Blood Flow Restriction Rehabilitation for Extremity Weakness: A Case Series

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ABSTRACT

Background: Blood flow restricted (BFR) training, the brief and partial restriction of venous outflow of an extremity during low load resistance exercises, is a safe and effective method of improving strength in healthy, active individuals. A relatively unexplored potential of this adjunctive modality lies in treating patients with severe musculoskeletal trauma, persistent chronic quadriceps and hamstring weakness despite traditional therapy, and low improvement during early postoperative strengthening. **Methods:** This case series describes patients with chronic quadriceps and hamstring weakness who received an intervention of BFR at low loads, 20% of 1 repetition max (1RM), to restore strength. A case series was conducted of seven patients, all located at one hospital and all with traumatic lower extremity injuries. The seven patients were treated at the same medical center and with the same BFR protocol. All seven patients had isokinetic dynamometer testing that showed persistent thigh muscle weakness despite previous rehabilitation with traditional therapy and 35% to 75% peak torque deficit in either knee extension or flexion compared with the contralateral lower extremity. Patients underwent 2 weeks of BFR training therapy using a pneumatic tourniquet set at 110mmHg while performing leg extensions, leg presses, and reverse leg presses. All affected extremities were retested after 2 weeks (six treatment sessions). Dynamometer measurements were done with flexion and extension at two speeds: 90º and 300º/sec. The data recorded included peak torque normalized for body weight, average power, and total work. **Results:** All seven patients demonstrated improvements in peak torque, average power, and total work for both knee flexion and extension, with power being the most improved overall. Peak torque improved an average of 13% to 37%, depending on contraction direction and speed. Average power improved an average of 42% to 81%, and total work improved an average of 35% to 55%. **Conclusion:** BFR therapy at low loads can affect improvement in muscle strength in patients who are unable to perform high-resistance exercise or patients who have persistent extremity weakness despite traditional therapy.

KEYWORDS: *strengthening, muscle mass, tourniquet, physical therapy, blood flow restriction, vascular occlusion*

Introduction

BFR training has been studied in the preclinical setting through animal testing, primarily in an equine model.[1] Preliminary clinical testing includes low-intensity walk-training in the elderly and more targeted studies looking at the muscle of younger, healthy subjects; the combination of these studies show BFR training being linked to changes in hormones, myogenic stem cell proliferation, and protein synthesis.[1–7] It has also been proved to be safe and effective in achieving muscular strength and hypertrophy in healthy adults or in elderly patients with sarcopenia.[3,8,9] BFR training is not widely used in rehabilitation for chronic muscle weakness secondary to trauma. Based on a search of the literature through online databases (using "occlusion training" or "blood flow restriction" and "rehabilitation" or "physical therapy"), this case series is the first to incorporate BFR use as part of a physical therapy rehabilitation protocol in a patient population who has difficulty performing high-resistance exercises due to their injuries.

Discussion

Rehabilitation programs primarily focus on regaining muscular strength and endurance, but need to include restoration of joint range of motion (ROM). Muscles must be strong enough to withstand long periods of physical activity to improve proprioception, independence in daily living activities, and (lost or weakened) sports-specific or job-specific skills.

Because strength is such an important foundation, the American College of Sports Medicine (ACSM) published guidelines on the best resistance training practices to achieve the goals of strength, power, and endurance.[10] The recommended muscular load for a given resistance exercise ranges from 60% to 100% of the one-repetition maximum (1RM).[10] Traditionally, loads less than this do not achieve type II muscle recruitment, muscle hypertrophy and strength, and improvement in endurance during resistance training.[7,11]

An issue inherent in the ACSM guidelines, when applied to musculoskeletal injuries, is that some patients are unable to tolerate these high resistance loads due to instability, pain, post-traumatic osteoarthritis, neurologic deficits, volumetric muscle loss, or postsurgical restrictions.[12–16] BFR therapy, however, is not hindered by the same limitations.[16] This modality improves muscular strength and power with resistance at 20% 1RM, changes that are typically only seen when exercising at 80% of an individual's 1RM.[1,17–19] As a result, we believe that orthopedic-injured rehabilitation patients who are unable to tolerate heavy mechanical loads may benefit from low load BFR training.

