Effects of Blood Flow Restriction Training on Rehabilitaion of Patients Who Have Undergone Anterior Cruciate Ligament Reconstruction: A Narrative Review

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Abstract

The anterior cruciate ligament (ACL) tear and its subsequent reconstruction surgery can lead to many complications, such as strength deficit and muscle size reduction. Heavy load resistance training is an established method for improving muscle mass and strength but may be intolerable by patients recovering from ACL injuries due to its vigorous modality. Blood flow restriction (BFR) training is a novel technique which has been recognized as a promising alternative strategy, causing physiological adaptations with lower levels of resistance training and joint loading. Given the growing popularity of blood flow restriction, this narrative review seeks to explore the impact of BFR training on various facets of post-ACL reconstruction rehabilitation, comparing it to non-BFR training. A thorough literature search was conducted, and the effect of BFR training were examined on muscle strength, muscle size, pain, function, balance, comfort, willingness to use, bone mineral density, return to sport and ACL graft laxity. The results of this review suggests that BFR training post-ACL reconstruction may offer advantages in terms of muscle strength, muscle mass, bone mineral density, balance, knee joint pain, and function when compared to non-BFR training. However, there is a high variability in methodologies across existing studies, necessitating high-quality research with standardized methodologies and protocols to enable more effective application of BFR training in rehabilitation settings.

Keywords: Anterior cruciate ligament; Blood Flow Restriction; Rehabilitation

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Introduction

The anterior cruciate ligament (ACL), located within the knee joint, serves as a crucial restraint against excessive anterior tibial movements and is the most frequently compromised knee ligament (1, 2). The annual incidence of ACL tears stands at 68.6 per 100,000 person-years, with the majority of cases affecting individuals between the ages 14 and 25 (3). A study focusing on military personnel in Iran reported a high prevalence of ACL tears, with 285 out of 402 patients (70.9%) diagnosed with this injury (4). This injury often occurs atraumatically during sporting activities particularly during sudden directional changeswhich involve deceleration and rotational movements (5, 6). Notably, female patients face a significantly higher risk 2 to 8 times more likely of injuring their ACL compared to male patients (5, 7).

ACL reconstruction is a widely accepted standard and the most used option to restore joint stability in ACL tears (3, 8). Following the tear, a notable strength deficit and muscle size reduction occur in the affected leg, and these effects are further accentuated after surgical intervention irrespective of graft type or concurrent meniscal procedures (9-12). Thigh muscle atrophy (10,13-16), along with weakness in the quadriceps and hamstring muscles (13,14,17-19) are commonly observed after ACL reconstruction. Remarkably, these specific deficits may persist for over two years after surgery (13,20,21), exerting a negative impact on patient-reported outcome measures (22) functional performance (22, 23), the risk of recurrent ACL injury (24), kinesiophobia (25), and the ability to return to physical activity (23, 26, 27) ultimately influencing long-term health outcomes. Consequently, prioritizing muscle strength and size becomes crucial for patient recovery. However, several factors, including pain management, swelling control, neuromuscular coordination, proprioception, joint effusion, and range of motion limitations, collectively contribute to the complexity of post-surgery rehabilitation (28-30).

Intensive heavy load resistance (HLR) training, using external loads exceeding 60% of one repetition maximum (1RM), is a well-established method for enhancing muscle strength and mass (31, 32). However, patients recovering from ACL injuries may experience some challenges in tolerating such loads due to pain, inflammation, swelling, and their overall perception of knee function especially during the perioperative phase (33, 34). In addition, an early return to vigorous training could potentially compromise graft stability (35, 36). Therefore, it becomes imperative to devise tailored training protocols that address these specific considerations for optimal patient outcomes.

An alternative development that addresses these limitations is blood flow restriction training (BFR-t), which has garnered attention as a promising strategy to induce physiological adaptations with lower levels of resistance training and joint loading (37-39). By utilizing approximately 20% to 40% of the patient's one-repetition maximum, BFR-t involves applying an extremity tourniquet, often proximally, which permits arterial inflow while concurrently restricting venous outflow. This creates an anaerobic environment conducive to muscle hypertrophy, comparable to those observed with higher-intensity training loads (29, 40). The precise mechanisms driving clinical improvements through BFR training remain a subject of debate. However, potential contributors include elevated systemic hormone production, reactive oxygen species generation, cellular swelling, recruitment of fast-twitch muscle fibers, and intramuscular anabolic signaling (41-43).

Given the growing popularity of blood flow restriction (BFR) training in ACL rehabilitation, a critical evaluation of its efficacy becomes imperative. Consequently, this narrative review seeks to explore the impact of BFR training on various facets of post-ACL reconstruction rehabilitation, comparing it to non-BFR training.

BFR training effect on muscle size

Various studies have indicated a significantly smaller reduction in muscles cross-sectional area following low-load blood flow restriction (BFR) training compared to non-BFR training (44-46).

