Sheley et al. (2018) *Int J Res Ex Phys*. 14(1):10-20.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

International Journal of Research in Exercise Physiology

Original Research Article

Personalized Blood Flow Restriction: a Pilot Study for Total Knee Arthroplasty Rehabilitation

Stephanie R. Sheley[1], Todd Ward[2], Blake C. Clifton[3], Christina A. Buchanan[1]
[1]High Altitude Exercise Physiology Program, Western State Colorado University, Gunnison, CO, USA
[2]Rehabilitation and Sports Medicine Program, Gunnison Valley Health, Gunnison, CO, USA
[3]gO Orthopedics, Gunnison, CO, USA

Abstract

Introduction: This study examined the effects of personalized blood flow restriction (PBFR) on quadriceps girth following a total knee arthroplasty (TKA). **Methods:** 6 individuals participated (CON: n=3, R: n=3). PBFR paired with light intensity resistance training (LIRT) was administered 4 weeks postoperative for 9-weeks, 2 times per week. Girth measurements at 10cm and 15cm above the knee joint were taken 1, 4, and 12 weeks postoperative for CON and R-groups. The control group participated in traditional physical therapy modalities that did not include BFR. **Results:** The study found that PBFR training is 87.5% likely beneficial at increasing quadriceps girth at 10cm above the knee joint, and 92.8% likely beneficial at increasing quadriceps girth at 15cm above the knee joint. **Conclusion:** This study demonstrates that PBFR+LIRT can be an effective modality for increasing quadriceps girth, when used in conjunction with a rehabilitation program following a TKA.

Key Words: Joint Replacement, Muscle Atrophy, Occlusion Training, Physical Therapy, Postoperative

Introduction

The practice of exercising with blood flow restriction (BFR) has been around for 40 years. Blood flow restriction training was popularized in Japan by Yoshiaki Sato and is now known as Kaatsu training[1]. Personalized BFR (PBFR) training is performed with a specialized tourniquet unit where a cuff is placed on the proximal part of the limb. This cuff provides a personalized occlusion rate, typically 80%, based on the individual's arterial pressure. The occlusion pressure can range from 120-230 mmHg for an individual. BFR has been demonstrated to stimulate muscle protein synthesis cascades, resulting in muscle hypertrophy and strength gains while working at lower loads, typically 20-30% of 1 repetition maximum (1RM)[1-2]. According to the American College of Sports Medicine (ACSM), in order to see strength gains and muscle hypertrophy, a high intensity resistance training protocol at workloads between 70-90% of 1RM, must be implemented[3]. By occluding blood flow to a working limb anaerobic metabolites build up, causing extra stress to the muscle tissue. This hypoxic environment and extra stress from a buildup of metabolites results in several signal cascades that initiate the upregulation for muscle protein synthesis and muscle fiber recruitment[4].

Based on the known effects that BFR has on hypertrophy and muscle strength, many research studies have examined its use for sports performance[1-2]. Several professional teams including the NFL, NHL, MLB, and NBA are currently using BFR training as a way to increase athletic performance and enhance injury recovery time. However, little research has been done to look at the possible benefits of BFR in a clinical setting for postoperative joint replacement patients. BFR has been utilized to help improve limb strength for wounded U.S. soldiers and postoperative patients.

In patients recovering from injury or surgery there is a reduction in muscle use which results in a substantial loss in muscle mass and strength. Muscle loss occurs at a rate of 0.5%-0.6% per day during limb immobilization[5]. After 5 days of limb immobilization it has been demonstrated that there is a 3.4% decrease in muscle cross sectional area (CSA) and a 9.0% loss of muscle strength[5]. Due to postoperative limitations on weight bearing and limb use, patients are not able to engage in a typical resistance exercise program. BFR allows these patients to still work their postoperative limb at lighter loads while not overworking the injured muscle tissue and joints, potentially accruing the benefits seen with traditional high-resistance training. The novel idea of incorporating BFR post-joint replacement surgery is an area slowly gaining interest for research.

