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Context: Blood flow restriction (BFR) training utilizes a tourniquet, applied to the proximal portion of one or more extremities, to occlude blood flow during exercise. Significant gains in strength and cross-sectional area can be achieved in muscles, both distal and proximal to BFR cuff application. ***Purpose:*** To compare strength gains of the rotator cuff and changes in tendon size in subjects who performed side-lying external-rotation exercise with or without BFR. ***Methods:*** Forty-six subjects (mean age 25.0 [2.2] y) were randomized to either a BFR + exercise group or to the exercise-only group. Subjects performed 4 sets of the exercise (30/15/15/15 repetitions) at 30% 1-repetition maximum 2 days per week for 8 weeks. ***Results:*** Subjects in both groups experienced strength gains in the supraspinatus and the external rotators ($P = .000$, $P = .000$). However, there was no difference in strength gains between groups for the supraspinatus ($P = .750$) or the external rotators ($P = .708$). Subjects in both groups experienced increases in supraspinatus tendon thickness (BFR $P = .041$, exercise only $P = .011$). However, there was no difference between groups ($P = .610$). ***Conclusions:*** Exercise with BFR applied to the proximal upper extremity did not augment rotator cuff strength gains or tendon thickness when compared with subjects who only exercised. This study did demonstrate that performing multiple sets of high repetitions at a low load led to significant increases in rotator cuff strength and tendon size in the dominant upper extremity.

Keywords: diagnostic ultrasound, exercise, external rotation, occlusion training, shoulder

Blood flow restriction (BFR) training utilizes a tourniquet, applied to the proximal portion of one or more extremities, to occlude arterial and venous blood flow as one exercises.[1–3] Prior research has demonstrated that one can perform a low-load exercise with BFR and achieve significant gains in strength and muscle cross-sectional area (CSA), whereas those who only perform the low-load exercise fail to achieve similar results.[4–7] In addition, individuals performing a low-load exercise with BFR can achieve gains in strength and muscular CSA similar to the results experienced by those who train at a higher intensity.[6]

There are several proposed mechanisms associated with the aforementioned gains during BFR training including metabolite accumulation, growth hormone release, mammalian target of rapamycin complex 1 activation, downregulation of myostatin, and cellular swelling.[8–17] One or more of these factors are likely involved in the strength gains that are observed in muscles distal to the BFR tourniquet application.

Increases in strength and muscular size have also been observed in muscles proximal to tourniquet application.[5,18,19] Abe[18] had subjects perform 3 sets of 15 repetitions (reps) of the squat and leg curl exercises at 20% of 1-rep maximum (1RM) twice a day, 6 days a week, for a 2-week period. Significantly greater gains in lower-extremity strength occurred in the BFR group as well as a significant increase in gluteus maximus volume.[18] Bowman et al[19] compared changes in lower-extremity strength in subjects who performed 4 exercises (straight leg raise, sidelying hip abduction, long-arc quadriceps extension, and standing hamstring curl) at 30% 1RM (4 sets: 30/15/15/15 reps each) with or without BFR. Bowman et al[19] reported significantly greater gains in hip abduction and hip extension strength in the BFR group when compared with controls. Madarame et al[5] had untrained men perform 3 sets of 10 reps of the bicep curl at 50% 1RM. Subjects in the experimental group then performed 3 sets of the leg extension and leg curl exercises (30/15/15 reps; 30-s rest between sets per exercise) at 30% 1RM with BFR applied to both lower extremities, whereas subjects in the control group only performed the 2 leg exercises.[19] After 20 training sessions (2 times per week for 10 wk), subjects in the experimental group experienced significant increases in isometric torque and CSA of the elbow flexors and the thigh, whereas there were no changes in the control group.[19] The changes in strength and muscle volume proximal to BFR application have not been fully elucidated.[8–17]

Based on the results from the aforementioned studies, it is reasonable to assume that application of BFR to the upper extremities could increase strength and CSA to muscles of the chest and shoulders. For example, a 2-week bench press program, performed twice daily (4 sets, 75 reps, performed at 30% 1RM) for a total of 24 training sessions resulted in significant increases in muscle thickness of the pectoralis major and triceps and a significant increase in 1RM bench press strength in subjects who performed bilateral BFR.[20] A subsequent study by Yasuda et al[21] evaluated changes in strength and CSA in adult males after performing the bench press exercise 3 times a week for 6 weeks. Subjects were randomized to one of the 4 groups: a high-intensity training group (75% 1RM; 3 sets of 10 reps), a low-intensity BFR group (30% 1RM; 4 sets of 30/15/15/15 reps), a mixed training group (2 sessions per week of low-intensity BFR training and 1 session of high-intensity training), and a nontraining control group.[21] Increases in pectoralis major and triceps brachii CSA and bench press 1RM were greater in the high-intensity and in the mixed training group; however, all 3 training groups experienced significant improvements.[21] These

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aforementioned studies suggest applying BFR to the upper extremities can lead to significant strength and CSA changes of the pectoralis major and the triceps; however, to date, there are no studies that have assessed the benefits of BFR to the rotator cuff.

