DOI: 10.7860/JCDR/2026/84238.22384

Original Article

Physiotherapy Section

Effects of Blood Flow Restriction Training on Muscular Adaptations among Fitness Enthusiasts: A Scoping Review

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ABSTRACT

Introduction: Blood Flow Restriction (BFR) training has proved to be a viable option to cause muscular adaptations under low loads, thus ideal for persons who cannot tolerate high-resistance training. By creating external pressure that limits venous return with continued arterial inflow, BFR causes local hypoxia, metabolic stress, and enhanced recruitment of muscle fibres. These physiological processes create adaptations equivalent to high-intensity training, which has endeared BFR as a valuable option for athletes and fitness enthusiasts seeking to enhance performance with less mechanical tension on joints and tissues.

Aim: To examine the effect of BFR on muscular strength, hypertrophy, endurance, and aerobic capacity in healthy, active subjects.

Materials and Methods: A scoping review was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses – Scoping Review Extension (PRISMA-ScR) guidelines, for a period of six months i.e., from February 2025 to July 2025. Electronic databases such as PubMed, Scopus, Web of Science, and Sports Documentation and Information Service were searched for peer-reviewed English-language articles from inception until 2025. Eligible studies were experimental and observational designs that studied BFR in recreationally active healthy adults. A total of 25 Randomised Controlled Trials (RCTs) were included after screening.

Results: BFR training improved muscle strength and hypertrophy in all age groups and training backgrounds with consistency. Such improvements were present even at low intensities {(20-30%, one Reptition Maximum (1RM)}, where the results were often as good as high-load training. A number of studies also showed that muscular endurance and systemic adaptations, including cross-education effects, were improved. Aerobic capacity and vascular function outcomes were inconsistent with probable protocol differences. BFR exercise was safe and tolerated well, with minor and transient side-effects. Personalised occlusion pressures and training loads optimised safety and efficacy.

Conclusion: BFR is a potent, low-load training modality that increases strength, hypertrophy, and muscular endurance in healthy individuals. It provides a joint-sparing intervention for those with load constraints and has future potential in sport and rehabilitation. Standardisation of training parameters and additional research on long-term adaptations, gender differences, and ideal pressure values are required to further develop its clinical and sporting application.

Keywords: Endurance, Hypertrophy, Low-load training, Mechanical tension, Strength

INTRODUCTION

The BFR training has emerged as a novel and evidence-backed approach in both resistance training and rehabilitation settings. It involves the controlled application of external pressure using pneumatic cuffs or elastic bands to partially restrict venous return while maintaining arterial inflow to the working muscles. This occlusive stimulus, when paired with low-load resistance exercises (typically 20-30% of one-repetition maximum), can elicit muscular adaptations-such as hypertrophy, strength, power, and endurance-comparable to those achieved through traditional high-load training (≥70% 1RM) [1,2].

Initially developed in Japan as "KAATSU training," BFR has gained worldwide recognition for its capacity to induce significant muscular benefits with minimal mechanical stress. This feature makes it especially advantageous for populations who cannot tolerate high-load training, such as older adults, individuals undergoing postsurgical rehabilitation, or those with joint limitations [3].

Physiologically, BFR induces a hypoxic and metabolically stressful environment, triggering a cascade of adaptations including the recruitment of fast-twitch muscle fibres, cell swelling, and elevated secretion of anabolic hormones such as Growth Hormone (GH) and Insulin-like Growth Factor-1 (IGF-1) [4,5]. These responses facilitate increased protein synthesis and neuromuscular activation, promoting both hypertrophy and strength gains. Although strength improvements from BFR may be slightly lower than those from traditional resistance training, BFR can enhance neuromuscular efficiency and accelerate recovery, especially when used as an adjunct to high-load protocols [6-8].

In addition to strength and hypertrophy, BFR training has demonstrated potential for improving muscular power and endurance. Studies suggest that integrating BFR with plyometric or ballistic exercises can improve the Rate of Force Development (RFD), which is critical for sports requiring explosive movements [9,10]. Moreover, BFR-induced metabolic stress has been associated with increased capillary density, mitochondrial efficiency, and oxidative enzyme activity- key factors in enhancing endurance performance. BFR has even been successfully applied to aerobic training modalities like walking, cycling, and swimming, showing improvements in Maximal Oxygen Volume Uptake (VO_2max) and time-to-exhaustion [11].

Despite its growing application, current literature reveals inconsistencies in training protocols, participant demographics, and outcome measures. While some affirm BFR's effectiveness in promoting lower-limb strength and aerobic gains, others report limited benefits for anaerobic power or sport-specific performance. Additional barriers, such as uncertainty around optimal cuff pressure, equipment accessibility, and long-term adherence, remain challenges to its widespread implementation [12].

The purpose of this scoping review is to systematically appraise the existing evidence with regard to the effects of BFR training on muscle strength, hypertrophy, power, and endurance among physically active individuals. It also aimed to point out research gaps, summarise the underlying physiological mechanisms, and present recommendations for optimising BFR training, considering both recreational and clinical uses.