Currently, most postoperative research has focused on BFR and anterior cruciate ligament (ACL) reconstruction. When looking at a 16 week protocol with BFR for post-ACL, a significant increase in muscular strength was found in the BFR group vs. no-BFR group[6]. Furthermore, BFR combined with low-intensity resistance training for post-operative ACL patients has been shown to reduce the amount of atrophy in the quadriceps and hamstrings[6]. When utilizing BFR on postoperative knee arthroscopic patients, a significant increase in thigh CSA and knee extensor strength was found[7]. In summary, current research supports that BFR can help postoperative ACL reconstruction and arthroscopic knee patients reduce post-surgery atrophy and strength loss[6-7]. However, little research has been done to look at the possible effectiveness of BFR therapy on total knee arthroplasty (TKA). Therefore, the purpose of this study was to determine the effectiveness of PBFR training as a therapy for reducing muscle atrophy post-TKA. We hypothesized that the post-TKA patients using BFR will have a significant reduction in muscle atrophy, compared to a usual care control group.

Methods

Participants

Six participants, 4-weeks post-TKA volunteered for the study. All participants underwent a TKA procedure performed by the same orthopedic surgeon. All participants were cleared by the orthopedic surgeon and their physical therapist to participate in the study. All 6 participants went to Gunnison Valley Health (Gunnison, Colorado) for physical therapy (PT). Three of the participants gave consent to participate in the experimental group (R-group) which received PBFR training. The other 3 participants chose not to participate in the BFR treatment and were placed in the control group (CON-group). Participant descriptors can be seen in Table 1.

Table 1. Participant descriptors for both the experimental R-group (BFR) and control groups.

Parameter	BFR	Control
Age (years)	59.33±11.59	63±6.55
Sex	1M, 2F	3F
Occlusion % (mmHg)	161.7±32.21	---
Total Length of PT	12 weeks	12 weeks
Initial LEFS	25	20
12 week LEFS	67	54

Values are mean ± SD. M: Male, F: Female, mmHg: millimeters of Mercury, PT: physical therapy, LEFS: lower extremity functional scale.

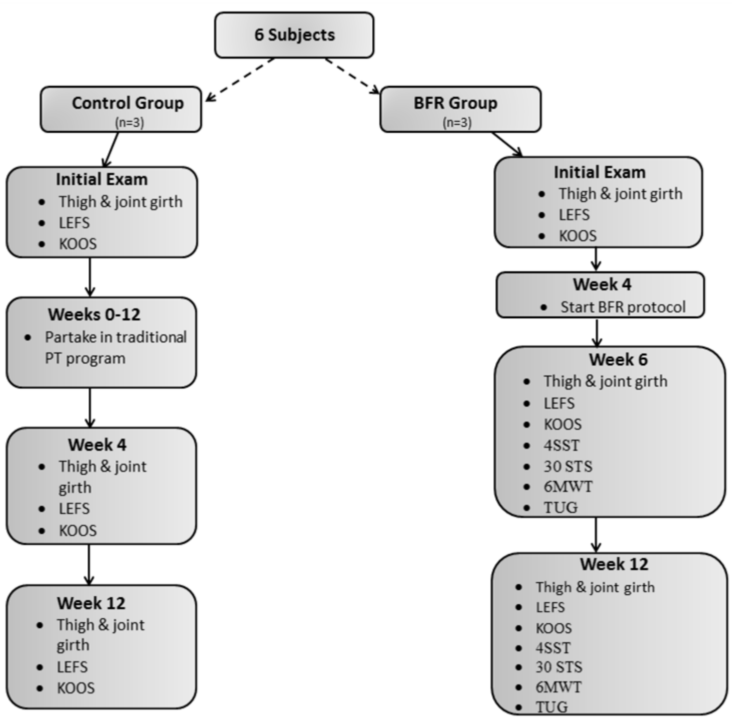

Figure 1. Experimental Flow Chart. Blood flow restriction (BFR), lower extremity functional scale (LEFS), knee osteoarthritis outcome score (KOOS), 4 square step test (4SST), 30 second sit to stand (30STS), 6-minute walk test (6MWT), timed up and go (TUG). BFR group started BFR 4 weeks post-op.