Weakness of one or more of the rotator cuff muscles is a common feature of shoulder pathology.[22,23] Addressing strength deficits of the rotator cuff with therapeutic exercise is a primary component of therapy programs prescribed by rehabilitation clinicians.[23,24] Exercises for the rotator cuff are also frequently included in strength training programs for overhead throwing athletes (eg, baseball players).[25–27] Therefore, evaluating the ability of BFR to augment strength gains of the rotator cuff associated with exercise is warranted. The purpose of this study was to compare strength gains of the supraspinatus and the external rotators of the shoulder and changes in tendon size of the supraspinatus in subjects who performed the sidelying external rotation (ER) exercise with or without BFR.

Methods

Subjects

Subjects (N = 46) were recruited from a university setting consisting primarily of graduate school students (mean age 25.0 [2.2] y). The exclusion criteria for this study were as follows: under the age of 18 years; current neck, shoulder (or general upper extremity), and/or thoracic spine pathology; shoulder surgery (or general upper-extremity surgery) during the prior 6 months; cervical or thoracic surgery during the prior year; or having at least 1 contraindication for BFR training.

Design

Subject pretesting was performed the week prior to initiating the training program. Subjects were randomly allocated to either the experimental group (BFR + exercise) or to the control group (exercise only) using a random number generator. Each subject also provided their age and the number a days a week that they performed weightlifting exercises for the shoulder. The trial was prospectively registered with ClinicalTrials.gov (NCT03815760). The institutional review board of George Fox University (Newberg, OR) approved this study. Informed consent was obtained from each subject prior to study participation.

Methodology

Subjects first had their dominant supraspinatus tendon imaged by a coinvestigator (M.K.H.: total 28 y of experience with 7 y of experience in performing diagnostic ultrasound) who was blinded to group allocation.[28] To image the supraspinatus, subjects were positioned in sitting with their head and neck in neutral and their arm in the modified Crass position (subject's hand on the ipsilateral hip, elbow directed posteriorly).[29,30] Long- and short-axis views of the supraspinatus were obtained. The footprint of supraspinatus was identified in long axis at the superior facet of the great tuberosity. The transducer was turned 90° to obtain a short-axis image of the supraspinatus bringing into view the long head of biceps tendon as well. The thickness of the supraspinatus tendon was measured in the short axis at 3 points (10, 20, and 30 mm) lateral to the long head of the biceps tendon.[30] The average of these 3 points was used to represent the thickness of the tendon.[30] The aforementioned imaging methodology of the supraspinatus has an ICC = .933.[30] (Note: The reliability of performing ultrasound imaging of the infraspinatus or teres minor has not been reported in the literature; therefore, it was not performed.) An Affinity 50 ultrasound machine (Philips Healthcare, Andover, MA) fitted with a 50-mm linear array probe was used at a depth of 4.0 cm for all images.

Next, baseline strength measurements were collected for the supraspinatus and the external rotators of the dominant upper extremity. A coinvestigator (D.K.; 19 y of experience), blinded to group allocation, performed all manual muscle tests utilizing a handheld dynamometer (MicroFET 2; Hoggan Scientific, Salt Lake City, UT). Prior to the start of the study D.K.'s test–retest reliability for manual muscle test measurements was performed. The test–retest reliability ($ICC_{3,3}$) of strength measures was established a priori: .985 (.932, .997) for the supraspinatus and .942 (.742, .987) for the external rotators. Manual muscle test descriptions[31] are presented in Table 1. Order of manual muscle testing was randomized with 3 tests performed for each muscle with the mean score used for statistical analysis.

