Case Report

Effects of Blood Flow Restriction on Pain and Muscle Thickness Following Tendinopathy: A Case Study

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ABSTRACT

Introduction: Blood flow restriction (BFR) training, in which an inflatable cuff partially occludes blood flow around the proximal portion of a limb, coupled with low-load resistance exercise (LLRE) has resulted in gains comparable with traditional progressive resistive exercise in healthy populations. The use of BFR with LLRE may help people with supraspinatus tendinopathy through proximal effects to improve strength and muscle size. The purpose of this case report is to describe the proximal effect of the LLRE+BFR program on a patient with supraspinatus tendinopathy.

Materials and Methods: The patient was a 40-year-old man with a history of shoulder pain and weakness for the past months. He received an LLRE+BFR program for his right shoulder including rotator cuff and scapular strengthening exercises and lower limbs aerobic exercises based on protocols of strengthening and aerobic exercises of BFR. Outcomes measured at baseline and 4 weeks included the 4 items: 1) Strength of supraspinatus muscle and four scapular stabilizer muscles including serratus anterior strength, middle trapezius strength, and lower trapezius strength by dynamometer, 2) supraspinatus thickness by ultrasound, 3) pain pressure threshold of supraspinatus and deltoid muscles by algometer, and 4) pain reported bay in each session based on pain numeric scale.

Results: After 6 weeks, the strength of supraspinatus and scapular stabilizers except for the lower trapezius increased. The supraspinatus thickness and pain pressure threshold in the supraspinatus and deltoid muscle also increased after 4 weeks. The mean of pain reported by the patient based on the pain numeric scale before and after each session was also decreased.

Conclusion: The patient had measurable improvements following the use of an LLRE+BFR program. LLRE+BFR program may be an option for strength training in people with supraspinatus tendinopathy; however, more research is needed to determine effectiveness across the population of people with supraspinatus tendinopathy.

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1. Introduction

Strengthening exercises with high load (more than 70% of 1 RM) can be effective on muscle strength and lead to hypertrophy [1]. However, this load may not be appropriate for the elderly or those with tissue injuries and cause further disorders for the tissues [2, 3]. In 1990, Yoshiaki Sato applied KAATSU exercises, known later as blood flow restriction (BFR), for himself to prevent muscle atrophy following the casting of his lower limb after an accident [2]. The BFR includes a cuff that goes around the proximal upper or lower limb. This cuff can be filled with air and increasing the pressure on the extremity leads to a decrease in arterial blood circulation. It also causes interruption of venous return. The air in the cuff may be emptied between the exercise sets [1]. In recent years, low-load resistance exercises (20-30% of 1 RM) with BFR (LLRE+BFR) have also been applied to increase the strength and hypertrophy of muscles [4]. Hughes and Lixandrao in 2017 in a systematic review explained that LLRE+BFR could increase muscle hypertrophy at the level of High-Load Resistance Exercises (HLRE), but muscle strength improvement following LLRE+BFR was lower compared to HLRE effectiveness [5, 6]. Another systematic review in 2020 showed that LLRE+BFR helps decrease tissue stress and increase strength and hypertrophy at the level of HLRE exercises [7]. Hypertrophy and muscle strength can also be reached earlier following LLRE+BFR compared to HLRE [8]. There were various studies on pain-reducing effects following exercise therapy with BFR (exercise-induced hypoalgesia) on different musculoskeletal disorders and healthy individuals [9, 10]. As a result, the application of LLRE+BFR may increase strength and hypertrophy of the muscles, and reduce pain in patients with muscle injuries. So, it may be effective in tendinopathies as well [9-11].

Many studies focus on the distal effects of BFR (increase in strength and hypertrophy in distal muscles of the cuff), while proximal and also contralateral effects for lower or upper extremities were under research. Most of these studies reported improvement following BFR exercises [11, 12]. The studies by Bowmann and also Lambert (2020) on healthy individuals showed that using BFR with low-load exercises may increase strength and hypertrophy in shoulder muscles proximal to the cuff. These authors have suggested BFR exercises with low load exercises can be applied for the injuries such as shoulder tendinopathy, scapular dyskinesis, and instabilities before and after shoulder surgeries [11-13].

