Systematic Review

Lower Extremity Blood Flow Restriction Training in Athletes Significantly Improves Strength-Related Outcomes in 58% of Studies Compared to Non—Blood Flow Restriction Control

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Purpose: To examine the role of lower extremity blood flow restriction (BFR) in the athletic population. **Methods:** This study was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines. Searches of Level I and II studies were performed on PubMed, Embase, and Cochrane databases. Article identification was performed in August 2024. Studies related to BFR in the lower extremity in athletic populations were included. The data collected included athlete demographics; treatment groups; BFR training protocols; control training protocol; exercises performed; training duration and frequency; cuff type, size, and pressure; muscles targeted; strength improvement; endurance improvement; muscle growth; and sport-specific metrics (speed, jump height, etc.). **Results:** Twenty studies were identified for inclusion. Significant within-group strength increases from pre- to post-training in the BFR group were reported in 19 of 20 studies, with at least 1 strength outcome being significantly increased in the BFR group compared to the control group in 11 of 19 studies (58%). Outcomes related to muscle size were reported in 14 studies, with 10 of these studies reporting within-group increases for the BFR group in at least 1 muscle size metric. Sport-specific metrics were reported in 12 studies, and 4 studies reported on endurance outcomes and generally favored the BFR group over the control group. Five of 6 studies comparing low-load exercise with BFR to high-load exercise without BFR reported comparable outcomes between groups. **Conclusions:** In this systematic review, we found that 58% of studies reporting on lower extremity BFR use in athletes observed significant strength improvements in the BFR group compared to a non-BFR group. Additionally, when comparing low-intensity exercise with BFR to high-intensity exercise without BFR, 5 of 6 studies reported either improved or comparable outcomes between the BFR and control groups. In general, exercise with and without BFR led to improvements in lower extremity strength, muscle size, endurance outcomes, and sport-specific metrics, and most of the included studies reported greater improvements within the BFR group. **Level of Evidence:** Level II, systematic review of Level I and II studies.

Exercise with blood flow restriction (BFR) has recently gained increased attention due to its role in enhancing muscle size/hypertrophy and strength.[1,2] Exercise programs that include BFR have increased in popularity in both the rehabilitation and strength and conditioning settings as an adjunct strength training method for athletes.[3-5] Blood flow restriction involves the placement of a restrictive cuff/tourniquet around the most proximal region of the targeted limb(s) for the purpose of partially occluding arterial inflow while significantly obstructing venous return.[6] Exercise with BFR is thought to create a localized hypoxic-like environment within the muscle, which has been observed to enhance acute muscular fatigue, augment muscle activation, and stimulate anabolic cell signaling; these physiological responses may partially explain the observations of enhanced muscular hypertrophy and strength when combining low load exercise with BFR.[7,8]

To increase muscular size (also known as hypertrophy) and strength, the American College of Sports Medicine recommends resistance training exercise should be performed at >70% of an individual's

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concentric 1-repetition maximum (1-RM).[9] In contrast, many BFR protocols typically utilize low-intensity resistance exercise at 20% to 50% 1-RM.[10]

With the development of more sophisticated BFR devices, such as automated devices that can control arterial occlusion pressure (AOP) in real time, administering BFR within the rehabilitation setting has become safer and more precise.[6] Exercise with BFR has been shown to play an important role within the rehabilitation setting.[11] Preoperative and postoperative patients, or individuals who have been injured, may benefit from rehabilitation programs that include BFR due to its potential to reduce muscle atrophy without the need for a high-intensity exercise/load, which could harm healing tissue and/or compromise a surgical procedure.[12,13] Although many studies have shown the benefits of BFR within injured or postoperative populations early in rehabilitation,[11,12] less is known specifically about how BFR affects athletes later in the rehabilitation of common athletic injuries (e.g., anterior cruciate ligament reconstruction) or within healthy athletic cohorts seeking to optimize muscle size and strength and/or improve athletic performance, especially within a competitive season.[3-5,14] Recent and ongoing research has better defined the role of BFR within an athletic population, and it has been proposed that low-load resistance training with BFR may result in similar or improved performance outcomes when compared to traditional high-load resistance training.[3-5,13]

The purpose of this systematic review was to examine the role of lower extremity BFR in the athletic population. It is hypothesized that lower extremity exercise with BFR may lead to improvements in strength, muscle size (or hypertrophy), sport-specific metrics, and endurance, and low-load training with BFR may potentially provide similar benefits to athletes as traditional high-load resistance training (e.g., >70% 1-RM) without BFR.

Methods

Article Identification and Selection

This study was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines and registered on the PROSPERO International prospective register of systematic reviews (CRD42024574910). Searches were performed on PubMed, Embase, and Cochrane databases. Article identification was performed in August 2024. The following search terms were used: blood flow restriction, occlusion training, kaatsu, restricted blood flow, ischemia, vascular occlusion, athlete, and outcomes. The search strategy utilized was as follows: (((blood flow restriction) OR (kaatsu) OR (occlusion training) OR (restricted blood flow) OR (ischemia)) AND ((athlete) OR (sport) OR (team) OR (club) OR (academy)) AND ((lower extremity) OR (thigh) OR (quadriceps) OR (knee extension)) AND (randomized)).