The final component of the pretesting session was to determine the subjects' 1RM when performing the sidelying ER exercise. The sidelying ER exercise was selected for this study because it is an exercise frequently included in strength training programs for overhead throwing athletes, it is a primary exercise prescribed for most musculoskeletal conditions of the shoulder, and for its ability to activate the supraspinatus and the external rotators.[24–27,32] Reinold et al[32] reported that the sidelying ER exercise activated the infraspinatus at 62% (±13%) of a maximum voluntary isometric contraction (MVIC), 67% (±34%) of MVIC for the teres minor, and 51% (±47%) of MVIC for the supraspinatus. Subjects were asked to select a dumbbell (weight options: 1–5 lb [0.45–2.27 kg]) and to perform as many reps of the sidelying ER exercise as possible. Subject performance of the sidelying ER exercise was supervised by the primary investigator (20 y of experience) with 1RM testing terminated at the point of subject fatigue or when the subject was no longer able to perform the exercise with proper technique. Each subjects' 1RM was estimated using the following formula: 1RM = (0.033 reps) RepWt + RepWt. (Note: RepWt was the weight used by the subject during testing.[33,34]) Subjects' training weight (ie, the weight that they used during the study) was set at 30% of their 1RM.

Table 1 Description of Manual Muscle Tests for the Supraspinatus and Shoulder External Rotators[31]

Muscle or muscle group	Test position
Supraspinatus	Subject assumes a sitting position on the table. The shoulder is in a neutral position and abducted to 30°. The elbow is flexed to 90°. The therapist applies resistance laterally to the upper extremity above the elbow region.
Shoulder external rotators (ie, infraspinatus, teres minor)	Subject assumes a prone position on the table with the elbow and forearm not supported by the table. A small towel is positioned between the table and the upper extremity. The upper extremity is positioned at 90° of shoulder abduction. The shoulder is externally rotated 90° with the elbow flexed to 90°. The therapist applies resistance to the distal portion of the forearm.

Subjects participated in twice weekly exercise sessions, for 8 weeks, which were supervised by the primary investigator. Subjects in the experimental group performed the sidelying ER exercise with the BFR cuff (Delfi Personalized Tourniquet System; Delfi Medical, Vancouver, Canada) applied to the proximal portion of the upper extremity with the limb occlusion pressure set to 50% (Figure 1). Subjects performed 4 sets of the exercise with the 30 reps performed for the first set followed by 15 reps for sets 2 through 4. A metronome was used to regulate the speed of the concentric (2 s) and eccentric (2 s) phases of the exercise. Subjects were allowed a 30-second rest period between sets; the total time under occlusion was 8 minutes. Subjects in the control group performed the same exercise (without BFR), the same number of sets and reps, and were required to take a 30-second rest break between sets. Each subject was allowed to continue with their current exercise program; however, they were asked to not perform any exercises specific for the shoulder external rotators. Posttests, using the same aforementioned testing procedures, were performed within 5 days of the completion of the 8-week training program.

Statistical Analysis

Prior BFR-related research that demonstrated significant increases in proximal muscular strength utilized sample sizes ranging from 15 to 26 subjects.[5,19] In this study, 47 subjects were recruited with 24 randomized to the experimental group and 23 to the exercise-only group. A 2-way analysis of variance was performed to determine changes in tendon size and strength within and between groups. Analysis was performed for all subjects (N = 46; note: one subject from the control group withdrew during week 2) and for a subset of subjects (n = 25) who reported performing shoulder exercises infrequently (ie, 1 d a week or less). Statistical analysis was performed using SPSS (version 25.0; IBM Corp, Chicago, IL) with alpha level set at .05.

Figure 1 — Proximal application of the blood flow restriction cuff during performance of the side-lying external rotation exercise.

Results

A total of 47 subjects were recruited for this study with 46 subjects (women = 20, men = 26; mean age 25.0 [2.2] y) completing the 8-week training program. One subject, from the exercise-only group, withdrew from the study after 2 weeks due to a change in the subject's availability.

All subjects experienced significant increases in strength for the supraspinatus (*P* = .000) and for the external rotators (*P* = .000); however, there was no difference between groups (*P* value = .750 for the supraspinatus; *P* value = .708 for the external rotators) (Table 2). Subjects who reported training the shoulder 0 to 1 day per week also experienced significant within-group increases in strength of the supraspinatus and the external rotators (*P* = .000); however, there were no between-group differences (*P* value = .553 for the supraspinatus; *P* value = .546 for the infraspinatus) (Table 2).

Forty-three of the 46 subjects had pretest and posttest supraspinatus images that were analyzed; 3 of the subjects had one or more images that were excluded due to the quality of the images. All subjects in both groups experienced significant increases in supraspinatus tendon thickness (BFR + ER *P* value = .041; ER only *P* value = .011) (Table 3). However, there was no difference between groups (*P* = .610). Among subjects who reported training the shoulder 0 to 1 day per week only the subjects in the control group (ie, exercise only) had significant increases in tendon size at posttest (*P* value = .033; Figures 2 and 3). There was no difference between groups (*P* value = .799; Table 3).

