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# Efficacy of blood flow restriction training in chronic ankle conditions: a systematic review and meta-analysis

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## Abstract

**Background** Chronic ankle conditions often lead to persistent functional limitations. Blood flow restriction (BFR) training is a potential adjunct to rehabilitation, but its specific efficacy for chronic ankle conditions remains to be synthesized.

**Objective** To systematically evaluate the effects of BFR-assisted rehabilitation on primary outcomes (dynamic balance and patient-reported ankle stability) and secondary outcomes (ankle range of motion and muscle strength) in individuals with chronic ankle conditions (including chronic ankle instability, chronic ligamentous injury, and tendinopathy).

**Methods** A systematic search of PubMed, Web of Science, Embase, CNKI, and Wanfang databases was conducted up to April 13, 2025. We included randomized controlled trials (RCTs) involving adults with chronic ankle instability (CAI) defined by a history of sprain and/or Cumberland Ankle Instability Tool (CAIT) score $< 24$. Grey literature was excluded. The protocol was registered on PROSPERO (CRD420251249207). Methodological quality was assessed using the Cochrane Risk of Bias (RoB) 1.0 tool. Data were pooled using random- or fixed-effects models.

**Results** Seven RCTs ($n = 204$) were included. The overall risk of bias across the included studies was generally low to moderate. Meta-analysis of post-intervention values indicated that BFR-assisted rehabilitation significantly improved the primary outcome of dynamic balance (MD = 5.75; 95% CI [2.10, 9.40]; $P < 0.01$; $I^2 = 34\%$, $P = 0.22$) compared with conventional rehabilitation. Significant improvements in the other primary outcome, CAIT scores were also observed (MD = 3.68; 95% CI [0.26, 7.11]; $P = 0.05$). However, secondary outcomes for dorsiflexion and plantarflexion range of motion exhibited high heterogeneity and unstable pooled estimates, showing no significant benefit. Muscle strength data were insufficient for meta-analysis.

**Conclusions** BFR-assisted rehabilitation appears to enhance dynamic balance and perceived ankle stability in patients with chronic ankle conditions. However, evidence regarding its effect on joint range of motion remains inconclusive because of data instability. Current evidence supports BFR as a functional intervention, though standardized protocols are needed to further validate its clinical utility.


**Keywords** Blood flow restriction therapy, Chronic ankle disease, Ankle instability, Meta-analysis, Rehabilitation

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## Introduction

Chronic ankle conditions represent a spectrum of persistent musculoskeletal disorders, among which chronic ankle instability (CAI) is the most prevalent and debilitating [1, 2]. CAI is characterized not merely by mechanical laxity but by a spectrum of sensorimotor deficits, including impaired proprioception, delayed peroneal reaction time, and altered landing mechanics [3–6]. These persistent dysfunctions disrupt normal gait patterns and compromise dynamic stability, creating a cycle of "giving way" episodes [3, 7, 8] that predispose individuals to secondary injuries and early-onset osteoarthritis [5, 6, 9]. Consequently, rehabilitation strategies must go beyond restoring passive range of motion to effectively target the underlying neuromuscular deficits.

Current conservative management for chronic ankle conditions typically emphasizes proprioceptive training and progressive strengthening [10]. However, clinical outcomes are often variable. A key barrier to effective rehabilitation in this population is arthrogenic muscle inhibition (AMI)—a presynaptic reflex inhibition of musculature surrounding the injured joint—which prevents the complete voluntary activation of motor units, particularly in the peroneal complex [11]. High-load resistance training, while effective for hypertrophy, is often limited in the early rehabilitation phases due to pain, mechanical sensitivity, or the inability of the patient to generate sufficient torque to overcome AMI.

Blood Flow Restriction (BFR) training has emerged as a promising intervention to bridge this gap [12]. BFR involves performing low-intensity exercise (20–30% of 1-repetition maximum) under partial vascular occlusion. Unlike general resistance training, BFR creates a localized hypoxic and acidic environment that accelerates metabolic stress (accumulation of lactate and protons) [13, 14]. Theoretically, this metabolic accumulation stimulates group III and IV afferents, leading to the early recruitment of high-threshold Type II motor units that are typically only active during high-load exercises [15, 16]. For patients with chronic ankle conditions, who often exhibit selective atrophy of Type II fibers and neuromuscular inhibition, BFR offers a mechanistic advantage: it may bypass the mechanical stress required to activate these fibers, potentially mitigating AMI and enhancing sensorimotor integration without exacerbating joint pathology [17–19].

Despite these theoretical advantages, the application of BFR has largely been studied in post-operative knee conditions or healthy populations. The evidence regarding its specific efficacy for chronic ankle conditions remains fragmented [20]. Previous reviews have often pooled heterogeneous ankle pathologies, failing to distinguish between instability-driven deficits and non-specific chronic pain. Furthermore, it remains unclear whether the physiological benefits of BFR translate into functional improvements relevant to chronic ankle conditions, such as dynamic balance and self-reported stability.

Therefore, the primary objective of this systematic review is to evaluate the therapeutic efficacy of BFR training in individuals with chronic ankle conditions. Specifically, we define the primary outcomes as patient-reported ankle stability (e.g., CAIT scores) and dynamic balance. Secondary outcomes include ankle range of motion (dorsiflexion and plantarflexion) and muscle strength (evertor/invertor torque). We hypothesize that BFR-integrated rehabilitation will yield superior improvements in functional and patient-reported outcomes compared to conventional low-load rehabilitation alone.

## Methods

### Protocol and registration

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and was prospectively registered in PROSPERO (CRD420251249207).

Minor deviations from the registered protocol were made during the review process and are explicitly acknowledged here. First, the final search strategy was refined by expanding ankle-related terminology and updating the search end date to April 13, 2025, to ensure the most comprehensive evidence capture. Second, several secondary outcomes were reclassified during data synthesis to better reflect the reporting patterns of the included studies and improve statistical interpretability. For example, dorsiflexion and plantarflexion outcomes were synthesized under the broader category of ankle range of motion. These modifications did not alter the primary review objective and were made solely to improve methodological transparency, consistency, and interpretability.

### Search strategy

We systematically searched PubMed, Web of Science, Embase, CNKI, and Wanfang from inception to April 13, 2025. The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to blood flow restriction and chronic ankle conditions. The core search string was: ("Blood Flow Restriction" OR "Kaatsu" OR "Occlusion Training" OR "BFR") AND ("Ankle" OR "Ankle Injuries" OR "Ankle Instability" OR "Sprain" OR "Tendinopathy"). The search was limited to studies published in English or Chinese. In addition, the reference lists of all included studies were manually screened to identify any potentially eligible articles.