Tendinopathy is a common musculoskeletal injury [14]. Pain in the shoulder area is also the third most common musculoskeletal compliment [14]. The prevalence of rotator cuff tendinopathy increases with age to 50% more from 40 to 60 years, and 80% more at age 80 [14, 15]. Among rotator cuff muscles, the supraspinatus tendon might be involved more than the others [14]. Various intrinsic and extrinsic factors are associated with these injuries [14]. Intrinsic factors such as aging (over 40 years), inflammation, oxidative stress, circulatory impairment, lipid disorders, and high blood sugar cause degeneration process in the rotator cuff tendon [14, 16, 17]. Extrinsic factors such as subacromial and internal impingement increase pressure on the rotator cuff tendon [14]. Scapular kinematics (as an extrinsic risk factor) is one of the important factors in the development of shoulder impingement and rotator cuff tendonitis [18].

Kibler et al. (2013) and Keshavarz et al (2017) showed that the scapula played an important role in all shoulder injuries. However, it is still a question whether the scapula plays the main role in causing these problems or it is the consequences of shoulder joint injuries [19, 20] like labral tear [21, 22], internal impingement [23], rotator cuff tendonitis [24], and elbow injuries [23]. Scapular dyskinesia is caused by a false position and an abnormal orientation/motion of the scapula on the thorax [21]. It can lead to a reduction of subacromial space [24, 25] and decrease rotator cuff strength since the scapula malposition causes the rotator cuff to stay at an inappropriate length to produce proper power [26-28]. Scapular dyskinesia may also lead to rotator cuff tendonitis by scapular stabilizers imbalances or dysfunction [27]. So, strengthening exercises of rotator cuff muscles is beneficial for patients with supraspinatus tendinopathy [29, 30]. Supraspinatus tendinopathy may cause referral pain in the shoulder, increase central sensitization, and make the lower pain threshold. However, pain may arise not following the injury but because of an increase in central sensitization [31, 32].

Exercise therapy may be one of the primary treatment methods to decrease pain associated with subacromial injuries [33, 34]. Exercise therapy using low-load exercises (20-40% of 1 RM) combined with BFR in adults with subacute supraspinatus tendonitis may have proximal effects in a shorter period and help decrease tissue stress and pain and increase strength and hypertrophy in scapular stabilizers and supraspinatus. The purpose of this study is to study the effects of LLRE+BFR on the strength and thickness of supraspinatus, the strength of scapular stabilizers, and its pain-relieving effects on a patient with supraspinatus tendinopathy.

Case presentation

A 40-year-old man with BMI (kg/m^2) equal to 23 with pain in the shoulder area was referred by an orthopedic doctor to the physiotherapy clinic on May 8, 2021. The chief complaint was pain in the shoulder since last month while he slept with his trunk in rotation. He also reported weakness in shoulder abduction and flexion when he was trying to reach 90 degrees or more. He had 10 sessions of physiotherapy (PT) treatment including electrotherapy (transcutaneous electrical nerve stimulation - TENS, low-power laser, and magnet therapy). The PT methods helped to make temporary relief on pain when he reached session eight and based on the results of the pain numeric scale (PNS) in rest and during active movements. However, this relief was not stable and the pain returned, especially following shoulder elevation, after 3 days of PT accomplishment. There were no improvements in shoulder strength and elevation range of motion following treatment. There was no exercise therapy through these ten PT sessions. The patient had followed a sedentary lifestyle. The clinical evaluation of the shoulder was applied with high validity [35, 36] including Hawkin's, empty can, full can, and painful arch tests. The methods were applied to evaluate supraspinatus impingement. All evaluation methods lead to aggravating the symptoms except the painful arch test. Based on the results of history and clinical tests, the reason that led to pain and weakness in shoulder elevation might be supraspinatus tendinopathy and the BFR exercises might be helpful to improve the patient's disorder.

