Level V Evidence

The Role of Blood Flow Restriction Therapy Following Knee Surgery: Expert Opinion

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Abstract: Blood flow restriction (BFR) therapy is becoming increasingly popular in musculoskeletal injury rehabilitation. In particular, this form of therapy is being utilized more often in the postoperative setting following knee surgery, including anterior cruciate ligament reconstruction. BFR therapy provides patients and clinicians an alternative treatment option to standard muscle strengthening and hypertrophy guidelines in the setting of postoperative pain, weakness, and postoperative activity restrictions that contribute to muscle atrophy. The ability to complete exercise in a low load environment and achieve similar physiological adaptations as high-intensity strength training makes this modality appealing. With poor patient-related outcomes associated with continued muscle atrophy, pain, and muscle weakness, some researchers have investigated BFR training postoperatively following arthroscopic knee surgery with promising results. However, owing to the current paucity of research studies, inconsistency among reported protocols, and mixed results, it may be some time before a mass adoption of BFR therapy is made into the world of orthopaedic rehabilitation. Although the current data is inconclusive, we choose to utilize BFR in postoperative knee patients, regardless of weight-bearing status, for whom maintenance of existing muscle mass or improvement of decreased postoperative strength levels is important. Therefore, the purpose of this expert opinion is to review the background of BFR, describe the clinical evidence of BFR following knee surgery, and report the authors' current recommendations for application of BFR postoperatively.

Historical Background

The first study on blood flow restriction (BFR) training was published in 1998.[1] However, the concept of BFR appears to have originated from Japan in the 1970s by Dr. Yoshiaki Soto with the inception of *Kaatsu* resistance training, or ischemic exercise in which a tourniquet is applied to a limb and restricts muscular venous blood flow. However, the modes of vascular occlusion in the beginning were not sophisticated and included ropes and bands. In 1984, first-generation electronic tourniquet systems were invented, and it was not until the development of third-generation tourniquet systems in the early 2000s before BFR could be performed with precision and safety. This led to the clinical implementation and investigation of using BFR in select patients who could not exercise with heavy resistance due to various restriction (elderly, sedentary, etc.) but needed some means to resist muscle atrophy. In recent years, BFR has been adopted as an adjunct to traditional therapy for musculoskeletal injuries and orthopaedic-related trauma. Popularized by Johnny Owens, M.P.T., BFR was initially implemented in his clinic for building muscle strength and hypertrophy in military limb salvage patients.[2] Within just a few years, the potential for BFR in other subspecialties was recognized and there was a transition from trauma patients to treating sports medicine injuries. Twenty years after the first publication, clinical evidence has allowed for a potential paradigm shift in sports medicine rehabilitation and the scientific literature continues to expand on this topic.

Current Concepts

Muscle atrophy is a significant challenge during rehabilitation after knee surgery that can lead to

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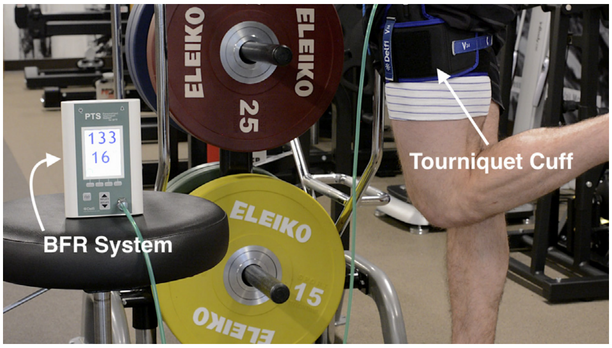

Fig 1. Blood flow restriction (BFR) therapy application. Delfi Personalized Tourniquet System for BFR with pneumatic cuff (third-generation tourniquet), utilized for minimal- to no-resistance, weight-bearing, and non—weight-bearing exercises.

prolonged recovery and diminished patient outcomes. Due to extensive periods of joint unloading and muscular inhibition secondary to pain and joint effusion, the rate of muscle mass reduction of the quadriceps muscles is higher in patients who have undergone knee surgery when compared with healthy subjects.[3,4] Difficulty in regaining muscle mass, strength, and volume has been reported, in addition to the potential for atrophy to persist for several years postsurgery.[5-8] Therefore, reducing the rate of muscle atrophy and stimulating muscle hypertrophy is desired for patients to decrease recovery time and promote earlier return to activities.

