Blood Flow Restriction Therapy for the Upper Extremity: An Emerging Adjunct for Patient Recovery and Rehabilitation

T. Kyle Summers, MD, Matthew D. Smith, MD,
William J. Weller, MD*

KEYWORDS

• Blood flow restriction therapy • BFRT • Kaatsu • Low-intensity training • Low-load resistance • Limb occlusion

KEY POINTS

- Current blood flow restriction therapy (BFRT) literature is largely focused on the lower extremities.
- Some existing and emerging studies for the upper extremity show promising results.
- Standardization for BFRT application and therapy regimens need to be established.

INTRODUCTION

After an injury, whether treated operatively or nonoperatively, pain limitations, immobilization, or physician-directed restrictions inevitably lead to some degree of muscular atrophy and deconditioning of the affected extremity. Recovery and/or maintenance of prior muscle composition and strength are important to successful rehabilitation after an injury. In the past, heavy load exercises were considered standard for promoting strength and muscle mass.[1] It is largely accepted that to attain significant strength and increased muscle mass, lifting loads greater than 70% of a person's 1 repetition maximum (1-RM) for certain exercises is required.[2] In patients with injuries or postoperative protocols precluding heavy lifting, frail patients, or those with nonfunctioning extremities (eg, stroke victims or patients with neuromuscular disorders or nerve injuries), often this is not possible and may even be restricted by their treating physician. Blood flow restriction therapy (BFRT), often coupled with low-intensity training, fosters muscle recovery and has gained recognition as an alternative therapy to high-resistance training for its ability to produce similar effects on muscle strength and size.[3–10] Through this approach, training with a lower load intensity around 20% to 40% of a patient's 1-RM paired with BFRT yields those results.[4–6,11,12] This option is more practical for patients such as those previously mentioned with impediments to high-load exercises.

History

BFRT was developed in Japan in 1966 by Dr Yoshiaki Sato and referred to as Kaatsu training.[10–14] This was described in the literature by Eiken and Bjurstedt in 1987.[12] It is proposed that the Japanese words *ka* and *atsu* can be interpreted to mean added or additional pressure,[15] which describes the underlying mechanism through which BFRT exerts its effects.

Department of Orthopaedic Surgery and Biomedical Engineering, University of Tennessee Health Science Center - Campbell Clinic, 1211 Union Avenue, Suite 510, Memphis, TN 38104, USA
* Corresponding author.
E-mail address: wjweller@campbellclinic.com

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Abbreviations	
1-RM	1 repetition maximum
BFRT	blood flow restriction therapy
DVT	deep vein thrombosis
EMG	electromyography
EMGa	electromyographic amplitude
HLRT/LLRT	high-load and low-load resistance therapies
LL-BFRT	low-load resistance training with BFRT
LOP	limb occlusion percentages
RC	rotator cuff

Specifically, a tourniquet is applied to the proximal portion of the limb with the goal of occluding a certain, predetermined percentage of arterial inflow and complete venous outflow, creating an anaerobic environment that induces a hypertrophic response.[3,7,8,10,12–14,16–23] Hypertrophic changes are primarily attributed to mechanical tension during high-resistance exercise, but in the case of BFRT with low-resistance training, the mechanism is more elusive.[1] One proposed mechanism includes a synergistic coupling between mechanical tension and the ischemic environment, the latter of which leads to the accumulation of metabolites that initiates multiple signaling pathways (eg, mitogen-activated protein kinase and mammalian target of rapamycin complex1), increased hormone production and muscle protein synthesis (actin and myosin), increased fast-twitch muscle fiber recruitment, cellular swelling, and proliferation of satellite cells. All of these downstream effects have been implicated to some degree in the benefits produced by BFRT, but it is generally agreed upon that the exact mechanism needs further investigation.[1,3,5,9–11,13–17,24–27]

