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COMPARISON OF UPPER LIMB MUSCULAR AND VASCULAR RESPONSES FOLLOWING TRADITIONAL HIGH-LOAD AND LOW-LOAD RESISTANCE TRAINING WITH BLOOD FLOW RESTRICTION IN COLLEGE-AGED MALES

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DAEYEOL KIM
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COMPARISON OF UPPER LIMB MUSCULAR AND VASCULAR RESPONSES FOLLOWING TRADITIONAL HIGH-LOAD AND LOW-LOAD RESISTANCE TRAINING WITH BLOOD FLOW RESTRICTION IN COLLEGE-AGED MALES

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

BY

Dr. Michael G. Bemben, Chair

Dr. Debra A. Bemben

Dr. Travis W. Beck

Dr. Rebecca D. Larson

Dr. Hairong Song

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Abstract

Low-load combined with blood flow restriction (BFR) resistance training has been reported to increase muscle size and muscle strength similar to traditional high-load resistance training. However, the mechanism of muscle hypertrophy induced by low-load resistance training with BFR is not clear. Additionally, the cardiovascular responses to low-load resistance training have not been elucidated. **PURPOSE:** To investigate the muscular (muscle thickness, arm circumference muscle activity and muscle strength) and cardiovascular (arterial stiffness and forearm blood flow) responses of eight weeks of low-load unilateral elbow flexor resistance training with BFR compared to traditional high-load resistance training, and to compare the acute skeletal muscle responses (muscle thickness, muscle activity, isometric strength, hematocrit and blood lactate) between traditional high-load and low-load with BFR unilateral elbow flexor resistance exercise in college-aged males. **METHODS:** Fourteen healthy college-aged males were randomly assigned to either the experimental group (n = 9) or control group (n = 5, CON) and each arm of the participants in the experimental group were randomly assigned to either the traditional high-load protocol (HI, 75% 1-RM and 3 sets of 10 reps) or low-load with BFR protocol (LI-BFR, 30% 1-RM and 30 reps following 3 sets of 15reps with 50% arterial occlusion pressure). The participants in the experimental group completed eight weeks of unilateral elbow flexor training (3 times per week). Both arms of participants in the CON group were assigned to the control protocol and the participants in the CON group maintained their daily physical activity and did not participate in any exercise sessions during the training period. All of the participants completed muscular and cardiovascular measurements two times before the training began (PRE 1 and PRE2) and once after the training ended (POST). Additionally, the participants in the experimental group completed the acute response testing during the first and second sessions of the fourth week of the training period and measurements were determined before and after an acute bout of HI or LI-BFR protocol in each session. The values at PRE1 and PRE 2 were averaged for further analysis. When there were no group differences at the baseline, ANOVA with post-hoc testing was utilized, and when significant group differences were detected at the baseline, ANCOVA with post-hoc testing was used to examine main effects (time and group) and interaction (time × group) effects. Alpha was set at $p < 0.05$. **RESULTS:** Muscle thickness and arm circumference at all sites in both HI and LI-BFR groups were significantly increased over time, but not in the CON group. 1-RM and isometric strength in both HI and LI-BFR groups were significantly increased over time, but not in the CON group, and the 1-RM in the HI group was significantly greater than the CON at the POST test. There were group differences at baseline for arterial stiffness (PWV) and forearm blood flow (FBF). PWV and FBF were unchanged over time when analyzed by ANCOVA. In the acute response testing, muscle thickness, arm circumference, muscle strength, muscle activity, blood lactate, and hematocrit values in both HI and LI-BFR groups showed similar responses. **CONCLUSION:** Both traditional high-load and low-load with BFR unilateral elbow flexor resistance training resulted in similar muscle hypertrophy and strength gains without any changes in cardiovascular function. In addition, acute cell swelling induced by a single bout of the LI-BFR protocol may represent the best explanation of a mechanism for BFR related muscle hypertrophy.

Chapter I: Introduction

Traditional high-load (greater than 70% 1-RM) resistance exercise is generally utilized for improving skeletal muscle size and strength, thus it may be beneficial to combat sarcopenia in the elderly (9). However, not all populations are able to perform high-load resistance exercise due to joint or cardiorespiratory problems (54, 84). Additionally, some literature suggests that regular low-load resistance exercise is not sufficient to improve muscle size and strength (60).

However, low-load exercise combined with blood flow restriction (BFR) has shown to induce muscle hypertrophy (52). In previous studies, low-load blood flow restricted exercise (both aerobic and resistance) has been reported to improve muscle mass, size and strength (1, 8, 24, 56, 86-88, 97). Moreover, some studies showed similar muscle hypertrophy and strength gains after low-load resistance exercise with BFR as high-load resistance exercise (35, 37, 69, 87) in young and old males.

Several mechanisms may explain muscle hypertrophy induced by low-load resistance exercise with BFR. Generally, recruitment of type II (fast twitch) fibers during high-load resistance exercise, plays an important role in muscle hypertrophy and strength gains (38). Low-load resistance exercise with BFR also recruits type II fibers because applying BFR in exercising muscles (a hypoxic intramuscular environment) leads to intramuscular metabolic stress similar as high-load resistance exercise resulting in the additional recruitment of type II fibers (81). During exercise with BFR, pooling of blood in the limbs caused by a delayed venous return (42, 68) may produce cell swelling which may stimulate muscle hypertrophy though pathways that include mammalian target of rapamycin (mTOR) and mitogen-activated proteinkinase (MAPK) (49).

Safety is a potential issue with BFR exercise because reactive oxygen species (ROS) that may be induced by the hypoxic intramuscular environment is possibly related with muscle damage (85), but several BFR studies have reported muscle hypertrophy without any side effects such as muscle damage, or thrombosis (53, 55, 64). Thus, low-load resistance exercise with BFR appears to increase muscle size and strength with minimal risks.

Arterial compliance (inverse relationship with arterial stiffness) is decreased with advancing age, and it is a risk factor for cardiovascular disease. Generally aerobic exercise improves arterial compliance (32), but high-load resistance exercise may be related to arterial stiffness (11) even though it is beneficial for muscle hypertrophy and strength gains (9). However, previous studies have shown that arterial compliance after acute and chronic low-load resistance exercise with BFR was not changed (13, 20, 21, 37). Moreover, a study reported that high-load resistance exercise improved muscle hypertrophy and strength gains while reducing carotid arterial compliance whereas low-load resistance exercise with BFR increased muscle mass and strength without altering carotid arterial compliance (69).

In previous BFR studies, much of the data for muscle hypertrophy and strength gains after BFR studies are not consistent due to the use of a standard uniform pressure to induce BFR across all subjects (48). One study reported that the use of a standard pressure for all subjects is not suitable due to different limb sizes (vessels surrounded by different components of muscle and subcutaneous fat) and that using individualized

BFR pressures based on the limb size may result in better responses (48). Furthermore, many previous BFR studies did not compare their findings to high-load exercise, and there are no studies that used low-load upper body resistance exercise combined with individualized BFR on muscular and vascular responses compared to traditional high-load resistance exercise.

Purpose of the Study

The purpose of this study was to compare the skeletal muscle (arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) and vascular responses (forearm blood flow and peripheral arterial stiffness) following eight weeks of unilateral elbow flexor resistance exercise with either a traditional high-load without BFR or a low-load with BFR (50% of arterial blood flow occlusion) in untrained college-aged males.

A secondary purpose of this study was to compare the acute skeletal muscle responses (muscle thickness, muscle activity, isometric strength, hematocrit and blood lactate) between traditional high-load and low-load with BFR unilateral elbow flexor resistance exercise in college-aged males.

Research Questions

1. Will low-load elbow flexor resistance training with BFR produce a similar skeletal muscle response (arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) as traditional high-load elbow flexor resistance training in untrained college-aged males?
2. Will there be differences in the vascular responses (forearm blood flow and peripheral arterial stiffness) between low-load elbow flexor resistance training

with BFR and traditional high-load elbow flexor resistance training in untrained college-aged males?

Research Hypotheses

1. Low-load elbow flexor resistance training with BFR will produce skeletal muscle responses (increases in arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) similar to traditional high-load elbow flexor resistance training.
2. Low-load elbow flexor resistance training with BFR will produce increased forearm blood flow response similar to traditional high-load elbow flexor resistance training but unchanged or decreased peripheral arterial stiffness response different from traditional high-load elbow flexor resistance training.
3. High-load elbow flexor resistance training will produce vascular responses (increases in forearm blood flow and peripheral arterial stiffness) different from a control (non-exercise) group and the low-load elbow flexor resistance training with BFR will produce vascular responses (increase in forearm blood flow and unchanged or decreased peripheral arterial stiffness) different from a control (non-exercise) group.

Subquestion

1. Will low-load elbow flexor resistance exercise with BFR produce similar acute skeletal muscle responses (muscle thickness, hematocrit, blood lactate, and isometric strength,) as traditional high-load elbow flexor resistance exercise in college-aged males?

Subhypothese

1. Low-load elbow flexor resistance exercise with BFR will produce acute skeletal muscle responses (increases in muscle thickness, hematocrit and blood lactate and decrease in isometric strength and muscle activity) similar to traditional high-load elbow flexor resistance exercise.

Significance of the Study

Many studies of low-load resistance exercise with BFR have been shown to induce muscle hypertrophy without altering arterial compliance. However, most studies have not compared low-load exercise with BFR to traditional high-load exercise which generally induces skeletal muscular adaptations (31). Therefore, this study is the first study to compare unilateral elbow flexor training at a low-load with individualized BFR to traditional high-load training without BFR. The skeletal muscle and vascular responses from this study may then be used to design an appropriate individualized low-load BFR training program for future studies with various populations. Additionally, acute skeletal muscle responses from low-load elbow flexor resistance exercise with BFR may provide information for one of the possible BFR muscle hypertrophy mechanisms (cell swelling).

Assumptions

The assumptions of the study included:

1. Each participant will give maximal effort during strength tests and exercise protocols.
2. Each participant will honestly answer and complete health history questionnaire and PAR-Q truly.

3. Each participant will maintain their physical activity and diet during this study period.
4. Each participant will follow protocols that will include (at outcome testing):
    - 2 hours fasting before testing.
    - No caffeine consumption on the testing day.
    - No alcohol consumption for 24 hours prior to testing.
    - No exercise for 24 hours prior to testing.

Delimitations

The delimitations of the study included:

1. The outcomes of this study will only be applicable to untrained college-aged males (18 – 35 years old).
2. Participants will be free of any medical or physical issues that would prevent them from exercise.

Limitations

The limitations of the study included:

1. All participants will be willing to participate this study as volunteers, thus this sample will not be random; therefore, they may not represent all college-aged (18 - 35 years) males.
2. Since only untrained college-aged males will be eligible to participate in this study, outcomes may be different from the outcomes of other age groups and gender.
3. Participants will maintain normal daily activities, and outside activities of this study will not be managed.

Operational Definitions

The operational definitions for this study included:

1. **Blood Flow Restriction (BFR) exercise:** While participants perform low to moderate intensity exercise, restricted cuffs with specific pressure are placed at the most proximal portion of the lower or upper body to reduce arterial blood flow and restrict venous return to the exercising limbs.
2. **One Repetition Maximum (1-RM) test:** 1-RM is the greatest weight that can be lifted once throughout a complete range of movement, using correct form.
3. **Test-retest reliability:** a consistent result from same participants in the same measurements between 2 different time periods.
4. **Maximal Voluntary Contraction (MVC):** maximally generated force when participants perform an isometric strength test.
5. **Pulse Wave Velocity (PWV):** A determination of the velocity of pulse wave propagation from one site to another site to assess regional arterial stiffness (smaller values indicate a lower stiffness).
6. **Untrained Subjects:** participants who are not resistance trained no more than once a week, running no more than 5 miles per weeks, or recreationally exercised (example: basketball, tennis, swimming and so on) no more than once a week.

Chapter II: Literature Review

Exercise with Blood Flow Restriction

Exercise with blood flow restriction (BFR) was invented in Japan and has been popular in Japan since the mid-1980s, and the concept of exercise with BFR is that specialized pressure cuffs are placed on the most proximal site of limbs for occluding venous blood flow and reducing arterial blood flow while performing exercise at a low-intensity (77). In previous studies, various intensities (20 – 50% 1-RM), BFR pressures (100 – 300 mmHg), size of BFR cuffs (2 – 20.5 cm) and types of BFR cuffs (pneumatic cuffs, regular blood pressure cuffs, elastic belts containing pneumatic bags, and elastic knee wraps) have been utilized for BFR exercise (18).

This BFR exercise results in muscle hypertrophy that is similar to traditional high-load exercise (104) and greater than low-load resistance exercise without BFR (24). In addition, not only resistance exercise with BFR (1, 35, 37, 86, 87, 97) but also aerobic exercise (walk or cycle training) with BFR (2, 4, 5, 7, 70) leads to muscle hypertrophy and strength gains. Thus, BFR exercise may be appropriate for several populations to induce muscle hypertrophy and strength gains due to the use of low-intensity exercise with various types of modalities (walking, cycling, etc). In addition, applying BFR without exercise may also elicit cell swelling leading to muscle anabolic / anticatabolic signaling pathways (49).

However, the mechanism of muscle hypertrophy induced by BFR exercise is unclear, but there are several possible mechanisms such as enhanced motor unit recruitment caused by locally accumulated metabolites such as lactate and H^+ (95), cell swelling caused by pooling of blood in limbs (47), decreased myostatin gene expression

(45), enhanced systemic anabolic hormones (85), increases in myogenic stem cells (65), and enhanced mTOR signaling caused by greater hyperemia after releasing BFR cuffs and increasing blood flow (17).

Generally, type II fibers, which are a greater factor for muscle hypertrophy than type I fibers (27), are recruited during high-intensity exercise based on the size principle, but blood flow restricted exercise also recruits type II fibers (87) due to an acidic and hypoxic intramuscular environment which stimulates chemosensitive group III and IV afferents leading to increased muscle fiber recruitment (58). Suga et al. (82) showed that changes of intramuscular metabolites and pH and recruitment of type II fibers in exercise with BFR (during both exercise and resting period) were similar to a high-load exercise group. In addition, generally the eccentric phase of high-load resistance exercise induces increases in muscle mass and strength; however, the concentric phase of low-load resistance exercise with BFR has been shown to elicit muscle hypertrophy and strength gains (89, 101), and this concentric phase of BFR exercise leads to cell swelling, which can stimulate muscle protein synthesis and can inhibit protein breakdown (101).

During exercise with BFR, the applied pressure of the BFR cuffs on the most proximal portion of the limbs induces pooling of blood because of occluded venous blood flow and reduced arterial blood flow (42). The pooling of blood in the limbs decreases the return of blood to the heart and stroke volume, resulting in increases in heart rate and blood pressure (42, 68) and accumulate metabolites (95). Thus, the BFR pressure is important to regulate the degree of both arterial and venous blood flows.

However, most previous BFR studies have used a standardized pressure for all subjects (18). One study using lower body BFR exercise found that a standardized pressure was not suitable for all subjects, and that the restricted pressure should depend on the circumference of the limbs (48). Ultimately, there may be a better adaptive response if the BFR pressure is individualized during exercise.

Muscular Responses to Exercise with Blood Flow Restriction

Recently, BFR exercise has become a popular research topic, and varied types of exercise (resistance or aerobic exercise) combined with BFR have been investigated (73). Traditionally, muscle hypertrophy and strength gains are induced by high-load resistance exercise; however, BFR studies have also resulted in muscle hypertrophy and strength gain even though the exercise load is low to moderate (58).

Many previous BFR studies compared their results with non-BFR exercise groups. Abe et al. (3) reported that muscle mass (muscle-bone cross sectional area (CSA) and muscle thickness (MTH)) and 1-RM strength in a BFR group were increased but not in a non-BFR group after 8 days (2 times per day) of squat and leg curl resistance exercise in college athletes. Yasuda et al. (94) showed 1-RM and muscle fiber CSA by biopsy in a BFR group were improved but not in a non-BFR group following two weeks of squat and leg curl resistance training (20% 1-RM with and without 160 – 240 mmHg, 2 times per day, 6 days per weeks) in young males. Similarly, Ohta et al. (66) investigated subjects (males and females, 18 – 52 years old) performing lower body training with or without BFR (180 mmHg) for 16 weeks after anterior cruciate ligament surgery and reported that strength (isokinetic and isometric) and muscle CSA (by MRI) in the BFR group were greater than the non-BFR group. Another

BFR study reported that two weeks of bench press training (30% 1-RM with 100- 160 mmHg, twice per day and 6 days per week) in untrained young males increased muscle CSA in a BFR group on both the restricted upper body limbs as well as for the unrestricted chest but not in a non-BFR group. This result indicated exercise with BFR stimulates both restricted and unrestricted exercising muscle groups (97).

Moreover, some low-load resistance exercise with BFR studies have shown muscle hypertrophy and strength gains that were similar to high-load resistance exercise. Takarada et al. (87) reported after 16 weeks (2 times per week) of low-load elbow flexion training at high-load (80% 1-RM) and low-load with and without BFR (~50% 1-RM with ~110 mmHg) in old females (aged 47 to 67 years), that muscle CSA, isometric strength, and isokinetic strength in the low-load with BFR exercise group were increased to the same extent as the high-load non-BFR exercise group, and were greater than the non-BFR low-load exercise group. Similarly, Yasuda et al. (103) reported muscle CSA (triceps brachii and pectoralis major) was improved following low-load bench press exercise with BFR for 6 weeks (3 times per week) in young males and there results were similar to a high-load exercise group. Also, Kubo et al. (41) showed muscle volume (quadriceps femoris) and isometric knee extension strength in both high-intensity and low-intensity with BFR groups were increased after 12 weeks (3 times per week) of knee extension training in young males. Moreover, tendon stiffness may be inversely related to exercise performance (40), but low-load resistance exercise with BFR may not alter tendon stiffness. Kubo et al. (41) reported that low-load knee extension training with BFR for 12 weeks (3 time per week) did not change tendon stiffness with improving muscle volume (quadriceps femoris) and isometric strength whereas a high-load exercise group had increased tendon stiffness.

Laurentino et al. (44) examined high (6-RM) - and moderate (12-RM)-load knee extension training with or without BFR for 8 weeks (2 times per week) in physically active young males and found that muscle hypertrophy (quadriceps CSA) and strength gains (1-RM) were also similar, indicating that high-load and moderate-load resistance exercise combined with BFR did not additionally enhance muscle hypertrophy and strength gain compared to high-load and moderate-load resistance exercise without BFR (44).

Cardiovascular Responses to Exercise with Blood Flow Restriction

The cardiovascular system also responds to BFR exercise. During exercise with BFR, heart rate (HR) is increased and stroke volume (SV) is decreased due to pooling of blood in the limbs caused by a delayed venous return. Blood pressure (BP) during the initial phase of BFR exercise increases and then is decreased due to greater total peripheral resistance induced by an enhanced vasoconstrictor response (norepinephrine) (42).

Arterial stiffness (inverse relationship with arterial compliance) is increased with advancing age and related to renal problems and high-blood pressure (68). Moreover, increases in arterial stiffness is a risk factor for cardiovascular disease (10). In fact, some literature has shown that high-load resistant training decreases arterial compliance (62).

Heffernan et al. (28) showed that central arterial stiffness, as determined by pulse wave velocity (PWV), was increased by an acute bout of high-load resistance exercise in young males. Similarly, a meta-analysis reported that high-load resistance exercise is strongly associated with arterial stiffness, but not moderate-load resistance exercise (61). Collier et al. (14) reported that both central and peripheral arterial stiffness was increased after 4 weeks of resistance exercise (3 days per week) at 10-RM in pre or stage 1 hypertensive old males and females (aged 30 to 60 years). Also, Miyachi et al. (62) examined arterial stiffness, measured by ultrasound, and reported that arterial stiffness was increased after high-load resistance exercise for 4 months (3 times per week) in young males compared with a non-exercising group but returned back to baseline following 4 months of detraining.

In contrast, one study indicated that acute unilateral leg exercise in young females and males at high-load (85% 1-RM and 6 sets to failure) did not alter central arterial stiffness but increased peripheral arterial stiffness compared to the non-exercising leg (29). Thus, changes in arterial compliance induced by high-load exercise are still uncertain.

In previous BFR studies, Clark et al. (13) showed peripheral arterial compliance was not changed after both high-load and low-load with BFR resistance exercise for 4 weeks (3 days per week) in young males. Similarly Fahs et al. (20) indicated that high-load, moderate-load, and low-load with BFR resistance exercise did not change arterial compliance measured by pulse contour analysis (PCA) after 6 weeks of resistance training (3 times per week) in young males. However, Ozaki et al. (69) showed carotid arterial compliance determined by ultrasound in the high-load group was reduced after 6 weeks of bench press training (3 days per week) in young males whereas the low-load with BFR group did not alter carotid arterial compliance. Furthermore, Hunt et al. (34)

reported brachial artery diameter was larger after 4 weeks of handgrip training with BFR (3 days per week) in young males but returned back to baseline following two weeks of detraining. On the contrary, Fahs et al. (22) reported peripheral arterial stiffness, assessed by PWV, in a BFR group was increased after low-intensity unilateral knee extension training to failure for 6 weeks (3 times per week) in young males.

In BFR studies with blood flow, one study suggested capillary growth in rat muscle may be increased after low-load resistance training with BFR for 6 weeks (2 times per week) compared to a non-BFR group (83). Several previous BFR studies also supported this suggestion. For example, Fahs et al. (20) reported resting calf blood flow was increased after low-load lower body resistance training with BFR for 6 weeks (3 days per week) similar to high- and moderate-load lower body training groups compared to a non-exercising group. Similarly Hunt et al. (33) showed 6 weeks of low-load unilateral plantar flexion training with BFR (3 times per week) increased calf blood flow compared with the non-exercise group in young males.

In contrast, Patterson and Ferguson (71) indicated calf blood flow was not changed after low-load (at 25% and 50% 1-RM) unilateral plantar flexion with and without BFR for 4 weeks (to failure, 3 days per week) in young females. Also, Fahs et al. (22) reported 6 weeks of low-load unilateral knee extension training with BFR (to failure, 3 times per week) in young males did not alter calf blood flow, but increased in the non-BFR group.

