Effectiveness of blood flow restriction in lower limb tendons: a systematic review

Efectividad de la restricción del flujo sanguíneo en tendones de extremidades inferiores: una revisión sistemática

Authors

Waldo Osorio-Torres [1]
Mauricio Venegas de la Paz [2]
Ronald Vargas-Foitzick [3]
Gonzalo Arias-Álvarez [1]

[1] Universidad San Sebastián (Chile)
[2] Universidad Metropolitana de Ciencias de la Educación (Chile)
[3] Universidad Finis Terrae (Chile)

Corresponding author:
Gonzalo Arias-Álvarez
Gonzalo.arias@uss.cl

Received: 02-05-23
Accepted: 20-08-25

How to cite in APA

Osorio-Torres, W., Venegas de la Paz, M., Vargas-Foitzick, R., & Arias-Álvarez, G. (2025). Effectiveness of blood flow restriction in lower limb tendons: a systematic review. *Retos, 72*, 654-663. https://doi.org/10.47197/retos.v72.99681

Abstract

Introduction: Lower limb tendinopathy is a common condition that leads to pain and functional limitations, particularly among physically active individuals. While high-load training promotes tendon adaptation, its early use in rehabilitation may aggravate symptoms. Blood flow restriction (BFR) training has emerged as a promising low-load alternative.
Objective: To evaluate the effectiveness of BFR training on the structural and functional properties of lower limb tendons through a systematic review of controlled clinical trials.
Methodology: Following PRISMA guidelines, five databases were searched up to March 2025. Five controlled clinical trials involving 232 participants with and without tendinopathy were included. Methodological quality was assessed using the Cochrane RoB 2 tool and the PEDro scale. Interventions involved low-load resistance exercise (20–35% 1RM) combined with BFR, compared against high-load training or no intervention.
Results: Studies reported significant improvements in tendon thickness, cross-sectional area, and muscle strength with low-load BFR training. These outcomes were generally comparable to high-load protocols. However, acute responses varied across studies, with inconsistent changes in tendon thickness observed post-exercise.
Discussion: BFR training appears to promote structural and functional improvements without requiring high loads, although more consistent studies are needed to standardize protocols and outcomes.
Conclusion: BFR is a promising strategy for managing lower limb tendinopathies, especially when high-load exercise is contraindicated. More robust studies are needed to standardize protocols and explore long-term benefits in both clinical and athletic populations.

Keywords

Blood flow restriction; kaatsu; lower extremity tendinopathy; tendon.

Resumen

Introducción: La tendinopatía de las extremidades inferiores es una condición frecuente que provoca dolor y limitaciones funcionales, especialmente en personas físicamente activas. Aunque el entrenamiento con altas cargas favorece la adaptación del tendón, su uso temprano en la rehabilitación puede agravar los síntomas. El entrenamiento con restricción del flujo sanguíneo (BFR, por sus siglas en inglés) ha surgido como una alternativa prometedora de bajo impacto.
Objetivo: Evaluar la efectividad del entrenamiento con BFR sobre las propiedades estructurales y funcionales de los tendones de las extremidades inferiores mediante una revisión sistemática de ensayos clínicos controlados.
Metodología: Siguiendo las directrices PRISMA, se realizaron búsquedas en cinco bases de datos hasta marzo de 2025. Se incluyeron cinco ensayos clínicos controlados que involucraron a 232 participantes con y sin tendinopatía. La calidad metodológica fue evaluada mediante la herramienta Cochrane RoB 2 y la escala PEDro. Las intervenciones consistieron en ejercicios de resistencia con baja carga (20–35% de 1RM) combinados con BFR, en comparación con entrenamientos de alta carga o ausencia de intervención.
Resultados: Los estudios reportaron mejoras significativas en el grosor tendíneo, el área transversal y la fuerza muscular con el entrenamiento de baja carga combinado con BFR. Estos resultados fueron, en general, comparables a los obtenidos con protocolos de alta carga. Sin embargo, las respuestas agudas variaron entre estudios, observándose cambios inconsistentes en el grosor del tendón tras el ejercicio.
Discusión: El entrenamiento con BFR parece favorecer mejoras estructurales y funcionales sin requerir altas cargas, aunque se necesitan estudios más consistentes para estandarizar protocolos y resultados.
Conclusión: El BFR es una estrategia prometedora para el manejo de tendinopatías de las extremidades inferiores, especialmente cuando el ejercicio con altas cargas está contraindicado. Se requieren estudios más sólidos que permitan estandarizar los protocolos y explorar los beneficios a largo plazo tanto en poblaciones clínicas como deportivas.