2. Materials and Methods

First, the patient was evaluated by an experienced physiotherapist for the BFR contradictions including a history of blood clots, blood pressure over 180/100, acute infection, cancer, hemorrhage, thrombotic stroke, history of deep vein thrombosis, atrial fibrillation, peripheral vascular problems such as varicose veins [37, 38]. There was no contraindication for the BFR application. The strength of supraspinatus and scapular stabilizers including serratus anterior, lower, and middle trapezius were evaluated by a dynamometer (MIE, medical research ltd, England) in the first session of the treatment. The supraspinatus thickness and pain pressure threshold on supraspinatus and deltoid muscles were also evaluated by ultrasound (HS-2600 by Honda Electronics Co, Japan) and algometry (Force-Gauge, 5020-Lutron, Taiwan) on the same day. The evaluation methods were as follows:

Muscle strength

Measuring scapular stabilizers' strength, serratus anterior, lower and middle trapezius, and supraspinatus was done. Measuring the strength of the aforementioned muscles using a fixed dynamometer with make test [39] in manual muscle testing (MMT) position with reference to Kendall [40] was completed.

For measuring the strength of the serratus anterior the patient laid on a bed and the device's strap was wrapped around the distal ulna on the styloid process and the other strap was perpendicularly attached to the handle of the dynamometer on the ground. Then, the shoulder was put to 120 degrees of forward flexion and external rotation. The starting position for supraspinatus is the same as serratus anterior with the only difference being that the shoulder is put to 90 degrees scaption (30 degrees medial to the frontal plane) and the thumb faces the ceiling.

For the middle trapezius, the patient lay prone with a towel under his forehead and the dynamometer's strap was wrapped around the distal end of the ulna (on the styloid process), and the other strap connected to the fixed handle of the device on the ground. The scapula is fixed using the body's weight and the therapist's hand. Then, the shoulder was put to 90 degrees of abduction with external rotation and the elbow was extended [39]. For the lower trapezius, maintaining the same position, the shoulder was put to 140 degrees abduction.

The test is used to evaluate muscle strength with a dynamometer. In this test, the person has to exert maximum isometric force in the test position opposite to the direction of the strap for 10 seconds. This trial was repeated 3 times and between each trial, there was a 30 seconds rest. In the end, the average was calculated as the final number. Between the examinations of each muscle, a maximum of 1-minute rest is needed. Also, to familiarize the patient with the test, it is practiced 2-3 times beforehand with submaximal load to reduce the error as well [39].

Supraspinatus thickness

Musculoskeletal ultrasound imaging was applied to determine the supraspinatus thickness. This method is a valid and reliable method to calculate the thickness of muscles and tendons [41]. The method that was used to find the proper location of the probe is similar to the protocol mentioned by Juul-Kristensen et al. (2000). For this method, the patient has to sit on a chair while his shoulder is in a neutral position and his elbow is extended. The therapist then palpates the scapular spine (linear probe 5-12 MHz HS-2600 by Honda Electronic Co, Japan) and draws the MA line from the beginning (M) to the end (A) of the scapular spine (Figure 1). The middle of this line is called the P point and the exact location of the probe is on this point [42]. The probe is held parallel with supraspinatus fibers so that the scapular notch is in the middle of the monitor (Figure 2). In this region, the maximum thickness of supraspinatus is visible [43]. The maximum thickness of the muscle is determined as shown below. After repeating this step 3 times, the average is taken as the muscle thickness.

Pain pressure threshold

Using an algometer, the Pain Pressure Threshold (PPT) of the patient was measured in the first and last treatment sessions. With a rate of 1kg f/s supraspinatus, the main bulk and the middle deltoid bulk are used to determine the patient's pain threshold in newtons [9]. Also, the patient was asked to rate his level of pain 15 minutes before and after every treatment session based on PNS.

Determining weight for exercise

The weight for exercise is determined based on a percentage of 1 RM test. Considering that low-load exercises were used in our treatment, the weight in exercise was 20-40% of 1 RM [8]. American College of Sports Medicine (ACSM) defines 1 RM as the maximum weight that a person can move once in a certain range of motion [44, 45]. This amount of weight can cause further pain and inflammation in people with injuries. For this patient, we used a formula like Brzycki (Equation 1).