Current exercise prescription protocols suggest that increased muscular strength and size is achieved by enduring loads of 60% to 100% of the patient's 1-repetition maximum.[9] Postoperatively, these loads are unable to be attained owing to the time required for sufficient structure repair or reconstruction graft healing, pain, and protection of the knee.[10,11] To combat this challenge, BFR has been suggested as an alternative to traditional strength rehabilitation.[9,12-14]

BFR occludes venous outflow while maintaining arterial inflow[15] by the application of an extremity tourniquet (Fig 1). This ultimately reduces oxygen delivery to muscle cells during low-resistance exercises. The induced anaerobic environment has been reported to promote muscle hypertrophy by initiating cell signaling[16] and hormonal changes[15,17] that stimulate protein synthesis,[16,18] proliferation of myogenic satellite cells,[19] and preferential activation and mobilization of type II muscle fibers.[17,20,21] When using BFR as an adjunct to postoperative rehabilitation, it has been suggested that exercises performed at lower loads (20%-50% of 1-repetition maximum) can promote muscle hypertrophy similar to traditional strengthening protocols while reducing pain and adverse joint loading.[21,22]

Clinical Evidence

Despite the promising claims surrounding BFR as an adjunct to standard physical therapy, there is a paucity of literature regarding its use following arthroscopic knee surgery. To date, 2 Level I randomized controlled trials and 1 Level II controlled trial have reported on the use of BFR following anterior cruciate ligament reconstruction (ACLR). All 3 studies utilized hamstring tendons (autograft and allograft; number of each not reported) for graft selection in all patients (BFR and control).[15,23,24] Of the 3 studies on ACLR, no studies have reported on the weight-bearing status of the patients immediately postoperatively. Furthermore, no studies have reported on concomitant injuries and/or procedures performed at the time of surgery—including meniscal pathology, chondral injuries, or multiligament knee reconstructions. Currently, only 1 Level I randomized controlled trial has reported on the use of BFR following knee arthroscopy.[25] Their exclusion criteria were any ligamentous, bony, or other soft tissue reconstruction performed at the time of the knee arthroscopy. However, their specific indications for arthroscopic treatment, including procedures performed, were not reported. Patients in both the control and BFR groups were allowed to bear weight immediately after the knee arthroscopy.[25] A more detailed overview of these studies is provided below.

Takarada et al.[15] investigated BFR without exercise in patients immediately following ACLR with hamstring tendon autografts. After 2 weeks of knee immobilization and BFR therapy, patients demonstrated significantly less muscle atrophy than immobilized controls with non-inflated occlusion cuffs (sham).[15] Similarly, Ohta et al.[24] reported significant increases in both muscle circumference and strength following ACLR with hamstring tendon grafts. Training interventions were conducted from weeks 2 to 16 postoperatively and consisted of combined resistance training with BFR compared with a matched protocol without BFR.[24] Between the control and BFR groups, there were no significant differences in knee range of motion or anterior knee stability between preoperative and postoperative training, thus supporting the use of BFR following ACLR without compromising ligamentous healing or graft integrity.[24] In a study of patients treated with ACLR using hamstring tendons, Iversen et al.[23] investigated the combination of low-load resistance and BFR compared with patients participating in a similar resistance training program without BFR; respective interventions began 2 days postoperatively. Results showed a significant reduction in quadriceps cross-sectional area from measures taken preoperatively to 2 weeks postoperatively in both groups.[23] Thus, the authors concluded that the application of BFR during the first 2 weeks following ACLR did not reduce muscle atrophy of the quadriceps.[23]

