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Blood Flow Restriction Therapy for Two Weeks Prior to Anterior Cruciate Ligament Reconstruction Did not Impact Quadriceps Strength Compared to Standard Therapy

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Blood Flow Restriction Therapy for Two Weeks Prior to Anterior Cruciate Ligament Reconstruction Did not Impact Quadriceps Strength Compared to Standard Therapy

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Purpose: To evaluate the efficacy of a 2-week home-based blood flow restriction (BFR) prehabiliation program on quadriceps strength and patient-reported outcomes prior to anterior cruciate ligament (ACL) reconstruction. **Methods:** Patients presenting with an ACL tear were randomized into two groups, BFR and control, at their initial clinic visit. Quadriceps strength was measured using a handheld dynamometer in order to calculate peak force, average force, and time to peak force during seated leg extension at the initial clinic visit and repeated on the day of surgery. All patients were provided education on standardized exercises to be performed 5 days per week for 2 weeks between the initial clinic visit and date of surgery. The BFR group was instructed to perform these exercises with a pneumatic cuff set to 80% of limb occlusion pressure placed over the proximal thigh. Patient-Reported Outcome Measurement System Physical Function (PROMIS-PF), knee range of motion, and quadriceps circumference were gathered at the initial clinic visit and day of surgery, and patients were monitored for adverse effects. **Results:** A total 45 patients met inclusion criteria and elected to participate. There were 23 patients randomized to the BFR group and 22 patients randomized into the control group. No significant differences were noted between the BFR and control groups in any demographic characteristics (48% vs 64% male [$P = .271$] and average age 26.5 ± 12.0 vs 27.0 ± 11.0 [$P = .879$] in BFR and control, respectively). During the initial clinic visit, there were no significant differences in quadriceps circumference, peak quadriceps force generation, time to peak force, average force, pain, and PROMIS scales ($P > .05$ for all). Following completion of a 2-week home prehabilitation protocol, all patients indeterminant of cohort demonstrated decreased strength loss in the operative leg compared to the nonoperative leg ($P < .05$ for both) However, there were no significant differences in any strength or outcome measures between the BFR and control groups ($P > .05$ for all). There were no complications experienced in either group, and both were compliant with the home-based prehabilitation program. **Conclusions:** A 2-week standardized prehabilitation protocol preceding ACL reconstruction resulted in a significant improvement in personal quadriceps peak force measurements, both with and without the use of BFR. No difference in quadriceps circumference, strength, or patient reported outcomes were found between the BFR and the control group. The home-based BFR prehabiliation protocol was found to be feasible, accessible, and well tolerated by patients. **Level of Evidence:** Level II, randomized controlled trial with small effect size

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Introduction

Blood flow restriction (BFR) therapy is a technique in which a pneumatic tourniquet system is placed around an extremity in order to occlude venous return while maintaining arterial flow during exercise.[1] BFR has recently gained popularity in physical therapy and rehabilitation protocols as a low-cost, low-risk nonsurgical modality.[2] Recent evidence suggests many potential benefits of BFR, such as enhanced muscular strength and hypertrophy while using low-resistance loads.[1,3,4] Several studies suggest that patients rehabilitating from recent surgery or acute injury receive

substantial benefit from BFR therapies, as low-resistance exercise enables patients to remain compliant with weight-bearing restrictions while receiving the benefits of high intensity exercise, such as reduced atrophy and strength loss, which improves functional outcomes without compromising a repair or reconstruction.[3,5-7] BFR uses the body's inherent response to fatigue, muscle tension, reactive hyperemia, and metabolic stress induced by periods of hypoxia, which is simulated by a tourniquet, in order to rehabilitate an injured muscle without the risk of overloading the injured extremity.[8-12]

