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Blood flow restriction therapy as a treatment in rehabilitation

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A Review of Literature

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Abstract

Blood flow restriction therapy, also known as BFR, is a treatment that is gaining popularity in the realm of rehabilitation and personal fitness. Commonly, BFR is used along with resistance training in physical therapy clinics for patients post-surgically, post injury, and for general muscle weakness (Congetti et al., 2022). BFR utilizes occlusion and pooling of blood, along with triggering the physiological processes of resistance training to decrease the hypertrophic threshold of a muscle (Congetti et al., 2022). This literature review aims to investigate the effects of BFR on patients in physical therapy after surgery by examining the history and origin of BFR along with current treatments. This review covers one study regarding distal-radius fracture repair surgery, and three studies regarding ACL reconstruction surgery. Each study examined obtained measures of recovery markers specific to each surgery. The study regarding the effects of BFR on distal radius repair measured pain at rest and with activity, patient reported questionnaire answers, range of motion, and grip strength (Cancio et al., 2019). The ACL reconstruction studies collected various measurements regarding weight bearing ability, strength, range of motion, and management of swelling (Massachusetts General Hospital, 2021). These studies highlight the wide range of treatments that BFR can be used to treat in both the upper and lower extremities. This review also examines the benefits and risks associated with BFR and examines potential side effects such as numbness, dizziness, and rhabdomyolysis. Despite the overall positive effects on musculoskeletal rehabilitation, controversy exists regarding the safety and effectiveness of BFR. Overall, this literature review examines the complexities regarding BFR, with the overall conclusion that research should be continued.

Introduction

Blood Flow Restriction therapy (BFR) is an injury rehabilitation treatment that reduces arterial inflow and occludes venous outflow commonly using a tourniquet or inflated cuff during resistance training (Congetti et al., 2022). This modality has become well understood to prevent muscular atrophy and has been widely accepted to decrease the hypertrophic threshold of a muscle (Congetti et al., 2022). Given that hypertrophy is defined as the increase in muscle size (Reggiani and Schiaffino, 2020), a decreased threshold indicates that less force and resistance is required to create an increase in muscle size. Essentially, a decreased hypertrophic threshold is viewed as beneficial in a rehabilitation setting because it decreases the amount of stress a joint must endure to reach the point of muscular benefit. In a practical setting, this looks like a decreased amount of weight along with a higher number of repetitions during resistance training for an exercise, while still reaching desired muscular hypertrophy.

BFR is currently used in multiple settings. The most common setting is in a rehabilitation clinic such as physical therapy. Overall, BFR has changed the way resistance training can be used for recovery and has helped to make the switch from high intensity resistance training with low repetitions to lower intensity resistance training and higher repetitions (Perera et al., 2022).

History

BFR began in Japan in 1967 by Yoshiaki Sato, who discovered the treatment by experimenting on himself (Freitas et al., 2021). BFR stems from the Japanese word "Kaatsu", meaning "added pressure". According to *The history and future of KAATSU Training* (Sato,

2005) KAATSU originated for the purpose of increasing muscle mass using low intensity exercises with high repetitions. It is also important to mention that KAATSU was developed over 40 years, and that it does not restrict blood flow to organs, but rather creates capillary pooling of blood within the targeted muscle. Within the first year of development, Sato stated that he was reckless with the personal use of KAATSU and it resulted in a pulmonary embolism. Despite being advised against it, Sato continued to experiment with KAATSU on himself to figure out a safe protocol.

In 1973 Sato began experimenting on his fractured leg while it was in a cast. The purpose of his experiment was to prevent muscular atrophy. When following up with his doctor, he found that his leg had hypertrophied from increasing and decreasing the blood flow using a cuff, without any resistance exercises, which helped accelerate healing. After the success with his own leg Sato made it his mission to make KAATSU accessible to the public. He carried out his desire by experimenting and following up with thousands of students. Sato continued to improve access, and in 1983 wrote generalized guidelines of KAATSU training. After the creation of his generalized guidelines, following years of work and determining the correct and safe measures, he built his company, which became known as KAATSU. He built KAATSU with the goal of marketing his ideas and products to the world. He first collaborated with PHENIX Co., to develop the garments and cuffs that can be purchased. The cuffs were designed to be adjustable for a perfect fit to ensure that the highest-pressure setting would not pose safety concerns. In addition to rehabilitation usage, KAATSU has been tested for use with the Japan Aerospace Exploration Agency testing to see if KAATSU may prevent muscular atrophy in astronauts spending prolonged amounts of time in space (Sato, 2005).

