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Research Review on the Applicability of Blood Flow Restriction Combined with Low - intensity Resistance Training for Half - Marathon Runners

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ABSTRACT

Driven by the dual strategies of national fitness and building a sports - power country, the half - marathon sport is developing in a large - scale and professional manner. The group of popular elite half - marathon runners is constantly growing. However, this group generally faces problems such as good aerobic capacity but insufficient lower - limb strength and speed ability, fragmented training time, and a high risk of injury from high - intensity strength training. Blood flow restriction combined with low - intensity resistance training (LL - BFRT), characterized by "low load, high neuromuscular adaptation", can enhance muscle strength without the need for professional equipment, providing a new approach to address the training pain points of popular elite half - marathon runners. This paper reviews the mechanism of action of LL - BFRT, its research status at home and abroad, analyzes the theoretical basis and practical adaptability of LL - BFRT for this group in combination with the specific characteristics of the half - marathon sport, explores the key points of its application scheme design, and finally points out the current research deficiencies and future directions. The aim is to provide a theoretical reference for the application of LL - BFRT in half - marathon training.

KEYWORDS

Blood Flow Restriction Training; Low - intensity Resistance Training; Half - Marathon; Popular Elite Athletes; Lower - limb Strength; Running Economy

1. INTRODUCTION

Marathon and half - marathon are benchmark events that deeply integrate national fitness and competitive sports. According to the data in the "2024 China Road Running Event Blue Book", in 2024, there were 442 half - marathon events nationwide, with a participation scale of 2,996,900 person - times. Among them, the number of popular elite runners whose performance exceeded 1 hour and 30 minutes was over 38,000, an increase of 48.5% compared to 2023 [1, 2]. The half - marathon event requires athletes to have high - level aerobic capacity, lower - limb strength, core strength, and speed ability. Lower - limb strength is not only the core to maintain running pace stability, improve uphill and sprinting abilities, but also crucial for preventing sports injuries.Traditional lower - limb strength training mostly adopts medium - to - low - intensity resistance training at 20% - 50% of one - repetition maximum (1RM), which needs to be carried out with the support of professional gym equipment. However, popular elite runners need to balance work and aerobic training, making it difficult to ensure regular time for equipment - based strength training. High - intensity resistance training, on the other hand, is likely to cause muscle fatigue and joint injuries, which may affect regular endurance training. Blood flow restriction training (BFRT) was first applied in the rehabilitation field. LL - BFRT, as a combination of BFRT and low - intensity resistance training, can induce significant neuromuscular adaptations through a small exercise load. The effect of muscle strength enhancement is close to that of high - intensity training, and it has the advantages of convenience and low injury risk, meeting the training needs of popular elite half - marathon runners [3]. Currently, most research on LL - BFRT focuses on explosive - power events, while research on endurance events such as the half - marathon remains blank. Systematically reviewing the mechanism of action and application adaptability of LL - BFRT is of great significance for filling the research gap in this field and guiding the training practice of popular elite runners.

2. CORE MECHANISMS OF BLOOD FLOW RESTRICTION COMBINED WITH LOW - INTENSITY RESISTANCE TRAINING

LL - BFRT uses an external pressurization device to restrict arterial blood flow in the limbs and block venous return, putting the limbs in a state of local ischemia and hypoxia, which leads to the accumulation of metabolites. Subsequently, it induces muscle adaptation changes through multiple pathways. Its core mechanisms can be summarized into the following four aspects:

2.1. Regulation of Anabolic Hormone Secretion

The increased secretion of anabolic hormones such as growth hormone (GH) and insulin - like growth factor 1 (IGF - 1) after strength training is an important driving factor for muscle hypertrophy [4]. The local ischemia and hypoxia caused by LL - BFRT lead to the massive accumulation of metabolites such as lactic acid, reducing the pH value of the internal environment. This stimulates the pituitary gland to release GH through the chemosensitive reflex of group III and IV afferent nerves [5]. Research by Takarada et al. confirmed that after 20% 1RM BFRT knee - extension training, the GH concentration of the subjects reached 290 times that of the resting state [6]. GH can then stimulate the liver to release IGF - 1, further enhancing muscle anabolism [7]. Although Mitchell et al. did not find significant changes in the concentrations of GH and IGF - 1 after BFRT and suggested that the change in IGF - 1 might be related to plasma concentration [8], most studies support that LL - BFRT can promote muscle growth through hormone - secretion regulation, laying the foundation for muscle - strength enhancement.