The theoretical benefits of BFR are especially important to consider in patients following an anterior cruciate ligament (ACL) injury. These patients benefit from preoperative rehabilitation ("prehab") prior to ACL reconstruction (ACLR), which restores knee range of motion (ROM), lower extremity function, and quadriceps strength with little stress on the knee.[13,14] The integration of BFR into prehab protocols has demonstrated varying results when compared to sham controls, including improved isometric endurance and surface electromyograph amplitude of the vastus medialis at 12-week follow up, but no significant changes in postoperative quadriceps volume.[15,16] Following ACLR, patients experience a period of quadriceps atrophy leading to side-to-side strength asymmetry, with quadriceps weakening of the surgical extremity.[17] Athletes have been found to have lasting quadriceps weakness up to 9 months following ACLR.[18] Persistent quadriceps weakness can lead to altered lower extremity mechanics, potentially limiting functional performance and increasing potential risk for reinjury or contralateral injury.[19,20] Therefore, sports medicine providers have focused on various methods to mitigate quadriceps atrophy and weakness following ACLR, including BFR.

While perioperative BFR therapy has gained popularity and merit, available studies have suffered from significant limitations, such as short follow-up, lack of standardized protocols, and outcome measures, which have led to a lack of consensus regarding recommendations for use.[21] The purpose of the present study was to evaluate the efficacy of a 2-week home-based blood flow restriction (BFR) prehabiliation program on quadriceps strength and patient-reported outcomes prior to anterior cruciate ligament (ACL) reconstruction. It is hypothesized that patients who complete BFR prehabilitation will have similar strength and patient-reported outcomes without complications as compared to patients who did not use BFR during prehabilitation using a standard home-based therapy regimen.

Methods

Studies were performed at the Department of Orthopaedic Surgery at Henry Ford Hospital. Consolidated Standards of Reporting Trials (CONSORT) statement was used to conduct this prospective randomized control trial (Fig 1). This study was granted institutional review board approval by the Henry Ford Hospital Institutional Review Board (no. 13080) and was registered with ClinicalTrials.gov (NCT04374968). A hypothesis was developed prior to starting the study. Inclusion criteria consisted of patients aged 14 or older who were diagnosed with an ACL tear within the last 3 months and were scheduled to undergo primary ACL reconstruction. A total of 45 patients presented to 3 fellowship-trained sports surgeons (V.M., K.R.O.) between June 2020 and March 2021 and met inclusion criteria. Exclusion criteria included patients who did not receive or delayed their surgery after the 2-week rehabilitation period, personal or family history of deep venous thrombosis (DVT), peripheral artery disease, same-joint surgery within the previous year, active anticoagulation therapy, uncontrolled hypertension, BMI over 40, and a family or personal history bleeding disorder.

After discussion was completed and surgical management was elected, all patients presenting during the study period were queried regarding study involvement. At this time, a separate member of the research team fully discussed the study involvement and obtained study consent from each patient. Consenting patients were then randomized to a BFR or non-BFR physical therapy protocol with 1:1 allocation using simple randomization computer software (MD Anderson Cancer Center, Houston, TX). Patients who used BFR during their prehabilitation protocol were placed into the "BFR" group, while patients who were to perform the exercises without the use of BFR were placed into the "control" group. Patient data were kept in a secured digital database during the length of the study, which was thereafter discarded. Patients were informed of study group at the time of consent. Blinded observers conducted data entry both at the initial clinic visit (ICV) and preoperatively.

Intervention

During the ICV, all patients indeterminant of treatment group were instructed to perform preoperative exercises 5 times a week for the 2 weeks prior to surgery, in addition to aggressive knee range of motion and edema control. Patients in the study were consistently scheduled for surgery 2 weeks after their ICV to allow for the same amount of preoperative rehabilitation for both groups. Exercises included quadriceps contractions in end-range extension, straight leg raises and long arc quads on the operative leg, as well as quarter squats performed bilaterally. These exercises were all chosen to work on volitional quadriceps activation and knee extension range of motion simultaneously. All exercises were performed for a total of 75