MATERIALS AND METHODS

This scoping review was conducted for a period of six months i.e., from February 2025 to July 2025, following the PRISMA Extension for Scoping Reviews (PRISMA-ScR) guidelines, which provide a structured framework for synthesising evidence and identifying gaps in the literature. The review aimed to map the existing research on the effects of BFR training on muscular strength, power, endurance, and muscle girth among fitness enthusiasts.

Inclusion criteria:

- Investigated BFR training in healthy, recreationally active adults or fitness enthusiasts;
- Reported outcomes related to muscular strength, power, endurance, or muscle girth;
- Peer-reviewed articles published in English;
- Experimental, quasi-experimental, or observational designs.

Exclusion criteria:

- Clinical populations (e.g., rehabilitation, elderly, or post-surgical patients).
- Reviews, commentaries, or conference abstracts without full data.

Information sources and search strategy: A comprehensive search was conducted across PubMed, Scopus, Web of Science, and SPORTDiscus using keywords and MeSH terms such as "BFR," "BFR training," "muscular strength," "power," "endurance," "hypertrophy," and "fitness enthusiasts." This search included studies published from 2015-2025. Manual screening of reference lists from relevant articles supplemented the search.

Selection of sources of evidence: A systematic process of screening was employed. Abstracts and titles were screened independently by two reviewers. Disagreements at either stage were resolved first by discussion between the two reviewers; persistent disagreements were adjudicated by other reviewers. Full texts of the potentially eligible studies were assessed against the eligibility criteria [Table/Fig-1].

Data charting process: A standardised form for data extraction was developed, which was then pilot-tested on a subset of studies to ensure consistency and clarity. Two reviewers independently extracted data from all included studies using this predefined form. Extracted information included author details, publication year, study design, participant characteristics (age, gender, training status), intervention details (type of exercise, cuff pressure, cuff width, training duration, frequency, and load intensity), comparator groups (if any), and reported outcomes related to muscular strength, power, endurance, or muscle girth.

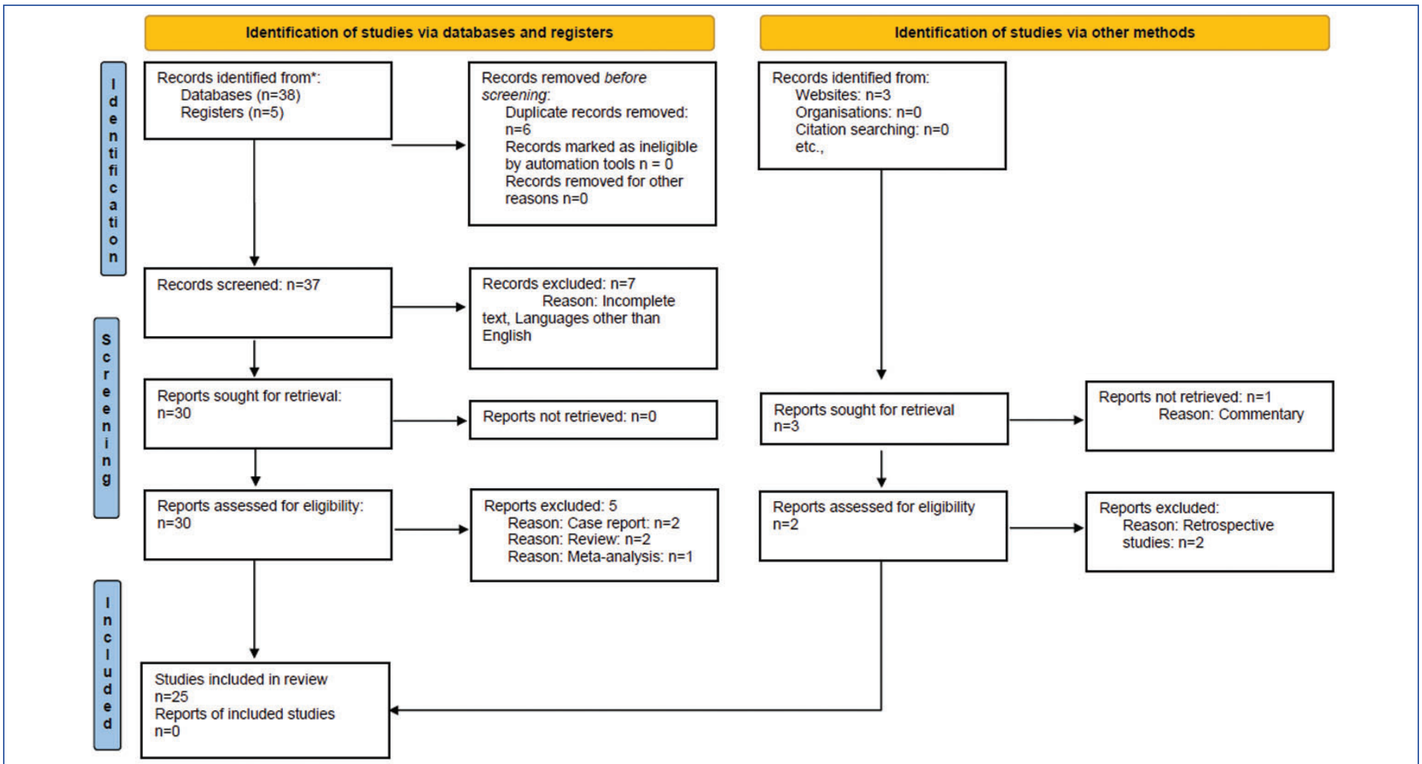
Data extraction was conducted by each reviewer separately to minimise bias and ensure accuracy. The results were then compared for agreement. Any discrepancies found were discussed and resolved through consensus, with other reviewers arbitrating when disagreement persisted. All the extracted data were recorded in Microsoft Excel for consistency and later verification. Once finalised, the data were reviewed for completeness before synthesis.