All studies from each database were uploaded to EndNote Reference Manager for duplicate article deletion. Two independent investigators (L.V.T. and E.P.M.) reviewed all abstracts for inclusion criteria. Inclusion criteria consisted of articles that published results on patients (1) ≥15 years old, (2) athletes, (3) randomized studies, (4) utilized BFR in some capacity during training, (5) studies reporting on lower extremity outcomes, (6) patients having at least 1 objective outcome measure (strength, hypertrophy, endurance, or performance), and (7) consisted of Level I or II evidence. Exclusion criteria included (1) patients from nonathlete populations; (2) ankle/foot-related outcomes; (3) technique papers, case reports, and systematic reviews; and (4) higher than Level II evidence studies. Three reviewers (L.V.T., J.S., and B.S.) examined all full texts of abstracts meeting the inclusion criteria. Furthermore, all systematic reviews found in the database were examined for additional relevant studies that may have been missed.

Data Collection

The data collected included athlete demographics; treatment groups; BFR training protocols; control training protocol; exercises performed; training duration and frequency; cuff type, size, and pressure; muscles targeted; strength improvement; endurance improvement; muscle growth; and sport-specific metrics (speed, jump height, etc.). The statistical significance between pre- to post-training and between BFR groups and control groups from each individual study was noted to be utilized in our analysis.

Data Analysis

We examined all studies that described the use of BFR for training in athletes. We specifically analyzed studies that utilized BFR on the lower extremity (cuff on the proximal thigh) and measured knee-related outcomes. These outcomes included quadriceps and hamstring strength and muscle size; sports-specific metrics like jumping height, sprinting speed, and rowing/biking power; and endurance metrics for running and rowing.

Due to the heterogeneous nature of the data and outcomes, a statistical analysis or meta-analysis was not possible. The data available were compiled into Excel (Microsoft) to summarize and analyze the data. The data were sorted based on whether it was a strength-related outcome, muscle size—related outcome, sports-specific outcome, or endurance-based outcome. The data are summarized in tables in the results.

Risk of Bias Assessment

Risk of bias assessment was performed for all studies in this systematic review. Although all studies were described as randomized studies, all studies utilized volunteers, most were not blinded, and the randomization technique was often not described. Due to this, the studies in this review were treated as comparative studies, and the Methodological Index for Non-Randomized Studies (MINORS) criteria were utilized.[15] All studies were evaluated using 12 questions, each scoring between 0 and 2 for all questions. A score of 0 was given when the question was not answered, a score of 1 was given when the question was answered but not properly, and a score of 2 was given when the question was answered properly. A score of <14 was considered poor quality, 15 to 20 was considered moderate quality, and 21 to 24 was considered high quality.

Results

Study Selection and Patient Demographics

A total of 288 studies were identified based on the initial search criteria. Thirty full-length studies were identified and screened for final inclusion. After removing 3 ankle-related studies, 5 studies not reporting on athletes, 1 study reporting on the same cohort as another study, and 1 study with no pre- versus post-training analysis, a total of 20 studies were selected for inclusion (Fig 1). These 20 studies included a total of 546 athletes with a mean age of 22.7 years (range, 18.7-29.9 years). Only 95 (17.4%) of the athletes in this study were women. The athletic patient population included participation in American football, canoe, soccer, futsal, netball, recreational athletics, rowing, rugby, running, swimming, track and field, and volleyball. The MINORS criteria revealed an average score of 18.4 out of 24 (range, 15-22) (see Appendix 1, available at www.arthroscopyjournal.org).

Training Protocol and BFR Use

Table 1 includes the exercise exposure and BFR protocol use from each individual study. Training periods ranged from 8 days (Abe et al.[16]) to 14 weeks (Centner et al.[17]) with session frequency ranging from 2 to 5 per week, with the most common being 3 BFR training sessions per week. The BFR cuff or elastic bands were placed on the upper thigh in all studies. Fourteen studies used inflatable BFR cuffs of varying widths, and the other 6 studies used elastic wraps. The BFR method used and the applied pressure (for studies using BFR cuffs) for each study are summarized in Table 1.

Strength Outcomes

Muscle strength was the most reported BFR testing outcome measure, with all studies reporting on at least 1 strength outcome. Significant within-group strength increases from pre- to post-training in the BFR group were reported in 19 of 20 studies, with strength outcome measures that included a 1-RM (or 3-RM) and

