Blood Flow Restriction Training After Knee Arthroscopy: A Randomized Controlled Pilot Study

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Introduction: Quadriceps strength after arthroscopic knee procedures is frequently diminished several years postoperation. Blood flow restriction (BFR) training uses partial venous occlusion while performing submaximal exercise to induce muscle hypertrophy and strength improvements. The purpose of this study was to evaluate BFR as a postoperative therapeutic intervention after knee arthroscopy.

Methods: A randomized controlled pilot study comparing physical therapy with and without BFR after knee arthroscopy was conducted. Patients underwent 12 sessions of supervised physical therapy. Subjects followed the same postoperative protocol with the addition of 3 additional BFR exercises. Outcome measures included thigh girth, physical function measures, Knee Osteoarthritis Outcome Score (KOOS), Veterans RAND 12-Item Health Survey (VR12), and strength testing. Bilateral duplex ultrasonography was used to evaluate for deep venous thrombosis preintervention and postintervention.

Results: Seventeen patients completed the study. Significant increases in thigh girth were observed in the BFR group at 6-cm and 16-cm proximal to the patella ($P = 0.0111$ and 0.0001). All physical outcome measures significantly improved in the BFR group, and the timed stair ascent improvements were greater than conventional therapy ($P = 0.0281$). The VR-12 and KOOS subscales significantly improved in the BFR group, and greater improvement was seen in VR-12 mental component score ($P = 0.0149$). The BFR group displayed approximately 2-fold greater improvements in extension and flexion strength compared with conventional therapy (74.59% vs 33.5%, $P = 0.034$). No adverse events were observed during the study.

Conclusions: This study suggests that BFR is an effective intervention after knee arthroscopy. Further investigation is warranted to elucidate the benefits of this intervention in populations with greater initial impairment.

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INTRODUCTION

Over 950 000 knee arthroscopy procedures are performed yearly.[1] The goal of many of these surgeries is to return to sport, a higher level of function, or improve the overall quality of life. Although the surgical procedure is often able to remove the limiting intraarticular pathology, adequate quadriceps rehabilitation is essential to return to full function and activity. Complete recovery is frequently limited for several years postoperatively, likely due to arthrogenic muscle inhibition, despite early physical therapy.[2–5]

Rehabilitation clinical practice guidelines recommend the use of progressive strength and range of motion to safely regain the preinjury level of strength, motion, and function.[6] Furthermore, current guidelines suggest that a minimum of 60% to 100% of a patient's single maximum repetition (1RM) is required for increases in muscular strength, power, and endurance.[7] These loads are required for adequate recruitment of type II muscle fibers, which is not achieved at weights below this threshold. However, many postoperative patients are either limited by their inability to attain these requisite loads or are limited by their need to protect their postoperative extremity.[7–9]

In contrast to the physiologic loads recommended by the ACSM guidelines, blood flow restriction (BFR) training uses brief periods of partial venous blood flow restriction during the performance of exercises at 20% to 30% of a patient's 1RM.[7,10–13] The relative anaerobic environment created during these periods of venous occlusion induces several localized cellular and hormonal changes that stimulate muscle hypertrophy.[14–16] This technique has been successfully and safely used in athletes to improve performance and in the elderly to improve strength and function.[10,17–24] The purpose of this study was to evaluate the addition of BFR-based exercise to traditional methods of physical therapy to improve strength, hypertrophy, functional outcomes, and patient self-reported outcomes after postoperative nonreconstructive knee arthroscopy.

METHODS

This study was approved and conducted in accordance with the local institutional review board. The study design was a randomized controlled trial comparing physical therapy augmented with BFR to comparable work-matched non-BFR

interventions after nonreconstructive knee arthroscopy. All patients were between 18 and 65 years of age. Exclusion criteria included inability to consent, any ligamentous, bony, or other soft tissue reconstruction, history of deep venous thrombosis (DVT), history of endothelial dysfunction, peripheral vascular disease, diabetes, easy bruising, surgical procedure on their contralateral extremity, active infection, cancer, and pregnancy.