Palabras clave

Restricción del flujo sanguíneo; kaatsu; tendinopatía de la extremidad inferior; tendón.

Introduction

Tendinopathy is a common pathology of the lower limb, accounting for up to 30% of musculoskeletal consultations.(Millar et al., 2017). The societal costs are significant due to work absenteeism and medical expenses, resulting in functional limitations and persistent pain.(Dean et al., 2017; Hopkins et al., 2016) Lower limb tendinopathies often evolve over time, leading to morphological changes such as increased tendon thickness, collagen fibril disorganization, and neovascularization.(Magnusson & Kjaer, 2019; Millar et al., 2021)

Initial tendon pain under external load is a key challenge in clinical practice. High-load exercises stimulate adaptive responses in the tendon's mechanical properties. However, applying high loads too early in rehabilitation may hinder tendon healing.(Couppé et al., 2015; Loenneke et al., 2012). Progressive loading and precise dosing parameters during rehabilitation are essential for tendon repair.(Bohm et al., 2015) These training programs have demonstrated positive clinical effects, improving symptoms, tendon structure, and strength.(Beyer et al., 2015; Kongsgaard et al., 2010) During muscle contraction under load, tendons experience mechanical tension that promotes mechanotransduction processes, activating cellular signaling pathways that stimulate collagen synthesis and favor the reorganization of the extracellular matrix (Domínguez-Gavia et al., 2025). These adaptations include an increase in tendon stiffness and improvements in force transmission capacity, which contribute to injury prevention and performance optimization (Panza et al., 2025). Moreover, progressive exposure to appropriate mechanical loading has been shown to enhance local vascularization and modulate the inflammatory response, both of which are key factors in tendon repair and remodeling (Bohm et al., 2015). However, traditional high-load tendon training typically utilizes around 70% of the one-repetition maximum (1RM). In contrast, low-load training typically ranges from 20% to 40% of 1RM. Therefore, low-load exercises are recommended for patients in the early stages who cannot tolerate high training loads due to pain.(Centner et al., 2019; Krzysztofik et al., 2019)

Blood flow restriction (BFR) is a rehabilitation modality that uses a cuff or strap around the limb to partially reduce arterial blood flow.(Lorenz et al., 2021) Originally, BFR or Kaatsu training was developed to enhance strength and muscle hypertrophy. Today, it is widely used as a rehabilitation tool for various musculoskeletal disorders.(Barber-Westin & Noyes, 2019; Hughes et al., 2019; Nitzsche et al., 2021) The physiological benefits extend beyond the musculoskeletal system, also impacting the cardiovascular, endocrine systems, and psychosocial components..(Karabulut et al., 2021; Neto et al., 2017; Silva et al., 2018) Several theories explain the mechanism of action. It is now widely accepted that the combination of metabolic stress from vascular occlusion and mechanical tension from exercise or training promotes greater muscle hypertrophy and strength.(Barber-Westin & Noyes, 2019; Burton, 2023) At the cellular level, metabolites, hormonal variations, cellular signaling pathways, and inflammation play a key role. The hypoxic condition is thought to accelerate fatigue, enhancing motor unit recruitment and stimulating greater activation of type II muscle fibers. Additionally, it promotes satellite cell proliferation, leading to increased muscle protein synthesis, myofiber growth, and improved muscle strength.(Bjørnsen et al., 2019)

BFR training has been shown to trigger exercise-induced hypoalgesia through endocannabinoid and endogenous opioid mechanisms. This method could serve as an effective alternative for managing acute pain in musculoskeletal dysfunctions.(Hughes et al., 2021; Korakakis et al., 2018; Patterson et al., 2019)

Evidence on the effects of low-load training and BFR on lower limb tendons remains limited. While muscle gains may contribute to tendon repair by improving its morphological and mechanical properties, this relationship is not yet fully understood. (Burton & McCormack, 2022)

Although BFR training has shown clinical benefits in other musculoskeletal disorders, its actual impact on tendons has received little attention. Therefore, this review aims to assess whether scientific evidence supports the effectiveness of BFR in lower limb tendons.

Method

Protocol and registry

This systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The study protocol was prospectively registered in the International Platform of Registered Systematic Review Protocols platform (inplasy.com) (registration number 202520087).

Eligibility criteria for the studies

Studies were considered eligible if they met the following inclusion criteria:

Population: Subjects over 18 years old with tendon injuries of any duration or healthy lower limb tendons.