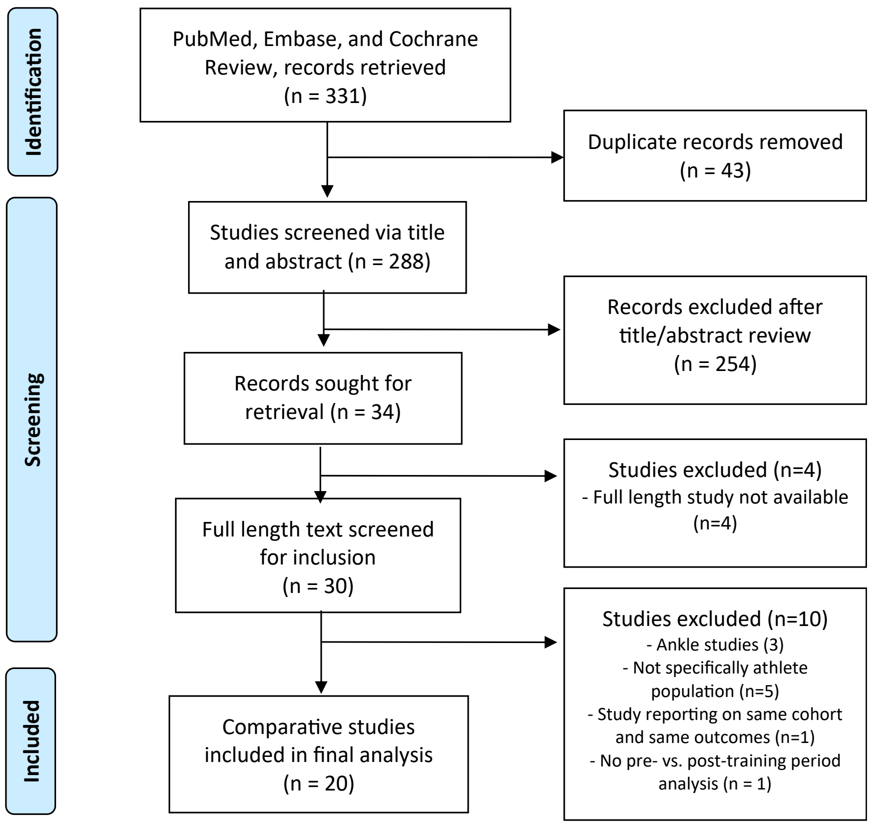

Fig 1. Flowchart for the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Table 1. Summary of Study Enrollment and BFR Treatment Protocol Details

First Author, Year (LOE)	Athlete Cohort	Patients (Females)	BFR Training Protocol	Control Training Protocol	Training Frequency and Duration	Cuff Location and Pressure	Physiological Adaptations (Between-Group Comparisons)	Sport-Specific Adaptations (Between-Group Comparisons)
Abe 2005 (II)[16]	Track and field	15 (0)	3 sets × 15 reps for squats and leg curls (30-s rest between sets) 20% 1-RM (LL)	No resistance exercise	2× per day for 8 days	Upper thigh, pneumatic cuff Cuff pressure: Day 1: 160 mm Hg, + 20 mm Hg per day until 240 mm Hg	↑ 1-RM leg press ↑ Muscle-bone cross-sectional area ↑ Quadriceps and hamstrings mid-thigh muscle thickness	↓ 30-m dash times ↔ Standing jump, triple jump, standing 5-step jump
Amani-Shalamzari 2020 (II)[18]	Futsal players	12 (0)	Futsal games Sessions 1-3: 4 games, sessions 4-7: 6 games, sessions 8 and 9: 8 games, session 10: 4 games Game: 3 min of high activity with 2-min rest (HL)	Same protocol but without BFR (HL)	10 training periods over 3 weeks	Upper thigh, pneumatic cuffs Cuff pressure: 110% systolic blood pressure, 10% increase per 2 training periods		↑ Run time to fatigue ↑ Mean power on max 30-s bike test ↑ Running economy ↔ VO_2 max
Beak 2022 (I)[19]	Recreational runners	30 (0)	2 min running, 1 min rest, repeated for 5 sets 40% VO_2 max (LL)	Same protocol but without BFR (LL)	3× per week for 8 weeks	Upper thighs (bilateral), occlusion cuff Cuff pressure: 160-240 mm Hg	↑ Muscle mass ↑ Right thigh circumference ↔ Left thigh circumference ↔ Fat mass or body fat % ↔ Vascular responses	↔ VO_2 max ↔ Power via vertical jump
Behringer 2017 (II)[20]	Sport students	24 (0)	6 consecutive sprints with 1 min rest between sprints. 60%-70% of maximum sprint (HL)	Same protocol but without BFR (HL)	2× per week for 6 weeks	Upper thigh, elastic knee wraps Cuff pressure: 7/10 perceived pressure	↑ Rectus femoris muscle thickness ↔ Biceps femoris, biceps brachii muscle thickness ↑ Rate of force development on leg press ↔ Max isometric force on leg press ↓ Muscle damage ↔ Growth hormone, testosterone, insulin-like growth factor 1, cortisol	↓ 100-m dash times

(continued)

Table 1. Continued

First Author, Year (LOE)	Athlete Cohort	Patients (Females)	BFR Training Protocol	Control Training Protocol	Training Frequency and Duration	Cuff Location and Pressure	Physiological Adaptations (Between-Group Comparisons)	Sport-Specific Adaptations (Between-Group Comparisons)
Bjornsen 2019 (II)[21]	National-level power lifters	17 (3)	Normal training (weeks 2 and 4-7): 6-7 sets, 1-6 reps BFR training (weeks 1 and 3): 4 sets of 30/15/12/8 reps Normal: 60%-85% 1-RM (HL) Extra sessions: 30% 1-RM (LL)	1-6 reps, 6-7 sets 60%-85% 1-RM (HL)	5× per week for 6.5 weeks	Upper thigh, elastic knee wraps Cuff pressure: simulated 120 mm Hg	↑ Type I fiber myofiber areas ↑ Myonuclear number ↑ Vastus lateralis CSA ↑ Maximal voluntary isokinetic torque leg extension ↔ Type II fiber myofiber areas ↔ Satellite cells ↔ 1-RM front squat	
Bowman 2019 (I)[22]	Recreational athletes	26 (16)	4 sets at 30/15/15/15 reps 30% 1-RM (LL)	Same protocol but without BFR (LL)	2× per week for 6 weeks	Upper thigh, tourniquet Cuff pressure: 80% arterial occlusion	↑ Isokinetic knee extension peak torque, total work, and average power ↑ Limb circumference in thigh and leg ↑ Contralateral nontourniquet limb: thigh girth and knee extension strength	
Centner 2022 (II)[17]	Recreational athletes	29 (0)	4 sets at 30/15/15/15 reps with 60 s rest between sets 20% 1-RM increased 5% every 4 weeks until max of 35% 1-RM (LL)	3 sets of dynamic exercise with reps determined by % of 1-RM of work 70% 1-RM (HL) (12 reps) increasing 5% every 4 weeks until max of 85% 1-RM (HL) (6 reps) 75% 1-RM = 10 reps, 80% 1-RM = 8 reps	3× per week for 14 weeks	Upper thigh, pneumatic tourniquet Cuff pressure: 50% arterial occlusion	Comparable ↑ in patellar tendon stiffness and CSA, muscle mass and strength for both LL-BFR and HL but not significantly different between groups ↑ Knee extension 1-RM	