Table 1. BFR Training Postoperative Protocols

Protocol	Frequency	Duration	Pressure	Intensity	Rest Periods	Volume	Exercise Progression
Resisting muscle atrophy	3-6 days per week	6-12 weeks	Personalized, 80% total LOP	Body weight with minimal to no resistance	15-30 seconds with cuff inflated	4 sets of 30/15/15/15 repetitions	Resisted weight-bearing exercise when treatment focus is muscle strength
Building muscle strength	3-6 days per week	6-12 weeks	Personalized, 80% total LOP	≤30% 1 RM	30-45 seconds with cuff inflated	4 sets of 30/15/15/15 repetitions	Discontinue BFR when treatment focus is muscle power

NOTE. Resisting muscle atrophy is desired for patients who have weight-bearing restrictions and are in the acute or subacute phases of healing. Building muscle strength involves patients who are full weight bearing and are usually in the remodeling phase of healing postoperatively.

BFR, blood flow restriction; LOP, limb occlusion pressure; RM, repetition maximum.

Physiological Adaptations

Knee joint unloading (via non—weight bearing) has been reported to result in an 8.4% decrease in total muscle volume after 14 days[4] and a 20% to 33% reduction from time of injury to 3 weeks postsurgery.[3] Skeletal muscle atrophy occurs from type I (slow-twitch) and type II (fast-twitch) fiber-specific degradation by regulatory signaling cascades after periods of disuse and lack of high resistance exercises.[26] Following knee surgery, atrophy begins to occur during the immobilization phases where reflex-arc dependent type I muscle fibers are predominately inhibited due to decreased reflex activation from muscle spindles.[27] Considering that the quadriceps muscles have a proportionately larger composition of type I fibers (around 55%),[28-30] the quadriceps are relatively more sensitive during short-term rigid immobilization than the hamstring muscles, which are primarily composed of type II muscle fibers.[26,28-30] Postoperatively, the treated knee functions well with slow-twitch activating exercises such as simple weight bearing, body weight, or low-resistance exercises.[31] In this case, it has been predicted that early traditional rehabilitation counteracts potentially significant type I—related atrophy.[31]

However, to date, most basic science studies have noted the effects of BFR on type II muscle fiber activation rather than reporting on the effects of BFR on type I muscle fibers. Baugher et al.[31] reported that overall thigh muscle atrophy after anterior cruciate ligament injury is primarily due to the decrease of larger type II muscle fibers. Long-term postoperative restrictions and the physical inability to perform high-resistance, anaerobic exercises limits the ability to stimulate type II muscle fibers, reportedly leading to a more severe overall impairment of muscle size and strength.[26,31] The use of BFR has been primarily reported to reduce type II fiber atrophy by producing a relatively anaerobic environment at the cellular level via a tourniquet, which cannot be achieved with traditional rehabilitation protocols.[16-20,25,32] It has been theorized that low-load exercises performed in this state can lead to the preferential mobilization and synthesis of type II muscle fibers that are correlated with muscle hypertrophy and strength. [16-20,25] Therefore, BFR as an adjunct to standard rehabilitation seems optimistic following knee-related surgery because of the potential to reduce type II fiber-specific muscle atrophy during long recovery periods.[20]

Despite the reported physiological adaptations of increased quadriceps circumference and strength following ACLR, previous studies have only utilized hamstring tendon grafts. However, it has been theorized that there may be greater extent of muscle atrophy following anterior cruciate ligament surgeries that disrupt the extensor mechanism, such as bone-patellar tendon-bone (BTB) autografts. Several