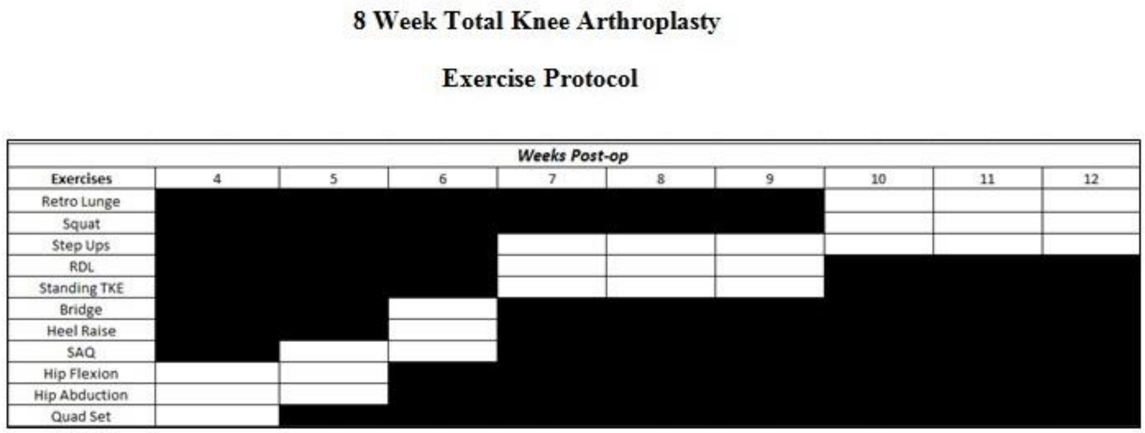

Figure 2. BFR exercise protocol. White squares indicate exercises to be performed for that week. Weight was progressively increased as tolerated for each BFR participant.

Experimental Design

This was a between groups, quasi-experimental design in which the participants were required to participate in 12-weeks of PT. The R-group was required to participate in 18 PT sessions of PBFR over a nine-week time frame. R-group started BFR 4-weeks post-TKA to allow enough time for proper wound healing. All participants in the CON-group participated in normal PT modalities and received standard care. Both groups received PT exercises based on the orthopedic surgeon's post-TKA protocol. Baseline measurements were taken on the participant's initial evaluation for PT, which included the knee osteoarthritis outcome survey (KOOS), lower extremity functional scale (LEFS), and thigh and joint girth. These same measurements were taken again at 4-weeks postoperative for both groups, prior to starting BFR. At weeks 6 and 12 postoperative, the R-group performed a 6-minute walk test (6MWT), timed up and go test (TUG), 4 square step test (4SST), and 30 second sit to stand test (30STS) were performed to assess performance, along with KOOS, LEFS, thigh and joint girth. All measurements were taken prior to any BFR session. The CON-group performed post-testing on their 12th week postoperative which consisted of: LEFS, thigh and joint girth; no other measurements were assessed with the CON-group due to lack of access to these participants.

Procedures

Experimental group

During the first week of personalized BFR training all participants started at 70% of limb occlusion pressure (LOP). As the weeks progressed, LOP was increased as tolerated until 80% LOP was reached. No deception was used for the R-group when BFR was used.