After being cleared by their operating surgeon at their 2-week postoperative visit, each patient underwent 12 sessions of supervised physical therapy as per their respective protocols. Before beginning therapy and at the end of 12 sessions, bilateral lower extremity duplex ultrasounds were obtained to evaluate for the presence of DVT. Furthermore, all patients underwent strength testing, physical functional outcome testing, and patient-reported outcome surveys at the beginning and the end of the study period.

Randomization was performed using a random number generator. These were then placed into individual unmarked envelopes. At the time of enrollment, a research coordinator not involved with patient care chose a random envelop to assign each subject to one of the 2 groups: blood flow restriction therapy or standard physical therapy. All physical therapy was conducted under the direct supervision of a licensed physical therapist with experience using all interventions. Both groups followed the same supervised accelerated physical therapy protocol for nonreconstructive knee arthroscopy as per our facility's guidelines consisting of immediate weight bearing, immediate formal physical therapy, and unrestricted range of motion. The BFR group performed 3 additional exercises under partial vascular occlusion: leg press, leg extension, and reverse press (Figure 1). The BFR group performed the occlusion-specific exercises at an initial estimated 1RM of 30%. Subjects performed 4 sets of 30/15/15/15 repetitions during each strengthening exercises. A 30-second rest period was used between sets. The tourniquet inflation was maintained during the entire exercise including rest periods for the BFR group. A 1-minute rest period was used between each individual exercise, and the tourniquet was inflated for a maximum period of 5 minutes.

Blood Flow Restriction Protocol

To attain partial vascular occlusion, a PTS ii portable tourniquet system (Delphi Medical, Vancouver, BC, Canada) with a corresponding size-specific tourniquet was placed around the patient's proximal thigh. This system allows for precise control of cuff pressure throughout training despite the changes in muscle volume that naturally occur while performing exercises. Total limb occlusion pressure (LOP) was identified by determining the pressure required to eliminate a detectable pulse using Doppler ultrasound. Partial vascular occlusion was achieved by setting the tourniquet to 80% of the LOP. This ensured that venous occlusion was obtained while still allowing arterial inflow and was personalized to each patient despite variations in thigh girth, cuff size, and systolic blood pressure. This individualized approach to determining LOP prevents excessive pressure in individuals with lower LOPs. An Easy-Fit Tourniquet Cuff (Delfi Medical, Vancouver, VC, Canada) was used with the PTS ii system. The same cuff width was used for all patients; however, the length of the cuff varied based on the patient's thigh size and was subsequently sized using the manufacturer's recommendations. The use of wider contoured cuffs and personalized LOPs has been demonstrated to improve safety while using tourniquet systems.[25,26]

Thigh Girth

Thigh girth measurements were taken at 6-cm and 16-cm measured proximal to the superior patellar pole using a standard tape measure. The treating physical therapist

FIGURE 1. Three additional blood flow restriction exercises performed in conjunction with other physical therapy interventions. A, Example of seated leg press with tourniquet in place. B, Example of seated leg extension with tourniquet in place. C, Example of standing reverse leg press with tourniquet in place.

circumferentially measured thigh girth at the onset and at the conclusion of the 12 sessions of physical therapy. The same provider performed all measurements and was blinded to which arm of the treatment study the patient was assigned at the time of measurement.

Physical Performance Outcome Measures

Self-selected walking velocity (SSWV), sit-to-stand 5 times (STS5), 4 square step test (FSST), and timed stair ascent (TSA) were performed at the beginning and the end of the study period.[27] Physical performance outcome measures were chosen based on those previously validated by Wilken et al[27] in a healthy active population. The SSWV is performed by instructing the patient to walk 20 m at a comfortable pace. The time required to traverse the middle 10 m is recorded. The STS5 is performed by instructing the patient to stand up and sit down as quickly as possible 5 times while maintaining his/her arms crossed over his/her chest the entire time. The time required to perform this motion 5 times is recorded. The FSST is performed by instructing the patient to step sequentially over 4 1-inch diameter canes that are placed flat on the floor in the shape of a cross. Subjects begin in the left rear square and are required to step over each pole as fast as possible in the following pattern: (1) forward, (2) sidestep right, (3) back, and (4) sidestep left then as quickly as possible repeat back to the starting position in the opposite direction. The patient must keep 1 foot in contact with the ground at all times. Timing is begun as soon as the patient's foot is placed in the box with the first step to the right and stopped when both feet are placed back in the final box (left rear). The total time required to perform this is recorded. Finally, the TSA is performed by instructing the patient to ascend 12 steps as quickly and safely as possible without relying on a handrail, touching each step with at least 1 foot. The time is recorded from the moment the subject touches the first step to the time the patient places both feet on the top step. All measures were repeated 4 times and their results averaged.