KAATSU vs Delfi Portable Tourniquet System

Worldwide there are several manufacturers of portable tourniquet systems. One of the main competitors for KAATSU is the Delfi system which originated in Europe. It is important to distinguish the key differences between KAATSU and Delfi methods of BFR.

The main difference between the KAATSU and Delfi is the beginning phases of pressurizing the limb. KAATSU focuses closely on moderation of blood flow rather than restriction or occlusion (Sato, 2005). The flow moderation engorges the limbs with blood during and following usage, additionally, the moderation rather than restriction is said to help blood continue to flow into the limb and slow the flow of blood to the heart. This difference is important to Sato due to the pulmonary embolism he experienced when experimenting on himself (Sato, 2005). KAATSU equipment involves air bands made of flexible material which are specifically designed to adhere to the shape of the limb.

On the other hand, Delfi Medical provides several options and methods to be used during BFR. Their most highly marketed version of BFR is the personalized tourniquet system or PTS. PTS includes Limb Occlusion Pressure (LOP) (*Personalized BFR*, 2023). This is purchased as a small electronic monitor that attaches to the cuff through a hose. The monitor measures the blood pressure of the limb, and calculates the necessary pressure given the size of the limb and the desired outcome. The use of the PTS is marketed as a safer approach to BFR because there is much less room for user error in determining the correct pressure. Though KAATSU and Delfi are marketed competitors, the differences between each brand and method of BFR are minute details.

Physiology of BFR

The physiological components of BFR have been investigated to see the effects on hypertrophy. The elements include metabolic stress, mechanical tension, and hypoxia. These three components are interconnected and create a cascade of events thought to result in muscular hypertrophy (Schoenfeld, 2010). Metabolic stress is a process in which metabolites such as lactate and phosphate accumulate in the muscles during exercise, also known as metabolite accumulation (de Freitas, 2017). Because there are so many components involved in metabolic stress, it is difficult to determine the connection between the effects of BFR specifically, and the general nature of metabolic responses during resistance exercise. The main conclusion to be drawn is that the accumulation of metabolites in the muscle is due to a decrease in blood flow during anaerobic exercise, which in turn results in an increase in the hypertrophic effect on the muscle (Schoenfeld, 2010). It is also known that metabolic stress is associated with resistance training in general, but again, is increased with the usage of BFR.

A component that parallels metabolic stress is mechanical tension. Mechanical tension is the stretch of the muscle that occurs with activation (Martin et al., 2022). With resistance training, mechanical tension uses similar mechanisms to metabolic stress to achieve hypertrophy. Two of the main mechanisms are muscle damage and fiber recruitment, however the involvement of muscle fiber recruitment in BFR requires further research (Pearson and Hussain, 2015).

Another important factor that should be considered for general muscular hypertrophy is hypoxia. Hypoxia is when the muscle is not adequately able to utilize oxygen and is usually caused by low oxygen content in the blood or hypoxemia (Bhutta et al., 2022). Hypoxia during resistance training has been thought to be linked to an increase in hypertrophy through an increase in lactate accumulation, causing an increase in cell swelling, which leads to stimulation of protein synthesis (Schoenfeld, 2010), ultimately resulting in an increased muscle size. With this being said it is clear that hypoxia plays a large factor in BFR, additionally the link can also be seen through the fact that BFR produces regional hypoxia to a limb through roughly 80% occlusion (Joshi et al, 2020).

As mentioned above in relation to hypoxia, cell swelling may be another mechanism for hypertrophy for BFR (Loennke et al., 2012). The normal process of the cell swelling cascade involves swelling of the muscle cells, and the sensor activations that follow. An example of this cascade involves volume sensors triggering muscle protein synthesis that leads to hypertrophy (Loennke et al., 2012). It is thought that the usage of BFR may lead to a faster trigger of these protein pathways through a smaller cascade of mechanisms (Loennke et al., 2012). Though the exact mechanisms causing the decreased hypertrophic threshold have yet to be confirmed, it is important to acknowledge each of the above components have been thoroughly investigated and researched regarding the matter. Additionally, it is important to mention that while these proposed mechanisms hold to be true in that they effect the general hypertrophy of the muscle, it is difficult to determine whether these processes are caused exclusively by BFR, or if the processes are due to the combined effects of BFR with resistance training exercises (Loennke et al., 2012).