There are some possible mechanisms for improved vascular function induced by exercise with BFR. Vascular endothelial growth factor (VEGF) expression is increased due to hypoxia status during exercise with BFR leading to an enhanced lactate accumulation (84) and hyperemia after releasing restricted blood flow may also stimulate microvasucular function (17). There is no consistence finding for the vascular responses with BFR exercise; therefore, further research is required.

Muscle Activation to Exercise with Blood Flow Restriction

Muscle activation and the recruitment of muscle fibers are strongly associated with generating increased force production (76). Thus, a smaller number of fibers and fewer type I fibers are recruited at low-intensity exercises, and a greater number of fibers and more type II fibers are recruited at high-intensity exercises (63) based on the size principle (30). However, low-load resistance exercise with BFR results in greater muscle activation similar to a high-load resistance exercise group when compared to a low-load resistance exercise without BFR group (87) due to an increased hypoxic intramuscular environment inducing the additional recruitment of type II fibers (39). Furthermore, the concentric phase of low-load resistance exercise with BFR stimulates muscle hypertrophy and strength gains whereas the eccentric phase in high-load exercise stimulates muscle hypertrophy (89, 101). Thus, Yasuda et al. (101) reported EMG for biceps brachii in concentric portion during acute dumbbell curl exercise with BFR was greater than eccentric portion, and these results match with the results of muscle hypertrophy induced by concentric BFR training after 6 weeks of dumbbell curl training (3 times per week) in young males.

In acute exercise with BFR, Yasuda et al. (96) showed muscle activation for the triceps brachii and pectoralis major in the BFR group during low-load bench press exercise in young males was higher than the non-BFR group. Moore et al. (63) indicated that the biceps brachii in the BFR group had greater muscle activation after unilateral elbow flexion compared with the non-BFR group. Similarly, Yasuda et al. (98) reported EMG activity for the biceps brachii in young males during elastic band resistance exercise with BFR was greater than a non-BFR group.

However, Takarada et al. (87) indicated that EMG activity from the biceps brachii in low-load elbow flexor exercise without BFR was lower than the high-load group, and that the low-load exercise group with greater BFR pressure group (100 mmHg) had higher EMG activity than the lower BFR pressure group (50 mmHg). Similarly, Kubo et al. (41) reported that acute low-load knee extension exercise with BFR did not increase EMG activity from the vastus lateralis, but EMG activity in the high-load group was improved.

In general, muscle activation for restricted and non-restricted exercising muscles during low-load resistance exercise with BFR is greater than non-BFR group and that the greater the BFR pressure, the greater the response of muscle activation, but still may be lower than traditional high-load resistance exercise. Thus, individualized BFR pressures may produce a better response of muscle activation.

Summary

In the previous literature, muscle hypertrophy and strength gains induced by high-load resistance exercise are maximized, but high-load resistance exercise may have a negative relationship with arterial compliance. Also not all populations are able to exercise at a high-intensity due to joint and cardiac problems (54, 84). However, low-load resistance exercise with BFR elicits muscle hypertrophy and strength gains similar to high-load training without exacerbating joint and cardiac problems. Moreover, low-load resistance exercise with BFR may have a positive relationship with cardiovascular function. Most previous BFR studies have used general BFR pressures for all subjects; however, a general BFR pressure may not be appropriate for all subjects based on different sizes of limbs and limb circumferences (48). Thus, low-load resistance exercise with individualized BFR pressure based on limb size may be needed to maximally simulate muscular and vascular responses.

Chapter III: Methodology

This study investigated the muscular (arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) and vascular (forearm blood flow and arterial compliance) responses following eight weeks of traditional high-load and low-load with BFR (estimated 50% of arterial blood flow occlusion) unilateral elbow flexor resistance exercise. This section described the research subjects, experimental design, procedure of data collection, instrumentation, and data analyses.

Subjects

Eighteen untrained young subjects (males, 18 - 33 years old) participated in this study but only fourteen subjects completed all of testing and exercise sessions. The subjects did not perform any regular resistance or endurance training (no more than once per week) for at least six months prior to this study. The subjects were randomly assigned to either an experimental group (n = 9) or a control group (n = 5). All subjects were recruited from the Norman and Oklahoma City Metropolitan area through fliers, web listing, word of mouth, and e-mail. A non-probability sampling technique was utilized due to voluntary participation in this study. All forms and materials were approved by the University of Oklahoma Health Sciences Center Institutional Review Board.

Inclusion Criteria:

1. Male (between the ages of 18-35 years).
2. Untrained.
3. Non-smoker.

4. Participants were ambulatory and have no disabilities or hemodynamic disorders preventing them from sustaining short bouts of limb compression.

Exclusion Criteria:

1. Female.
2. Outside the age range of 18-35 years.
3. Physically active (participant who is currently engaged in regular resistance or endurance training more than two times per week).
4. Smokers (cigarettes, cigars, chew/snuff etc.).
5. Having more than one risk factor for thromboembolism:
   - Classified as obese based on a body mass index of > 30 kg/m^2
   - Diagnosed crohn's or inflammatory bowel disease
   - Past fracture of a hip, pelvis, or femur
   - Major Surgery within the last 6 months
   - Varicose veins
   - Family history of deep vein thrombosis or pulmonary embolism
6. Hypertensive (>140/90 mmHg).
7. Ankle brachial index of <0.9.
8. Any disease or medical condition documented in the Health History Questionnaire and Physical Activity Readiness Questionnaire (PAR-Q) that would prevent them from training and testing.

Experimental Design

This study used a pre- and post-test comparison group design. The total length of the present study was 10 weeks, including one week of pre (PRE 1 and PRE 2 to establish reliability of the measurements) and one week of post outcome (POST) testing and eight weeks of unilateral elbow flexor training (three times per week (total 24 sessions)). The initial portion of the study included initial screening, a familiarization session, and pre outcome testing. Within one week after the first pre outcome testing, the second pre outcome testing was completed for measurement reliability. Subjects in the experimental group then trained three times per week for eight weeks, then post outcome testing was completed (Figure 1). In the first and second session of fourth week, acute response measurements were assessed for the experimental group. During the 8 week training period, the subjects in the control (non-exercise, CON) group maintained their current activity levels and then completed the post outcome testing.

Exercise Training Protocols

The subjects were divided to either an experimental group (n = 9) or a control group (n =5). In the experimental group, each subjects' arm was randomly assigned to perform one of two exercise protocols (unilateral elbow flexor exercise (1 second concentric and 1 second eccentric cadence) with a dumbbell at traditional high-load (75% 1-RM, HI) or low-load (30% 1-RM) with blood flow restriction (50% AOP, LI-BFR)). Thus, one arm was assigned to perform one exercise protocol and the other arm was assigned to perform the other protocol. During each training session, the starting order for each arm was randomized. For example, a subject performed 3 sets of 10 repetitions with one minute rest between sets of unilateral elbow flexion in the HI protocol and then completed 30 repetitions followed by three sets of 15 repetitions with 30 seconds rest between sets of unilateral elbow flexion for the LI-BFR protocol. Subjects rested for 5 minutes on a chair between exercise protocols. During each session, RPE and a discomfort scale were administered at the end of every set. In the control group, the subjects did not perform any exercise session during the training period and their both arms were used as a sample.

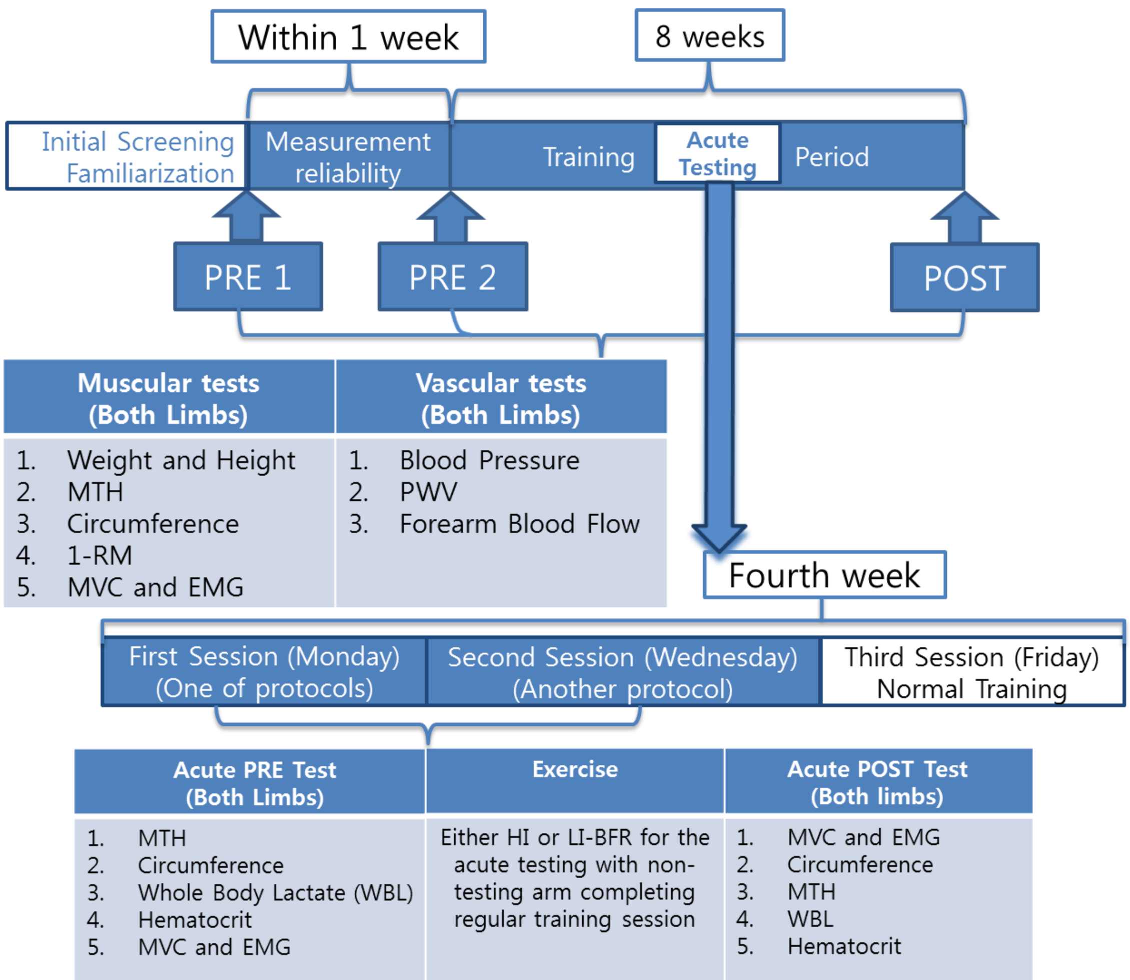

Figure 1. Experimental Design

Acute Response Testing

In the experimental group, the acute response testing was measured in the fourth week of training in order to reduce the chances of possible muscle damage that may occur during the initial three weeks. In the first exercise session of the fourth week, subjects were randomly ordered to perform one of two exercise protocols (traditional high-load (75% 1-RM, HI) and low-load (30% 1-RM) with BFR (50% of AOP, LI-BFR) with acute response measurements at pre (Acute PRE) and post (Acute POST). After finishing one of the protocols, the subject rested for 5 minutes on a chair, and then completed the other exercise protocol as part of the regular training session. In the second exercise session of the fourth week, subjects performed the untested exercise protocol from the first session with acute responses being assessed before and after exercise. After completing the exercise protocol, the subject rested for 5 minutes and then completed the other exercise protocol as part of the regular training session. In third exercise session of the fourth week, subjects resumed their normal exercise training session.

All protocols and measurements for the training and acute responses were completed at the Neuromuscular and Ultrasound Labs in the Department of Health and Exercise Science at the University of Oklahoma.

Initial Screening and Familiarization

After initial screening for inclusion and exclusion criteria, subjects completed an informed consent, HIPPA, health status questionnaire, and physical activity readiness questionnaire (PAR-Q), and then their height, body mass, blood pressure, forearm circumference, and ankle brachial index (ABI) were measured. If inclusion criteria were not met, the subject was excluded from this study. After finishing the initial screening (completing forms, and measurements: height, body mass, blood pressure, forearm circumference, and ABI), subjects performed a familiarization session for blood flow restriction, isometric strength testing and the one-repetition maximum (1 RM) strength test.

Questionnaires

At the start of the initial screening period, a desk was set up so that subjects were able to read the consent form, sign the document and were asked questions. After completing consent and HIPPA forms, subjects filled out a PAR-Q and health status questionnaire.

Body Mass and Height

A digital scale (Tanita BWB-800, Tanita Corporation of America, Inc., Arlington Heights, IL) was utilized for determining subject's body mass, and a wall stadiometer (PAT #290237, Novel Products, Rockton, IL, USA) was used for measuring subject's height, and then body mass index (BMI (kg/m^2)) was calculated: weight (kg) divided by height (m^2).

Brachial Blood Pressure

After measuring body mass and height, subjects laid down on a plynth in a supine position for 10 minutes of rest. An automatic blood pressure cuff (Model HEM-773, Omron®, Shelton, CT) was utilized for determining brachial blood pressure following the rest period. This was measured two times and the values were averaged.

Ankle Brachial Index (ABI)

After brachial blood pressure, ABI was measured. A blood pressure cuff was applied on the subject's right arm and inflated, and then blood flow through the brachial artery was determined by a Bidirectional Doppler probe (MD6, Hokanson Inc, Bellevue, WA). When the blood pressure cuff on the arm was slowly decreased, the Bidirectional Doppler probe detected blood flow. The highest blood pressure was determined when blood flow was first detected. Following the measurement on the right arm, the blood pressure cuff was placed at the subject's right ankle and inflated, and then blood flow through the posterior tibial artery was measured while the inflated blood pressure cuff was slowly deflated. The ankle blood pressure was determined by the Bidirectional Doppler probe when blood flow was first detected. This measurement was repeated on the left ankle and left arm. The ABI was calculated by the highest ankle blood pressure divided by the highest brachial blood pressure, and the value was compared to a reference value (< 0.9). If a subject's ABI was < 0.9, the subject was excluded from this study.

Forearm Circumference

While the subject was supine on the medical bed, a tape measure was applied to measure forearm circumference of both arms at the largest circumference site (nearest 0.1 cm). The forearm circumference was used to determine the size of the strain gauge for measurement of forearm blood flow. The same procedure was completed on the other arm.

Familiarization Session

Blood flow restriction

When the subject was standing, a specialized blood pressure cuff (5 cm width, Hokanson, Bellevue, WA) was worn at the most proximal end of one of the arms, and arterial occlusion pressure (AOP) was determined in order to calculate the target BFR pressure that was used during training. The pressure of the cuff was incrementally increased (inflating 30 seconds and deflating 10 seconds) from 50 mmHg to the AOP, and the Bidirectional Doppler probe on the brachial pulse detected occluding arterial blood flow. After determining the AOP, the subject performed unilateral elbow flexor exercise (1 second concentric and 1 second eccentric cadence) with a dumbbell. The subject completed unilateral elbow flexion for 2 sets of 15 repetitions with 30 seconds rest between sets at 30% 1-RM combined with BFR (50% of the AOP). Following BFR protocol, the subject rested for 5 minutes on a chair and performed unilateral elbow flexion with the arm that did not exercise for 2 sets of 5 repetitions at 75% 1-RM with 1 minute rest between sets.

Rating of Perceived Exertion (RPE) and Discomfort

The RPE and Discomfort scales were explained to subjects during the initial visit. During each exercise protocols, a rating of perceived exertion and discomfort was obtained at the end of each set throughout the exercise bout by the standard Borg's RPE Scale (from 6 to 20) and Borg’s Discomfort scale (from 0 to 10+).

Maximal Isometric Voluntary Contraction (MVC)

Subjects were seated on an isokinetic dynamometer (Biodex System 3, Biodex Medical System, Shirley, NY) and one arm was immobilized at a 90 degree angle perpendicular to the floor. The arm performed isometric elbow flexion against the lever arm of the isokinetic dynamometer for 3 seconds to measure the highest torque. Three submaximal contractions (3 seconds with 30 seconds rest period between attempts, at approximately 30%, 50%, and 70% of maximal efforts) were performed as a warm up followed by two maximal contractions (3 seconds with 30 seconds rest period between attempts). The subject's arm was then moved to a 120 degree angle, and two additional maximal contractions (3 seconds with 30 seconds rest period between attempts) were completed. The same procedures were completed by the other arm.

One-Repetition Maximum (1-RM)

A dumbbell with microloading plates (Platemate, Boothbay Harbor, ME) was used for measuring 1-RM testing. The 1-RM testing was performed to determine the maximum strength for the elbow flexors of each arm. Subjects completed a standard warm-up procedure (5 - 8 repetitions at approximately 50% of estimated 1-RM following by and 2– 3 repetitions at approximately 70% of estimated 1-RM with 1 minute rest period between attempts). Following 1 minute rest period, the subjects began the 1-RM procedure. Weight was incrementally increased until the maximum weight that can be lifted in one repetition with correct form was reached. The 1-RM values were achieved within 5 attempts with one minute rest periods between each attempt.

Outcome Testing

After finishing the initial screening and familiarization session, pre-training testing ((PRE 1) height, body mass, muscle thickness, forearm blood flow, pulse wave velocity, 1 RM, and isometric strength tests) was completed. A second pre-training

(PRE 2) session took place at least 48 hours after the PRE 1, but before the end of 10 days to assess measurement reliability. Then, following eight weeks of training, post-training testing (POST) completed the data collection process.

Body Mass and Height

A digital scale (Tanita BWB-800, Tanita Corporation of America, Inc., Arlington Heights, IL) was utilized for determining subject's body mass, and a wall stadiometer (PAT #290237, Novel Products, Rockton, IL, USA) was used for measuring subject's height, and then body mass index (BMI (kg/m^2)) will be calculated: weight (kg) divided by height (m^2).

Muscle Thickness (MTH)

Subjects stood with their arms fully extended downward at their side and relaxed. MTH sites at the anterior surface of 50%, 60% and 70% sites between the medial acromion process of the scapula and the lateral epicondyle of the humerus for both arms were marked and then MTH was determined by a B-mode ultrasound (UF-750XT, Fukuda Denshi, Tokyo, Japan) and a 5 MHz linear probe. Transmission gel was placed on the probe and this probe was located on the marked skin surfaces, perpendicular to the long axis of the muscle, and 3 scans were taken at each marked site. Both arms were assessed.

Upper Arm Circumference

While the subject was standing with their arms hanging downward at their side and relaxed, a tape measure was applied to measure upper arm circumference at 50%, 60% and 70% sites between the medial acromion process of the scapula and the lateral epicondyle of the humerus in both arms (nearest 0.1 cm). Both arms were assessed.

Brachial Blood Pressure

After measuring body mass and height, subjects laid down on a plynth in a supine position for 10 minutes of rest. An automatic blood pressure cuff (Model HEM-773, Omron®, Shelton, CT) was utilized for determining brachial blood pressure following the rest period. This was measured two times and the values were averaged.

Pulse Wave Velocity (PWV)

Peripheral arterial stiffness was determined by measuring carotid and radial pulse wave velocity for both arms. A tape measure was applied to measure the distances (nearest 0.1 cm) between the carotid artery pulse and sternal notch (Dis 1) and between the sternal notch and radial artery pulse (Dis 2) and then subtract Dis 1from Dis 2. The value was entered into the PWV program. Electrocardiography (ECG) sites were marked at lateral sites below the right and left clavicles and below the left rib cage, and then electrode placement sites were prepared. The hair around the ECG sites were shaved by a razor, and cleaned with an alcohol prep pad. A pen shaped high fidelity strain-gauge transducer (SphygmoCor, AtCorMedical, Sydney, Australia) was used for determining pulse waveforms at the marked carotid artery and then the radial artery. At the same time, ECG was recorded to obtain the electrical signal of heart contractions and used as a timing marker. The same procedure was used on both arms. In the analyzing program, the distance between the carotid and radial pulses and the recording of the time delay between the proximal (carotid) and distal (radial) waveforms relative to the peak of the R-wave recorded from the ECG was utilized for calculating pulse wave velocity and it was expressed as meters per second (m/s).

Forearm Blood Flow

The forearm was placed on a foam pad (10-15 cm above heart level) and a blood pressure cuff will be placed on the wrist (11 x 85 cm) and on the upper arm (13 x 85 cm). A mercury-filled strain gauge (3 - 4 cm smaller than the largest circumference) was placed at the largest circumference site of forearm. The blood pressure cuff on the wrist was inflated to 200 mmHg for 1 minute, and then the blood pressure cuff on the upper arm was inflated to 50 mmHg for 7 seconds and then deflated for 8 seconds. Six measurements were obtained and averaged by using the Noninvasive Vascular Program (NIVP3, D.E. Hokanson Inc., Bellevue, WA). Both arms were assessed.

One-Repetition Maximum (1-RM)

A dumbbell with microloading plates (Platemate, Boothbay Harbor, ME) was used for measuring 1-RM testing. The 1-RM testing was performed to determine the maximum strength for the elbow flexors of each arm. Subjects completed a standard warm-up procedure (5 - 8 repetitions at approximately 50% of estimated 1-RM following by and 2– 3 repetitions at approximately 70% of estimated 1-RM with 1 minute rest period between attempts). Following 1 minute rest period, the subjects began the 1-RM procedure. Weight was incrementally increased until the maximum weight that can be lifted in one repetition with correct form was reached. The 1-RM values were achieved within 5 attempts with one minute rest periods between each attempt. During training period, the 1-RM testing was re-assessed by every two weeks in order to adjust the subject’s workload.

Maximal Isometric Voluntary Contraction (MVC)

Subjects were seated on an isokinetic dynamometer (Biodex System 3, Biodex Medical System, Shirley, NY) and one arm was immobilized at a 90 degree angle perpendicular to the floor. The arm performed isometric elbow flexion against the lever arm of the isokinetic dynamometer for 3 seconds to measure the highest torque. Three submaximal contractions (3 seconds with 30 seconds rest period between attempts, at approximately 30%, 50%, and 70% of maximal efforts) were performed as a warm up followed by two maximal contractions (3 seconds with 30 seconds rest period between attempts). The subject's arm was then moved to a 120 degree angle, and two additional maximal contractions (3 seconds with 30 seconds rest period between attempts) were completed. The same procedures were completed by the other arm. The highest isometric MVC peak torque value for each arm was used in further analysis.

