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A Review of Studies on the Effects of Blood Flow Restriction Training on Endurance Athletes

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Abstract

In the context of the Healthy China Strategy and the national goal of building a sports power, marathon and half-marathon events are developing rapidly, reflecting a growing public enthusiasm for endurance sports. This momentum has led to a rising demand among mass elite athletes—non-professional but high-performing runners—for efficient and scientifically grounded training models. However, traditional high-intensity training methods often pose risks of overtraining or injury. In this context, Blood Flow Restriction Training (BFRT), known for its "low-load-high-benefit" profile, emerges as a promising alternative. The objective of this study is to systematically explore the conceptual framework and physiological mechanisms of BFRT, assess its current application in endurance sports both domestically and internationally, and evaluate its potential benefits and limitations specifically for mass elite half-marathon athletes. This study adopts a literature review methodology, integrating empirical findings from sports science databases, journal publications, and expert analyses to map the research landscape surrounding BFRT. Findings indicate that BFRT can significantly enhance lower limb muscle strength, capillarization, and endurance performance when used appropriately. However, research involving mass elite half-marathon athletes remains limited, with gaps in long-term intervention studies, individualized training parameters, and understanding of BFRT's integration with traditional endurance programs. The future research prioritizes longitudinal studies to examine BFRT's sustained effects, optimize cuff pressure, frequency, and duration specific to endurance demands, and investigate its synergistic potential when combined with conventional aerobic training. These efforts are essential to ensure the safe, targeted, and effective implementation of BFRT in endurance sports development.

Keywords: *Blood Flow Restriction Training (BFRT); half-marathon; lower limb strength; mass elite athletes; running economy.*

A. Introduction

Driven by the policies of the Healthy China Strategy and the construction of a sports power, marathon and half-marathon sports—benchmark projects for the deep integration of national fitness and competitive sports—are demonstrating a dual-driven trend of scaled development and professional upgrading. According to the 2024 China Road Running Events Blue Book released by the Chinese Athletics Association, a total of 442 half-marathon events were held nationwide in this year, marking a 17.2% increase from 2023. The total scale of participants reached nearly 2.997 million person-times, with 38,897 elite athletes breaking the 1 hour 30 minutes barrier—representing a 48.5% increase compared with 2023 (Chinese Athletics Association, 2023, 2024).

These data not only highlight the remarkable effectiveness of the national strategy for promoting fitness but also reflect the systematic improvement of China's competitive capacity in endurance sports. In terms of policy, the National Fitness Plan (2021–2025) by the State

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Council calls for the widespread organization of national fitness activities, including community sports meets and city marathons. It also emphasizes the importance of empowering social organizations and encouraging private-sector event organization (State Council, 2021). Furthermore, the General Administration of Sport of China and related ministries promote a marathon development mechanism based on government guidance, social participation, and market operation (General Administration of Sport of China & 11 Other Ministries, 2018).

Under this framework, cities have innovated integrated “sports + culture and tourism” models. For instance, Wuhan established the Yangtze River Economic Belt Marathon Series, and Chengdu developed a park city greenway system for half marathons, aligning event economies with urban development.

Competitively, as more runners meet mass elite half-marathon standards, many events—like the Wuxi Marathon and Beijing Half-Marathon—now feature segmented start and registration mechanisms to support mass runners transitioning to elite levels (Chinese Athletics Association, 2025).

Looking ahead, the implementation of the Healthy China 2030 Plan Outline will continue to elevate the value of marathon sports. On a national fitness level, these events promote the practice of "one hour of daily exercise"; competitively, they support a pyramid-style talent reserve system; and for urban development, they help build globally influential sport-cultural brands (Central Committee of the Communist Party of China & State Council, 2016). This integrated development model exemplifies sports industry supply-side reform and offers a progressive approach to modernizing China's sports governance system.

Mass elite half-marathon athletes, however, face a unique dilemma: they often lack sufficient time and physiological capacity for high-intensity strength training. Without structured programming, recovery is slow and injury risk increases, compromising endurance performance. Given the critical role of lower limb strength in maintaining pace, handling elevation, and enabling final sprints, there is an urgent need for strength training models that deliver high neural adaptation under low physiological load—a key strategy for overcoming amateur performance plateaus.

B. Methods

This study employs a qualitative literature review design with a descriptive-analytical approach. The research focuses on systematically reviewing existing empirical and theoretical studies related to Blood Flow Restriction Training (BFRT) in the context of endurance sports, particularly among mass elite half-marathon athletes. The design is selected to allow in-depth analysis of the conceptual foundation, physiological mechanisms, and applied outcomes of BFRT training. This design also enables the identification of research gaps and the formulation of informed recommendations for future empirical research and training implementation (Snyder, 2019).

