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Effects of Blood Flow Restriction Training on Healthy Individuals Using the (B)Strong Training System: A Randomized Controlled Trial

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ABSTRACT

The purpose of the study was to examine and compare muscular fitness and subjective muscle pain between blood flow restriction (BFR) training using the (B)Strong Training System and traditional resistance training program after a 7-week intervention. Thirty-one healthy male and female young adults volunteered to participate (age; 23 ± 3.6y, height; 169.7 ± 8.9cm, and weight; 74.4 ± 15.4kg). Participants were randomly selected into three groups: HIRES (high intensity resistance training), LIBFR (low intensity blood flow restriction training) or CON (control). All participants refrained from structured activity outside of this study for the duration of the entire study. Anthropometrics, body composition, muscular strength and endurance were measured prior to and post training. Delayed onset muscle soreness (DOMS) was assessed 24-hours post each exercise session in the HIRES and LIBFR groups using the Visual Analog Scale (VAS) and McGill Pain Questionnaire (MPQ). At pre-testing, there were no significant differences among groups in muscular fitness ($p>0.05$). Post-training, HIRES and LIBFR increased their 1RM in all exercises (bicep curl, triceps extension, calf raise, hamstring curl, leg extension) along with increased their score in the 1-minute push-up test to a similar degree ($p<0.05$). The control group did not improve their muscular strength. Hypertrophy occurred in the forearms in the HIRES and LIBFR group by increasing forearm circumference significantly ($p<0.05$). HIRES reported a higher level of DOMS compared to LIBFR as the duration of the training program continued, with a significantly higher report of DOMS after the last session was completed ($p<0.05$). LIBFR training of 7-weeks does increase muscular strength in the upper and lower body with less DOMS over the duration of the program.

KEYWORDS: Blood Flow Restriction, Resistance Training, Muscular Fitness, Delayed Onset Muscle Soreness.

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LIST OF ABBREVIATIONS

BFR	Blood Flow Restriction
ACSM	American College of Sports Medicine
1RM	1-repetition maximum
K^+	Potassium ions
H^+	Hydrogen ions
HGH	Human Growth Hormone
DOMS	Delayed-Onset Muscle Soreness
RPE	Ratings of Perceived Exertion
MPQ	McGill Pain Questionnaire
VAS	Visual Analog Scale
PAR-Q	Physical Activity Readiness Questionnaire
HIRES	High Intensity Resistance Training
LIBFR	Low Intensity Resistance Training
BIA	Bioelectrical Impedance Analysis
BMI	Body Mass Index

CHAPTER 1: LITERATURE REVIEW

1.1 Introduction

Traditional resistance training programs are used to increase muscular size and strength by progressing intensity and volume of exercise. These programs can be geared towards many populations such as elite athletes, obese, children, or older adults and tailored to the goals of the individual. In addition to these populations, resistance training programs have shown health benefits in rehabilitation settings. These individuals use resistance training to regain muscular strength and size after a period of detraining due to many different reasons including injury or post-surgery. Detraining causes atrophy and a decline in muscular strength caused by the decrease in fiber size and motor unit recruitment efficiency [1]. One major limitation in rehabilitation populations is that a high volume of exercise may not be attainable to these populations due to such atrophy. An alternate method to high volume resistance training is combining lower exercise volumes with blood flow restriction (BFR) training.

Blood flow restriction (BFR) combined with lower exercise volumes has been shown to elicit the same muscular response as traditional resistance training [2]. In addition, elimination of muscle pain post-exercise is another potential positive attribute of occlusion training [3]. There is limited research regarding post-BFR exercise training on delayed onset muscle soreness. To quantify muscular pain levels, a common method shown in multiple BFR studies is taking the rate of perceived exertion (RPE) post-exercise, but is inconsistently administered throughout the literature [4, 5]. The purpose of this literature review is to study the previous research completed on BFR training, and expose the gaps in the literature for future research.

1.2 Mechanisms of Traditional Resistance Training

A traditional resistance training program will cause muscular hypertrophy and increased muscular strength by applying the progressive overload principle. The American College of Sports Medicine (ACSM) recommends a resistance training program with an initial intensity of 70-80% of an individual's one-repetition max (1RM) combined with 2-3 sets of 8-12 repetitions to produce results in healthy adults. The progressive overload principle is achieved by increasing either the sets or repetitions by 10% over the time course of an exercise program lasting approximately 8 weeks.

Resistance training consists of muscular movements involving both concentric and eccentric phases of an exercise. During the concentric phase, or muscle shortening phase, force is being generated by the targeted muscle to lift the weight against gravity. The eccentric phase, or muscle lengthening phase, is where majority of muscle damage occurs eventually leading to increased muscle size [6, 7]. Muscle damage is when muscle fiber deterioration occurs followed by muscle fiber regeneration. With the overload principle, as intensity of exercise increases, the process of muscle fiber deterioration and regeneration last around 24-48 hours continues which finally leads to muscle hypertrophy. Muscle damage post-exercise is accompanied by the symptoms of delayed-onset muscle soreness (DOMS). DOMS is problematic because the muscle damage can lead to stiffness, pain, tenderness, and impaired muscle function.

Several theories explain the mechanisms behind DOMS. The muscle damage theory is based on the idea that after eccentric exercise, the contractile component of the muscle tissue is disrupted typically at the z-line level due to the increased tension per unit [8]. The tissue damage will then generate an inflammation response, which causes the release of chemical substances that result in producing edema; it is suggested that the muscular pain is a direct cause from the accumulation of chemical substances and edema [9]. The inflammation theory comes from the findings that inflammation follows muscle damage post-eccentric exercise. Even though there was no significant difference, the white blood cell count was increased 48-hours post exercise compared to pre-exercise measures suggesting an inflammatory response. Inflammation can cause decrease in muscle function and mobility temporarily [9] [8].

Byrne et al. (2004) examined knee extensor power using a Wingate test one, two and three days post-muscle damaging exercise. These findings showed that the inflammatory response to the muscle damage lead to a decline in power at the 1-day post-exercise mark suggesting a decline in power may limit the ability to reach the progressive overload of exercise needed to see adaptations in muscle [6]. Using a visual analog scale, Werndom found a higher level of DOMs reported at the 48-hour mark post traditional exercise compared to the 24-hour mark. At the 72-hour post-exercise mark, DOMs decreased below what was reported at the 24-hour mark. This suggests than DOMs starts to decrease after the 48-hour mark, but does not completely disappear [10].

Lastly, protein synthesis is essential to muscle repair and growth. By gradually increasing the volume of exercise by manipulating sets, repetitions and weight over the time course of a program, a higher load of resistance training can be obtained. With high-load training larger threshold motor units will be recruited, which will result in mechanical stress, endocrine responses and metabolite accumulation. The skeletal muscle responds with enhancing rates of protein synthesis within the muscle fibers that will lead to increased muscular size and strength. In addition, human growth hormone (HGH) is secreted immediately after high intensity exercise, including resistance training. HGH has cascading effects where it then stimulates the secretion of insulin-like growth factors (IGF-1) causing enhanced protein synthesis [2]. IGF-1 induces the activation of satellite cells which are important for muscle growth and repair. Satellite cells provide new myonuclei during the process of muscle growth [11].

1.3 Mechanisms of Occlusion Training

BFR training is similar to the Kaatsu method, which was founded in the 1970s and 1980s by Yoshiaki Sato in Japan [12]. Individuals train at a lower volume (~20-40 1RM) and apply BFR to decrease blood flow to the limbs. To create an ischemic environment, blood flow is restricted by applying a band or cuff over the proximal area of the exercising limb. This still allows for arterial flow, but occludes venous flow. Due to the ischemic environment with BFR, levels of metabolic stress will increase resulting in an accumulation of metabolites such as potassium ions (K+), hydrogen ions (H+) and lactate [7]. Metabolites promote the increase of fast-twitch fiber recruitment, hormone production and production of nitric oxide from the vascular endothelium. Nitric oxide causes expansion of blood vessels leading to increased blood flow when the restriction is removed. Nitric oxide also causes the release of intracellular calcium which promotes muscle growth. These potential mechanisms explain why hypertrophy occurs with BFR training and provide similar benefits to traditional resistance training while exercising at a lower intensity [7].