### Eligibility criteria

#### Participants

We included adults (age ≥ 18 years) diagnosed with chronic ankle conditions characterized by persistent functional impairment. This encompassed chronic ankle conditions (defined by history of sprain and/or standardized questionnaires e.g., CAIT), chronic ligamentous injury, or chronic tendinopathy resulting in functional instability. We pooled these conditions based on the rationale that they share common rehabilitation goals: restoring neuromuscular control and overcoming arthrogenic muscle inhibition.

#### Interventions

The experimental group must have performed rehabilitation exercises combined with BFR.

#### Comparators

The control group must have performed conventional rehabilitation (e.g., identical low-load exercise without BFR, or standard high-load care) to isolate the effects of the BFR stimulus.

#### Study design

Only Randomized Controlled Trials (RCTs) were included.

#### Exclusion criteria

Studies were excluded if: (1) participants had acute fractures, recent surgery (< 3 months), or severe cardiovascular contraindications to BFR; (2) data were insufficient for extraction (e.g., missing standard deviations) despite contacting authors; or (3) the study was a conference abstract without a full report.

### Data extraction and quality assessment

Two independent reviewers (Qingyi Wu and Liyue Tan) extracted data using a standardized form.

#### BFR parameters

To address dose–response variables, we specifically extracted: Arterial Occlusion Pressure (AOP) determination method (e.g., Doppler ultrasound, predictive equations), applied pressure (% of AOP or absolute mmHg), cuff width, and device type.

#### Intervention details

Frequency, duration, rest intervals, and load progression.

#### Risk of bias

Methodological quality was assessed independently by two reviewers using the Cochrane Risk of Bias tool (RoB 1.0). The following domains were evaluated: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other potential sources of bias. Each domain was judged as low risk, unclear risk, or high risk.

### Outcome measures

#### Primary outcome

1. Dynamic Balance, explicitly defined as performance on the Star Excursion Balance Test (SEBT) or Y-Balance Test (YBT).
2. Self-reported Instability: Assessed via the CAIT.

#### Secondary outcomes

1. Muscle Strength: Peak torque of dorsiflexors and plantarflexors measured via isokinetic dynamometry or handheld dynamometry.
2. Range of Motion (ROM): Dorsiflexion and plantarflexion range measured by goniometer or inclinometer.

### Statistical analysis

Meta-analysis was performed using Review Manager (RevMan 5.4) and Stata 18.0. Continuous outcomes were analyzed using Standardized Mean Differences (SMD) or Mean Differences (MD). We prioritized the pooling of post-intervention values to account for potential baseline imbalances. For trials reporting multiple follow-up time points, the time point immediately post-intervention was used. For trials with multiple intervention arms (e.g., different BFR pressures) compared to a single control, we combined the BFR groups to avoid unit-of-analysis errors. Heterogeneity was assessed using the $I^2$ statistic. An $I^2 > 50\%$ indicated substantial heterogeneity, triggering the use of a random-effects model; otherwise, a fixed-effect model was used. Publication bias was assessed using Egger's test for outcomes with more than 10 studies.

For outcomes measured on the same scale, we consistently report MD with 95% confidence intervals. For outcomes assessed using different instruments or scales, we report SMD to enable meaningful pooling.

## Results

### Study selection

The initial database search yielded 3,052 potentially relevant records. After removing 51 duplicates, 3,001 unique records were screened. Title and abstract screening led to the exclusion of 2,938 records. The full texts of the remaining 63 studies were assessed for eligibility. Of these, 56 were excluded for the following specific reasons: 9 had a population not compliant with the inclusion criteria, 12 involved an intervention not compliant with the definition of blood flow restriction training (BFRT), 5 lacked a control group, 22 had outcome measures not compliant with the review objectives, 6 were not RCTs, and 2 could not be accessed in full text. Ultimately, seven RCTs met the inclusion criteria. The selection process is detailed in the PRISMA flow diagram (Fig. 1).

### Study characteristics

The seven included RCTs involved a total of 204 participants (BFR group: $n = 100$; control group: $n = 104$). All participants were adults (≥ 18 years) diagnosed with chronic ankle conditions or related chronic impairments; the population comprised collegiate athletes in three studies and generally active individuals in the remaining four. Considerable heterogeneity existed in both the base rehabilitation protocols and BFR application across studies. As detailed in Table 1, interventions ranged from isolated strength training (e.g., Wen et al., Lee et al.) to balance/proprioceptive training (e.g., Werasirirat et al.) and multimodal approaches incorporating joint mobilization (e.g., Kim et al., Liu et al.) [21–27]. Similarly, BFR was applied using varying pressure protocols—some studies used fixed absolute pressures, while others individualized cuff pressure as a percentage of limb occlusion pressure (LOP).