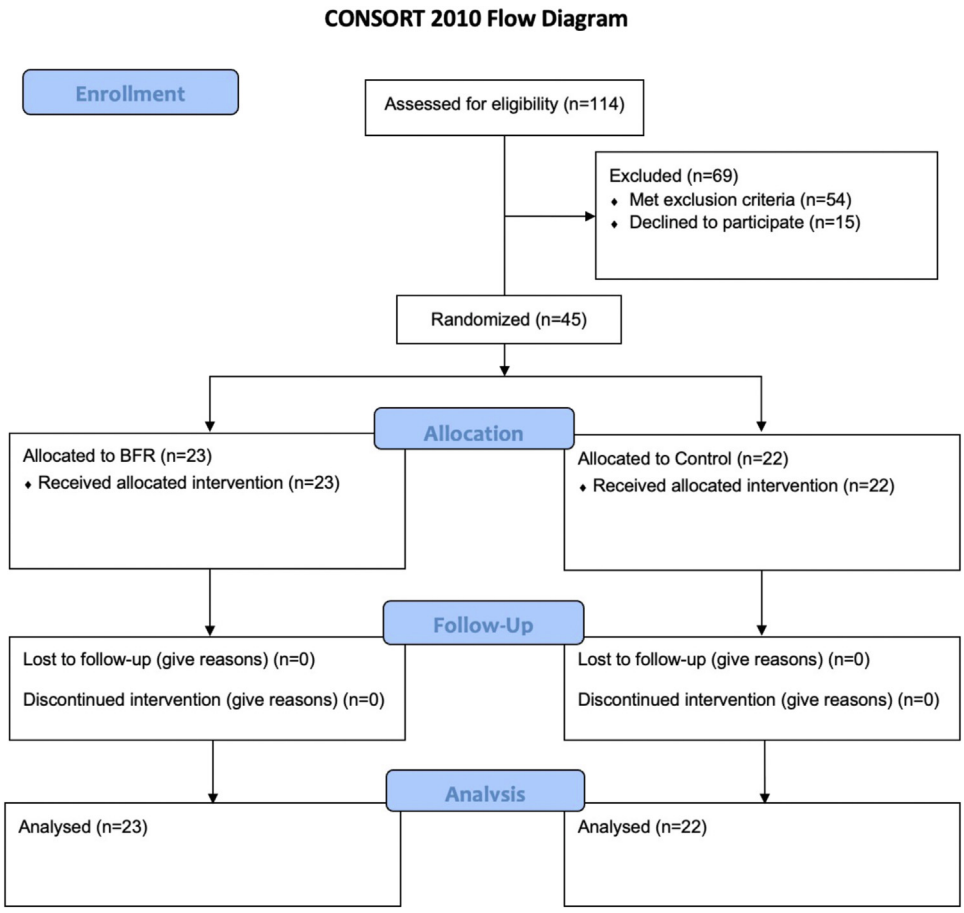

Fig 1. CONSORT 2010 flow diagram.

repetitions with a repetition scheme of 30-15-15-failure, allowing for 30 seconds of rest between sets. The last set was performed to failure or to a maximum of 2 minutes, whichever comes first to maximize hypoxia within the limb. During the ICV, all patients were educated on how to properly perform the required exercises and were asked to sign a log, which would be returned during the preoperative visit to demonstrate compliance. All exercises were performed under body weight conditions initially, and patients were instructed to increase weights in small increments at successive sessions, as needed, to ensure near failure was reached with each exercise. Patients randomized to the BFR cohort had a personalized limb occlusion pressure (LOP) measured using a Doppler ultrasound placed on the dorsalis pedis pulse (Fig 2). BFR patients were provided a single-chamber pneumatic torniquet (Smart Tool Plus, Strongsville, OH) and were instructed to set the pressure to 80% of LOP when performing prehabilitation exercises. Patients were instructed to leave the cuff inflated for the duration of each exercise, ensuring a rest period of at least 2 minutes between exercises with the cuff deflated. All patients were shown how to inflate and deflate the cuff properly and tested on their compliance in the clinic prior to taking home the cuff.

