

An Updated Panorama of Blood-Flow-Restriction Methods

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Background: Exercise with blood-flow restriction (BFR) is being increasingly used by practitioners working with athletic and clinical populations alike. Most early research combined BFR with low-load resistance training and consistently reported increased muscle size and strength without requiring the heavier loads that are traditionally used for unrestricted resistance training. However, this field has evolved with several different active and passive BFR methods emerging in recent research. **Purpose:** This commentary aims to synthesize the evolving BFR methods for cohorts ranging from healthy athletes to clinical or load-compromised populations. In addition, real-world considerations for practitioners are highlighted, along with areas requiring further research. **Conclusions:** The BFR literature now incorporates several active and passive methods, reflecting a growing implementation of BFR in sport and allied health fields. In addition to low-load resistance training, BFR is being combined with high-load resistance exercise, aerobic and anaerobic energy systems training of varying intensities, and sport-specific activities. BFR is also being applied passively in the absence of physical activity during periods of muscle disuse or rehabilitation or prior to exercise as a preconditioning or performance-enhancement technique. These various methods have been reported to improve muscular development; cardiorespiratory fitness; functional capacities; tendon, bone, and vascular adaptations; and physical and sport-specific performance and to reduce pain sensations. However, in emerging BFR fields, many unanswered questions remain to refine best practice.

Keywords: KAATSU, vascular occlusion, resistance training, aerobic exercise, muscle

Since the late 1990s, numerous studies have demonstrated that substantial improvements in muscle strength and size are possible using low-load resistance training if combined with wearing limb tourniquets or inflatable cuffs during exercise.¹ While the precise mechanisms are not known, these adaptations are likely facilitated by acute augmentation of metabolic stress, muscle fiber recruitment, and intramuscular signaling processes that result from restricting blood flow to and from the exercising musculature.² The consensus is that blood flow should be partially restricted rather than fully occluded when implemented during exercise,³ and so this technique is primarily referred to as “blood flow restriction” (BFR), regardless of whether it is applied passively or during exercise.

Considering the benefits for low-load BFR resistance training (BFR_{RT}), practitioners and scientists have implemented BFR combined with other exercise stimuli (eg, energy systems training or sports-specific activities), or even passively, to take advantage of the heightened physiological responses to BFR. The purpose of this commentary is to synthesize these evolving BFR methods across cohorts ranging from healthy athletes to clinical and load-compromised populations (Figure 1). These different BFR methods have been distinguished as “active” (ie, BFR combined with exercise training) or “passive” (ie, implementing BFR separate from exercise), and further categorized into methods which can be considered as “established” (ie, have substantial research to support their use) or “developing” (ie, potential benefits, but more evidence

needed). Additionally, we will highlight practical applications for BFR methods and areas requiring further research.

Active BFR Methods: Resistance Training Low-Load Resistance Training

The most heavily researched and established application of active BFR is in combination with low-load resistance training to improve muscular development. While heterogeneity exists in the protocols implemented, researchers generally agree that training with low loads (20%–40% 1-repetition maximum), moderate volumes (eg, 4 sets of 30/15/15/15 repetitions or sets to failure), and brief rest periods (30–60 s), combined with BFR at 40% to 80% of the pressure required to occlude arterial blood flow at rest (ie, the arterial occlusion pressure), results in substantial muscular adaptation.³ Increases in muscle size⁴ and strength⁵ following low-load BFR_{RT} have previously been reported as comparable to traditional high-load resistance training, though more recent analyses suggest that high-load training elicits greater muscular adaptations.⁶ Benefits for muscles proximal to the cuff have also been reported, with BFR during bench press increasing *pectoralis major* muscle thickness over a 2-week training intervention compared with unrestricted exercise.⁷ The benefits of low-load BFR_{RT} on muscular development have been demonstrated in cohorts ranging from healthy trained powerlifters⁸ to older people.⁹


Aside from improvements in muscle size and force-generating capacity, low-load BFR_{RT} has been shown to induce similar tendon hypertrophy to high-load unrestricted training.¹⁰ There is emerging evidence indicating that low-load BFR exercise can increase markers of bone formation,¹¹ while incorporating BFR during postsurgery rehabilitation training can attenuate bone loss.¹²