Common Protocol for BFR

General guidelines for BFR protocol include recommended pressures, duration, injury usage, and use for resistance training and aerobic fitness.

The guidelines for BFR resistance training (BFR-RE) include frequency, load, restriction time, type, sets, and mode of exercise. The frequency of BFR-RE is between two and three times per week for more than three weeks or one to two times per day for one to three weeks. This should involve five-to-10-minute session with a minimum 30 second rest to restore blood flow between sets. The load lifted is between 20-40% of the users one repetition maximum or 1RM. BFR-RE can be used on small and large muscle groups for between two and four sets. Restriction may be continuous or intermittent (Patterson et al., 2019).

Another major guideline to ensure the safe usage of BFR is arterial occlusion pressure or AOP. This guideline contains the most variation because AOP depends on the size of the limb BFR is being applied to, the size of the cuff, the type of cuff, and the blood pressure of the user (Patterson et a. 2019). It is important to note that there are varying perspectives on AOP and whether there should be generalized guidelines because there is a strong argument that personalized pressures are more beneficial. Benefits of personalized pressure include avoiding using the wrong pressure due to limb size or blood pressure, relative intensity of exercise, and fatigue level (McEwen et al., 2017). Despite the arguments both for and against generalized AOP guidelines, it has been determined that the pressure of the cuff should be used at a pressure of 40-80% maximum. (Patterson et al., 2019).

BFR Utilizations

It is important to acknowledge the wide array of conditions BFR may be used to treat. BFR can be used for post-injury rehabilitation, or for muscle general weakness or atrophy, and post surgically in rehabilitation (Congetti et al., 2022). Not only can BFR be used in a variety of settings, and with a variety of injuries, BFR can also be used on different parts of the body and is not limited to lower limbs. BFR can be used on upper extremity injuries, most commonly in the elbow and shoulder for athletes playing sports such as tennis, baseball, and softball, which involve frequent throwing (Stevens et al., 2022).

One example of BFR treatment for an upper extremity injury can be seen through a study done by Cancio et al., (2019). They evaluated 13 patients who were in a cast due to a distal radius fracture. This study followed six participants who received a BFR protocol, and seven who received standard protocol for the fracture. The study measured results over eight weeks. This study measured pain at rest, pain with activity, patient reported wrist evaluation (PWRE) scores, range of motion of wrist and forearm, and several forms of grip strength. It was found that there were significant decreases in pain ($p = 0.03$) in the group that received BFR treatment, while the range of motion and strength between the groups did not find significant differences (Cancio et al., 2019).

It is more common to use BFR on the lower extremities. BFR treatment for lower extremities can be used from below the hip joint to below the knee. One example of BFR usage for the lower extremities is from a study done by Burkhardt et al., (2021). In this study, muscle activation in patients with chronic ankle instability was evaluated. There were 25 participants with a history of chronic ankle instability, each patient performed the same balance and strength exercises. The group who received BFR treatment showed greater strength in vastus lateralis ($p < 0.001$) and soleus ($p = 0.03$) activation.

Additionally, BFR has been used alongside resistance training to treat chronic conditions such as rheumatoid arthritis and psoriatic arthritis and has been found to lead to a significant decrease in the number of painful joints for both types (Bauer et el. 2023). BFR has also been used following a bone fracture or break, and was found to help decrease muscular atrophy, but not necessarily speed up the healing process (Robertson and Butler 2023). Another method gaining popularity is post-surgical usage. There are several studies supporting the use of BFR after ACL reconstruction.

The Anterior Cruciate Ligament (ACL) is the most injured ligament in the knee (Evans and Nielson 2022). The ACL works with the posterior cruciate ligament (PCL), to stabilize the knee at rest and in motion. Both ligaments are composed of collagen fibers and connective tissue and reach from the top of the tibial plateau and back to the lateral part of the femoral condyle (Evans and Nielson 2022). ACL tears are commonly diagnosed with imaging such as an MRI. Because ACL reconstruction surgery is favorable over conservative treatment of a tear and typically is performed using a tendon graft from either the hamstring or patellar tendon. Surgery has become the primary treatment in both active and inactive patients (Paschos and Howell 2016).

