# Blood Flow Restriction Training in Patients With Rotator Cuff Tendinopathy: A Randomized, Assessor-Blinded, Controlled Trial

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## Abstract

**Objectives:** To investigate the effects of low-load blood flow restriction (BFR) training on shoulder muscle thickness, rotator cuff (RC) strength, and shoulder symptoms in patients with RC tendinopathy. **Design:** A randomized, assessor-blinded, controlled trial. **Settings:** Physiotherapy clinic at a university. **Participants:** Twenty-eight patients were randomized into an 8-week (2 times/week) shoulder rehabilitation, that is, BFR or non-BFR group. **Interventions:** BFR training. **Main outcome measures:** (1) RC, deltoid, scapula retractor, and biceps muscle thicknesses and shoulder internal rotation (IR) and external rotation (ER) strengths. (2) Shoulder pain/function. **Results:** The BFR group had a greater increase in biceps muscle thickness ($P = 0.002$) and shoulder IR strength at 60 degrees/s ($P = 0.040$) than the non-BFR group. No differences between the 2 groups were observed in other measurements. Significant improvements in supraspinatus, infraspinatus, and scapula retractor muscle thicknesses and in shoulder ER and IR strengths were observed over time in both the groups (all $P < 0\ .05$). Also, shoulder pain decreased and shoulder function increased over time in both the groups (all $P < 0\ .05$). **Conclusions:** Low-load BFR training resulted in a greater increase in biceps thickness and shoulder IR strength compared with the non-BFR group in patients with RC tendinopathy. However, there was no superiority of either exercise training regarding the RC, scapula retractor, deltoid muscle thicknesses, or improvements in shoulder ER strength and shoulder pain/function. **Clinical Trial Registry Name and Registration Number:** The study was registered in ClinicalTrials.gov named Blood Flow Restriction Training in Patients with Shoulder Pain and the registration number is NCT04333784.

**Key Words:** resistance training, shoulder, pain, rehabilitation, hypertrophy

(*Clin J Sport Med* 2024;34:10–16)

## INTRODUCTION

Similar to high-load exercise (>70% one-repetition maximum, 1-RM), low-load resistance training with blood flow restriction (BFR, 20%-30% 1-RM) is known to facilitate muscle hypertrophy and increase strength.[1] It has become popular in recent years as an alternative to high-load exercise especially in groups that cannot tolerate high load.[2] The low-load nature and strengthening capacity of this training can provide positive musculoskeletal rehabilitation results without a high level of joint stress.[3] Previous studies reported that low-load BFR training results in muscle hypertrophy not only in the blood flow–restricted limb but also in proximal muscles and even on the contralateral limb, owing to its potential local/systemic effects.[1,4–8] When the pneumatic cuff is inflated in the most proximal part of the shoulder, especially the biceps brachii, triceps brachii, wrist flexor, and extensor muscles are expected to be directly exposed to BFR because they are located in the distal sites of occlusion. However, the blood flow in the muscles located proximal to the upper extremity, such as the rotator cuff (RC), pectoral muscles, trapezius, and rhomboids cannot be directly restricted by the application of BFR. The effects on these muscles may occur by means of indirect mechanisms.[1]

Evidence suggests that structured physiotherapy programs that progressively load the RC are combined with scapular stabilization training and flexibility exercises in the treatment of RC tendinopathy.[9] Open-chain, closed-chain, concentric or eccentric exercises seem to be effective as long as the RC is dynamically loaded.[9–12] However, it is very unlikely to strengthen the RC with high-load exercises without increasing the shoulder pain, especially in the early period of rehabilitation.

To date, most studies have focused on the effects of low-load BFR exercises in lower-extremity rehabilitation whereby

*Submitted for publication May 11, 2023; accepted August 6, 2023.*

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*The authors report no conflicts of interest.*

*The study protocol was approved by the Hacettepe University Institutional Review Board in Ankara, Turkey (Approval number: 2020/02-28 (KA-19146).*

*The authors affirm that human research participant provided informed consent for the publication of the images in the supplementary file.*

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*Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.cjsportmed.com).*



*http://dx.doi.org/10.1097/JSM.0000000000001191*

beneficial effects are shown especially in knee pain and postoperative knee rehabilitation.[3,13–15] Little is known about its effectiveness in the upper extremity, such as RC and scapular muscles. In addition, all upper-extremity BFR training studies were performed with healthy individuals.[4,5,7,16–18] To our knowledge, there are only 4 studies that investigated the effects of low-load BFR training on RC muscles in healthy individuals, with mixed results.[7,16–18] There is currently no study on the effectiveness of BFR training in patients with shoulder pain.