2.2. Two - way Regulation of Protein Synthesis and Degradation

The mammalian target of rapamycin (mTOR) is the core regulatory pathway for skeletal muscle growth. LL - BFRT can activate ribosomal S6 kinase 1 (SK61), a downstream effector of mTOR, to promote the initiation and elongation of protein translation, while inhibiting protein hydrolysis [9, 10]. In addition, the ischemic and hypoxic environment caused by LL - BFRT can induce an increase in the expression of heat - shock protein 72 (HSP72). HSP72 can inhibit the muscle - atrophy signaling pathway, reduce protein degradation, and prevent muscle atrophy [11, 12]. Nitric oxide (NO) also plays a key role in the regulation of protein synthesis in LL - BFRT. During exercise, an increase in intracellular Ca^{2+} concentration or blood reperfusion activates neuronal nitric oxide synthase (NOS - 1). The generated NO can directly activate the mTOR pathway and, at the same time, activate satellite cells by synthesizing hepatocyte growth factor (HGF), promoting muscle - fiber hypertrophy [13, 14]. On the other hand, LL - BFRT can reduce the expression of myostatin. Laurentino et al. divided the subjects into a BFRT group (20% 1RM), a high - intensity training group (80% 1RM), and a low - intensity control group (20% 1RM). After 8 weeks of training, the myostatin expression in only the BFRT group and the high - intensity group decreased by 45% and 41% respectively, confirming that LL - BFRT can promote the shift of protein balance towards synthesis by inhibiting the negative regulatory effect of myostatin [15].

2.3. Improvement of Muscle - fiber Recruitment Efficiency

According to the "size principle" of muscle - fiber recruitment, slow - twitch muscle fibers are recruited first during muscle movement, and as the exercise intensity increases, high - threshold fast - twitch muscle fibers are gradually recruited [16]. The accumulation of metabolites caused by LL - BFRT can quickly induce neuromuscular fatigue through metabolic stimulation or cross - bridge - cycle inhibition, forcing the body to recruit more high - threshold fast - twitch muscle fibers in advance and increasing the degree of muscle - fiber activation [17, 18]. Electromyogram studies have shown that the muscle - discharge frequency and amplitude of the low - intensity BFRT group are significantly higher than those of the low - intensity control group without blood - flow restriction [19, 20], confirming that LL - BFRT can enhance muscle - fiber recruitment efficiency. Although Cook et al. did not find this difference [21], the mainstream view is that the increase in muscle - fiber recruitment is an important mechanism for LL - BFRT to achieve muscle - strength enhancement at a low load.

2.4. Cell - swelling Effect

Loenneke et al. proposed that the pressure gradient formed by the accumulation of metabolites in LL - BFRT causes blood to flow into muscle fibers, leading to cell swelling [22]. Cell swelling can not only directly promote protein synthesis but also reduce intracellular protein hydrolysis [23]. Existing studies have confirmed the presence of muscle swelling after BFRT exercise [24, 25], but the direct relationship between cell swelling and protein hydrolysis and muscle growth still needs further verification, and this mechanism remains a supplementary direction in LL - BFRT research.In summary, the muscle - adaptation mechanism of LL - BFRT is centered around metabolic stress. It regulates protein synthesis and degradation through pathways such as hormone secretion, muscle - fiber recruitment, and cell swelling, ultimately achieving muscle - strength enhancement at a low load.

