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RESEARCH

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# Effects of blood flow restriction training on aerobic capacity and performance in endurance athletes: a systematic review and meta-analysis

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## Abstract

**Background** Although blood flow restriction (BFR) training has been increasingly investigated for its potential to enhance aerobic capacity and performance in endurance athletes, its overall effectiveness remains inconclusive. This systematic review and meta-analysis aimed to evaluate the impact of BFR training on aerobic capacity, muscle strength, and endurance performance in endurance athletes compared to the same training without BFR.

**Methodology** Databases searched included PubMed, Scopus, Web of Science, and SPORTDiscus through September 2024. The methodological quality of the included studies was assessed using the PEDro tool, with meta-analyses conducted using the R program.

**Results** A total of 20 studies, involving 407 subjects, were included in the meta-analysis. The results revealed that BFR training had moderate effects on improving $VO_{2max}$ (ES = 0.465, 95% CI [0.222, 0.707], $P < 0.001$)) and endurance performance (ES = 0.693, 95% CI [0.252, 1.135], $P < 0.01$). Additionally, it demonstrated a large effect on maximal strength (ES = 1.022, 95% CI [0.267, 1.778], $P < 0.01$) and a small effect on aerobic power (ES = 0.315, 95% CI [0.015, 0.616], $P < 0.05$). Furthermore, subgroup analyses showed that age, athlete level, training duration, frequency, type, and cuff pressure did not significantly moderate the effectiveness of BFR training.

**Conclusions** BFR training significantly enhances aerobic capacity, muscle strength, and overall performance in endurance athletes compared to similar training without BFR. This approach provides a practical strategy for improving endurance and strength, especially during periods when high-intensity training is less feasible, such as recovery phases or in-season maintenance.

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**Keywords** Occlusion training, Physical endurance, Maximal strength, Physical functional performance, Athletes

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## Introduction

As athletes achieve higher levels of skill and physical conditioning in competitive sports, the potential for making further substantial improvements in performance becomes increasingly constrained [1]. Consequently, optimizing training outcomes through innovative methods has become a critical focus of research and practice. Blood Flow Restriction (BFR) training has gained considerable attention for its ability to induce high levels of metabolic stress, shear stress, and cardiovascular stress under low-intensity conditions, offering physiological adaptations comparable to those achieved through high-intensity training [2–4]. BFR training involves the use of external compression devices, such as blood pressure cuffs, elastic bands, or tourniquets, to restrict arterial blood flow while blocking venous return during exercise [5]. This restriction reduces oxygen delivery and slows metabolite clearance, creating a metabolic stress environment that triggers muscle growth and hypertrophy [6]. Additionally, the restricted blood flow generates shear stress on the vascular walls, stimulating endothelial cells to release growth factors, enhancing both muscle and vascular adaptations [7]. The reduced oxygen supply also forces the cardiovascular system to compensate by increasing heart rate, thereby improving cardiovascular efficiency [4]. These combined stresses enable BFR training to significantly improve muscle strength, endurance, and overall performance.

Although initially developed for sports rehabilitation [8], BFR training has shown significant improvements in muscle characteristics and strength when combined with resistance training, generating considerable interest among coaches [9, 10]. Recent research has extended the application of BFR training into aerobic training, particularly in conjunction with running or other specific sports, revealing its potential to enhance aerobic capacity metrics (e.g., $VO_{2max}$, lactate threshold) and overall athletic performance [11, 12]. However, existing reviews indicate that most studies have predominantly focused on untrained or physically active healthy adults, potentially limiting the generalizability of findings due to the lack of consideration for training experience.[2] For trained endurance athletes, their unique physiological characteristics (e.g., higher baseline adaptations) and training backgrounds may significantly influence the effectiveness of BFR training, necessitating further investigation into its application in this population.

Furthermore, the literature presents discrepancies regarding the effects of BFR training on aerobic capacity and performance in endurance athletes. While some studies report notable improvements [13–15], others show minimal or no effects [16, 17]. These inconsistencies may be attributed to variations in study design, training protocols, or athlete characteristics. Additionally, although the concurrent training of strength and endurance may lead to an interference effect (e.g., conflicting adaptive responses), muscle strength remains a critical factor for endurance performance [18]. Improved strength can enhance exercise efficiency (e.g., running economy) and delay the onset of fatigue, thereby contributing to better overall performance [19]. Given the inconsistencies in existing literature and the potential limitations of individual studies, a systematic review and meta-analysis are necessary to comprehensively evaluate the specific effects of BFR training on physical fitness and sports performance in endurance athletes. Specifically, this study aims to systematically evaluate the impact of BFR training on aerobic capacity, muscle strength, and endurance performance in endurance athletes, providing a scientific basis for future training methods and research.