The research procedure includes four stages: (1) identification of keywords and themes (e.g., BFRT, endurance performance, mass elite athletes, running economy); (2) systematic search and selection of relevant literature from scientific databases such as PubMed, Scopus, CNKI, and Web of Science; (3) categorization of selected studies based on methodology, sample characteristics, training outcomes, and research findings; and (4) synthesis of key themes and trends to build an integrative framework that contextualizes the current state of knowledge on BFRT in endurance sports.

Data were collected through documentary analysis, involving the selection and review of peer-reviewed journal articles, official reports, policy documents, and meta-analyses published between 2000 and 2024. Inclusion criteria focused on studies related to BFRT application in endurance training, physiological outcomes, and training efficiency, particularly among sub-elite or mass elite athletes. Exclusion criteria included studies unrelated to endurance contexts or those with insufficient methodological transparency.

The collected literature was analyzed using qualitative content analysis. Studies were coded thematically to identify recurring patterns, theoretical perspectives, and empirical findings. A comparative analysis was conducted to highlight areas of consensus and divergence, as well as to uncover under-researched aspects, such as long-term intervention effects and BFRT's integration with conventional endurance training. Thematic synthesis allowed for the formulation of evidence-based conclusions and research recommendations (Thomas & Harden, 2008).

C. Results and Discussion

1. Blood Flow Restriction Training (BFRT)

Blood Flow Restriction Training (BFRT), also known as KAATSU training, refers to a training method where external pressure is applied to the proximal part of limbs (upper and/or lower extremities) through special pressurized devices (typically pneumatic cuffs or elastic bandages) during exercise. This pressure occludes venous blood flow while partially blocking arterial blood flow to enhance training effects (Wei et al., 2019). By partially restricting arterial blood flow and blocking venous return, BFRT achieves muscle strength gains similar to high-intensity training at low loads (20–30% of 1RM), which has been widely applied in rehabilitation medicine and physical training in recent years (Patterson et al., 2019). However, research on BFRT for endurance athletes is extremely limited, especially regarding BFRT protocols for half-marathon events, which lack practical parameters and standardized guidance.

Low-Intensity Blood Flow Restriction Training (LI-BFRT) refers to an innovative training method combining low-intensity resistance training with blood flow restriction training, with a load intensity of 20-30% 1RM.

Mass elite half-marathon athletes refer to non-professional participants who have achieved elite-level performance in half-marathon road running events, as defined in the Implementation Measures for Rating Mass Runners in Road Running Events issued by the Chinese Athletics Association (Chinese Athletics Association, 2025). This study selects mass elite runners aged 20–39 as the research subjects.

The lower limbs refer to the part of the human body below the abdomen, including the hips, buttocks, thighs, calves, and feet. Huang Qichuang integrated the concepts of lower limb muscle strength at home and abroad, defining it as the body's ability to provide power by overcoming internal and external resistance through the coordinated participation of calf and thigh muscle groups in sports dominated by walking, running, and jumping. The lower limb strength mentioned in this paper mainly includes lower limb explosive power, maximum strength, and endurance.

2. Mechanism of Blood Flow Restriction

The main effects of BFR on limbs are reduced arterial blood flow and venous blood accumulation, leading to a relatively ischemic and hypoxic state in the limbs (Yasuda et al., 2010). As metabolic products such as lactate cannot be effectively cleared during this process (Teixeira et al., 2017; Yasuda et al., 2014), the level of metabolic stress significantly increases.

Based on this, different scholars have explained the mechanism of BFRT from various perspectives, involving aspects such as hormone secretion, protein synthesis and inhibitory synthesis regulation, muscle fiber recruitment, and cell swelling.

3. Research Status at Home and Abroad

Foreign Studies

Originating in Japan in the 1980s, Blood Flow Restriction Training (BFRT) has attracted extensive attention in the field of exercise science in recent years. Its core mechanism involves partially blocking limb blood flow through external pressure devices (such as inflatable cuffs) and combining low-intensity exercise to induce muscular adaptive changes. In comparative studies on the effects of resistance training, compared with traditional high-intensity resistance training (HIRT, ≥70% 1RM), five out of six controlled trials have confirmed that low-intensity BFRT (≤40% 1RM) is equivalent to high-intensity training in key indicators such as muscle strength gain, myofibrillar hypertrophy, and exercise performance improvement (Tollefson et al., 2024).