Existing BFRT literature largely describes its uses and results for the lower extremity. Articles detailing its application in the upper extremities are relatively sparse.[1,3,7,11,14,16,27] Although this review is focused on current applications and outcomes of BFRT in the upper extremity, it is important to highlight the documented primary benefits to the lower extremities and the added benefits to other areas of the body, all of which have inevitably led to adapted uses in the upper extremities. Meta-analyses have well established that low-load intensity exercises of the lower extremity coupled with BFRT leads to enhanced strength, muscle mass, and even improvements in perceived pain in patients undergoing rehabilitation.[2,3,11,12] Additionally, it has repeatedly shown promise for enhanced rehabilitation in other lower extremity, orthopedic pathologies including osteoarthritis of the knee, cruciate ligaments injuries, osteochondral fractures, myositis, sarcopenia, patellofemoral syndrome, Achilles ruptures, and other foot and ankle injuries as well as after knee arthroscopy.[3,9–12,21,23,28] Improved strength and muscle mass distal to the site of cuff application in the involved extremity have been routinely described, but added benefits outside of this have been identified and explored. Some studies have found that subjects also demonstrated increases in strength and muscle mass proximal to the site of cuff application.[1,6,7,9,12,16,25,26] It is theorized that this may be due to a systemic increase in hormone synthesis and neuronal activity.[1] A unique phenomenon resulting from BFRT is "cross education," in which adaptive changes are seen in the contralateral, or nonexercised, limb. It is proposed that during BFRT, the motor cortex activates muscles on the opposite side of the body; however, this is a debated finding.[1,18] Some studies have reported increases in electromyography (EMG) activity and motor potentials in the nonexercised limb when unilateral BFRT training is performed.[1] While cross education is still under investigation, a purported benefit is the ability to target and rehabilitate an untrainable limb in cases of patients with stroke or spinal cord injury.[1] The effects of BFRT on tendon and bone health also have been studied. Reviews suggest potential benefits of BFRT for strengthening and healing healthy and pathologic tendons, respectively.[3,7] Regarding bone health, increases in bone mineral density and bone formation and decreases in bone resorption have been seen.[17] Another debated and surprising potential effect of BFRT is improved cardiovascular health. Supplemental cardiovascular benefits have been reported in some studies; however, adaptation within the cardiovascular system secondary to BFRT are not well established and the literature is conflicting.[1,9,21] More studies are needed, but it is included here to ensure mention of all known possible secondary benefits. When it comes to applications and changes among men and women, similar improvements have been seen in muscular strength and endurance between the 2 groups after 6 weeks of BFRT.[29]

What is known about BFRT is largely based on studies aimed at therapy in the lower extremities. Authors posit the reason for this imbalance is related to the ease in which the lower

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extremity can be safely rehabilitated when compared with the upper extremity; the shoulder, elbow, and wrist, which contribute to wide ranges of motion and finite motor movements, are inherently more prone to injury.[1] The positive benefits seen in increased strength, muscle mass, endurance, and rehabilitation potential touted in the lower extremity literature coupled with the earlier listed secondary benefits have no doubt fueled its expanded utility in the upper extremity. Literature for BFRT application in the upper extremities is less established; however, an increasing number of studies are documenting the potential benefits of BFRT in this area. In the next section, we will discuss the findings of these studies.

Blood Flow Restriction Therapy in the Upper Extremity

Existing applications and outcomes of BFRT in the upper extremity is an expanding field with more data being added regularly. A large portion of studies and reviews are aimed at BFRT's role in chest and shoulder strengthening.[7,14,19,22,25,26] Lending to the growth in this area of literature is the observation that muscles proximal to the site of cuff application experience increases in strength and mass. Other studies and reviews detail the effects of BFRT distal to the site of cuff application and/or changes throughout the entire extremity or even the contralateral extremity.[1,11,12,16,27,30]