## Methods

### Search strategy and study selection

This systematic review and meta-analysis adhered to the PRISMA guidelines [20] and was registered with Prospero (registration number: CRD42024581910). A comprehensive search was performed across electronic databases, including PubMed, Scopus, Web of Science, and SPORTDiscus, up to September 5, 2024. The search employed Boolean operators AND and OR with the keywords: "blood flow restriction," "vascular occlusion," "KAATSU," "tourniquets," "endurance," "runner," "marathon," "triathlon," "cyclist," "swimmer," "rower," and "skier," with detailed search strings provided in the S1 File. Following deduplication, titles and abstracts of the retrieved articles were screened, and full-text reviews were conducted as illustrated in Fig. 1. Additionally, reference lists of the included studies were examined for further relevant articles. Two researchers (Z.Z. and X.G.) independently retrieved the articles, and any discrepancies were resolved by a third researcher (L.G.).

### Eligibility criteria

The criteria for article inclusion were as follows: (a) studies involving endurance athletes; (b) study designs that allowed for comparisons between BFR training and non-BFR conditions; (c) assessments of aerobic capacity, muscle strength, power, and/or endurance performance conducted pre- and post-training; (d) interventions that lasted at least 2 weeks; and only studies with a Physiotherapy Evidence Database (PEDro) scale score of 4 or higher were considered, indicating adequate methodological quality.

### Risk of bias

The methodological quality of the included studies was assessed using the PEDro scale [21], which evaluates key