Strength Measures and Outcomes

At the ICV the patients' demographic and anthropometric measurements, including age, BMI, gender, leg length, and quadriceps circumference were collected. Quadriceps circumference was measured 15 cm proximal to the superior pole of the patella. Objective measures collected included quadriceps peak force (newtons), time to peak force (seconds), average force (newtons), and knee range of motion (degrees). Strength measurements were collected using a handheld dynamometer (Lafayette Instruments, Lafayette, IN) in a standardized fashion previously described in the literature (Fig 3).[21] This methodology consisted of placing the patient in a seated position with their leg over the end of the clinic bed and the knee in 90° of flexion. A belt was then placed across the patients' thighs to minimize movement during strength testing and to hold the hips in place. A handheld dynamometer was then positioned behind the leg of the clinic bed using a flat attachment, and a belt was placed around the dynamometer and roughly 5 cm proximal to the

Fig 2. Measurement of personalized limb occlusion pressure using a single-chamber pneumatic tourniquet. The tourniquet was inflated until the dorsalis pedis pulse was noted to be occluded on the Doppler, and this was considered the limb occlusion pressure.

distal aspect of the lateral malleolus. Patients where then instructed to extend their knee and encouraged verbally to make maximal effort. This protocol has been previously evaluated in comparison to traditional isokinetic quadriceps strength testing and found to correlate with findings on isokinetic testing, as well as producing high reliability measurements.[22-24] All isometric data were collected for a total of 3 times per patient encounter with 1 minute of rest between each test. Patient-reported outcomes (PROs) collected included visual analog score (VAS), Patient-Reported Outcome Measurement System Physical Function (PROMIS-PF), Patient-Reported Outcome Measurement System Pain (PROMIS-PI) and Patient-Reported Outcome Measurement System Depression (PROMIS-D). All outcome measures were collected at the ICV, as well as 2 weeks later on the day of surgery, prior to surgery.

Statistical Analysis

The primary outcome of this study was average quadriceps torque generation in the operative leg before and after prehabilitation prior to ACLR. Torque (N•m) measures were calculated from the data collection by using measurement in centimeters from the lateral knee joint line to 5 centimeters proximal to distal aspect of the lateral malleolus and multiplying this value by the force (N) measures recorded by the dynamometer. Since 3 force measurements were taken at each time interval, the average value of the 3 measure was used during all statistical analysis. A power analysis was performed before beginning data collection. With 15 patients per group, we can detect an effect size (the detectable difference in standard deviation units) of 0.74 with 80% power on a two-sample *t*-test with a significance level set to .05. On the basis of prior literature, the minimal clinically important difference in quadriceps strength was determined to be a 7.5-Nm difference between legs.[25] A sample of 45 patients was selected to allow for incomplete data collection. To account for potential error in individual strength measurements, an outlier analysis was conducted, and individual torque measurements that fell outside of 2 standard deviations from the population mean were excluded. Categorical variables are reported as frequency counts and percentages, while continuous variables are summarized in terms of means and standard deviations. Because of skewness and nonnormality of data, nonparametric equivalents are substituted in the place of conventional parametric

Fig 3. Demonstration of belt stabilized handheld dynamometer placement used to measure quadriceps strength.

Table 1. Demographics

		BFR	Control
Number of Subjects		23	22
Age (years)		26.5 ± 12.0	27.0 ± 11.0
BMI (kg/m^2)		25.3 ± 3.2	26.8 ± 4.9
Sex	Male	11 (48%)	14 (64%)
	Female	12 (52%)	8 (36%)
Laterality of injury	Right	11 (48%)	10 (45%)
	Left	12 (52%)	12 (55%)
Operative limb length (cm)		88.6 ± 7.3	90.4 ± 8.3
Non-Operative limb length (cm)		88.6 ± 7.3	90.4 ± 8.3
Graft choice	BTB	15 (62.5%)	19 (73.1%)
	HS	7 (29.2%)	6 (37.5%)
	QT	2 (8.3%)	1 (3.8%)