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Table 1. Continued

First Author, Year (LOE)	Athlete Cohort	Patients (Females)	BFR Training Protocol	Control Training Protocol	Training Frequency and Duration	Cuff Location and Pressure	Physiological Adaptations (Between-Group Comparisons)	Sport-Specific Adaptations (Between-Group Comparisons)
Cook 2014 (I)[23]	Semi-professional rugby players	20 (0)	5 sets of 5 reps 70% 1-RM (HL)	Same protocol but without BFR (HL)	3× per week for 3 weeks	Upper thigh, occlusion cuff Cuff pressure: 180 mm Hg	↑ 1-RM squat ↑ Exercise-induced salary testosterone	↓ 40-m sprint time ↑ Leg power via vertical jump
Giles 2017 (II)[24]	Recreational athletes	69 (38)	4 sets of 30 reps 30% 1-RM (LL)	3 sets of 7-10 reps 70% 1-RM (HL)	3× per week for 8 weeks	Upper thigh, pneumatic cuff Cuff pressure: 60% arterial occlusion	↔ Worst pain, Kujala Patellofemoral Score, knee extensor torque, quadriceps thickness ↑ Knee extensor torque in subgroup with painful resisted knee extension	↓ Pain with activities of daily living by 93%
Held 2020 (II)[25]	Elite rowers	31 (8)	Cuff used during low-intensity rowing training (LL)	Same low-intensity training without cuff (LL)	3× per week for 5 weeks	Upper thigh, elastic knee wrap Cuff pressure: unspecified	↔ 1-RM squat ↑ Rowing power	↑ VO_2 max

(continued)

Table 1. Continued

First Author, Year (LOE)	Athlete Cohort	Patients (Females)	BFR Training Protocol	Control Training Protocol	Training Frequency and Duration	Cuff Location and Pressure	Physiological Adaptations (Between-Group Comparisons)	Sport-Specific Adaptations (Between-Group Comparisons)
Luebbers 2014 (II)[26]	Collegiate football players	62 (0)	Group 1: High-intensity squats (low reps with high % 1-RM (HL—No BFR)) + supplemental low-intensity training (20% 1-RM (LL-BFR)) at 4 sets of 30/20/20/20 reps Group 2: No high-intensity squats + supplemental low-intensity training (20% 1-RM (LL-BFR)) at 4 sets of 30/20/20/20 reps	Group 3: High-intensity squats (low reps with high % 1-RM (HL)) + supplemental low-intensity training (20% 1-RM (LL)) at 4 sets of 30/20/20/20 reps Group 4: Only high-intensity squats (HL)	2× per week for 7 weeks	Upper thigh, elastic knee wraps Cuff pressure: unspecified	↑ 1-RM squat for group 1 compared to the other 3 groups ↔ Thigh size	
Manimmanakorn 2013 (I)[27]	Netball players	30 (0)	3 sets of leg extension followed by 3 sets of leg curls to failure 20% 1-RM (LL)	Same protocol but without BFR (LL)	3× per week for 5 weeks	Upper thigh, Kaatsu cuff Cuff pressure: 160 mm Hg increasing gradually to 230 mm Hg at day 8	↑ Isometric leg extension: 3 s (strength) and 30 s (strength endurance) maximal voluntary contraction ↑ Combined extensor and flexor CSA	↓ 5-m sprint time ↓ 505 Agility time ↑ Predicted VO_2 max ↓ Maximal multistage 20-mr shuttle run time ↑ Predicted maximal attained speed ↑ Repetitions to fatigue (dynamic muscle endurance) ↔ "Unclear" improvements in vertical jump, 10-m sprint

(continued)