Electromyography (EMG)

During the initial testing, surface EMG sites were marked at 33% of the biceps brachii (BB) in both arms and the 7th cervical vertebrae of the neck. In the preparing electrode placement, the hair around the EMG sites were shaved by a razor, abraded to remove dead skin, and cleaned with an alcohol prep pad. Subsequently, bipolar electrodes (inter electrode distance of 2 cm, Instatrace ECG Electrode, ConMed, Utica, NY) were affixed at the 33% site of BB on both arms, and an electrode was affixed on the 7th cervical vertebrae as a reference. EMG signals were recorded from the 33% site of BB during the MVC testing and both arms were assessed. An EMG amplifier (EMG100C, Biopac system Inc., Goleta, CA) obtained the EMG signals. The signals were filtered (low-pass filter: 500 Hz and high-pass filter: 10 Hz), amplified (1000 times) and sampled at a rate of 2 KHz.

EMG Analysis

The EMG data were analyzed using computer software (Labview 7.1, National instrument corporation, Austin, TX). The collected EMG data included EMG amplitude (root mean square (RMS)) and mean power frequency (MPF).

Acute Response Testing

Acute response measurements (muscle thickness (MTH) and upper arm circumference, whole blood lactate (WBL), hematocrit (HCT), maximal voluntary contraction (MVC) and electromyography (EMG)) were obtained before (Acute PRE) and after one of the exercise protocols (Acute POST) in the first and second sessions of fourth week. The same measurements of MTH, upper arm circumference, and EMG as in the outcome testing were utilized. However, during the Acute POST testing period following the acute testing session, two MVC's at both 90 and 120 degree (similar to the outcome testing) were obtained without the initial warm-up period. Pre acute EMG data were used to normalize the post acute EMG data.

Whole Blood Lactate (WBL)

Fingertip blood lactate samples were obtained before and after exercise protocols. The subjects' finger was cleaned with an alcohol prep pad and Kimwipes, and the finger was pricked by a lance and then was lightly pressed to form a drop of blood. After removing the first drop of blood with the Kimwipes, a second drop of blood was made (approximately 0.7 µL by volume) for determining blood lactate. The blood lactate was measured by a lactate analyzer (Nova Biomedical Corporation, Waltham, MA).

Hematocrit (HCT)

Following blood lactate measurements, hematocrit was measured. Two capillary tubes were filled the blood from the fingertip. These capillary tubes were centrifuged with a CritSpin Microhematocrit Centrifuge (StatSpin, Norwood, MA) for 2 minutes, and read on a CritSpin Digital Reader (StatSpin, Norwood, MA).

Maximal Voluntary Contraction (MVC)

Subjects were seated on an isokinetic dynamometer (Biodex System 3, Biodex Medical System, Shirley, NY) and one arm was immobilized at a 90 degree angle perpendicular to the floor. The arm performed isometric elbow flexion against the lever arm of the isokinetic dynamometer for 3 seconds to measure the highest torque. Three submaximal contractions (3 seconds with 30 seconds rest period between attempts, at approximately 30%, 50%, and 70% of maximal efforts) were performed as a warm up followed by two maximal contractions (3 seconds with 30 seconds rest period between attempts). The subject's arm was then moved to a 120 degree angle, and two additional maximal contractions (3 seconds with 30 seconds rest period between attempts) were completed. After exercise protocol, the subject immediately completed two maximal contractions (3 seconds with 30 seconds rest period between attempts) at both 90 and 120 degree without three submaximal contractions (warm-up).

Electromyography (EMG)

During the initial testing, surface EMG sites were marked at 33% of the biceps brachii (BB) in both arms and the 7^{th} cervical vertebrae of the neck. In the preparing electrode placement, the hair around the EMG sites were shaved by a razor, abraded to remove dead skin, and cleaned with an alcohol prep pad. Subsequently, bipolar electrodes (inter electrode distance of 2 cm, Instatrace ECG Electrode, ConMed, Utica, NY) were affixed at the 33% site of BB on tested arms, and an electrode was affixed on the 7^{th} cervical vertebrae as a reference. EMG signals were recorded from the 33% site of BB during the MVC testing. An EMG amplifier (EMG100C, Biopac system Inc., Goleta, CA) obtained the EMG signals. The signals were filtered (low-pass filter: 500 Hz and high-pass filter: 10 Hz), amplified (1000 times) and sampled at a rate of 2 KHz.

EMG Analysis

The EMG data were analyzed using computer software (Labview 7.1, National instrument corporation, Austin, TX). The collected EMG data included EMG amplitude (root mean Square (RMS)) and mean power frequency (MPF). The values were normalized for analysis.

Statistical Analysis

Means and standard deviations were reported for each dependent variable. In the control group, both arms were measured to compare with the two training groups. Baseline comparisons between the three protocols (HI, LI-BFR and CON) for each variable were evaluated by an one-way analysis of variance (ANOVA). If differences were detected, analysis of covariance (ANCOVA) was utilized in further data analyses. In the training testing, time-points comparisons between the PRE 1 and PRE 2 for each variable were evaluated by a paired t-test. If there was no significant difference between PRE1 and PRE2, each variable was averaged (PRE) for further analysis. Between protocol comparisons over time were made by a two-way (protocols: HI, LI-BFR, and

CON) × time (PRE and POST test) repeated measures ANOVA. If there are any significant differences between protocols, a Bonferroni post-hoc test was used.

In the acute response testing, between protocol comparisons over time was made by a two-way (conditions: HI and LI-BFR) × time (acute pre and acute post test) repeated measures ANOVA.

In addition, the minimal difference (MD, formula = SEM $\times 1.96 \times \sqrt{2}$) was calculated from the standard error of measurement (SEM, formula = $SD\sqrt{1-ICC}$ and the $ICC_{3,1}$, intraclass correlations coefficient) to reduce systemic error and $ICC_{3,1}$ (model 3; a fixed-effect model) was used due to only considers random error whereas model 2 (random-effects model) considers both systemic and random error (91). Also, % coefficient of variation (%CV) was calculated using the formula; [(pooled SD of PRE1 and PRE2 /pooled mean of PRE1 and PRE2) $\times 100$].

The data were analyzed by SPSS 18.0 (SPSS Inc., Chicago, IL). The level of significance was set at $p < 0.05$. Effect size (ES) were calculated by subtracting the mean of pre-test from the mean of post-test and then dividing by standard deviation of pre-test (SD) (74).

Chapter IV: Results and Discussion

Purpose of the Study

The purpose of this study was to compare the skeletal muscle (arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) and vascular responses (forearm blood flow and peripheral arterial stiffness) following eight weeks of unilateral elbow flexor resistance exercise with a traditional high-load without BFR program and a low-load with BFR program (50% of arterial blood flow occlusion) in untrained college-aged males.

A secondary purpose of this study was to compare the acute skeletal muscle responses (muscle thickness, muscle activity, isometric strength, hematocrit and blood lactate) between traditional high-load and low-load with BFR unilateral elbow flexor resistance exercise in college-aged males.

Participant Characteristics

A total of eighteen physically inactive males (age range: 18 – 33 years old) participated in this study, but four participants did not complete the study due to their personal schedules. Three subjects were withdrawal before groups were assigned and one subject in the control group was withdrawal after the PRE2 test. Thus only fourteen participants completed all of testing and training sessions. The description of the baseline participant characteristics is shown in Table 1. At baseline, there were no significant differences between groups. Results are expressed as means ± standard deviation (SD) for all variables. The description of exercise protocols is shown in Table 2.

Table 1. Participants Characteristics.

	Group		
Variables	Experimental (n = 9)	Control (n = 5)	*p* - value
Age (years)	21.8 ± 2.5	27.6 ± 6.4	0.071
Height (cm)	177.9 ± 7.1	175.2 ± 5.4	0.478
Weight (kg)	76.0 ± 9.3	73.7 ± 18.4	0.762
BMI (kg/m^2)	24.1 ± 3.2	23.8 ± 4.5	0.901

Values : mean ± SD; BMI, body mass index

Table 2. Exercise Protocols for Each Group.

	Group		
Variables	HI	LI-BFR	CON
Work load	75 % 1-RM	30 % 1-RM	None
Set #	3	4	None
Repetition #	10, 10, 10	30, 15, 15, 15	None
Cuff pressure (mmHg)	None	72.0 ± 10.9	None

RM, repetition maximum; AOP, arterial occlusion pressure

Pre-testing 1 to Pre-testing 2 Measurement Stability

Paired t-tests and Pearson correlation coefficients were used to compare values between pre-testing 1 (PRE1) and pre-testing 2(PRE2) for measurement reliability. Pearson *r* values were statistically significant except for forearm blood flow ($p = 0.051$) and the t-value (3.167) for pulse wave velocity indicated a significant mean difference ($p = 0.004$) which indicated that these values were somewhat inconsistent between PRE1 and PRE2. The description of measurement stability is shown in Table 3 and 4. PRE1 and PRE2 values were then averaged to compare with POST values.

Table 3. Measurement Stability

Variables	PRE1	PRE2	*r*	t	sig.
MTH at 50% (cm)	2.98 ± 0.54	2.98 ± 0.52	0.973	0.038	0.970
MTH at 60% (cm)	3.35 ± 0.50	3.31 ± 0.47	0.961	1.361	0.185
MTH at 70% (cm)	3.75 ± 0.49	3.74 ± 0.46	0.956	0.403	0.690
AC at 50% (cm)	30.96 ± 3.47	30.98 ± 3.49	0.995	-0.276	0.785
AC at 60% (cm)	30.09 ± 3.45	30.09 ± 3.50	0.993	-0.094	0.926
AC at 70% (cm)	28.93 ± 3.16	28.98 ± 3.20	0.993	-0.641	0.527
FAC (cm)	27.04 ± 1.83	27.13 ± 1.79	0.996	0.735	0.469
SBP (mmHg)	116.3 ± 7.3	115.9 ± 9.7	0.858	0.365	0.721
DBP (mmHg)	73.1 ± 8.8	72.2 ± 8.3	0.862	0.773	0.454
1-RM (kg)	15.10 ± 2.82	15.23 ± 2.79	0.978	-1.250	0.222
MVC 90 °(Nm)	44.72 ± 14.85	45.47 ± 15.79	0.964	-0.947	0.352
MVC 120 °(Nm)	54.33 ± 16.17	53.61 ± 13.14	0.891	0.509	0.615
EMG-RMS 90 °(mV)	706.5 ± 236.4	670.5 ± 255.8	0.668	0.946	0.352
EMG-MPF 90 °(Hz)	83.45 ± 14.90	81.60 ± 12.45	0.603	0.790	0.436
EMG-RMS 120 °(mV)	682.1 ± 255.8	683.5 ± 290.0	0.613	-0.031	0.976
EMG-MPF 120 °(Hz)	77.79 ± 11.10	77.07 ± 11.55	0.633	0.390	0.700
PWV (m/s)	7.82 ± 0.98	7.60 ± 0.92	0.921	3.167	0.004^{*}
FBF (ml/min/100ml)	2.33 ± 0.75	2.53 ± 0.53	0.372	-1.417	0.168

MTH, muscle thick ness; AC, arm circumference; FAC, forearm circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; 1-RM, one repetition maximum; MVC, maximal voluntary contraction; EMG-RMS; Electromyography-root mean square; EMG-MPF; Electromyography-mean power frequency; PWV, pulse wave velocity; FBF, forearm blood flow; $^{*}p < 0.05$ significant difference between PRE1 and PRE2

Table 4. Measurement Stability

Variables	$ICC_{3,1}$	SEM	MD	%CV
MTH at 50% (cm)	0.973	0.09	0.25	17.72
MTH at 60% (cm)	0.959	0.10	0.28	14.33
MTH at 70% (cm)	0.954	0.11	0.29	12.67
AC at 50% (cm)	0.995	0.25	0.68	11.14
AC at 60% (cm)	0.993	0.29	0.80	11.52
AC at 70% (cm)	0.993	0.27	0.74	10.93
FAC (cm)	0.996	0.12	0.32	6.62
SBP (mmHg)	0.822	3.06	8.49	7.26
DBP (mmHg)	0.860	3.28	9.08	11.51
1-RM (kg)	0.978	0.42	1.16	18.35
MVC 90 °(Nm)	0.963	2.86	7.91	33.68
MVC 120 °(Nm)	0.872	5.79	16.03	27.06
EMG-RMS 90 °(mV)	0.665	136.80	378.93	35.54
EMG-MPF 90 °(Hz)	0.594	9.49	26.30	16.52
EMG-RMS 120 °(mV)	0.608	160.14	443.60	39.68
EMG-MPF 120 °(Hz)	0.632	6.74	18.66	14.51
PWV (m/s)	0.919	0.28	0.77	12.27
FBF (ml/min/100ml)	0.351	0.61	1.68	26.99

ICC, intraclass correlation coefficient, SEM, standard error of measurement; MD, minimal difference; %CV, % coefficient of variation; SEM and MD, expressed units being measured

PRE and POST Assessments

Muscular Responses

At baseline, MTH at 50% (p = 0.888), 60% (p = 0.963) and 70% (p = 0.920) were not significantly different between groups. The description of the MTH at 50%, 60% and 70% at PRE and POST for each group is shown in Table 5.

For MTH at 50%, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.008) and time (p = 0.000) effects, but no group effect (p = 0.318). The Bonferroni post-hoc test showed the MTH at 50% in both HI (p = 0.000) and LI-BFR (p = 0.01) groups was significantly increased over time, but not in the CON group (p = 0.372), and there was no group difference at the POST (p = 0.175).

Table 5. MTH at 50%, 60%, and 70% at PRE and POST for Each Group

Variables	Group	PRE	POST	%Δ	ES
MTH at 50% (cm) $^{\S\S,\,**}$	HI (n=9)	3.03 ± 0.47	3.31 ± 0.44**	9.2	0.60
	LI-BFR (n=9)	3.00 ± 0.58	3.34 ± 0.48**	11.3	0.59
	CON (n=10)	2.91 ± 0.58	2.95 ± 0.55	1.4	0.07
MTH at 60% (cm) $^{\S,\,**}$	HI (n=9)	3.37 ± 0.42	3.59 ± 0.47*	6.5	0.52
	LI-BFR (n=9)	3.33 ± 0.44	3.56 ± 0.48*	6.9	0.52
	CON (n=10)	3.31 ± 0.60	3.27 ± 0.58	-1.2	-0.07
MTH at 70% (cm) $^{\S\S,\,**}$	HI (n=9)	3.79 ±0.41	4.09 ± 0.50*	7.9	0.73
	LI-BFR (n=9)	3.72 ± 0.46	3.99 ± 0.50*	7.3	0.59
	CON (n=10)	3.71 ± 0.47	3.66 ± 0.56	-1.3	-0.11

Values : mean ± SD; $^{*}p < 0.05$ time effect; $^{**}p < 0.01$time effect; $^{\S}p < 0.05$ group × time interaction effect; $^{\S\S}p < 0.01$ group × time interaction effect; MTH, muscle thickness

For MTH at 60%, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.016) and time (p = 0.002) effects, but no group effect (p = 0.663). The Bonferroni post-hoc test showed the MTH at 60% in both HI (p = 0.035) and LI-BFR (p = 0.02) groups was significantly increased over time, but not in the CON group (p = 0.344), and there was no group difference at the POST (p = 0.329).

For MTH at 70%, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.001) and time (p = 0.009) effects, but no group effect (p = 0.601). The Bonferroni post-hoc test showed the MTH at 70% in both HI (p = 0.013) and LI-BFR (p = 0.032) groups was significantly increased over time, but not in the CON group (p = 0.293), and there was no group difference at the POST (p = 0.184).

The magnitude of change for MTH at 50% in both HI and LI-BFR (0.28 and 0.34) groups was greater than MD (0.25) for MTH at 50% indicating a real change since it was greater than the expected normal variability associated with the measurement. The magnitude of change for MTH at 70% in HI group (0.29) was also greater than the MD (0.29) for MTH at 70% and statically similar to MTH at 70% in the LI-BFR group (0.27) even though the value was slightly below the MD. However, the magnitude of change for MTH at 60% in both HI and LI-BFR (0.22 and 0.23) groups was lower than the MD (0.28) for MTH at 50% and therefore may be only due to normal expected variability associated with the measurement.

The individual muscle thickness responses for the HI or LI-BFR group at 50%, 60%, and 70% are shown in Figure 2, 3, 4, 5, 6, and 7, respectively.

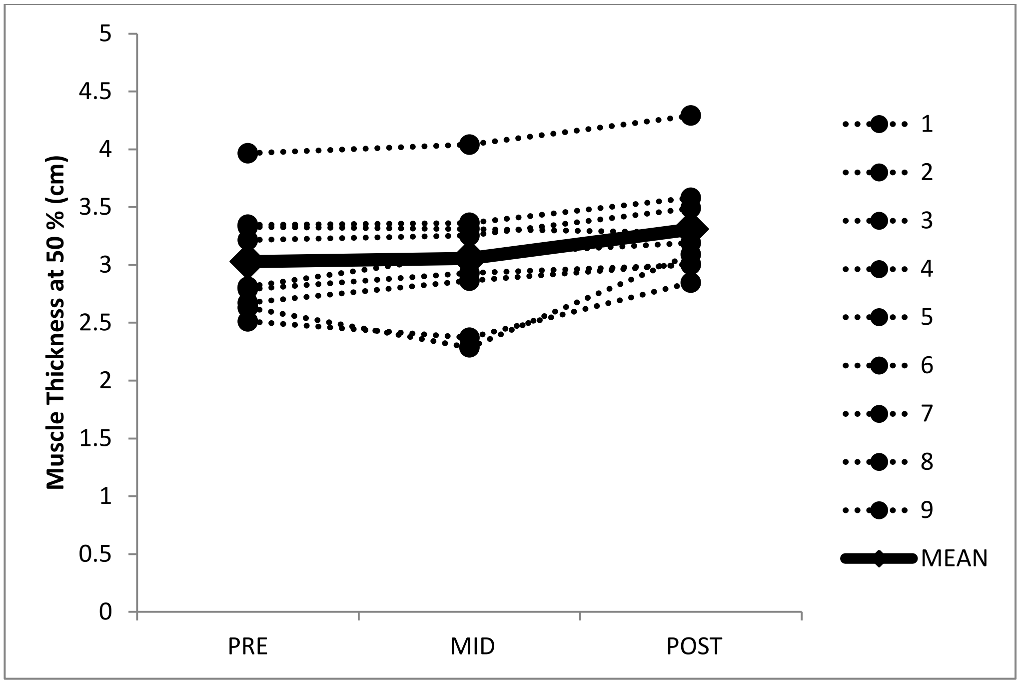

Figure 2. Individual Muscle Thickness Responses at 50% for the HI Group

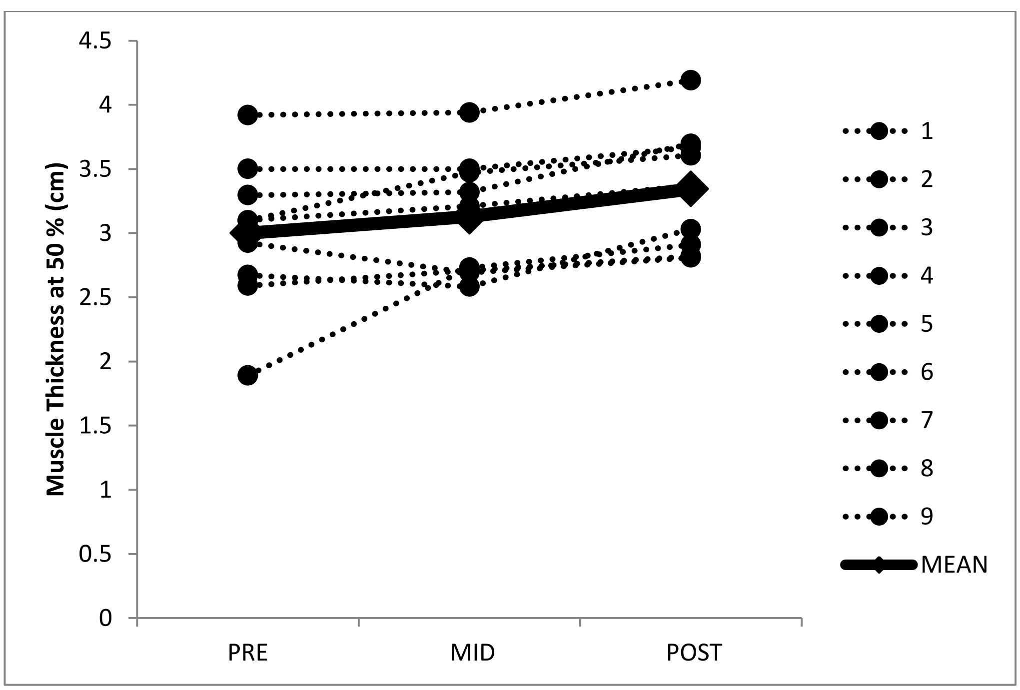

Figure 3. Individual Muscle Thickness Responses at 50% for the LI-BFR Group.

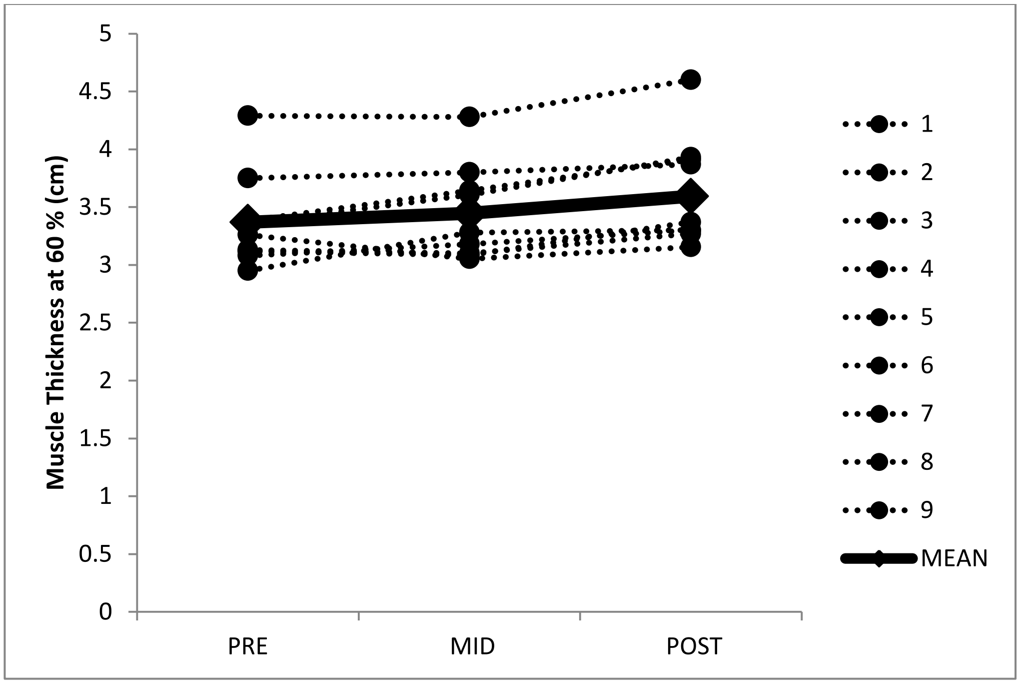

Figure 4. Individual Muscle Thickness Responses at 60% for the HI Group.