Each study employed distinct methodologies, resulting in heterogeneity in parameters and protocols. Study by Ohta *et al.* (44) showed improvements in terms of muscles cross-sectional area but also exhibited several methodological limitations, warranting cautious interpretation of its findings. Additionally in research by Jack *et al.* (47), BFR was found to mitigate the loss of lower extremity lean mass and body mass during a 12-week rehabilitation period post-ACLR. The meta-analysis by Wengle *et al.* (37) also indicated that BFR significantly reduces quadriceps muscle atrophy post-surgery.

Conversely, some studies have reported no significant difference in muscle mass increase between low-load BFR (LL-BFR) and non-BFR training.Hughes *et al.* (30) utilized ultrasound to assess changes in vastuslateralis muscle thickness and found no significant difference in quadriceps increase between LL-BFR and non-BFR training. Unlike previous studies, the non-BFR group in this research underwent high-load resistance training (HL-RT) rather than low-load resistance (LLR) training. Following eight weeks of training, muscle thickness increased by 5.8% and 6.7% with BFR resistance training (BFR-RT) and HL-RT, respectively, indicating that BFR-RT can enhance skeletal muscle hypertrophy to a similar extent as HL-RT.

Iversen *et al.* (48) reported a loss of quadriceps cross-sectional area (approximately 13%) in both the BFR and non-BFR groups 14 days post-ACLR, with no significant difference between the groups. Methodological differences in the Iversen study may explain these findings. Participants started from a higher level of muscle function, resulting in fewer impairments to overcome. Additionally, the Iversen study used a wider cuff compared to other studies and did not individually adjust the restrictive pressure for each participant, likely failing to effectively limit arterial inflow and venous outflow in the exercising muscle group. Furthermore, the initiation timeframe for BFR training may have influenced the results, as participants did not begin using an occlusion cuff until 10 days post-surgery.

Although most of the mentioned studies support the efficacy of BFR training in maintaining or improving muscle size in ACL-reconstructed patients, this benefit remains inconclusive, and the literature on this topic is heterogeneous.Multiple potential confounding factors affect the efficacy of BFR training, including the population, assessment method, condition, exercise protocol, and intervention timing. The high variability in assessment methods and protocols highlighted in this review, underscores the importance of standardized methodologies and protocols when employing BFR training in rehabilitation clinical practice and research.

BFR training effect on muscle strength

Although each study in this domain employed distinct methodologies regarding BFR application and protocols, the majority reported that BFR enhances muscle strength compared to standard non-occlusion rehabilitation (44, 45, 49, 50).

De Melo *et al.* (50) assessed the isometric muscle strength of the quadriceps and hamstrings using a portable dynamometer preoperatively and immediately post-ACLR at 4, 8, and 12 weeks. Their findings indicated that the group utilizing BFR with lower training loads exhibited significantly greater muscle strength improvements over a shorter rehabilitation period compared to the group performing rehabilitation exercises with higher loads. A meta-analysis by Fernández *et al.* (51) observed strength gains in knee flexors and extensors through BFR training. Additionally in a study conducted by Roman *et al.* (52), the adolescent population demonstrated a clinically relevant difference, with the BFR training group showing 20% greater isometric knee extension peak torque and 23% greater isokinetic knee extension peak torque in the ACLR limb compared to the control group. Kong *et al.* (53) evaluated the application of NMES and BFR post-ACL reconstruction and found it effective in enhancing the muscle strength and endurance of the quadriceps and biceps femoris compared to the control group.

BFR training in the preoperative setting before ACLR was examined in two studies (49, 54). Both studies implemented protocols within 10 days before surgery, involving only five sessions. While one study demonstrated improved muscle endurance postoperatively, neither showed any clinical effect on quadriceps femoris muscle strength postoperatively. The systematic review by Barber-Westin and Noyes (55) concluded that a minimum of 12 sessions is necessary to achieve measurable strength gains with BFR training. Therefore, a preconditioning period with longer duration and higher frequency is recommended to enhance muscle strength and prevent atrophy. With only two identified studies utilizing BFR preoperatively, the clinical benefit of this training remains unclear.

The study by Hughes *et al.* (30) was the only study that did not observe significant strength gains between the BFR and non-BFR groups. However, the control group performed heavy-load resistance training, and the BFR group showed similar muscle strength improvements to the heavy-load resistance training group post-ACLR and rehabilitation, indicating that BFR resistance training can enhance skeletal muscle strength to a similar extent as heavy-load resistance training.

It appears that BFR training, post-ACL reconstruction can be beneficial for muscle strength compared to non-BFR training. However, more randomized controlled trials with operational definitions, standardized intervention protocols, and outcome measurements are needed to provide further evidence on the clinical value of BFR training.

BFR training effect on pain

Pain in the knee joint was measured using a numerical rating scale in two investigations, while another utilized the Knee Injury and Osteoarthritis Outcome Score (KOOS) for pain assessment (30, 56, 57). Evaluations were conducted after each session, 24 hours post-exercise, or 10 weeks postoperatively (30, 56, 57). Two studies reported significantly lower knee pain scores with low-load blood flow restriction training compared to non-BFR training (56, 57). Additionally, one study found a significantly greater increase in KOOS pain scores following LL-BFR training compared to non-BFR training (30).