Data are expressed as means ± SD or number (%). BFR, blood flow restriction; BMI, body mass index; BTB, bone-patella tendon-bone autograft; HS, hamstring tendon autograft; QT, quadriceps tendon autograft.

tests. For within-group comparisons, Wilcoxon signed-rank tests are used. For between-group comparisons, Wilcoxon rank sum tests are used. Effect sizes are calculated and interpreted according to Cohen, where the thresholds were defined as >0.80 is considered large, 0.80 to 0.50 is considered moderate, and <0.5 is considered small. Variables operationalizing the differences from ICV to preop for both average and peak forces follow the structure of preop-ICV. Negative differences imply that the scores at preop were lower than the scores at initial visit to clinic. Statistical significance is set at $P < .05$. Statistical analysis was performed using SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

A total of 114 patients were assessed for study participation, with 54 meeting exclusion criteria and 15 declining to participate. Forty-five patients met the inclusion criteria, agreed to participate in the study, and completed the ICV, as well as the preoperative testing and measurements; there were 23 patients in the BFR group and 22 in the control group (Fig 1). All patients in both groups reported compliance with the prescribed therapy program. There were no significant differences between the demographics of the two groups, including age, body mass index, sex, laterality, limb length, and graft choice (Table 1).

During the preoperative measurements, there were no significant differences between the group measurements of quadriceps circumference, peak quadriceps torque generation, average quadriceps torque generation, time to peak quadriceps torque generation, ROM, pain, or PROMIS scores (Table 2).

Following completion of a 2-week prehabilitation protocol, all patients indeterminant of cohort demonstrated decreased strength loss in the operative leg compared to the nonoperative leg ($P < .05$), except for average torque in the control group ($P = .365$) (Table 3). There was no statistically significant difference between the BFR and control cohort in affected leg quadriceps circumference (48.3 ± 3.8 cm vs 48.0 ± 5.6 cm; $P = .854$), affected leg knee ROM (120.8 ± 18.6 degrees vs 120.9 ± 21.6°; $P = .988$), and VAS pain score (1.9 ± 2.0 vs 2.0 ± 2.0; $P = .883$), PROMIS-PF (42.7 ± 5.1 vs 44.1 ± 7.1; $P = .418$), PROMIS-PI (56.6 ± 5.5 vs 54.9 ± 6.8; $P = .361$), and PROMIS-D (42.2 ± 7.3 vs 42.6 ± 9.0; $P = .863$).

When comparing quadriceps circumference as a percentage of the contralateral leg, there were no significant differences between the BFR group and controls, at either the initial clinic visit (99.9% ± 3.0% vs 99.2% ± 2.4%; $P = .432$) or following the completion of the prehabilitation protocol (98.6% ± 3.8% vs 99.4% ± 3.0%; $P = .417$). Comparing force generation as a percentage of nonoperative leg between cohorts at each time point, there was also no statistically significant

Table 2. Initial Clinic Visit Measurements

	BFR Group	Control
Operative quadriceps circumference (cm)	48.4 ± 3.7	48.3 ± 6.3
Nonoperative quadriceps circumference (cm)	48.5 ± 3.6	48.6 ± 6.0
Peak quadriceps torque generation operative leg (N•m)	101.0 ± 54.3	111.5 ± 52.3
Peak quadriceps torque generation nonoperative leg (N•m)	143.7 ± 72.5	148.9 ± 41.0
Average quadriceps torque generation operative leg (N•m)	76.6 ± 41.2	84.9 ± 35.8
Average quadriceps torque generation nonoperative leg (N•m)	109.1 ± 57.0	115.9 ± 33.5
Average time to peak torque operative leg (seconds)	2.1 ± 1.6	2.1 ± 0.5
Average time to peak torque nonoperative leg (seconds)	1.9 ± 0.7	2.2 ± 0.6
Operative leg range of motion (degrees)	113.8 ± 21.2	120.0 ± 21.6
Nonoperative leg range of motion (degrees)	133.7 ± 9.8	132.6 ± 10.6
Pain on visual analog scale	2.8 ± 2.4	1.9 ± 2.0
PROMIS-PF	40.9 ± 6.0	41.2 ± 10.4
PROMIS-PI	59.2 ± 5.6	58.8 ± 5.6
PROMIS-D	44.2 ± 8.2	45.4 ± 9.1