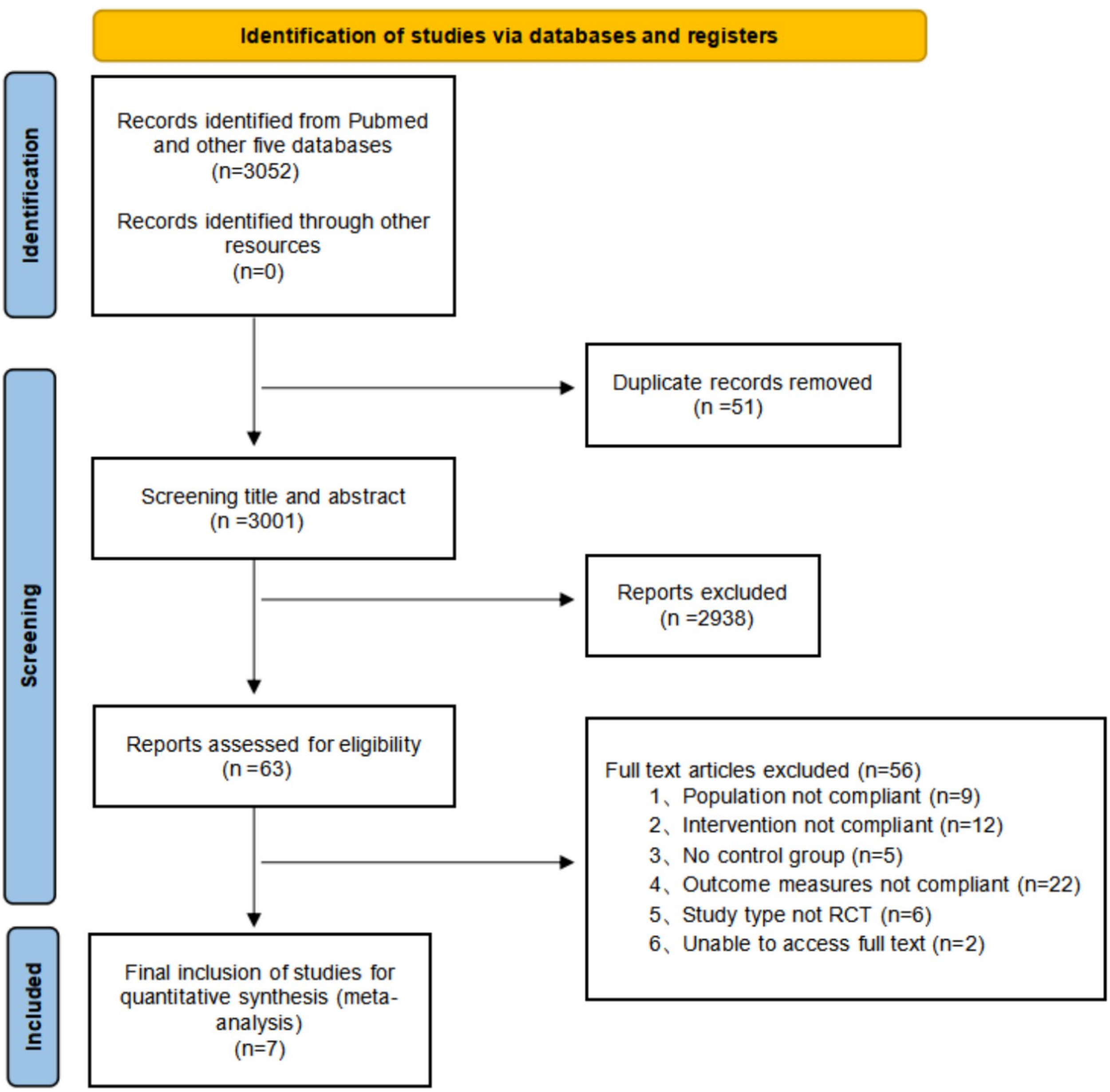


**Fig. 1** PRISMA 2020 flow diagram of study selection

**Table 1** Characteristics of included RCTs (sample size, age, gender, intervention, outcomes)

| Study(ref.) | Country | Research | Sample Size(T/C) | Man/Woman | Age (years) (T/C) | T | C | Main Outcomes |
|---|---|---|---|---|---|---|---|---|
| J. Kim | South Korea | RCT | 15/15 | 20/10 | 21.53 ± 2.47<br>21.27 ± 1.87 | 6 weeks<br>10AJM autonomous movements with BFR | Six weeks<br>10AJM autonomous movements | ①② |
| J. Lee | South Korea | RCT | 12/12 | 0/24 | 51.25 ± 3.09<br>49.85 ± 4.12 | 4 weeks<br>Ankle strength training with BFR | four weeks<br>Ankle strength training | ②③④ |
| Waleed | Saudi Arabia | RCT | 15/12 | 0/27 | 23.33 ± 1.98<br>24.5 ± 2.23 | 4 weeks<br>BFR with joint strength and balance | four weeks<br>joint strength and balance | ⑤⑥⑦⑧ |
| Wen | China | RCT | 23/23 | 20/26 | 22.13 ± 1.84<br>21.61 ± 2.06 | 6 weeks<br>LL-BFR and ankle joint training at 20% to 40% and 70% to 85% of maximum strength | Six weeks<br>ankle joint training at 20% to 40% and 70% to 85% of maximum strength | ⑤⑥⑦⑧ |
| Werasirirat | Thailand | RCT | 8/8 | 12/4 | 20.50 ± 1.06<br>20.50 ± 1.07 | 4 weeks<br>Single-leg weight bearing, single-leg support, standing on a single leg balance ball with BFR | Four weeks<br>Single-leg weight bearing, single-leg support, standing on a single leg balance ball | ②⑦⑧ |
| Liu | China | RCT | 12/11 | 6/17 | 20.67 ± 1.30<br>20.82 ± 1.47 | 4 weeks<br>Strength training, balance training, joint mobilization and BFR | Four weeks<br>Strength training, balance training, joint mobilization | ②④⑨ |
| Liu | China | RCT | 15/23 | 11/27 | 20.47 ± 1.64<br>19.38 ± 1.71 | 6 weeks<br>conventional ankle strength and stability training with BFR | SIX weeks<br>conventional ankle strength and stability training | ④⑩ |

①Static balance ability; ②dynamic balance ability; ③digital muscle measurement; ④CAIT; ⑤Dorsiflexion; ⑥Toe flexion; ⑦Adductor muscle; ⑧Abductor muscle; ⑨One-leg standing time with eyes closed; ⑩Foot and ankle ability test (FAAM); ⑪Ankle Joint Mobilization (AJM)

*T* trial group, *C* control group

## Risk of bias and quality assessment

### *Cochrane risk of bias assessment*

Methodological quality assessment using the Cochrane RoB 1.0 showed that six of the seven included randomized controlled trials presented at least one domain rated as high risk of bias, primarily due to inadequate allocation concealment and the inability to blind participants and personnel—common limitations in BFRT studies owing to the overt nature of the intervention (Figs. 2 and 3). Only one study employed a placebo-controlled design with a non-pressurized cuff, effectively blinding both participants and therapists, and was thus judged to be at low risk of bias overall. While most studies reported low risk for random sequence generation, outcome assessor blinding, and data completeness, the lack of allocation concealment and participant/therapist blinding significantly compromises internal validity across the majority of the evidence base.

### *GRADE evidence quality*

The certainty of evidence was evaluated using the GRADE framework, and the summary of findings is presented in Table 2. The certainty of evidence for BFRT compared to control interventions in patients with ankle instability was assessed as low across all measured outcomes,including dynamic balance, self-reported instability, and dorsiflexion/plantarflexion range of motion. Because all included studies were randomized controlled trials, the evidence initially started at a high certainty level. However, it was downgraded by two levels due to serious risk of bias (mainly inadequate allocation concealment and lack of blinding in most included studies) and serious imprecision, reflected by small sample sizes and wide confidence intervals crossing clinically relevant thresholds.