This low-intensity exercise paired with restricted muscular venous blood flow was first developed with the intent of restricting venous outflow and thus increasing fatigue of the affected muscle at low-intensity resistance.[18,20] Early human studies indicate muscle hypertrophy and strength gains in healthy adults and eldery patients with sarcopenia.[2,3,8,19] Some studies have also indicated that BFR maintains these gains for a longer duration after training compared with standard practices. [6]

A persistent problem in chronic injuries, especially in the extremities, is regaining the required strength and endurance of atrophied or traumatized musculature.[21] This is demonstrated repeatedly in the literature where even relatively simple lower extremity fractures can leave patients with strength deficits years after their injury.[22-26] An example of the pervasiveness of this problem was demonstrated by Lebrun, who studied patients with patella fractures.[26] Even years after operative treatment and bone healing, patients continued to show functional deficits, including an average 30% deficit in knee extension power. [26] Neuromuscular recruitment is the initial step in the rehabilitation process, but once this is achieved further gains must be made with muscle hypertrophy as muscle regeneration is limited.[14,15,27] Trauma-induced musculoskeletal injuries are associated with several factors that limit rehabilitation.[21,27] A common factor is the frequent post-operative restriction on strengthening following fixation of fractures or reconstruction of soft tissue injuries.[13,15,21] Another is volumetric muscle loss, which has emerged as a debilitating condition for wounded Servicemembers due to associated functional weakness.[21,28,29] There are no current solutions for functionally addressing volumetric muscle loss for these patients.[21]

Previous studies have demonstrated that with BFR training, individuals obtain significant strength gains, improved muscular endurance, and muscle hypertrophy.[1,20,30] Both elderly populations and healthy, young athletes improve ambulation and muscular strength.[2,3,8,19] Patients benefit from BFR who cannot participate in traditional strength-training exercises or those with chronic muscle weakness. Due to these solid, projected benefits, BFR has been incorporated into a supervised physical therapy program for patients with chronic muscle weakness after trauma at our institution.

Methods

Participants

All seven patients were seen at our facility, a rehabilitation center dedicated to active duty Servicemembers. The patients had attended regular physical therapy sessions for lower extremity rehabilitation for a variety of reasons. All had chronic quadriceps and/or hamstring muscle weakness and were at least 3 months from their last surgical procedure, and their strength improvement was limited by their inability to successfully use traditional resistance training. To objectively monitor improvements in strength, our patients were tested with a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Inc; http://www.biodex.com/). All individuals had their contralateral extremity measured for comparison, but some patients also had bilateral rehabilitation needs. All patients had dynamometer measurements for the affected lower extremity on at least two occasions during their course of treatment and were using BFR therapy as part of their rehabilitation routine for a minimum of 2 weeks (six treatment sessions).

The BFR therapy resistance training at our facility is the same for all lower extremity rehabilitation patients. The equipment used includes a Hokanson AG 101 cuff insulator air source, E20 rapid cuff inflator, and cc17 thigh cuff (Hokanson, Bellevue, WA 98005). All patients participated in BFR training 3 days a week for 2 weeks during their physical therapy sessions. Initially, all exercises were performed without BFR to determine the individual's one repetition maximum (1RM). Then, an appropriately sized cuff was selected so that it fit around the patient's thigh, as proximal to the groin as comfortable, and covered approximately one-third of the thigh length. The weight for each individual exercise started at no more than 20% of the patient's measured 1RM of the injured limb. With the cuff inflated to 110mmHg for the duration of one exercise performance, each exercise (knee extension, leg press, and reverse leg press) was performed in four sets, each set to failure, with a 30-second rest between sets. All sets for the knee extension were performed before moving to the leg press and later the reverse leg press. The time to reach muscle failure was recorded for each of the four sets. When a patient was able to perform any one set for more than 120 seconds before failure, the weight for that exercise was increased by 10% to allow for progression of resistance.

After 2 weeks (six treatment sessions) of BFR training, the patients' involved extremities were again measured on the Biodex dynamometer and compared with previous values. Those patients being presented are individuals who started BFR training from July through December 2013, had bilateral lower extremities measured with the dynamometer, and had two sets of dynamometer measurements (before and after 2 weeks of BFR training) for the affected extremity available for review.