RESULTS

Study selection: A total of 25 RCTs met the eligibility criteria, investigating the effects of BFR training on muscular, functional, and physiological outcomes in healthy, physically active, or recreationally trained individuals [13-37]. These included recreational exercisers, athletes, older adults, military personnel, and individuals undergoing sport-specific conditioning [Table/Fig-2] [13,15,16,19, 20,22,24,25,27,33,34].

Most of the studies used low-load resistance exercise protocols of 20-40% of 1RM in combination with BFR [13,15,16,18,20-23,27,28,30-32,34,35]. The other types of interventions included aerobic cycling, treadmill running, posture correction exercises, interval sprints, and combinations such as BFR with Neuromuscular Electrical Stimulation (EMS) [14,17,19,24-26,29,33,36,37].

The length of the training ranged from a single session to 4-12 weeks, and the training frequency was 2-3 sessions per week in most studies.



[Table/Fig-1]: PRISMA flowchart of included articles.

Sr. No.	Author	Place of study	Sample size and Population	Purpose	Study design	Intervention	Outcome Measures	Findings
01	Biral TM et al., 2025 [13]	Center for studies and assistance in physiotherapy and rehabilitation of FCT/ UNESP	61 healthy adults	To investigate the effect of different loads during eccentric training with BFR on muscle hypertrophy, strength, and performance	Randomised Controlled Trial (RCT)	10 sessions of eccentric knee extension: groups trained with 20% 1RM with BFR, 40% 1RM with BFR, or 40% 1RM without BFR	Muscle Cross-Sectional Area (CSA), isokinetic strength, Countermovement Jump (CMJ) performance	All groups improved in strength and hypertrophy; 40% 1RM with BFR showed greater gains in muscle CSA and jump performance; higher load BFR is more effective for muscle size and functional performance
02	Almeida G et al., 2025 [25]	University of Texas Health Sciences Center, at San Antonio, USA	52 healthy adults	To examine the effects of aerobic cycling exercise with BFR on knee stability, muscle strength, and aerobic capacity	Randomised Controlled Trial (RCT)	4 weeks (3x/ week) of stationary cycling: BFR group trained with 180 mmHg occlusion pressure during cycling sessions; control group performed same cycling without BFR	Isometric quadriceps strength (dynamometer), knee joint laxity (KT1000 arthrometer), VO_2peak (aerobic capacity test)	BFR group showed significantly greater improvements in quadriceps strength and VO_2peak compared to control; knee stability (laxity) was not negatively affected; BFR cycling is a safe and effective method to enhance strength and aerobic performance in healthy adults
03	Nancekievill D et al., 2025 [22]	University of New Brunswick, Fredericton, NB, Canada	38 healthy adults	To examine the impact of low-load resistance training with Blood Flow Restriction (BFR) on muscle hypertrophy and physical performance in men and women	Randomised Controlled Trial (RCT)	Bilateral knee extensions at 30% 1RM with BFR (training 2x/week); cuffs inflated to 80% AOP; pre- and post-testing of all outcomes	Muscle thickness (via ultrasound), strength (1RM), power (vertical jump), muscular endurance (max reps at 50% 1RM)	Both men and women significantly improved muscle thickness, strength, and muscular endurance; no significant change in jump power; no sex differences in response to BFR training; BFR is effective for hypertrophy and endurance improvements regardless of sex