Accordingly, this study primarily aimed to investigate the effects of low-load BFR training on shoulder muscle thickness and RC strength in patients with RC tendinopathy. The secondary aim was to determine the changes in shoulder pain and function. It was hypothesized that patients in the BFR group would experience a greater increase in shoulder muscle thickness and rotator cuff strength, less pain, and better function than those in the non-BFR group.

## METHODS

This was an assessor-blinded, prospective, randomized, controlled trial in patients with RC tendinopathy as BFR versus non-BFR groups. Patients were recruited from the Sports Physical Therapy Unit at the Hacettepe University between December 2020 and January 2022. The Consolidated Standards of Reporting Trials (CONSORT) statement was applied, and the study was registered in ClinicalTrials.gov (NCT04333784).

### *Participants*

Patients (aged 18-45 years) with a diagnosis of RC tendinopathy were included if they had unilateral shoulder pain lasting at least 3 months, no symptoms in the contralateral shoulder, and at least 3 of the following criteria: positive Neer sign, positive Hawkins sign, positive Jobe sign, painful arc, and positive resistance test against shoulder external rotation (ER).[11,19] An ultrasonographic evaluation was performed for RC tendinopathy findings in addition to clinical evaluation. Patients were excluded if they had hypertension, cardiovascular/neurological disease, deep vein thrombosis, systemic inflammation, cancer, obesity, diabetes, full-thickness RC tear, bilateral shoulder symptoms, corticosteroid injection within the past 6 months, prior surgery or shoulder dislocation, cervical spine–related neurological symptoms, or limited shoulder range of motion. Patients who did/could not attend the treatment sessions >2 times or those who had COVID-19 infection during the training were also excluded from the study.

A random number generator was used for 1:1 assignment to either BFR (intervention) or control (non-BFR) group, and block randomization was performed according to sex (Figure 1). Patients in the BFR group performed the rehabilitation exercises while a 5-cm-wide pneumatic cuff (KAATSU Nano; KAATSU Global, Inc., Huntington Beach, California) was placed on the most proximal portion (end point of deltoid muscle) of the painful shoulder. Patients in the control group performed the same exercise protocol without the cuff. It was not possible to blind the physical therapists due to the nature of the interventions. However, patients were unaware of which group was considered as the intervention and the control. Ultrasonographic evaluation for RC tendinopathy or measurements during the study was performed by a physiatrist with 20-year experience in musculoskeletal ultrasound (L.Ö.) who was blinded to the study group allocation.

### *Procedures*

All measurements were performed 2 times at baseline (1 week before the start of the rehabilitation) and follow-up (at the end of 16 sessions, at least 72 hours after the last training). Demographics (sex, age, height, body weight), dominant shoulder and affected shoulder, and duration of pain were recorded. Muscle thickness, RC strength, pain, and shoulder function were evaluated.

Supraspinatus, infraspinatus, deltoid, biceps brachii, and scapula retractor (middle trapezius and rhomboids) muscle thicknesses were measured using a 5 to 12 MHz linear probe (Logiq P5, GE Medical Systems, Wisconsin). All muscles were imaged while patients were in the relaxed sitting position, with the arms beside the trunk, elbows flexed and supported on the knees, and the palms facing together. All the aforementioned muscle thicknesses (in centimeters) were measured as the linear distance at the center of the muscle within the fascial borders.[20] Probe compression and the amount of gel were kept optimal.

Concentric strength was assessed at 60 degrees/s and 180 degrees/s using isokinetic testing (IsoMed 2000, D&R Ferstl GmbH, Germany) for shoulder internal rotation (IR) and ER. A 10-minute warm-up and stretching period were given before the isokinetic testing, then the patients performed 5 to 6 submaximal repetitions at each angular velocity for getting familiar with the procedure. The patients were in a sitting position, and the belts were fixed to the device from both shoulders and waist during the measurements. The shoulder was positioned in the scapular plane, at 45 degrees elevation, and with the elbows at 90 degrees flexion. The shoulder range of motion was set at 30 degrees IR and 40 degrees ER (total rotation range of 70 degrees). Patients performed 6 repetitions at 60 degrees/s and 10 repetitions at 180 degrees/s under verbal encouragement. Maximum concentric strength/body weight was recorded as newton meters/kilogram (Nm/kg). Shoulder pain that may occur during the isokinetic testing was evaluated by a visual analog scale (VAS; 0: no pain; 10: worst pain) after the test.