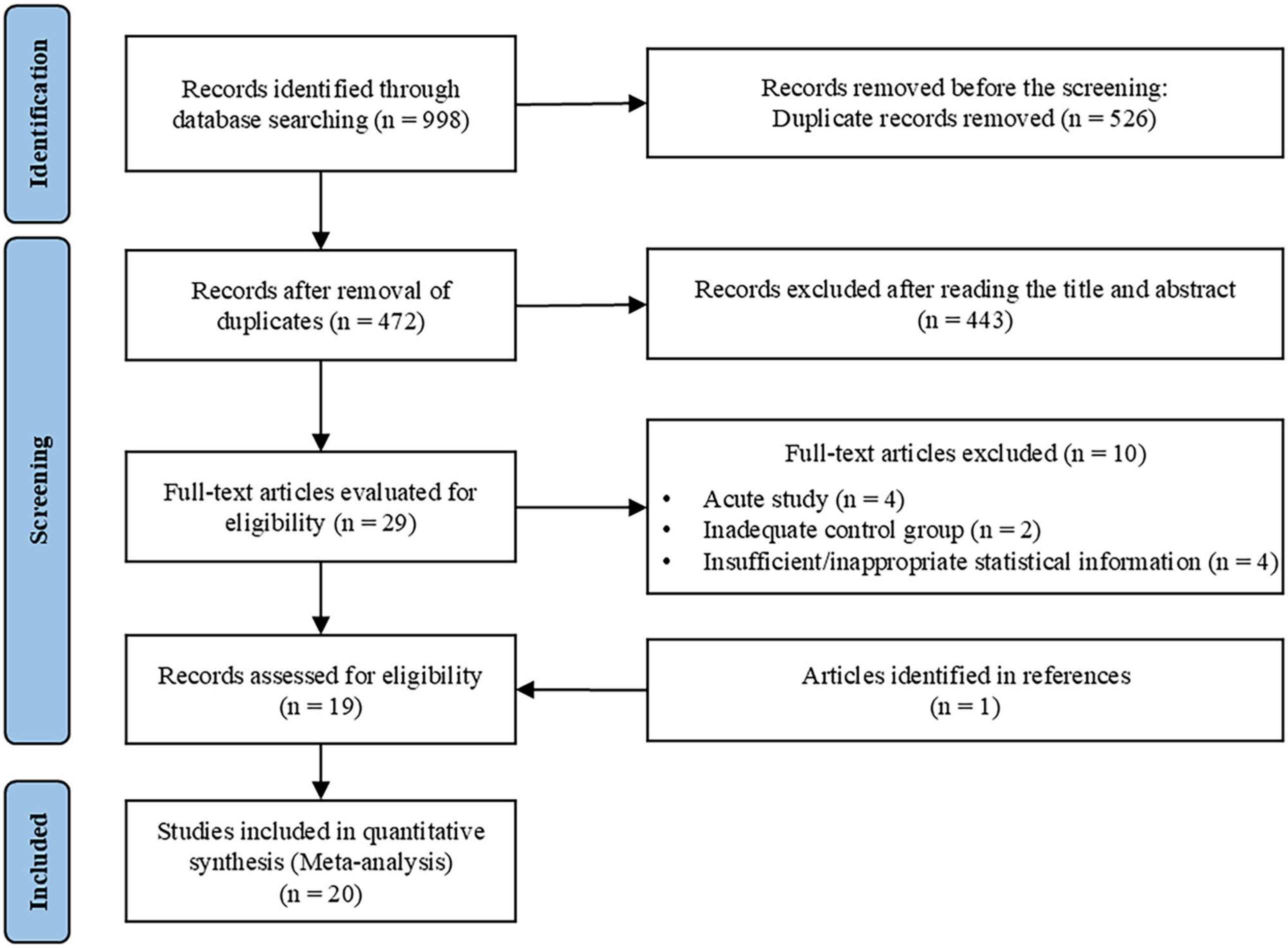


**Fig. 1** PRISMA flow diagram

aspects such as randomization, blinding, and the validity of outcome measures across 11 criteria. The scale assigns up to 10 points, with the first criterion not contributing to the total score. In alignment with established research guidelines [22, 23], studies scoring below 4 were excluded to ensure the inclusion of only those with sufficient methodological rigor. In addition, the GRADE approach was used to assess the overall quality of the evidence [24]. Potential publication biases were further examined through a detailed visual inspection of funnel plot symmetry and Egger's test.

### Data extraction

Primary outcomes extracted from each study included aerobic capacity (e.g., $VO_{2max}$ and maximal aerobic power), maximal muscle strength (e.g., dynamic, isometric, and isokinetic strength), and endurance performance (e.g., long-distance running, cycling, or rowing). Secondary outcomes included participant details (e.g., age, gender, type of sport) and training attributes (e.g., duration, frequency, intensity of training, and occlusion pressure). For studies reporting multiple time points, the most recent post-training measure was used for analysis. When necessary data were not present in the published reports, requests were directed to the authors. Studies were omitted if no response was received. The specific study characteristics are presented in Table 1.

### Statistical analyses

Meta-analyses were performed using R version 4.3.0 (R Foundation for Statistical Computing, Vienna, Austria). The effect size difference for between-group comparisons was calculated based on pre- and post-intervention means, standard deviations, and sample sizes. The standard deviation change ( $SD_{change}$) was derived using the formula:

$$SD_{change} = \sqrt{\frac{((n_1 - 1) \times \ SD_1{}^2 + (n_2 - 1) \times \ SD_2{}^2)}{(n_1 + n_2 - 2)}}$$

The magnitude of effect size was categorized as small (< 0.40), moderate (0.40–0.70), and large (> 0.70) [41]. A