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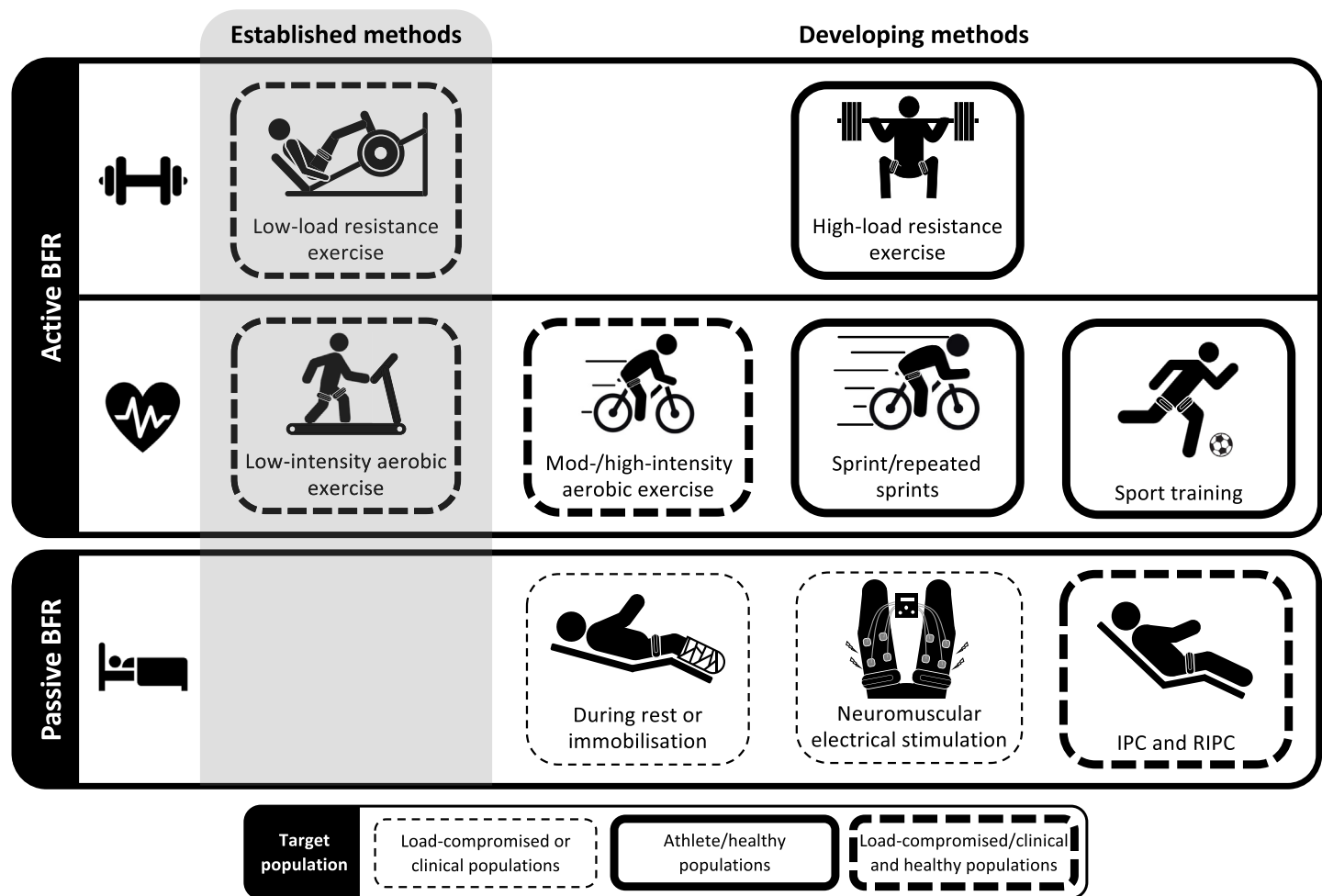


Figure 1 — Schematic overview of the BFR methods that have been developed and assessed in scientific literature. BFR indicates blood-flow restriction; IPC, ischemic preconditioning; Mod, moderate; RIPC, remote IPC.

Vascular adaptations have also been reported following BFR_{RT}.¹³ Interestingly, the effects of BFR on mRNA expression of hypoxia inducible factor-1 α and vascular endothelial growth factor seem more potent when combined with resistance than for aerobic exercise.¹³ Finally, a developing application of low-load BFR exercise is in reducing sensitivity to pain, with growing evidence suggesting that BFR exercise can increase pressure pain thresholds.¹⁴ The cuff pressure and whether or not exercise is performed to failure also impact the exercise-induced hypoalgesia.¹⁴

High-Load Resistance Training

Traditionally, high-load ($\geq 70\%$ 1-repetition maximum) resistance training is prescribed to athletes and healthy populations to increase muscle size and strength.¹⁵ Researchers have been interested in whether adding BFR to high-load resistance training might augment these training outcomes, as has been shown for low-load resistance training, for over 15 years.¹⁶ However, results for this approach have been equivocal, with a recent well-designed investigation of 49 healthy men finding no differences between BFR or control groups in muscle size or strength outcomes following an 8-week training program, despite an increase in metabolic stress with BFR.¹⁵