Lactate levels are also increased post BFR training which creates an acidic environment. The acidic environment stimulates chemoreceptors which send signals to the central nervous system. The central nervous system then stimulates the sympathetic nerve activity, leading to the secretion of HGH which is important to muscle growth. Greater levels of HGH are found post-occlusion training versus traditional resistance training possibly due to the decreased rate of lactate removal. Significantly higher levels of both blood lactate and serum HGH have been found post-occlusion exercise compared to without occlusion using the same intensity of 20% 1RM [13]. Another possibility of the increased level of HGH is due to the increased accumulation of certain metabolites during exercise including K+, H+ and lactate [14].

To increase muscular strength with traditional resistance training, you must activate type fast twitch muscle fibers by exercising the muscle at a higher intensity [7]. Slow twitch fibers will be recruited first, then fast twitch muscle fibers are recruited as needed as intensity increases. With low intensity occlusion training, fast twitch fiber recruitment will still occur because of the lack of oxygen availability in the muscle. Slow twitch fibers are aerobic in nature whereas fast twitch fibers are anaerobic. With BFR, oxygen availability is decreased leading to the recruitment of fast twitch fibers regardless of intensity [14]. Electromyography (EMG) is a commonly used therapy technique that evaluates the electrical activity within a muscle contraction and can indicate muscular dysfunction and nerve to muscle signal transmission. When comparing the electromyography of the bicep brachii during a dumbbell curl with low-intensity occlusion training of 53% 1RM and high-intensity resistance training of 76% 1RM, the EMG was almost equal suggesting that occlusion training does in fact cause the activation of fast-twitch fibers regardless of the low intensity [15].

Increase in initial muscular strength with BFR could also come from early adaptations such as neural adaptations. With just a 4-week BFR training program focusing on the calves in a population of sixteen healthy females, their 1RM in a calf raise improved by ~10 kg. This muscular strength increase is suggested to have come from neuromuscular adaptations which normally occur 4-6 weeks into an exercise program [16]. Although no structural changes may occur in the muscle, the neural recruitment of additional muscle fibers and increased rate of firing by motor units allow for increases in strength.

1.4 Blood Flow Restriction Techniques

To receive the benefits of BFR training, several methodological challenges exist such as optimal pressure. The pressure should be low enough to allow arterial flow, but high enough to prevent venous return in order to cause enhanced metabolic stress and fast-twitch fiber recruitment [17, 18]. A pressure as low as 50 mmHg has shown to produce benefits, but most studies do use at least 100 mmHg to ensure venous blood restriction. This is important in order to produce effective protocols with BFR [19]. A cuff inflated to 200 mmHg does not show any more of an increase in muscular adaptations compared to 150 mmHg, thus a threshold may exist [20]. However, a review by Slysz et al. (2016) found greater increase in muscular size and muscular strength with a cuff pressure >150 mmHg compared to <150 mmHg, but more research is needed due to the varying training programs [12]. Some studies increase the blood flow restriction cuff pressure throughout a training program, which has not been proven to increase the rate of muscular strength or hypertrophy. A higher pressure might also be more painful to the participant during and after exercise.

With BFR training, the idea is to receive the same improvements as traditional resistance training with a lower intensity of exercise. Traditionally, a low intensity training program would be considered 20-50% 1RM according to ACSM guidelines. Muscular hypertrophy has been shown to occur with an intensity as low as 20% 1RM with BFR training [12, 19]. ACSM guidelines suggest 2-3 sets of 8-12 repetitions per exercise [21]. With BFR training, there is not a set protocol due to inconsistent methods in the literature. Studies have varied with the amount of sets and repetitions, but a common protocol is a total of four sets with 30 repetitions in the first set, and 15 repetitions in the second, third and fourth set. This protocol was used in a study to examine effects of BFR training in a bicep curl and triceps extension to promote muscular hypertrophy in young, healthy males with resistance training experience. Results showed that this was an effective protocol to promote muscular hypertrophy due to the findings that muscle activation increased in a BFR session [22]. Vechin et. al. (2015) also used this protocol with low intensity BFR training at 20% 1RM when comparing BFR to resistance training using a leg press. The resistance group used four sets of ten repetitions at 70% 1RM as their protocol. Both groups did improve their muscular strength significantly with this protocol, BFR with an 17% increase whereas traditional resistance training with an 54% [23]. Madarame et al. (2008) used a similar idea but with only three sets of 30, 15, 15 repetitions at 30% 1RM with a population of healthy, young males with no previous resistance training experience. Results also concluded that this protocol will increase muscular strength and size [24]. These studies together suggest that a protocol for BFR training should include high repetitions in order to promote fatigue in the muscle.

1.5 Training Frequency and Duration

ACSM guidelines suggest a frequency of 2-3 days per week for traditional resistance training. [20] compared multiple BFR studies in regards to different factors such as training frequency. The analysis showed that 2-3 days per week of BFR training did elicit a significantly greater increase in strength and muscle size compared to studies using 4-5 days per week [20].

Traditionally the increase in muscular strength occurs in the first 4-6 weeks of a resistance training program comes from neuromuscular adaptations. Around the 6-week mark is when the hypertrophy normally occurs. Loenneke and colleagues found that it might be reverse with low intensity blood flow restriction training. Muscular strength may be a result from muscle hypertrophy initially and not neuromuscular adaptations with occlusion training [20].

BFR training has produced greater strength grains in programs lasting more than six weeks compared to those under six weeks, suggesting a threshold for adaptations to occlude. When examining muscular hypertrophy, previous BFR research found eight weeks or more is associated with greater increases than programs lasting less than eight weeks [12]. Therefore, a successful BFR program should continue for at least 8-weeks to produce both hypertrophy and increased muscular strength.

1.6 Post BFR Exercise Muscle Pain

Muscle damage occurs with resistance training and is essential to muscle growth. With BFR, increased muscle damage and swelling along with muscle thickness occur, however, with less muscle soreness after exercise [3]. Thiebaud et al. (2013) examined muscle soreness changes post low intensity BFR with concentric and eccentric exercises. Results showed that participants had increased muscle soreness 1-day post eccentric exercise, but did not show an increase in muscle soreness post concentric exercise [25], suggesting exercise protocol may effect DOMS when using BFR. There is limited research on comparing delayed onset muscle soreness post BFR exercise training with traditional resistance training, but many BFR studies use RPE as an indication of pain.

Yasuda et al. (2011) compared ratings of perceived exertion (RPE) after the final repetition in all three sets of each exercise between a high intensity resistance training group and a low intensity BFR training group. Results showed that there was a lower RPE in the low intensity BFR group compared to the high intensity resistance training group [5]. Kim et al.

(2016) also used the RPE scale at the end of each training session to compare between a group doing vigorous intensity cycle training and low intensity BFR cycle training. Results showed that those exercising at a vigorous intensity did in fact report a higher RPE [4], which would be expected immediately following exercise.

Assessed through a verbal analog scale, there was a higher level of soreness reported 24-hours post-BFR lower-body exercise compared to traditional exercise. This suggests that BFR training does cause a higher level of DOMS at the 24-hour mark [26]. Inversely, Page and colleagues found a significant lower level of DOMS in the lower-body reported through a VAS 48-hours and 72-hours post-exercise compared to traditional exercise, but not at the 24-hour mark [27]. Wernbom et al. (2009) found a higher report of DOMS post-traditional exercise compared to post-BFR exercise at the 24-hour, 48-hour and 72-hour mark [10]. There are inconsistent findings with DOMS with BFR training. Just as a VAS in common in DOMS research, MPQ is also commonly used. A study done by Cleather et al.(2007) demonstrated there were no significant differences between the VAS and MPQ when assessing DOMS [28].