**Table 1** Characteristics of the included studies

| Author | Subjects; *N* (BFR, CG); Age | Duration; Frequency | Exercise mode | Outcomes (Percentage increase) |
|---|---|---|---|---|
| Beak et al., 2022 [25] | Male runners; 14, 15; 30 ± 4.1 years | 8 weeks<br>3 days/week | 5 sets, 2 min treadmill running (40% $VO_{2max}$) | $VO_{2max}$: BFR, 6.4%, CG, 5.7% |
| Billaut et al., 2022 [26] | Endurance athletes; 9, 6; NG | 3 weeks<br>3 days/week | 3 sets, high-intensity interval training | Aerobic power: BFR, 5.1%, CG, 1.1% |
| Bourgeois et al., 2024 [27] | Male cyclists, swimmers, runners; 10, 8; 24.9 ± 3.5 years | 3 weeks<br>3 days/week | 4 sets, high-intensity interval training bouts (8–30 reps squat) | $VO_{2max}$: BFR, 2.0%, CG, 1.8%<br>5 km cycling time: BFR, -0.9%, CG, -1.2%<br>Aerobic power: BFR, 1.3%, CG, -0.3% |
| Chen et al., 2021 [13] | Endurance male athletes; 10, 10; 21.6 ± 0.8 years | 8 weeks<br>3 days/week | 4 × 3 min treadmill running at 50% HRR | $VO_{2max}$: BFR, 4.8%, CG, -1.7%<br>Maximal strength: BFR, 7.1−13%, CG, 0−7.7% |
| Chen et al., 2022 [28] | Endurance male athletes; 10, 10; 21.6 ± 2.2 years | 8 weeks<br>3 days/week | 5 × 3 min treadmill running at 50% HRR | Maximal strength (leg extensor or flexor): BFR, 9.4–9.9%, CG, 1.5–2.4%<br>Maximal running performance: BFR, 12.6%, CG, 4.5% |
| Geng et al., 2021 [29] | Elite skiers; 8, 7; 20.7 ± 1.3 years | 3 weeks<br>4 days/week | 3 × 20–25 resistance exercises; 30 min cycling at 80% HRR | Maximal strength (knee extension): BFR, 18.0%, CG, 7.5% |
| Giovanna et al., 2022 [30] | Male cyclists and runners; 10, 10; 25.6 ± 5.7 years | 2 weeks<br>3 days/week | 4 sets, 5 × 10s sprint | $VO_{2max}$: BFR1, 4.1%, BFR2, 3.5%, CG, -1.9%<br>Cycling power: BFR1, 4.4%, BFR2, 1.8%, CG, -1.4% |
| Guo 2021 [31] | Male rowers; 9, 9; 16.8 ± 0.8 years | 8 weeks<br>3 days/week | 3 × 15–30 Squat, bench press, and pull-down (30% 1RM) | Maximal strength: 6.7 ± 2.4, 3.8 ± 2.4<br>Maximal running performance: 6.56 ± 3.47, 6 ± 2.45<br>Aerobic power: 63.3 ± 15.3, 61 ± 20.2 |
| Held et al.,2020 [32] | Elite rowers; 16, 15; 21.8 ± 3.5 years | 5 weeks<br>3 days/week | 2 × 10 min low-intensity rowing at 65% HRR | $VO_{2max}$: BFR, 9.1 ± 6.2%, CG, 2.5 ± 6.1%<br>Aerobic power: BFR, 15.3 ± 9.7%, CG, 3.1 ± 9.7%<br>Maximal strength (squat): BFR, 5.4 ± 5.7%, CG, 4.6 ± 5.3% |
| Held et al.,2023 [33] | Male swimmers; 10, 8; 22.7 ± 3 years | 5 weeks<br>3 days/week | 2 sets, 10 min low-intensity swimming | $VO_{2max}$: BFR, 2.5%, CG, -4.7% |
| Herda et al.,2024 [16] | Trained runners; 11, 11; 32.9 ± 11 years | 4 weeks<br>3 days/week | 5 sets, 2 min walking at 4.83 km/h | $VO_{2max}$: BFR, 0.2%, CG, 2.1%<br>40 m sprint time: BFR, 1.5%, CG, -0.4% |
| Liang, 2023 [34] | Male cyclists; 10, 10; 19.5 ± 0.2 years | 8 weeks<br>3 days/week | 30 min cycling at 45–60% HRR | $VO_{2max}$: BFR, 6.0%, CG, 2.7%<br>20 km cycling time: BFR, -7.8%, CG, -2.6% |
| Mitchell et al., 2019 [14] | Cyclists and triathletes; 11, 10; 23.0 ± 5.0 years | 4 weeks<br>2 days/week | 4–7 sets, 30s maximal cycling sprint | $VO_{2max}$: BFR, 4.9%, CG, -0.3%<br>Cycling power: BFR, 8.3%, CG, 5.4% |
| Tang et al., 2020 [35] | Female cyclists; 6, 6; 19.5 ± 1.2 years | 4 weeks<br>2 days/week | Cycling training (60–65% $VO_{2max}$) | $VO_{2max}$: 3.83 ± 1.72, 1.33 ± 1.21;<br>Aerobic power: 13.33 ± 10.33, 3.33 ± 12.11 |
| Tang et al., 2022 [36] | Male cyclists; 6, 6; 23.0 ± 1.8 years | 4 weeks<br>2 days/week | 4 × 15–30 half squat (40% 1RM) | Maximal strength (squat): 8.6 ± 8.9, 4.4 ± 18.4 |
| Tangchaisuriya et al., 2021 [15] | Male cyclists; 17, 16; 40.9 ± 4 years | 12 weeks<br>2 days/week | 6 min cycling at 25% PPO, 2 min at 50% PPO, and 2 min at 60% PPO | $VO_{2max}$: BFR, 7.8%, CG, 3.6%<br>Cycling power: BFR, 6.8%, CG, 1.6% |
| Taylor et al., 2016 [37] | Male cyclists; 10, 10; 26.5 ± 5.9 years | 4 weeks<br>2 days/week | 4–7 sets, 30s maximal cycling sprint | $VO_{2max}$: BFR, 5.0%, CG, 1.0%; 15 km Cycling time: BFR, -0.6%, CG, 0% |
| Tosun et al., 2023 [38] | Male Canoe athletes; 17,16; 18.7 ± 0.9 years | 8 weeks<br>2 days/week | 3 × 10 resistance exercises (30% 1 RM) | 1 km rowing time: BFR, 5.1%, CG, 0%<br>Maximal strength (thigh): BFR, 4.0%, CG, 2.5% |

**Table 1** (continued)

| Author | Subjects; *N* (BFR, CG); Age | Duration; Frequency | Exercise mode | Outcomes (Percentage increase) |
|---|---|---|---|---|
| Wan 2024 [39] | Female Canoe athletes; 7, 7; 19.8 ± 1.4 years | 8 weeks<br>3 days/week | 4 × 15 back squat (BFR, 30% 1 RM; CG, 70% 1RM) | Maximal strength (squat): 6.4 ± 0.7, 3.6 ± 0.4<br>Endurance performance: 1.86 ± 0.26; 0.85 ± 0.26 |
| Wang et al., 2023 [40] | Male swimmers; 8, 8; 19.7 ± 1.6 years | 4 weeks<br>3 days/week | 4 sets, 15–30 reps back squat | Maximal strength (squat): BFR, 14.7%, CG, -3.2% |