Post-surgical patients complete physical therapy sessions that may last up to six months. While there are several variations of guidelines for ACL rehabilitation, according to the Massachusetts General Hospital (2021), a few of the regulations are as follows. Goals for the first two weeks of rehabilitation following surgery include weight bearing, swelling management, range of motion, strengthening. Criteria for the first two weeks include complete knee extension and quadricep contraction. Phase two of the protocol goes to week five of rehabilitation and requires that the patient must continue with no swelling and continue improving knee flexion and extension. Typically, around three-to-five-months post operation, patients will begin to undergo strength testing performed by their physical therapist, and strengthening exercises will target gluteus muscles, quadricep muscles, and hamstrings.

During the process of ACL reconstruction rehabilitation, there are specific goals and measures that are to be met. To truly show the impact of BFR on a patient after ACL reconstruction, a study done with 23 post-operative patients was examined. The study was divided into three groups, one group received BFR treatment at 40% AOP, another at 80% AOP, and one control group that did not receive BFR treatment. Each patient received their respective level of BFR and performed targeted quadricep rehabilitation for a period of eight weeks. Assessments evaluated strength at complete knee extension, at 60 degrees and at 180 degrees, and the thickness of the rectus femoris and vastus intermedius, Y-balance test, and the International Knee Documentation Committee (IKDC) questionnaire, collecting responses before and after the treatment (Li et al., 2023).

The results of the study conducted by Li et al., (2023) showed that at 40% and 80% AOP an improvement was found regarding the indicators that were tested relative to the control group. More specifically, it was found that the 80% AOP group showed an increase muscle strength and thickness in the quadriceps femoris (Li et al., 2023). When comparing that benefits of the 80% AOP group to the 40% AOP group it was clear that the 80% AOP group reaped grater benefits than the 40% AOP group, in areas of measurement including thickness, strength, and torque at an angular velocity (Li et al., 2023). The conclusion was clearly drawn from this study that the combined usage of BFR with low-intensity resistance exercise for the quadriceps femoris is beneficial to the thickness of knee extensors, improve knee joint function, and overall strength (Li et al., 2023).

In a literature review conducted by Spada et al., (2022), they aimed to evaluate if there was a significant difference in the treatment of post-operative ACL patients that receive BFR as a part of their treatment, and those who do not. They focused on the effects of BFR on decreasing the amount of range of motion lost early in the rehabilitation process. The demographics of the studies evaluated were similar in that they both utilized participants with an average age of 29 years old. While the small sample sizes of the studies were a concern, it was still indicated that the usage of BFR in early post-operative rehabilitation is beneficial to the ability of the knee to perform flexion and extension (Spada et al., 2022).

Risk and Side Effects of BFR in rehabilitation

Although BFR has been thought to have many benefits it is also important to examine the side effects and risks. Because BFR involves the occlusion of veins and blood flow there are certain risks that it poses. With the usage of BFR comes potential risk and side effects, it is important to state the difference between the two. A side effect is defined as an unintended effect of the usage of a treatment (Due et al., 2023). While a risk or adverse effect is defined as uncertainty about the effects that may occur (Pascarella et al., 2021). In the case of BFR, a side effect may occur after usage such as muscle soreness. While a risk may also occur after BFR usage, an example may be an embolism, something that is far less common than soreness, yet more serious.

In a literature review done by Anderson et al., (2022), there were a mix of case reports, case series, national surveys, questionnaires, randomized controlled studies, and systematic reviews. This review concluded that based upon the various forms of data collection that were used there were 1,672 out of 25,813 people that experienced adverse effects following BFR usage (Anderson et al., 2022). The most common adverse effects experienced out of the 1,672 people where numbness, dizziness, subcutaneous hemorrhage, and rhabdomyolysis, however it was also stated that it was common for these adverse effects to take place within individuals who exhibited a comorbid condition such as hypertension (Anderson et al., 2021). Of the listed effects rhabdomyolysis was the most discussed, potentially due to its severity. Rhabdomyolysis is the dissolution of damaged or injured muscles tissue into the blood stream, potentially leading to organ damage or failure (Torres et al., 2015).