Therefore, the true effect of BFRT remains uncertain, and further high-quality, adequately powered randomized controlled trials are required to strengthen the evidence base.

## Primary outcomes

### *Dynamic balance ability*

To avoid unit-of-analysis errors, multiple datasets from multi-arm trials were combined or prioritized to ensure independent comparisons. A total of seven trials provided data on dynamic balance.

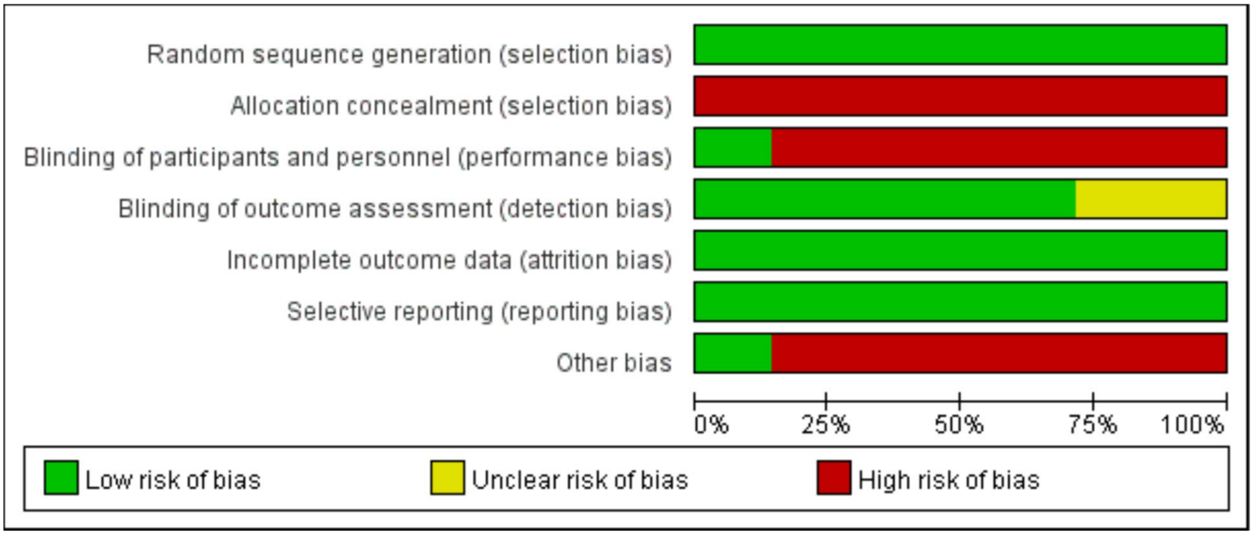


**Fig. 2** Risk of bias summary: review authors' judgements about each risk of bias item for each included study

The pooled fixed-effects analysis demonstrated a statistically significant advantage of BFR training in improving dynamic balance performance compared with conventional rehabilitation alone (MD = 5.75; 95% CI [2.10, 9.40]; $P = 0.002$) (Fig. 4). Statistical heterogeneity was low to moderate ($I^2 = 34\%$; $P = 0.22$), indicating acceptable consistency across the diverse protocols. Leave-one-out sensitivity analysis confirmed the robustness of the findings (see Supplementary Figure S1). Visual inspection of the funnel plot did not suggest marked asymmetry.

#### *Cumberland Ankle Instability Tool (CAIT)*

Three RCTs provided post-intervention CAIT scores. The pooled analysis demonstrated that BFR-assisted rehabilitation resulted in significantly greater improvements in CAIT scores compared with conventional rehabilitation (MD = 3.68; 95% CI [0.26, 7.11]; $P < 0.05$) (Fig. 5).

Moderate heterogeneity was observed ($I^2 = 66\%$). Due to the limited number of studies ($n < 10$), statistical tests for publication bias (Egger's test) were not performed to avoid spurious findings; visual inspection of the funnel plot (Fig. 6) showed no obvious asymmetry. Sensitivity analysis indicated stability in the direction of the effect (see Supplementary Figure S2).

### Secondary outcomes: range of motion

#### *Dorsiflexion range of motion*

Four RCTs ($n = 125$) evaluated dorsiflexion. The pooled analysis using a random-effects model showed a trend toward improvement with BFR but failed to reach statistical significance (SMD = 0.97; 95% CI [−0.00, 1.95]; $P = 0.05$) (Fig. 7). Heterogeneity was substantial ($I^2 = 84\%$). This high inconsistency likely reflects the variability in measurement techniques (weight-bearing vs. non-weight-bearing) and intervention types. Sensitivity analysis revealed that the result was unstable and driven by outlier studies (see Supplementary Figure S3); consequently, these findings should be interpreted with caution.

#### *Plantarflexion range of motion*

Four RCTs ($n = 125$) evaluated plantarflexion. The pooled analysis found no significant difference between BFR and control groups (SMD = 0.86; 95% CI [−0.32, 2.05]; $P = 0.15$) (Fig. 8). Similar to dorsiflexion, heterogeneity was high ($I^2 = 89\%$). Sensitivity analysis (see Supplementary Figure S4) indicated significant fluctuations in the pooled estimate.

### Adverse events and safety

Reporting of adverse events was limited across the included trials. Three studies explicitly stated that no serious adverse events (e.g., deep vein thrombosis, nerve injury) occurred during the intervention. Minor side effects, such as subcutaneous bruising, temporary numbness, mild skin irritation under the cuff, or transient paresthesia, were noted in a total of 7 participants across two trials ([13, 17, 22]; Liu S et al. 2024). The remaining studies [12, 14–16, 18] did not explicitly report safety monitoring data, including whether adverse events were actively monitored, recorded, or defined a priori.