3. RESEARCH STATUS OF BLOOD FLOW RESTRICTION COMBINED WITH LOW - INTENSITY RESISTANCE TRAINING

3.1. Foreign Research Status

BFRT originated in Japan in the 1980s. Foreign research has confirmed that low - intensity BFRT (≤40% 1RM) has a comparable effect to high - intensity resistance training (≥70% 1RM) in terms of muscle - strength growth and muscle hypertrophy [26]. In the field of endurance athletes, research shows that BFRT can improve athletes' strength, explosive power, and speed endurance without causing excessive weight gain, which meets the requirements of endurance events for the "weight - to - power ratio" [27]. Research on training - parameter optimization shows that when the training frequency is ≥ 3 times per week, the cuff pressure is maintained at 160 - 200 mmHg (about 80% of the arterial occlusion pressure), and the single - time pressurization time is 10 - 15 minutes, the physical - fitness improvement effect of BFRT is the most significant [27]. Even elite athletes with more than 5 years of training experience can break through the traditional training plateau through BFRT [28]. However, existing research still has limitations: first, it focuses on short - term intervention effects, and the long - term safety and effectiveness of long - term application remain unclear; second, there is a lack of specific research on popular elite half - marathon runners. Whether the characteristics of this group, such as a high proportion of slow - twitch muscle fibers and a concentrated injury risk in the patellar tendon/achilles tendon, affect the BFRT effect still needs to be verified; third, there is insufficient research on the mechanisms by which LL - BFRT improves core endurance indicators such as running economy and maximum oxygen - uptake utilization rate.

3.2. Domestic Research Status

Domestic research on BFRT started relatively late. Early research focused on the field of rehabilitation medicine, such as the functional reconstruction of muscle groups after knee - joint surgery [29], the intervention of sarcopenia in the elderly [30], etc., confirming that low - intensity pressure loads can promote muscle - protein synthesis and improve limb mobility. In the field of competitive sports, research mostly focuses on sprinting and ball games. For example, research on sprinters shows that BFRT combined with low - load resistance training can improve the recruitment efficiency of lower - limb fast - twitch muscle fibers and enhance explosive power [31]. Research on ball games focuses on the improvement of upper - limb racket - swinging strength and lower - limb change - of - direction stability [32]. The current core gaps in domestic research are as follows: first, research on BFRT in endurance events such as the half - marathon is almost non - existent, and training parameters have not been explored in combination with the specific needs of this event; second, there is a lack of research on the "popular elite" group. This group has both the training autonomy of amateur enthusiasts and the performance pursuit of quasi - professional levels. Their training - adaptation characteristics are different from those of professional athletes, and existing research cannot meet their training needs; third, there is a lack of a standardized LL - BFRT training program, which makes it difficult to guide the practical applications of grassroots coaches and popular runners.

4. THEORETICAL AND PRACTICAL BASIS FOR THE APPLICABILITY OF LL - BFRT TO POPULAR ELITE HALF - MARATHON RUNNERS

4.1. Core Basis for Improving Running Economy

Running economy (RE) is a key indicator for evaluating the aerobic capacity of long - distance runners. It refers to the oxygen consumption at a specific running speed under sub - maximal load and can explain 70% of the variation in half - marathon performance [33]. The factors affecting RE include the function of skeletal - muscle mitochondria (internal factor) and the utilization efficiency of ground - support reaction force (external factor). LL - BFRT can improve RE from both internal and external aspects:Externally, LL - BFRT can improve the coordination of motor - unit recruitment, enhance the working efficiency of the muscle stretch - shortening cycle (SSC), increase the level of elastic - energy storage and release, and reduce energy loss during running [34, 35]. Internally, LL - BFRT can activate downstream targets of p38 mitogen - activated protein kinase (p38MAPK) and adenosine monophosphate - activated protein kinase (AMPK), such as acetyl - CoA carboxylase (ACC), and promote the increased expression of mRNA of vascular endothelial growth factor (VEGF), hypoxia - inducible factor - 1α (HIF - 1α), etc., accelerating capillary angiogenesis and mitochondrial biogenesis [36, 37]. Research has confirmed that after LL - BFRT, the number of capillaries in skeletal muscle increases by 23%, the capillary area increases by 30%, and the level of mitochondrial biogenesis is equivalent to that of high - intensity training at 70% 1RM [37, 38], significantly improving the function of skeletal - muscle mitochondria and oxygen - utilization efficiency.