Patient-Reported Outcome Measures

The Knee Osteoarthritis Outcome Score (KOOS) and the Veterans RAND 12-Item Health Survey (VR-12) were completed before initiating physical therapy and at the end of physical therapy. The KOOS is a knee-specific self-administered questionnaire that assesses both the long-term and short-term consequences of knee injury and osteoarthritis.[28,29] It consists of 42 questions across 5 domains as follows: pain, symptoms, activities of daily living, quality of life, and sport functions. The VR-12 is a general health questionnaire used to measure quality of life and disease burden.[30]

Strength Testing Protocol

Knee flexion and knee extension strength was tested on a Biodex System 3 dynamometer (Shirley, NY). All strength testing was performed after a 5-minute warm-up on a stationary bike. Each patient was positioned on the dynamometer as per manufacturer's instructions in an upright, seated position. One repetition of flexion and extension was performed to provide familiarization. A total of 5 repetitions were performed at 60 degrees of knee flexion with a 30-second rest period in between each repetition. Peak torque was calculated as a measure of maximum strength attained throughout the range of motion.

Duplex Ultrasonography

Bilateral lower extremity duplex ultrasound was performed at approximately 2 weeks postoperatively before the initiation of physical therapy and at the end of the study period. All imaging was performed by the institution's radiology department and results read and provided by a board-certified radiologist who was unaware of treatment allocation.

Statistics

Descriptive statistics, 2-tailed *t* test, and ANOVA tests were used for normally distributed data. Grubb test for outliers was used as appropriate. For nonparametric data, Wilcoxon signed-rank test was used. The type 1 level of significance was set at 0.05. The data were summarized using means with standard errors. JMP v9.2 was used to do the analysis.

RESULTS

Patient allocation is shown in Figure 2. Seventeen patients were enrolled, randomized, and completed the study (10 BFR and 7 control). Three patients failed to initiate therapy after enrollment. Demographic information is found in Table 1. Both groups initiated physical therapy at approximately 3 weeks (23.4 vs 23.1 days, $P = 0.7238$) postsurgery and completed 12 sessions of physical therapy in approximately 6 weeks (41.6 vs 41.4, $P = 0.554$). Although there were no significant differences in subjective initial functional scores, pain ratings, physical functional outcome measures (SSWV, TSA, FSST, and STS5), or thigh girth, the BFR group had generally lower measures in these domains at the onset of the study (Tables 2 and 3).

Thigh girth significantly improved in the BFR group at both 6-cm (median: 1.75 cm, range 1-4.6 cm; $P = 0.0111$) and 16-cm (median: 2.25 cm, range 0.75-3 cm; $P = 0.0001$) proximal to the patellar pole. Corresponding significant changes were not seen in the controls. Furthermore, increases in thigh girth were significantly greater in the BFR group compared with conventional therapy ($P = 0.0069$) at 6 cm (Table 2).

Although KOOS pain, symptoms, and sport subscales showed significant improvements for the control group, the BFR group showed significant improvements for all subscales (Table 3). The VR-12 physical component score (PCS) showed significant improvements in both the BFR and control groups, and the groups were not significantly different at the end of the study (Table 3). In contrast, the VR-12 mental component score (MCS) only showed significant improvements in the BFR group ($P = 0.0371$), which was also significantly better than the conventional therapy group ($P = 0.0149$) (Table 3).

Although SSWV, FSST, and STS5 significantly improved in the control group, all BFR group physical functional outcome measures significantly improved and displayed generally greater improvements (Table 2). Furthermore, the TSA improved significantly more in the BFR group.