During each PT visit, the Delfi Personalized Tourniquet System (DPTS) (Delfi Medical Innovations Inc., Vancouver, BC, Canada) Easi-Fit Tourniquet Cuff (Delfi Medical Innovations Inc., Vancouver, BC, Canada), and the matching limb protection sleeve were applied to the proximal portion of the's participant's surgical limb. The DPTS was calibrated while the participant was in a supine position and told to refrain from any movement or talking. The DPTS used Doppler readings to detect the participant's blood pressure for the day in order to calibrate the proper occlusion pressure. This Doppler reading allowed for the BFR occlusion pressure to be personalized, and varied from day to day. The occlusion pressure was set to 70% for the first week and 80% for the following PBFR sessions. Once calibrated, the DPTS was inflated and the participant then proceeded to complete the first exercise. The exact exercise protocol can be seen in Figure 2. Each exercise was performed with four sets of 30/15/15/15 repetitions with 30 second rest periods between sets. The participant was given eight minutes to complete all four sets per exercise. After the participant successfully completed all four sets, the tourniquet was deflated for 1 minute to allow reperfusion into the limb. This exact procedure was used for every exercise during each PT visit, which lasted approximately 45 minutes. The total amount of blood occlusion time was no longer than 24 minutes. Most exercises were completed without additional weight initially, though additional weight was added as tolerated throughout the nine-week protocol. If a subject reported any dizziness, feeling of faintness, or any discomfort or pain in the occluded limb, exercise was terminated and the tourniquet was removed. During each PBFR session a licensed physical therapist and researcher monitored the participant to ensure they were safe and comfortable.

Control Group

These participants executed their physical therapy at GVH with the use of traditional modalities, following a non-standardized exercise protocol as directed by a licensed physical therapist. This group did not receive PBFR treatment and followed the typical 12-week post-TKA protocol.

Measured Variables

Knee Osteoarthritis Outcome Survey (KOOS)

The KOOS is a questionnaire developed to assess changes in a participant's knee post-surgery or post-injury. The questionnaire consists of 5 categories: pain, symptoms, function in daily living (ADL), function in sport and recreation, and knee related quality of life. Standardized answers are given and each question is assigned a score from 0-4. A normalized score is calculated for each subscale, with 100 indicating no symptoms and 0 indicating extreme symptoms. The KOOS typically takes 10 minutes to complete. Participants were provided this survey and instructed to complete it to the best of their abilities.

Lower Extremity Functional Scale (LEFS)

The LEFS is a 20 question survey about a participant's ability to perform everyday tasks. Each question has a possible score range of 0-4. The total score can be between 0-80 with 0 being extremely limited and 80 being no limitations at all. The LEFS typically takes 10 minutes to complete. Participants were provided this survey and instructed to complete it to the best of their abilities.

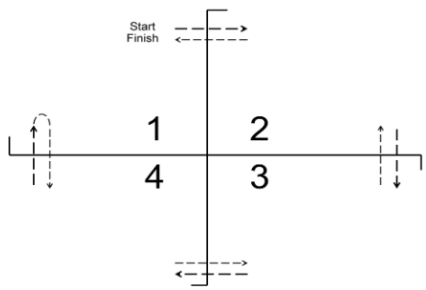

Figure 3. 4 square step test directions

Thigh and Joint Girth

Thigh and joint girth were measured in cm using a tape measure. The joint was located by bending the participant's surgical limb then 10cm and 15cm were measured up the thigh and marked with a pen. Circumference measurements were taken at the joint line, 10cm, and 15cm marks to assess joint swelling and muscle atrophy/hypertrophy.

6 Minute Walk Test

The 6 minute walk test is a submaximal exercise test used to assess endurance and gait. The object of this test is to have the participant walk as far as possible in 6 minutes. Each participant walked on a 200 meter, indoor track at a self-selected pace for 6 minutes. They were able increase or decrease their speed if necessary. A researcher and physical therapist were with each individual at all times during the test to ensure they were safe. If the participant felt any pain or discomfort during the 6 minutes the test was terminated.

Timed Up and Go Test (TUG)

The TUG test assesses an individual's mobility. The participant was sitting in a chair and when instructed, walked three meters, turned around, walked back to the chair, and sat. The test was timed. This test was performed twice and the best time was recorded.

4 Square Step Test (4SST)

4 SST assesses dynamic balance, stepping, weight shift, spatial ability and sequencing skills. A cross was made with tape on the floor to create 4 square boxes. The participant was instructed to stand in square 1 facing square number 2. The participant was required to step as fast as possible into each square in the following sequence: 2, 3, 4, 1, 4, 3, 2, and 1, see Figure 3. The participant had to place both feet in each square and had to complete the sequence as fast as possible without touching the tape lines; the participant remained facing forward during the entire sequence. The participant performed the test twice for time and the best time was recorded.