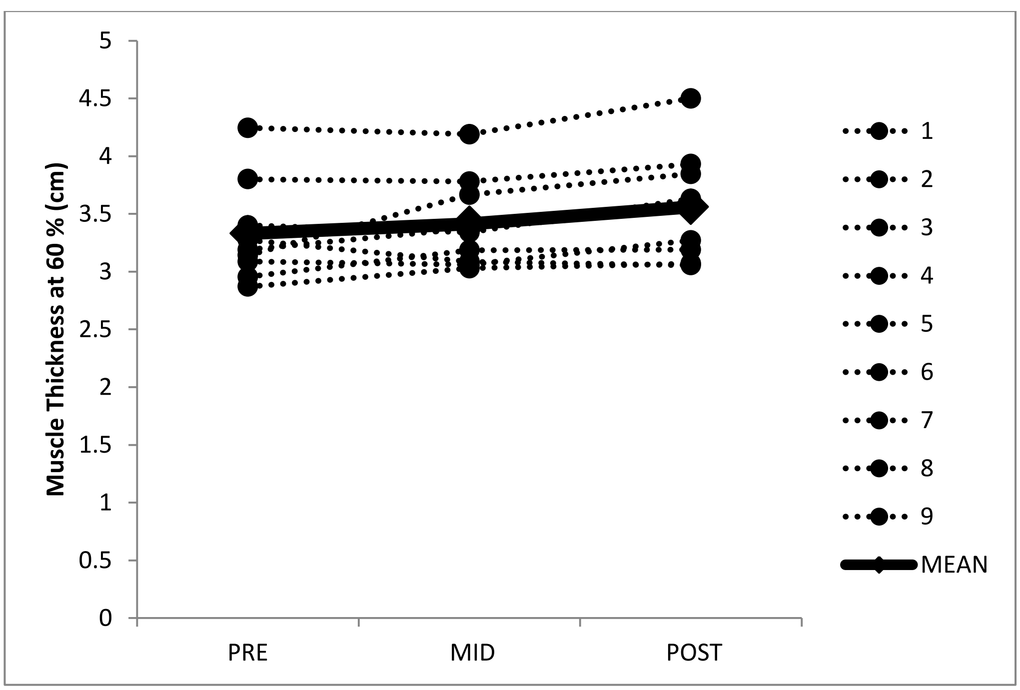

Figure 5. Individual Muscle Thickness Responses at 60% for the LI-BFR Group.

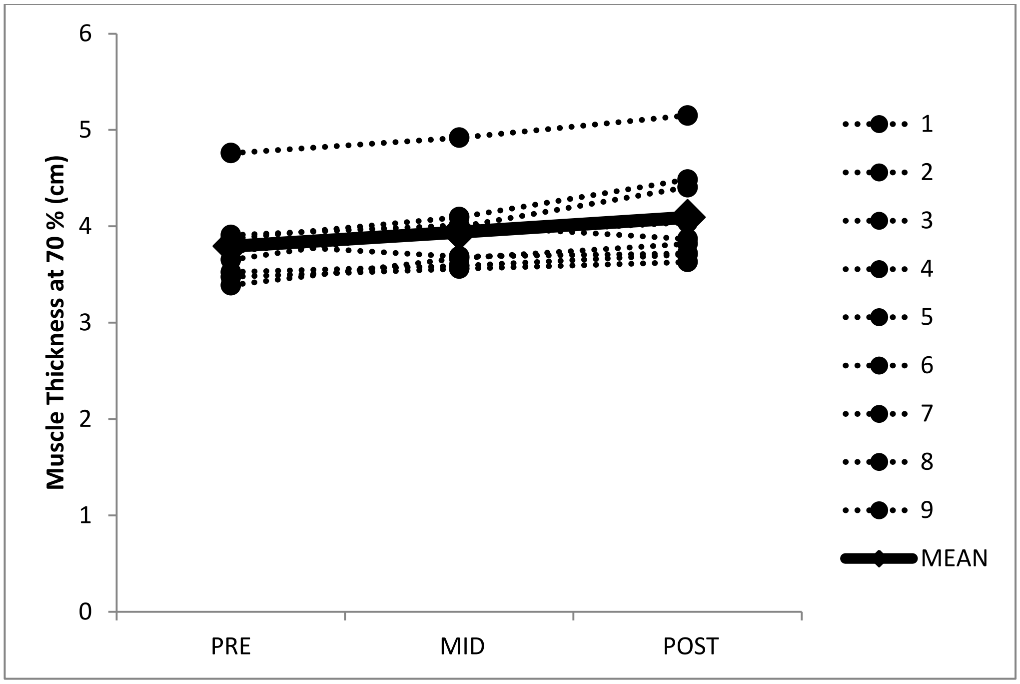

Figure 6. Individual Muscle Thickness Responses at 70% for the HI Group.

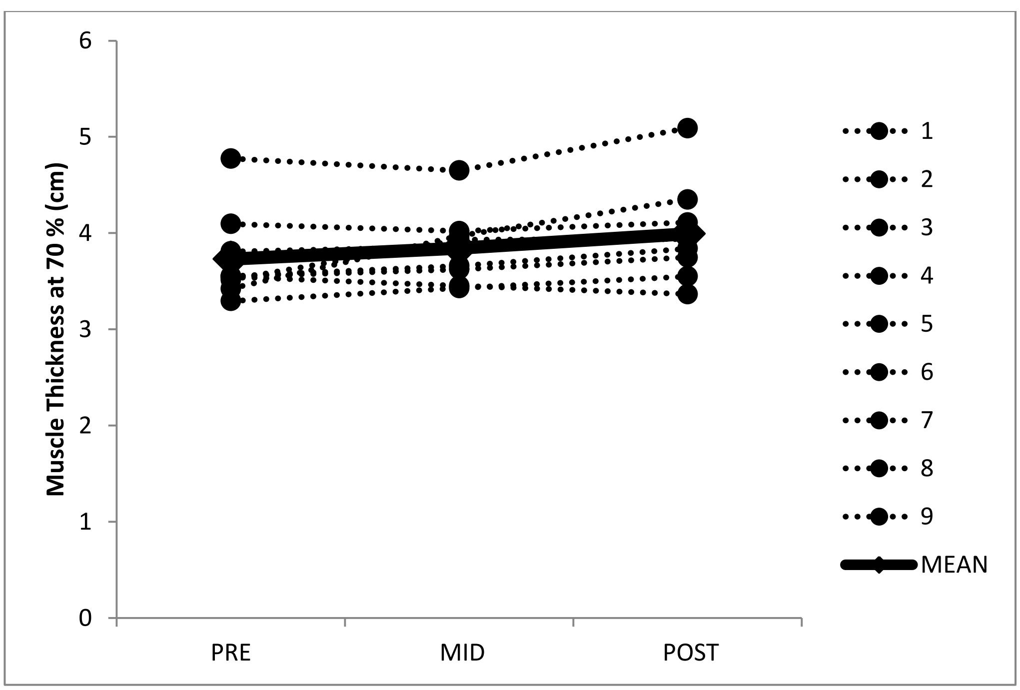

Figure 7. Individual Muscle Thickness Responses at 70% for the LI-BFR Group.

At baseline, AC at 50% (p = 0.496), 60% (p = 0.700) and 70% (p = 0.632) and FAC (p = 0.901) were not significantly different between groups. The description of the AC at 50%, 60% and 70% and FAC at PRE and POST for each group is shown in Table 6.

Table 6. AC at 50%, 60% and 70% and FAC at PRE and POST for Each Group.

Variables	Group	PRE	POST	%Δ	ES
AC at 50% (cm)$^{§§, **}$	HI (n=9)	31.59 ± 2.97	32.45 ± 2.61**	2.7	0.29
	LI-BFR (n=9)	31.53 ± 2.90	32.16 ± 2.85**	2.0	0.22
	CON (n=10)	29.90 ± 4.36	29.94 ± 4.35	0.1	0.01
AC at 60% (cm) $^{§§, **}$	HI (n=9)	30.47 ± 3.21	31.59 ± 2.76**	3.7	0.35
	LI-BFR (n=9)	30.56 ± 3.11	31.29 ± 2.76*	2.4	0.23
	CON (n=10)	29.33 ± 4.15	29.28 ± 4.06	-0.2	-0.01
AC at 70% (cm) $^{§§, **}$	HI (n=9)	29.34 ± 3.00	30.60 ± 2.73**	4.3	0.42
	LI-BFR (n=9)	29.46 ± 2.82	30.23 ± 2.41*	2.6	0.27
	CON (n=10)	28.16 ± 3.78	28.28 ± 3.71	0.4	0.03
FAC (cm) §§**	HI (n=9)	27.10 ± 1.91	27.54 ± 1.80**	1.6	0.23
	LI-BFR (n=9)	27.28 ± 1.33	27.63 ± 1.52*	1.3	0.26
	CON (n=10)	26.89 ± 2.21	26.83 ± 2.28	-0.2	-0.03

Values : mean ± SD; $^{*}p < 0.05$ time effect; $^{**}p < 0.01$time effect; $^{§§}p < 0.01$ group × time interaction effect; AC, arm circumference; FAC, forearm circumference

For AC at 50%, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.007) and time (p = 0.01) effects, but no group effect (p = 0.348). The Bonferroni post-hoc test showed the AC at 50% in both HI (p = 0.005) and LI-BFR (p = 0.01) groups was significantly increased over time, but not in the CON group (p = 0.725), and there was no group difference at the POST (p = 0.228).

For AC at 60%, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.001) and time (p = 0.000) effects, but no group effect (p = 0.470). The Bonferroni post-hoc test showed the AC at 60% in both HI (p = 0.001) and LI-BFR (p = 0.011) groups was significantly increased over time, but not in the CON group (p = 0.726), and there was no group difference at the POST (p = 0.264).

For AC at 70%, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.000) and time (p = 0.000) effects, but no group effect (p = 0.406). The Bonferroni post-hoc test showed the AC at 70% in both HI (p = 0.000) and LI-BFR (p = 0.019) groups was significantly increased over time, but not in the CON group (p = 0.091), and there was no group difference at the POST (p = 0.216).

For FAC, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.001) and time (p = 0.000) effects, but no group effect (p = 0.379). The Bonferroni post-hoc test showed the FAC in both HI (p = 0.000) and LI-BFR (p = 0.019) groups was significantly increased over time, but not in the CON group (p = 0.0379), and there was no group difference at the POST (p = 0.604).

The magnitude of change for AC at 50% and 60% in the HI group (0.86 and 1.12) was greater than the MD (0.68 and 0.80) for AC at 50% and 60% and statically similar to AC at 50% and 60% in the LI-BFR group (0.63 and 0.77), respectively, even though these values were slightly below the MD. The magnitude of change for AC at 70% and FAC in both HI (1.26 and 0.44) and LI-BFR (0.77 and 0.35) groups was greater than the MD (0.74 and 0.32) for AC at 70% and FAC, respectively, indicating a real change since it was greater than the expected normal variability associated with the measurement

The individual arm circumference responses for the HI or LI-BFR group at 50%, 60%, and 70% are shown in Figure 8, 9, 10, 11, 12, and 13, respectively.

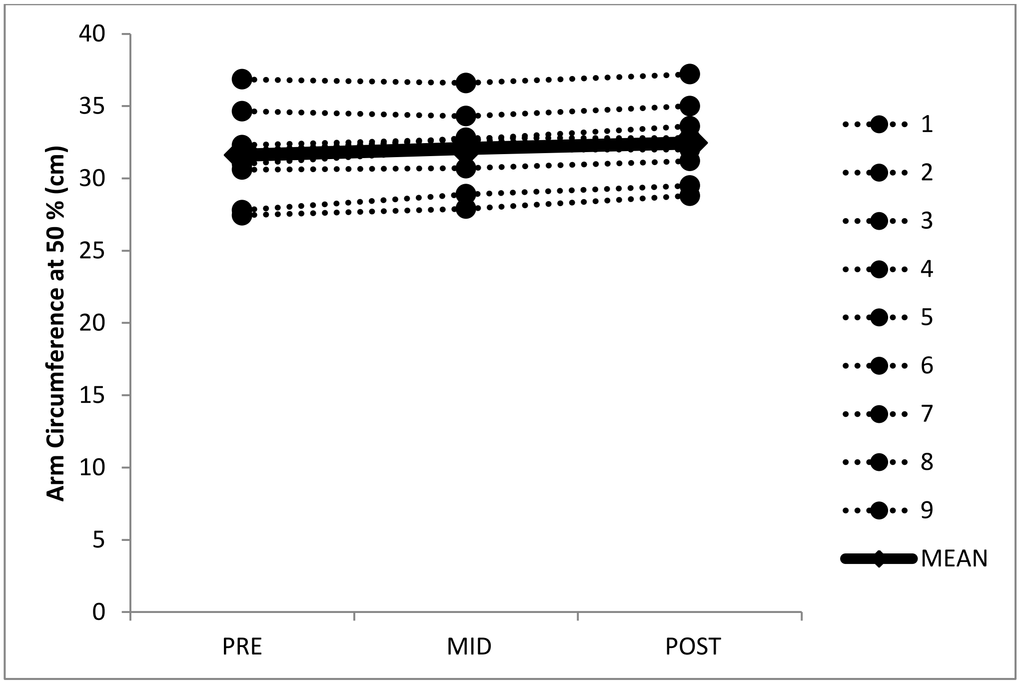

Figure 8. Individual Arm Circumference Responses at 50% for the HI Group.

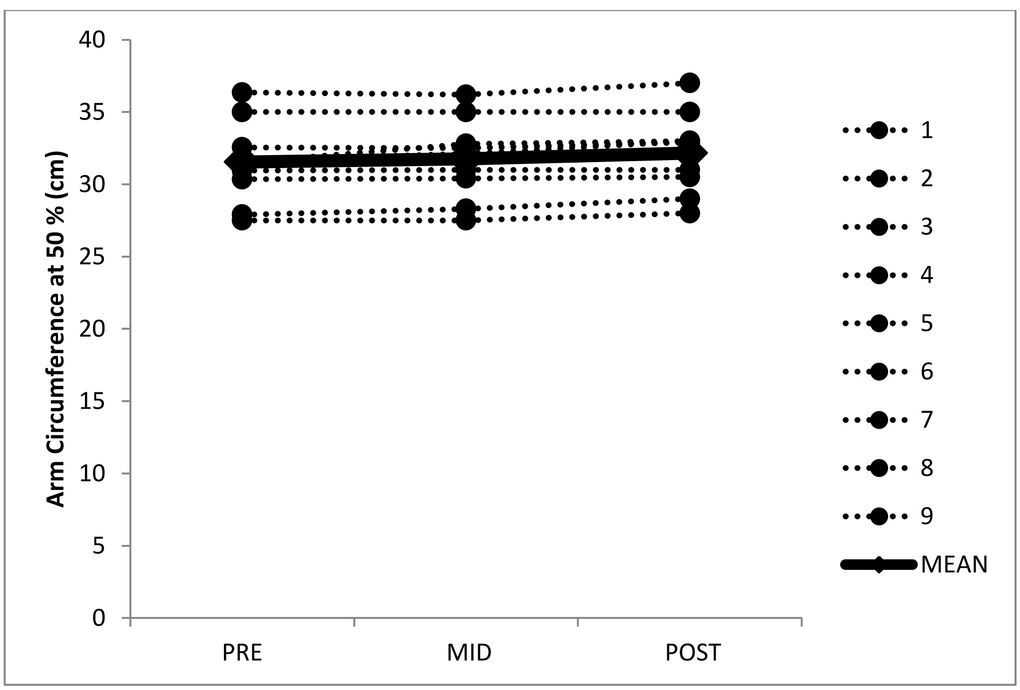

Figure 9. Individual Arm Circumference Responses at 50% for the LI-BFR Group.

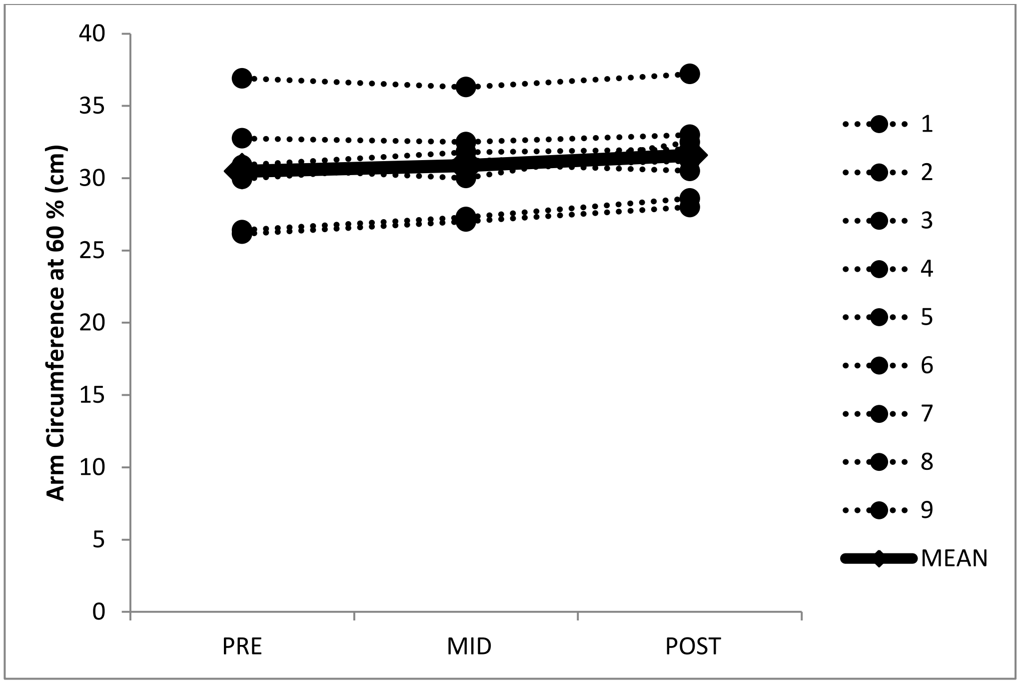

Figure 10. Individual Arm Circumference Responses at 60% for the HI Group.

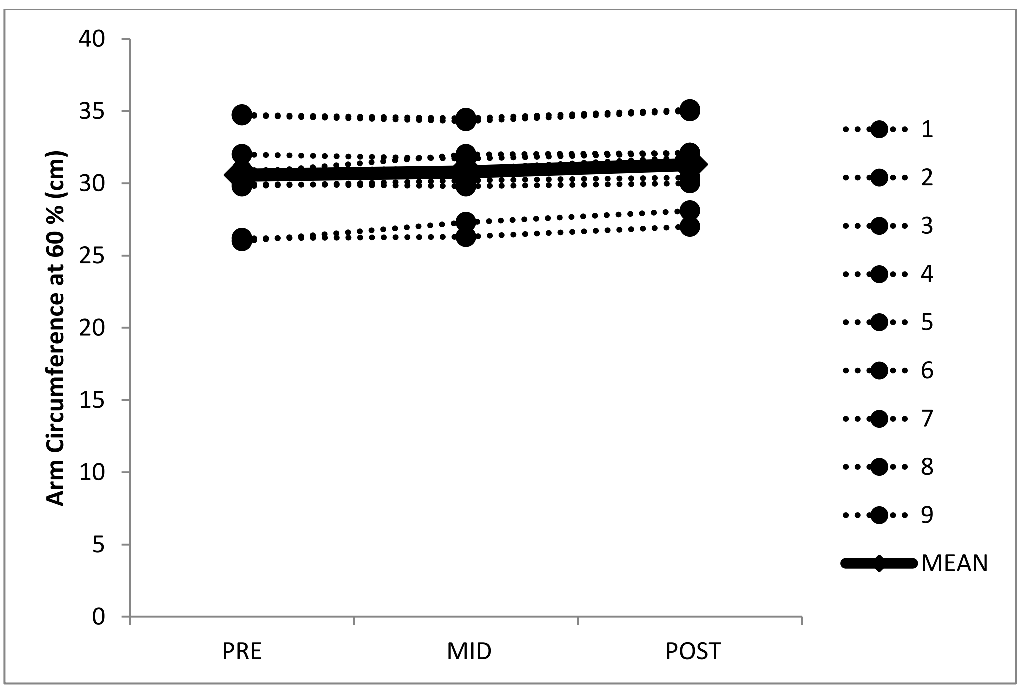

Figure 11. Individual Arm Circumference Responses at 60% for the LI-BFR Group.