Shoulder pain and function were evaluated by Shoulder Pain and Disability Index (SPADI; 0: less shoulder disability; 100: more shoulder dysfunction). Pain at rest, night, and activity were evaluated by VAS.

After initial assessments, a 10-minute rest period was given, and the amount of resistance to be used during the exercises was determined. The 1-RM test was used for the exercises performed with free weights,[21] and the OMNI-Resistance Exercise Scale of perceived exertion with elastic bands (OMNI-RES EB) was used for the exercises performed with elastic resistance [Theraband Elastic Band (Hygienic Corporation, Akron, OH)].[22] Four main exercises were selected to activate the RC, biceps brachii, and scapular stabilizer muscles, and they progressed throughout the entire rehabilitation. Exercise intensities were determined according to the following exercises: full can (free weight) for supraspinatus,[23] side-lying external rotation (free weight) for infraspinatus–teres minor,[23] biceps curl (elastic resistance) for biceps brachii, scapular retraction (elastic resistance) for middle/lower

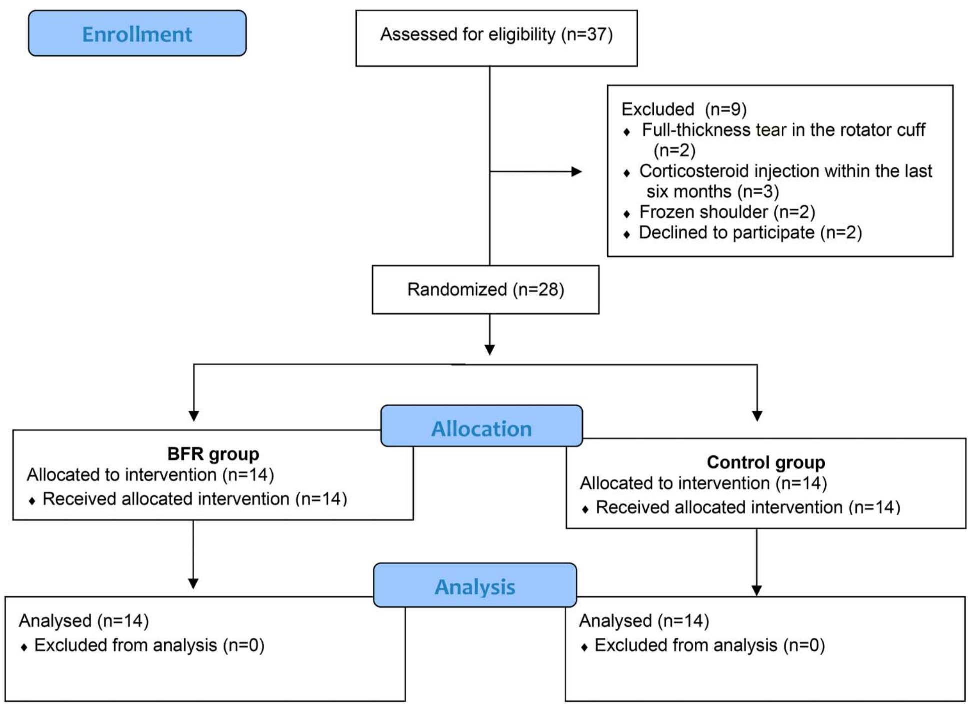


**Figure 1.** Flow diagram.

trapezius.[24] For each free weight exercise, the initial weight was calculated as 30% of the 1-RM. The exercise load for elastic resistance exercises was adjusted in the range of 3 to 5 according to the OMNI-RES EB scale.

Activity modification, cold application for pain (at least 3 times/day, for 15 minutes), and anterior and posterior capsular stretching exercises (3 repetitions, 3-4 times/day) were recommended to the patient at the end of the assessment session.

The amount of cuff pressure in the BFR group was measured at the beginning of the first rehabilitation session. Limb occlusion pressure (LOP) was evaluated in all patients in the supine relaxed position, and the pressure was verified with a handheld Doppler on the radial artery. The unit of LOP measurement was expressed as Standard KAATSU Units (SKU) as specified in the device's user manual.