Table 1. Continued

First Author, Year (LOE)	Athlete Cohort	Patients (Females)	BFR Training Protocol	Control Training Protocol	Training Frequency and Duration	Cuff Location and Pressure	Physiological Adaptations (Between-Group Comparisons)	Sport-Specific Adaptations (Between-Group Comparisons)
Sakuraba 2009 (II)[28]	Track and field	21 (0)	3 sets of 10 reps at high speed (300°/s) or low speed (90°/s) (ME)	3 sets of 10 reps at high speed (300°/s) or low speed (90°/s) (ME)	2× per week for 4 weeks	Upper thigh, pressure belt Cuff pressure: 200 mm Hg	↑ Isokinetic quadriceps strength at multiple velocities ↔ Muscle volume measurements	
Scott 2017 (II)[29]	Semi-professional soccer players	18 (0)	4 sets of 30/15/15/15 20% 1-RM for weeks 1-5, 25% 1-RM for weeks 6-10, and 30% 1-RM (LL) for weeks 11-14	Same protocol but without BFR (LL)	3× per week for 5 weeks	Upper thigh, elastic powerlifting wraps Cuff pressure: perceived 7/10	↔ 3-RM squat ↔ Squat muscle endurance ↔ Vastus lateralis muscle architecture	↔ 40-m sprint ↔ Vertical jump
Takarada 2002 (II)[30]	Rugby players	17 (0)	4 sets to failure 50% 1-RM (LL)	Same protocol but without BFR (LL)	2× per week for 8 weeks	Upper thigh, occlusion belt Cuff pressure: 200 mm Hg	↑ Isokinetic knee extension torque at all velocities ↑ Knee extensor CSA ↑ Dynamic endurance of knee extensors	
Ugur Tosun 2023 (I)[31]	Elite canoe athletes	33 (0)	Weeks 1-4: 3 sets for 10 reps Weeks 5-8: 4 sets for 15 reps 30% 1-RM (LL)	Same protocol but without BFR (LL)	2× per week for 8 weeks	Upper thigh, Kaatsu cuff Cuff pressure: 180 mm Hg with 10 mm Hg increase per session until 230 mm Hg	↑ Bilateral rectus femoris CSA and vastus lateralis thickness ↑ Isokinetic knee extension and flexion torque at 300°/s on right ↑ Isokinetic knee extension at 60°/s on left ↔ Hamstring CSA ↔ Rectus femoris or vastus medialis oblique thickness	↑ Indoor rowing ergometer performance at 200, 500, and 1,000 m
Wang 2023 (II)[32]	Swimmers	16 (0)	4 sets of 30/15/15/15 30% 1-RM (LL)	4 sets of 8-12 reps 70% 1-RM (HL)	3× per week for 4 weeks	Upper thigh, occlusion cuff Cuff pressure: 200 mm Hg	↔ 1-RM Back squat ↔ Left ventricular function	

(continued)

Table 1. Continued

First Author, Year (LOE)	Athlete Cohort	Patients (Females)	BFR Training Protocol	Control Training Protocol	Training Frequency and Duration	Cuff Location and Pressure	Physiological Adaptations (Between-Group Comparisons)	Sport-Specific Adaptations (Between-Group Comparisons)
Wang 2022 (II)[33]	Volleyball players	18 (0)	Group 1: 4 sets at 30/15/15/15 Group 2: 4 sets of 8 reps Group 1: low intensity: 30% 1-RM (LL) Group 2: high intensity: 70% 1-RM (HL)	4 sets at 8 reps 70% 1-RM (HL)	3× per week for 8 weeks	Upper thighs (bilateral), B-strong cuff Cuff pressure: 50% arterial occlusion	↑ 1-RM half-squat strength in HL-BFR compared to LL-BFR ↓ 1-RM half-squat strength in LL-BFR compared to HL ↔ Isokinetic flexion and extension between HL-BFR and HL	↔ Vertical jump between HL-BFR and HL ↔ Vertical jump between HL and LL-BFR ↑ Vertical jump and height of 3 footed takeoff for HL-BFR compared to LL-BFR
Yamanaka 2012 (I)[34]	Division I collegiate football players	32 (0)	4 sets at 30/20/20/20 reps 20% 1-RM (LL)	Same protocol but without BFR (LL)	3× per week for 4 weeks	Upper thigh, elastic band Cuff pressure: unspecified	↑ 1-RM squat	
Zhou 2024 (II)[35]	Recreational athletes	26 (0)	3 sets of 15 reps followed by 6 jumps 20% 1-RM for weeks 1-4, 30% 1-RM (LL) for weeks 5-8	3 sets of 15 reps followed by 6 jumps 75% 1-RM for weeks 1-4, 80% 1-RM (HL) for weeks 5-8	3× per week for 8 weeks	Upper thigh, occlusion cuff Cuff pressure: 200 mm Hg for weeks 1-4, 220 mm Hg for weeks 5-8	↑ Mean power ↑ Peak power ↑ Peak bar velocity ↑ Mean bar velocity ↔ 1-RM squat	↔ Squat jump ↔ Vertical jump

BFR, blood flow restriction; CSA, cross-sectional area; LOE, level of evidence; HL, high load; LL, low load; ME, maximal effort; reps, repetitions; 1-RM, 1 repetition maximum.

peak power for back squats,[23,26,29,32,34,35] half-squats,[33] leg presses,[16,17] or squat jumps[35]; peak power for owing or cycling[18,25]; isokinetic torque for leg extension[21,22,27,28,30,31]; isometric strength for leg extension,[17,24] and rate of force development for leg press.[20]

When directly comparing strength outcomes after exercise with BFR to those of a control group, 11 studies reported at least 1 strength outcome significantly increased in the BFR group relative to the control group. These strength outcomes included a 1-RM for squats,[23,26,34] peak power during a squat jump,[35] peak power while cycling,[18] isometric peak torque using leg extension,[17] and isokinetic quadriceps strength during leg extensions.[22,27,28,30,31] In 7 additional studies, significant strength increases for both the control and the BFR group were reported with no significant difference between groups.[17,20,24,29,32,33,35] These studies measured 1-RM back squat strength,[32,35] 3-RM back squat strength,[29] 1-RM half-squat strength,[33] isometric leg extension peak torque,[24] leg press 1-RM,[17] and rate of force development on leg press.[20] One study reported on the maximal voluntary isokinetic torque for leg extension and reported significant improvements in the BFR group compared to baseline, no significant improvements in the control group compared to baseline, and no significant between-group differences.[21] This study reported the opposite findings for a 1-RM front squat, where the control group increased from baseline and the BFR group did not; however, neither strength metric showed significant between-group differences.[21] One study reported increased leg press 1-RM in the BFR group compared to baseline, however, their control group was a non-training control so between-group comparisons were not included in our analysis.[16] Another study reported on power during vertical jump as their strength outcome and reported no within-group or between group differences.[19] Strength outcomes are highlighted in Table 2.