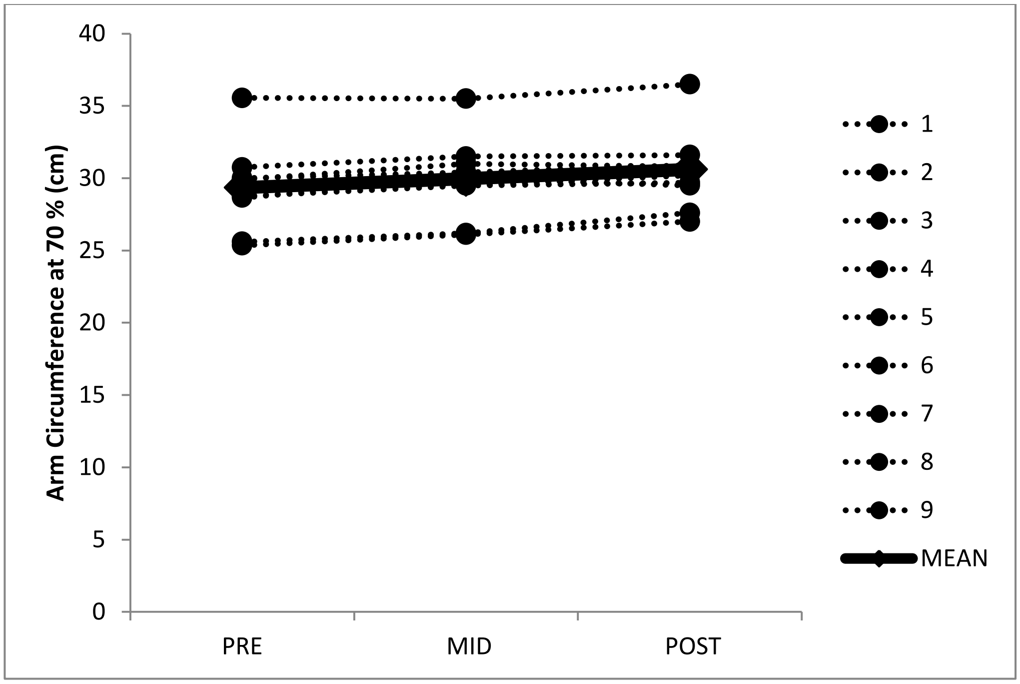

Figure 12. Individual Arm Circumference Responses at 70% for the HI Group.

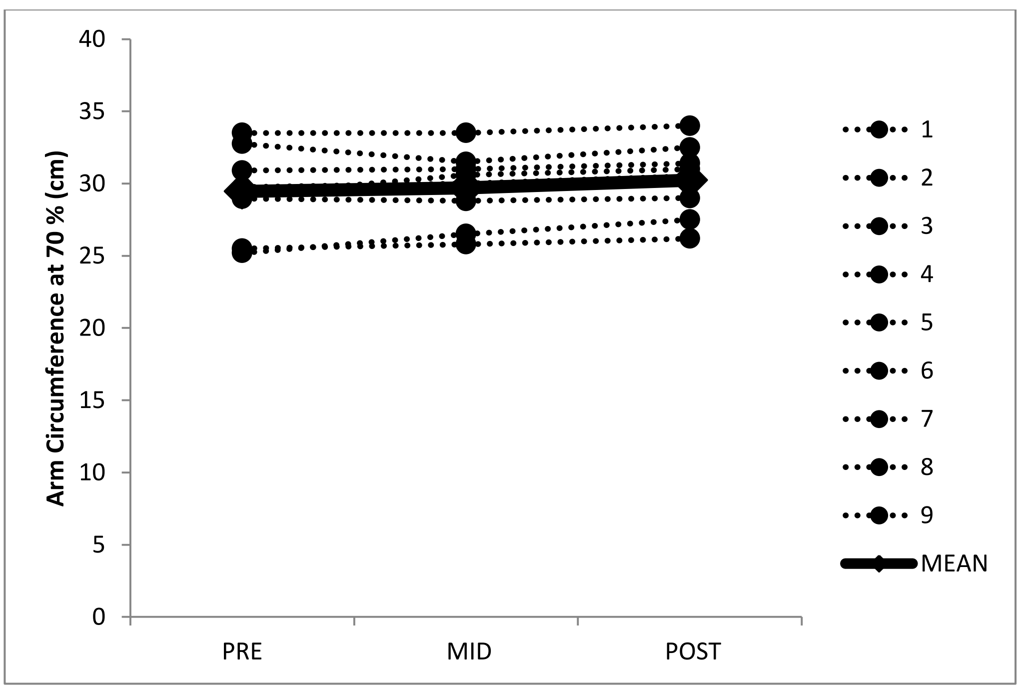

Figure 13. Individual Arm Circumference Responses at 70% for the LI-BFR Group.

At baseline, 1RM (p = 0.793), MVC 90 °(p = 0.914) and MVC 120 °(p = 0.588) were not significantly different between groups. The description of the 1RM, MVC 90 ° and MVC 120 °at PRE and POST for each group is shown in Table 7.

Table 7. 1-RM, MVC 90 °, and MVC 120 °at PRE and POST for Each Group.

Variables	Group	PRE	POST	%Δ	ES
1-RM (KG) §§, **, #	HI (n=9)	15.57 ± 2.85	19.33 ± 4.79**	24.1	1.32
	LI-BFR (n=9)	15.28 ± 2.75	17.67 ± 3.26**	15.6	0.87
	CON (n=10)	14.69 ± 3.00	14.26 ± 3.35	-2.9	-0.14
MVC 90 ° (Nm) §	HI (n=9)	45.61 ± 18.70	51.53 ± 13.07*	13.0	0.32
	LI-BFR (n=9)	46.40 ± 16.62	51.04 ± 18.54*	10.0	0.28
	CON (n=10)	43.46 ± 11.40	40.51 ± 9.02	-6.8	-0.26
MVC 120 ° (Nm) **	HI (n=9)	56.62 ±18.48	63.56 ± 17.12*	12.3	0.38
	LI-BFR (n=9)	55.53 ± 13.13	60.28 ± 18.21*	8.6	0.36
	CON (n=10)	50.19 ± 11.29	54.34 ± 11.92	8.6	0.37

Values : mean ± SD; *p < 0.05 time effect; **p < 0.01time effect; §p < 0.0 group × time interaction effect; §§p < 0.01 group × time interaction effect; #p < 0.05 group effect between HI and CON at the POST; 1-RM, one repetition maximum; MVC, maximal voluntary contraction

For 1-RM, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction (p = 0.000) and time (p = 0.000) effects, but no group effect (p = 0.156). The Bonferroni post-hoc test showed the 1-RM in both HI (p = 0.001) and LI-BFR (p = 0.000) groups was significantly increased over time, but not in the CON group (p = 0.062). There was significantly group different at the POST (p = 0.024). The HI group was significantly greater than the CON group at the POST (p =0.025), but there were no group differences between HI and LI-BFR groups and between LI-BFR and CON groups.

For MVC 90 °, results from the two-way repeated measures ANOVA indicated there was significant group × time interaction effect (p = 0.021), but not time (p = 0.067) and group (p = 0.470) effects. The Bonferroni post-hoc test showed the MVC 90 °in the

HI (p = 0.043) group was significantly increased over time, but not in both LI-BFR (p = 0.091) and CON group (p = 0.180), and there was no group difference at the POST (p = 0.166).

For MVC 120°, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.000), but no group × time interaction (p = 0.635) and group (p = 0.501) effects. The Bonferroni post-hoc test showed the MVC 120° in both HI (p = 0.011) and CON group (p = 0.036) was significantly increased over time, but not in and LI-BFR (p = 0.112) group, and there was no group difference at POST (p = 0.447).

The magnitude of change for 1-RM in both HI and LI-BFR (3.76 and 2.39) groups was greater than the MD (1.16) for 1-RM indicating a real change since it was greater than the expected normal variability associated with the measurement. However, the magnitude of change for MVC 90° and MVC 120° in both HI (5.92 and 6.94) and LI-BFR (4.64 and 4.75) groups was lower than the MD (7.91 and 16.03) for MVC 90° and MVC 120°, respectively, but were still significantly increased following training.

The 1-RM at PRE, Week 2, Week 4, Week 6 and POST in Both HI and LI-BFR is shown in Figure 14.

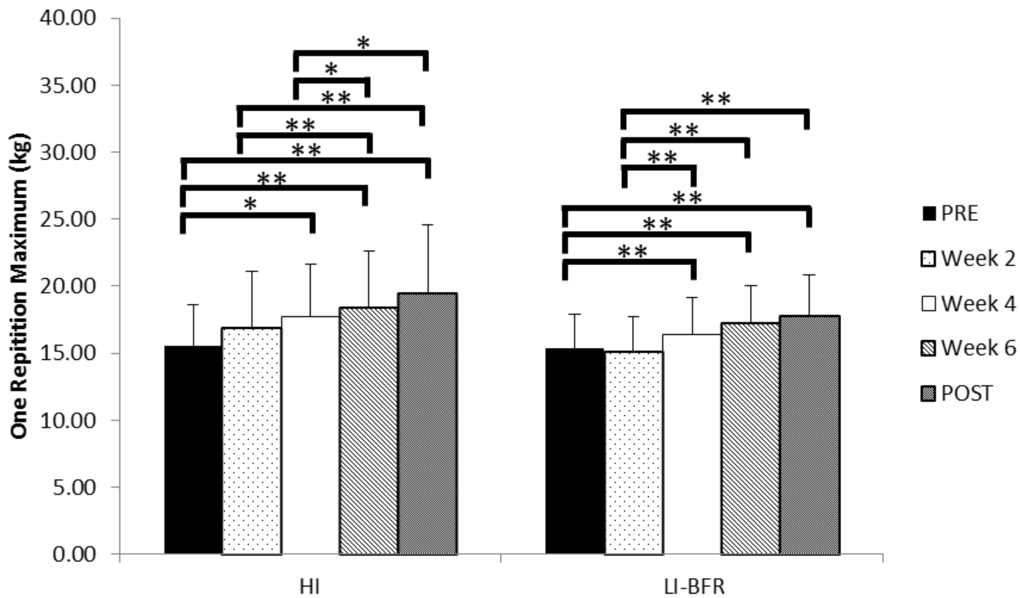

Figure 14. 1-RM at PRE, Week 2, Week 4, Week 6 and POST in Both HI and LI-BFR Groups.
*$p < 0.05$ time effect; **$p < 0.01$time effect

The individual 1-RM, MVC 90 °, and MVC 120 °responses for the HI or LI-BFR group are shown in Figure 15, 16, 17, 18, 19, and 20, respectively.

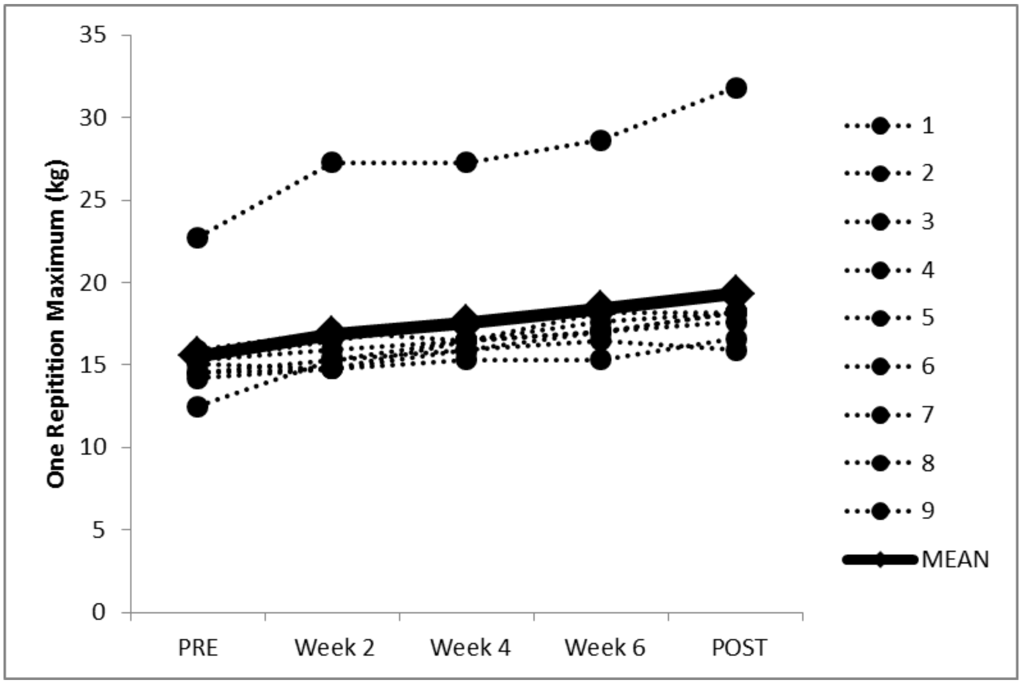

Figure 15. Individual 1-RM Responses for the HI Group.

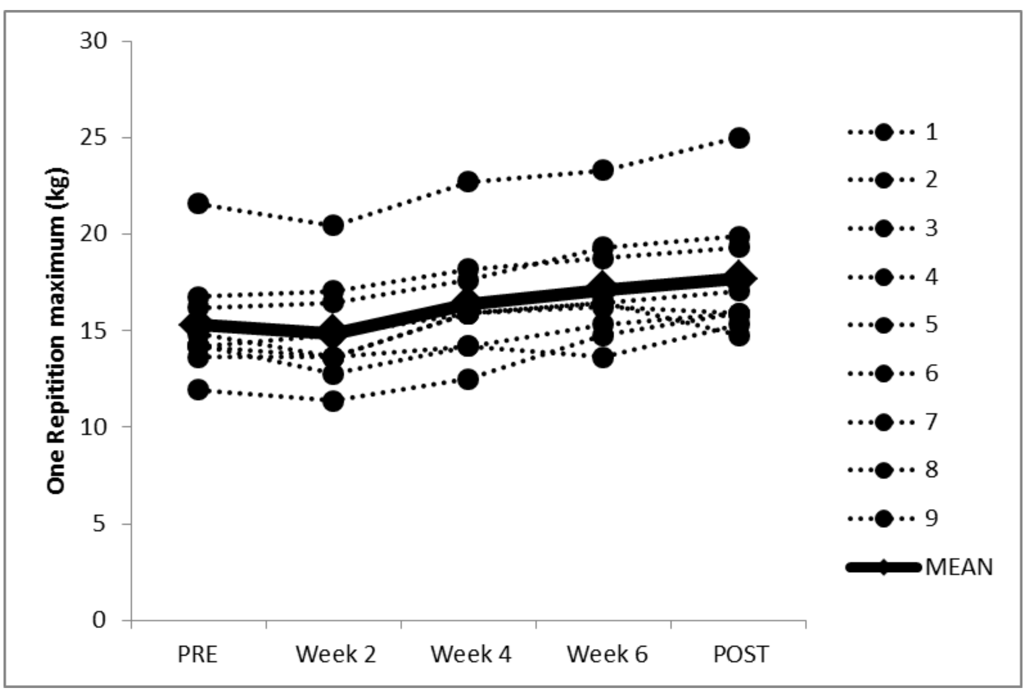

Figure 16. Individual 1-RM Responses for the LI-BFR Group.

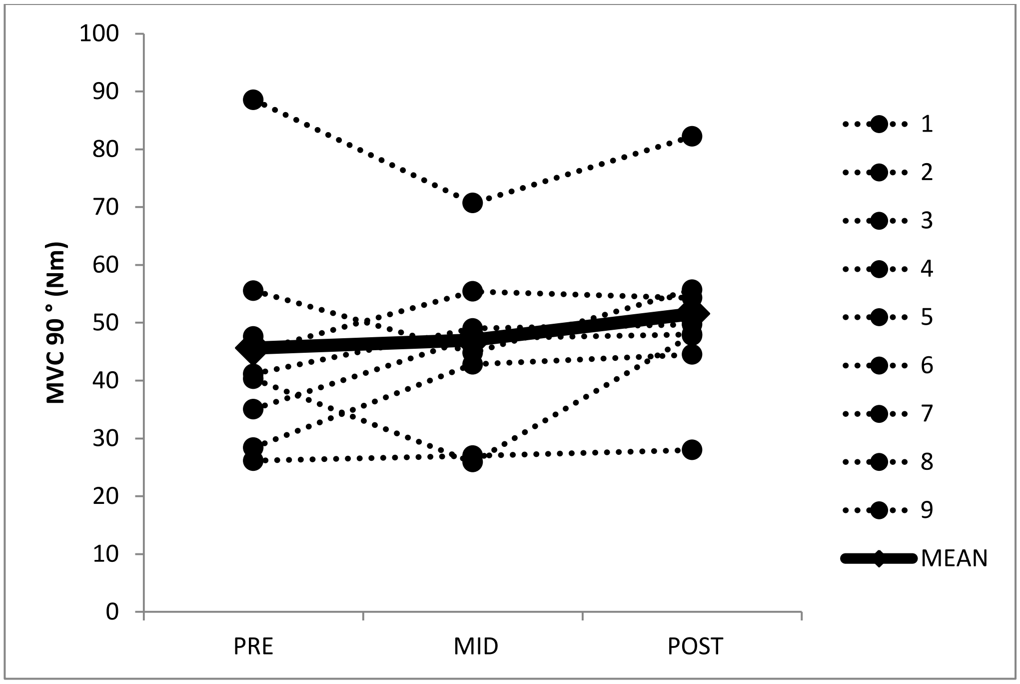

Figure 17. Individual MVC 90 °Responses for the HI Group.

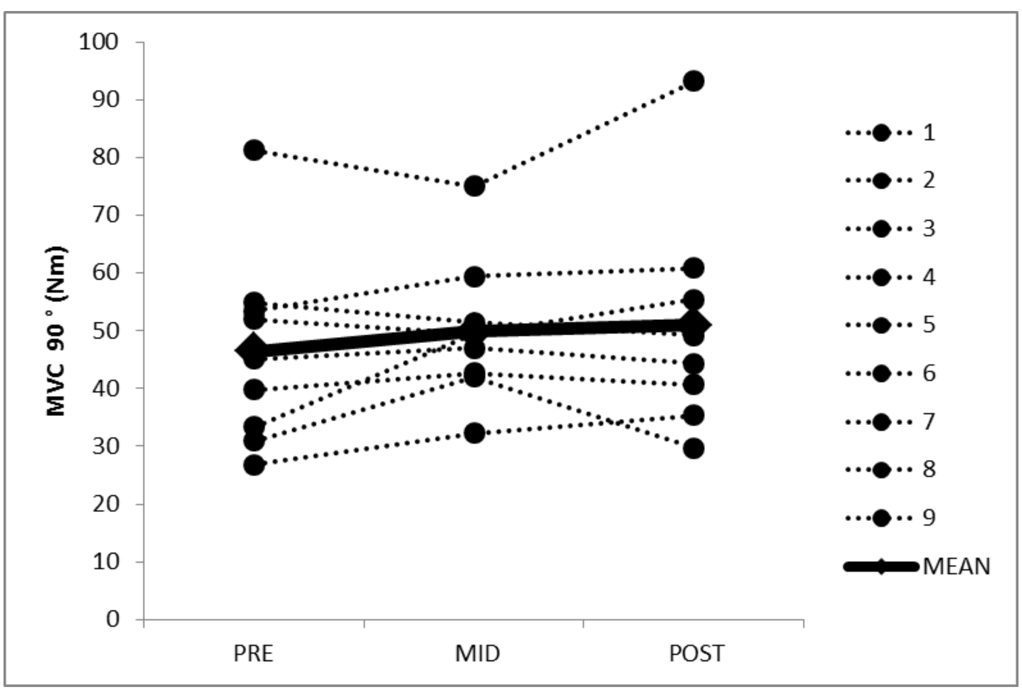

Figure 18. Individual MVC 90 °Responses for the LI-BFR Group.

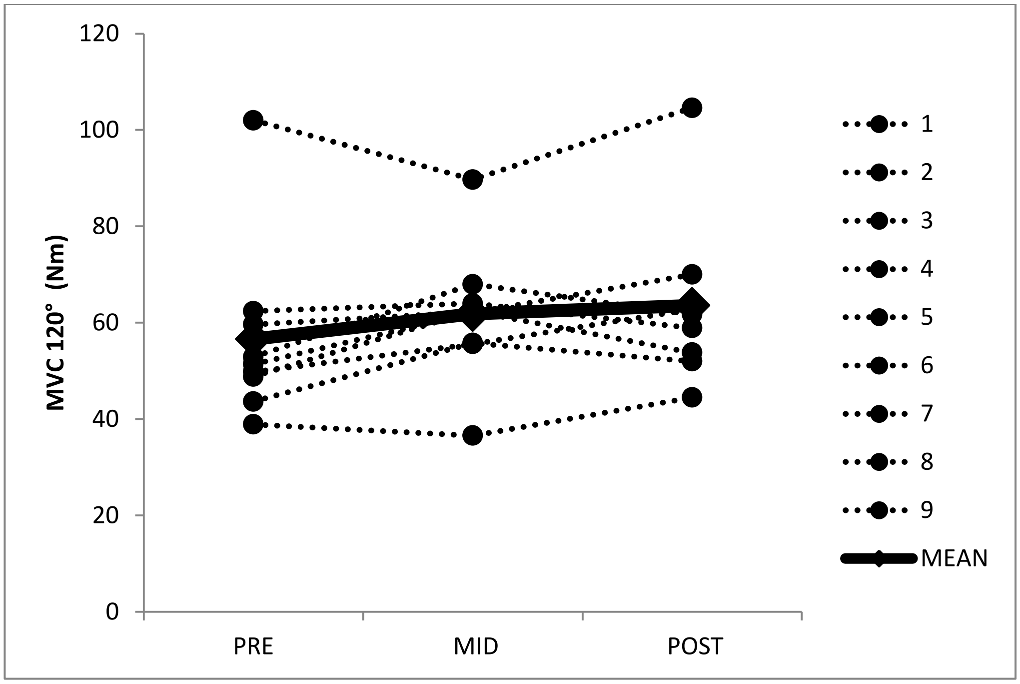

Figure 19. Individual MVC 120 °Responses for the HI Group.