Note: BFR, blood flow restriction training; CG, control group; HRR, heart rate reserve; PPO, peak power output

random effects model was employed to account for variability and heterogeneity among the studies. Heterogeneity was assessed using the $I^2$ statistic, with thresholds set at ≤ 25% for low, 25–75% for moderate, and > 75% for high heterogeneity [42]. A total of four meta-analyses were performed to evaluate the effects of BFR training versus no-BFR training on outcomes including on aerobic capacity (i.e., $VO_{2max}$), maximal muscle strength, muscle power, and endurance performance. Sensitivity analyses were performed to assess the robustness of the results. Statistical significance was determined with a criterion of $p < 0.05$.

Subgroup analyses were conducted to explore potential moderating effects of key variables that may influence the efficacy of BFR training, including age, athlete level, training duration, training frequency, training type, and BFR cuff pressure. Each subgroup analysis was performed by categorizing the data based on the mean values of the respective variables to ensure meaningful group distinctions. Athlete level was classified into two categories: amateur and elite. Elite athletes were defined as those competing at national or international levels, while amateur athletes included individuals participating in regional or recreational events. Training type was categorized into strength training and endurance training. Due to the predominance of male athletes in the included studies, a subgroup analysis based on gender was not conducted.

## Results

### Study selection

An initial search identified 998 studies. After a thorough screening of titles and abstracts, 29 studies were selected for full-text review based on stringent eligibility criteria. Of these, 19 studies were found to meet the inclusion criteria, with one additional study identified through a meticulous review of reference lists. As a result, 20 studies were included in the final systematic review and meta-analysis, as illustrated in Fig. 1.

### Risk of bias

Among the studies evaluated, four were classified as moderate methodological quality (scores of 4–5), while 16 were deemed high methodological quality (scores of 6–10). The median score across all studies was 6 out of 10, with an interquartile range of 5 to 7, indicating that the overall methodological quality ranged from moderate to high. This level of quality supports the reliability of the findings. Most of the studies did not employ blinding during the intervention phase, which may introduce some methodological bias. GRADE assessment for the four meta-analyses determined the overall quality of evidence to be moderate. Detailed PEDro scores and GRADE profiles are presented in S2 File. Funnel plots