30 Second Sit to Stand Test

The purpose of the 30STS test is to assess leg strength and endurance. The participant sat on a PT exam table, with their knees at 90 degrees and their hands on the opposite shoulder, crossed at the wrists. They kept their back straight and arms crossed the whole time. When told to "Go" the participant rose to a full standing position, then sat back down again until their glutes touched the exam table, and repeated this for a 30 second duration. This test was performed twice and the highest number was recorded.

Statistical analyses

SPSS version 24 (SPSS Inc., Chicago, IL, USA) was used to determine the mean and standard deviation (mean $\pm$ SD), along with percent change (%), for all 4-week and 12-week measures. In order to make inferences about true population values of the effect of both interventions on quadriceps girth, the uncertainty in effect was expressed as 90% confidence limits and as likelihoods that the true value of the effect represents a substantial and clinically meaningful change (harm or benefit). Effects were deemed unclear if its confidence interval overlapped thresholds. All probabilistic magnitude-based inferences were calculated using a published spreadsheet[8].

Results

Changes in quadriceps girth after occlusion

Pre and postoperative knee extensor girth values and the percent change for surgical limbs can be seen in Table 2. Magnitude-based inferences suggests that a 9-week BFR intervention is 87.5% likely beneficial, 8.5% trivial, and 4.0% harmful at 10cm, and 92.8% likely beneficial, 4.7% trivial, and 2.5% harmful at the 15cm for improving quadriceps girth above joint line in post-TKA patients. Figure 4 shows the change in quadriceps girth for the R-group and CON-group. Table 3 shows the effects of BFR training on mean changes in quadriceps girth and changes that the true differences are substantial. There were likely beneficial changes in quadriceps girth at 10cm and 15cm above the joint line in the R-group.

Table 2. Pre and postoperative quadriceps girth values in centimeters and total percent change for each patient in the experimental (BFR) and control groups.

Quadriceps Girth Pre and Post for Surgical Limb							
		10 cm (mid girth)			15 cm (distal girth)		
	Case	4 weeks postop	12 weeks postop	% Change	4 weeks postop	12 weeks postop	% Change
BFR	1	39.5	41.5	5.1	42.0	45.0	7.1
	2	36.5	35.8	-0.1	35.8	38.0	2.1
	3	64.0	68.5	7.0	69.0	76.0	10.1
CON	4	48.4	47.4	-2.1	53.4	51.4	-3.7
	5	64.6	58.5	-9.4	70.0	66.0	-5.7
	6	40.9	40.6	-0.7	45.7	43.7	-4.6