Reviews of muscles proximal to the cuff

In a meta-analysis comparing 19 articles, Dankel and colleagues[27] found that BFRT increases muscle mass and strength in various muscle groups not restricted to the limbs (ie, improvement in chest, shoulder, and back musculature). They did, however, note that these muscle groups may require additional repetitions to achieve results equal to those seen in muscle groups distal to the cuff. The authors also reported that the degree of restrictive pressure is of little importance and that using high pressure does not necessarily enhance results. Overall, the group found that results of BFRT coupled with low-load resistance training yields results in the chest, shoulder, and back similar to what has been shown in the lower extremities.[27] Nine studies were included in a meta-analysis by Pavlou and colleagues[7] to evaluate the effect of low-load BFRT compared to low-load, or high-load resistance training without BFRT on musculature located proximal to cuff placement. The findings of their review do suggest low-load BFRT may result in improved strength and size compared to exercise without BFRT for musculature proximal the cuff, but the quality of evidence within their review was low, and results were mixed. Overall, they concluded that low-load-BFRT is equally effective to high-load resistance training when it comes to improving strength in the upper extremity proximal to the area of BFR and that low-load BFRT may increase mass, but the adaptation seen are not superior to low-load and high-load resistance training without BFRT. They also note that a minimal threshold and time under occlusion for a significantly beneficial response has yet to be established.[7]

Studies of muscles proximal to the cuff

In a study of 32 adults randomized into BFRT and non-BFRT groups, Lambert and colleagues[26] similarly assessed whether low-intensity training coupled with BFRT with the cuff placed on the brachial region of the arm provided superior results in the shoulder compared to low-intensity training alone. They found the addition of BFRT to low-load training demonstrated greater increase in shoulder lean mass, strength, and endurance compared to low-load training alone.[26] While occlusion pressures are not yet standardized among studies, the degree of occlusion pressure at the brachium has been shown to have differential effects on outcomes. Wilk and colleagues[22] conducted a 7 week, randomized crossover study to assess baseline performance of 12 resistance-trained men compared with their performance after acute external compression with BFR. They assessed 1-RM bench press and the number of repetitions to failure in a set using 60% of the subjects' 1-RM in 3 different settings: no BFR, BFR at 100% arterial occlusion pressure, and BFR at 150% occlusion pressure. In the study, BFR, whether at 100% or 150% arterial occlusion pressure led to significant increase in 1-RM, number of repetitions in a set, and time under tension in each set. Moreover, occlusion pressure at 150% versus 100% showed significant increases in number of repetition and time under tension.[22] In another study by Lambert and colleagues,[19] benefits of BFRT in a specific athletic group, baseball pitchers, were examined. Specifically, rotator cuff (RC) adaptations from training with BFRT in 28 division IA college pitchers were assessed. The group found that when combined with low-load resistance exercise, defined as less than 30% of the 1-RM, BFR therapy at 50% arterial occlusion at the brachium demonstrated greater increases in shoulder area lean mass and internal rotation strength compared to the non-BFR group. The

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BFR group also demonstrated an increase in workload exercised in the scapular plane compared to the non-BFR group. Given the findings of the study, they suggest performing BFRT with low-intensity exercise, in conjunction with the standard offseason strength and training regimen could augment mass and endurance that ultimately improve outcomes in these athletes.[19] Adding useful data for the potential standardization in pressures, Roehl and colleagues[25] looked at shoulder muscle recruitment, determined by electromyographic amplitude (EMGa) changes at different limb occlusion percentages (LOP). Fifteen subjects performed common RC exercises (cable internal rotation and external rotation and dumbbell scaption) at 20% of their maximal strength to failure at 0%, 25%, 50%, and 75% LOP. They recorded EMGa in the shoulder musculature proximal to the site of occlusion and found differences in muscle activation based on exercise performed and LOP applied. Increasing the LOP led to increases in EMGa with reportedly diminished returns past 50% LOP. A decrease in repetition to failure was noted at 75% for external rotation and for scaption exercises, and there was a corresponding increase in discomfort for all exercises with increasing LOP. Ultimately, they determined that 25% to 50% LOP may be the most beneficial occlusion pressure when targeting the shoulder and RC musculature.[25] In patients with RC tendinopathy, the effects of BFR on symptoms, cuff strength, and thickness of the shoulder musculature have been studied.[6] In a randomized control trial by Kara and colleagues,[6] patients with RC tendinopathy were randomized into BFR and non-BFR groups undergoing shoulder rehabilitation to assess outcomes on shoulder pain and function, shoulder internal and external rotation strength, and shoulder musculature thickness (RC, deltoid, scapula, and biceps). The cuff was placed at the distal aspect of the deltoid. The group found that while biceps thickness and shoulder internal rotation increased in the BFR group compared to the non-BFR group, no marked difference was noted for thickness in the other muscles listed, improvements in external rotation strength, or in shoulder pain/function. The conclusion was that their study partially supports the effects of BFR on muscle strength and hypertrophy.[6]