Intervention: Exercise-based intervention using low-load training with BFR.

Comparison: Any high- or low-load exercise intervention or no intervention.

Outcomes: Changes in tendon mechanical and morphological properties, tendon cross-sectional diameter, and assessment of maximum voluntary contraction strength.

Study Type: Controlled Clinical Trials (CCT) or Randomized Clinical Trials (RCT), published in English or Spanish.

The following were excluded from the systematic review: Studies including participants with concurrent injuries or medical conditions unrelated to tendons, studies conducted on experimental models and Unpublished reports, reviews, and scientific posters.

Sources of information

To identify potentially relevant articles, searches were conducted in five databases from inception until March 1, 2025. The databases used were Medline (via PubMed), Web of Science, Scopus, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Physiotherapy Evidence Database (PEDro).

Search strategy

A search strategy was conducted following the recommendations of the Cochrane Collaboration. Subsequently, the reviewer performed an independent search.

The search included keywords from two main concepts: Blood Flow Restriction ("Kaatsu", "Occlusion Training") and Tendon ("tendon", "tendinopathy", "lower limb tendinopathy"). Boolean operators "OR" and "AND" were used to connect keywords within each concept and to link the concepts themselves, respectively.

Selection of studies

Records obtained from the databases were imported into the Rayyan electronic platform. After eliminating duplicates, records were screened by titles and abstracts to identify studies that potentially met the inclusion criteria. Then, the full texts of the remaining studies were retrieved to assess their eligibility. Two independent reviewers carried out this process, and discrepancies were resolved by a third author.

Data extraction

One reviewer independently extracted the data, while a second reviewer verified the extracted information, resolved discrepancies, and synthesized the data into a table.

The following data were extracted: population (sample size, age, and diagnosis), intervention (frequency, type, and exercise dosage), training parameters (number of sets, repetitions, and % of 1RM), cuff parameters (placement and % of occlusion pressure), and outcomes related to tendon morphological properties, cross-sectional area, and maximum voluntary contraction strength.

Risk of bias in the studies

The risk of bias in the analyzed studies was independently assessed by the lead researcher, following the guidelines of the *Cochrane Handbook for Systematic Reviews of Interventions*. The evaluation considered potential sources of bias in participant selection, intervention implementation, outcome measurement, participant follow-up, and data reporting. Each domain was classified as low risk, some concerns, or high risk. In cases where consensus was not reached, a second reviewer was consulted to resolve discrepancies.

Synthesis of results

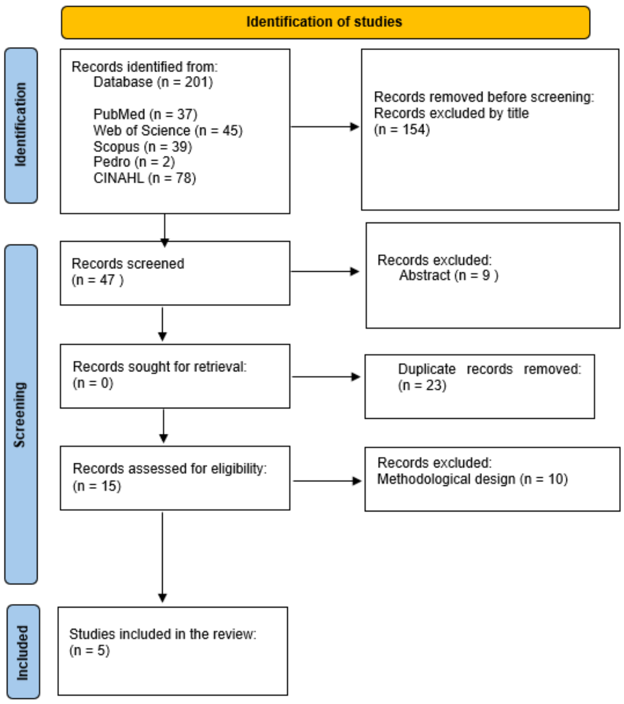
Descriptive analyses were conducted for studies with insufficient data for general pooling, and a descriptive synthesis was performed following the guidelines of the Cochrane Collaboration.(Higgins & Cochrane Collaboration, 2019)

Results

Study Selection

A total of 201 studies were identified through the electronic search (Fig. 1). Finally, five studies met the eligibility criteria and were included in this systematic review.(Centner et al., 2019, 2022, 2023; Chulvi-Medrano et al., 2020; Picón-Martínez et al., 2021)

Figure 1. Flow Diagram based on PRISMA 2020



The five RCTs included a total sample of 232 subjects.(Centner et al., 2019, 2022, 2023; Chulvi-Medrano et al., 2020; Picón-Martínez et al., 2021) The studies included patients with patellar tendinopathy,(Centner et al., 2022) Achilles tendinopathy (Centner et al., 2019, 2023) and healthy lower limb tendons.(Chulvi-Medrano et al., 2020; Picón-Martínez et al., 2021) The characteristics of the included studies are presented in Table 1, along with a narrative synthesis accompanying the tabulated results.