Table 2. Pearls and Pitfalls

Pearls	Pitfalls
Limp protection: tourniquet cuff should be applied to the most proximal portion of the thigh	Inability to occlude blood flow to the trunk musculature, which may limit proximal gains such as strength to the hip abductors
Use wider tourniquet cuffs to reduce potential for complications, including increased pain	Narrow cuffs may increase complications such as increased pain post-treatment
Tourniquet pressure should be patient specific and based on total limb occlusion pressure, with 80% recommended for lower extremity tourniquet use	High pressure gradients may cause complications such as nerve injury and limb ischemia
Limb occlusion pressure should always be tested supine with the patient as still as possible	Expensive cost for third-generation tourniquet systems
Use 4 sets of 30/15/15/15 with a 30-second rest between sets and a 2-second concentric and a 2-second eccentric contraction for a metabolite response	
Manipulate rest periods first if the patient is missing his or her target	

studies have reported significant differences in strength deficits in patients who received a BTB autograft compared with those receiving hamstring tendon autografts,[29,33-35] supporting the theory mentioned previously. Furthermore, ACLR studies utilizing BFR have not evaluated weight-bearing versus non—weight-bearing protocols. Future research is needed to evaluate the efficacy of BFR on delayed muscle atrophy for ACLR with BTB autografts and in patients who are non—weight bearing following complex knee surgery.

Exercise Prescription and Application Technique

The literature indicates that postoperative rehabilitation combined with BFR therapy may be effective in improving thigh muscle circumference, strength, and functional outcomes following knee surgery in comparison to standard physical therapy without BFR. BFR therapy is indicated following knee surgery in patients with protected weight-bearing status, those with muscular inhibition, or those who have significant postoperative pain to resist muscular disuse atrophy. Patients possibly at risk for adverse reactions are those with poor circulatory systems, obesity, diabetes, arterial calcification, sickle cell trait, severe hypertension, or renal compromise.[36] Potential contraindications to consider are venous thromboembolism, peripheral vascular compromise, sickle cell anemia, extremity infection, lymphectomies, cancer/tumor, or medications known to increase clotting risk.[36] In our practice, we have not had any adverse events with BFR following knee surgery. However, the main detrimental side effect reported by our patients who use BFR with outside facilities is an increase in muscular pain when a thinner blood pressure cuff is used and inflated. Nonetheless, all patients should be screened for contraindications to BFR prior to application in the clinic.

In our personal experience using BFR following knee surgery (both open and arthroscopic), we have seen some encouraging results—particularly for delaying or reversing muscle atrophy and improving generalized anterior knee pain owing to quadriceps weakness. We often prescribe BFR for patients who are non—weight bearing for extended periods or for those who have plateaued in their postoperative recovery and cannot lift heavy weights owing to either surgical restrictions or recurrent exacerbations of knee swelling and pain associated with the heavy load. In addition, BFR can begin immediately after surgery because deep venous thrombosis has not been reported with postoperative BFR use. Table 1 outlines the current authors' recommended postoperative protocols for BFR following knee surgery, and Table 2 outlines essential pearls to follow as well as pitfalls to avoid while administering BFR therapy.

Limitations

BFR therapy is not without limitations. The main limitation with BFR application that patients report is an inadvertent increase in muscular pain during treatment. However, this may be directly related to the cuff width, because narrow cuffs may cause increased pain than that found with wider cuffs. Another potential complication that may occur with BFR use is prolonged knee swelling postoperatively. Furthermore, research has demonstrated only short-term improvements (2-16 weeks) in muscle strength and hypertrophy with BFR application following knee surgery; thus, the long-term benefits have yet to be determined.

Conclusions

As with the prescription of any exercise modality, physicians should be educated on the different uses of BFR and work closely with their physical therapist team to create an optimal BFR training regimen that is patient specific. In the future, perhaps BFR therapy will be adopted by orthopaedic rehabilitation centers across the globe; but for now, more clinical research is needed for this modality to be fully endorsed following knee surgery. Furthermore, future research should focus on establishing specific rehabilitation guidelines for postoperative application of BFR, including its administration technique, dosage, and parameters.

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