Especially in the field of physical fitness enhancement for endurance athletes, multiple studies have shown that BFRT can significantly improve athletes' strength, explosive power, speed endurance, and body composition by regulating local ischemia-reperfusion stimulation, but has no significant effect on absolute body weight (Yang et al., 2024). This "low-load-high-benefit" training characteristic makes it an ideal solution for endurance athletes to optimize lower limb strength—it can avoid excessive weight gain caused by high-intensity training (to prevent affecting the weight-power ratio required for endurance events) and promote muscle fiber type transformation (type I to type IIa) through the synergistic effect of metabolic pressure and mechanical tension.

Optimization studies on training parameters further indicate that when the training frequency is ≥3 times/week, the cuff pressure is maintained at 160–200 mmHg (close to 80% of the occlusion pressure), and the single pressurization time is 10–15 minutes, BFRT exhibits the most significant improvement effect on physical fitness parameters (Yang et al., 2024). It is noteworthy that even elite athletes with more than five years of training experience and a high level of athletic performance can still gain strength from BFRT and break through the traditional training plateau (Davids et al., 2023), which provides empirical support for the application of this training model among high-level athletes.

However, existing studies mainly focus on short-term interventions and general athlete populations, leaving a research gap in the long-term effects of BFRT on mass elite half-marathon athletes—a special group with distinct training needs. Half-marathon running places extremely high demands on lower limb muscle endurance, buffering capacity, and energy metabolism efficiency, often facing the contradiction between "high-intensity training loads and fatigue accumulation" during training cycles. Whether BFRT can reduce traditional resistance training loads (e.g., decreasing training intensity by over 50%) while continuously maintaining and enhancing lower limb strength (e.g., eccentric contraction strength, jumping stiffness), thereby improving athletic performance (e.g., pace stability, finishing sprint capacity), has not yet formed a systematic conclusion.

Additionally, whether the training adaptation characteristics of this population (e.g., higher proportion of slow-twitch muscle fibers, injury risks concentrated in patellar/Achilles tendons, etc.) affect BFRT efficacy, and the potential impact of long-term BFRT application on core endurance indicators such as running economy and maximal oxygen uptake utilization, all require further empirical research. Although existing evidence confirms BFRT's role in strength maintenance, the specific adaptation mechanisms for half-marathon-specific performance still need in-depth exploration through long-term controlled trials.

Domestic Research

Domestic research in the field of Blood Flow Restriction Training (BFRT) started relatively late, with early explorations mainly focused on the category of rehabilitation medicine. In clinical practice, this technology has been gradually applied to functional reconstruction after sports injuries, such as progressive activation training for muscle groups after knee joint surgery (Liu et al., 2017), and interventional treatment for sarcopenia in the elderly, which promotes muscle protein synthesis and improves limb mobility in the elderly through low-intensity pressure load stimulation (Kong et al., 2024).

In the field of competitive sports research, existing literature mostly focuses on events such as sprinting and ball games. Studies on sprint athletes have shown that BFRT combined with low-load resistance training can significantly improve the recruitment efficiency of lower limb fast-twitch muscle fibers and enhance explosive force output (Zhang et al., 2022). In ball games, relevant research focuses on the improvement effects of upper limb racket swinging strength or lower limb direction-changing stability, confirming the positive role of this training model in enhancing the functional strength of specific muscle groups (Yan & Guo, 2018).

It is worth noting that there is a clear blind spot in the coverage of sports events in current research: as representatives of endurance sports, marathon and half-marathon events have not been systematically explored for the adaptability between the required lower limb continuous force generation ability, muscle endurance maintenance mechanism, and the existing BFRT action targets. Especially for the special group of "mass elites"—this group has both the training autonomy of amateur enthusiasts and quasi-professional performance pursuit. There are significant differences in the fatigue resistance mechanism and strength decay law of their lower limb muscles during long-distance exercise compared with professional athletes. However, there is no research on the application of BFRT for this population at home and abroad so far.

4. Theoretical Basis of the Study

Rationale for Applying Strength Training to Long-distance Runners

Running economy (RE) refers to the energy demand for maintaining a specific submaximal running speed. Together with maximal oxygen uptake (VO_2max) and anaerobic threshold (AT), it accounts for 70% of the variance in long-distance running performance (Midgley et al., 2007). RE serves as an important indicator for evaluating the aerobic capacity of general-level long-distance runners (Jones & Carter, 2000) and a key metric for distinguishing performance among high-level athletes (Denadai et al., 2017).