Discussion

To our knowledge, this is the first study to investigate the effects of BFR, applied to the proximal portion of the upper extremity, on

Table 2 Within- and Between-Groups Differences in Rotator Cuff Strength, Mean (SD)

		Supraspinatus dynamometry, lbs		*P*		External rotators dynamometry, lbs		*P*	
	Number of subjects	Pretest	Posttest	Within group	Between groups	Pretest	Posttest	Within group	Between groups
All subjects									
Exercise with BFR	24	34.22 (7.44)	41.58 (7.63)	.000	.750	20.00 (3.63)	29.84 (10.89)	.000	.708
Exercise only	22	34.75 (7.30)	42.48 (9.04)	.000		19.78 (4.30)	29.44 (12.58)	.000	
Subjects[a]									
Exercise with BFR	14	32.63 (7.49)	40.31 (7.14)	.000	.553	19.52 (3.26)	28.35 (10.57)	.000	.546
Exercise only	11	35.57 (8.54)	41.41 (11.4)	.000		19.36 (3.62)	32.12 (13.68)	.000	

Abbreviation: BFR, blood flow restriction.

[a]Group consisting of subjects who reported 1 day or less of resistance training for the shoulders per week.

Table 3 Within- and Between-Groups Differences in Supraspinatus Tendon Thickness, Mean (SD)

	Number of subjects	Supraspinatus tendon thickness, mm		*P*	
		Pretest	Posttest	Within group	Between groups
All subjects					
Exercise with BFR	21	0.427 (0.05)	0.444 (0.06)	.041	.610
Exercise only	22	0.436 (0.07)	0.453 (0.07)	.011	
Subjects[a]					
Exercise with BFR	12	0.422 (0.05)	0.434 (0.60)	.334	.799
Exercise only	11	0.425 (0.05)	0.442 (0.05)	.033	

Abbreviation: BFR, blood flow restriction.
[a]Group consisting of subjects who reported 1 day or less of resistance training for the shoulders per week.

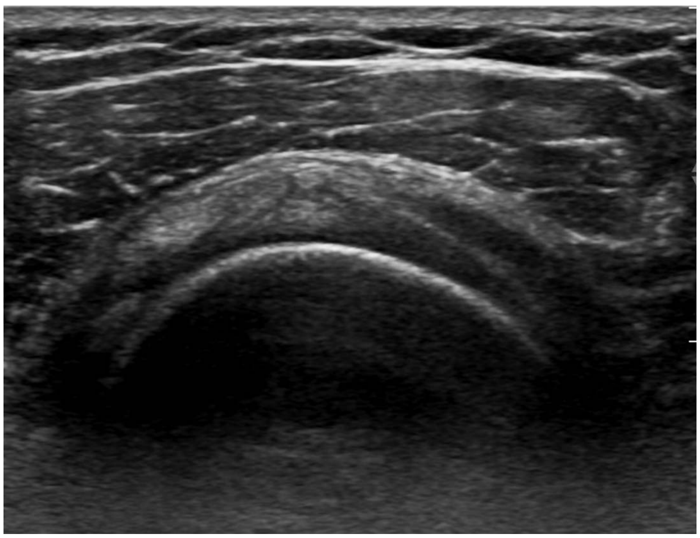

Figure 2 — Pretest image of the supraspinatus tendon from a 23-year-old female subject (blood flow restriction group). Tendon thickness =44 mm.

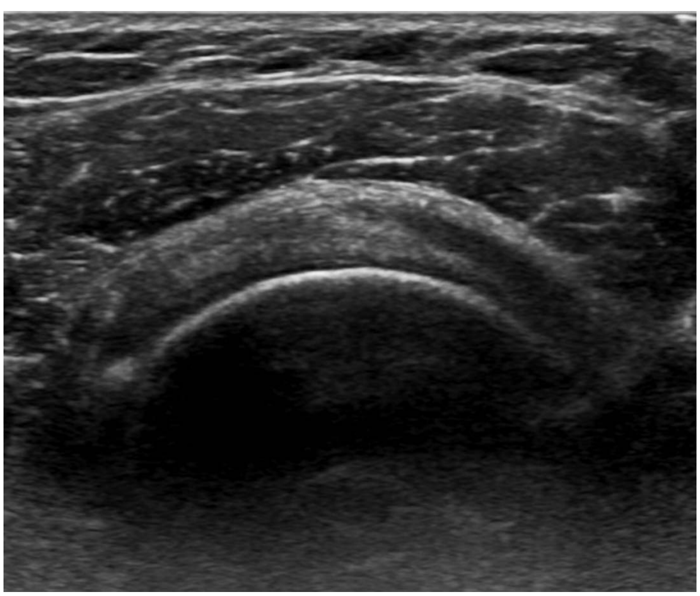

Figure 3 — Posttest image of the supraspinatus tendon from a 23-year-old female subject (blood flow restriction group). Tendon thickness =55 mm.