## Discussion

The present meta-analysis synthesizes the currently available randomized evidence on BFR training in individuals with chronic ankle conditions. The pooled findings suggest that BFR-assisted rehabilitation may provide superior improvements in dynamic balance and CAIT scores compared with conventional rehabilitation alone. However, the certainty of evidence ranged from low to

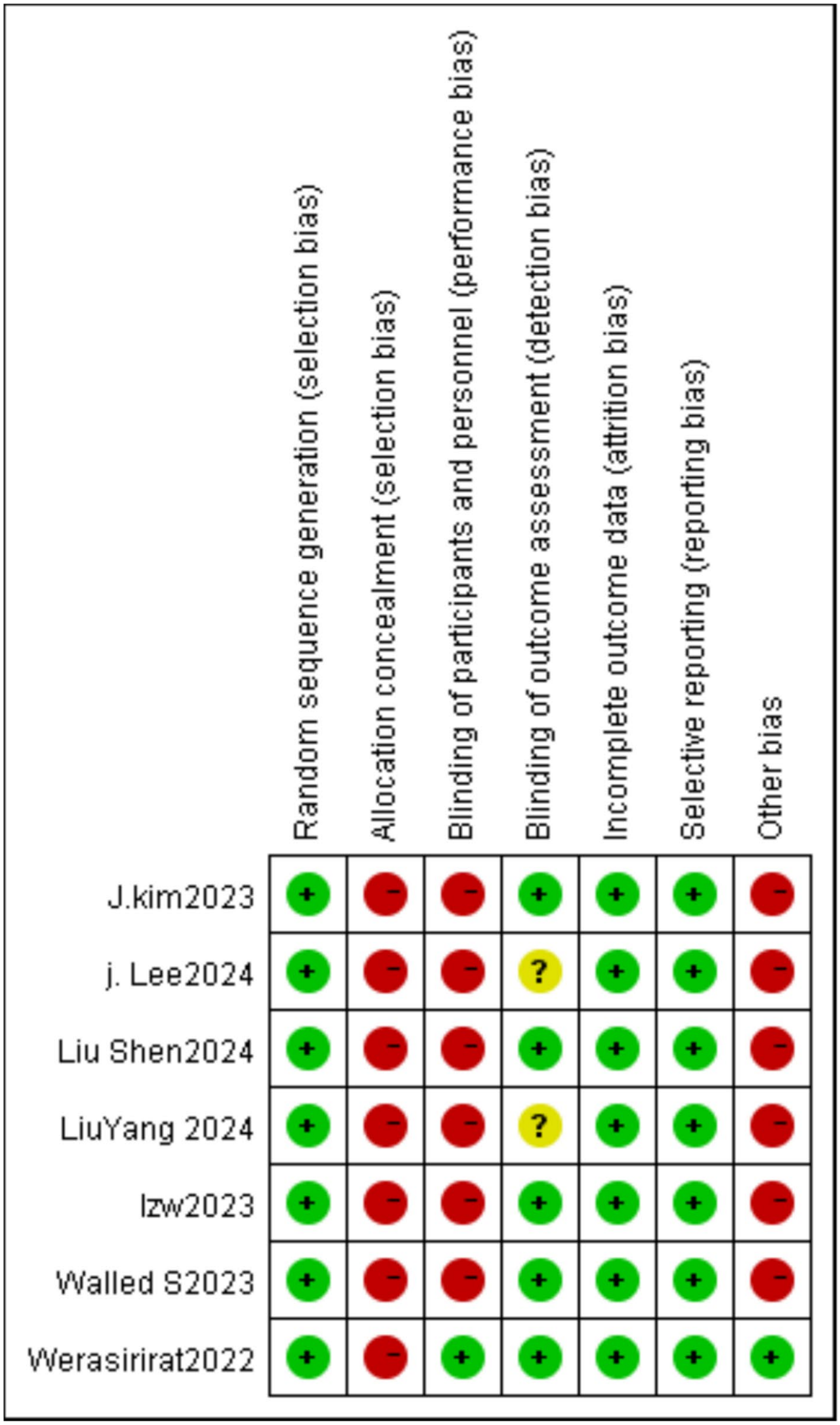


**Fig. 3** Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies

**Table 2** GRADE summary of findings

| Certainty assessment | | | | | | | № of patients | | Effect | | Certainty | Importance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| № of studies | Study design | Risk of bias | Inconsistency | Indirectness | Imprecision | Other considerations | [experimental] | [control] | Relative (95% CI) | Absolute (95% CI) | | |
| **Dynamic balance ability** | | | | | | | | | | | | |
| 3 | randomised trials | serious[a] | not serious | not serious | serious[b] | none[c] | 35 | 35 | - | **MD 5.75 more** (2.1 more to 9.4 more) | ⊕⊕◯◯ Low[a,b,c] | |
| **Cumberland Ankle Instability Tool (CAIT)** | | | | | | | | | | | | |
| 3 | randomised trials | serious[a] | not serious | not serious | serious[b] | none | 39 | 36 | - | **MD 3.68 higher** (0.26 higher to 7.11 higher) | ⊕⊕◯◯ Low[a,b] | |
| **Dorsiflexion range of motion** | | | | | | | | | | | | |
| 4 | randomised trials | serious[a] | not serious | not serious | serious[b] | none | 65 | 60 | - | **MD 3.68 higher** (0.26 higher to 7.11 higher) | ⊕⊕◯◯ Low[a,b] | |
| **plantarflexion** | | | | | | | | | | | | |
| 4 | randomised trials | serious[a] | not serious | not serious | serious[b] | none | 65 | 60 | - | **MD 0.97 higher** (0 to 1.95 higher) | ⊕⊕◯◯ Low[a,b] | |

*CI* confidence interval, *MD* mean difference

Explanations

[a]The quality of evidence was downgraded by one level due to high risk of bias across the included studies

[b]Imprecision was present due to small sample sizes and low event rates, resulting in wide confidence intervals that crossed the threshold for clinical significance; therefore, the evidence was downgraded by one level