On the other hand, it is not uncommon for users to experience less severe side effects. Some of the most common side effects of BFR include tingling, delayed onset muscle soreness (DOMS), and fainting (de Queiros et al., 2021). These side effects are far less serious than the adverse effects listed above. Additionally, less severe side effects were determined to be found more commonly. For example, 92% of users reported observing some form of side effect, of these responses 71.2% experienced tingling, and 55.8% experienced DOMS (de Queiros et al., 2021). The frequency of these low-risk side effects is important to acknowledge, this indicates that each professional or healthcare provider should be well versed and aware of the correct usage, and tailor pressure to each individual patient or user.

Contradictions for BFR

While the benefits of BFR after ACL reconstruction have been discussed, along with potential side effects, it is also important to include information that displays the finding that BFR may not have as much of an impact. Because BFR is a newer treatment, there still lies controversy surrounding the effectiveness, despite the finding of several studies indicating positive effects. In the following study it was stated by Kaarre et al., (2023), that BFR in fact does not accelerate the strengthening of quadricep muscles following ACL reconstruction. Before further evaluating this study, it is important to be clear regarding the difference between this study and the two mentioned above. The first study evaluated directly compared ACL reconstruction patients using BFR to those who were not using BFR, over an eight-week period, and found that BFR users had greater strength after treatment. However, this study states that BFR does not accelerate strength rather than stating there is no increase in strength.

The study done by Kaarre et al., (2023) examined 36 patients after ACL reconstruction surgery. The patients examined had an average age of 19.5 years old, and the groups exhibited no significant differences regarding surgery or demographics. Strength measurements tested included knee extension ratio, and peak knee extension torque. The two groups tested included a group that received BFR in rehabilitation and those who did not. In the group that received BFR, there was an average of 35 total treatments between surgery and the third obtained measurement. When analyzing the differences between groups it was found that at the first of three measurements obtained, the average peak knee extension torque was lower for the BFR group, but at the third and final measurement, there was no difference (Kaarre et al., 2023). Additionally, it was found the for the second set of measurements the BFR group exhibited a lower knee extension ratio, and yet again exhibited no difference from the control group at the final measurement. This study indicates that there were no significant differences between the BFR and non-BFR groups in level of strength, and that both groups indicated similar improvement. It was concluded that BFR does not accelerate strength gains in the quadricep after ACL reconstruction. However, due to the differences in first and second measurements for the BFR group, and still ending with similar measurements, the use of BFR cannot be written off as a potential treatment (Kaarre et al., 2023).

Conclusion

Blood Flow Restriction (BFR) is a treatment that will continue to grow and gain popularity. In the setting of physical therapy, BFR entails a cuff or tourniquet inflated to the preference of the physical therapist, tailored specifically to the condition and goals of the patient. BFR is commonly coupled with resistance training exercise and carried out at an occlusion of 40-80% AOP, with the goal of achieving a decreased hypertrophic threshold. In addition to resistance training, BFR may be used for aerobic exercise as well. The aerobic exercise guidelines are similar in occlusion and frequency recommendations, but time spent exercising is measured instead of repetitions (Patterson et al., 2019).

While BFR originated and was further developed in Japan, it has made its way across the world and has become widely used in physical therapy in the United States. Though this paper focused on the findings of the impact of BFR in a rehabilitation setting, BFR is also commonly used for personal fitness.

Due to the ever-changing nature of BFR, and constant research that has occurred, side effects and risks were evaluated, highlighting severe risks such as rhabdomyolysis, and less severe side effects such as dizziness and DOMS. These effects are important to include in the education and training for BFR, not only for healthcare providers, but for patients as well. It is imperative to ensure that each patient is aware of the risks and benefits of BFR before undergoing treatment of any kind.

It has been found that there are few limitations to the injuries or conditions that BFR may be used to help treat, with this it is also important to acknowledge that BFR is not limited to young and active individuals but may benefit people of any age with any level of physical fitness (Freitas et al., 2021). In terms of musculoskeletal injury and rehabilitation BFR can be used on both upper and lower extremities to strengthen the muscles, while decreasing the amount of pressure the joint receives. Specifically, in lower extremity injuries and rehabilitation some studies have shown benefits with the use of BFR after ACL reconstruction. It was found that the range of motion, strength and muscle thickness increased with the application of BFR. On the other hand, it was found that BFR does not increase the speed at which recovery occurs. Based upon these findings it may be said that BFR may increase the quality and longevity of recovery rather than the speed of recovery. Once again, due to the constant research that takes place regarding BFR, it is important to proceed forward on the matter not only with caution, but also with a mind open to the possibilities that the treatment may continue to provide.

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