1.7 Rehabilitation with BFR

Exercise prescription is altered for rehabilitation programs based on the disease or condition, often times with the same goal of improving muscular size and strength. ACSM recommends a high load of resistance training in order to see strength gains in these special populations such as diseased, injured or elderly. However, the intensity and volume of exercise may be decreased due to lack of ability, limitations of the injury/disease, or for safety reasons [21]. Rehabilitation populations are typically composed of individuals that are unable to put high mechanical stress on their muscles, tendons and joints due to age, injury, disease or surgery, therefore professionals have worked towards finding safe alternatives including utilizing low intensity exercises combined with the BFR method [29]. In addition, rehabilitation populations may benefit from less DOMS elicited and therefore continue to adhere to the BFR method.

An increase in muscular size is a common benefit found in the rehabilitation setting with low intensity BFR training programs. Iverson and colleagues studied muscular size in the quadriceps by examining the cross sectional area with a magnetic resonance image (MRI) in a population that underwent anterior cruciate ligament (ACL) reconstruction surgery. After 16-days of BFR training, muscular size significantly increased, suggesting BFR was effective despite ACL injury [30]. Libardi et al. (2015) studied an elderly, sedentary population in regards to muscular size and strength in their lower body. After 4 days per week for 12-weeks of either BFR training or traditional training, improvements were made in the cross sectional area of the quadriceps and their 1RM of a leg press, suggesting that populations who may not be able to put high mechanical stress of their bodies can still achieve the same results with low intensity BFR training [31].

An important aspect of using the BFR training method in rehabilitative population is the belief that BFR decreases muscle pain post-exercise [3]. Reducing muscle pain is important to this population because individuals seeking rehabilitation may already be in pain from atrophy, surgery, disuse, etc. Previous BFR research has used RPE as an indication of muscle pain and although it has been recorded inconsistently post-exercise, research shows that using BFR causes less muscular pain than traditional resistance training [4, 5]. This suggests that BFR is not only safer, but is more fitting to the rehabilitation population to enable them to comply with exercise prescriptions.

1.8 Conclusion

BFR has become a widely used method within populations seeking rehabilitation because of its' attainable low intensity and low risk. Research has proven that an intensity of 20% 1RM occlusion training will improve an individual's muscular strength and size during the duration of a program of 2-3 days per week lasting for 8 weeks. Although muscular pain is inconsistently measured in previous research, overall BFR groups have experienced less pain compared to traditional resistance training, making it beneficial for rehabilitation populations. Further research should aim to demonstrate the idea that BFR will cause less muscular pain at the time of DOMS.

CHAPTER 2: EFFECTS OF BLOOD FLOW RESTRICTION TRAINING ON HEALTHY INDIVIDUALS USING THE (B)STRONG TRAINNG SYSTEM

2.1 Introduction

To effectively increase muscular size and strength, an individual generally complies with a resistance training program using high volumes of exercise. However, such high volumes may not be attainable to those who need to regain muscular strength and size due to a period of detraining. Blood flow restriction (BFR) is becoming a popular technique used in rehabilitation settings because it allows for hypertrophy and increased muscular strength with a lower volume of exercise. The same muscular gains with BFR with an intensity as low as 20% 1-repetition maximum (1RM) may be experienced as the American College of Sports Medicine (ACSM) recommends of an intensity of 70-80% of a 1RM [19] [21] [12].

BFR is accomplished by applying a band or cuff around the proximal area of the limb to occlude venous flow while still allowing for arterial flow creating an ischemic environment. Due to this ischemic environment, levels of metabolic stress will increase resulting in an accumulation of metabolites such as potassium ions (K^+), hydrogen ions (H^+) and lactate. Lactate levels are increased due to the lack of oxygen post BFR training which creates an acidic environment stimulating the sympathetic nerve activity. In addition, decreased rate of lactate removal generates greater levels of human growth hormone (HGH) are found post-occlusion training compared to traditional resistance training [14]. This will increase fast twitch fiber recruitment, hormone production, and muscle damage [7]. Activating fast twitch muscle fibers is essential to increase muscular strength with traditional resistance training by exercising the muscle at a high volume [7]. Normally, slow twitch fibers will be recruited first, but as intensity increases, fast twitch muscle fibers are recruited as needed. With occlusion training, fast twitch fiber recruitment will occur faster regardless of the intensity due to the lack of oxygen availability in the muscle [14].

Muscle damage is when muscle fiber deterioration occurs followed by muscle fiber regeneration, which is essential to muscle growth. A symptom to muscle damage is that it's accompanied by delayed-onset muscle soreness (DOMS), which leads to impaired muscular function and pain. There is a lack of research comparing high intensity, resistance training DOMS to low intensity, BFR training DOMS. Previous BFR research has used ratings of perceived exertion (RPE) as an indication of pain directly following exercise, and found BFR at a low intensity reported lower RPE compared to a resistance training group [5]. However, the RPE scale is subjective and may not be an accurate reflection of pain. In addition, DOMS symptoms typically appears 24-72 hours post exercise [32]. Other techniques of measuring muscle pain with DOMS include pain scales such as the McGill Pain Questionnaire (MPQ) and the Visual Analog Scale (VAS) [28]. Cleather et al. (2007) compared the differences of the MPQ and VAS over a 7-day period post DOMS-inducing exercise of eccentric preacher biceps curls [28]. No significant differences between the pain rating using the VAS vs. MPQ were found suggesting both VAS and MPQ are useful, valid tools in assessing DOMS.

The theory behind BFR cuffs is that individuals will exercise at a low-load and receive the same benefits of high-load resistance training. The (B)Strong Training System advertises to be a new, safe and affordable option to perform occlusion training. (B)Strong claims to help elicit a greater level of hormone release which will allow athletes to recover faster. This cuff system is unique because they are an on-the-go fitness system and do not stop blood flow to the limb thus mitigating serious complications. In addition, the system can be applied to a variety of fitness levels or ages making BFR training applicable to large populations; they are made to be beneficial to all users such as the elderly, those who are injured, those who are healthy, novice athletes and elite athletes. The purpose of the study was to examine and compare muscular fitness outcomes and subjective muscle pain after a 7-week BFR training using the (B)Strong cuffs or traditional resistance training program.

2.2 Methods

Participants

Thirty-one overtly healthy male and female adults were recruited to participate in this study. The criteria to be included in data collection is as followed: (1) age of 18-40 years, and (2) answered no to all questions on the Physical Activity Readiness Questionnaire (PAR-Q). The criteria to be excluded from data collection is as followed: (1) known significant cardiovascular disease or disorder, (2) currently taking any chronic medications, (3) resting systolic blood pressure ≥ 160 mmHg and/or resting diastolic blood pressure > 100 mmHg, and (4) any other significant medical conditions including respiratory, gastrointestinal, or neuromuscular deemed unsafe by the researchers to participate in exercise. Before any testing, this study was approved by the Institutional Review Board at Columbus State University and participants completed a consent form.

Study Design

This training study consisted of three phases: pre-testing, training program, post-testing. Participants were randomly selected into one of the three groups: high-intensity resistance training (HIRES), low-intensity blood flow restriction training (LIBFR), or the control group (CON). All participants were instructed to refrain from outside exercise for the duration of the entire study. The participants who were selected into the HIRES and LIBFR groups completed a total of twenty supervised exercise sessions that took approximately 30-45 minutes each to complete. Subjective pain scales were completed 24-hours post each exercise session.

Pre- and Post-Testing

Pre-testing was conducted the week prior to starting the exercise training program, and post-testing was conducted 48-hours after the last exercise session. Participants were required to refrain from all exercise 48-hours prior to these two visits. Upon arrival to the laboratory, height was measured in centimeters using a standometer (SECA, Hamburg, Germany) with no socks or shoes. Bicep, forearm, thigh and calf circumferences were measured per limb in centimeters using the Gulick tape measure according to ACSM guidelines [21]. Body fat percentage, body weight (kg), fat-free mass (kg) and fat mass (kg) was recorded from the BodPod (COSMED USA, Concord, CA) following manufacturer's instructions. Bioelectrical impedance analysis (BIA) was completed using the InBody (520-Model D). Arm and leg weight (kg) along with segmental analysis for all four limbs were recorded. Lastly, resting heart rate and blood pressure were measured using a manual sphygmomanometer after resting in a supine position for 30 minutes. The 30-minute rest period was required for vascular testing (not reported).