Numerous factors influence RE, including morphological, physiological, biomechanical, and environmental aspects. However, based on the characteristics of exercise energy production and utilization efficiency, these factors can be roughly categorized into internal and external causes. Internal causes refer to the efficiency of energy generation per unit of oxygen consumption, which is primarily related to the function of skeletal muscle mitochondria. External causes refer to the efficiency of converting unit energy into running mechanical work, mainly associated with the human body's utilization of ground reaction forces. Therefore, enhancing functional economy during running from both internal and external perspectives forms the main basis for RE training design (Gao et al., 2019).

There are many training methods used to enhance RE, typically including endurance running training, altitude training, and strength training. Although endurance running training can effectively increase the volume and function of skeletal muscle mitochondria, optimize blood components, and improve buffering capacity, the training cycle is relatively long, and it generally takes 14 to 20 weeks to observe significant improvements in athletes' RE (Barnes & Kilding, 2015). Altitude training at 2,000 to 4,500 meters above sea level can shorten the time (2 to 5 weeks) for adaptive changes in blood components, cardiovascular function, and metabolic efficiency through hypoxic stimulation (Gore et al., 2007; Saunders et al., 2009), but there are certain difficulties in implementing such training. In comparison, strength training can effectively improve the level and coordination of motor unit recruitment, enhance the efficiency of the muscle stretch-shortening cycle (SSC) (Yamamoto et al., 2008), and increase the level of elastic energy storage and release (Fouré et al., 2010). It not only promotes functional economy from the perspective of external causes but is also simple to implement and has a relatively short effective period (4 to 14 weeks) (Barnes & Kilding, 2015), thus showing greater application prospects. Some scholars also suggest that middle- and long-distance runners should try to intersperse explosive strength training during training to improve their running economy by enhancing the work efficiency of the SSC (Ren, 2010).

Rationale for Applying Blood Flow Restriction Training to Long-distance Runners

Exercising with BFR induces an enhanced training stimulus (beyond the same exercise performed alone), promoting molecular signaling related to steady-state disturbance and endurance adaptation. This greater stimulus appears to induce enhanced physiological adaptations, including increased muscle capillary supply and mitochondrial function, which contribute to improved endurance performance (Ferguson et al., 2021).

Although not typically associated with endurance adaptation, growing evidence suggests that combining low-load resistance exercise (LLRE, with a load of 20% of one-repetition maximum [1RM]) with BFR can enhance endurance-related signaling responses and physiological adaptations. Evaluation of the main signals for angiogenesis and mitochondrial biogenesis has shown that phosphorylation of p38 mitogen-activated protein kinase (p38MAPK) is higher after low-load resistance exercise (LLRE) with blood flow restriction (BFR) compared to LLRE without BFR with matched work (Ferguson et al., 2018). Similar levels of p38MAPK phosphorylation were observed after LLRE with BFR (at 30% of 1RM) compared to high-load resistance exercise (HLRE, at 70% of 1RM) (Groennebaek et al., 2018). Although the activities of adenosine monophosphate-activated protein kinase (AMPK) and calmodulin kinase II (CaMKII) did not change, phosphorylation of acetyl-CoA carboxylase (ACC), a downstream target of AMPK, increased to a similar extent after both LLRE with BFR and HLRE (Groennebaek et al., 2018).

Further studies have shown that when LLRE is combined with BFR, there is a greater increase in the content of skeletal muscle messenger ribonucleic acid (mRNA) related to angiogenesis and mitochondrial biogenesis. At 4 hours after LLRE with BFR (loaded at 40% of 1RM), increased mRNA content of vascular endothelial growth factor (VEGF), vascular endothelial growth factor receptor-2 (VEGFR-2), hypoxia-inducible factor-1α (HIF-1α), and neuronal nitric oxide synthase (nNOS, i.e., NOS1) was observed (Larkin et al., 2012). The magnitude of these increases was significantly higher than that induced by LLRE alone. In the same study, 24 hours after exercise, the mRNA content of VEGF, VEGFR-2, and nNOS remained elevated following exercise with BFR. Ferguson et al. (2018) also made similar observations, where higher mRNA content of VEGF, VEGFR-2, HIF-1α, endothelial nitric oxide synthase (eNOS), and peroxisome proliferator-activated receptor γ coactivator-1α (PGC-1α) was found after LLRE with BFR compared to work-matched LLRE without BFR.

