karanasios et al. (Karanasios et al., 2022) found no structural changes, suggesting that functional recovery may precede or occur independently of morphological adaptations.

Evidence regarding tendon vascularity was limited, with one study reporting a reduction in neovascularization following LL-BFRT. Skovlund et al. (Skovlund et al., 2020) reported a 31% reduction in tendon neovascularization after three weeks of LL-BFRT in patients with patellar tendinopathy. These findings suggest that LL-BFRT may influence vascular responses; however, the clinical relevance of these changes for tendon rehabilitation remains uncertain. However, evidence regarding the effects of LL-BFRT on tendon vascularity remains limited, and further studies are required to determine the clinical significance of these vascular changes. These findings highlight the importance of interpreting changes in tendon thickness cautiously, as such changes do not necessarily reflect tendon remodeling or healing.

Several included studies reported improvements in functional and strength outcomes following LL-BFRT in tendinopathy rehabilitation (Karanasios, Lignos and Gioftsos, 2023; Kinandana et al., 2023; Kara et al., 2024). Cuddeford & Brumitt (Cuddeford and Brumitt, 2020) reported improvements in pain, lower-extremity strength, functional performance, and VISA-P scores, with both athletes able to compete throughout the track season following the BFR-based rehabilitation program. Høgsholt et al. (Høgsholt et al., 2022) reported improvements in VISA-G scores, functional performance, and isometric hip and knee strength following the LL-BFR intervention. These outcomes may partly reflect neuromuscular adaptations with BFR, including increased motor-unit recruitment under conditions of metabolic stress (Lorenz et al., 2021; Rosario et al., 2024), with strength gains reported even without tendon hypertrophy (Skovlund et al., 2020). Mechanistically, BFR has been associated with anabolic responses, including changes in GH and IGF-1 signaling; however, the extent to which these responses contribute to tendon-specific adaptations remains unclear (Patterson et al., 2019; Aram, Khodaei and Zolfaghar Didani, 2024). However, Karanasios et al. (2025) found that a single session of wrist

extensor training with BFR did not significantly improve pressure pain thresholds compared with non-BFR exercise, while changes in pain-free grip strength favored BFR but appeared to be influenced by participants' baseline characteristics (Karanasios et al., 2025).

The available evidence indicates potential improvements in functional outcomes following LL-BFRT; however, the small number of studies, methodological heterogeneity, and limited evidence on tendon morphology preclude firm conclusions regarding its effectiveness. Despite these limitations, LL-BFRT may represent a potentially useful low-load rehabilitation approach when high mechanical loads are not well tolerated; however, its clinical effectiveness and safety in tendinopathy require further investigation. Future studies should investigate standardized approaches to LOP assessment, pressure adjustment, exercise intensity, and periodization to determine their influence on clinical and tendon-related outcomes.

LIMITATIONS

This review has several limitations that should be considered when interpreting its findings. The included studies differed in design, patient populations, sample size, intervention duration, and BFRT protocols, limiting definitive conclusions. Inconsistent reporting of occlusion parameters and the absence of standardized dosing protocols further limit comparability across studies and the reproducibility of BFRT protocols. Moreover, changes in tendon thickness should not be interpreted as evidence of tendon healing in the absence of complementary structural or biological measures. Consequently, the available measures provide limited insight into tendon remodeling, highlighting the need for more comprehensive structural and biological assessments in future studies. Future research should prioritize large, well-designed RCTs with standardized BFRT protocols and extended follow-up to better characterize tendon-specific responses and compare the effectiveness of different BFRT protocols. A further limitation is that no formal critical appraisal or risk-of-bias assessment was conducted, which limits the ability to evaluate the methodological quality of the included studies and the certainty of the conclusions drawn from the available evidence. Additionally, the small number of included studies and the limited evidence available for individual tendinopathy sites highlight the need for further high-quality clinical research.

CONCLUSION

This review identified limited and heterogeneous evidence examining LL-BFRT in clinically diagnosed tendinopathy. Across the included studies, improvements in pain, strength, and functional outcomes were frequently reported, whereas findings regarding tendon morphology were inconsistent. The available evidence was derived from a small number of studies with variable designs, intervention parameters, and follow-up periods, limiting the ability to draw definitive conclusions regarding clinical effectiveness. Further well-designed controlled studies using standardized LL-BFRT protocols and clearly defined tendon-related outcomes are required to clarify its potential role in tendinopathy rehabilitation.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **Supplementary File 1.** Full Database Search Strategies and Study-Selection Summary. DOI: https://doi.org/10.5334/paah.590.s1

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

All authors contributed equally to all stages of the review process, including conceptualization, methodology, analysis, writing, and revision of the final manuscript. All authors have read and approved the final version of the manuscript.

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This article was originally published with the name 'Yasser Alakhadar' in the author list. This was a typo. As of 03/11/2026 the author name has been corrected to 'Yasser Alakhdar'.

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