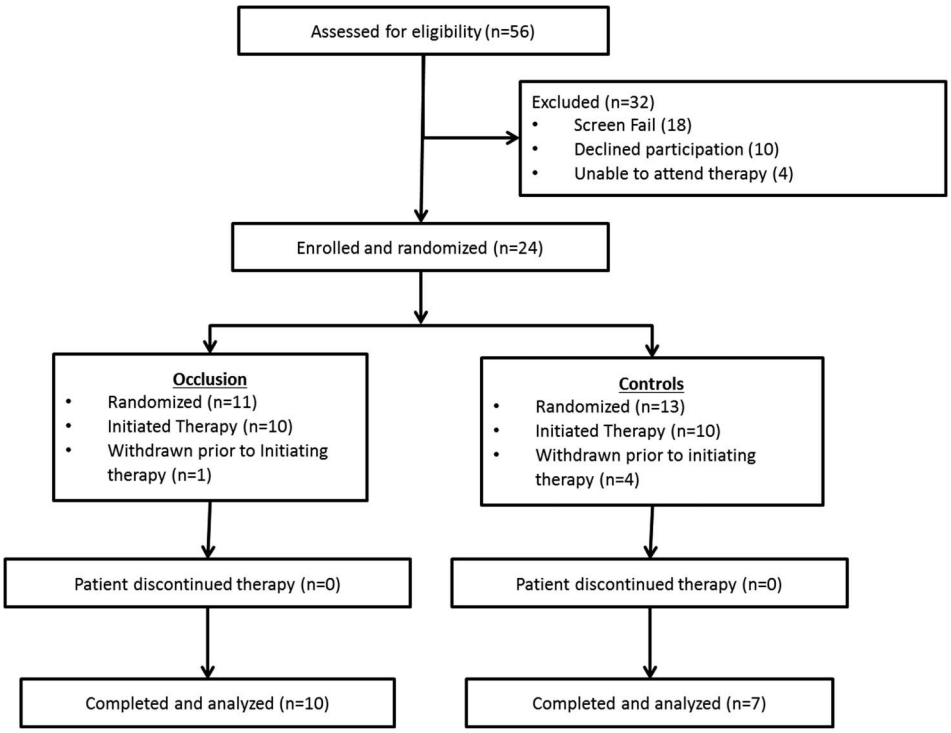

FIGURE 2. CONSORT diagram.

Significant extension and flexion strength improvements over time were seen in both groups (Table 4). When including significant outliers, final strength testing was not different at the end of therapy. However, quadriceps extension strength in the BFR showed an approximate 2-fold strength improvement compared with controls (77.92% vs 40.80%, $P = 0.0969$) (Table 4). This degree of change was also seen in the degree of knee flexion improvement (39.00% vs 15.70%, $P = 0.125$).

When testing for normal distribution of data, a single significant outlier was seen in both groups. With the removal of both of these outliers, one from each group, the variability seen in quadriceps strength decreased. After this removal, significantly greater quadriceps strength change was observed in the BFR group compared with the controls ($P = 0.034$) (Table 5). All DVT ultrasound studies were negative at the initiation and conclusion of the study period, and no patient-reported adverse events were seen throughout the study.

TABLE 1. Demographics

	Occlusion	Control	*P*
Age	37.0 (30-46.2)	37.0 (32-47)	0.6600
Male, (%)	70.00	71.43	1.0000
Right knee, (%)	80	57.14	0.5928
Days from surgery	21.5 (19.5-28.5)	20.0 (15-27)	0.4935
Total length of PT	42.0 (31.25-53.25)	41.0 (33-47)	0.9611
Initial functional score	65.0 (60-70)	72.5 (55-75)	0.5011
Initial pain rating	6 (0.5-24.25)	1.76 (1.5-39.5)	0.8830

†Data shown as median (Interquartile ranges).

DISCUSSION

This is the first study, to our knowledge, to demonstrate the benefit of BFR when used as an adjunct to postoperative physical therapy after knee arthroscopy. When compared with conventional therapy, a significant difference were seen in the primary outcome of knee strength. Furthermore, significantly greater changes in thigh girth, VR-12 MCS, and the TSA was seen in the BFR group compared with controls. The utility of BFR training is further substantiated by the greater degree of improvement seen across all physical, functional, and patient-reported outcome measures. Finally, there were no DVTs or adverse events observed in our study.