Reviews of changes not only proximal to the cuff

As discussed previously, data on BFRT are better established in the lower extremity, as are the protocols for its application in this area. In the upper extremity, a paucity of literature has led to essentially nonexistent standardization for its use. In a systematic review of conducted by Ponce-Fuentes and colleagues[16] detailing 9 different studies, they found there were generally large improvements reported in muscle mass, strength, pain, and function in the upper extremity after BFRT but that the studies poorly describe their protocols and exercise interventions bringing into question reproducibility. Ultimately, they concluded BFRT is beneficial in select patients with upper limb pathology but with very low evidence and strength for making a definitive recommendation.[16] Jing and colleagues[11] similarly echoed this finding in a systematic review and metanalysis of 11 randomized control trials aimed at studying the effects of low-load resistance training with BFRT (LL-BFRT) versus high-load and low-load resistance therapies (HLRT/LLRT) alone. Specifically, they assessed muscle strength (including 1-RM), peak torque, and muscle hypertrophy measured by MRI. They found with low-to-moderate certainty that LL-BFRT and HLRT have similar effects on upper extremity musculature in terms of strength and hypertrophy and that with low-certainty evidence LL-BFRT has a significant impact on strength and hypertrophy when compared to LLRT alone. Though the number of studies included were insufficient, per the author, they still were able to determine that the effects of LL-BFRT on upper extremity musculature were influenced by age and region. Despite the limited studies and low-level evidence, they suggest considering these factors when formulating an LL-BFRT training plan. Their overall conclusion is that LL-BFRT could be used as an alternative therapy to HLRT to enhance upper extremity strength and muscle hypertrophy.[11] In a scoping review by Sinnott and colleagues,[1] 33 studies from 2014 to 2024 were examined to analyze current literature for BFR training in the upper extremities, the group found BFRT can be effective for improving muscular strength in muscles proximal to the cuff, distal to the cuff, and even in the contralateral limb, which, as was discussed in the opening of this review article, is known as "cross-training." Conclusively, they found BFR has led to improved strength, muscle size, and endurance in the upper extremity musculature in numerous populations (eg, elderly and athletes). They also found that, while further research and standardization of protocols for BFRT are needed, low-load BFR has generally shown improvements like those seen with high-load exercises while decreasing the cardiovascular strain and mechanical stress on tissues in

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joints, the latter of which is critical for the elderly and those recovering from injuries or surgery.[1]

Studies of changes not only proximal to the cuff

Despite the consensus from reviews and studies that BFRT positively effects muscle strength, endurance, and hypertrophy, albeit with sometimes low-level evidence as mentioned in some of the earlier analyses, a limited number of authors have found BFRT to be ineffective.[30] In a randomized control trial by de Castro and colleagues,[30] 19 subjects were divided in 2 groups, a low-load training group with complete intermittent BFRT (100% arterial occlusion pressure) and a low-load training without BFRT. They assessed resulting neural adaptions (via EMG activity) and strength changes of the biceps brachii within the 2 groups after 3 weeks of assessment and 6 weeks of training. The group found that low-load training with intermittent blood flow restriction was not effective in inducing neural adaptations or enhancing strength in the biceps brachii. They concluded that if the goal is to increase strength and neural activity in the short-term, alternative methods, such as high-load strength training, are preferable to low-intensity training with blood flow restriction.[30] Contrasting this study, Bowman and colleagues[12] performed a randomized control trial in 24 healthy subjects where outcomes of low-level training with and without BFRT were assessed. Participants were randomized into a BFR group (N = 14) and a non-BFR group (N = 10). Outcomes assessed were limb circumference and strength. After a 6 week training program consisting of various exercises including external rotation, internal rotation, bicep curl, triceps extension, and shoulder abduction training at 30% of the subjects 1-RM, the group found favorable results. Compared to the non-BFR low-intensity controls, the low-intensity BFR training group demonstrated increased manual strength and muscle hypertrophy for muscles proximally and distally to the applied cuff as well as in the noninvolved, or contralateral extremity. The authors stated their study affirmed the beneficial effects of low-load training combined with BFRT on strength and muscle hypertrophy in the upper extremity and suggested their findings could help characterize clinical efficacy and safety for BFR use in orthopedic conditions of the upper extremity.