1. Brzycki Equation= $\frac{W}{(1.0278-0.0278\times R)}$

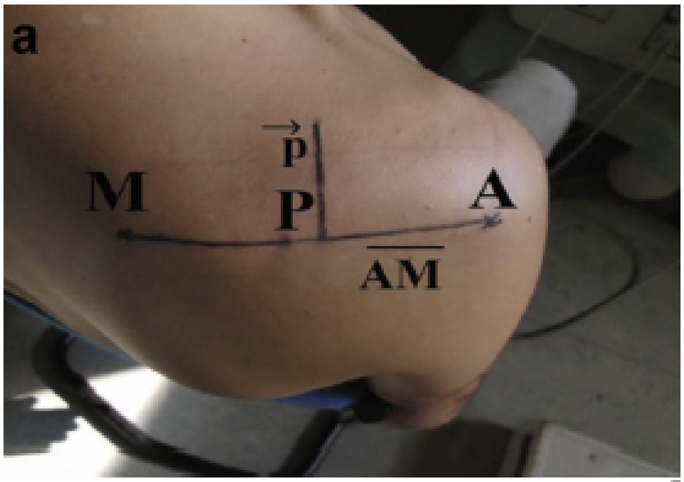

Figure 1. This picture shows how to draw MA line and P point

JMR

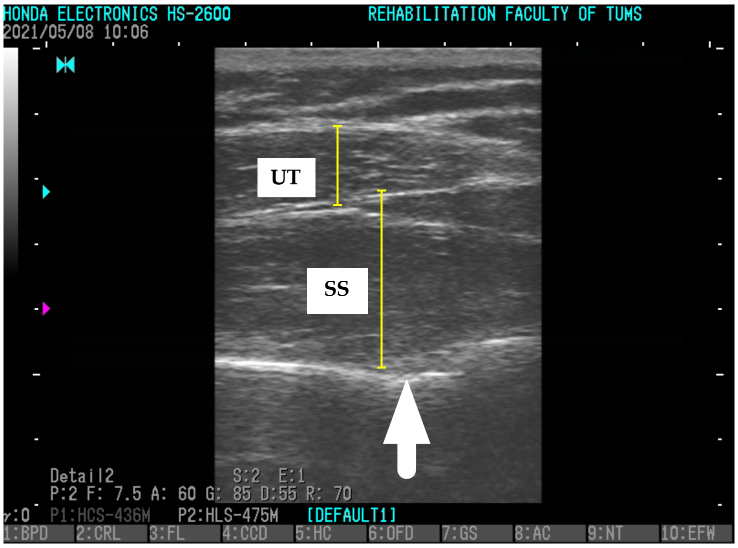

Figure 2. SS: Supraspinatus and UT: Upper trapezius

JMR

W=Weight used for repetitions to failure

R=Repetitions to failure.

Considering the Equation, the patient was asked to use a lightweight (1-2 kg) to do a scaption in a pain-free range of motion until muscular fatigue stops him from moving the weight further (repetition to failure).

Determining limb occlusion pressure

After determining the weight, to conduct exercise therapy with BFR, the Limb Occlusion Pressure (LOP) had to be determined using a manual doppler (8 MHz, EDAN doppler). The LOP is the minimum pressure that zeros and turns off the acoustic noise in the doppler device. In the exercise therapy protocol with BFR, 50% of LOP for the upper limb and 80% of LOP for the lower limb is considered optimal pressure in the cuff during the exercise [8].

Specifications of the BFR device used in the current study are as follows:

Smart cuff BFR that includes portable vascular doppler (EDAN vascular doppler 8 MHz) and medium cuffs (17.5-23 inches) for the lower limb and a small cuff (17 inches) for the upper limb.

LOP was determined as follows: At first, the patient has to sit relaxed for 10 minutes on a chair and the cuff is wrapped around the most proximal region of the shoulder. The manual doppler is put on the radial artery in the upper limb and the posterior tibialis (behind the medial malleolus) in the lower limb at an angle of 45 degrees (to avoid pressure and blood flow restriction). Then, the minimum pressure that fully stops the radial pulse (turning off the acoustic noise in the device) is calculated using the cuff and manometer. To reduce peripheral nerve damage, the cuff is wrapped around the most proximal region of the upper limb. Following the initial measurements, the patient follows a 4-week (3 times a week) exercise therapy plan that is summarized in Table 1. Finally, 15 minutes before and 15 minutes after the treatment session, the patient's pain level is determined using PNS. The exercise plan includes the following parts: (details of the exercise plan are mentioned in Table 1).