[c]Dynamic balance ability

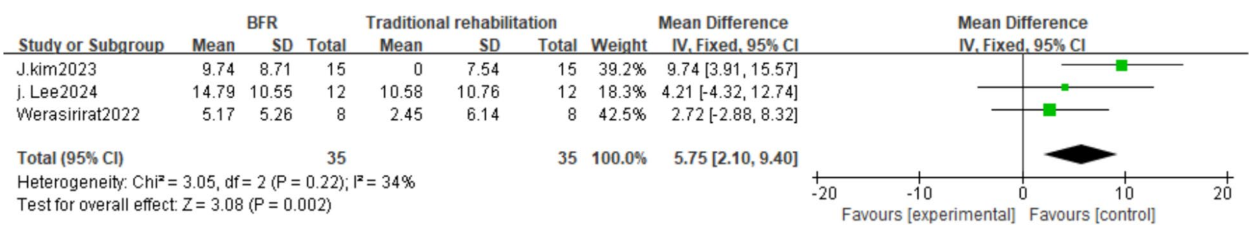


**Fig. 4** Forest plot of dynamic balance

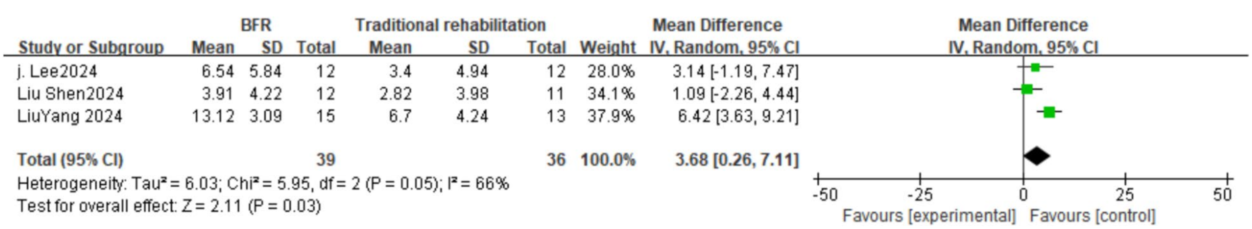


**Fig. 5** Forest plot of CAIT scores comparing BFR-assisted rehabilitation versus conventional rehabilitation

moderate, and the findings should therefore be interpreted cautiously. In contrast, evidence regarding ankle range of motion (dorsiflexion and plantarflexion) remains inconsistent and highly heterogeneous, indicating that the role of BFR in improving passive mobility mechanics is still uncertain.

Dynamic balance demonstrated the most consistent response to BFR training, with relatively low statistical heterogeneity. Given that postural control deficits are a hallmark of chronic ankle instability and related chronic ankle conditions, this finding may be clinically relevant. Previous literature suggests that BFR may enhance motor unit recruitment and sensorimotor responsiveness through metabolite accumulation and Group III/IV afferent stimulation [28, 29]. Nevertheless, it should be emphasized that none of the included trials directly assessed neuromuscular parameters such as electromyographic activity, cortical excitability, or nerve conduction indices. Accordingly, the observed benefits should be interpreted as functional adaptations rather than direct evidence of neural reorganization. A plausible explanation is that the increased fatigue induced by BFR during low-load exercise requires greater sensorimotor engagement to maintain postural stability, thereby acting as an enhanced balance-training stimulus.

In contrast, the effects of BFR on dorsiflexion and plantarflexion range of motion were inconclusive. The pooled analyses for ROM were characterized by substantial heterogeneity ($I^2 > 80\%$) and sensitivity to individual small studies. This variability likely reflects major differences

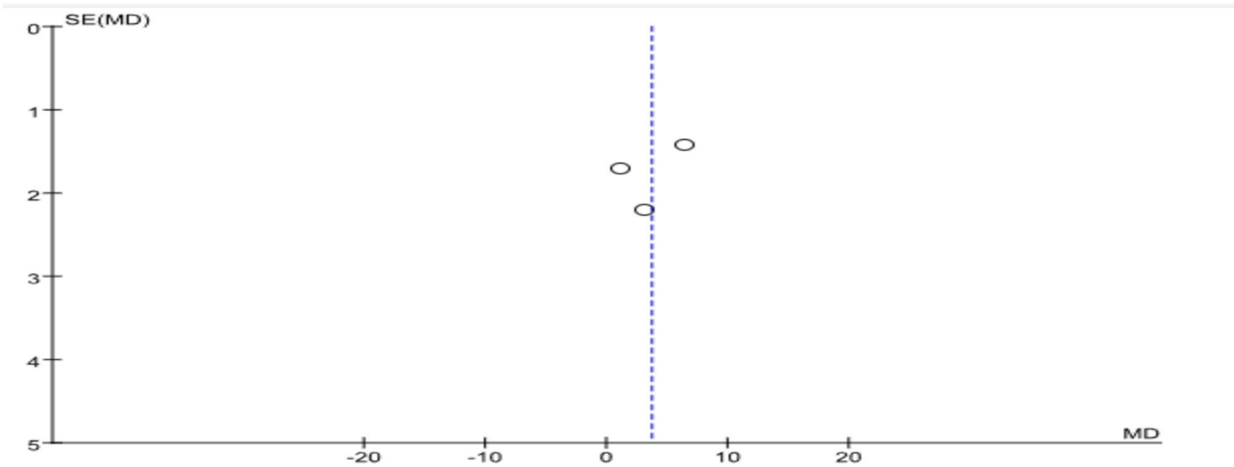


**Fig. 6** Funnel plot of CAIT scores

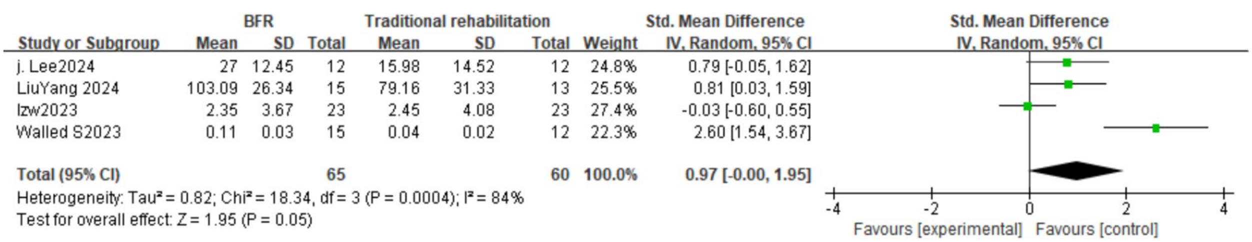


**Fig. 7** Forest plot of dorsiflexion range of motion

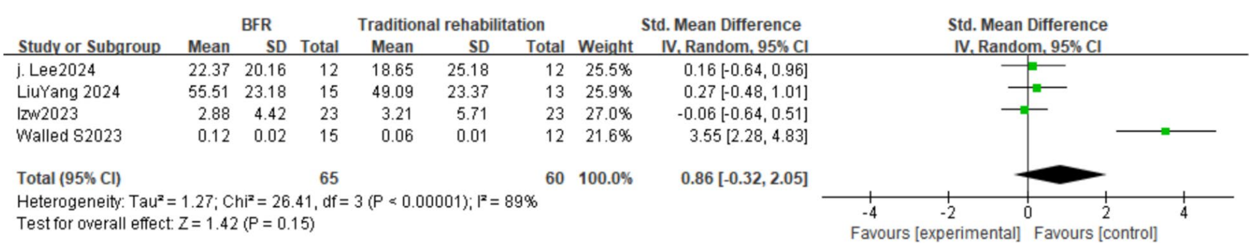


**Fig. 8** Forest plot of plantarflexion range of motion

in measurement methods (e.g., weight-bearing versus non-weight-bearing goniometry), intervention duration, and concurrent rehabilitation strategies. In addition, BFR is primarily designed to induce metabolic stress and improve muscle function [30], whereas its direct mechanical influence on connective tissue extensibility or joint arthrokinematics remains theoretically limited. Therefore, the current evidence does not support BFR as a superior intervention for passive ROM restoration in chronic ankle conditions.