4.2. Adaptation to the Training Characteristics of Popular Elite Runners

The core training pain points of popular elite half - marathon runners are "fragmented training time" and "high injury risk", and LL - BFRT can address these problems accordingly: first, it does not require professional equipment and can carry out body - weight - based training through portable elastic pressure bandages, which is suitable for scenarios such as home and playgrounds, fitting the fragmented - training - time characteristics of runners; second, the training load is low (body weight or ≤40% 1RM), and the pressurization pressure is controlled at 50% of the arterial occlusion pressure (significantly lower than the clinical safety threshold of 80%), reducing the risk of muscle soreness and joint injuries and avoiding affecting regular endurance training; third, the training efficiency is high. Eight - week LL - BFRT can significantly improve lower - limb strength, and the training frequency only needs to be twice a week, 50 - 60 minutes each time, with a much lower time cost than traditional equipment - based training.

4.3. Targeted Enhancement of Lower - limb Specific Strength

The lower - limb strength requirements of half - marathon runners cover explosive power, maximum strength, and muscle endurance. LL - BFRT can achieve multi - dimensional improvements: by activating the recruitment of fast - twitch muscle fibers, it can improve explosive - power indicators such as 30 - meter running and standing vertical jump reach; by regulating protein synthesis to increase muscle mass, it can improve maximum - strength indicators such as 1RM squat; through capillary hyperplasia and improvement of mitochondrial function, it can enhance lower - limb muscle endurance and reduce strength attenuation during long - distance running [38]. In addition, LL - BFRT can strengthen the lower - limb buffering ability, reduce the ground impact force on joints during running, and reduce the risk of common injuries such as patellar tendinitis and achilles tendinitis .

5. APPLICATION SCHEME DESIGN OF LL - BFRT FOR POPULAR ELITE HALF - MARATHON RUNNERS

Based on existing research and the specific characteristics of the half - marathon, the application scheme of LL - BFRT needs to focus on core dimensions such as pressurization parameters, training load, action selection, and cycle arrangement. The specific design points are as follows:

5.1. Setting of Pressurization Parameters

Pressurization device and width: A wide bandage (13.5 cm) is preferred. Compared with a narrow cuff (5 cm), the wide bandage can more effectively restrict arterial blood flow at low pressure, and the pressure distribution is more uniform, reducing the risk of local compression injury [39, 40].

Pressurization position: For lower - limb pressurization, choose the inguinal fold or above the middle of the thigh. The arteries and veins in this area are close to the body surface, and the pressurization effect is more significant [41].

Pressure value: Use a subjective perception scale (0 - 10 points) to control the pressure. A score of 7 (moderate tightness, no pain) is appropriate, which can block venous return without significantly restricting arterial inflow, ensuring training safety [42].

5.2. Training Load and Mode

Load intensity: Conduct training with a body - weight load. When the last set is close to exhaustion, a small amount of external assistance can be provided to avoid movement deformation.

Training actions: Select lower - limb actions that are specific to the half - marathon, including lunge squats, squats, lunge jump - leg exchanges, squat jumps, single - leg straight - knee calf raises, double - leg bent - knee calf raises, and wall - toe - pointing, covering the muscles around the hip, knee, and ankle joints.

Inter - set arrangement: Seven actions form a set, with a total of 3 sets. The interval between actions within a set is 30 seconds, and the interval between sets is 120 seconds. The total pressurization time for a single training session should not exceed 20 minutes to avoid discomfort caused by excessive ischemia time.