Case Presentation 1

The patient is a 37-year-old man who sustained a right ankle inversion injury in 2005. He did not have an associated fracture; however, he did have persistent ankle instability following multiple soft tissue surgical procedures, the last in 2010. He was referred to us after 2 years of rehabilitation, which failed to return him to a satisfactory level of function, to be fit for a specialized brace, the Intrepid Dynamic Exoskeletal Orthosis (IDEO™; TechLink, http://techlinkcenter.org/summaries/ideo%E2%84%A2-intrepid-dynamic-exoskeletal-orthosis).

Initial Biodex testing demonstrated a 36% deficit in knee flexion peak torque in the right lower extremity as compared with the contralateral side (Table 1) at the 90º/sec speed. His weakness was more significant for knee flexion than knee extension. His deficits in power and work are shown on Tables 2 and 3. He initiated our institution's BFR training program; and after 2 weeks, the patient showed a 53% increase in peak torque and a 69% increase in both power and work performed on the right lower extremity for flexion (Tables 4–6).

Table 1 *Percent Difference Peak Torque (%)*

Case	Extension Speed 1	Flexion Speed 1	Extension Speed 2	Flexion Speed 2
1	21.6	36.4	–0.5	–17.7
2	51.9	29.5	43.3	25.0
3	42.7	–10.6	–95.0	–29.8
4	67.3	37.0	53.8	29.8
5	49.4	28.1	38.9	20.8
6	65.3	64.7	49.3	53.6
7	55.1	36.9	32.3	31.8

Notes: Peak torque difference of the affected to the nonaffected extremity, with all values normalized by body weight and given as a percentage. Speed 1 is 90º/sec. Speed 2 is 300º/sec. Negative values indicate no deficit compared with contralateral extremity.

Table 2 *Percent Difference Average Power (%)*

Case	Extension Speed 1	Flexion Speed 1	Extension Speed 2	Flexion Speed 2
1	23.4	34.5	–12.2	–2.2
2	61.1	38.9	14.1	0.7
3	56.3	–0.3	–128.2	–178.6
4	75.9	45.9	73.2	58.5
5	39.3	21.1	41.3	13.9
6	71.0	70.6	72.5	84.8
7	45.1	45.3	35.8	22.0

Notes: Average power difference of the affected to the nonaffected extremity, expressed as a percentage. Speed 1 is 90º/sec. Speed 2 is 300º/sec.

Table 3 *Percent Difference Total Work (%)*

Case	Extension Speed 1	Flexion Speed 1	Extension Speed 2	Flexion Speed 2
1	24.5	36.1	–5.1	–2.5
2	57.7	31.3	31.8	9.1
3	58.8	7.7	102.5	143.5
4	73.8	38.5	72.9	43.2
5	39.8	19.5	34.8	11.0
6	68.2	71.6	70.2	84.2
7	50.8	47.9	43.7	35.4

Notes: Average total work difference of the affected to the nonaffected extremity, expressed as percentage. Speed 1 is 90º/sec. Speed 2 is 300º/sec.

Table 4 *Change in Peak Torque (%)*

Case	Extension Speed 1	Flexion Speed 1	Extension Speed 2	Flexion Speed 2
1	2.5	53.5	–15.3	21.3
2	27.2	25.3	25.9	11.7
3	63.1	9.8	21.2	18.2
4	13.4	2.3	35.8	19.4
5	25.9	25.3	16.7	4.3
6	35.9	73	33.2	52.4
7	65.8	12.2	–1.7	25.6

Notes: All measurements are affected extremity comparing peak torque (Nm) after 2 weeks of BFR training to baseline measurement before BFR training started, expressed as a percentage. Speed 1 is 90º/sec. Speed 2 is 300º/sec.