All studies employed high-load resistance (HLR) training as the non-BFR protocol. Consequently, the observed pain relief may be attributed to the lower external loads and hypoalgesic effects of LL-BFR training compared to HLR training.

This review provides evidence supporting the use of LL-BFR, as three studies evaluating pain reported enhanced pain relief with LL-BFR training compared to non-BFR training in patients undergoing ACL surgery.

BFR training effect on function

Hughes *et al.* (30) found that participants undergoing BFR resistance training exhibited significantly greater improvements in self-reported function and Star Excursion Balance Test (SEBT) performance. These enhancements may be attributed to the substantial reduction in pain and effusion, as well as improved range of motion (ROM).Similarly, Roman *et al.* (52) investigated the impact of BFR on the rehabilitation of adolescents. Their study revealed that the BFR training group showed superior self-reported function, as measured by the Pediatric International Knee Documentation Committee (Pedi-IKDC) scores, compared to the control group. Additionally, significant improvements in Pedi-IKDC scores were observed over time within the BFR training group.

These findings underscore the potential of BFR training as an early intervention in rehabilitation, leading to enhanced subjective outcomes throughout the rehabilitation process.

BFR training effect on dynamic balance

The research conducted by Kong *et al.* (53) demonstrated that incorporating neuromuscular electrical stimulation and blood flow restriction post-ACL reconstruction significantly enhanced participants' performance in the Y Balance Test (YBT), a measure of dynamic balance. The YBT scores were found to correlate with peak torque of knee extensors and flexors in individuals who had undergone ACL reconstruction (58, 59). Moreover, prior studies have indicated that the anterior reach component of the YBT tends to decrease following standard rehabilitation in ACL reconstruction patients (60,61). Consequently, the observed improvement in anterior reach following BFR application is a noteworthy finding.

BFR training effect on comfort and willingness to use

In research conducted by Telfer *et al.* (62), participants reported that performing step-up exercises with blood flow restriction was significantly more challenging and uncomfortable compared to exercises without restriction. Despite this increased difficulty and discomfort, participants' willingness to pursue the technique remained unaffected.

BFR training effect on bone mass and bone mineral density

In the research conducted by Jack *et al.* (47), it was found that incorporating blood flow restriction significantly mitigated the reduction of lower extremity lean mass, body mass, and bone mineral density over a 12-week rehabilitation period following anterior cruciate ligament reconstruction.

BFR training effect on return to sport

Jack *et al.* (47) reported a reduction in return-to-sport (RTS) time for the BFR group compared to the control group in their study. Conversely, Devana *et al.* (63) found that student athletes undergoing BFR training experienced significantly longer RTS times compared to those receiving traditional physical therapy alone post-ACLR (409 *vs.* 332 days).Previous research on elite athletes' RTS post-ACLR has indicated a range of 6 to 13 months from surgery (64). In this study, the BFR training cohort had longer RTS times than the non-BFR group, averaging 13.45 months post-ACLR, which exceeds the published range.

These findings highlight the variability in BFR's effectiveness on RTS, underscoring the need for more randomized controlled trials with standardized intervention protocols and specific populations.

BFR training effect on ACL graft laxity

Two investigations employed a knee ligament arthrometer to assess alterations in ACL graft laxity (30, 44) with measurements taken pre-operatively and between 10 to 16 weeks postoperatively. The results indicated no significant differences in ACL graft laxity between low-load blood flow restriction training and non-BFR training.

Further randomized controlled trials are necessary to determine the impact of LL-BFR training on ACL graft laxity in comparison to high-load resistance training.

Conclusion

Blood flow restriction training is a relatively novel approach, and thus, the body of evidence assessing its effectiveness in ACL rehabilitation is limited. This narrative review suggests that BFRT post-ACL reconstruction may offer advantages in terms of muscle strength, muscle mass, bone mineral density, balance, knee joint pain, and function when compared to non-BFR training, without adversely affecting ACL graft laxity. However, the review also underscores the necessity for high-quality research to fully elucidate the impact of BFRT on patients who have undergone ACL reconstruction.

The variability in methodologies across existing studies, including differences in study duration, exercise parameters, and outcome measures, contributes to inconsistencies in the reported results. This lack of standardization hinders the generalizability of findings. Therefore, future research on BFRT should prioritize larger sample sizes, standardized BFR and exercise protocols, clearly defined outcome measures, and sufficient study durations to allow for muscular adaptations. Such rigorous studies will enable more effective application of BFRT in rehabilitation settings.

Additionally, future investigations should explore the effects of preconditioning with BFRT prior to surgery, employing protocols with extended duration and frequency to determine its potential benefits.

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Conflict of interest

None.

Authors' contributions

AK: Data collection and evaluation, MMR: formal analysis, investigation, methodology and supervision, SMH: writing, original draft, investigation, and methodology All of authors made substantial contributions to the conception, design, and interpretation of data.

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