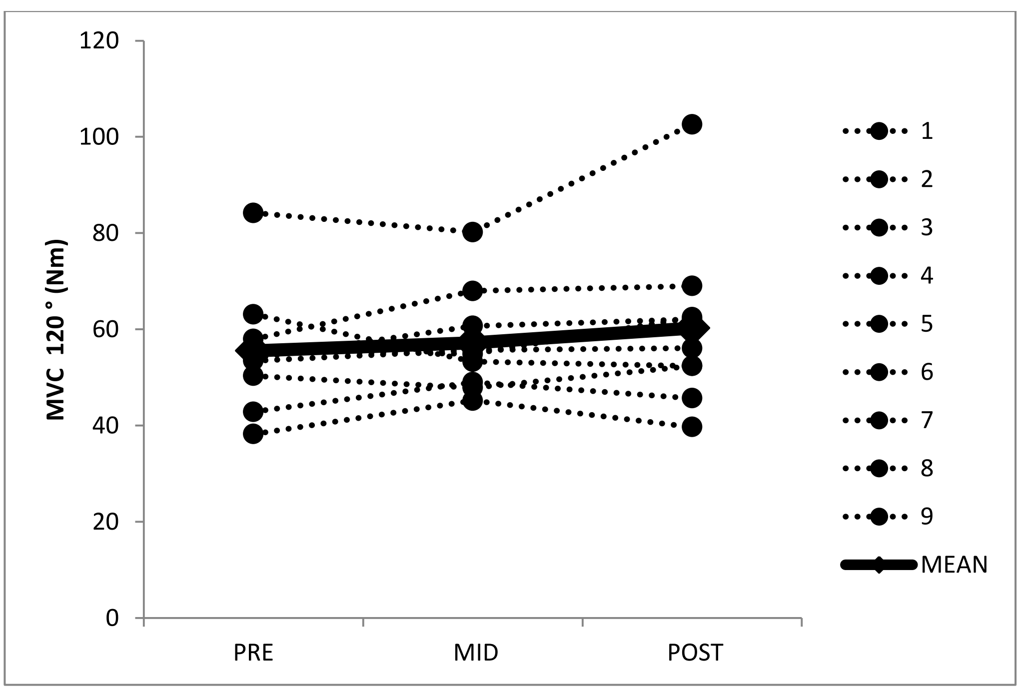

Figure 20. Individual MVC 120 °Responses for the LI-BFR Group.

Electromyography Responses

At baseline, EMG-RMS 90° ($p = 0.376$), EMG-MPF 90° ($p = 0.556$), EMG-RMS 120° ($p = 0.245$) and EMG-MPF 120° ($p = 0.359$) were not significantly different between groups. The description of the EMG-RMS and MPF 90° and 120° at PRE and POST for each group is shown in Table 8.

Table 8. EMG-RMS and MFP 90° and 120° responses at PRE and POST for Each Group.

Variables	Group	PRE	POST	%Δ	ES
EMG-RMS 90°	HI (n=9)	615.5 ± 201.1	781.5 ± 317.0	27.0	0.83
(mV)	LI-BFR (n=9)	766.3 ± 222.3	818.2 ± 274.5	6.8	0.23
	CON (n=10)	688.5 ± 245.4	663.9 ± 228.0	-3.6	-0.10
EMG-MPF 90°	HI (n=9)	84.98 ± 16.54	74.20 ± 5.30	-12.7	-0.65
(Hz) *	LI-BFR (n=9)	83.86 ± 12.47	79.44 ± 13.90	-5.3	-0.35
	CON (n=10)	79.12 ± 6.95	76.67 ± 5.29	-3.1	-0.35
EMG-RMS 120°	HI (n=9)	697.1 ± 189.8	788.0 ± 243.3	13.0	0.48
(mV)	LI-BFR (n=9)	775.7 ± 281.5	793.9 ± 191.4	2.3	0.06
	CON (n=10)	586.2 ± 242.2	590.0 ± 225.0	0.6	0.02
EMG-MPF 120°	HI (n=9)	80.58 ± 11.48	75.94 ± 11.33	-5.8	-0.40
(Hz)	LI-BFR (n=9)	78.24 ± 10.63	75.89 ± 11.89	-3.0	-0.22
	CON (n=10)	73.86 ± 8.49	72.97 ± 7.30	-1.2	-0.10

Values : mean ± SD; $^*p < 0.05$ time effect; EMG-RMS; Electromyography-root mean square; EMG-MPF; Electromyography-mean power frequency

For EMG-RMS 90°, results from the two-way repeated measures ANOVA indicated there was no significant time ($p = 0.155$), group × time interaction ($p = 0.250$) and group ($p = 0.486$) effects. The Bonferroni post-hoc test showed there was no time effect for the EMG-RMS 90° in the HI ($p = 0.147$), LI-BFR ($p = 0.465$) and CON ($p = 0.740$) groups, and there was no group difference at the POST ($p = 0.447$).

For EMG-MPF 90°, results from the two-way repeated measures ANOVA indicated there was significant time effect ($p = 0.011$), but no group × time interaction ($p = 0.271$) and group ($p = 0.389$) effects. The Bonferroni post-hoc test showed there was no time effect for the EMG-RMS 90° in the HI ($p = 0.067$), LI-BFR ($p = 0.241$)

and CON (p = 0.306) groups, and there was no group difference at the acute POST (p = 0.476).

For EMG-RMS 120°, results from the two-way repeated measures ANOVA indicated there was no significant time (p = 0.249), group × time interaction (p = 0.501) and group (p = 0.151) effects. The Bonferroni post-hoc test showed there was no time effect for the EMG-RMS 120° in the HI (p = 0.239), LI-BFR (p = 0.764) and CON (p = 0.911) groups, and there was no group difference at the POST (p = 0.090).

For EMG-MPF 120°, results from the two-way repeated measures ANOVA indicated there was no significant time (p = 0.213), group × time interaction (p = 0.755) and group (p = 0.455) effects. The Bonferroni post-hoc test showed there was no time effect for the EMG-MPF 120° in the HI (p = 0.304), LI-BFR (p = 0.516) and CON (p = 0.735) groups, and there was no group difference at the POST (p = 0.769).

The magnitude of change for MVC 90°-RMS, MVC 90°-MPF, MVC 120°-RMS and MVC 120°-MPF in both HI (166.0, -10.8, 90.9 and -4.6) and LI-BFR (51.9, -4.4, 18.2 and -2.4) was lower than the MD (378.9, 26.3, 443.6 and 18.7) for MVC 90°-RMS, MVC 90°-MPF, MVC 120°-RMS and MVC 120°-MPF, respectively, and may only represent normal expected variability associated with the measurement.

The individual EMG-RMS and MPF 90° and 120° responses for the HI or LI-BFR group are shown in Figure 21, 22, 23, 24, 25, 26, 27 and 28, respectively.

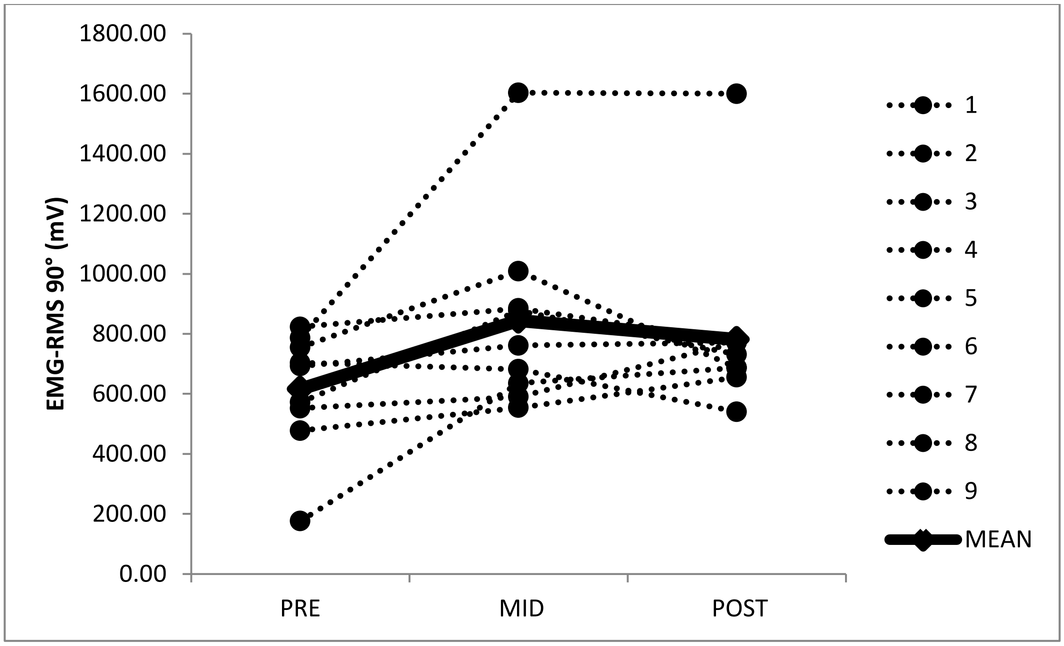

Figure 21. Individual EMG-RMS 90 °Responses for the HI Group.

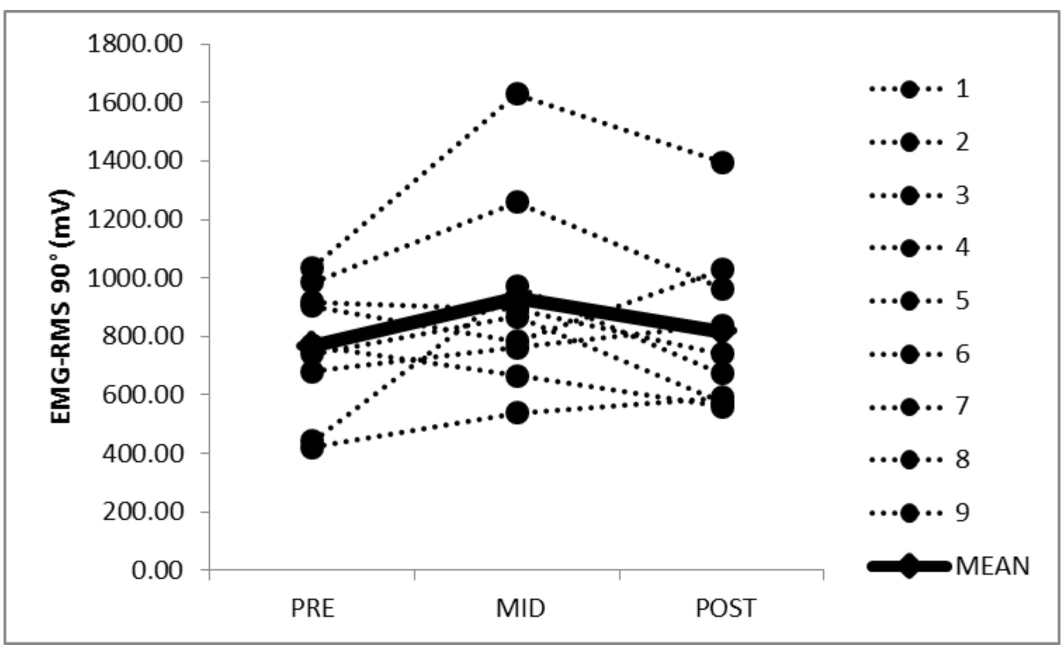

Figure 22. Individual EMG-RMS 90 °Responses for the LI-BFR Group.

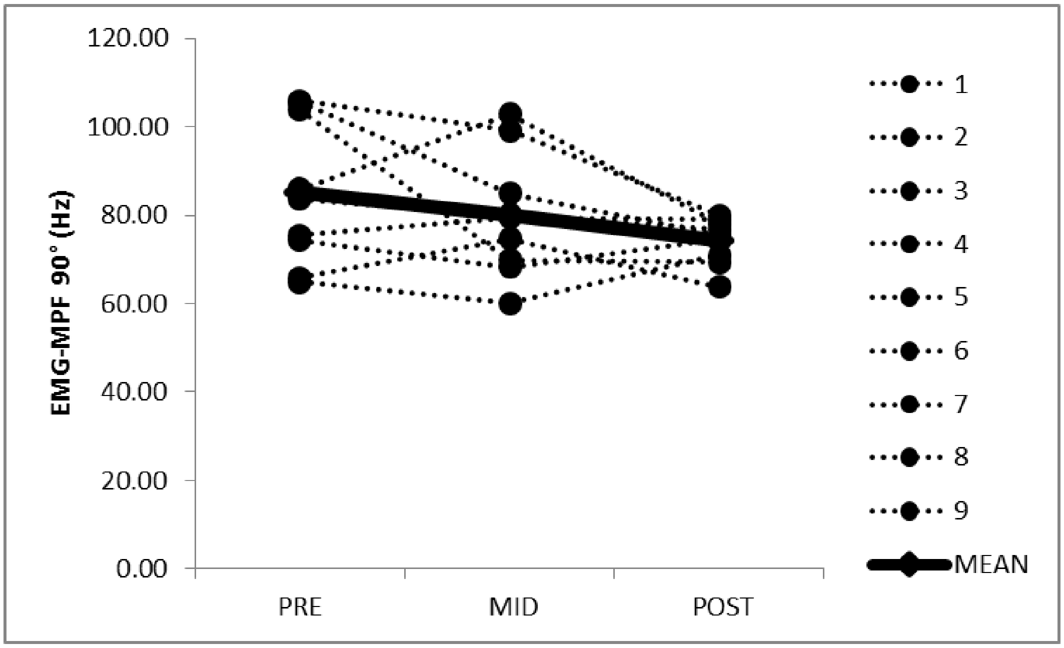

Figure 23. Individual EMG-MPF 90 °Responses for the HI Group.

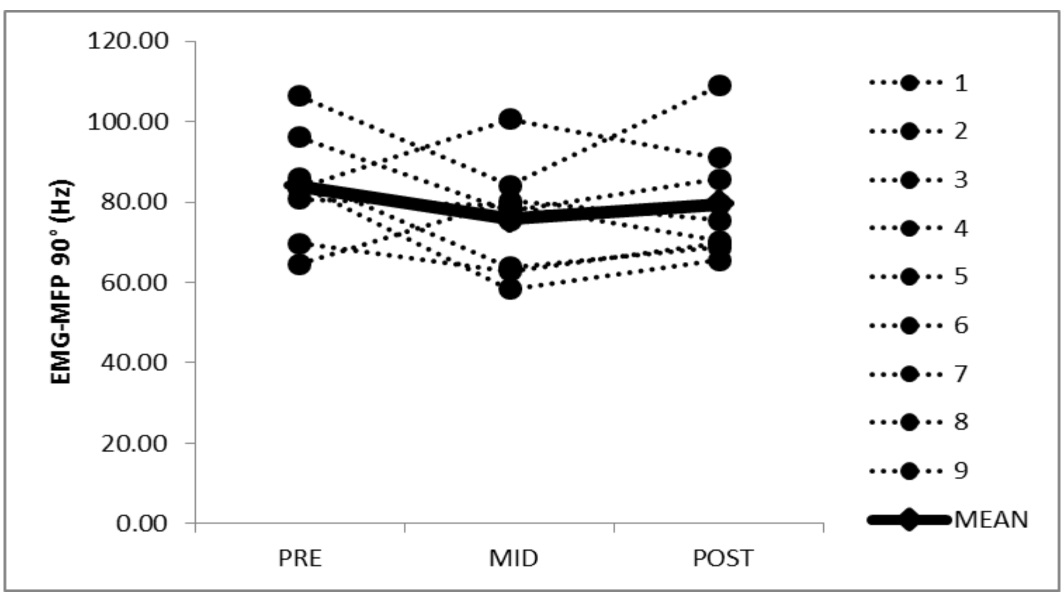

Figure 24. Individual EMG-RMS 90 °Responses for the LI-BFR Group.

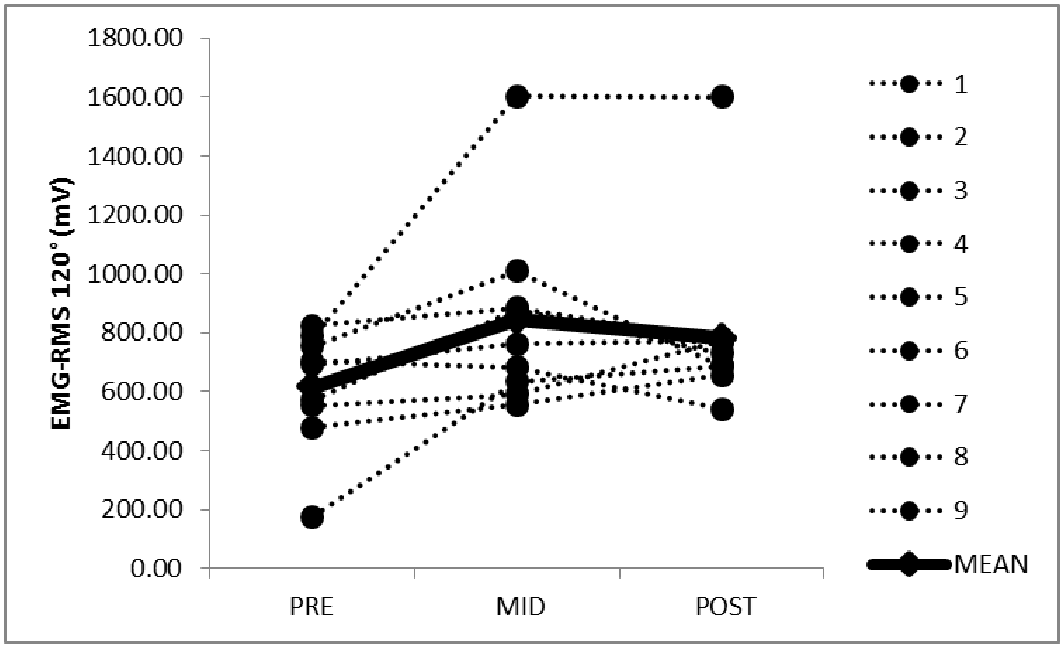

Figure 25. Individual EMG-RMS 1200 °Responses for the HI Group.

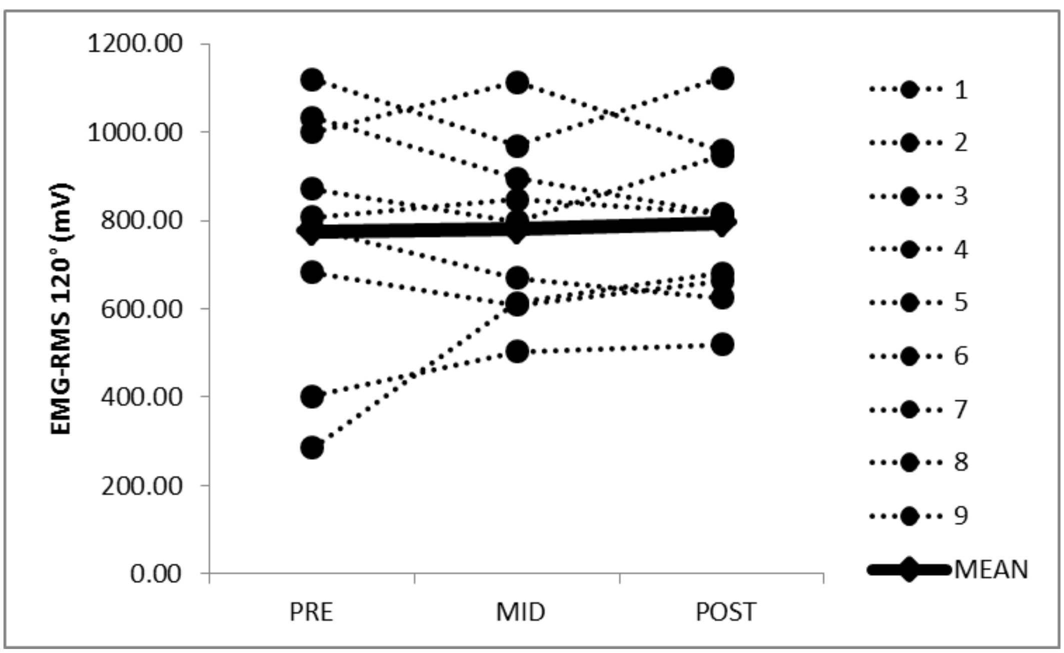

Figure 26. Individual EMG-RMS 90 °Responses for the LI-BFR Group.

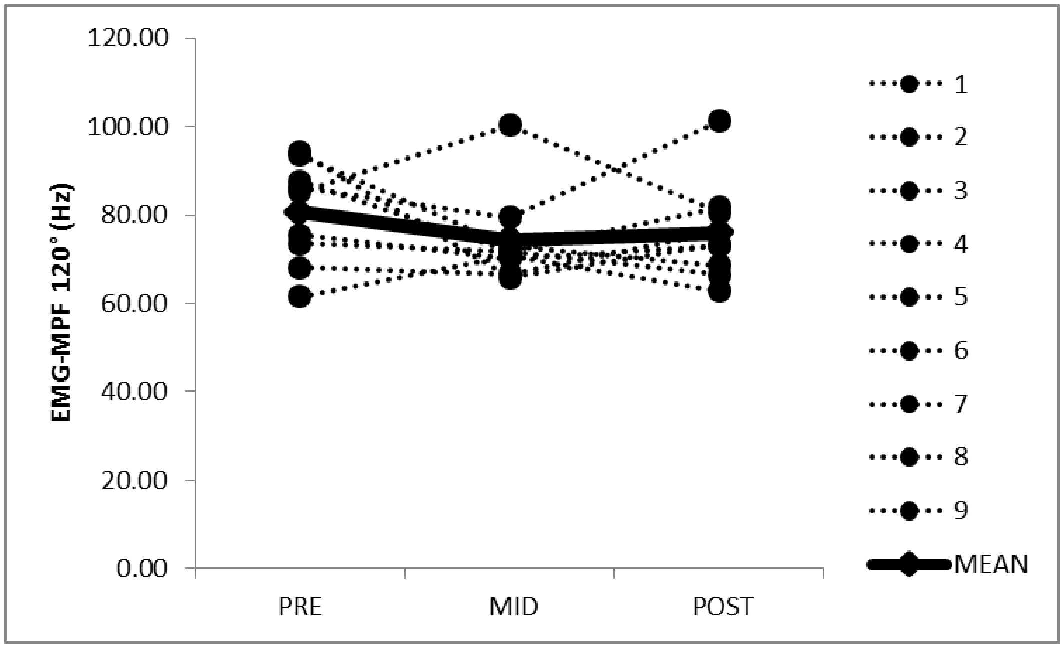

Figure 27. Individual EMG-MPF 120 °Responses for the HI Group.