Although not definitive, theories explaining the mechanism of action regarding BFR training based on increased anabolic hormones, increased type II muscle fiber recruitment, and increased cellular swelling have been proposed.[11,12,14,16,31–33] These changes likely occur due to the relatively anaerobic environment created by a tourniquet while performing exercises. This environment consequently may create the requisite anaerobic state to allow muscle fiber hypertrophy and corresponding strength gains to occur at 20% to 30% 1RM rather than the >60% 1RM recommended by the ACSM.

Thigh girth has previously been shown to be effected postoperatively.[34] Girth was measured mid-quadriceps at 6-cm and 16-cm proximal to the proximal patellar pole (Table 2). In this study, only subjects assigned to the BFR group showed significant differences in quadriceps girth at 6-cm and 16-cm. In this study, only the BFR group showed significant improvements in quadriceps size at 6-cm and 16-cm. Furthermore, this difference was significantly more in the BFR group at 6-cm compared with the control group. This is consistent with the previous BFR literature which has shown increased

TABLE 2. Thigh Girth (cm) Proximal to Superior Patellar Pole (cm)†

	Initial Uninvolved	Initial Involved	Final Involved	Change Involved	*P*
6-cm proximal					
Occlusion	46.50 (43-53.25)	44.50 (42.3-50.5)	47.25 (45.5-53.6)	1.75 (1 to 4.6)	0.0111*
Control	50.00 (44-52)	49.00 (45.5-51)	50.00 (45.5-50.5)	0 (−1 to 0.5)	1
16-cm proximal					
Occlusion	58.00 (51.4-63.3)	54.50 (50.3-61.4)	57.50 (51.6-64)	2.25 (0.75 to 3)	0.0001*
Control	59.50 (53-62)	60.00 (54-61)	60.00 (54-61)	0.50 (0 to 1.5)	0.1453

*Significance set at $P < 0.05$.
†Data shown as median (Interquartile ranges).

hypertrophy compared with work-matched controls.[24,35,36] Furthermore, this correlates with the other changes seen between groups and should be included in future investigations.

Although the exact mechanism for the early hypertrophy seen after BFR is still under investigation, increased protein synthesis and satellite cell activation may play a role. Gunderman et al[33] demonstrated increased activation of the mTORC1 signaling pathway and increased muscle protein synthesis compared with work-matched controls. The authors demonstrated that even 24 hours after training, the BFR group had a 69.4% increase in muscle protein synthesis compared with baseline.[33] Similarly, Fry and Rasmussen[37] demonstrated

TABLE 3. Patient-Reported and Physical Outcome Measures

	Occlusion				Control				Group Differences
	Initial	Final	Improvement	*P*	Initial	Final	Change	*P*	*P*
KOOS									
Pain	52.8 (40.3-61.8)	75.0 (58.3-84.7)	22.22 (7.64 to 30.56)	0.0001*	69.40 (66.7-72.2)	77.80 (61.1-91.7)	8.33 (5.6 to 19.4)	0.0412*	0.1420
Symptoms	47.10 (42.0-64.3)	76.8 (58.9-89.3)	25.00 (7.1 to 33.0)	0.0028*	67.90 (39.3-75)	71.40 (46.4-89.3)	7.14 (0 to 21.4)	0.0781	0.1711
ADL	58.08 (44.5-72.1)	88.24 (50.4-95.2)	23.52 (4.8 to 34.2)	0.0009*	73.50 (66.2-75.0)	75.00 (63.2-98.5)	5.88 (1.5 to 25.0)	0.0844	0.2029
QOL	31.3 (15.6-46.9)	59.34 (46.9-70.3)	15.63 (0 to 50.0)	0.0034*	43.80 (31.25-50)	62.50 (37.5-81.25)	18.75 (−6.3 to 31.25)	0.0755	0.4612
Sport	10.00 (0-33.75)	47.5 (37.5-71.25)	40.00 (6.3 to 52.5)	0.0009*	35.00 (10.0-45.0)	70.00 (10.0-90.0)	15.00 (0.0 to 45.0)	0.412*	0.4054
VR-12									
PCS	30.86 (22.4-39.4)	46.3 (38.2-52.1)	10.92 (−1.1 to 22.2)	0.0098*	36.50 (25.3-40.1)	47.70 (35.6-50.5)	8.32 (1.4 to 21.9)	0.0451*	0.8738
MCS	51.20 (41.2-59.5)	60.24 (55.5-63.9)	13.05 (3.4 to 14.8)	0.0371*	57.60 (54.2-63.9)	56.20 (50.4-61.5)	−1.77 (−5.7 to 2.4)	0.4047	0.0149*
Physical outcome									
SSWV	1.31 (0.9-1.6)	1.80 (1.5-2.0)	0.49 (0.15 to 0.75)	0.0030*	1.45 (1.6-1.3)	1.91 (1.6-1.4)	0.45 (0.27 to 0.78)	0.0289*	0.8073
Stair climb	9.50 (5.9-12.9)	5.11 (4.5-8.0)	3.77 (1.3 to 7.3)	0.0001*	5.84 (4.5-8.0)	4.92 (4.0-7.1)	0.78 (0.5 to 1.5)	0.2235	0.0281*
FSST	7.39 (6.5-10.0)	5.89 (5.6-6.8)	2.07 (0.2 to 2.7)	0.0015*	8.45 (7.2-9.4)	6.36 (5.9-7.6)	1.30 (0.9 to 2.1)	0.0097*	0.6256
Sit-Stand	10.62 (9.6-12.7)	7.77 (6.5-9.3)	2.8 (1.0 to 4.9)	0.0107*	11.27 (10.0-13.0)	7.98 (7.6-10.1)	3.13 (2.1 to 4.7)	0.0062*	0.6256