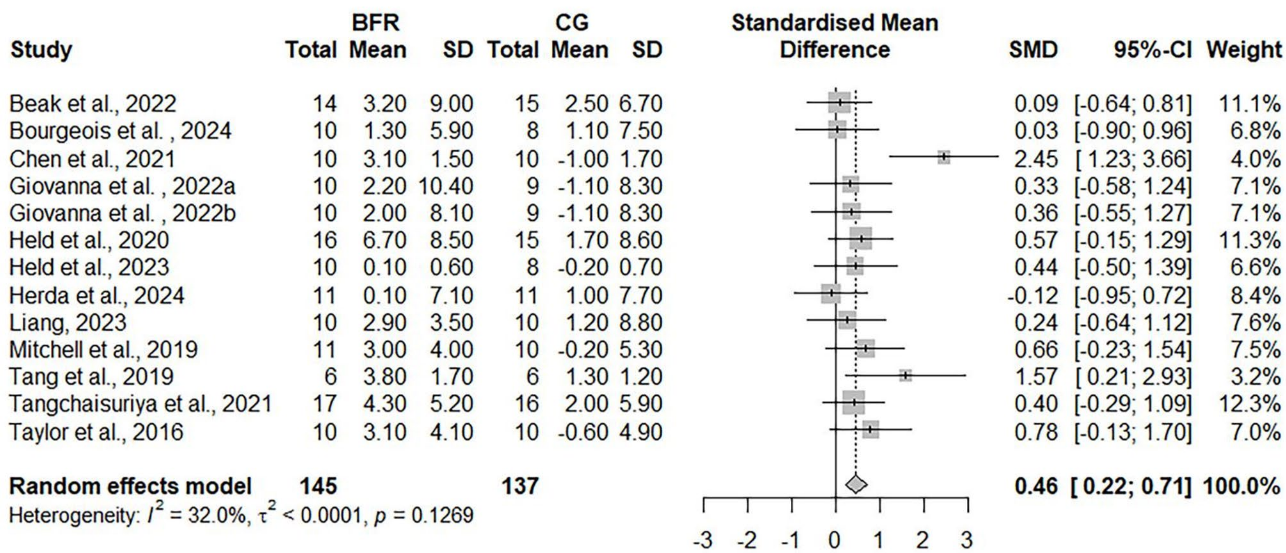


**Fig. 2** Forest plot demonstrating the effects of BFR training on $VO_{2max}$

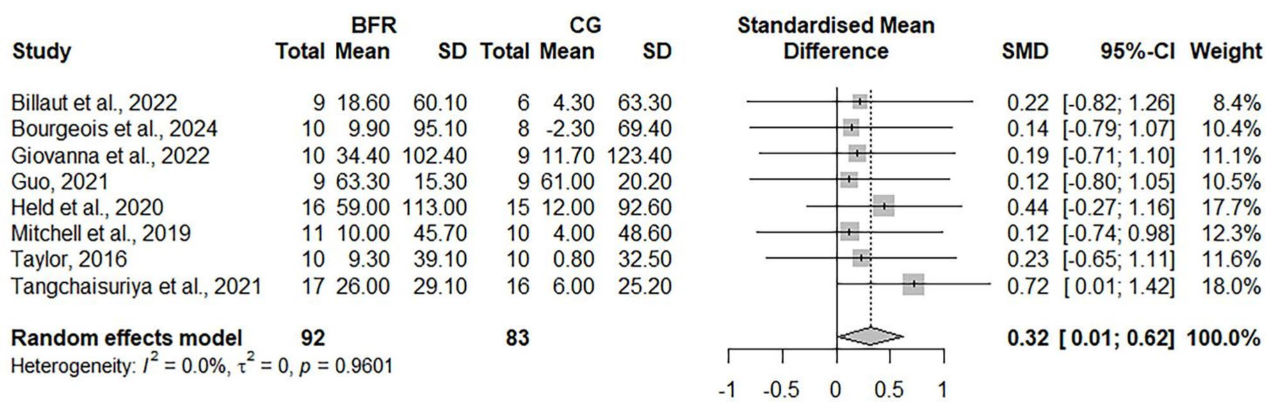


**Fig. 3** Forest plot demonstrating the effects of BFR training on aerobic power

from the meta-analyses showed a uniform distribution, indicating no significant publication bias or selective reporting (see S3 File). Egger's test showed no significant risk of bias for $VO_{2max}$ (b = 4.44, t = 2.83, $p = 0.16$). Egger's test was not applied to the other meta-analyses due to the inclusion of fewer than 10 studies.

### Meta-analysis results

In this meta-analysis, 12 studies evaluated the effects of BFR training on $VO_{2max}$ in endurance athletes, showing that BFR training has a moderate effect on improving $VO_{2max}$ (ES = 0.465, 95% CI [0.222, 0.707], $P < 0.001$) (Fig. 2). Eight studies examined the effects of BFR training on aerobic power, with results showing a small effect on improving power (ES = 0.315, 95% CI [0.015, 0.616], $P < 0.05$) (Fig. 3). Nine studies assessed the impact of BFR training on maximal strength, indicating a large effect of BFR training on strength improvement (ES = 1.022, 95% CI [0.267, 1.778], $P < 0.01$) (Fig. 4). Additionally, eight studies evaluated the effects of BFR training on endurance performance, revealing a moderate effect (ES = 0.693, 95% CI [0.252, 1.135], $P < 0.01$) (Fig. 5).

Sensitivity analysis showed stable effect sizes and heterogeneity after excluding individual studies, supporting the robustness of the results (see S4 File). In addition, subgroup analyses indicated that age, athlete level, training duration, training frequency, training type, and BFR cuff pressure did not significantly moderate the effects of BFR training (see S5 File), with no significant differences observed between subgroups.

## Discussion

This meta-analysis provides strong evidence for the effectiveness of BFR training in enhancing athletic performance. The findings demonstrate that BFR training significantly improves $VO_2$max, aerobic power, maximal strength, and endurance performance in endurance athletes, underscoring its value in performance