### *Training Protocol*

Patients in both groups participated in the shoulder rehabilitation training for 8 weeks (2 days/week), which were supervised by the primary investigator (D.K.). All patients completed a total of 16 supervised sessions. During training, patients were told to maintain a controlled cadence throughout the exercises, that is, 2-second concentric and 2-second eccentric contractions. All exercises were bilaterally performed in both the groups. Exercises were progressed for 8 weeks by changing body positions (from standing to prone), shoulder abduction angles, or increasing the load (Table 1). For rehabilitation exercises, please see **Supplemental Digital Content 1**, (**Supplementary File**, http://links.lww.com/JSM/A395). During the rehabilitation, cold application for pain and capsular stretching exercises were continued, if needed. The rating of perceived exertion (RPE; a scale of 1-10) at the end of each exercise session was recorded to document difficulty. Patients were told to continue the exercises at home 3 times a day.

### *Blood Flow Restriction Training Protocol*

The BFR cuff pressure was set to 50% LOP throughout the rehabilitation. Patients were familiarized with the exercise intervention with the 150 SKU inflated BFR cuff in the first session. Then, the BFR pressure was increased in each session (10-30 SKU), and the desired training pressure was reached at the end of 3 sessions. The cuff pressure was not changed after the fourth session. Patients performed the exercises 1 set of 30 repetitions followed by 3 sets of 15 repetitions. A 30-second rest was given between the sets, and 2-minute rest between the exercises. The BFR cuff was kept inflated throughout the sets and deflated for 2 min in between each exercise that targeted a specific muscle group. The training load was increased by 0.5 to 1 kg every 2 weeks for each free weight exercise, and 1 advanced color was used for each elastic resistance exercise. If the total number of repetitions (ie 75) could not be completed, the load was reduced to the previous level.

### *Statistical Analysis*

A priori sample size was calculated based on the data obtained from a pilot study including 5 patients in each group. The calculations were based on shoulder ER muscle thickness with a between-group difference of 0.27 cm, a SD of 0.22 cm, an effect size of 0.61, an alpha level of 0.05, and the desired power of 95%. A sample of 12 patients per group was required. Therefore, anticipating up to a 10% dropout rate, a

**TABLE 1. Training Protocol**

| |
|---|
| 0-1 wk |
| Biceps curls (elastic resistance) |
| Scapular retraction at 0° of shoulder abduction and 90° of elbow flexion (elastic resistance) |
| 1-2 wk |
| Biceps curls and scapular retraction exercise were continued |
| Full can (free weight) |
| Side-lying external rotation (free weight) |
| 2-4 wk |
| Biceps curls, full can, and side-lying external rotation were continued |
| Scapular retraction at 45 degrees of shoulder abduction and 90 degrees of elbow flexion (elastic resistance) |
| Wall push-ups |
| 4-6 wk |
| Biceps curls, full can, side-lying external rotation, and wall push-ups were continued |
| Prone-T exercise (free weight) |
| 6-8 wk |
| Biceps curls, full can, and side-lying external rotation were continued |
| Prone-Y exercise (free weight) |
| Prone external rotation at 90 degrees abduction (free weight) |
| Table push-ups |

total of 28 patients were recruited. Statistical analysis was performed using IBM SPSS 23.0 statistical package (Armonk, NY: IBM Corp). The normality of the data was evaluated by Kolmogorov–Smirnov/Shapiro–Wilk tests. Values were presented on mean and 95% confidence interval (CI) or median and interquartile range (IQR), where appropriate. Baseline differences between the groups were analyzed using the Student *t*-test, and duration of pain scores and average RPE at the end of exercise sessions were analyzed using the Mann–Whitney *U* test. Changes in muscle thickness, RC strength, shoulder pain, SPADI score, and pain during isokinetic testing were analyzed using a $2 \times 2$ (group $\times$ time) mixed-model analysis of variance. The BFR and control groups were defined as the "group factor," and the pretest and posttest were defined as the "time factor." The alpha level was set at $<0.05$.

## ETHICAL CONSIDERATIONS

The XX Institutional Review Board approved the study protocol, and written informed consent was obtained from all patients.

## RESULTS

Twenty-eight patients with a diagnosis of RC tendinopathy met the inclusion criteria and participated in the rehabilitation protocol (Figure 1). There were no significant differences in baseline demographic characteristics and initial pain scores ($P > 0.05$, Table 2). Baseline measurements were similar between the groups ($P > 0.05$). The average LOP during the exercises was 189 ± 19 SKU (min–max 160-220 SKU) in the BFR group.