The five studies assessed the tendon cross-sectional area, (Centner et al., 2019, 2022, 2023; Chulvi-Medrano et al., 2020; Picón-Martínez et al., 2021) Only two studies evaluated the mechanical and morphological properties of the tendon;(Centner et al., 2019, 2022) Three studies assessed muscle strength of the plantar flexors through maximum voluntary contraction. (Centner et al., 2019, 2022, 2023)

The duration of the interventions in the included studies was 14 weeks(Centner et al., 2019, 2022, 2023) and only one intervention session.(Chulvi-Medrano et al., 2020; Picón-Martínez et al., 2021) The total number of sessions was 42 sessions.(Centner et al., 2019, 2022, 2023) The frequency of the intervention sessions was 2-3 times per week.(Centner et al., 2019, 2022, 2023)

The interventions proposed for the experimental groups were diverse and included low-load muscle strengthening (30% 1RM) combined with BFR.(Centner et al., 2019, 2022, 2023; Chulvi-Medrano et al., 2020; Picón-Martínez et al., 2021) The control groups received high-load exercise at 70% 1RM.(Centner et al., 2019, 2022, 2023; Chulvi-Medrano et al., 2020; Picón-Martínez et al., 2021) Only one study compared the dominant limb with the non-dominant limb as a control.(Chulvi-Medrano et al., 2020)

Table 1. Characteristics of the included randomized clinical trial

	Study type	Population	Intervention	Training Dosage	Cuff Parameters	Outcome Measures	Results
PICON, 2021	ECA	n = 52, healthy active young adults	G1. Low-load exercise (n = 13). G2. Low-load exercise + BFR (n = 24). G3. High-load exercise (n = 15). 1 session of plantar flexors .	G1 and G2: 4 sets x 30, 15, 15, 15 repetitions. Intensity: 30% of 1RM. Rest: 60 s between sets. G3: 1 set x 30 repetitions at 30% 1RM and 3 sets x 10 repetitions at 75% 1RM. Rest: 90 s between sets	Occlusion cuff on the dominant calf, inflated to 30% of the occlusion pressure (OP)	Ultrasound Achilles tendon thickness: immediately, 60 min post, and 24h post acute exercise session	In G2, Achilles tendon thickness significantly decreased immediately after, 60 minutes, and 24 hours post-session ($p < 0.001$). No changes were observed in the other groups ($p > 0.05$)
CENTNER, 2022	ECA	n = 29, male participants with patellar tendinopathy	G1: Low-load exercise + BFR. G2: High-load exercise. Both groups performed bilateral lower extremity leg press, knee extension, and standing and seated calf raises	G1 and G2: 3 times/week for 14 weeks. G1. Sets: 4 x 30, 15, 15, 15 repetitions. Intensity: 20-35% 1RM. G2. Sets: 3, Intensity: 70-85%. Repetitions: 70% 1RM = 12 reps, 75% 1RM = 10 reps, 80% 1RM = 8 reps, and 85% 1RM = 6 reps. Rest: 60 seconds.	Cuff fixed at the proximal part of each thigh. Occlusion pressure (OP) was set at 50%	Mechanical and morphological properties of the tendon (Ultrasound). Quadriceps strength assessment (1RM). Cross-sectional area (CSA) (MRI)	Both groups showed significant increases in tendon stiffness, cross-sectional area, and strength, with no differences between the groups. Quadriceps strength was statistically higher in G1 for knee extension ($p = 0.044$).
CENTNER, 2019	ECA	n = 55 male participants with Achilles tendinopathy.	G1: Low-load exercise + BFR. G2: High-load exercise. G3: Control group with no exercise.	Both groups: 3 times/week for 14 weeks. 1.Low-load exercise + BFR: 4 sets, 30, 15, 15, 15 repetitions at 20-35% 1RM. 2.High-load exercise: 3 sets, 6-12 repetitions of standing and seated calf raises at 70-85% 1RM. 3.Control: No exercise. Rest: 1 minute.	The cuff was fixed at the most proximal part of each thigh. The occlusion pressure (OP) was set at 50%	Mechanical and morphological properties of the tendon (Ultrasound). Maximum voluntary contraction (MVC) strength assessment. Cross-sectional area (CSA).	G1 and G2 significantly increased their cross-sectional area (CSA) and tendon stiffness. Plantar flexor strength significantly increased in both groups. The control group showed no changes.
CENTNER, 2023	ECA	n = 40 male participants with Achilles tendinopathy.	G1: Low-load exercise + BFR. G2: High-load exercise.	Both groups trained 3 times per week for 14 weeks, with one rest day between each exercise session. Standing and seated calf raises were performed. G1: Sets: 4 x 30, 15, 15, 15 repetitions. Intensity: 20-35% 1RM.	The cuff was fixed at the most proximal part of each thigh. The occlusion pressure (OP) was set at 50%.	Achilles tendon morphology (MRI) and dynamic plantar flexor strength.	Both groups improved dynamic strength in the plantar flexors. Additionally, there was a significant increase in the Achilles tendon cross-sectional area (CSA) in G1.