While there is little evidence that muscle size or strength are further improved by incorporating BFR during high-load resistance

training, a recent systematic review has reported some potential benefits.¹⁷ Adding BFR to high-load resistance exercise can acutely increase lifting velocity and post-BFR performance (ie, postactivation performance enhancement).¹⁷ However, further research is required in this area, with Tian et al¹⁷ reporting on only 3 studies, one of which observed BFR to negatively impact on performance.¹⁸

Active BFR Methods: Energy Systems Training

Low-Intensity Aerobic Training

Combining BFR with low-intensity aerobic training (BFR_{AT}) at intensities $< 50\%$ aerobic capacity or heart rate reserve³ has emerged as an innovative training modality that may combine the benefits of aerobic and resistance training. There is reasonable evidence demonstrating that BFR_{AT} can yield cardiovascular and muscular benefits in populations ranging from healthy young athletes to older adults.¹⁹ Improvements in functional capabilities have also been reported in older people.⁹ Other benefits may include acute improvements in executive function,²⁰ as well as significant local and systemic hypoalgesia effects.²¹ These benefits make BFR_{AT} an attractive option for various compromised

populations, including those who may not tolerate high-intensity exercises, traditional resistance training, or even BFR_{RT}.

Although BFR_{AT} is generally considered less perceptually and hemodynamically demanding than BFR_{RT},²² observed muscle hypertrophy and strength changes are superior to work-matched low-intensity aerobic training but inferior to BFR_{RT}.¹⁹ This is particularly beneficial for older adults, load-compromised populations, or individuals recovering from injury, as it can facilitate improvements in muscular strength, endurance, and functional capacity without imposing excessive stress on joints or the cardiovascular system.

Despite the growing body of evidence supporting the benefits of BFR_{AT} as an established training method, more work is needed to optimize the protocols used in research and practice. Existing literature on BFR_{AT} is characterized by considerable heterogeneity in terms of exercise modalities, cuff pressure, and training durations, making it challenging to determine the most effective approach for different populations and goals.¹⁹ However, as researchers continue to investigate BFR_{AT} using the personalized pressures which are currently recommended,³ a better understanding of protocols needed to attain the desired benefits from BFR_{AT} will be achieved.

Moderate- and High-Intensity Energy Systems Training

Recently, BFR has been examined during moderate- or high-intensity interval training (BFR_{IT}) as a developing method to exacerbate the physiological stimulus for adaptation. Moderate- to high-intensity running or cycling BFR_{IT} has been shown to improve leg muscle size and strength,²³ rate of force development,²⁴ maximal aerobic capacity²³ or its physiological determinants,²⁵ and anaerobic performance,²⁴ compared with unrestricted exercise. Applying BFR in the period immediately following each effort during sprint interval training (4–7 × 30-s sprints separated by 4.5-min rest) increases aerobic capacity compared with a non-BFR group.²⁶ While 2 weeks of repeated sprint training (10-s sprints with 20-s recovery) can improve aerobic and anaerobic performance, completing this training with BFR did not further improve these responses.²⁷ Practitioners should consider that higher intensity BFR training may exacerbate fatigue, which could negatively impact training quality or exercise tolerance if appropriate exercise prescription adjustments are not made.

Active BFR Methods: Sport Training

Performing sport-specific drills (eg, lunges in badminton) and activities (eg, small-sided games in team sports) with BFR has recently gained popularity, yet most of our knowledge comes from soccer and futsal.^{28–30} Combining BFR with small-sided games is an intervention to boost aerobic and anaerobic fitness, while simultaneously improving technical and tactical skills.²⁸ In semi-professional soccer players, for instance, sport-specific training with BFR to the legs improved lower body muscular endurance, change-of-direction ability, and aerobic and soccer-specific fitness.³⁰ Adding BFR to sport-specific training likely enhances muscle activation and hormonal responses without increasing training time.²⁹ Therefore, this approach may become useful during intense training periods in both uninjured (eg, preseason or training camps) and load-compromised (eg, rehabilitation settings) athletes. Potential drawbacks to this developing method include using faster fatigue development and “unnatural” movement patterns, requiring

exercise prescription adjustments (eg, exercise-to-rest ratios) so that training loads are carefully managed, and movement quality or technique is not sacrificed if important for sport-specific adaptations.