Scapular stabilizers' exercise plan (Table 1) shows that the ratio of the activity of upper trapezius to lower trapezius, upper trapezius to middle trapezius, and upper trapezius to serratus anterior that is one or a bit less [46] (Figure 3 & 4).

The exercises that induce the maximum activity of supraspinatus and infraspinatus (external rotation from 0 degrees abduction with a flexed elbow to 90 degrees, empty can, and full can) [47] (Figure 3-5).

3- Lower limb aerobic exercises (strengthening the kinematic chain that is closely tied with the scapula) to increase blood flow in the region. Walking backward is used as an aerobic exercise for the lower limb that decreases pressure on the knee joint [32] and increases the activity of core muscles that are related to the scapula and thus can be beneficial for the patient [48, 53] (Figure 6). The exercise plan and the exercises are summarized in Table 1.

Based on what has been said in prior protocols for strengthening exercises with BFR, the protocol with 30 repetitions in the first set and 15 repetitions in the next 3 sets was used (the rest between sets was 30 seconds). The cuff's pressure was not emptied between the sets and the continuous technique was used [8]. The exercises were done in 12 sessions (3 sessions per week) and once a day in the presence of the therapist. While doing the exercises the patient was asked to rate the difficulty of the exercise based on the perceived exertion scale to let the

Table 1. The exercise plan and prescription

Name of Exercises	Protocol of BFR Training	Frequency	Intensity	Type of Exercises
Scaption/Robbery	Rep:30/15/15/15 50% LOP Rest between sets: 30-60 s	Three times a week	Low intensity with 20-40% 1RM	Scapular stabilization
Standing external rotation at 0 degrees of abduction full can	Rep:30/15/15/15 Rest between sets: 30-60 s	Three times a week	The low intensity with 20-40% 1RM	Rotator cuff strengthening
Backward walking	10 minutes LOP for backward walking=80 mmHg	Three times a week	speed 1-2 m/h	Aerobic

JMR

Figure 3. Scaption exercise JMR

Figure 5. External rotation exercises JMR

therapist know about the difficulty of the exercise which must be between 6-8 (moderate to hard) [11]. In the first session, the weight was calculated using Brzycki's Equation 1RM=2 Kg. Then, 15-20% of this weight was used in the first two weeks and 30-40% of the weight was used in the second two weeks (Table 2). The following table shows a summary of LOP in the upper and lower limb and its advancement during the exercises to avoid a feeling of discomfort and delayed onset muscle soreness and also the advancement of the treadmill's speed in backward walking.

Figure 4. Robbery exercise JMR

3. Results

Table 3 presents a comparison of the mean of the variables measured in the first and last session and the patient's pain based on the PNS. There was a rise in the strength of the supraspinatus, serratus anterior, and middle trapezius muscles after 12 sessions of treatment whilst the lower trapezius strength decreased. In addition to changes in strength, we checked for alterations in muscle thickness. Both supraspinatus and upper trapezius showed an increase after the intervention period. The changes were more prominent for the upper trapezius. The mean of pain pressure threshold of the supraspinatus and deltoid muscle also improved. The mean of reported pain based on PNS, 15 minutes before and after each session decreased (Table 3, 4). We also calculated the percentage of change in all variables. Despite lower trapezius strength, all variables improved after the intervention. Figure 7 shows muscle strengths before and after BFR application. Figure 8 shows changes in muscle thickness and Figure 9 shows before and after amounts of PPT for deltoid and supraspinatus muscles. Figure 10 shows the pain level that the patient reported based on PNS before and after the intervention for each session.