Muscle Size Outcomes

Outcomes related to muscle size, including measurement of muscle cross-sectional area for the quadriceps and hamstring muscles using magnetic resonance imaging (MRI), muscle thickness using ultrasound, and thigh circumference using a calibrated tape, were reported in 14 studies, with 10 of these studies reporting within-group increases in at least 1 muscle size metric.[16,17,19-22,26,27,30,31] Of the 10 studies reporting on an increase in muscle size after exercise with BFR, 8 reported a significant increase in the BFR group compared to the control group; measurements included muscle cross-sectional area,[16,21,27,30,31] thigh circumference,[19,22] and muscle thickness.[20] Two study reported significant improvements in thigh circumference in both the BFR and control groups with no significant difference between groups.[17,26] Lastly, 4 studies reported no significant difference in cross-sectional area,[28] thigh circumference,[34] or muscle thickness[24,29] between pre- and post-treatment for either the BFR or the control groups.

Table 2. Tabulation of Number of Studies Showing the Response to Blood Flow Restriction (BFR) Treatment Versus Controls With the Variable Performance Measures Utilized

Outcome Measure Utilized	Details of Outcome Measure	Number of Studies Reporting Within-Group Pre- to Post-Training Improvements in BFR Group (19 Studies)	Number of Studies Showing Improved Outcomes in BFR Group Compared To Control Group (Significant Between Group Differences) (12 Studies)	Number of Studies Showing Improvements in Both Groups (No Significant Between-Group Difference) (8 Studies)
1-Rep max				
	Back squat	6[23,26,29,32,34,35] (3-Rep max[29])	3[23,26,34]	3[29,32,35]
	Half-squat	1[33]		1[33]
	Leg press	2[16,17]		1[17]
Peak power				
	Rowing or cycling	2[18,25]	1[18]	
	Squat jump	1[35]	1[35]	
Isokinetic torque				
	Knee/leg extension	6[21,22,27,28,30,31]	5[22,27,28,30,31]	
Isometric strength				
	Knee/leg extension (quadriceps)	2[17,24]	1[17]	1[24]
Rate of force development				
	Leg press	1[20]		1[20]
Endurance outcomes				
	VO_2 max	3[18,25,27]	2[25,27]	1[18]
	Time to fatigue	1[18]	1[18]	

Sport-Specific Outcomes

Sport-specific metrics were reported in 12 studies.[16,18-20,23-25,27,29,31,33,35] Compared to the control group, 4 studies reported significantly improved sprint times for 5-m and 10-m,[27] 30-m,[16] 40-m,[23] and 100-m[20] sprints in the BFR group; 3 studies reported significantly improved ergometric rowing and biking scores in the BFR group[18,25,31]; 1 study reported a significant increase in mean and peak bar velocity (i.e., lower extremity power) during a half-squat jump task in the BFR group[35]; 1 study reported a significant decrease in patellofemoral pain during activities of daily living for patients in the BFR group[24]; and 1 study reported a significant improvement in leg power during vertical jumping for the BFR group.[23] Five studies showed no significant difference in jumping tasks when comparing BFR to non-BFR groups.[16,19,27,33,35] Additionally, 1 study reported no significant difference within or between a BFR and control group for jumping or sprinting.[29]

Endurance Outcomes

Four studies reported specifically on endurance outcomes. Two studies reported a significant increase in VO_2 max in the BFR group compared to a control group.[25,27] One study reported a significant increase in VO_2 max for both the BFR and control groups but no significant between-group difference.[18] One study reported an increase in time to fatigue/exhaustion during training,[18] and another reported an increase in maximum repetitions of leg extension at a 20% 1-RM for the BFR group compared to the control group.[27] One study reported improvements in VO_2 max for both the BFR group and control group from baseline, however, both were non-significant within-group and between-group.[19] Endurance outcomes are highlighted in Table 2.

Prescribed Intensities Between BFR and Control Groups

Varied BFR exercise intensities (% of 1-RM) were prescribed among the studies in this systematic review. One study prescribed maximal effort exercise on an isokinetic dynamometer within the BFR and control groups, and the BFR group showed significantly increased isokinetic quadriceps strength at multiple velocities compared to the control group.[28] Eight studies compared low-load exercise both with and without BFR,[19,22,26,27,29-31,34] where 7 of these 8 studies reported significantly improved outcomes in the BFR group compared to the control group.[19,22,25,27,31,34,31,34] Five studies compared high-load exercise with and without BFR,[18,20,23,26,33] and 4 of the 5 reported significantly improved outcomes in the BFR group.[18,20,23,26] Six studies compared low-load exercise with BFR to high-load exercise without BFR,[17,21,24,32,33,35] and 5 of the 6 studies showed comparable or improved outcomes in the low-load BFR group compared to the high-load control (non-BFR) groups.[17,21,24,32,35] Two studies had more than 2 comparison groups.[26,33] For 1 study, no resistance program was performed for the control group.[16]

Complications

In terms of complications, no subjects reported any notable injuries other than transient localized muscle soreness due to the BFR cuff during the resistance training performed in these studies.