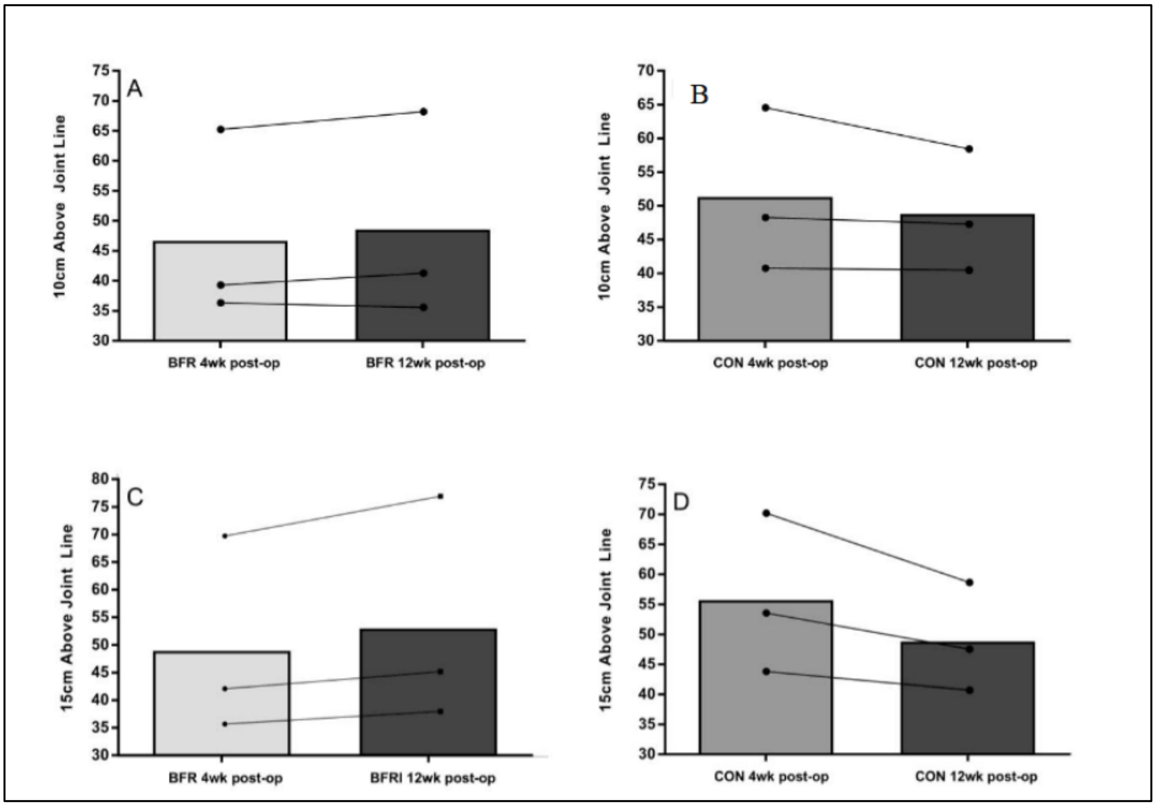

Figure 4. Thigh girth mean percent change responses for R-group (BFR) and CON-groups for 10cm and 15cm above joint line on the post-surgical limb are represented as the bars. Image A represents 10cm girth changes for R-group. Image B represents 10cm girth changes for CON-group. Image C represents 15cm girth changes for R-group. Image D represents 15cm girth changes for CON-group. Individual changes in quadriceps girth from 4 to 12 weeks postop are indicated by the lines.

Table 3. Effect of BFR training on mean changes in quadriceps girth and chances that the true differences are substantial.

			Chances that the true effect has substantial…		
	Mean difference	**± 90% Confidence limits**	**Benefit (%)**	**Harm (%)**	**Practical assessment**
10cm above joint line	1.92	1.8, ±2.1	87.5	4.0	Likely beneficial
15cm above joint line	4.08	2.4, ±2.2	92.8	2.5	Likely beneficial

Discussion

It has been reported that TKAs are one of the most common surgeries performed with nearly 500,000 done every year in the U.S[9]. Despite the high patient satisfaction rate, the loss of quadriceps muscle CSA and strength are inevitable with a TKA[10-11]. Quadriceps CSA has been known to decrease by 5% to 20% within the first month after surgery[11-13]. The purpose of this study was to determine if PBFR could be used to reduce the amount of postoperative atrophy in TKA patients. The main finding of this study was that a 9-week PBFR protocol was effective at reducing the amount of postoperative quadriceps atrophy following a TKA. Whereas, traditional PT modalities, that did not include PBFR, resulted in a significant reduction in quadriceps girth in the surgical limb for post-TKA patients. Our study suggests that training with BFR and LIRT can increase quadriceps girth in postoperative TKA patients. The results suggest that it is not only effective in improving girth but also safe to use on postoperative patients.