04	Werasirirat P et al., 2023 [24]	Burapha University, Chonburi, THAILAND	28 participants with rounded shoulder posture	To investigate the effect of BFR combined with strengthening exercises on posture correction and muscle function	Randomised Controlled Trial (RCT)	Group-1: Strengthening exercises with BFR; Group-2: Strengthening without BFR; Group-3: Control (no intervention); 3x/week for 4 weeks	Acromion-To-Table Distance (ATD), Pectoralis Minor length Index (PMI), upper trapezius EMG activity	BFR + strengthening group showed significant improvements in ATD and PMI and reduced EMG activity compared to other groups; effective for posture correction and muscle function improvement
05	Królikowska A et al., 2023 [20]	Wroclaw Medical University, Poland	15 recreational male athletes	To investigate the effect of BFR on knee flexor muscle fatigue during low-load resistance training	Randomised double-blinded placebo-controlled pilot study	3 groups: BFR group (occlusion at 80% AOP), placebo group (20 mmHg), and control group (no BFR); performed leg curls at 30% 1RM	Surface EMG (muscle fatigue), isokinetic peak torque	BFR group showed greater muscle fatigue (EMG changes) without significant loss in peak torque; suggests enhanced fatigue stimulus with low-load BFR in recreational athletes.
06	Li N et al., 2023 [16]	Sichuan University, Chengdu, Sichuan, China	40 healthy college-aged male	To explore whether combining Blood Flow Restriction (BFR) with electrical muscle stimulation (EMS) enhances neuromuscular adaptations	Randomised Controlled Trial (RCT)	All training involved low-load leg extension at 20% 1RM; BFR-EMS group had both BFR and EMS, BFR group used only BFR, control had no training	Muscle strength (1RM), muscle thickness (ultrasound), surface EMG (muscle activation), peak torque	BFR-EMS group showed the greatest improvements in muscle strength, thickness, and activation, significantly greater than BFR or control; BFR group also improved significantly over control; combining BFR with EMS enhances neuromuscular adaptation beyond BFR alone
07	Fekri-Kourabbaslou V et al., 2022 [33]	Faculty of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran	20 untrained young men	To investigate the effect of different recovery modes (active vs passive) during LL-BFR training on hormonal response and performance	Randomised Controlled Trial (RCT)	Resistance training at 30% 1RM, 3x/week with BFR (130 mmHg); one group used active recovery (cycling), another passive	Growth Hormone (GH) levels (pre/ post), 1RM, muscular endurance	Active recovery group had significantly higher GH response (~423% vs 151%), and greater improvements in strength and endurance
08	Beak HJ et al., 2022 [27]	Konkuk University, Chungju, Korea	30 healthy recreational male runners	To evaluate the effects of 8 weeks of low-intensity aerobic training with Blood Flow Restriction (LABFR) on body composition, physical fitness, and vascular responses	Randomised Controlled Trial (RCT)	Treadmill running (5 × 2 min at 40% VO_2max, 3×/ week); LABFR group used thigh cuffs (160-240 mmHg) while control did not	Body composition (muscle mass, fat %, thigh circumference), physical fitness (VO_2max, power), vascular responses (FMD, baPWV, ABI, BP)	LABFR group showed significant increases in muscle mass and right thigh circumference; no significant differences in fat mass, VO_2max, vascular function, or blood pressure compared to control; LABFR improves muscle size but not aerobic capacity or vascular function in trained runners