Case Presentation 2

The patient is a 48-year-old man who was in a motorcycle accident in 2009 and sustained a left tibia plateau fracture and ipsilateral tibia plafond fracture. Due to the severity of his injuries, he was initially placed in a knee and ankle spanning external fixator and subsequently treated with definitive internal fixation. Since that time, he has continued to have weakness and limited function of his left lower extremity. Due to persistent knee pain, he was considering

Table 5 *Change in Average Power (%)*

Case	Extension Speed 1	Flexion Speed 1	Extension Speed 2	Flexion Speed 2
1	14.2	70.1	–11.9	47.4
2	42.2	19	33.5	90.9
3	7.6	26.2	44.5	29.4
4	12.8	24.8	29.2	47.1
5	33.2	35	29.4	18.3
6	76.4	102.5	108.4	212.1
7	75.3	63.6	79.7	86.1

Notes: All measurements are affected extremity comparing power (W) after 2 weeks of BFR training to baseline measurement before BFR training started, expressed as percentage. Speed 1 is 90º/sec. Speed 2 is 300º/sec.

Table 6 *Change in Total Work (%)*

Case	Extension Speed 1	Flexion Speed 1	Extension Speed 2	Flexion Speed 2
1	7	69.6	–13.6	49.5
2	27.3	3.9	22.8	-20.1
3	77.6	17.1	34.9	26.3
4	26.1	6.4	54.1	20.8
5	24.8	25.2	26.9	17.9
6	40.8	64.8	77.3	159.4
7	62.7	61.9	63.4	78.7

Notes: All measurements are affected extremity comparing work (J) after 2 weeks of BFR training to baseline measurement before BFR training started, expressed as percentage. Speed 1 is 90º/sec. Speed 2 is 300º/sec.

total knee replacement surgery; however, he first needed to increase his quadriceps strength and function. He was referred for BFR training 4 years after his last surgery.

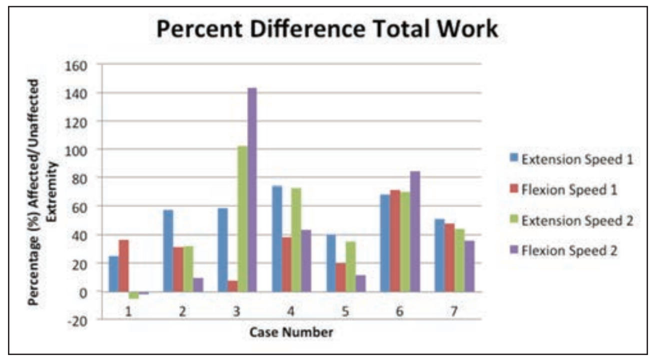
Initial Biodex testing demonstrated a more significant deficit in knee extension, with a 52% deficit in peak torque (Table 1), 61% deficit in average power (Table 2), and 57% deficit in knee extension total work in the left lower extremity compared with the contralateral side (Table 3), with the largest deficits shown in extension at 90º/sec. After 2 weeks of BFR therapy, he had a 42% increase in power (Table 5) and a 27% increase in both peak torque (Table 4) and total work (Table 6) at 90º/sec.

Case Presentation 3

The patient is a 24-year-old man who sustained major left lower extremity trauma in 2011 resulting in tibia plafond, fibula, and calcaneus fractures. He subsequently underwent multiple surgical interventions for management of his injuries and most recently had a right knee arthroscopy to include microfracture. He was referred for BFR training for his right lower extremity 6 months after his most recent surgery.

The patient had an initial bilateral Biodex test performed; however, the ability to compare strength to the contralateral limb was limited because of trauma sustained to his lower left extremity 2 years earlier. He had a 43% deficit in peak torque (Table 1), 56% deficit in average power (Table 2), and 58% deficit in total work (Table 3), all with knee extension at 90º/sec. He demonstrated deficiency at 300º/sec only in total work (Table 3). After 2 weeks of training on the right lower extremity, the patient's improvements were greatest in extension at 90º/sec with peak torque increasing 63% (Table 4), average power 8% (Table 5), and total work 77% (Table 6, Figure 1).

Figure 1 *Average percent total work difference of the affected to the nonaffected extremity. Speed 1 is 90º/sec. Speed 2 is 300º/sec.*



Case Presentation 4

The patient is a 26-year-old man who in 2009 sustained a gunshot wound to the right femur. He underwent open reduction and internal fixation, but subsequently developed osteomyelitis. After a prolonged course of treatment—including removal of all hardware, multiple debridements, and both local and systemic antibiotics—his fracture healed following revision fixation in 2011. To treat an acquired quadriceps contracture, he had a soft-tissue release approximately 1 year later. He was referred for BFR training 1 year after his last surgery.