rotator cuff strength. The results of this study demonstrate that the use of BFR did not augment increases in strength or tendon thickness when compared with subjects who exercised without BFR. This study did demonstrate that the performance of the sidelying ER exercise, performed twice a week for 8 weeks, led to significant increases in rotator cuff strength and supraspinatus tendon thickness regardless of group allocation.

There were several strengths to this study. First, this study utilized a randomized controlled trial study design. Second, this current study utilized similar training loads (eg, 30% 1RM) and similar training volumes (4 sets with each set performed for at least 15 reps) as prior studies that have reported increases in strength and/or CSA in muscles proximal to cuff application.[19–21,35,36] Third, this current study also was as long in duration (ie, 8 wk) and, in most cases, longer than studies that demonstrated augmented strength gains from BFR.

There are 3 potential reasons as to why there was no greater effect in the exercise + BFR group when compared with the exercise-only group. First, it is possible that allowing subjects to continue with their regular exercise routine allowed a training effect for the rotator cuff despite the request to not perform any exercises specific for shoulder ER. For example, the bench press exercise activates the supraspinatus and infraspinatus muscles similar to exercises that are used in rehabilitation programs for the shoulder (eg, prone flexion and prone extension exercises).[37] However, prior research by Luebbers et al[38] found the addition of BFR to a weight-training program for collegiate football players enhanced 1RM squat performance in the experimental group. The supplemental squat program with BFR was performed twice a week, during the 7-week study, at the end of a lower body training days.[38] Subjects performed the squat at 20% 1RM performing 4 sets (30/20/20/20 reps) with 45-second rest between sets.[38] Based on the results from Luebbers et al,[38] it would be reasonable to expect that there would be significant differences between groups for strength; however, this was not observed in this study.

The second potential reason as to why there was no difference between groups in this study may be due to the location of BFR application. In this study, the BFR tourniquet was applied to the proximal UE, whereas other studies that have investigated changes in proximal muscular strength have applied the cuff to one or more lower extremities.[5,18,19] The mechanism(s) associated with strength gains observed during BFR training may be the result of systemic pathways and/or muscular fatigue distal to cuff application; however, the contributions of potential mechanisms are not known.[8–17] It is possible that the application of the BFR cuff to the proximal upper extremity may not facilitate the same physiologic response that has been observed when the lower extremity(-ies) are occluded. The third potential reason may be due to the number of exercises performed while under occlusion. When performing an exercise under occlusion, there is an increase in lactate ions.[6,17,39] The presence of lactate can increase muscle activation and stimulate the release of growth hormone.[17,40,41] For example, a 2 exercise program for the lower extremities had a significantly greater increase in growth hormone concentration when compared with performing a 2 exercise program for the upper body.[14] In this study, only one exercise was performed and the primary muscles (ie, shoulder external rotators) involved were not under occlusion. Two or more exercises may need to be performed distal to BFR cuff application to maximize a physiologic responses associated with an increase in lactate ions.

The limitations of this study include the subject population and the location of BFR application. Future studies that investigate the ability of BFR to augment the training effect on muscles of the rotator cuff should recruit a population who are not currently participating in a resistance training program and should have subjects perform multiple lower body exercises, under occlusion, in addition to exercises for the rotator cuff.

Practical Applications

The performance of the sidelying ER exercise with BFR applied to the proximal upper extremity did not augment rotator cuff strength gains or supraspinatus tendon thickness when compared with subjects who only exercised. This study did demonstrate that performing multiple sets of high reps with a low load led to significant increases in rotator cuff strength and supraspinatus tendon size. Strength training professionals who design programs for athletes or rehabilitation clinicians who treat patients with shoulder pathology should have their athletes/patients perform multiple sets of an exercise for high reps to increase rotator cuff strength.

Conclusions

The performance of the sidelying ER exercise with BFR applied to the proximal upper extremity did not augment rotator cuff strength gains or supraspinatus tendon thickness when compared with subjects who only exercised. This study did demonstrate that performing multiple sets of high reps performed at a low load led to significant increases in rotator cuff strength and supraspinatus tendon size in the dominant upper extremity.

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