All measurements expressed as average ± SD. D, depression; PF, physical function; PI, pain interference; PROMIS, Patient-Reported Outcomes Measurement Information System.

Table 3. Mean Difference in Strength Between ICV and Preop

Strength Measure	Cohort	Change in Operative Leg	Change in Nonoperated Leg	Difference	*P* Value
Peak torque	BFR	−16.5 ± 30.1	−55.0 ± 43.1	36.5 ± 47.8	**<.001**
	Control	−15.6 ± 48.3	−46.0 ± 40.3	25.2 ± 61.3	**.003**
	CI	−20.2 to 30.2	−14.3 to 35.7	−14.3 to 35.7	
	P Value	.946	.473		
Average torque	BFR	−5.7 ± 23.9	−24.5 ± 41.5	18.3 ± 24.0	**.012**
	Control	−10.7 ± 27.8	−20.7 ± 41.5	10.4 ± 45.7	.365
	CI	−11 to 20.0	−11.5 to 28.5	−11.5 to 28.5	
	P Value	.528	.706		

Significant difference, $P < .05$, is indicated by bold text. BFR, blood flow restriction; ICV, initial clinic visit.

difference in the average or peak torque at either the ICV or following completion of prehabilitation (Table 4). However, a statistically significant difference was present in both the BFR and control group when comparing peak torque generation from the ICV to the preoperative time point as a percentage of nonoperative leg (Table 5).

Patients did not report any adverse events such as pain intolerance, BFR cuff dysfunction, paresthesia, pressure injury, or blood clots. Additionally, all patients reported that they were able to complete the prescribed exercises and number of therapy sessions.

Discussion

This prospective randomized controlled trial (RCT) evaluated patients undergoing 2 weeks of a home-based BFR prehabilitation program prior to ACLR compared to a control group with standardized exercises and found that while both the BFR and control groups demonstrated a statistically significant improvement in peak and average quadriceps torque over the study period in the injured leg, there were no significant differences in quadriceps strength or PROs between the two groups. Patients tolerated the intervention without reporting complications, and each were able to successfully complete the home-based rehabilitation program. Overall, using preoperative BFR was demonstrated to be a safe and well-tolerated intervention prior to ACL surgery.

The initiation of prehabilitation prior to ACLR was initially intended to combat quadriceps atrophy, knee flexion contractures or extension deficits, and persistent hematoma, and to mitigate surgical complications.[26] Several prehabilitation programs focus on achieving full ROM, as well as quadriceps strengthening.[27] Shaarani et al. randomized patients into an exercise versus control group for 6 weeks prior to ACLR and found that the intervention group had significantly better outcomes in the single-leg hop test score (144.91 ± 15.52 vs 113.33 ± 25.54), as well as modified Cincinnati score (85.3 vs 77.6) compared to the control group at 12 weeks postoperativly.[13] In their study, there was no significant difference in measured quadriceps strength at any short-term timepoints between groups, as measured by isokinetic dynamometry performed at 90°/second. Additionally, as quadriceps contraction in the ACL-deficient knee can initiate a shear force with anterior translation of the tibia, an antishear device was used with a testing arc of 20-100° to minimize potential shearing.[28] Kim et al. also evaluated the effects of a preoperative exercise program for 4 weeks prior to ACL reconstruction and found that at 3 months postsurgery, the prehabilitation group had significantly greater isokinetic quadriceps strength preservation tested at 60° and 180°/second, as well as