Discussion

The most important finding of this study was that lower extremity exercise with BFR yielded a significant within-group improvement (baseline to final follow-up within the BFR group) in strength-based outcomes in 19 out of the 20 studies and a significant between-group improvement (exercise with BFR vs a control group) in 11 of 20 studies. Although inconsistent exercise protocols, training periods, and occlusion pressures were observed within the included studies, low-load/intensity exercise with BFR was observed to produce similar strength gains as the high-load/intensity control groups without BFR. One limitation from this study was that there was a gender disparity in the patients, with only 17.3% of the reported patients being females.

This systematic review found that, out of the 19 studies that reported improvements in strength from baseline using BFR, 11 (57.9%) had significantly improved strength outcomes compared to a non-BFR group. When analyzing studies by prescribed intensity (% of 1-RM), 8 studies compared low load with BFR to a low-load control, 5 studies compared high loads with BFR to a high-load control, and 1 study compared maximal intensity leg extension with and without BFR. Of these studies, 7 of the 8 low-load BFR versus low-load control studies, 4 of the 5 high-load BFR versus high-load control studies, and 1 of the 1 maximal effort study (total, 12 of 14 [85.7%]) reported significant improvements in outcomes of the BFR group compared to the control group. These findings suggest that utilizing BFR in conjunction with normal training may lead to improved strength, muscle, sport-specific, or endurance gains when compared to not using BFR. These findings correlate well with results from a systematic review by Hughes et al.,[11] to which low-load exercise with BFR (e.g., <50% 1-RM) was observed to produce significantly greater improvements in muscular strength when compared to low-load exercise without BFR. Altogether, these findings suggest that the use of BFR, especially in settings of lower intensity with higher repetitions, may be more beneficial for performance outcomes when compared to low-intensity controls that are not using BFR.

Eight of this systematic review's strength outcome studies reported no significant difference in outcomes between the BFR and control groups, and 6 of these studies compared low-load exercise with BFR to a high-load exercise group. When comparing outcomes of low-load exercise with BFR to high-load exercise without BFR groups, 5 out of the 6 studies observed at least 1 lower extremity metric within the low-load exercise with BFR group that was comparable or improved compared to the high-load exercise (without BFR) group.[17,21,24,32,35] This suggests low-load exercise with BFR may be an effective short-term strength training intervention for athletes who have had recent exposure to traditional forms of high-load exercise, and similar findings have been described elsewhere.[36] Additionally, Centner et al.[17] reported an increase in knee extension 1-RM in the low-load exercise with BFR group when compared to the high-load exercise group, and Giles et al.[24] observed that a subgroup of athletes specifically experiencing patellofemoral pain during resisted knee extension may benefit more from low-load exercise with BFR than high-load exercise without BFR.[24] Thus, it appears that adding a low-load BFR program to an athlete's in-season or maintenance training protocol, either as supplemental training or as a full-time program, may lead to comparable strength improvements when compared to a traditional high-load training without BFR.

In terms of muscle size outcomes reported within this systematic review's studies, 8 of the 14 studies observed a significant increase in muscular hypertrophy within the BFR group relative to a control. Six studies included in this review used elastic wraps, and 4 of these 6 studies assessed lower extremity muscle size. When looking specifically at these study's outcomes, 2 found mixed results[20,21] and 2 found no between-group muscle size differences.[26,29] This observation is of significance because it is possible the elastic wraps did not provide consistent occlusion during exercise with BFR. Previous work has investigated the interaction between the level of arterial occlusion applied during exercise with BFR and the prescribed exercise intensity,[36] to which higher percentages of arterial occlusion (e.g., 80%-100% AOP) appear important for optimizing increases in muscle size when the exercise intensity is low (i.e., 20%-30% 1-RM).[10,36] Considering this, it is possible higher occlusion pressures were not achieved and/or consistently maintained while occluding blood flow with an elastic wrap, and therefore, it may explain why consistent increases in muscular hypertrophy were not achieved across studies using an elastic wrap.

In the current systematic review, sports-specific outcomes were analyzed in 12 studies. Jumping outcomes (e.g., a single-effort jump test) generally did not show significant improvements following low-load exercise with BFR.[16,19,27,29,33,35] However, improvements in vertical jump performance were observed in 2 studies that prescribed higher load exercise with BFR[23,33]; these observations suggest higher resistance training loads/intensities are still needed in athletic cohorts to facilitate improvements in explosive, single-effort tasks. Somewhat in contrast to single-effort tasks, the included studies investigating the effect of exercise with BFR on sprinting and time-to-fatigue outcomes (i.e., running, ergometer testing) did observe a significant difference in favor of the BFR group relative to a control.[16,18,20,23,25,27,31] These findings may be best explained by the difference in fatigue between a single-effort task and a task that requires multiple high-effort muscle contractions in a repeated sequence; peripheral fatigue is minimal during a single-effort task compared to a repeated-effort task, and therefore, fatigue may more directly contribute to the outcome of a sprinting test.[37-39] Considering this, exercise with BFR may mitigate the effects of fatigue during a repeated-effort task by improving local muscular endurance in athletes who have not previously maximized their aerobic fitness.