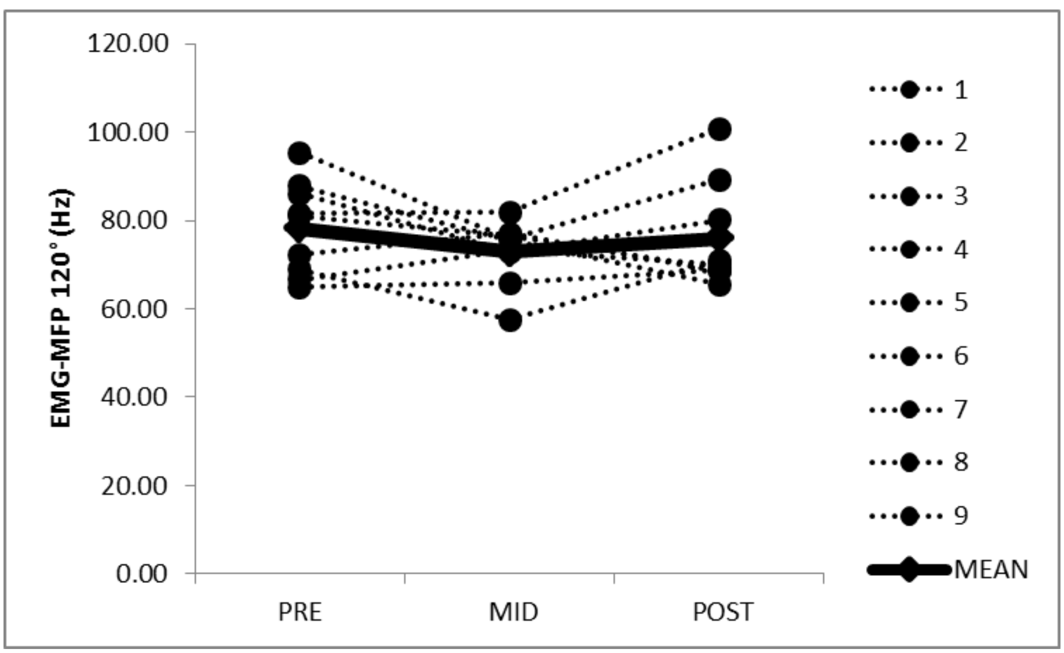

Figure 28. Individual EMG-RMS 120 °Responses for the LI-BFR Group.

Cardiovascular Responses

At baseline, SBP (p = 0.944) was not significantly different between the experimental and control groups whereas DBP (p = 0.011) was significantly different between groups, thus the ANOVA was used for the SBP analysis and the ANCOVA was used for the DBP analysis (the PRE was used as covariate). The description of the SBP and DBP at PRE and POST for experimental and control groups is shown in Table 9.

Table 9. SBP and DBP at PRE and POST for Experimental and Control Groups.

Variables	Group	PRE	POST	%Δ	ES
SBP	Experimental (n=9)	116.06 ± 4.97	115.33 ± 8.25	- 0.6	-0.17
(mmHg)	Control (n=5)	116.40 ± 13.01	120.00 ± 13.00	3.1	0.28
DBP	Experimental (n=9)	68.83 ± 5.09	67.11 ± 5.23	- 2.5	-0.34
(mmHg)	Control (n=5)	79.60 ± 8.61	80.80 ± 7.23	1.5	0.13

Values : mean ± SD; SBP, systolic blood pressure; DBP, diastolic blood pressure

For SBP, results from the ANOVA indicated there were no significant group × time interaction (p = 0.113) time (p = 0.277) and group (p = 0.629) effects. The paired t-test showed the SBP in Experimental (p = 0.658) and Control (p = 0. 125) groups was not significantly different.

For DBP, results from the ANCOVA indicated there were no significant group × time interaction (p = 0.992) and group (p = 0.818) effects. The paired t-test showed the DBP in Experimental (p = 0.193) and Control (p = 0.483) groups was not significantly different.

The magnitude of change for SBP and DBP in both Experimental (- 0.73 and – 1.72) and Control (3.6 and 1.2) groups was lower than the MD (8.5 and 9.1) for the SBP and DBP, respectively, and may represent normal expected variability associated with the measurement.

At baseline, PWV (p = 0.000) and FBF (p = 0.030) were significantly different between groups (PWV; HI vs CON, p = 0.000 and LI-BFR vs CON, p = 0.000 and FBF; LI-BFR vs CON, p = 0.033), thus the ANCOVA was utilized for data analysis (the PRE was used as covariate). The description of the PWV and FBF at PRE and POST for each group is shown in Table 10.

Table 10. PWV and FBF at PRE and POST for Each Group.

Variables	Group	PRE	POST	%Δ	ES
PWV	HI (n=9)	7.21 ± 0.57	7.56 ± 0.85	4.9	0.61
(m/s)	LI-BFR (n=9)	7.23 ± 0.66	7.24 ± 0.58	0.1	0.02
	CON (n=10)	8.60 ± 0.74	8.69 ± 0.83	1.0	0.12
FBF	HI (n=9)	2.52 ± 0.54	3.11 ± 1.00	23.4	1.09
(ml/min/100ml)	LI-BFR (n=9)	2.70 ± 0.35	2.84 ± 0.77	5.2	0.40
	CON (n=10)	2.09 ± 2.30	2.30 ± 0.80	10.0	0.09

Values : mean ± SD; PWV, pulse wave velocity; FBF, forearm blood flow

For PWV, results from the ANCOVA indicated there were no significant group × time interaction (p = 0.503) and group (p = 0.343) effects. The paired t-test showed the PWV in HI (p = 0.237), LI-BFR (p = 0.942) and CON (p = 0.559) groups was not significantly different.

For FBF, results from the ANCOVA indicated there were no significant group × time interaction (p = 0.106) and group (p = 0.241) effects. The paired t-test showed the FBF in HI (p = 0.223), LI-BFR (p = 0.595) and CON (p = 0.356) groups was not significantly different.

The magnitude of changes for PWV and FBF in both HI (0.35 and 0.59) and LI-BFR (0.01 and 0.14) was lower than the MD (0.77 and 1.68) for the PWV and FBF, respectively, and may represent normal expected variability in these measurement.

The individual PWV and FBF responses in the HI, LI-BFR, and CON groups are shown in Figure 29 and 30, respectively.

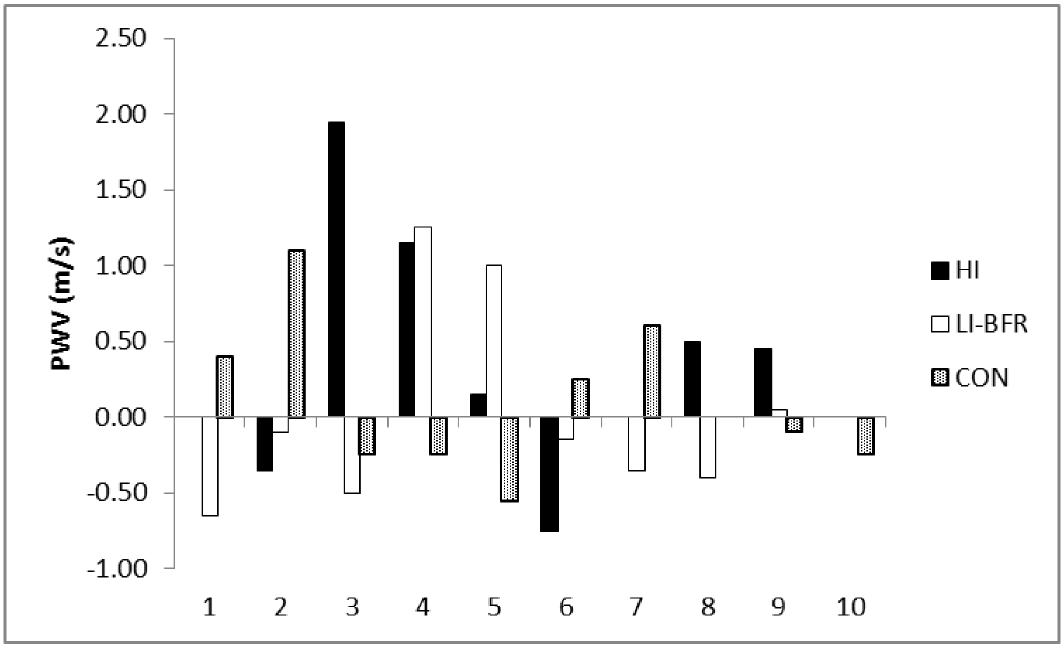

Figure 29. Individual PWV responses in the HI, LI-BFR and CON Groups.

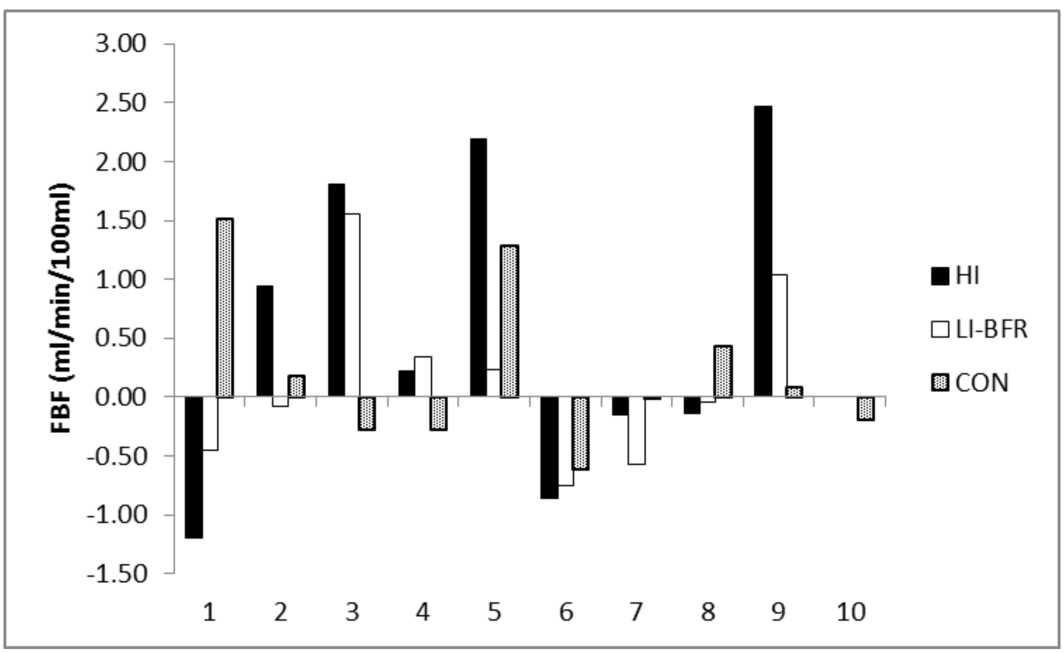

Figure 30. Individual FBF responses in the HI, LI-BFR and CON Groups.

Acute Response Testing

Acute Muscular Responses

At baseline, acute MTH at 50% (p = 0.402), 60% (p = 0.368) and 70% (p = 0.098) were not significantly different between groups. The description of the acute MTH at 50%, 60% and 70% at PRE and POST for each group is shown in Table 11.

Table 11. Acute MTH at 50%, and 60% and 70% responses at PRE and POST for Each Group.

Variables	Group	Acute PRE	Acute POST	%Δ	ES
MTH at 50%	HI (n=9)	3.06 ± 0.53	3.19 ± 0.55**	4.2	0.25
(cm) **	LI-BFR (n=9)	3.13 ± 0.47	3.28 ± 0.53*	4.8	0.32
MTH at 60%	HI (n=9)	3.45 ± 0.42	3.63 ± 0.42*	5.2	0.43
(cm) **	LI-BFR (n=9)	3.41 ± 0.39	3.72 ± 0.48**	9.1	0.79
MTH at 70%	HI (n=9)	3.94 ±0.42	4.13 ± 0.53*	4.8	0.45
(cm) §,**	LI-BFR (n=9)	3.84 ± 0.37	4.16 ± 0.49**	8.3	0.86

Values : mean ± SD; $^{*}p < 0.05$ time effect; $^{**}p < 0.01$time effect; $^{§}p < 0.05$ group × time interaction effect; MTH, muscle thick ness

For acute MTH at 50%, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.002), but no group × time interaction (p = 0.919) and group (p = 0.318) effects. The paired sample t-tests showed the MTH at 50% in both HI (p = 0.005) and LI-BFR (p = 0.046) groups was significantly increased over time, but there was no group difference at the acute POST (p = 0.402).

For acute MTH at 60%, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.000), but no group × time interaction (p = 0.193) and group (p = 0.577) effects. The paired sample t-tests showed the MTH at 60% in both HI (p = 0.014) and LI-BFR (p = 0.000) groups was significantly increased over time, but there was no group difference at the acute POST (p = 0.368).

For acute MTH at 70%, results from the two-way repeated measures ANOVA indicated there were significant group × time interaction ($p = 0.046$) and time ($p = 0.001$) effects, but no group effect ($p = 0.569$). The paired sample t-tests showed the MTH at 70% in both HI ($p = 0.014$) and LI-BFR ($p = 0.000$) groups was significantly increased over time, but there was no group difference at the acute POST ($p = 0.657$).

The individual acute changes of muscle thickness responses for the HI or LI-BFR group at 50%, 60%, and 70% are shown in Figure 31, 32, and 33, respectively.

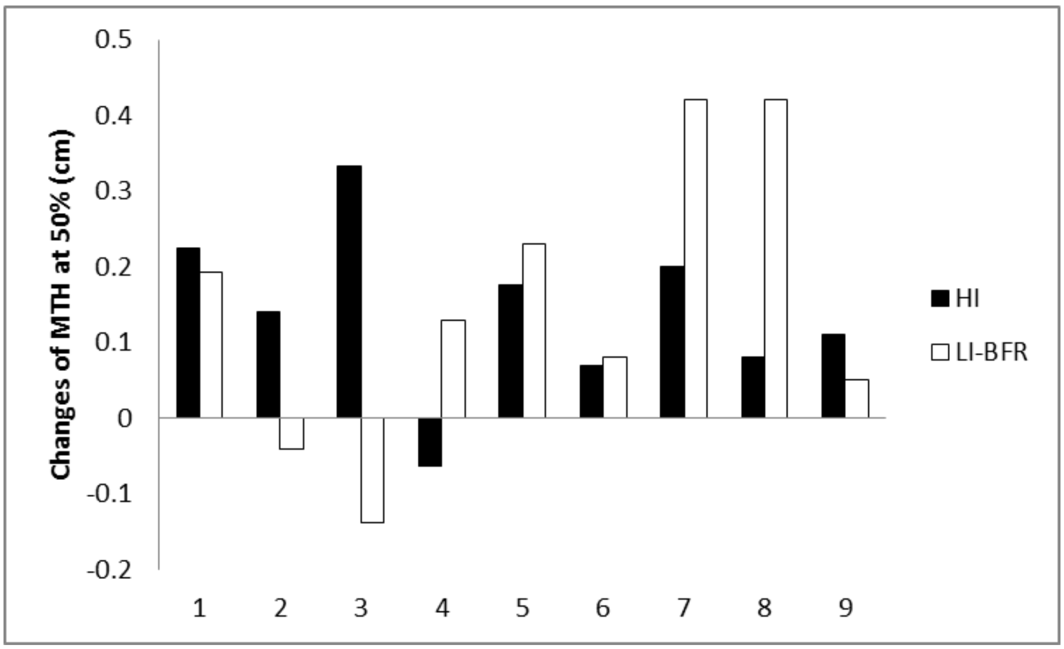

Figure 31. Individual Acute Changes of MTH at 50% in Both HI and LI-BFR Groups.

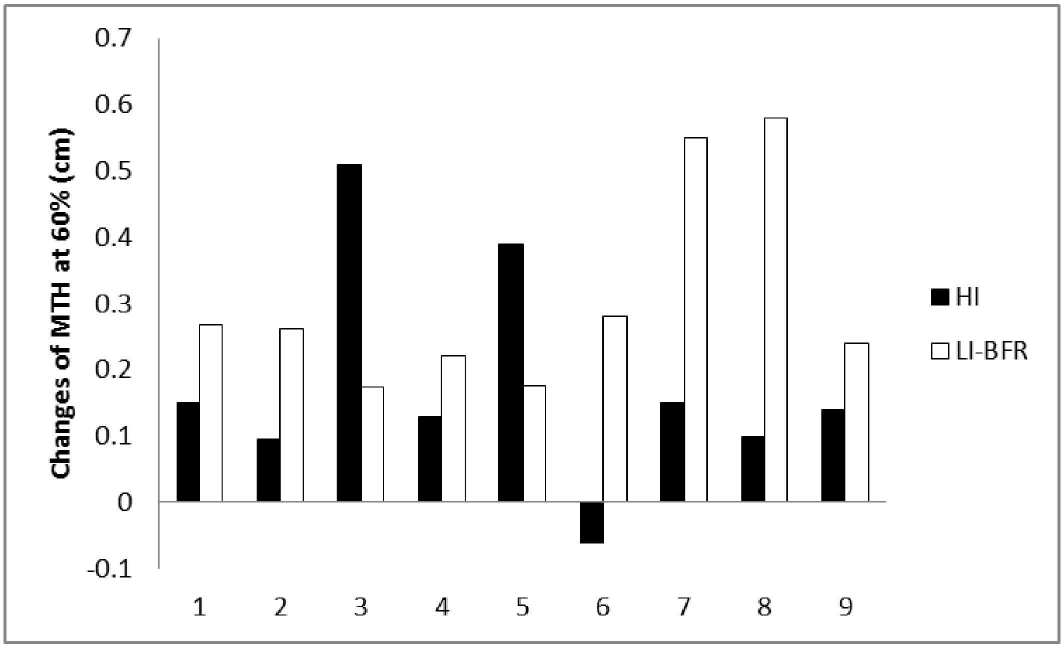

Figure 32. Individual Acute Changes of MTH at 60% in Both HI and LI-BFR Groups.

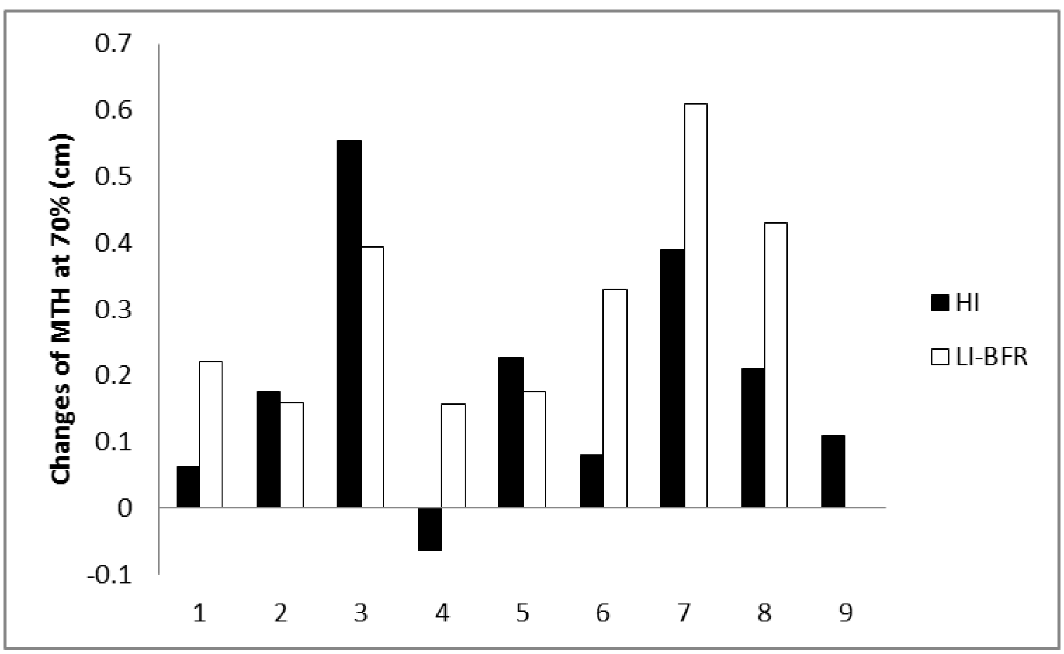

Figure 33. Individual Acute Changes of MTH at 70% in Both HI and LI-BFR Groups.

At baseline, acute AC at 50% (p = 0.406), 60% (p = 0.842) and 70% (p = 0.440) were not significantly different between groups. The description of the acute AC at 50%, 60% and 70% at PRE and POST for each group is shown in Table 12.

Table 12. Acute AC at 50%, and 60% and 70% responses at PRE and POST for Each Group.

Variables	Group	Acute PRE	Acute POST	%Δ	ES
AC at 50%	HI (n=9)	32.07 ± 2.65	32.30 ± 2.68**	0.7	0.09
(cm)**	LI-BFR (n=9)	31.76 ± 2.84	32.16 ± 2.71*	1.3	0.14
AC at 60%	HI (n=9)	30.88 ± 2.78	31.31 ± 2.81**	1.4	0.15
(cm)**	LI-BFR (n=9)	30.79 ± 2.79	31.35 ± 2.69**	1.8	0.20
AC at 70%	HI (n=9)	29.97 ±2.82	30.39 ± 2.87*	1.4	0.15
(cm)**	LI-BFR (n=9)	29.71 ± 2.41	30.31 ± 2.39**	2.0	0.20

Values : mean ± SD; $^{*}p < 0.05$ time effect; $^{**}p < 0.01$time effect; AC, arm circumference

For acute AC at 50%, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.001), but no group × time interaction (p = 0.335) and group effect (p = 0.516). The paired sample t-tests showed the acute AC at 50% in both HI (p = 0.007) and LI-BFR (p = 0.015) groups was significantly increased over time, but there was no group difference at the acute POST (p = 0.678).

For acute AC at 60%, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.001), but no group × time interaction (p = 0.419) and group effect (p = 0.957). The paired sample t-tests showed the acute AC at 60% in both HI (p = 0.007) and LI-BFR (p = 0.003) groups was significantly increased over time, but there was no group difference at the acute POST (p = 0.910).

For acute AC at 70%, results from the two-way repeated measures ANOVA indicated there was significant time effects (p = 0.001), but not group × time interaction (p = 0.269) and group effect (p = 0.593). The paired sample t-tests showed the acute AC at 70% in both HI (p = 0.017) and LI-BFR (p = 0.001) groups was significantly increased over time, but there was no group difference at the acute POST (p = 0.804).

The individual acute changes of arm circumferences for the HI or LI-BFR group at 50%, 60%, and 70% are shown in Figure 34, 35, and 36, respectively.