Table 4. Torque Generation Between Cohorts at Each Timepoint as a Percentage of Nonoperative Leg

	Group	Means ± SD	*P* Value	Effect Size
Average torque ICV	BFR	72% ± 24%	.708	−0.07
	Control	76% ± 35%		
Peak torque ICV	BFR	76% ± 20%	.705	−0.01
	Control	79% ± 35%		
Average torque preop	BFR	95% ± 30%	.591	−0.06
	Control	88% ± 24%		
Peak torque preop	BFR	96% ± 29%	.916	−0.16
	Control	95% ± 21%		

Continuous variables are presented using adjusted means ± SD. BFR, blood flow restriction; ICV, initial clinic visit; preop, preoperative.

Table 5. Torque Generation From ICV to Preop as a Percentage of the Nonoperative Leg

Group	Variable	Means	*P* Value	Effect Size
BFR	Average torque IVC	72% ± 24%	.002	0.53
	Average torque preop	95% ± 30%		
	Peak torque IVC	76% ± 20%	.004	**0.49**
	Peak torque preop	96% ± 29%		
Control	Average torque IVC	76% ± 35%	.349	**−0.49**
	Average torque preop	88% ± 24%		
	Peak torque IVC	79% ± 35%	.036	**−0.41**
	Peak torque preop	95% ± 21%		

Continuous variables are presented using adjusted means ± SD. Significant difference, $P < .05$, is indicated by bold text. BFR, blood flow restriction; ICV, initial clinic visit; preop, preoperative.

improved distance on single-leg hop testing in the exercise group compared to controls.[29] Failla et al. compared patients from 2 large cohorts of patients following ACLR, the Multicenter Orthopaedic Outcomes Network, and Delaware-Oslo ACL Cohort, and concluded that extended preoperative rehabilitation consisting of neuromuscular training done by the Delaware-Oslo ACL Cohort resulted in improved functional outcomes and return-to-play rates at 2 year follow-up.[30] Overall, quadriceps muscle deficits at the time of surgery can potentially lead to worse long-term functional outcomes.[31] In the present cohort, regardless of study group, all patients demonstrated less strength loss in the operative leg undergoing therapy compared to the contralateral limb, highlighting the usefulness of preoperative rehabilitation in maximizing strength prior to surgery. Our results demonstrate that a home-based prehabilitation protocol is feasible and tolerable in the present cohort and resulted in decreased strength loss in the operative extremity.

Blood flow restriction training has gained popularity, as patients and providers seek an expeditious return to sporting activity. Currently, studies are mixed as to the efficacy of BFR in the perioperative period surrounding ACLR, and there is no consensus on optimal uses or protocols in this patient population.[32,33] Furthermore, there is very limited data investigating the use of BFR specifically as a prehabilitation intervention prior to ACLR. Zargi et al. examined 20 patients who performed 5 low-load exercise sessions in the 8 days prior to ACLR with and without the use of BFR.[16] The authors found that the BFR group demonstrated potential advantages in quadriceps muscle endurance, as measured by time of sustained quadriceps contraction at 60° of flexion, and perfusion, as measured by blood flow to the vastus lateralis via near-infrared spectroscopy, compared to the controls at 4 weeks following surgery. However, the difference in muscle endurance was not present at 12 week follow-up, and there were no significant differences in torque generation between groups. The same research group performed a similar study investigating standard knee-extension exercise versus low-load ischemic knee extension exercise with BFR and found that there were also no differences in quadriceps femoris muscle mass, isometric strength, or knee function following 5 sessions of training in the 10 days prior to ACLR.[15] Both the aforementioned studies, as well as the present investigation, had a small number of BFR sessions, which may limit the ability of BFR to exert its effect. It must also be noted that there is significant variety in strength testing conditions between studies, with the present investigation using methodology that has been previously validated in tracking quadriceps strength in the ACL reconstructed knee, but not specifically evaluated in the ACL-deficient knee.[23] Other investigations have also noted that testing patients at 90° of flexion may lead to less quadriceps accuracy in recreating submaximal torques, as well as lower vastus medialis obliquus activation but without differences in maximal torque generation compared to testing at 60°.[34,35] Additionally, despite subjects in the present study completing a variety of exercises, these studies used only low-resistance exercise in combination with BFR, which may not confer the same benefit as high-resistance exercise. Although the BFR group did demonstrate less strength loss with therapy compared to the contralateral leg, this was not significantly different than the control group. Future research is warranted to determine whether more sessions or higher-intensity BFR is necessary to exert a difference compared to standard physical therapy protocols.