Following resting vitals and body composition measures, muscular strength and endurance were evaluated. For muscular strength, participants completed 1RM testing for handgrip, bicep curl, triceps extension, leg extension, hamstring curl and calf raise according to ACSM guidelines [21]. Handgrip strength was evaluated per hand using three trials, recording the highest trial as their 1RM in kilograms (kg). Briefly, a light upper- and lower-body exercise was performed for warm-up. Bicep curls and triceps extensions were done with free weights whereas the leg extensions, hamstring curls and calf raises were done with machines (CYBEX, International, INC). For each exercise, participants selected a weight that represented ~60-70% of their perceived 1RM, increasing 10% until failure. 1RM was recorded as the most weight lifted within 3 to 5 trials. For muscular endurance, the number of push-ups completed in 1 minute was recorded.

Exercise Protocol

The duration of the exercise program was 7 weeks with 2-3 exercise sessions per week for a total of 20 exercise sessions. Each session the HIRES and LIBFR participants were instructed on a light warm-up, followed by 7 resistance exercises that were progressive. The HIRES group began 3 sets of 8 repetitions at 60% 1RM while the BFR group conducted 3 sets of 30 repetitions at 20%1RM. The LIBFR group used the (B)Strong BFR cuffs worn on the upper portion of the arms and legs that were inflated to 250 mmHg. The cuff placement, inflation pressure and training scheme were conducted according to company recommendations. The CON group refrained from any structured activity throughout duration of the study.

Muscular Pain Analysis

Subjective muscle pain and soreness was assessed 24-hours after each exercise session using two different pain scales. The VAS consisting of a 100 millimeter line with terminal descriptors (no pain, severe pain) was used to measure muscle pain severity 24-hours after the previous exercise session [33]. The VAS was recorded in millimeters (mm) with higher values indicating higher degrees of muscle pain intensity. The MPQ was used to assess pain using descriptor words and present pain intensity (based on a 1-5 scale) that best fit their symptoms at the given time [34].

Statistical Analysis

Data was analyzed using SPSS (Version 23.0, SPSS Inc., Chicago, IL). All data was assessed for normality using the Shapiro-Wilks test. One-Way ANOVAs were used to examine differences in main outcome variables (body composition, muscular strength and endurance) between groups at pre-testing. A 2 (time) by 3 (group) repeated-measures ANOVA was used to examine effects exercise training in regards to outcome variables, followed up with post-hoc testing where appropriate. A 2 (time) by 2 (group) ANOVA was used to examine differences in average pain response on the VAS between groups (HIRES vs. LIBFR) after exercise training. Pain pattern and strength assessed by the MPQ were examined using frequencies. Data is reported as mean ± standard deviation. Significant difference is set at $p<0.05$.

2.3 Results

Participants

Characteristics of the participants are described in Table 1. There was no particular targeted population, and there were no significant differences found between the three groups during pre-testing ($p>0.05$). Participants included a total of 11 males and 20 females, for total amount of 31 participants. Their body composition ranged from a normal body mass index (BMI) of 18.5 kg/m^2 to an obese BMI of 38.6 kg/m^2 based on ACSM guidelines [21]. Participants varied in their level of training experience within this study ranging from no experience at all to 15 years of being recreationally active with resistance training. In comparison to females, males were significantly taller ($p<0.001$) with a significantly lower body fat percentage (p<0.001). Males had a significantly lower ($p=0.03$) fat mass with a significantly higher fat free mass ($p<0.001$) than females. Males also had a significantly higher 1RM in all exercises including handgrip, bicep curl, triceps extension, calf raise, hamstring curl, leg extension ($p<0.001$) along with a higher score in the 1-minute push-up test ($p=0.02$).

In comparing novice participants (0 years of experience), intermediate (1-5 years) to experts (>5 years), results showed that there were no significant differences between the novice and intermediate participants ($p>0.05$) in regards to body composition and strength assessments. However, the expert group had significantly lower body fat percentage ($p=0.02$) when compared to the novice group. The expert group had a significantly higher fat free mass ($p=0.02$) compared to the intermediate group, but no difference with the novice group. The expert group also had a significantly higher 1RM in handgrip, bicep curl, triceps extension, calf raise along with a higher score in the 1-minute push-up test ($p<0.05$), but not with 1RM of hamstring curl or leg extension ($p>0.05$).

Table 1. Demographics of participants represented in mean ± SD.

	LIBRF	**HIRES**	**CON**
N	11	10	10
Gender (M/F)	27%/73%	50%/50%	30%/70%
Age (y)	24 ± 4	22 ± 3	23 ± 3
Height (cm)	169.4 ± 9.2	170.4 ± 10.1	169.3 ± 8.0
Weight (kg)	71.7 ± 15.1	79.7 ± 16.0	72.0 ± 15.3
BodPod Body Fat (%)	24.8 ± 9.9	28.8 ± 16.4	31.2 ± 6.9
Resting HR (bpm)	67 ± 8	70 ± 3	74 ± 9
Resting SBP (mmHg)	108 ± 9	117 ± 8	117 ± 10
Resting DBP (mmHg)	78 ± 8	76 ± 7	73 ± 19
Experience Resistance Training (yrs)	4 ± 4	4 ± 4	4 ± 6

No significant differences between groups at pre-testing ($p>0.05$).

Exercise Compliance and Training

There was an overall exercise compliance of 99.3%. One participant in the LIBFR group did not complete all 20 exercise sessions due to a lower extremity injury unrelated to the study. As participants progressed throughout the 7-weeks of exercise training, the HIRES exercise intensity continuously remained higher than LIBFR for all 6 machine and free weight exercises performed (Figure 1). There is a significant main effect between groups ($p<0.001$) and across time ($p<0.001$) in regards to bicep curl, triceps curl, push-up, calf raise, leg extension and hamstring curl exercise intensity. There was no main effect between groups or across time in regards to handgrip strength ($p>0.05$).