*Significance set at $P < 0.05$.
†Data shown as median (Interquartile ranges).
ADL, Activities of Daily Living; QOL, Quality of life.

TABLE 4. Peak Torque (N·m)/Body Weight (kg)

	Initial Uninvolved	Initial Involved	Initial Deficit	Final Uninvolved
Extension uncorrected				
Occlusion	209.68 (150.13-209.68)	92.81 (68.97-153.41)	106.86 (29.97 to 165.82)	230.76 (173.07-272.15)
Control	189.81 (185.62-204.15)	124.35 (55.3-156.03)	79.81 (39.16 to 145.27)	201.76 (169.78-222.98)
Flexion uncorrected				
Occlusion	121.21 (95.35-154.16)	91.47 (67.33-108.43)	35.57 (13.38 to 59.26)	125.69 (111.94-142.73)
Control	124.64 (83.99-126.14)	99.24 (43.34-122.85)	12.85 (−14.05 to 46.63)	130.92 (98.04-139.59)
	Final Involved	**Final Deficit**	***P***	**% Improvement Involved**
Extension uncorrected				
Occlusion	194.59 (132.49-228.51)	34.82 (−4.56 to 73.76)	0.0010*	77.92 (42.4-129.6)
Control	181.14 (128.53-217.31)	41.25 (−17.93 to 117.47)	0.0078*	40.80 (3.6-74.6)
Flexion uncorrected				
Occlusion	131.07 (95.05-140.79)	−1.79 (−15.99 to 9.57)	0.0010*	39.00 (25.7-66.5)
Control	130.62 (106.78-146.016)	2.39 (−15.99 to 9.57)	0.0234*	15.70 (0.5-56.7)

*Significance set at $P < 0.05$.
†Data shown as median (Interquartile ranges).

a significant increase in muscle protein synthesis in subjects who performed exercise under vascular occlusion versus work-matched controls. Furthermore, the proliferation and incorporation of myogenic satellite cells after BFR lead to increased myocyte content and subsequent increased muscle protein synthesis capability.[38]

The physical function outcome measures used in this study have established reliability in a young, active military population.[27] Although the mean age of the patients used to establish the initial normative reference data was younger (Mean age: 24) than the cohort tested in this study (Table 1) (Mean age: 39.7), the reference data are likely still relevant given they were drawn from a similarly active population.[27] Compared with the norms established by Wilken et al,[27] the overall functional outcomes of both groups improved to levels approximating the median ranges of normal. The TSA of the BFR group displayed the greatest change over the study period, with over 4 seconds of improvement. This change may be most relevant regarding the overall quadriceps improvement as ascending stairs is more functionally demanding and requires significantly more quadriceps strength than walking.

As further seen in Table 3, KOOS scores significantly improved in both groups across several subscales, which is expected in postoperative patients progressing through physical therapy. Furthermore, although not significant, the BFR group displayed between a 1.5 to 2 times greater improvement in all subscales. This greater change is similar to the improvements seen in overall quadriceps strength and functional outcome scores.