A further consideration in interpreting these findings is the nature of the comparator interventions. In several included studies, the BFR groups received more structured and supervised rehabilitation, whereas comparator groups often received standard care with potentially different therapist interaction intensity. As such, it remains uncertain whether the observed benefits are exclusively attributable to the physiological effects of vascular occlusion or are partially influenced by increased supervision, intervention novelty, or adherence-related factors. Future studies should better control these non-physiological variables to isolate the true therapeutic contribution of BFR.

## Limitations

Several important limitations should be acknowledged. First, the number of included randomized controlled trials was limited, and most studies had relatively small sample sizes, reducing statistical power and increasing uncertainty in pooled estimates. Second, several methodological weaknesses were identified across the included studies, including limited allocation concealment, difficulty in participant and therapist blinding, and substantial variability in BFR parameters such as cuff width, occlusion pressure, and intervention duration. These factors may have contributed to both clinical and statistical heterogeneity.

Third, the included evidence was geographically concentrated, with a substantial proportion of studies originating from China, alongside a smaller number from South Korea, Saudi Arabia, and Thailand. This regional clustering may limit the external validity and generalizability of the findings to other healthcare systems, rehabilitation settings, and patient populations. In particular, outcomes such as CAIT scores and dynamic balance performance may be influenced by regional rehabilitation practices, patient expectations, and cultural differences in reporting. The possibility of regional publication bias therefore cannot be excluded.

Fourth, most studies evaluated outcomes only immediately after short intervention periods (typically 4–8 weeks), limiting insight into the long-term maintenance of functional gains and prevention of recurrent sprains.

Fifth, the secondary outcomes of dorsiflexion and plantarflexion ROM exhibited high heterogeneity and fragile pooled estimates, suggesting that the evidence supporting ROM-related benefits is considerably weaker than that for the primary functional outcomes.

Overall, according to the GRADE framework, the certainty of evidence ranged from low to moderate, primarily due to methodological limitations, imprecision related to small sample sizes, and heterogeneity across intervention protocols.

## Conclusion

Based on the current systematic review and meta-analysis, BFR training appears to be a promising therapeutic intervention for improving dynamic balance and patient-reported ankle stability in individuals with chronic ankle conditions. However, the certainty of the current evidence is low to moderate, and these findings should therefore be interpreted with appropriate caution.

These functional improvements suggest that BFR may serve as an effective low-load alternative for patients who are unable to tolerate high mechanical stress due to pain or pathology.

However, the current evidence base is constrained by small sample sizes, high heterogeneity in range-of-motion outcomes, and methodological variability across trials. Consequently, BFR should not yet be viewed as a universally superior adjunct to conventional care, particularly for improving passive joint mobility mechanics, where data remain inconsistent.

To advance the clinical applicability of BFR for chronic ankle conditions, future research must move beyond small-scale efficacy trials and address specific methodological gaps. We specifically recommend that future RCTs adopt standardized protocols for occlusion pressure, explicitly report safety endpoints, and utilize consistent outcome batteries. In summary, while BFR shows potential for functional rehabilitation in chronic ankle disorders, rigorous, standardized, and larger-scale investigations are required to definitively establish its clinical utility and safety profile.

### Abbreviations

| | |
|---|---|
| AJM | Ankle joint mobilization |
| AOP | Arterial occlusion pressure |
| BFRT | Blood flow restriction training |
| BFR | Blood flow restriction |
| CAI | Chronic ankle instability |
| CI | Confidence interval |
| FAAM | Foot and ankle ability test |
| GRADE | Grading of Recommendations Assessment, Development and Evaluation |
| $I^2$ | Heterogeneity statistic |
| LOP | Limb occlusion pressure |
| MD | Mean difference |
| RCT | Randomized controlled trial |
| ROM | Range of motion |
| RoB | Risk of bias |
| SEBT | Star excursion balance test |
| SMD | Standardized mean difference |
| YBT | Y-Balance test |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-026-09863-1.

Supplementary Material 1.

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### Authors' contributions

All authors contributed to this work. Both investigators jointly designed the study, performed the literature search, screened articles, extracted data, and conducted quality assessments. Data interpretation, manuscript drafting, and critical revisions were completed collaboratively. All authors approved the final manuscript.

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### Data availability

The datasets used and analyzed during the current study are derived from published randomized controlled trials included in this systematic review. All data are available within the published articles and their supplementary materials.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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**References**