Group-by-time interactions are given in Table 3. The biceps brachii muscle thickness [$F(1,26) = 11.83$, $P = 0.002$] and shoulder IR strength at 60 degrees/s [$F(1,26) = 4.67$, $P = 0.04$] showed significant changes whereby the BFR group demonstrated higher biceps brachii muscle thickness and shoulder IR strength at 60 degrees/s after the training.

There was a significant main effect of time on the pretest and posttest in supraspinatus ($P = 0.007$), infraspinatus ($P = 0.001$), scapula retractor ($P = 0.031$) muscle thicknesses, and shoulder ER muscle strength at 60 degrees/s ($P = 0.001$) and 180 degrees/s ($P = 0.002$) and shoulder IR muscle strength at 60 degrees/s ($P = 0.017$) and 180 degrees/s ($P < 0.001$) (Table 3). These muscle thicknesses and shoulder rotational strengths were increased over time in both the groups. There was also a significant main effect of time on shoulder pain at rest ($P = 0.002$), night ($P < 0.001$), activity ($P < 0.001$), and SPADI score ($P < 0.001$) (Table 3). Shoulder pain decreased and shoulder function increased over time in both the groups.

Pain during the isokinetic testing decreased over time (mean: 2.86-0.21 in the BFR group; and mean: 3.93-0.86 in the control group, $P = 0.001$); no differences between the 2 groups [$F (1.26) = 0.58$, $P = 0.46$] were found. During exercises, RPE was significantly higher in the BFR group [median (IQR): 6.8 (6-8)] compared with the control group [median (IQR): 4.8 (4-5.5), $P < 0.001$].

## DISCUSSION

To the authors' best knowledge, this study is the first to investigate the effects of BFR training on RC, scapular stabilizer, and other muscles (deltoid, biceps brachii) in the painful shoulder. We observed a greater increase in biceps brachii muscle thickness and shoulder IR strength at 60 degrees/s in the BFR group than in the control group. However, there was no superiority of either exercise training in other muscle thicknesses, shoulder ER strength, and shoulder IR strength at 180 degrees/s. Our primary hypothesis partially affirmed the effects of BFR training on muscle strength and hypertrophy in the proximal/distal sites of the occlusion.

Biceps brachii hypertrophy is consistent with previous studies that reported hypertrophy distal to the site of occlusion with BFR training.[5,7,18,25] Disorders of the long head of the biceps often occur in conjunction with other shoulder pathologies. Yet, the tendon is tender with palpation and is believed to be the source of shoulder pain.[26,27] It is recommended that appropriate strengthening is important to augment the healing response in the biceps.[27] From a clinical point of view, we believe that BFR training could significantly benefit to increase the loading capacity on the biceps tendon during (painful) shoulder rehabilitation.

Owing to its possible/proximal effects, recent studies have suggested that BFR training may provide an effective exercise tool that increases the size/strength of muscles proximal to the cuff, for example, in the shoulder and chest.[1,6–8] The increase in shoulder IR muscle strength at 60 degrees/s in this study is consistent with this proximal effect. We think that the increase might have occurred with the support of surrounding large muscle groups, for example, pectoralis major and subscapularis. Progressive push-up exercises with BFR might have caused an increase in the thickness/activation of these muscles.

**TABLE 2. Clinical Characteristics at the Initial Assessment**

| | BFR Group ($n$ = 14) | Control Group ($n$ = 14) | $P$ |
|---|---|---|---|
| Sex (n) | 7 Female, 7 Male | 7 Female, 7 Male | |
| Age (yr) * | 31.1 (28.2-34.1) | 34.9 (31.7-38.1) | 0.074 |
| BMI (kg/m2)* | 23.9 (22.4-25.4) | 24.1 (22.1-25.9) | 0.869 |
| Duration of pain (mo)† | 7.5 (5-12) | 7 (4-8) | 0.444 |
| Dominant side (n) | 11 Right, 3 Left | 13 Right, 1 Left | |
| Affected side (n) | 8 Dominant<br>6 Nondominant | 6 Dominant<br>8 Nondominant | |
| Partial RC tears (n) | 2 Patients | 3 Patients | |

** Values are given as mean, 95% CI.*
*† Values are given as median, IQR.*
*BMI, body mass index.*

However, because we did not evaluate these muscles in our study, it is not possible to reach a definite conclusion.