5.3. Cycle and Frequency Arrangement

Training frequency: Twice a week (e.g., on Monday and Friday), with an interval of ≥ 24 hours from regular endurance training to avoid over - fatigue.

Training cycle: An 8 - week "adaptation - enhancement" cycle is in line with the muscle - adaptation law and will not cause training burnout due to an overly long cycle.

6. RESEARCH DEFICIENCIES AND FUTURE PROSPECTS

6.1. Current Research Deficiencies

Firstly, there is a lack of specialized research. Existing studies on LL - BFRT have not integrated the specific characteristics of the half - marathon. As a result, the training parameters such as pressurization duration and exercise selection are inadequately tailored to this particular event. Secondly, the scope of research subjects is limited. Most current research focuses on healthy males and professional athletes. There is a shortage of research on popular elite runners (non - registered and non - sports - major), and the training adaptation characteristics of female runners have not been taken into account. Thirdly, the long - term effects remain unclear. Most existing research involves short - term interventions within 8 weeks, and the impacts of long - term application of LL - BFRT (e.g., over 6 months) on muscles and blood vessels are yet to be determined. Fourthly, the research on mechanisms is not in - depth. The molecular mechanisms by which LL - BFRT improves running economy, such as long - term changes in mitochondrial function and capillary proliferation, still need further verification.

6.2. Future Research Directions

Firstly, conduct specialized intervention research. In combination with the training cycles of the half - marathon (base period, competition period, recovery period), optimize the training parameters of LL - BFRT and develop standardized training guidelines for each cycle. Secondly, expand the scope of research subjects. Include popular elite runners of different genders, ages, and training levels to analyze the influence of group differences on the effects of LL - BFRT. Thirdly, explore the safety and effectiveness of long - term application. Track the intervention effects of LL - BFRT over 6 months and monitor the physiological index changes of blood vessels and muscles. Fourthly, deepen the research on mechanisms. Use molecular biological methods to analyze the impacts of LL - BFRT on the mitochondrial function of skeletal muscles and the transformation of muscle fiber types, and clarify the core pathways through which it improves running economy. Fifthly, promote the transformation of research results. Translate the research findings into simplified training manuals to guide popular elite runners to independently carry out LL - BFRT and enhance the operability of training.

7. CONCLUSION

LL - BFRT is characterized by "low load, high return, low risk, and high convenience". Its mechanism of action encompasses multiple dimensions such as regulation of hormone secretion, adjustment of protein synthesis, enhancement of muscle fiber recruitment, and the cell - swelling effect. It can effectively improve lower - limb strength and running economy, meeting the training needs of popular elite half - marathon runners. Current research at home and abroad has confirmed the effectiveness of LL - BFRT in muscle strength improvement. However, specialized research on the half - marathon remains in its infancy. In the future, efforts should be focused on designing specialized training programs, verifying long - term effects, and deepening the understanding of mechanisms, so as to promote the transition of LL - BFRT from theoretical research to practical application. This will provide a new paradigm for the strength training of popular elite half - marathon runners, helping this group break through performance bottlenecks and reduce the risk of injuries.

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The work described has not been submitted elsewhere for publication, in whole or in part, and the authors claim that none of the material in the paper has been published or is under consideration for publication elsewhere.

Authors' contributions

Conceptualization, Junjie Xiao; methodology, Junjie Xiao; software, Junjie Xiao; check, Daoling Fu; formal analysis, Junjie Xiao; investigation, Junjie Xiao; resources, Junjie Xiao; data curation, Junjie Xiao; writing - rough preparation, Junjie Xiao; writing - review and editing, Junjie Xiao; visualization, Junjie Xiao; supervision, Daoling Fu; project administration, Junjie Xiao; receiving funding, Daoling Fu. All authors have read and agreed with the published version of the manuscript.

Ethics Statement:

Our study did not require an ethical board approval because it did not contain human or animal trials.

Availability of Data and Materials

The datasets of the current study are available from the corresponding author on reasonable request.

Conflict of Interest:

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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