Figure 6. Backward walking exercise

JMR

Table 2. Progression of limb occlusion pressure, weight, and speed

Progression	First Two Weeks	Second Two Weeks
Weight (%1 RM) (Kg)	15-20% 1RM	30-40% 1RM
LOP (mmHg)	30-40% LOP in the upper limb (right shoulder) 60-70% LOP in the lower limb	50% LOP in the upper limb 80% LOP in the lower limbs
SPEED (mhp)	0.8-1 mph	1.5-2 mph

LOP: Limb occlusion pressure.

JMR

Table 3. Identified data analysis for pre and post intervention

Outcomes	Pre (mean)	Post (mean)	%Δ
Supraspinatus thickness	8.41 mm	8.64 mm	2.73
Upper trapezius thickness	2.938 mm	3.343 mm	13.78
Supraspinatus+upper trapezius thickness	11.554 mm	12.242 mm	5.94
Supraspinatus strength	3.16 N	7.23 N	128.79
Serratus anterior strength	2.36 N	4.63 N	96.18
Middle trapezius strength	1.53 N	2.06 N	34.64
Lower trapezius strength	5.80 N	4.90 N	-15.51
Pain pressure threshold of the deltoid muscle	4.09 Kg	7.64 kg	86.79
Pain numeric scale	3.58 cm	2.08 cm	-41.89
Pain pressure threshold of the supraspinatus muscle	5.08 kg	8.72 kg	71.65

JMR

Table 4. Pain assessment in each session

PNS (Before / after each session)	7	5	6	5	10	5	7	2	5	2	3	2	3	2	1	1	1	0	0	0	0	0	0	0
Date	15 May		17 May		19 May		24 May		26 May		31 May		2 Jun		7 Jun		9 Jun		12 Jun		14 Jun		16 Jun	

JMR

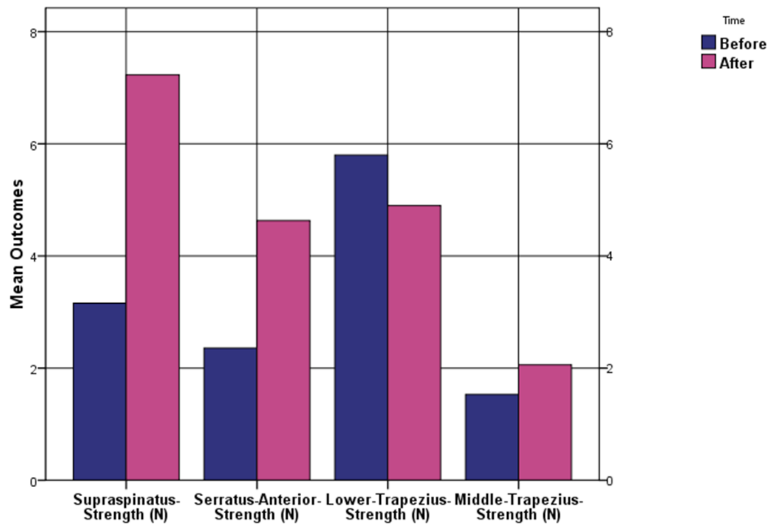

Figure 7. Mean of muscle strength

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4. Discussion

Here, we report on the use of LLRE+BFR for a patient with sub-acute supraspinatus tendinopathy. He had night pain and weakness in shoulder movement especially shoulder elevation since last month. He received 12 sessions (4 weeks) of LLRE+BFR. There were improvements in the supraspinatus and upper trapezius thickness, the strength of supraspinatus, serratus anterior and middle trapezius, PPT of deltoid and supraspinatus muscles, and PNS. The strength of the lower trapezius muscle decreased in the final assessment session. The reason for this regression might be muscle fatigue since the lower trapezius was the last muscle we evaluated its strength.