Current research has also shown that BFR training is a possible pain-modulation tool in individuals with acute/chronic pain.[28,29] Hughes et al[28] suggested that the reduction in pain sensitivity with BFR training is partly driven by endogenous opioid production. However, our findings showed that both training programs effectively reduced pain and improved shoulder function in RC tendinopathy. Exercise-induced pain modulation with different mechanisms might have occurred in both exercise groups. Therefore, our secondary hypothesis (ie improvement in pain and symptoms would be better in the BFR group) was rejected.

The favorable anabolic responses of BFR training shown in previous studies might have not occurred proximal to the cuff for 3 reasons in our study. First, the number of repetitions might have not been enough to sufficiently load the upper-extremity muscles. Second, deflating the cuff pressure between exercises might have impaired the occlusion effect. We used 30/15/15/15 (75 in total) repetitions and kept the cuff inflated between the exercise sets according to the recommended BFR training protocols.[8,30] In 1 review, Dankel et al[1] proposed that upper-body exercises involving musculature proximal to the cuff may show added benefit from a greater number of repetitions (>75 repetitions). In a study of BFR training with common RC exercises in healthy shoulders, Lambert et al[18] had their participants perform the final set of each exercise until fatigue, unlike our repetitions. They observed increased shoulder and arm lean mass, IR strength, and muscular endurance in the BFR group compared with the non-BFR group. The authors concluded that there was a greater contribution to the metabolic and mechanical work performed by the shoulder muscles. Third, multijoint and/or closed-chain exercises involving large muscle groups may be

**TABLE 3. Ultrasonographic Measurements and Evaluations for Shoulder Pain, Strength, and Function (Mean, 95% CI)**

| | BFR Group ($n$ = 14) | | Control Group ($n$ = 14) | | | |
|---|---|---|---|---|---|---|
| | Pretest | Posttest | Pretest | Posttest | Time effect | Group-by-time |
| Muscle thickness (cm) | | | | | | |
| Supraspinatus | 2.11 (1.92 to 2.31) | 2.35 (2.12 to 2.58) | 1.97 (1.64 to 2.30) | 2.10 (1.87 to 2.32) | **0.007** | 0.415 |
| Infraspinatus | 2.35 (2.08 to 2.62) | 2.74 (2.56 to 2.92) | 2.14 (1.85 to 2.42) | 2.43 (2.14 to 2.72) | **0.001** | 0.625 |
| Deltoid | 0.85 (0.70 to 1.0) | 0.94 (0.71 to 1.16) | 0.93 (0.70 to 1.16) | 0.87 (0.71 to 1.04) | 0.713 | 0.114 |
| Biceps brachii | 2.64 (2.36 to 2.91) | 2.87 (2.51 to 3.22) | 2.72 (2.37 to 3.06) | 2.62 (2.24 to 2.99) | 0.186 | **0.002** |
| Scapula retractor | 1.67 (1.47 to 1.86) | 1.79 (1.54 to 1.99) | 1.55 (1.26 to 1.85) | 1.80 (1.49 to 2.11) | **0.031** | 0.346 |
| Muscle strength (Nm/kg) | | | | | | |
| Shoulder ER (60 degrees/s) | 0.32 (0.28 to 0.37) | 0.37 (0.32 to 0.43) | 0.31 (0.25 to 0.37) | 0.34 (0.27 to 0.42) | **0.001** | 0.547 |
| Shoulder IR (60 degrees/s) | 0.44 (0.38 to 0.57) | 0.50 (0.43 to 0.57) | 0.42 (0.30 to 0.54) | 0.43 (0.32 to 0.54) | **0.017** | **0.040** |
| Shoulder ER (180 degrees/s) | 0.28 (0.24 to 0.32) | 0.32 (0.26 to 0.37) | 0.26 (0.21 to 0.31) | 0.32 (0.25 to 0.39) | **0.002** | 0.461 |
| Shoulder IR (180 degrees/s) | 0.39 (0.34 to 0.43) | 0.45 (0.39 to 0.52) | 0.39 (0.28 to 0.50) | 0.42 (0.31 to 0.53) | **<0.001** | 0.110 |
| Shoulder pain (VAS, cm) | | | | | | |
| Rest | 0.69 (0.10 to 1.27) | 0.01 (−0.02 to 0.05) | 1.20 (0.24 to 2.16) | 0.07 (−0.08 to 0.23) | **0.002** | 0.399 |
| Night | 2.52 (0.90 to 4.13) | 0.08 (−0.09 to 0.25) | 1.57 (0.37 to 2.77) | 0.18 (−0.09 to 0.45) | **<0.001** | 0.253 |
| Activity | 5.00 (3.85 to 6.15) | 0.76 (0.26 to 1.25) | 5.41 (4.44-6.39) | 1.12 (0.46 to 1.78) | **<0.001** | 0.941 |
| Shoulder function [SPADI-total (%)] | 41.1 (29.7-52.5) | 8.1 (4.1 to 12.2) | 48.5 (37.0 to 59.9) | 17.9 (7.6 to 28.1) | <0.001 | 0.727 |