Few studies have examined the safety and feasibility of a home-based BFR program. In a case report, Kilgas et al. published a protocol for at-home BFR following total knee replacement and found that their patient tolerated the intervention and significantly improved clinically over the study period.[36] The same institution identified 9 patients who were >5 year from ACLR with persistent quadriceps asymmetry (<90% extensor strength difference) and initiated them into a home BFR program. After 4 weeks, the authors found that the quadriceps asymmetry had resolved and was equivalent to a matched control group that had no history of ACL injury.[7] As in our investigation, the home-based BFR intervention was well tolerated, with all patients able to complete the study protocol without reported complications. Theoretical concerns of complications, such as blood clot formation, muscle damage, and changes to blood pressure with the use of BFR exist, but to our knowledge have not manifested clinically in the current research using BFR in the ACLR population.[37,38] Nonetheless, the current investigation excluded patients with a personal or family history of deep vein thrombosis, and we conducted routine, supervised compliance testing with teach-back methods to ensure patients were thoroughly educated on cuff use, exercise protocols and warning signs for potential complications prior to initiation of their home-based program.

Limitations

This investigation was not without limitations. Although the patients were educated thoroughly using the teach back method during their clinic visits on the prehabilitation exercise protocol, as well as the BFR cuff usage, their exercise was unsupervised, as there may be variability in how the rehab was performed or reported BFR tolerance. The goal of this study was to examine the utility of a 2-week course of prehabilitation; thus, potential long-term effects of BFR are outside the scope of this article. Patients also only underwent 2 weeks of prehabilitation in order to remain within our usual standard of practice, and, thus, may not have

performed enough exercise to see a strength difference. While we performed an a priori power analysis to determine appropriate sample sizes for the two groups, it remains a possibility that this was based on too large of a difference between groups, and a higher sample size could have detected a difference between groups. Maximal isometric knee extension was determined via handheld dynamometer; thus, we were unable to collect measurements of other types of movements, such as isokinetic contraction. The method for strength testing, while previously validated for healthy patients and those following ACL reconstruction, may not truly reflect quadriceps strength in the ACL-deficient knee, which may have contributed to the wide variation in results; however, this testing method was selected on the basis of multiple factors, such as comfort, cost, patient convenience, availability, and intent for long-term follow-up after reconstruction. Quadriceps contraction can initiate an anterior shear force in the ACL-deficient knee, which may have led to variation in force generation during strength testing and caused some of the variation in data, as well as potential for knee positioning to effect quadriceps muscle strength and activation.[28,34,35] We also recruited all patients presenting to our clinics with an ACL tear with plans to undergo reconstruction; thus, there was a variability in the age, sex, preoperative activity level, and athletic ability of our patient population, which may have also contributed to the rather large variation in measured strength via the dynamometer. Additionally, external quadriceps circumference was measured as a surrogate for quadriceps muscle size, which has limited accuracy compared to use of advanced imaging. Finally, although we did query patients regarding complications, there was no true objective measurement of safety, and long-term data are lacking.

Conclusion

A 2-week standardized prehabilitation protocol preceding ACL reconstruction resulted in a significant improvement in personal quadriceps peak force measurements, both with and without the use of BFR. No difference in quadriceps circumference, strength, or patient-reported outcomes were found between the BFR and the control group. The home-based BFR prehabiliation protocol was found to be feasible, accessible, and well tolerated by patients.

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