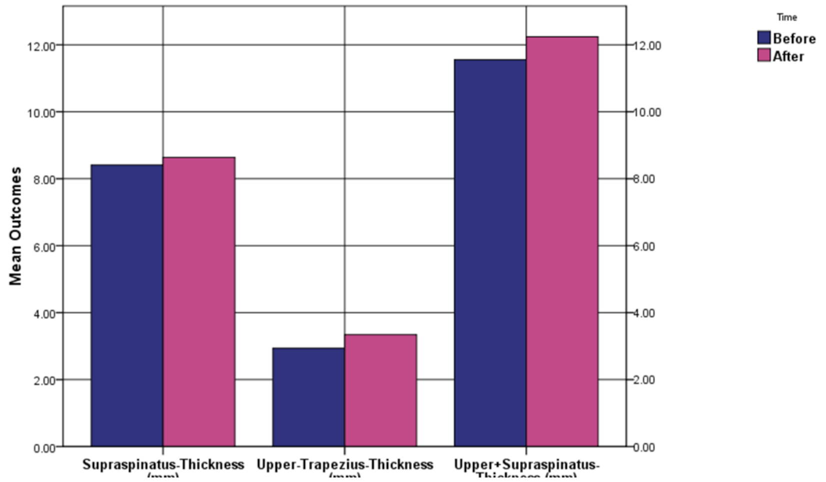

Figure 8. Mean changes of supraspinatus and upper trapezius thickness

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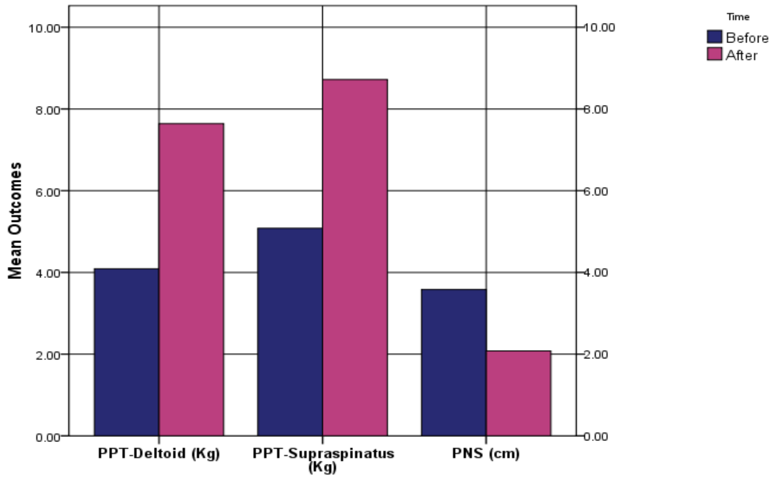

Figure 9. Mean changes of PPTs for deltoid and supraspinatus and PNS.

JMR

Abbreviations: PPT: Pain pressure threshold; PNS: Pain numeric scale.

The results of the present study are similar to Bowmann et al. (2020) and Brumitt et al. (2020). Bowmann et al. (2020) study showed that the LLRE+BFR may increase strength and mass in muscles proximal to the cuff in healthy individuals [11, 12]. The study of Brumitt et al. (2020) shows that both types of LLRE+BFR and LLRE can increase supraspinatus strength and tendon thickness in healthy people [53]. This study recommended that LLRE+BFR can be useful in patients with supraspinatus tendinopathy. The results of the current study showed that the BFR can increase strength and hypertrophy in the reported patient with supraspinatus tendinopathy. The results of the present study are similar to the study conducted by Hughes et al. (2020) on the effects of BFR on pain perception distal to the cuff, which also showed that low-load exercises with BFR can reduce pain in the muscles proximal and distal to the cuff in a patient with shoulder pain [9].

The proposed physiological changes for hypertrophy, strength increase, and pain relief following the BFR application with low-load exercise could be the following points. The exact mechanism behind increased strength and hypertrophy with applying the BFR is not known yet [50, 51]. Mechanical tension is very low in low-load exercises with BFR and possibly the primary reason behind the muscular adaptation is metabolic stress on muscle tissue following the BFR application [50, 51]. When the patients perform the LLRE with BFR, muscle ischemia causes considerable metabolic stress in muscle tissue [51]. Accumulation of metabolic material and lactate in cells facilitates the absorption of interstitial fluid into the cell and causes osmotic pressure [51]. This accumulation causes inflammation in the muscle cell and this inflammation activates protein generation pathways like mTOR and MAPK in the muscle cell [51]. This metabolic stress is one of the key mechanisms of the BFR