09	Green LL et al., 2020 [34]	Arkansas State University	11 physically active young males	To assess the effects of BFR on proximal upper extremity muscles (shoulder and chest)	Randomised Controlled Trial (RCT)	BFR group: unilateral exercises at 20% 1RM with 50% occlusion pressure; Control group: bilateral exercises at 70% 1RM (ACSM protocol), both 2x/week	Manual Muscle Testing (MMT) of 5 shoulder/chest muscles, 1RM for 4 exercises	BFR group had significant gains in pectoralis major, lower trapezius strength, and prone row 1RM; similar strength gains in proximal muscles compared to high-resistance training.
10	Bigdely S et al., 2020 [15]	Kharazmi University	30 older adults	To examine the effects of low-load BFR and high-load resistance training on muscle strength, mass, and function	Randomised Controlled Trial (RCT)	LL-BFR: leg press and leg extension at 30% 1RM with BFR; HL: same exercises at 80% 1RM, both 2x/ week	Quadriceps CSA (MRI), knee extensor strength, sit-to-stand time, stair climb, 6MWT	Both groups improved muscle CSA and functional tests. High-load group showed greater strength gains, while LL-BFR produced significant improvements with lower joint stress, making it suitable for older adults unable to tolerate heavy loads.
11	Early KS et al., 2020 [37]	Department of Kinesiology and Health Sciences Columbus	31 healthy adults	To assess effects of BFR vs. traditional resistance training on muscle strength, vascular function, and pain	Randomised Controlled Trial (RCT)	BFR: 30% 1RM using BStrong bands on 4 limbs, 2-3x/week for 8 weeks; compared with RES (60% 1RM, same schedule) and Control (no training)	Muscle strength (1RM), Flow-Mediated Dilation (FMD), pain (VAS, PPI)	BFR and traditional training both improved strength, with traditional showing slightly larger gains. BFR caused greater acute pain reduction and did not negatively affect vascular function. No adverse events occurred. BFR is a safe alternative for low-load training.
12	Bowman EN et al., 2020 [19]	Vanderbilt University Medical Center, Nashville, TN, USA	24 healthy participants	To assess the effects of upper-extremity BFR training on strength gains in proximal, distal, and contralateral muscles	Randomised Controlled Trial (RCT)	BFR group: unilateral low-load training with BFR cuff on arm; Control group: same training without BFR; both 3x/week	Strength (1RM) in shoulder (proximal), wrist (distal), and contralateral limb	BFR group showed significant strength gains in trained muscles (proximal and distal) and modest gains in contralateral limb; control group showed lesser or no improvements
13	Gavanda S et al., 2020 [23]	IST University of Applied Sciences, Du¨sseldorf, Germany,	30 healthy adults	To investigate whether a six-week low-intensity RT with BFR is superior to RT without BFR for inducing muscle mass and strength gains, when performed to volitional muscle failure.	Randomised Controlled Trial (RCT)	BFR group: knee extension at 30% 1RM with BFR (4 sets); Control: same without BFR; both 2x/ week	Knee extensor strength, resting limb blood flow	BFR group showed significant improvement in muscle strength without change in blood flow; control group showed no significant improvements
14	Christiansen D et al., 2020 [28]	University of Copenhagen, Copenhagen, Denmark	10 healthy young men	To investigate the effects of BFR resistance training on microvascular filtration capacity and angiogenic signaling in human skeletal muscle	Within-subject controlled study	Unilateral knee-extensor resistance training (3x/week, 4 sets @ 20% 1RM); BFR applied to one leg (180 mmHg cuff pressure)	Microvascular filtration capacity (via venous occlusion plethysmography), muscle biopsies for angiogenic markers (VEGF-A, VEGFR2, HIF-1α), muscle strength (MVC)	BFR leg showed increased microvascular filtration capacity (+46%) and elevated expression of VEGF-A and VEGFR2; muscle strength improved in both legs, but significantly more in BFR leg; BFR promotes microvascular and angiogenic adaptations in skeletal muscle
15	Amani-Shalamzari S et al., 2019 [26]	Kharazmi University, Tehran, Iran	32 physically active collegiate women	To examine the effects of different intensities of interval running with and without Blood Flow Restriction (BFR) on aerobic, anaerobic, and strength adaptations	Randomised Controlled Trial (RCT)	Groups trained at 40% or 70% VO_2max with or without BFR; BFR applied using elastic knee wraps during treadmill intervals	VO_2max (aerobic capacity), Wingate test (anaerobic power), 1RM squat and bench press (muscle strength)	All training groups improved aerobic, anaerobic, and strength measures. The 40% VO_2max with BFR group had similar or superior gains compared to 70% VO_2max without BFR. BFR enhances training adaptations even at low intensities, making it effective for populations requiring reduced load or impact.
16	Bowman EN et al., 2019 [18]	Vanderbilt University Medical Center, Nashville, Tennessee, Rochester Regional Health Orthopaedics, Pittsford, New York	26 recreationally active adults	To assess the effects of unilateral low-load BFR training on strength and limb girth, including non-occluded and contralateral limbs	Randomised Controlled Trial (RCT)	Low-load leg resistance training (20–30% 1RM) with BFR applied unilaterally; control group performed no training on non-training leg	Knee extension torque, total work, average power, thigh/leg circumference (girth)	BFR group had ~11% increase in strength vs. ~3% in control, ~15% gain in total work vs. ~6%, and ~3.5% increase in thigh/leg girth vs. ~0.8% in non-training control limb; strength gains also occurred in the non-occluded leg, indicating systemic adaptations