The VR-12 PCS displayed improvement in both groups. These improvements follow the changes seen in quadriceps strength, KOOS, and physical outcome measures. In contrast to the changes seen in the PCS, the MCS only

TABLE 5. Peak Torque (N·m)/Body Weight (kg)

	Initial Uninvolved	Initial Involved	Initial Deficit	Final Uninvolved
Extension corrected				
Occlusion	215.21 (147.51-251.97)	99.83 (73.83-153.79)	98.34 (29.44 to 145.57)	225.08 (168.88-285.75)
Standard	192.5 (175.76-192.5)	126.74 (100.88-170.75)	68.15 (34.9 to 137.2)	206.54 (192.87-250.93)
Flexion corrected				
Occlusion	123.15 (95.5-123.15)	99.83 (79.21-111.34)	31.09 (9.42 to 53.5)	130.02 (110.75-144.67)
Standard	125.09 (84.89-128.38)	105.51 (58.14-129.58)	7.77 (−16.44 to 38.65)	133.91 (97.29-141.17)
	Final Involved	**Final Deficit**	***P***	**% Improvement Involved**
Extension corrected				
Occlusion	211.92 (127.48-232.85)	23.01 (−9.12 to 64.56)	0.0020*	74.594 (42.16-98.88)
Standard	171.57 (120.53-217.9)	42.44 (14.348 to 119.71)	0.0156*	33.5 (2.99-51.81)
Flexion corrected				
Occlusion	141.68 (110.6-147.06)	−2.99 (−18.53 to 10.76)	0.0020*	40.20 (26.7-84.6)
Standard	132.71 (87.22-142.7)	1.79 (−12.2 to 21.89)	0.0469*	16.80 (0.9-119.3)

*Significance set at $P < 0.05$.
†Data shown as median (Interquartile ranges).

showed significant improvements only in the BFR group and a decrease in the MCS in the control group. As this study was not blinded and patients were aware of the other treatment arm due to therapy being performed at the same institution, this discrepancy in the MCS may likely be related to the patient's perception of receiving a higher level of physical therapy compared with those in the BFR group.

Significant improvements in strength were seen in both the BFR and control groups (Table 4). Furthermore, each of the groups had a single significant outlier that skewed the data regarding the overall strength improvements (BFR group: 464% Controls: 417% improvement). On further analysis and record review, these patients were unable to fully participate in the initial strength testing because of a high level of discomfort. Consequently, the strength data were analyzed with and without their results. Once these outliers were excluded, the strength changes seen in each group remained. However, the percent change between groups was found to be significant. This discrepancy with and without outliers may highlight the importance of ensuring that patients are able to fully participate in all testing and therapeutic interventions in future studies.

This study was conducted as a pilot study for future studies evaluating BFR interventions in more complex postoperative patients. As such, the small sample size limits the ability to make definitive statements regarding the effect of BFR as an adjunct to conventional physical therapy as it was underpowered and may be more susceptible to type I or type II errors. The greater changes seen in the BFR group in this study may also be influenced by the BFR group's perception that their treatment was more intensive or superior to therapy without BFR interventions. Blinding the patient to their treatment or placing a subocclusive tourniquet would help alleviate some of this bias in future studies.

Unlike previous studies evaluating BFR training, no patients in this study displayed any major complications, bruising, DVT, or failures of BFR treatment secondary to discomfort.[39] This study did evaluate for the presence of DVT using duplex ultrasonography both before and after BFR training. Although all patients were asymptomatic and no radiographic evidence of no DVTs were found on duplex ultrasonography, it must be noted that ultrasonography does have poor sensitivity for detecting DVT. However, these results are consistent with the previous literature noting the potential vascular protective effects of BFR training by improving vascular endothelial and peripheral blood circulatory function.[40,41] In conclusion, this study demonstrates that the addition of BFR interventions to a postoperative therapy program can induce improvements in strength, muscular hypertrophy, function, and patient-reported measures safely after knee arthroscopy. Although small, the results of this study are promising and warrant further investigation in more powerful, larger clinical trials investigating preoperative and postoperative surgical patients with a higher level of initial disability.

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