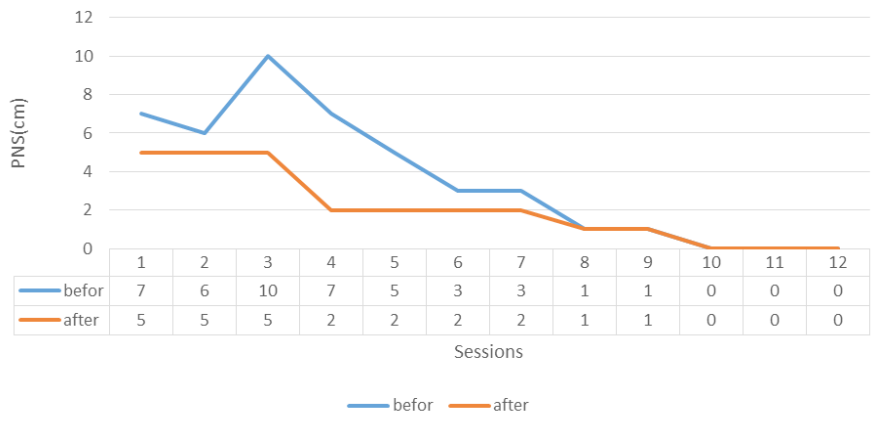

Figure 10. PNS before and after each session

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to cause anabolic effects [51]. These mentioned theories explained the increase in strength and hypertrophy in the muscles distal to the cuff. Despite former studies, it seems that the reason for the increase in strength and hypertrophy of the muscles proximal to the cuff is because of the distal muscles fatigue and compensatory activities of proximal muscles. Besides, both biceps and triceps which are located distal to the cuff, are prone to more increase in strength and hypertrophy as they are amongst the glenohumeral stabilizers, their activity can contribute to the improvement of the cuff's proximal muscles.

Another effect of the BFR application is pain relief [8, 9]. In a study by Hughes et al. (2019), four pathways were introduced to assess the BFR's neurophysiological effects on pain relief [52]. These pathways include the following: The BFR can stimulate baroreceptors in vessels thus stimulating regions of the CNS that are in charge of controlling pressure and pulse. This stimulation activates triggering descending inhibitory activities and pain relief. The second pathway is based on gate control and pain block pain theory, exercise with BFR can cause a feeling of discomfort and pain that will reduce the pain usually felt in the muscle. The third pathway is based on the accumulation of metabolic material around the muscle and no discharge due to lack of venous return stimulates metaboreceptors (type III and IV). Stimulating these receptors causes a feeling of discomfort and produces opioid and endocannabinoid materials that relieve pain. Finally, the fourth pathway is due to less blood flow and slow-twitch fibers' activity that helps decrease and compensate the brain recruits fast fibers. Considering the fast speed of transmission of messages by thick fast fibers, pain messages are suppressed. In general, high-intensity exercises can considerably reduce pain. Although exercise with the BFR is done with low load, adding the BFR to the exercises considerably increases exercise intensity and pressure.

Limitations

Pain sensation can decrease muscle strength and because of pain relief, the muscle strength might be evaluated higher by a dynamometer. Muscle strength evaluation based on the MMT position suggested by Kendall is not a fair standard to evaluate the exact amount of muscle strength improvement [32].

5. Conclusion

Based on our literature review, there were no studies that reported proximal effects of the BFR in patients with shoulder pain. So, the results of this case study can help provide a research frame to study the effectiveness of the BFR in comparison with low-load exercises without the BFR and also high-load exercises.

Ethical Considerations

Compliance with ethical guidelines

The study was approved by the Tehraan University of Medical Sciences (TUMS) Institution's ethics committee (Code: IR.TUMS.FNM.REC.1399.185). The participant was informed of all benefits and risks of the study before beginning and approved the informed consent form. The patient could leave the treatment and study at any time she wanted.

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Authors' contributions

Conceptualization, methodology, supervision, and data analysis: Zahra Poursaleh Begi; Writing, reviewing, and editing: Zahra Poursaleh Begi, Siamak Bashardoust Tajali, Seyyed Mohsen Mir, Saeed Talebian, Azadeh Shadmehr, and Zinat Ashnagar.

Conflict of interest

The authors declare no conflict of interest.

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