DISCUSSION

With the exception of one above-mentioned study, the reviews, meta-analyses, and trials included in our review suggest low-load training with BFRT has measurable, beneficial effects on muscle strength, hypertrophy, and endurance in the upper extremity. Based on the data, one can surmise that BFRT is a pivotal rehabilitation tool and should be considered in the injured and postoperative patient's recovery period, particularly in the elderly patient, neuromuscular patient, or the patient with weight-bearing restrictions where high-intensity or high-load training is not an option.

Challenges

A scarcity in literature and lack of detail within studies has made it difficult to standardize protocols for the use of BFRT in the upper extremities or to reproduce reported results. This creates difficulty for establishing a foundation of knowledge to build a bigger body of literature. It has been reported that 86% of studies on BFR training had no justification for their choice of percent limb occlusion pressure,[8] a finding that is not ideal for standardization. Studies have found that percentage of arterial occlusion pressure, body position, cuff width, and intermittent versus continuous occlusion can all impact the outcomes in BFRT. Given these findings, authors agree future research is necessary to establish protocols.[1,4,8]

Complications

Currently, the safety profile for BFRT appears favorable. Initial theorized complications of rhabdomyolysis or venous stasis and endothelial damage leading to the development of deep vein thrombosis (DVT) or pulmonary embolism have not been observed regularly. These complications are accepted to be extremely rare.[8] It is suggested that clinicians be mindful of inadvertently prescribing BFRT in a patient with an asymptomatic DVT.[23] Acute hypotension and reduction in vascular compliance have been described.[8] More commonly, cuff/exercise discomfort, soreness after therapy, and reduced exercise volumes have been associated with higher cuff pressures, and for this reason, authors suggest finding a minimum occlusion pressure that would afford patients the benefits of BFRT with a lower side-effect profile.[8]

SUMMARY

With an increasing number of articles reporting favorable outcomes, this alternative to high-load exercises could prove vital in the functional recovery and rehabilitation of patients with impediments to high-resistance exercises in the

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upper extremities. We believe the utilization of BFR in the upper extremity will become more prominent as its benefits continue to be elucidated. Based on the literature presented here, there is promise that it will play a pivotal role in the rehabilitation and recovery of injured and postoperative patients across many populations.

CLINICS CARE POINTS

Pearls:

- For elderly, neuromuscular, postoperative, or injured patients who are unable to undergo high-resistance exercises for rehabilitation, low-resistance with BFRT can provide similar outcomes and should be considered.
- Low-percent occlusion has been shown to provide equal benefits to high-occlusion pressure and should be considered to avoid patient discomfort while still maximizing outcomes.
- Intermittent occlusion therapy can also be considered to avoid cuff irritation.

Pitfalls:

- Some reviews suggest the reported benefits of BFRT for the upper extremity come from low-level evidence. Therefore, prescribing BFRT for this use should be done with a thorough understanding of the literature to avoid potential complications.
- Excessively high cuff pressures can not only cause patient discomfort but can also lead to negative effects.
- Avoid cuff application over existing pathology (eg, DVT), as this theoretically could cause systemic harm.

DISCLOSURE

The authors have nothing to disclose.

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