Three of the 4 studies in this systematic review investigating muscular endurance-based outcomes in athletes (i.e., VO_2 max, time to fatigue, and maximum repetitions-to-fatigue/failure) reported a significant improvement in favor of exercise with BFR. While both Manimmanakorn et al.[27] and Held et al.[25] reported a significant improvement in VO_2 max when comparing exercise with BFR to a control group, Amani-Shalamzari et al.[18] reported significant improvements in both the BFR and control groups, with no significant between-group differences and Beak et al.[19] did not observe any within-group or between-group improvement in VO_2 max for the BFR group and control group. When discussing the reasons for this observation, it is important to note that the baseline VO_2 max of the athletes included in the study by Beak et al.[19] was high because having a high aerobic fitness at baseline (i.e., VO_2 max) reduces an athlete's physiological capacity to further improve their postintervention scores on an aerobic fitness test. Considering this, exercise with BFR may be most valuable for endurance athletes attempting to improve muscular endurance/aerobic fitness scores after a period of de-training or injury; however, it appears that exercise with BFR may be only slightly more beneficial than other training strategies when baseline muscular endurance/aerobic fitness is high.

Limitations

This study is not without limitations. Although all the included studies were Level I or II evidence, the variability in BFR protocols, investigative techniques, sensitivity in the data collection instruments, and BFR cuff types, sizes, and pressures between studies made specific comparisons difficult. In addition, differing exposures to BFR training in terms of length and weekly frequency varied among studies. While some studies measured the occlusion pressure objectively, others did not. A statistical analysis from the studies included in this systematic review was also not possible due to the significant heterogeneity between outcomes of the studies and the relatively low quality of some of the studies. Furthermore, the findings from this systematic review are not directly applicable to other areas of sports medicine, specifically rehabilitation from lower extremity injuries, without further investigation into studies reporting on the use of BFR in the rehabilitation phase.

Conclusions

In this systematic review, we found that 58% of studies reporting on lower extremity BFR use in athletes observed significant strength improvements in the BFR group compared to a non-BFR group. Additionally, when comparing low-intensity exercise with BFR to high-intensity exercise without BFR, 5 out of 6 studies reported either improved or comparable outcomes between the BFR and control groups. In general, exercise with and without BFR led to improvements in lower extremity strength, muscle size, endurance outcomes, and sport-specific metrics, and most of the included studies reported greater improvements within the BFR group.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: J.M. declares that she has received a presenter honorarium for the Smith & Nephew MACKIS meeting and support for meeting travel from the OSET Meeting. C.M.L. receives speaking and lecture fees from Foundation Medical and Evolution Surgical and has a family member who reports a relationship with Ossur Americas, Smith & Nephew, Linvatec Europe, and Responsive Arthroscopy for consulting or advisory and Ossur Americas, Smith & Nephew, Arthroscopy Association of North America, and American Orthopaedic Society for Sports Medicine for funding grants. R.F.L. is a consultant or advisor for Ossur Americas, Smith & Nephew, Linvatec Europe, and Responsive Arthroscopy and receives funding grants from Ossur Americas, Smith & Nephew, Arthroscopy Association of North America, and American Orthopaedic Society for Sports Medicine for funding grants. All other authors (L.V.T., J.S., B.S., E.P.M.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. Methodological Index for Non-Randomized Studies (MINORS)

First author, year	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to the aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss to follow-up less than 5%	Prospective calculation of the study size	An adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analyses	Sum
Abe 2005[16]	2	0	2	2	0	1	2	0	2	2	2	2	17
Amani-Shalamzari 2020[18]	2	0	2	2	0	2	2	2	2	2	0	2	18
Beak 2022[19]	2	0	2	2	0	2	2	2	2	2	2	2	20
Behringer 2017[20]	2	0	2	2	1	2	2	0	2	2	1	2	18
Bjornsen 2019[21]	2	0	2	2	1	2	2	2	2	2	2	2	21
Bowman 2019[22]	2	0	2	2	0	2	2	0	2	2	2	2	18
Centner 2022[17]	2	0	2	2	2	2	1	2	2	2	2	2	21
Cook 2014[23]	2	0	2	2	0	2	2	0	2	2	1	2	17
Giles 2017[24]	2	0	2	2	2	2	1	2	2	2	2	2	21
Held 2020[25]	2	0	2	2	0	2	2	0	2	2	2	2	18
Luebbers 2014[26]	2	0	2	2	0	2	1	0	2	2	0	2	15
Manimmanakorn 2013[27]	2	0	2	2	2	2	2	0	2	2	0	2	18
Sakuraba 2009[28]	1	0	2	2	0	2	2	0	2	2	2	2	17
Scott 2017[29]	2	0	2	2	0	2	1	0	2	2	2	2	17
Takarada 2002[30]	2	0	2	2	0	2	2	0	2	2	0	2	16
Ugur Tosun 2023[31]	2	0	2	2	2	2	2	2	2	2	2	2	22
Wang 2023[32]	2	0	2	2	0	2	2	2	2	2	2	2	20
Wang 2022[33]	2	0	2	2	1	2	1	2	2	2	2	2	20
Yamanaka 2012[34]	2	0	2	2	0	2	2	0	2	2	0	2	16
Zhou 2024[35]	2	0	2	2	0	2	2	0	2	2	2	2	18