17	Pignanelli C et al., 2019 [31]	University of Guelph, Guelph, Ontario, Canada	10 healthy adults (mixed young men & women)	To compare adaptations from low-load resistance training with and without BFR	Within-subject randomised trial	LL-RE and LL-BFR performed to task failure (~20–30% 1RM), unilateral training; cuff pressure not specified	Muscle strength, Cross-Sectional Area (CSA), endurance power, microvascular and mitochondrial function	Both LL-RE and LL-BFR improved muscle strength and size despite 33% lower total volume in LL-BFR; only BFR training enhanced mid-task power output; mitochondrial capacity increased only with LL-RE; adaptations in capillary structure were similar
18	Jessee MB et al., 2018 [21]	The University of Mississippi	46 healthy, untrained adults	To compare muscle adaptations between high-load (70% 1RM) and very low-load (15% 1RM) resistance training with and without Blood Flow Restriction (BFR), and assess pressure dependency	Within/ between-subject experimental design (each leg assigned to different training condition)	Unilateral knee extension training, 4 conditions: 70/0 (70% 1RM, no BFR), 15/0 (15% 1RM, no BFR), 15/40 (15% 1RM with 40% AOP BFR), 15/80 (15% 1RM with 80% AOP BFR)	Muscle thickness (ultrasound), 1RM strength, isometric & isokinetic torque, endurance (reps to failure), exercise-induced swelling	1RM strength increased only in 70/0. Muscle thickness increased similarly across all conditions. Endurance improved most in 15/80. Isometric and isokinetic strength gains were similar in all groups. BFR reduced the training volume required for adaptations.
19	Libardi CA et al., 2015 [30]	University of São Paulo - USP, São Paulo, Brazil	25 healthy older adults	To compare effects of concurrent training (CT) with or without Blood Flow Restriction (BFR) on muscle mass, strength, and aerobic fitness	12-week Randomised Controlled Trial (RCT)	BFR-CT: 2x/week leg press with 20–30% 1-RM + BFR + endurance training (ET); CT: 2x/week leg press at 70–80% 1-RM + ET; Control: no training	VO_2peak, 1-RM leg press, quadriceps CSA (MRI)	Both CT and BFR-CT improved VO_2peak (~10%), strength (~35–38%), and CSA (~7.5%) similarly. BFR-CT achieved these with lower training loads, suggesting it is a safe and effective alternative for older adults.
20	Yasuda T et al., 2015 [29]	Seirei Christopher University, Mikatahara, Kita-ku, Hamamatsu, Shizuoka, Japan	14 Physically active older women	To examine the effects of BFR training and detraining on muscle size and arterial stiffness	24-week experimental study (12 weeks training + 12 weeks detraining)	BFR group: low-load elastic band training with BFR (20 min, 2x/ week); Control: same training without BFR	Muscle Cross-Sectional Area (CSA), arterial stiffness (baPWV)	BFR group showed increased CSA and reduced arterial stiffness after training; effects partially maintained after detraining; control group showed no changes
21	Kim D et al., 2015 [32]	Department of Kinesiology, Iowa State University, Ames, IA, USA	18 Physically active men	To compare acute muscular effects of high-intensity cycling vs. low-intensity cycling with 40% and 60% Blood Flow Restriction (BFR)	Randomised crossover experimental design	4 conditions: high-intensity cycling (75% VO_2peak), 40%BFR, 60%BFR (both at 40% VO_2peak), and control	Torque, muscle thickness, blood lactate, EMG (amplitude, MPF), heart rate, RPE, discomfort	High-intensity cycling induced greater lactate accumulation, EMG activation, and anterior thigh swelling than BFR conditions; no meaningful torque changes; no added benefit from 60% BFR over 40%
22	Lixandrão ME et al., 2015 [35]	University of São Paulo	26 healthy young males	To investigate the effects of different exercise intensities and occlusion pressures during blood-flow restriction (BFR) resistance training on muscle size and strength	Randomised Controlled Trial (RCT)	Resistance training 2×/week for 12 weeks: low-load (20% 1RM) or high-load (40% 1RM) combined with low (40% AOP) or high (80% AOP) occlusion pressure	Muscle Cross-Sectional Area (CSA) via MRI, muscle strength (1RM leg press and knee extension)	All BFR groups significantly increased muscle CSA and strength. No additional benefits were found from using higher loads or higher occlusion pressures. Thus, low-load BFR with low pressure was as effective as higher intensities or pressures for muscle hypertrophy and strength gains.
23	Kang DY et al., 2015 [36]	DongJu College, Republic of Korea	17 healthy college students	To investigate the effects of bodyweight-based BFR training on knee muscle strength and thigh circumference	Randomised Controlled Trial (RCT)	Front lunges and squats performed with BFR wraps (BFR group) vs. same exercises without BFR (control); RPE 11-13; 30 min/ session	Isokinetic knee muscular strength (60°/s and 180°/s peak torque/body weight) and thigh circumference	BFR group showed significant improvements in knee flexor strength (especially at 180°/s) and significant increases in thigh circumference compared to control; suggests BFR with wraps is effective for improving muscle power and hypertrophy in a clinical setting
24	Vechin FC et al., 2015 [17]	Federal University of Sa˜o Carlos	23 elderly men and women	To compare effects of low-intensity resistance training with Blood Flow Restriction (LRT-BFR) vs. high-intensity resistance training (HRT) on quadriceps strength and mass	Randomised Controlled Trial (RCT)	HRT: 4×10 reps at 70-80% 1RM; LRT-BFR: 1×30 + 3×15 reps at 20–30% 1RM with 50% arterial occlusion (2x/ week)	Leg press 1RM, quadriceps Cross-sectional Area (CSA via MRI)	Both groups improved CSA (HRT: 7.9%, LRT-BFR: 6.6%). Strength gain higher in HRT (54%) vs. LRT-BFR (17%, p=0.067). LRT-BFR is a viable alternative for elderly unable to perform HRT.