				G2: Sets: 3 x 70-85% Intensity. Repetitions: 70% 1RM = 12 reps, 75% 1RM = 10 reps, 80% 1RM = 8 reps, and 85% 1RM = 6 reps. Rest: 60 seconds.			
CHULVI, 2020	ECA	n = 56 healthy participants.	G1: Low-load exercise + BFR on the dominant limb. G2: High-load exercise on the non-dominant limb as control.	Plantar flexion exercise. Sets: 3 x 15 repetitions.	The occlusion cuff was placed on the dominant calf and inflated to 30% of the occlusion pressure (OP).	Ultrasound Achilles tendon thickness: immediately after training and 24 hours post-exercise.	The changes in Achilles tendon thickness for G1 were significant immediately after ($p < 0.05$) and 24 hours post-exercise ($p < 0.05$). In contrast, G2 showed a transient decrease immediately after exercise ($p < 0.05$), followed by a recovery in thickness 24 hours later ($p < 0.05$).

BFR: Blood Flow Restriction; LC: low load; HL: high load; 1RM: One Repetition Maximum; OC: Occlusion Pressure; CSA: Cross-Sectional Area; MVC: Maximum Voluntary Contraction

Methodological quality and risk of bias

To assess the methodological quality of the included studies, the Cochrane RoB 2 tool (2019 version) was applied. This instrument classifies the risk of bias as low, unclear, or high, with the latter category used when there is insufficient information regarding potential bias (Fig. 2).

Figure 2. Analysis Risk of Bias

Additionally, the PEDro scale was used to evaluate the internal validity of the studies. The assessment criteria are detailed in Figure 3. Each item was scored with 1 point when the criterion was met and 0 points when it was not, with a maximum possible score of 10 points.

Figure 3. PEDro scale scores.

	EC*	RA	CA	BC	BS	BT	BA	AF	ITA	BGC	PEaV	Total
PICON, 2021	1	1	0	1	0	0	0	1	1	0	1	5
CENTNER, 2022 Pat	1	1	1	1	0	0	0	1	1	1	1	7
CENTNER, 2019 Aq	1	1	1	1	0	0	0	1	1	1	1	7
CENTNER, 2023 Aq	1	1	1	1	0	0	0	1	1	1	1	7
CHULVI, 2020	1	1	0	1	0	0	0	1	1	0	1	5

*EC not included in the total score. EC Eligibility criteria; RA Random allocation; CA Concealed allocation; BC Baseline comparability; BS Blind subjects; BT Blind therapists;
BA Blind assessors; AF Adequate follow-up; ITA Intention-to-treat analysis; BGT Between-group comparisons; PEaV Point estimates and variability.