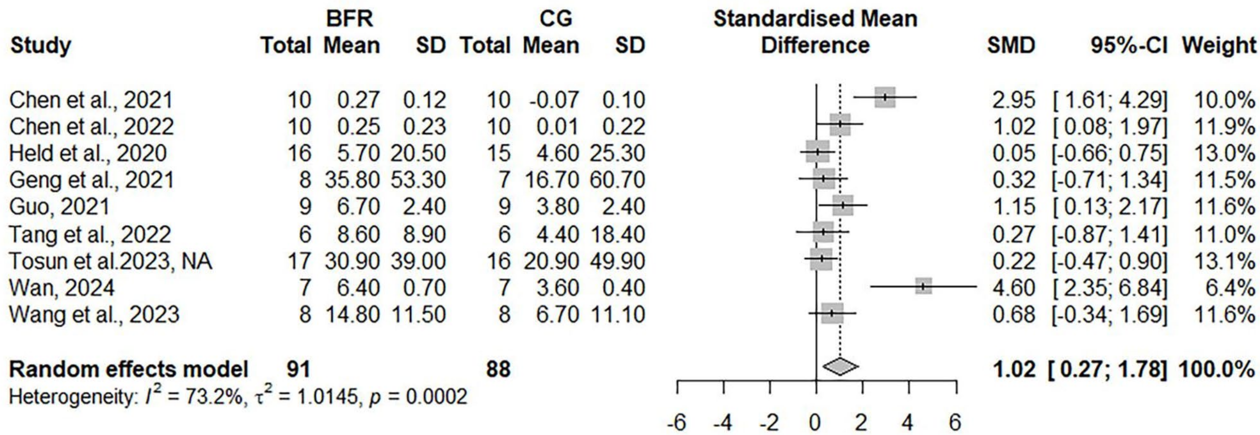


**Fig. 4** Forest plot demonstrating the effects of BFR training on maximal strength

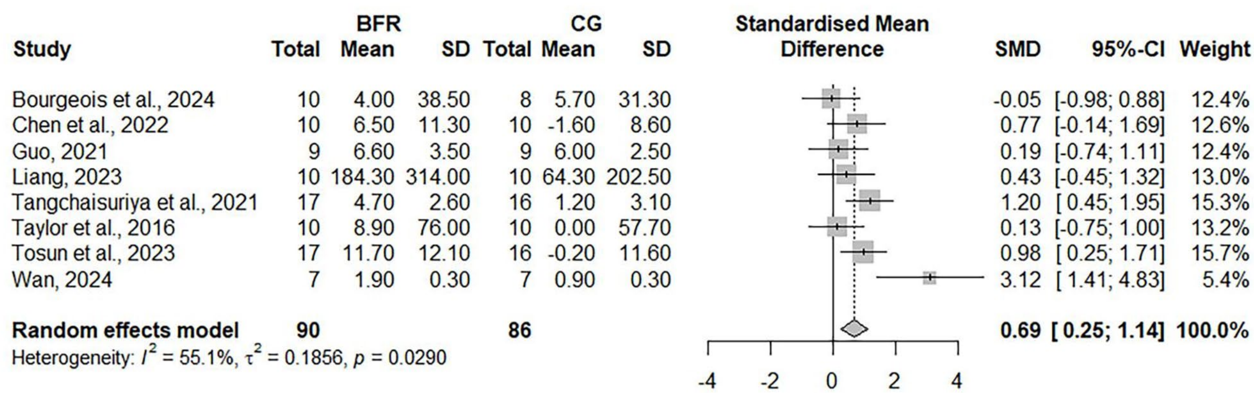


**Fig. 5** Forest plot demonstrating the effects of BFR training on endurance performance

optimization. However, age, athlete level, training duration, training frequency, training type, and BFR cuff pressure did not significantly influence its effectiveness.

**Aerobic capacity**

There was a significant effect of BFR training on $VO_{2max}$ compared to the same training without BFR. This finding aligns with the meta-analysis by Formiga et al. [12], which highlights the significant improvements in aerobic capacity for healthy young adults resulting with aerobic BFR training. However, unlike Formiga's focus on young adults, this study targets endurance athletes, a group with inherently higher baseline aerobic capacities. Given their advanced fitness levels, endurance athletes may require more specific stimuli to elicit further improvements, which BFR training may provide. The observed improvements may be partially explained by several interconnected physiological mechanisms [6, 43–45]. Blood flow restriction creates a localized hypoxic environment and elevates metabolic stress, which may stimulate mitochondrial biogenesis and increase oxidative enzyme activity, thereby enhancing muscle oxidative capacity [6]. Simultaneously, this stress environment may promote adaptive shifts in muscle fiber characteristics toward more oxidative and fatigue-resistant profiles, which are considered beneficial for endurance performance [43]. At the cardiovascular level, reduced oxygen availability during BFR may induce compensatory increases in heart rate and cardiac output [44]. Chronic exposure to this stress may, over time, enhance stroke volume and cardiac efficiency. Collectively, these muscular and cardiovascular adaptations may contribute to the observed improvements in aerobic capacity and endurance.

Despite these positive findings, three studies in this meta-analysis did not show significant improvements in $VO_{2max}$ [16, 25, 27]. The studies by Beak et al.[21] and Herda et al. [16] failed to achieve notable results, likely due to insufficient training intensity. Both studies relied solely on BFR training without incorporating regular training. In particular, Beak et al. [25]. used low-intensity walking as the intervention, which may have been insufficient to elicit significant aerobic adaptations. In contrast, other studies achieved better outcomes by combining BFR training with conventional training protocols.

Notably, the study by Bourgeois et al. [27] applied BFR during high-intensity training but still observed no improvement in $VO_{2max}$. This may be attributed to the excessive reliance on anaerobic metabolism at very high intensities, which could limit aerobic adaptations [40]. These findings underscore the importance of optimizing training intensity when implementing BFR, as both insufficient and excessive workloads may compromise its effectiveness.