*Bold indicates statistical significance.*

inducing more hypertrophic stimuli for the proximal shoulder muscles. The selected exercises in our study were mostly single-joint exercises used in shoulder rehabilitation.[10,12,31] However, in this study, progressive loading was achieved by changing both body positions and the amount of loading. Only push-up exercises, which activate several muscle groups at the same time, were performed by the patients during the training. In an early study (with only 10 participants), Yasuda et al[5] found a greater increase in pectoralis muscle size/strength after 8 weeks of bench press training in the BFR group compared with the non-BFR control group. In another study, they reported that the pectoralis major muscle cross-sectional area increased 8.3% following 6 weeks of bench press training with BFR.[32] Owing to the potential/cumulative effects of contractile activity, further evidence is needed to evaluate the effects of BFR training (using multijoint/closed-chain exercises) on shoulder muscle thickness.

To our knowledge, only 2 other studies investigated the effects of low-load BFR training on RC muscles, similar to our protocol in healthy shoulders. Brumitt et al[17] investigated 8 weeks of side-lying dumbbell ER exercises (30/15/15/15 repetitions at 30% 1-RM) with and without BFR and reported that both groups showed increased strength of the supraspinatus and shoulder ER and increased supraspinatus tendon thickness. However, no differences were detected between the groups. Although we implemented a more comprehensive training program, our findings are consistent with this study. Similarly, Bowman et al[7] implemented the side-lying ER, shoulder IR, biceps curls, triceps extensions, and prone horizontal abduction exercises at 60% LOP. They reported no differences in shoulder ER/IR strength changes between BFR and non-BFR groups; however, participants in the BFR group had a significantly greater gain in limb circumference/strength for shoulder flexion, abduction, and scaption after a 6-week training program. Their results and our findings are somewhat in line with previous findings that BFR may result in greater proximal muscle gains. Herein, we believe that the superiority of BFR training regarding shoulder muscle thickness/strength increase as compared with evidence-based shoulder rehabilitation protocols is controversial.

Low-load BFR training appears to induce metabolic stress similar to high-load exercise fatigue. Patients in the BFR group of our study felt more fatigue (significantly higher RPE scores) at the same exercise load. Previous studies aimed to have an RPE level of 7 or above or volitional fatigue during training to achieve muscle gains.[2,6,7,18] Although we did not set a limit for RPE during the exercises, we observed that the median fatigue level approached the limit of 7 RPE.

This study has several/potential limitations. First, pain was an important limiting factor in the initial strength measurements used for exercise loading because all participants had shoulder pain. It is also possible that the strength values in the final measurements did not demonstrate a real increase in strength—with the reduction of shoulder pain during isokinetic testing and in general. However, we think that this limitation can be acceptable because pain reduction was similar between the groups. Second, the shoulder exercises were performed with free weights, elastic bands, and push-ups in our study. Depending on the elongation of the elastic band and the patient's body weight, the amount of shoulder loading might have changed. Therefore, the exact load or volume could not calculate in these exercises. Finally, the potential local/systemic mechanisms of BFR training were not directly measured. As such, further studies are required to better understand such effects on the proximal site of occlusion in patients with shoulder pain.

## CONCLUSION

In patients with RC tendinopathy, low-load BFR training provided a greater increase in biceps brachii muscle hypertrophy and shoulder IR strength at slow angular velocity—when compared with the non-BFR group at the same load. This study partially affirms the effects of BFR training on muscle strength/hypertrophy in proximal and distal sites of the occlusion in patients with shoulder pain. However, there is no superiority of either exercise training as regards reducing pain and improving shoulder function in RC tendinopathy.

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