His knee extension weakness was substantial, with a deficit in peak torque of 67% and 54% compared with the contralateral limb at 90º/sec and 300º/sec, respectively (Table 1). Average power showed 76% and 73% deficits in knee extension (Table 2), and total work showed 74% and 73% deficits in knee extension (Table 3). After 2 weeks of BFR training, his peak torque improved 13% and 36% (Table 4), average power improved 13% and 29% (Table 5), and total work improved 26% and 54% at 90º/sec and 300º/sec, respectively (Table 6).

Case Presentation 5

The patient is a 29-year-old man who in 2010 sustained left open tibia and fibula fractures from an improvised explosive device blast injury. He underwent limb salvage treatment for approximately 2 years including placement of a ringed external fixator and bone transport for significant bone loss. He was definitively treated with an intramedullary tibia nail following ringed fixator removal. He was referred for BFR training 9 months after his last surgery.

Initial Biodex testing showed 49% peak torque (Table 1), 39% deficit average power (Table 2), and 40% deficit in total work (Table 3) in knee extension at 90º/sec. After 2 weeks of BFR therapy, he improved peak torque by 26% (Table 4), power by 33% (Table 5), and total work by 25% (Table 6) at the same extension speed and similar improvement in knee extension at 300º/sec as well.

Case Presentation 6

The patient is a 27-year-old man who 2012 sustained a right tibia plafond fracture with associated fibula and calcaneus fractures from an improvised explosive device. He underwent limb salvage to include placement of an ankle-spanning ringed fixator, which was removed over 1 year later, after the patient had healed. He was referred for BFR training 6 months after his last surgery.

Initial Biodex testing showed substantial weakness with both knee extension and flexion with a peak torque deficit of 49% to 65% (Table 1), an average power deficit of 71% to 85% (Table 2), and a total work deficit of 70% to 84% (Table 3). After 2 weeks of BFR therapy, he improved his peak torque by 33% to 73% (Table 4), average power by 76% to 212% (Table 5), and total work by 40% to 160% (Table 6).

Case Presentation 7

The patient is a 48-year-old man who in May 2013 sustained a comminuted left open calcaneus fracture due to a motor vehicle collision. Two months after his injury, he underwent staged procedures for extensive debridement followed by delayed closure with local rotated flap coverage. His calcaneus healed without hardware placement due to the significant damage. He was referred for BFR training 5 months after his last surgery.

Initial Biodex testing showed deficits in all measurements; however, the largest difference extensions were at 90º/sec. At this speed, his knee extension demonstrated a 55% deficit in peak torque (Table 1), 45% deficit in average power (Table 2), and 50% deficit in total work (Table 3). After 2 weeks of BFR therapy, his knee extension at 90º/sec improved peak torque 66% (Table 4), average power 75% (Table 5), and total work 63% (Table 6; Figure 2).

During the 2 weeks of BFR training, all patients were directly monitored by experienced physical therapists. None of the patients experienced any adverse events due to the training during this time. The only side effect experienced was immediate muscle soreness, which, per patient report, resolved by the next therapy session.

Lessons Learned

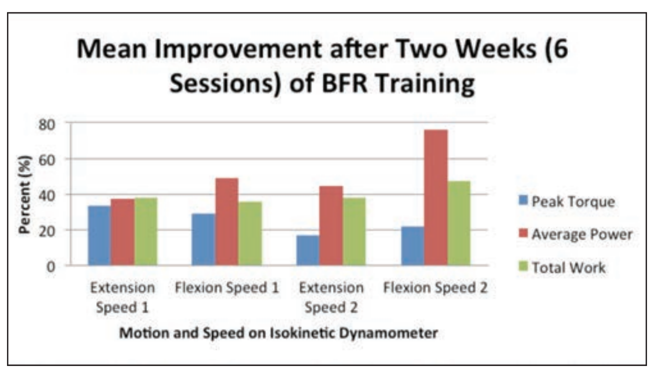
All of the patients in this series demonstrated improvements in knee extension and/or flexion testing after only 2 weeks of BFR training. The average gains in peak torque, average power, and total work are summarized on Table 7 and depicted in Figure 2.