1. Ventura A, Legnani C. Chronic ankle instability. Springer International Publishing; 2016. https://doi.org/10.1007/978-3-319-14815-1_50.
2. Garces JBG. Chronic ankle instability. Foot Ankle Clin. 2012;17(3):389–98. https://doi.org/10.1016/j.fcl.2012.06.001.
3. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. J Athl Train. 2002;37(4):364–75. PMID:12937557.
4. Gribble PA, Delahunt E, Bleakley C, Caulfield B, Docherty CL, Fourchet F, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. J Orthop Sports Phys Ther. 2013;43(8):585–91. https://doi.org/10.2519/jospt.2013.0303.
5. Wikstrom EA, Naik S, Lodha N, Cauraugh JH. Balance capabilities after lateral ankle trauma and intervention: a meta-analysis. Med Sci Sports Exerc. 2009;41(6):1287–95. https://doi.org/10.1249/MSS.0b013e318196cbc6.
6. Hoch MC, McKeon PO. Peroneal reaction time after ankle sprain: a systematic review and meta-analysis. Med Sci Sports Exerc. 2014;46(3):546–56. https://doi.org/10.1249/MSS.0b013e3182a6a93b.
7. Doherty C, Delahunt E, Caulfield B, Hertel J, Ryan J, Bleakley C, et al. The incidence and prevalence of ankle sprain injury: a systematic review and meta-analysis of prospective epidemiological studies. Sports Med. 2014;44:123–40. https://doi.org/10.1007/s40279-013-0102-5.
8. Valderrabano V, Hintermann B, Horisberger M, Fung TS. Ligamentous posttraumatic ankle osteoarthritis. Am J Sports Med. 2006;34(4):612–20. https://doi.org/10.1177/0363546505281813.
9. Xue X, Ma T, Li Q, Song Y, Hua Y. Chronic ankle instability is associated with proprioception deficits: a systematic review and meta-analysis. J Sport Health Sci. 2021;10(2):182–91. https://doi.org/10.1016/j.jshs.2020.09.014.
10. Maricot A, Dick E, Walravens A, Pluym B, Lathouwers E, De Pauw K, et al. Brain neuroplasticity related to lateral ankle ligamentous injuries: a systematic review. Sports Med. 2023;53(7):1423–43. https://doi.org/10.1007/s40279-023-01834-z.
11. Zhang Y, Guo Y, Cheng Y, Yang T. Effect of blood flow restriction training on the fitness benefit of upper limb muscles. Chin J Tissue Eng Res. 2024;28(14):2248–53. https://doi.org/10.12307/2024.292.
12. Cognetti DJ, Sheean AJ, Owens JG. Blood flow restriction therapy and its use for rehabilitation and return to sport: physiology, application, and guidelines for implementation. Arthrosc Sports Med Rehabil. 2022;4(1):e71–6. https://doi.org/10.1016/j.asmr.2021.09.025.
13. Takarada Y, Nakamura Y, Aruga S, et al. Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. J Appl Physiol. 2000;88(1):61–5. https://doi.org/10.1152/jappl.2000.88.1.61.
14. Ferguson RA, Mitchell EA, Taylor CW, Bishop DJ, Christiansen D. Blood-flow-restricted exercise: strategies for enhancing muscle adaptation and performance in the endurance-trained athlete. Exp Physiol. 2021;106(4):837–60. https://doi.org/10.1113/EP089280.
15. Pearson SJ, Hussain SR. A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. Sports Med. 2015;45(2):187–200. https://doi.org/10.1007/s40279-014-0264-9.
16. Fry CS, Glynn EL, Drummond MJ, et al. Blood flow restriction exercise stimulates mTORC1 signaling and muscle protein synthesis in older men. J Appl Physiol. 2010;108(5):1199–209. https://doi.org/10.1152/japplphysiol.01266.2009.
17. Christiansen D, Fyfe JJ, Loenneke JP, et al. Blood flow-restricted training enhances thigh glucose uptake during exercise and muscle antioxidant function in humans. Metabolism. 2019;98:15–26. https://doi.org/10.1016/j.metabol.2019.06.003.
18. Patterson SD, Brandner CR, McIlvenna L. Blood flow restriction exercise: considerations of methodology, application, and safety. Front Physiol. 2019;10:533. https://doi.org/10.3389/fphys.2019.00533.
19. Faltus J, Owens J, Hedt C. Theoretical applications of blood flow restriction training in managing chronic ankle instability in the basketball athlete. Int J Sports Phys Ther. 2018;13(3):552–60. PMID:30038841.
20. Yamada Y, Kang A, Seffrin A, Song JS, Kataoka R, Hammert WB, et al. Potential considerations with estimating blood flow restriction pressure in the lower body using a narrower cuff. Eur J Appl Physiol. 2023;123(5):937–43. https://doi.org/10.1007/s00421-022-05122-y.
21. Youn GM, Lee HJ. Effects of blood flow restriction exercise on ankle strength and balance ability in adults with chronic ankle instability. J Korean Soc Integr Med. 2023;11(1):121–30. https://doi.org/10.15268/KSIM.2023.11.1.121.
22. Wen Z, Zhu J, Wu X, Zheng B, Zhao L, Luo X, et al. Effect of low-load blood flow restriction training on patients with functional ankle instability: a randomized controlled trial. J Sport Rehabil. 2023;32(8):863–72. https://doi.org/10.1123/jsr.2022-0462.
23. Mahmoud WS, Radwan NL, Ibrahim MM, Hasan S, Alamri AM, Ibrahim AR. Effect of blood flow restriction as a stand-alone treatment on muscle strength, dynamic balance, and physical function in female patients with chronic ankle instability. Med. 2023;102(44):e35765. https://doi.org/10.1097/MD.0000000000035765.
24. Kim H, Jung J, Lee S. Contributory effect of additional blood flow restriction in active joint mobilization for young adults with chronic ankle instability: a pilot randomized controlled trial. Phys Ther Rehabil Sci. 2023;12(4):486–92. https://doi.org/10.14474/ptrs.2023.12.4.486.
25. Werasirirat P, Yimlamai T. Effect of supervised rehabilitation combined with blood flow restriction training in athletes with chronic ankle instability: a randomized placebo-controlled trial. J Exerc Rehabil. 2022;18(2):123–32. https://doi.org/10.12965/jer.2244018.009.
26. Liu S, Tang J, Hu G, Xiong Y, Ji W, Xu D. Blood flow restriction training improves the efficacy of routine intervention in patients with chronic ankle instability. Sports Med Health Sci. 2023;6(2):159–66. https://doi.org/10.1016/j.smhs.2023.11.001.
27. Liu Y, Wang Y. Effect of 6-week BFRT combined with IASTM therapy on international standard dancers with chronic ankle instability. Front Physiol. 2024;15:1417544. https://doi.org/10.3389/fphys.2024.1417544.
28. Dhillon MS, Patel S, Baburaj V. Ankle sprain and chronic lateral ankle instability: optimizing conservative treatment. Foot Ankle Clin. 2023;28(2):297–307. https://doi.org/10.1016/j.fcl.2022.12.006.
29. de Vries JS, Krips R, Sierevelt IN, Blankevoort L, van Dijk CN. Interventions for treating chronic ankle instability. Cochrane Database Syst Rev. 2011;8:CD004124. https://doi.org/10.1002/14651858.CD004124.pub3.
30. Cohen TJ, Choi MC, Kapur M, Lira VA, Yan Z, Yao TP. HDAC4 regulates muscle fiber type-specific gene expression programs. Mol Cells. 2015;38(4):343–8. https://doi.org/10.14348/molcells.2015.2278.


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