25	Farup J et al., 2015 [14]	Aarhus University, Aarhus, Denmark	10 healthy untrained men	To compare the effects of low-load BFR training and high-load traditional resistance training on muscle hypertrophy and strength when both are performed to fatigue	Randomised within-subject design	Unilateral knee-extension training 3x/week: one leg performed low-load (20% 1RM) BFR training to fatigue; the other leg performed high-load (70% 1RM) traditional training to fatigue	Muscle hypertrophy (MRI-measured CSA of quadriceps), muscle strength (1RM, isometric MVC), muscle endurance (repetitions at 50% 1RM), muscle architecture (pennation angle)	Both BFR and traditional training led to similar increases in muscle CSA (~8%), strength, and architectural changes; BFR also led to superior improvements in muscular endurance; suggests training to fatigue is key for hypertrophy, regardless of load

[Table/Fig-2]: Extracted data from the selected articles [13-37].
• LL-BFR – Low-load blood flow restriction, HL – High load, LL-RE – Low-Load resistance exercise, LRT-BFR – Low-load resistance training with blood flow restriction, HRT – High-load resistance training, RT – Resistance training, RFD – Rate of force development, AOP – Arterial occlusion pressure,1RM – One repetition maximum, VO_2max / VO_2peak – Maximal oxygen uptake, baPWV – Brachial–ankle pulse wave velocity, ATD – Acromion-to-Table distance, 6MWT – Six-minute walk test

Muscular Strength and Hypertrophy

All included studies reported an improvement in muscular strength and hypertrophy after BFR training. Increases were typically quantified through muscle Cross-sectional Area (CSA), ultrasound-derived muscle thickness, or limb circumference. In fact, low-load BFR training produced strength and hypertrophic outcomes equivalent to, or greater than, traditional high-load resistance training across numerous demographics, including young untrained individuals, middle-aged women, older adults, and athletes. Of the studies that used BFR in combination with eccentric exercise or electrical muscle stimulation, some showed further increases in strength and muscle thickness, which may indicate greater neuromuscular activation [13-15,18,21,22,31].

Resistance to Fatigue and Systemic Effects/ Endurance

Most of the studies evaluated muscular endurance and fatigue resistance, typically repetition-to-failure or time-to-exhaustion tests. Of these, the majority reported an improvement in local muscular endurance following BFR interventions. Several studies also found performance gains in the contralateral, non trained limbs as well, indicating a potential cross-education or systemic neuromuscular adaptation effect. Physiological markers, such as capillary recruitment and oxidative fibre activation, were improved in some trials, which supports the hypothesis that fatigue resistance has been improved locally by BFR training [17,19,23,29,30,32,34-37].

Aerobic Capacity and Vascular Adaptations

The findings of aerobic capacity and vascular responses to BFR training were inconsistent across studies. Interventions using aerobic BFR modalities, such as cycling or treadmill walking under occlusion, showed improvements in VO_2peak, running economy, or time-trial performance in some trials, while others showed no significant changes in VO_2max, FMD, or blood pressure. Some studies reported improved peripheral circulation and muscle perfusion along with reduced arterial stiffness after continuous low-intensity BFR programs. The variability in the results may be linked to the variance in occlusion pressure, training frequency, intensity, and also fitness status of the participants.

Safety and Tolerability

All the included studies assessed safety outcomes. No serious adverse events were recorded; the common but transient effects included localised muscle soreness, temporary discomfort, and short-term increases in blood pressure, all of which resolved post-exercise. Most of the trials emphasised the use of personalised arterial occlusion pressures to maximise safety and efficacy of training. Indeed, the protocols with moderate occlusion pressures combined with low mechanical loads (20-30% 1RM) were consistently associated with high participant compliance and favourable physiological outcomes [16,20,24-28,33].

DISCUSSION

The present scoping review synthesised evidence from 25 RCTs that investigated the effectiveness of BFR training among different populations and exercises. In general, the results consistently favour BFR for increasing muscle strength, hypertrophy, and endurance and, in some cases, functional and aerobic performance among trained and untrained, young, and older populations.

Muscle strength was the most often-measured outcome and showed consistent improvement with low-load BFR training. Studies by Biral TM et al., (2025) and Farup J et al., (2015) reported strength gains comparable to traditional high-load resistance training, even when using loads as low as 20-30% 1RM [13,14]. Biral TM et al., further demonstrated that eccentric BFR training at 40% 1RM resulted in greater increases in muscle CSA and countermovement jump performance, indicating that load magnitude still plays a role within BFR protocols [13]. In older adults, Bigdely S et al., (2020) supported BFR as a safer alternative to high-load training for improving strength among individuals at higher injury risk [15].

Improvements in muscle hypertrophy, as measured by MRI, ultrasound, and limb circumference across diverse populations, including healthy young individuals Li N et al., (2023), older adults Vechin FC et al., (2015), and recreational athletes Bowman EN et al., (2019), were widely reported [16-18]. Li N et al., showed that the addition of EMS to BFR produced greater muscle thickness, strength gains, and EMG activity compared with BFR alone. Cross-education effects were also apparent; Bowman EN et al., (2020) demonstrated contralateral strength gains in the untrained limb following unilateral BFR [19], indicating that BFR promotes both local and systemic neuromuscular adaptations [13-20].