Results of the individual studies

Primary Outcome: Mechanical and morphological properties of the tendon

After 14 weeks of low-load exercise + BFR intervention (Centner et al., 2019, 2022, 2023) They showed a statistically significant increase in tendon volume and thickness in the exercise group compared to the control group ($p < 0.05$). Additionally, Chulvi et al. showed that acute training following low-load exercise with BFR resulted in a significant increase in Achilles tendon thickness ($p < 0.05$) immediately after training and at 24 hours post-training. The Achilles tendon thickness at 24 hours was significantly different between the low-load exercise + BFR group and the low-load exercise-only group ($p < 0.01$).(Chulvi-Medrano et al., 2020)

However, Picon et al. (2021) found a statistically significant reduction in Achilles tendon thickness in the low-load exercise + BFR group immediately ($p < 0.001$), 60 minutes ($p < 0.001$), and 24 hours post-training ($p < 0.002$). When comparing the low-load + BFR and high-load groups, Achilles tendon thickness was significantly lower immediately after ($p < 0.003$) and 60 minutes after exercise ($p < 0.012$).(Picón-Martínez et al., 2021)

Secondary Outcome: Muscle Strength

After 14 weeks of low-load exercise + BFR intervention, a significant increase was observed, but no differences were found compared to the high-load exercise group in leg press strength.(Centner et al., 2022) In contrast, significant differences were found in knee extension strength between the low-load exercise + BFR group and the high-load exercise group ($p = 0.04$).(Centner et al., 2022)

Discussion

The findings of Centner et al. (2019) and Picón-Martínez et al. (2021) agree that both blood flow restriction (BFR) training combined with low-load exercise and traditional high-load training can induce positive changes in tendon properties. Both studies reported increases in tendon thickness, suggesting beneficial structural adaptations that could enhance tendon strength and functional capacity.

Similarly, more recent studies by Centner et al. (2022, 2023) identified comparable patterns of tendon hypertrophy and morphological and mechanical adaptations between BFR and high-load protocols. These results support the idea that BFR could serve as an effective alternative, offering similar benefits without imposing the same mechanical demands. However, Chulvi-Medrano et al. (2020) highlighted a significant difference in Achilles tendon thickness recovery time between training with and without BFR. In their study, the BFR group showed faster recovery, suggesting that this technique may offer additional advantages—particularly valuable for athletes seeking to minimize downtime and optimize short-term performance.

Another relevant point is the duration and sustainability of the observed adaptations. While studies by Picón-Martínez et al. (2021) and Centner et al. (2022) primarily focused on acute or short-term effects, there is a clear need for longitudinal research to assess the long-term impact of BFR on tendon function. In addition, the variability in BFR protocols across studies may have influenced the outcomes, underscoring the importance of standardizing application methods and directly comparing different approaches.

In this context, the physiological mechanisms associated with BFR, such as relative hypoxia and metabolic stress, may stimulate protein synthesis and tenocyte proliferation, thereby promoting collagen remodeling (Pearson & Hussain, 2014). These processes are further enhanced by the release of growth factors such as IGF-1 and TGF-β, which contribute to improving tendon stiffness and elasticity (Centner et al., 2019). Moreover, BFR may activate high-threshold motor units under low-load conditions (20–30% 1RM), offering a substantial advantage in the early stages of rehabilitation by inducing adaptations without increasing the risk of mechanical overload on the injured tissue (Loenneke et al., 2012). These characteristics could position BFR as a clinical and sports strategy with great potential, particularly for athletes who need to maintain strength stimuli while promoting tendon repair in a safe and progressive manner (Bahamondes-Avila et al., 2024).

Among the limitations of this review is the limited available evidence regarding the use of BFR in healthy or injured tendons, as well as the lack of large-scale, long-term clinical trials to confirm these findings. Furthermore, the heterogeneity of results limits their generalizability to broader populations affected by lower limb tendon disorders.

Looking ahead, several areas warrant further exploration. First, it is important to carry out randomized controlled trials that minimize bias in order to better assess how effective BFR is for treating lower limb tendons. Second, future studies should broaden the range of functional outcomes assessed—such as incorporating jump performance, VISA scales, and passive mobility tests. Third, there's a clear need to unify how BFR is applied, including consistent parameters and anatomical targeting. Lastly, it would be valuable to include more diverse populations beyond athletes and to investigate how gender differences may influence the development of tendinopathies and responses to treatment.

Conclusions

While the results of this review are promising, there is still not enough evidence to confidently confirm the effectiveness of blood flow restriction (BFR) interventions and low-load exercises in improving the function of lower limb tendons. Further research is needed, particularly to standardize application protocols. This is essential to ensure their appropriate use in both clinical and sports settings, as well as to gain a deeper understanding of their long-term effects.

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Authors' and translators' details:

Waldo Osorio-Torres	Klgo.wosorio@gmail.com	Author
Ronald Vargas-Foitzick	rvargasf@uft.edu	Author
Mauricio Venegas de la Paz	mauricio.venegas@umce.cl	Author
Gonzalo Arias-Álvarez	Gonzalo.arias@uss.cl	Author