Table 7 *Mean Changes After BFR Training (%)*

Measurement	Extension Speed 1	Flexion Speed 1	Extension Speed 2	Flexion Speed 2
Peak torque	33.4 ± 23.8	28.8 ± 25.6	16.5 ± 18.7	21.8 ± 15.2
	2.5 to 65.8	2.3 to 73	–15.3 to 35.8	4.3 to 52.4
Average power	37.4 ± 29.0	48.7 ± 30.9	44.7 ± 38.9	75.9 ± 65.8
	7.6 to 76.4	19.0 to 102.5	–11.9 to 108.4	18.3 to 212.1
Total work	38.0 ± 24.4	35.6 ± 28.9	38.0 ± 30.2	47.5 ± 57.9
	7.0 to 77.6	3.9 to 69.6	–13.6 to 77.3	–20.1 to 159.4

Notes: Mean ± SD with range of torque (Nm), power (W), and work (J) for all seven patients in case series. Speed 1 is 90º/sec. Speed 2 is 300º/sec.

Figure 2 *Mean change in peak torque (Nm), power (W), and work (J) for all seven patients in case series after 2 weeks (six sessions) of BFR training. Speed 1 is 90º/sec. Speed 2 is 300º/sec.*



Of note, some patients improved their peak torque in knee flexion more than knee extension, with the improvement in knee extension being less consistent. All patients had improvement in their average power, which was the most consistent strength gain demonstrated for all measurements. Total work was also improved in all cases.

Several of the individual gains were modest; however, it is important to recognize that these patients still had objective improvements with BFR training despite chronic muscle weakness that was resistant to prior standard rehabilitation techniques. These strength gains are important to improve patient functional outcomes.

This series demonstrated that BFR training is not only effective but also a safe method of improving strength in healthy, active individuals, which has been demonstrated in prior studies.[2,16,17,19,31–33] No patients in this series experienced any complications associated with the BFR training, and all patients were able to complete the 2 weeks of training. The patients in this case series achieved strength gains while training with weight that is at 20% of their 1RM. This is a much lighter load than what is recommended by the ACSM weight-training guidelines for standard resistance training. The lower load training may be beneficial for patients who are unable to tolerate heavier loads due to various reasons such as restrictions in the early postoperative period. Contrary to BFR training, traditional strength-training required loads up to 80% of the 1RM to affect muscle strength.[10]

Clinically, the applications for BFR training have continued to expand. The majority of studies evaluating BFR training have been performed on normal, healthy, active human subjects showing strength improvements in individuals both new to a strengthening program [5] and when expanding on a previous intense resistance exercise regimen. One example of the latter is a study by Yamanaka et al. demonstrating an increase in strength after 4 weeks of BFR training in college football players, including those who had already completed their regular training routine.[19]

Other studies have evaluated the implications of BFR training for elderly adults with sarcopenia, the loss of muscle mass with age.[8,9] This population often does not have the capacity to perform high-resistance exercises that would normally be required for significant strength gains. BFR training in these patients has improved muscle strength and maintained muscle mass.[8,9] It demonstrated success when used for rehabilitation of patients with with inflammatory myopathies as well. [34,35]

Our case series is the first known example to implement BFR training into a physical therapy program for chronic muscle weakness in patients with musuloskeletal trauma. The series of cases presented are evidence that strength gains can be achieved in a relatively short amount of time (2 weeks) using this low resistence therapy modality in these patients.

Future research is needed to determine if the improvements seen with BFR training are superior to standard therapy. In addition, follow-on evaluations are necessary to determine if the successful results obtained in this series persist in the long term. If this training method benefits chronic muscle weakness patients, it offers a new therapy to improve the functionality, and thus the independence and lives of our wounded Servicemembers and others with chronic muscle weakness.

Conclusion

This case series demonstrated that BFR training at low loads is an effective tool when used as part of a rehabilitation program in individuals with chronic thigh weakness.

Disclaimers

The view(s) expressed herein are those of the author(s) and do not reflect the official policy or position of Brooke Army Medical Center, the US Army Medical Department, the US Army Office of the Surgeon General, the Department of the Army, or Department of Defense or the US government.

Disclosures

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