These adaptations have been primarily attributed to the hypoxic and metabolite-rich intramuscular environment created by the occlusion. The restricted venous outflow, in conjunction with ongoing arterial inflow, results in metabolite accumulation, greater recruitment of fast-twitch fibres, and higher anabolic hormone responses. The activation of the Mechanistic Target of Rapamycin (mTOR) signalling pathway and proliferation of satellite cells are associated with increased protein synthesis and greater muscular growth. This can explain why low-load BFR can produce similar or higher benefits as traditional high-load resistance training while inducing much less joint stress.

Improvements in muscular endurance were also indicated. Królikowska A et al., (2023) and Jessee MB et al., (2018) reported an increase in fatigue resistance and endurance after BFR with low intensities [20,21]. In Nancekievill D et al., (2023), improved endurance with 30% 1RM knee extensions was observed in both males and females [22], while Jessee MB et al., mentioned a dose-response relationship based on the level of arterial occlusion pressure [21-24].

Functional performance gains were especially pronounced in athletic cohorts: for example, Gavanda S et al., (2020) have reported vertical jump improvements using BFR semi-squat training [23], and Biral TM et al., (2025) reported gains in countermovement jump and functional tasks with eccentric BFR [13]. Werasirirat P et al., in 2023 found improvements in upper trapezius activation and posture in rehabilitation settings [24-26].

Findings related to cardiovascular and aerobic capacity were more variable. Almeida G et al., (2022) and Amani-Shalamzari S et al., (2019) demonstrated improvements in VO_2peak during aerobic exercise with BFR [25,26], while Beak HJ et al., (2022) did not find similar benefits from BFR training on a treadmill [27]. In turn, Christiansen D et al., (2020) showed increased expression of angiogenic markers {VEGF-A (Vascular Endothelial Growth Factor A), VEGFR2 (VEGF Receptor 2) and improved microvascular function, and Yasuda T et al., (2015) reported reduced arterial stiffness following BFR elastic band exercise [28-31].

Overall, the safety outcomes reported were excellent, with no serious adverse events recorded across the various studies. Mild swelling, discomfort, or transient blood pressure elevations were occasionally experienced. Individualised occlusion pressures, often 40-80% AOP for the lower limbs, are critical to safety and efficacy. No consistent gender-based differences in responses were noted. Often, multiple combined interventions, such as BFR combined with EMS or aerobic training, showed additive effects [32-37].

The suggested practical protocols of BFR include 20-30% 1RM resistance load, often patterned into one set of 30 repetitions followed by three sets of 15, with 30-60 seconds rest, performed 2-3 times per week for 4-8 weeks. Other requirements are individualised pressure prescription, gradual familiarisation, and monitoring of perceived exertion and haemodynamic responses. In summary, BFR is a versatile, low-load training strategy that has the potential to evoke significant muscular and functional adaptations from a wide range of populations. When properly individualised and supervised, BFR offers a promising and effective approach to training and rehabilitation.

Limitation(s)

Even though the results are promising, some limitations apply. Most studies had a fairly small number of participants, and long-term consequences beyond 12 weeks were not well explored. Additionally, though BFR seems to be equally effective in both sexes and fitness levels, only one of the studies directly compared gender-specific responses, which needs to be further explored. Results are also not consistent for occlusion methods, cuff widths, and pressure settings across studies, which makes them difficult to compare.

Future research should aim for standardisation of occlusion procedures, establishment of long-term safety, and exploration of integration of BFR with varied exercise modalities.

CONCLUSION(S)

The current scoping review emphasises the effectiveness and malleability of BFR training as a means to enhance muscular strength, hypertrophy, endurance, and, in certain instances, cardiovascular health across varied populations and modalities. The evidence from 25 RCTs confirms the use of low-load BFR as an acceptable alternative to high-load resistance training, especially in populations where heavy lifting is impractical or contraindicated. BFR was also shown to be safe, well-tolerated, and able to induce systemic responses like hormonal and angiogenic signalling. Additionally, its applicability in both sexes, ages, and fitness levels makes it an even greater candidate for integration into clinical rehabilitation and sports conditioning programs. BFR may also be mixed with modalities like electrical muscle stimulation or aerobic exercise to promote neuromuscular and metabolic adaptation. Due to its established benefits with lower mechanical load, BFR is a convenient and effective intervention to improve performance and recovery.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Sep 17, 2025
- Manual Googling: Oct 28, 2025
- iThenticate Software: Nov 24, 2025 (5%)

ETYMOLOGY: Author Origin

EMENDATIONS: 6

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was informed consent obtained from the subjects involved in the study? No
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Sep 16, 2025**
Date of Peer Review: **Oct 22, 2025**
Date of Acceptance: **Nov 26, 2025**
Date of Publishing: **Feb 01, 2026**