Passive BFR Methods

During Rest or Immobilization

Prolonged inactivity as a result of illness, injury, surgery, or aging often results in reduced muscle size and strength.³¹ While exercise can often be prescribed to minimize atrophy, scenarios such as immobilization following surgery can make exercise difficult or impossible. The use of passive BFR (BFR_P) has been found to reduce atrophy in elderly coma patients³² and provide a superior treatment to isometric training in healthy adults undergoing cast immobilization.³³ However, it should be noted that Iversen et al³⁴ were not able to replicate these findings in physically active individuals following anterior cruciate ligament reconstruction. Furthermore, a recent systematic review³¹ noted that while BFR_P is potentially useful to mitigate atrophy during limb disuse, studies in this area are at high risk of bias. Further research is warranted to confirm the efficacy of BFR_P for attenuating atrophy.

Neuromuscular Stimulation

Adding BFR to neuromuscular electrical stimulation (BFR_{NMES}) has been investigated as an approach to facilitate muscular development without voluntary contractions. Developing evidence suggests that BFR_{NMES} protocols performed with high training frequencies (twice daily, 5 d/wk for 2 wk) can result in greater improvements in muscle strength and hypertrophy compared with neuromuscular electrical stimulation alone.³⁵ This is attributed to BFR's ability to enhance metabolic stress induced by neuromuscular electrical stimulation, stimulating muscle protein synthesis. The combination of BFR and neuromuscular electrical stimulation may create a synergistic effect that enables muscle hypertrophy as a passive intervention. Although positive effects are not always reported,³⁶ this technique holds promise for attenuating muscle atrophy. It can be recommended for individuals experiencing disuse with significant muscle weakness and atrophy, notably to enhance muscle strength, muscle size, and functional capacity in athletes recovering from orthopedic injuries (eg, knee or hip replacement surgery, anterior cruciate ligament reconstruction) and immobilized populations (eg, prolonged bed rest).³⁷

Ischemic Preconditioning

Local (IPC) and remote ischemic preconditioning (RIPC) involves a protocol of repeated vascular occlusion and reperfusion. While the application of IPC and RIPC is similar to the use of BFR during rest or immobilization (aimed to reduce atrophy), the intended outcomes are quite different. The use of IPC is primarily targeted at improving subsequent exercise performance in occluded muscle groups, while RIPC is usually implemented remotely to reduce subsequent ischemic injury. A 2016 meta-analysis concluded that while findings have proven equivocal, IPC results in small improvements to aerobic exercise performance, with unclear effects on power and sprint performance, potentially confounded by inconsistent methodologies.³⁸ Performance enhancement is thought to be driven not only by vascular responses to IPC, but also a range of neurophysiological, and psychophysiological factors.³⁹

The use of RIPC has also been extensively investigated and successfully implemented in a range of clinical settings where several benefits for patients have been reported.⁴⁰ Nevertheless, some of these results have been questioned in a double-blind design,⁴¹ and RIPC in surgical settings remains a developing area of research.

Practical Applications and Future Directions

The increasing interest in BFR from researchers and practitioners has led to a variety of cuffs being manufactured, incorporating features such as autoregulation of BFR pressure that may alter the acute or longitudinal responses to BFR exercise. Practitioners should familiarize themselves with device features that may impact tolerability, efficacy, and/or safety of BFR exercise. It is recommended to implement relative pressures, within the range of 40% to 80% arterial occlusion pressure.³ However, there is no consensus on which relative pressure is best for different applications of BFR. The manipulation of BFR prescription parameters (eg, cuff type, dimensions, and pressure) may also impact adaptations or participant perceptions of exercise technique.⁴² As such, practitioners should consult with clients performing BFR to monitor the stimulus.

For athletic applications of BFR, coaches must consider that internal training loads are augmented despite similar or reduced external loads,⁴² which should be incorporated in the training monitoring framework. If well considered, BFR may have applications for in-season management of overuse injuries.⁴³ While BFR appears to induce positive effects on multiple tissue types and populations, varied protocols and methodological approaches challenge effect size estimates. Future research should integrate relative pressures to reduce existing heterogeneities and refine the optimal protocols to elicit desired adaptations to BFR methods. Finally, while serious adverse responses to BFR application are seldom reported if it is prescribed as per published guidelines,⁴⁴ more data are needed to confirm the safety of these BFR methods for populations ranging from healthy athletes to older and clinical populations.

Conclusions

The blood-flow-restriction (BFR) literature has expanded on early research incorporating low-load BFR resistance training to include other modalities (high-load BFR resistance training, BFR combined with energy systems training of varying intensities, or sporting activities, and several passive BFR methods; Figure 1). The desired outcomes of BFR interventions have also expanded, with studies demonstrating improvements in muscular development, cardiorespiratory fitness, functional capacities, tendon, bone, and vascular adaptations, physical and sport-specific performance, reduced pain sensations, and attenuations in disuse atrophy.

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