The long-term effects of low-load resistance exercise with blood flow restriction (LLRE+BFR) on capillary growth and mitochondrial adaptation remain to be fully studied. Indirect assessments of microvascular filtration capacity have shown that skeletal muscle capillarization increases in healthy men after LLRE+BFR compared to work-matched exercise without BFR (Evans et al., 2010; Hunt et al., 2013). Recent studies have confirmed that LLRE+BFR enhances muscle capillary density. In elite powerlifters, the number of capillaries around type I muscle fibers increased after 6.5 weeks of high-frequency (daily) LLRE+BFR (loaded at ~30% 1RM), whereas no increase was observed after LLRE alone (Bjørnsen et al., 2018). Compared to work-matched non-BFR exercise, three weeks of high-frequency (1–2 sessions daily) LLRE+BFR to failure (20% 1RM) increased the capillary-to-fiber ratio (~23% increase) and capillary area (~30% increase) (Nielsen et al., 2020). These adaptive changes were accompanied by proportional increases in muscle fiber area (Nielsen et al., 2012), maintaining stable capillary density (capillaries per unit muscle cross-sectional area). The capillarization response to short-term (~3 weeks) BFR training is remarkable, as skeletal muscle capillary supply typically requires longer training durations (4–6 weeks) to increase (Klausen et al., 1981). Muscle capillary supply also increases after longer-term BFR interventions with lower training frequencies. After six weeks of LLRE+BFR to failure (30% 1RM, three sessions weekly), the number of capillaries in contact with type I fibers increased (Pignanelli et al., 2020). Although similar changes were observed after non-BFR LLRE (also to failure), the training volume was ~33% lower with BFR, highlighting the efficiency of BFR exercise (Pignanelli et al., 2020).

In healthy untrained men, the mitochondrial adaptive effects of 6-week low-load resistance exercise (LLRE) with blood flow restriction (BFR) at 30% 1RM and high-load resistance exercise (HLRE) at 70% 1RM were compared (Groennebaek et al., 2018). Mitochondrial biogenesis (assessed via fractional synthesis rates of mitochondrial proteins using heavy water (D2O) enrichment) and maximal coupled respiration increased similarly after BFR training and HLRE alone. This indicates that adding BFR can elicit adaptive changes similar to HLRE at much lower loads, although citric acid synthase activity did not change under both interventions in the same study. Conversely, after 6 weeks of LLRE with BFR at 30% 1RM to failure, mitochondrial respiratory function showed no change, while significant increases were observed in legs trained without BFR (Pignanelli et al., 2020). However, legs without BFR completed approximately 30% more total work than BFR-trained legs, which may explain the stronger mitochondrial adaptation in non-BFR legs (Granata et al., 2018). Therefore, BFR may enable LLRE to produce mitochondrial adaptations comparable to HLRE only when the total work done under control conditions does not exceed that under BFR conditions.

These studies suggest that combining BFR with LLRE provides a stronger stimulus for increasing muscle capillary supply and mitochondrial biogenesis despite reduced training loads.

D. Conclusion

As an innovative training modality, Blood Flow Restriction Training (BFRT) demonstrates significant potential in enhancing lower limb strength and improving athletic performance among endurance athletes. By inducing metabolic stress and mechanical tension through blood flow restriction, BFRT enables muscle strength gains and muscle fiber type transformation comparable to high-intensity training under low loads, while avoiding issues such as weight gain and recovery stress associated with traditional high-intensity training. Studies at home and abroad have preliminarily confirmed the effectiveness of BFRT in resistance training outcomes, physical parameter improvement, and molecular adaptation mechanisms. However, research on the specific population of elite half-marathon runners remains unexplored.

Future research should focus on the following directions: First, conduct long-term BFRT intervention studies on mass elite half-marathon athletes to explore its impacts on core indicators such as lower limb strength (e.g., eccentric contraction strength, jumping stiffness), running economy, and maximal oxygen uptake utilization. Second, analyze the correlation between the training adaptation characteristics of this population (e.g., slow-twitch muscle fiber ratio, injury-prone sites) and BFRT efficacy, and optimize training parameters (e.g., pressure level, training frequency, duration). Third, deeply explore the synergistic effects of BFRT and endurance training, and construct a composite training model of "low-load strength training + endurance training" to provide scientific solutions for addressing the contradiction of "training load and fatigue accumulation" among mass elite runners. In addition, combining molecular biology techniques to further reveal the specific adaptation mechanisms of BFRT in angiogenesis, mitochondrial biogenesis, and other aspects will lay a more solid theoretical foundation for the widespread application of this training model.

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