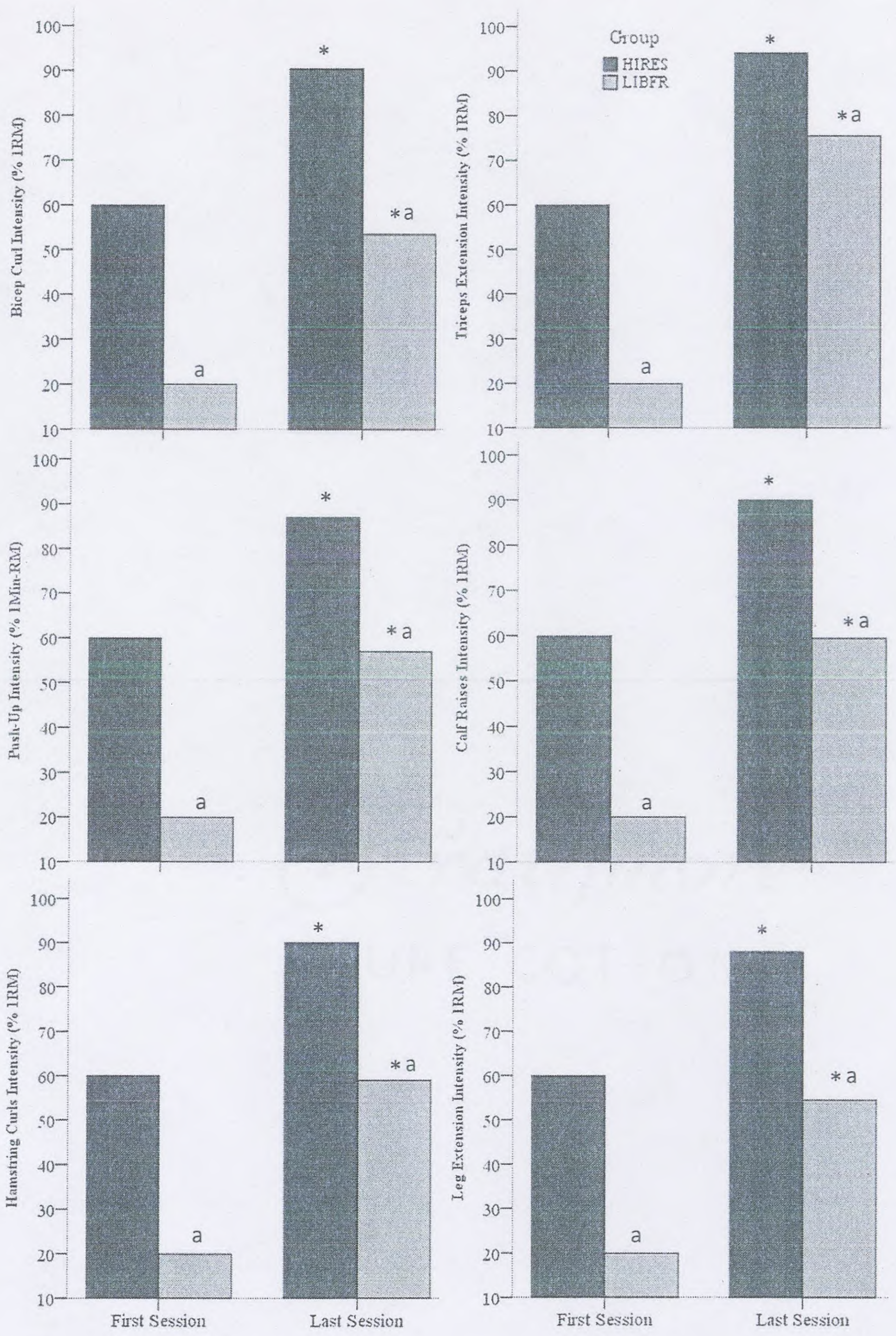

Figure 1. Average intensity of each exercise at the first session and last exercise session. [a]Significant difference between groups (p<0.001). *Significant difference across time (p<0.001).

Body Composition

There were no differences from pre-testing to post-testing between the three groups regarding body composition. Left arm weight significantly increased from pre- to post-testing within the LIBFR (p=0.02), HIRES (p=0.03) and CON (p=0.01). Right arm weight significantly increased in the LIBFR group post-training (p=0.01), but there were no significant differences found in the HIRES group (p=0.07) or the CON group (p=0.05). Additional data regarding body composition is shown in Table 2.

Table 2. Body composition variables from pre-testing vs. post-testing (mean±SD).

	LIBFR (n = 11)		**HIRES** (n = 10)		**CON** (n = 10)	
	Pre-Test	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*
Weight (kg)	72 ± 15	72 ± 15	80 ± 16	80 ± 17	72 ± 15	72 ± 15
BodPod BF (%)	24.8 ± 9.9	24.2 ± 10.9	28.8 ± 16.4	27.9 ± 17.2	31.2 ± 6.9	31.5 ± 6.5
Fat Free Mass (kg)	54.0 ± 14.1	54.4 ± 13.7	54.3 ± 10.8	56.1 ± 10.3	48.9 ± 8.9	49.0 ± 9.3
Fat Mass (kg)	17.7 ± 9.0	17.5 ± 10.1	24.5 ± 17.7	24.2 ± 18.8	22.9 ± 8.2	23.3 ± 8.3
Left Arm Weight (kg)	6.8 ± 2.3	7.0 ± 2.2 *	7.4 ± 1.7	7.6 ± 1.8*	5.9 ± 1.7	6.1 ± 1.7*
Right Arm Weight (kg)	6.8 ± 2.2	7.0 ± 2.1 *	7.6 ± 1.6	7.8 ± 1.8	6.1 ± 1.6	6.2 ± 1.8
Right Leg Weight (kg)	18.1 ± 3.5	18.2 ± 3.4	19.1 ± 3.5	19.1 ± 3.6	16.9 ± 3.2	17.0 ± 3.3
Left Leg Weight (kg)	18.1 ± 3.5	18.2 ± 3.4	18.4 ± 3.4	18.8 ± 3.4	16.9 ± 3.3	17.0 ± 3.3

*Significant difference within groups from pre-test to post-test (p<0.05).

Body circumference measurements are shown in Table 3. The circumference of the right and left forearm increased significantly in both the LIBFR and HIRES groups post-training (p<0.001), but the control group did not change. All other circumference measurements did not increase post-training, expect for the left bicep in the HIRES group (p=0.01) and the left calf in the LIBFR group (p=0.04).

Table 3. Body circumference measurements from pre-testing vs. post-testing (mean±SD).

	LIBFR (n = 11)		**HIRES** (n = 10)		**CON** (n = 10)	
	Pre-Test	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*
Right Bicep (cm)	27.7 ± 3.5	28.6 ± 3.8	29.5 ± 3.3	30.4 ± 3.9	28.2 ± 3.2	28.4 ± 3.0
Left Bicep (cm)	27.6 ± 4.0	28.3 ± 4.0	29.4 ± 3.4	30.4 ± 3.9*	28.3 ± 3.5	28.3 ± 3.0
Right Forearm (cm)	24.6 ± 2.5	25.5 ± 2.3[t]	26.6 ± 2.2	27.7 ± 2.3[t]	25.3 ± 2.2	25.4 ± 2.0
Left Forearm (cm)	24.1 ± 2.9	25.3 ± 2.3[t]	26.2 ± 2.1	27.3 ± 2.4[t]	25.0 ± 2.5	24.9 ± 2.2
Right Thigh (cm)	53.0 ± 9.9	56.9 ± 7.4	57.9 ± 10.2	59.5 ± 9.0	56.5 ± 5.4	55.7 ± 5.0
Left Thigh (cm)	52.9 ± 10.2	57.2 ± 7.4	58.6 ± 10.6	58.6 ± 8.7	56.1 ± 4.7	55.1 ± 5.3
Right Calf (cm)	37.3 ± 7.4	36.3 ± 3.1	38.9 ± 4.4	38.5 ± 4.3	35.9 ± 2.8	35.9 ± 2.8
Left Calf (cm)	37.4 ± 7.7	36.3 ± 3.0*	38.6 ± 4.3	38.5 ± 4.3	36.1 ± 3.1	36.4 ± 3.2

*Significant difference within groups from pre-test to post-test ($p<0.05$). [t]Significant difference within groups from pre-test to post-test ($p \leq 0.001$).

Muscular Strength and Endurance

There were no significant differences in 1RM, handgrip or push-ups found between groups at pre-testing ($p>0.05$). There were significant group by time interactions found between CON and both HIRES and LIBFR after post-testing ($p<0.05$), displayed in Figure 2. There was a significant increase in all six major resistance exercises in both LIBFR and HIRES groups post-training of similar magnitude. HIRES, compared to LIBFR, exhibited similar increases in 1RM strength after exercise training in bicep curls (21.4% vs. 19.7%, $p<0.001$), calf raises (29.9% vs. 28.9%, $p<0.001$), and leg extension (21.2% vs. 19.4%, $p=0.005$). HIRES had a tended to have more improvement in triceps extension (42.1% vs. 31.9%, $p<0.001$), hamstring curl (31.6% vs. 23.9%, $p<0.001$) and push-ups (76.1% vs. 46%, $p<0.001$), however there was no difference between groups. There were no significant differences within the control group for all six exercises from pre-testing to post-testing although 1RM of triceps extension, calf raise, hamstring curl and leg extensions did decrease ($p>0.05$).