In summary, BFR training can effectively enhance aerobic capacity compared to training without BFR in endurance athletes. To maximize its effectiveness, it is crucial to ensure adequate training intensity and incorporate BFR during exercise, as both insufficient and excessive intensities can hinder aerobic adaptations.

### Muscle strength

This meta-analysis provides strong evidence that BFR training significantly enhances maximal strength compared to the same training performed without BFR. Subgroup analysis further showed that training type (resistance training vs. endurance training) did not have a significant moderating effect, indicating that both training modalities led to comparable improvements in maximal strength when combined with BFR. This finding may be attributed to shared physiological adaptations induced by BFR training, such as increased muscle fiber recruitment, elevated metabolic stress, and adaptive responses to local hypoxia, which may play a role in both resistance and endurance training [2–4]. While the effectiveness of BFR in enhancing maximal strength through resistance training has been well-documented, evidence regarding its benefits when combined with endurance training remains limited [10, 45].

This review further validates the potential of BFR to enhance maximal strength during aerobic training. Traditionally, endurance training has been associated with limited strength adaptations due to the "interference effect," where concurrent endurance and strength training may compromise muscle strength and hypertrophy gains [18]. However, this analysis demonstrates that integrating BFR into endurance training still leads to significant improvements in maximal strength, suggesting that BFR may mitigate the interference effect and promote a more balanced development of both endurance and strength capacities.

This finding had important implications for the design of training programs. The ability of BFR to reduce the interference effect suggests that it can be strategically incorporated into endurance training to preserve or enhance strength gains without compromising endurance performance. This is particularly relevant for sports requiring a balance of both qualities, such as middle-distance running, cycling, and triathlon.

### Endurance performance

The results of this meta-analysis demonstrate that BFR training improves endurance performance in endurance athletes compared to the same training without BFR. This is consistent with the systematic review by Bennett and Slattery [2], which reported the effectiveness of BFR training in enhancing endurance performance across various populations. By employing meta-analytic methods, this study provides a quantitative synthesis of the benefits of BFR training, offering robust evidence specifically for endurance athletes and extending previous research in this field.

Key determinants of endurance performance include $VO_{2max}$, $VO_{2max}$ at lactate threshold, and running economy [46]. Muscle strength is also recognized as a significant contributor to endurance performance [47]. The present meta-analysis demonstrates that BFR training significantly improves muscle strength, a key determinant of endurance performance, suggesting that this improvement may directly or indirectly enhance endurance performance. Increased muscle strength not only supports high-intensity efforts but may also enhance fatigue resistance during prolonged submaximal exercise [19]. Furthermore, the observed improvements in $VO_2$max with BFR training highlight its potential to enhance cardiovascular efficiency and oxygen utilization, which are fundamental to endurance performance. These findings reinforce the applicability of BFR training as a strategic intervention to optimize endurance capacity by concurrently improving both muscular and cardiovascular function [2].

However, the studies included in this meta-analysis did not specifically assess $VO_2$max at lactate threshold or running economy, preventing definitive conclusions about the effects of BFR training on these variables. Future investigations should employ randomized controlled trials to explore the specific effects of BFR training on these key variables, providing a more comprehensive understanding of its impact on endurance performance.

### Limitations

This systematic review, while offering important insights, has several limitations. First, the limited number of included studies may reduce the statistical power of moderator analyses and limit the ability to explore potential moderators, such as gender differences. Most studies recruited only male athletes, further restricting the generalizability of the findings. Additionally, while the majority of the studies were of high quality, some were of only fair quality. A significant limitation is that nearly all studies failed to adequately blind participants, coaches, or assessors, which could introduce bias and affect the objectivity of the results. To enhance the reliability and reproducibility of future research, it is recommended to improve blinding and randomization procedures and to provide more detailed reporting on study design and analysis methods.

## Conclusions

The present systematic review and meta-analysis provide novel insights into the effects of BFR training on endurance athletes, indicating that applying BFR to endurance training significantly enhances aerobic capacity (including $VO_{2max}$ and maximal aerobic power), maximal strength, and endurance performance compared to the same training without BFR.

As practical applications, incorporating BFR training into endurance athletes' routines provides a strategic means to enhance both aerobic capacity and muscle strength. This approach is particularly beneficial during periods when high-intensity training is not feasible, such as during recovery or in-season maintenance. By integrating BFR into regular training sessions, athletes can achieve significant improvements in performance while reducing the risk of overtraining. This method supports continuous progress in both cardiovascular and muscular development, making it a valuable addition to comprehensive training programs.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01194-3.

Supplementary Material 1

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### Author contributions

Conceptualization: ZZ, LG. Project administration: ZZ. Resources: ZZ, XG. Data curation: ZZ, XG, LG. Software: ZZ, XG. Supervision: LG. Writing – original draft: ZZ, XG, LG. Writing – review & editing: LG.

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### Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## 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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