Our findings are similar to current research on BFR in regard to quadriceps hypertrophy. BFR combined with LIRT has consistently shown to elicit similar effects on CSA as high-intensity resistance training (HIRT). Similar results were found regarding CSA in a study by Vechin et al.[14] for LIRT+BFR and HIRT. The results demonstrated that after a 12-week protocol, 2xweek, the LIRT+BFR group had a significant increase in quadriceps CSA by 6.6%. In another study looking at the effects of BFR on CSA in knee extensors, they separated the subjects into three groups: BFR+ LIRT, BFR+ no exercise, and LIRT without BFR[15]. All subjects in this study underwent an 8-week protocol performing knee extension exercises. Both the BFR+LIRT and LIRT groups performed the same exercises while a third group simply received passive BFR. The results showed that the LIRT+BFR group had a significant increase in muscle CSA in the knee extensors by 10.3%. Previous research on BFR in post-operative participants has also exhibited an effect on increasing CSA and reducing post-surgical atrophy. Takarada et al.[16] performed a study to look at the effects of BFR without exercise on muscle mass in post-ACL surgery patients. After a 2-week protocol the BFR group showed a reduction in post-operative quadriceps atrophy by 9.4%, while the control group saw a 20.7% reduction in quadriceps CSA.

Our findings show the possibilities of this mode of training as a rehabilitative modality to reduce postoperative atrophy in conjunction with a PT program. Previous studies have determined that BFR and LIRT can improve muscle activation, muscle strength, and hypertrophy. This training could potentially reduce rehabilitation times, allowing participants to return to their normal activities of daily living sooner.

Mechanisms

In order to elicit muscle hypertrophy, an individual has to work at moderate to high intensities for resistance training[3]. HIRT creates enough mechanical stress on the body to induce muscle changes[17]. However, when dealing with injured or postoperative patients, loading of the joints is not an option due to pain or surgical restrictions. The use of BFR with LIRT has been shown to increase muscle CSA in the occluded limb. This hypertrophy is caused by the buildup of metabolites in the occluded limb. The main metabolite that is responsible for initiating the hypertrophic response is lactate. This buildup of lactate in the limb causes the pituitary gland to increase GH release. GH plays a key role in increasing body growth through the stimulation of the liver to release insulin-like growth factor 1 (IGF-1). IGF-1 is mainly responsible for muscle growth by initiating myoblast differentiation and proliferation[18]. The main role of IGF-1 is the fusion of satellite cells to current muscle fiber tissue. Once the satellite cells have been fused to the muscle tissue new myocytes begin to form in order to assist in repair and growth of the tissue. The relevance of myonuclear domain states that in order to significantly increase muscle size there needs to be an increase in myocytes[19-20]. This increase in myocytes contributes to muscle fiber hypertrophy. The overall effect of BFR combined with low-intensity exercise stimulates an increase in GH concentrations and subsequently IGF-1 resulting in an increase of muscle hypertrophy.

Future Research and Limitations

Further research needs to be conducted to examine how an increase in quadriceps girth effects muscle strength and functional outcomes in postoperative TKA patients. Furthermore, follow-up evaluations are necessary to determine whether the effects of BFR are long term and if activities of daily living have improved. Future research should also examine the relationship between altitude and BFR training. Overall, more research needs to be conducted on BFR to gain a better understanding of how it can impact postoperative participants and rehabilitation programs.

The main limitation of this pilot study was the use of convenience sampling which may lead to under-representation or over-representation of a particular population. Another limitation was the lack of measurements for the CON group. We were not able to capture functional measurement scores for the 6MWT, TUG, 4 square step test 4SST, and 30STS so comparisons between the R-group and CON-group were not made. There was also no pre-op data collected which limited the analysis of preoperative to postoperative changes in the post-TKA patients.

CONCLUSION

In conclusion, this study demonstrated that 9-weeks of PBFR training with LIRT is an effective modality for increasing CSA, when used in conjunction with a rehabilitation program following a TKA. These findings are similar to other studies[14-16] that also improved quadriceps CSA. Further research is necessary to determine whether PBFR can improve rehabilitation time, quadriceps strength, voluntary muscle activation, and patient subjective functional outcomes following a TKA.

Address for Correspondence

Christina Buchanan, Ph.D., High Altitude Exercise Physiology Program, 600 N. Adams St., Western Colorado University, Gunnison, CO, United States, 81231. Phone: 970-943-2027; Email: chbuchanan@western.edu

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