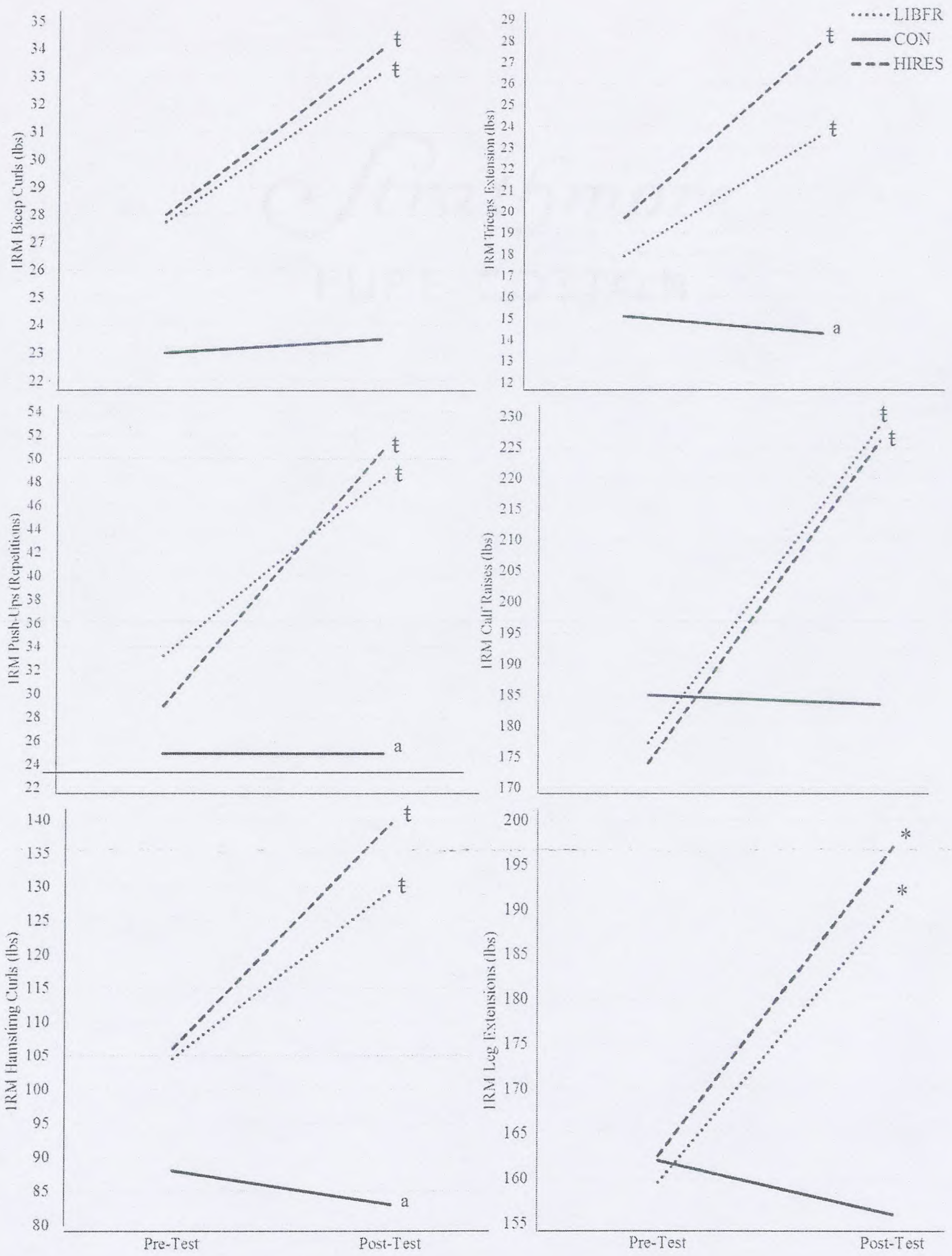

Figure 2. Pre-test vs. post-test muscular strength and endurance measurements. [a]Significant difference between CON and HIRES/LIBFR at the post-test ($p<0.05$). *Significant difference within groups from pre-test to post-test ($p<0.05$). [t]Significant difference within groups from pre-test to post-test ($p\leq0.001$)

Muscular Pain

Shown in Figure 3, there are results of the VAS from the throughout exercise training taken 24-hours post the respective exercise session. Session 20, which represents the last session of the exercise program, found HIRES reported more severe level of pain compared to the LIBFR group (p=0.001).

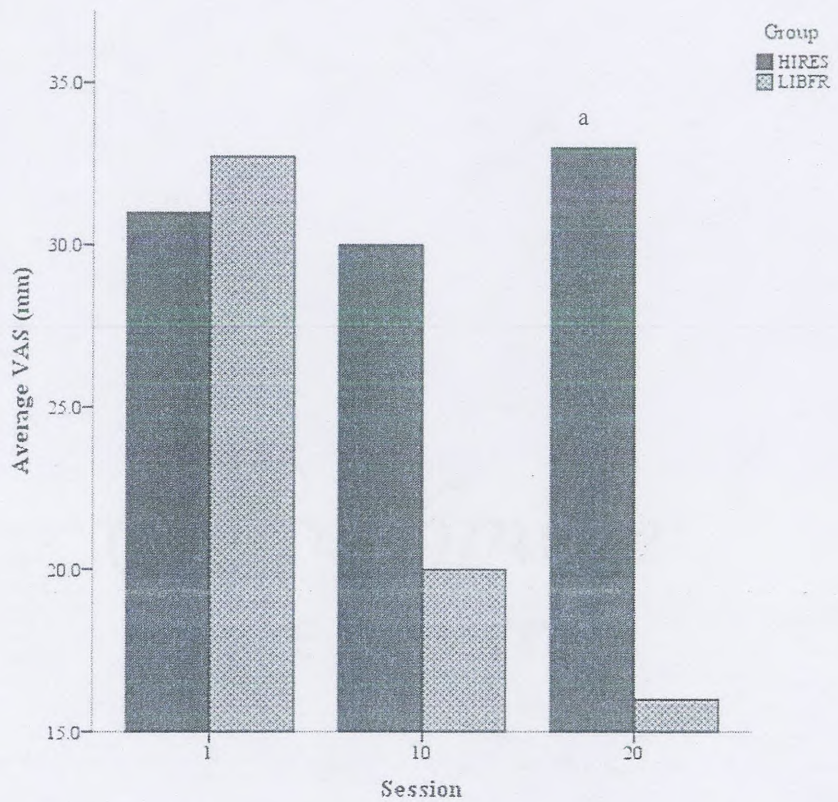

Figure 3. Results from the Visual Analog Scale (VAS) taken 24-hours post each exercise session. [a]Significant difference between groups ($p<0.05$).

Shown in Figure 4 are the results of current pain and pattern of pain from the MPQ taken 24-hours post each exercise session. In describing the pain intensity at 24-hours post exercise, participants in the HIRES (78%) and LIBFR (91%) most frequently reported pain as "mild". "Distressing" pain intensity was reported less frequently in LIBFR compared to HIRES 24-hours after exercise training. Majority of both HIRES and LIBFR also reported "no pain" in regards to the pattern of pain presently being experienced at the time of surveying. The HIRES did report more "rhythmic, periodic, intermittent" pattern of pain (29%) compared to the LIBFR group (4%).

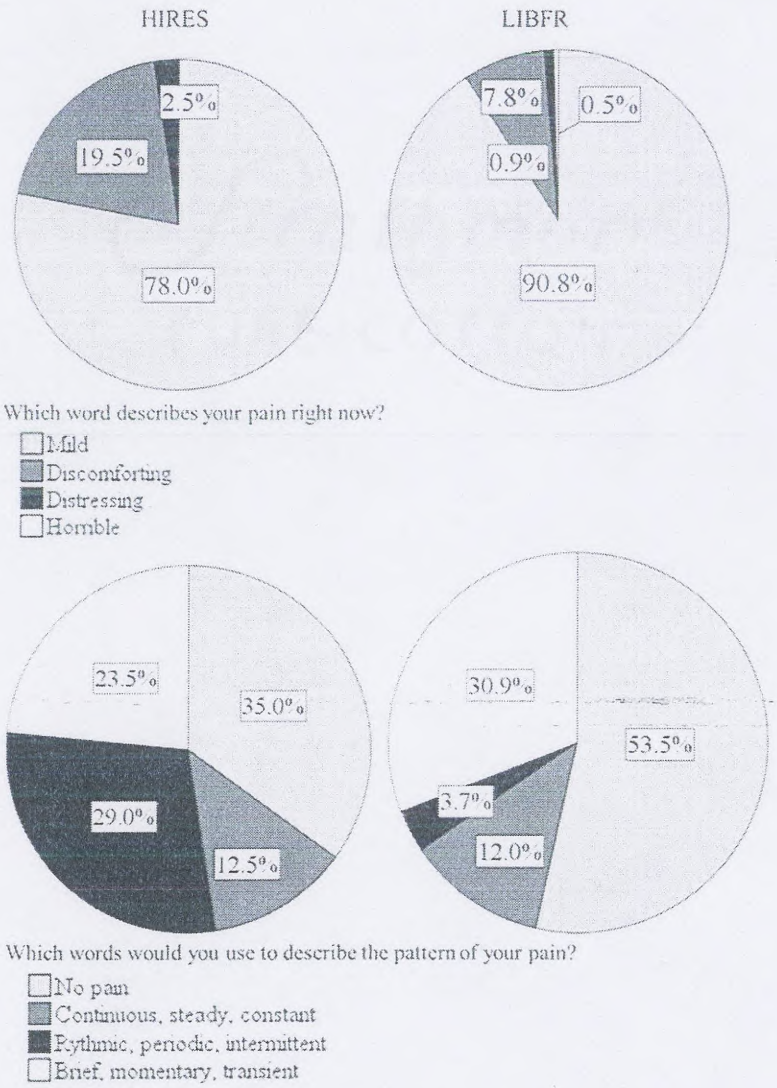

Figure 4. Results from the McGill Pain Questionnaire (MPQ) taken 24-hours post each exercise session. HIRES, high intensity, resistance training; LIBFR, low intensity, blood flow restriction training.

2.4 Discussion

The purpose of this study was to examine and compare muscular fitness outcomes and subjective muscle pain with BFR training using the (B)Strong Training System and traditional resistance training in the upper and lower body. Low intensity exercise combined with blood flow restriction was found to elicit results similar to traditional high intensity resistance exercise including increases in muscular strength in all upper and lower body exercises and hypertrophy occurring in the forearms. There has been varying methods of evaluating muscular pain, but most of the previous research has shown a decrease in muscular pain with BFR training compared to traditional resistance training. This study shows a decrease in muscular pain with the LIBFR group compared to the HIRES at the 24-hour mark as exercise sessions progressed over the course of the program.

Participants ranged in age from 19 to 33 years and included males and females with a wide range of resistance training experience from none to 15 years of experience. Studies have found increased muscle activation and hypertrophy in a population similar to this study in regards to height (175cm vs. 170cm) and weight (72kg vs. 74kg) [22].

Previous BFR studies have focused on male populations examining hormone production and protein synthesis post-BFR training with an occlusion pressure of 200 mmHg [35] [36]. Both studies demonstrated an increase in hormone production and protein synthesis post-BFR training in the male population, suggesting BFR training will promote an increase in muscular strength. The female population might differ due to hormonal differences, causing a slower rate of protein synthesis. Cook and colleagues (2007) studied young, healthy males and females, similar to this study, and found that with greater muscular fatigue with BFR resulted in a greater HGH secretion compared to a decreased amount of muscular fatigue with BFR. This suggests that with both genders, an increase of HGH with BFR exercise will increase HGH secretion thus possibly stimulating a greater impact on muscular growth across both genders [2]. These findings compare well with those of this study; while promoting fatigue in this study with the high repetitions in LIBFR, muscular strength was increased as a result of the exercise training. Thus, the increased rate of HGH secretion may contribute to gains in muscular strength.

There were little to no significant differences in the bicep, calf and thigh circumferences which may be due to the short exercise protocol of 7 weeks leading to minimal time for muscular adaptations to occur. Inversely, there were significant differences in both forearm circumferences within both LIBFR and HIRES. This could be due to increased familiarization with the handgrip dynamometer and the use of forearm muscles that are not normally trained on a regular basis. In addition, majority of the upper body exercises utilized forearm muscles, which may have affected the development of strength. Although non-significant, the HIRES did decrease body fat percentage and increase fat free mass which would signal muscular hypertrophy. Muscular hypertrophy has been demonstrated with various protocols of BFR. Madarame et al. (2008) found that BFR training with the same protocol as this study does in fact improve muscular size assessed by magnetic resonance imaging (MRI). Cross-sectional area of the elbow flexor muscles increased significantly in the occlusion training group, whereas the control group remained the same size [24].

With HIRES and LIBFR training, both group's 1-RM on the bicep curl, triceps extension, calf raise, hamstring curl and leg extension significantly increased after exercise training, suggesting that LIBFR is as effective as HIRES in regards to upper and lower-body muscular strength development. This suggests that a low intensity combined with BFR has similar benefits in regards to muscular strength as traditional resistance training with a high intensity, due to the mechanisms of BFR. Although fast twitch muscle fibers are recruited through increasing high intensities, with a low intensity combined with BFR, the lack of oxygen available promotes fast twitch fiber recruitment in order to increase muscular strength. When looking at muscular endurance assessed by the 1-minute push-up test using upper-body strength, both the HIRES and LIBFR improved suggesting that LIBFR is just as effective as HIRES. Vechin et al. (2015) found that muscular strength in the lower-body improves with BFR training at an intensity of 20% 1RM, but with only a 17% increase compared to a 54% increase with traditional resistance training. LIBFR and HIRES may not have improved to the same degree as this study because of population differences and program duration. This study was done with young adults for 7-weeks, whereas Vechin's study was done with the elderly for 12-weeks and required a 6-month period of no resistance training prior to the study, leaving a greater opportunity for growth [23]. Demonstrated by Loenneke et al. (2011), untrained populations gained more strength than those who were considered trained or recreationally active groups [20]. This suggests that with the wide variety of experience in this study, magnitude of change with muscular strength could be altered depending on individual differences.

Previous research has shown an increase in muscular strength and size within rehabilitation populations including the elderly, post-injury and post-surgery. Iversen et al (2016) conducted a study using a population that underwent anterior cruciate ligament (ACL) reconstruction surgery. Both men and women using occlusion training found significant improvements in muscular size assessed by the cross sectional area of the quadriceps using an MRI [30]. Libardi and colleagues (2015) found after training 4 days per week for 12 weeks in either a traditional resistance or BFR program, cross sectional area of the quadriceps significantly increased along with a significant increase in their 1RM of a leg press in sedentary older adults. [31]. These studies demonstrate that populations seeking rehabilitation or lacking the ability to perform high intensity activity can benefit from BFR-training in regards to increasing muscular size and strength. Although this study used overtly healthy, young adults, results still showed an increase in muscular strength in the upper and lower body along with an increase in muscular size in the forearms, suggesting that LIBFR training is beneficial for more than one population.

Results of this study showed that LIBFR began with slightly greater level of pain than HIRES in the first 5 exercise sessions. Yet, there was no significant difference in the VAS at this time. At the 6th session of exercise, which resembles the second week of training, LIBFR started to show a decline in pain severity, whereas HIRES started to show an incline in pain severity. By the last session, HIRES had a significantly higher pain severity compared to the LIBFR group. This shows that over the duration of a training program, LIBFR may experience less DOMS. DOMS might also be decreased in BFR training compared to KAATSU training due to the different techniques and equipment. Whereas KAATSU training is completely occluding blood flow with a tourniquet, BFR training is done with cuffs that control occlusion pressure, making is safer. KAATSU training comes with many complications such as but not limited to subcutaneous hemorrhage, numbness and cerebral anemia [37]. With BFR, there are not as many reported complications or muscular pain.

With the MPQ, LIBFR reported mild (i.e. the least amount of pain) 91% of the time when asked "which word describes your pain right now", compared only 78% of the time in HIRES. The HIRES group reported pain 24-hours post-exercise as discomforting 20% of the time, compared to the LIBFR group reporting it only 8% of the time. The MPQ in addition to the VAS shows that BFR training caused less muscular pain at the traditional point of peak DOMS than traditional resistance training. This is important for continuing motivation in various populations. For example, those seeking rehabilitation post-injury or post-surgery are already in pain, therefore BFR can help improve their muscular profile while limiting pain. RPE has been previously used as an indication of pain in BFR studies. Whether the RPE was taken after each repetition as done in Yasuda et al. (2011) study or after each training session as done in Kim et al. (2016), results still suggest that BFR groups had a lower RPE than traditional exercise [5] [4]. This helps demonstrate that BFR training is related to less muscular pain than high intensity traditional resistance exercise.

There are inconsistent findings among BFR studies relating to DOMS and muscular pain. This study used two different pain scales to indicate muscular pain at the same time DOMS would occur (24-hours post each exercise session). A study done by Umbel et al. (2009) showed that BFR exercise caused more soreness in the lower-body than traditional exercise 24-hours post-exercise assessed through a verbal analog scale [26]. Inversely, a study done by Wernbom et al. (2009) demonstrated a higher report of DOMS in the non-occluded group compared to the occluded group during the 24-hour, 48-hour and 72-hour post-exercise. DOMS was measured using the VAS scale, similar to this study [10]. Another study done by Page et al. (2017) showed that there is significantly lower level of DOMS in the lower-body 48-hours and 72-hours post-BFR training compared to traditional exercise, but not at the 24-hour mark assessed with the VAS [27]. These taken together demonstrate that different BFR protocols, such as cuff pressure, may elicit different results in regards to muscular pain. Page et al. (2017) used an occlusion pressure as high aa 220 mmHg and Wernbom (2009) used a pressure as low as 100 mmHg to produce less muscular pain in the BFR group. On the other hand, Umbel (2009) used a pressure between those two studies of 160-200 mmHg depending on individual's SBP and produced a greater level of DOMS in the BFR group.

2.5 Limitations

All participants who were recruited for this study were overtly healthy young adults with a wide variety of exercise training experience, potentially leaving less room for improvement in muscular adaptation. For example, if participants underwent a detraining or washout period prior to this exercise program, there would be more opportunity for muscular growth and strength increase. The inclusion of males and females was also a limitation due to hormone differences causing various rates of increases in muscular strength between genders along with the greater initial strength in males compared to females in all upper and lower body exercises. However, this study could not conclusively assess gender differences or hormone changes.

A BFR program eight weeks or more has shown greater increases in muscular size than programs under eight weeks [12]. A limitation to this study is the length of the exercise program duration. This could be an explanation to why there were no significant changes with muscular size due to it being under the 8-week mark. However, the changes in strength would suggest neural adaptations occurred. Although this study followed a set protocol determined by the company of (B)Strong, the BFR protocol is a debatable variable in BFR studies. There is no set protocol with BFR training, but with the varying intensities, sets and repetitions, multiple studies have still replicated the same results such as an increase muscular strength and size.

2.6 Conclusion

This study demonstrated improvements in muscular fitness outcomes and subjective muscle pain with BFR training using the (B)Strong cuffs and traditional resistance training in the upper and lower-body. These findings suggest that low intensity exercise combined with BFR is a useful, applicable method/alternative to resistance training. There were little to no improvements with muscular hypertrophy, potentially due to the length of the study. This study has also demonstrated that as exercise sessions progress, with the BFR cuffs, DOMS is not as serious in the LIBFR group compared to the HIRES. Future research should focus on optimizing a BFR training protocol that elicits training adaptations while causing the least amount of DOMS, and applying these findings to rehabilitation populations.

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APPENDIX

COLUMBUS STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD

Informed Consent Form

You are being asked to participate in a research project conducted by Mallory Rockhill, a graduate student in the Exercise Science program at Columbus State University.

I. Purpose:

The purpose of this project is to examine and compare muscular fitness outcomes and subjective muscle pain with BFR training using the (B)Strong cuffs and traditional resistance training in the upper and lower body.

II. Procedures:

Blood flow restriction training is used across the life-span and has been found to be a safe, effective way to stimulate muscular fitness changes while exercising at a lower intensity. This study will include a 7-week training program and pre and post testing of muscular fitness.

In your first visit (~1hr), you will be asked to wear "exercise" clothes (like Under Armor). During this visit we will collect the following information:

-Resting vitals: heart rate will be measured at your wrist and blood pressure with a cuff around your arm briefly

-Ultrasound: an ultrasound machine probe will be used on you arm to measure blood flow

-Anthropometric measures: height, weight, arm circumferences will be measured. Bio-electrical impedance (hand-held device for estimating body fat) and body composition using the BodPod technqiue where you will sit in a pod that estimates body fat percent.

-Strength tests: grip strength using a handgrip squeeze, one repetition maximum test of your upper and lower body strength, and an endurance test to determine how many push-ups you can perform in 1-minute.

During the 7-week program, you will be asked to visit the laboratry for ~30-45 minutes, 3 times per week to perform the exercises that you are randomized to. You may perform no outside-exercise, traditional resistance exercises, or traditional exercises with blood flow restriction using cuffs for the duration of the study. 24 hours after the exercise, we will survey your subjective muscle soreness.The exercises you may perform are: handgrip, bicep curls, tricep extensions, push-ups, calf raises, hamstring curls and leg extensions.

The last study visit (~1hr), you will repeat the testing from the first visit. This information collected will be used for development of future studies and manuscript publication.

III. Possible Risks or Discomforts:

Performing resistance exercises, including the 1-repetition maximum, may lead to muscle sorness or tenderness. This is a common occurance with exercise training. To ensure that you are exercising with-in limits, we will have you fill out two brief surveys after exercise. We will follow blood flow restriction protocols that have been previously used in the scientific literature and are published with manufacturer's guidelines. We will monitor your exercise sessions (~30-45minutes each) and ensure proper form and safe completion of the exercises.

The BodPod measurement requires you to enter a small chamber. You may be uncomforttable if you are anxious in small spaces. The risk is minimized by having a window, short test period (<60seconds) and easy exit if you feel uncomfortable.

IV. Potential Benefits:

You may potentially gain knowledge about your personal health and free body composition assessment. In addition, you will be provided with a training program for 7-weeks by experienced professionals.

V. Costs and Compensation:

There is no compensation for the participants. An instructor may offer extra credit for participating.

VI. Confidentiality:

The information obtained in this study will be confidential and will not be released to any person without your consent. Any personal information on paper that could potentially identify you will be de-identified and assigned a numeric code so that there is no link to you. Your information wil be stored by the principal investigator in a locked cabinet for 3 years. After which paper documents with your information will be destroyed. We may use this information collected for research reports or presentations, but your name and any other identifying information will not be disclosed.

VII. Withdrawal:

Your participation in this research study is voluntary. You may withdraw from the study at any time, and your withdrawal will not involve penalty or loss of benefits.

For additional information about this research project, you may contact the Principal Investigator, Mallory Rockhill at 623-734-7331 or Rockhill_Mallory@columbusstate.edu. If you have questions about your rights as a research participant, you may contact Columbus State University Institutional Review Board at irb@columbusstate.edu.

I have read this informed consent form. If I had any questions, they have been answered. By signing this form, I agree to participate in this research project.

______________________________ Signature of Participant	______________ Date

EFFECTS OF BLOOD FLOW RESTRICTION TRAINING ON HEALTHY INDIVIDUALS

USING (B)STRONG BRAND CUFFS: A RANDOMIZED CONTROLLED TRIAL

A THESIS SUBMITTED TO THE COLLEGE OF EDUCATION AND HEALTH PROFESSIONS IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF KINESIOLOGY AND HEALTH SCIENCES

By

Mallory Rockhill

2018

Kate A Early ______ 12/12/18 ______

Dr. Kate Early, Chair — Date

______ 12-12-18 ______

Dr. Brian Tyo, Member — Date

______ 12/12/18 ______

Dr. Alicia Bryan, Member — Date