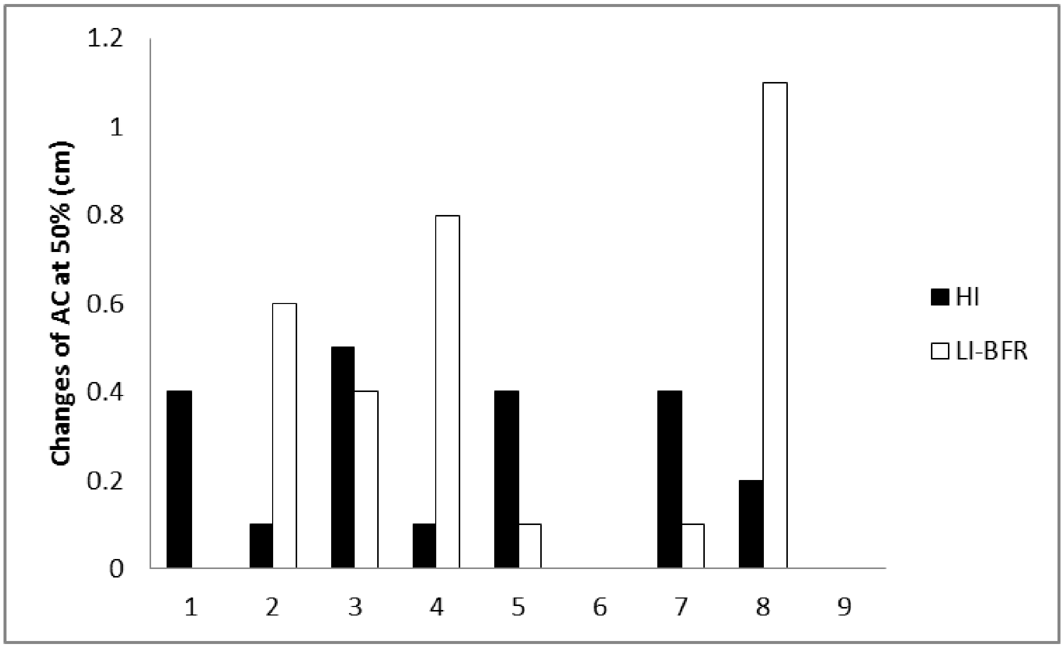

Figure 34. Individual Acute Changes of AC at 50% in Both HI and LI-BFR Groups.

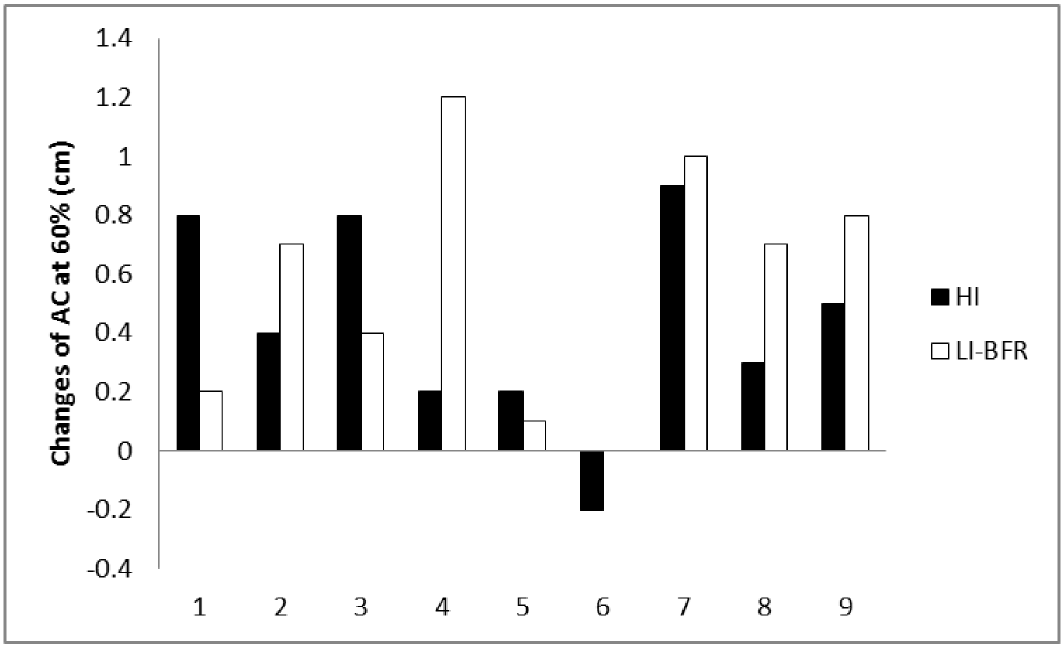

Figure 35. Individual Acute Changes of AC at 60% in Both HI and LI-BFR Groups.

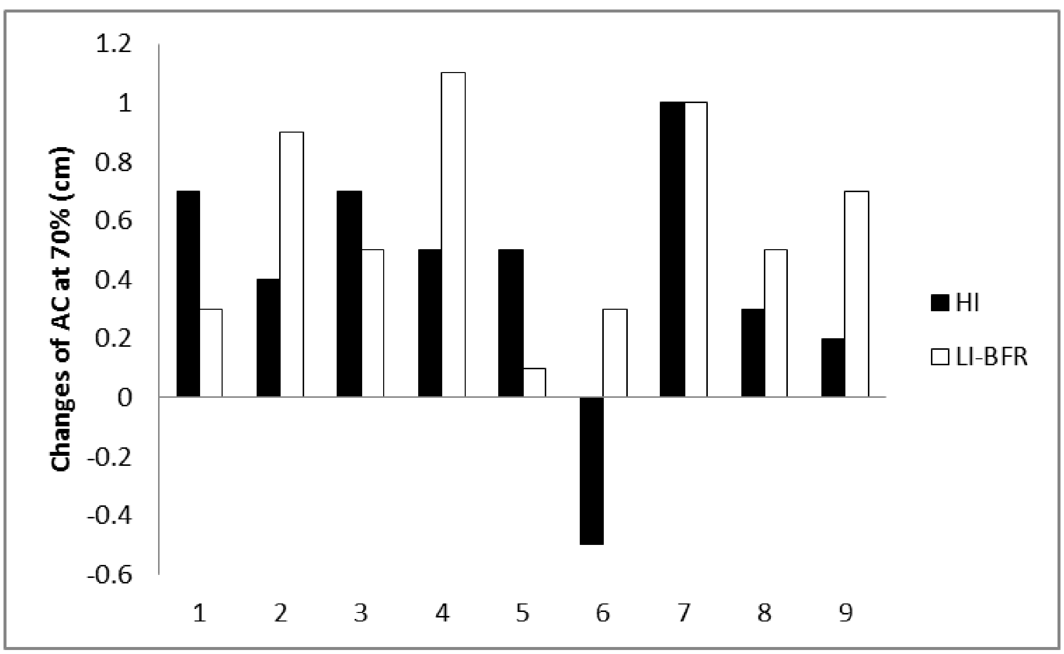

Figure 36. Individual Acute Changes of AC at 70% in Both HI and LI-BFR Groups.

Acute Whole Blood Lactate and Hematocrit Responses

At baseline, acute WBL (p = 0.825) and HCT (p = 0.756) were not significantly different between groups. The description of the acute WBL and HCT at PRE and POST for each group is shown in Table 13.

Table 13. Acute WBL and HCT responses at PRE and POST for Each Group.

Variables	Group	Acute PRE	Acute POST	%Δ	ES
WBL	HI (n=9)	1.37 ± 0.43	3.23 ± 1.31**	135.8	4.33
(mmol/L)**	LI-BFR (n=9)	1.41 ± 0.53	2.76 ± 0.72**	95.7	2.55
HCT (%)	HI (n=9)	45.29 ± 2.48	46.06 ± 2.21*	1.7	0.31
	LI-BFR (n=9)	44.97 ± 2.42	45.97 ± 2.14	2.2	0.41

Values : mean ± SD; $^{*}p < 0.05$ time effect; $^{**}p < 0.01$time effect; WBL, whole body lactate; HCT, hematocrit

For acute WBL, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.000), but no group × time interaction (p = 0.168) and group (p = 0.298) effects. The paired sample t-tests showed the WBL in both HI (p = 0.002) and LI-BFR (p = 0.000) groups was significantly increased over time, but there was no group difference at the acute POST (p = 0.161).

For acute HCT, results from the two-way repeated measures ANOVA indicated there were no significant time (p = 0.08), group × time interaction (p = 0.737) and group (p = 0.805) effects. The paired sample t-tests showed the HCT in the HI (p = 0.04) group was significantly increased over time but not in the LI-BFR (p = 0.194), and there was no group difference at the acute POST (p = 0.903).

The individual acute changes of whole body lactate and hematocrit for the HI or LI-BFR group are shown in Figure 37 and 38, respectively.

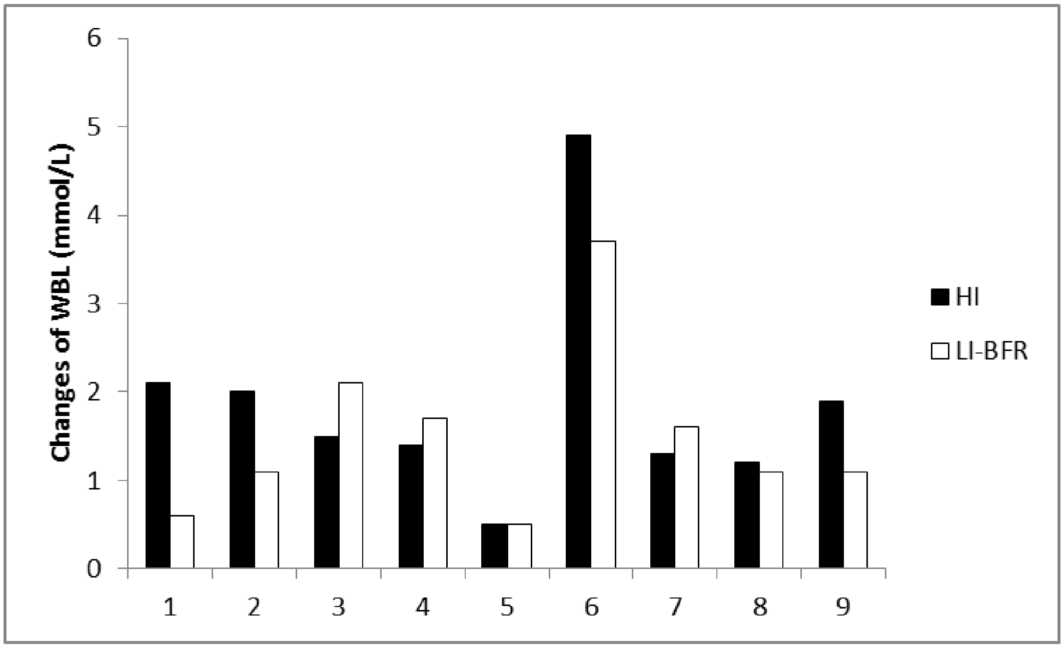

Figure 37. Individual Acute Changes of WBL in Both HI and LI-BFR Groups.

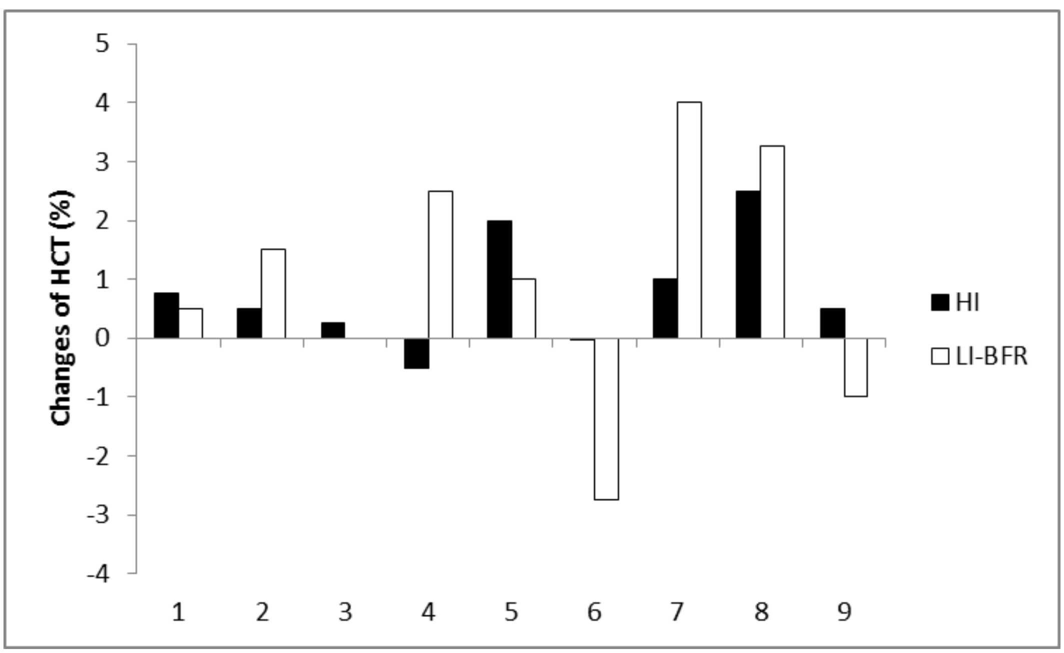

Figure 38. Individual Acute Changes of HCT in Both HI and LI-BFR Groups.

Acute Maximal Voluntary Contraction Responses

At baseline, acute MVC 90° (p = 0.545) and 120° (p = 0.096) were not significantly different between groups. The description of the acute MVC 90° and 120° at PRE and POST for each group is shown in Table 14.

Table 14. Acute MVC 90° and 120° responses at PRE and POST for Each Group.

Variables	Group	Acute PRE	Acute POST	%Δ	ES
MVC 90°	HI (n=9)	47.00 ± 13.29	38.37 ± 8.32*	-18.4	-0.65
(Nm)$^{**, \#}$	LI-BFR (n=9)	49.87 ± 12.02	33.53 ± 11.20**	-32.8	-1.36
MVC 120°	HI (n=9)	61.82 ± 13.84	48.82 ± 11.56**	-21.0	-0.94
(Nm)$^{**, \#}$	LI-BFR (n=9)	57.21 ± 11.06	43.80 ± 10.94**	-23.4	-1.21

Values : mean ± SD; $^{*}p < 0.05$ time effect; $^{**}p < 0.01$time effect; $^{\#}p < 0.05$ group effect at the acute POST

For acute MVC 90°, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.002), but no group × time interaction (p = 0.083) and group (p = 0.746) effects. The paired sample t-tests showed the MVC 90° in both HI (p = 0.042) and LI-BFR (p = 0.001) groups was significantly decreased over time, and there was group difference at the acute POST (p = 0.047).

For acute MVC 120°, results from the two-way repeated measures ANOVA indicated there were significant time (p = 0.000) and group (p = 0.028) effects, but no group × time interaction (p = 0.878) effect. The paired sample t-tests showed the MVC 120° in both HI (p = 0.000) and LI-BFR (p = 0.000) groups was significantly decreased over time, and there was group difference at the acute POST (p = 0.033).

The individual acute changes of MVC 90° and 120° for the HI or LI-BFR group are shown in Figure 40 and 41, respectively.

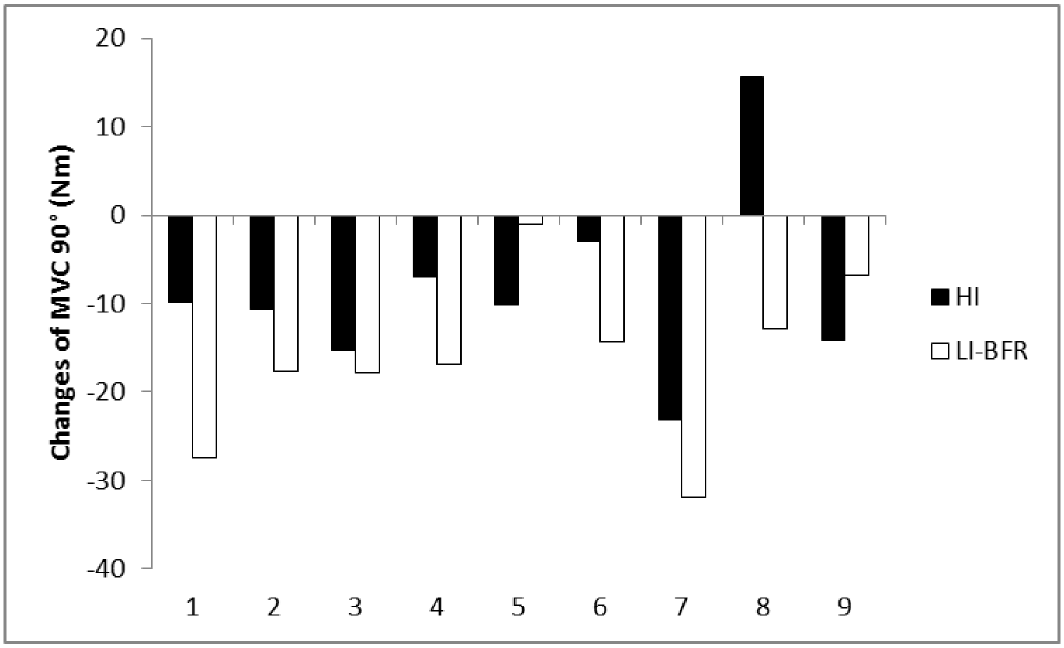

Figure 39. Individual Acute Changes of MVC 90 °in Both HI and LI-BFR Groups.

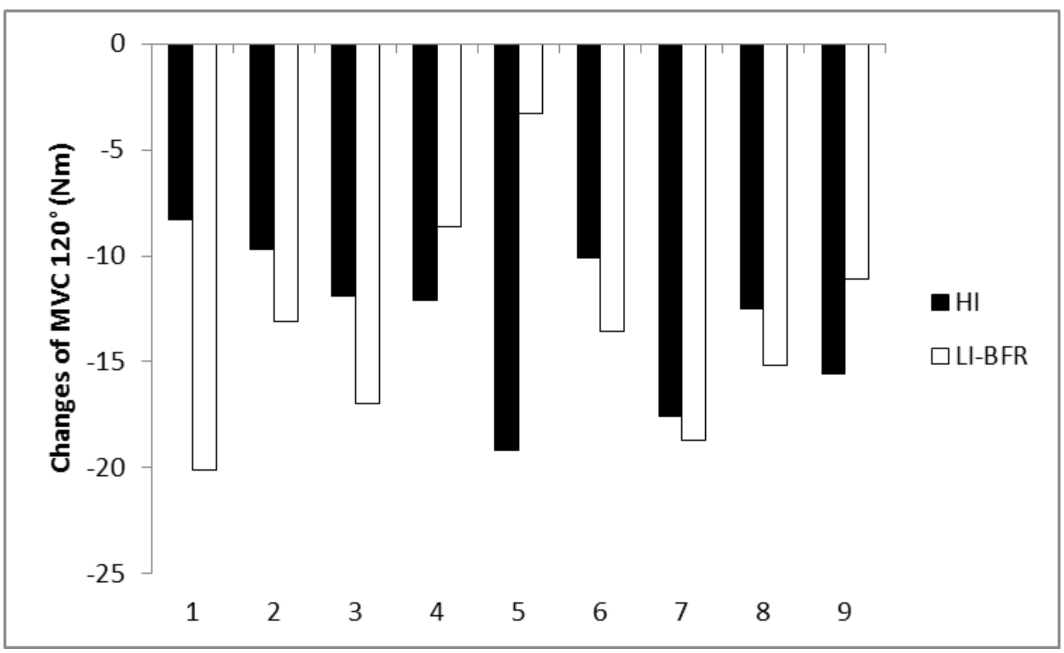

Figure 40. Individual Acute Changes of MVC 120 °in Both HI and LI-BFR Groups.

Acute Electromyography Response

All amplitude (RMS) mean power frequency (MPS) EMG values were normalized. The description of the acute EMG-RMS and MPF 90 ° and 120 ° at PRE and POST for each group is shown in Table 15.

Table 15. Acute EMG 90 ° and 120 ° responses at PRE and POST for Each Group.

Variables	Group	Acute PRE	Acute POST	%Δ
EMG-RMS 90 °	HI (n=9)	100.00 ± 0.00	73.23 ± 16.78**	-26.8
(%) **	LI-BFR (n=9)	100.00 ± 0.00	68.67 ± 17.60**	-31.3
EMG-MPF 90 °	HI (n=9)	100.00 ± 0.00	83.80 ± 9.72**	-16.2
(%) **	LI-BFR (n=9)	100.00 ± 0.00	86.47 ± 12.56*	-13.5
EMG-RMS 120 °	HI (n=9)	100.00 ± 0.00	85.33 ± 14.72*	-14.7
(%) *	LI-BFR (n=9)	100.00 ± 0.00	83.97 ± 26.63	-16.0
EMG-MPF 120 °	HI (n=9)	100.00 ± 0.00	93.97 ± 6.73*	-6.0
(%)	LI-BFR (n=9)	100.00 ± 0.00	95.90 ± 14.39	-4.1

Values : mean ± SD; *$p < 0.05$ time effect; **$p < 0.01$time effect

For acute EMG-RMS 90 °, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.000), but no group × time interaction (p = 0.459) and group effect (p = 0.459). The paired sample t-tests showed the EMG-RMS 90 ° in both HI (p = 0.012) and LI-BFR (p = 0.017) groups was significantly decreased over time, and there was no group difference at the acute POST (p = 0.459).

For acute EMG-MPF 90 °, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.001), but no group × time interaction (p = 0.582) and group effect (p = 0.582). The paired sample t-tests showed the EMG-MPF 90 ° in both HI (p = 0.001) and LI-BFR (p = 0.001) groups was significantly decreased over time, and there was no group difference at the acute POST (p = 0.582).

For acute EMG-RMS 120 °, results from the two-way repeated measures ANOVA indicated there was significant time effect (p = 0.019), but no group × time interaction (p = 0.893) and group (p = 0.893) effects. The paired sample t-tests showed the EMG-RMS 120 ° in the HI group ($p = 0.017$) was significantly decreased over time, but not in the LI-BFR group ($p = 0.109$) and there was no group difference at the acute POST ($p = 0.893$).

For acute EMG-MPF 120 °, results from the two-way repeated measures ANOVA indicated there was no significant time ($p = 0.091$), group × time interaction ($p = 0.727$) and group ($p = 0.727$) effects. The paired sample t-tests showed the EMG-MPF 120 ° in both HI ($p = 0.028$) and LI-BFR ($p = 0.417$) groups was significantly decreased over time, and there was no group difference at the acute POST ($p = 0.727$).

The individual acute changes of EMG-RMS and MPF 90 ° and 120 ° for the HI or LI-BFR group are shown in Figure 42, 43, 44, and 45, respectively.

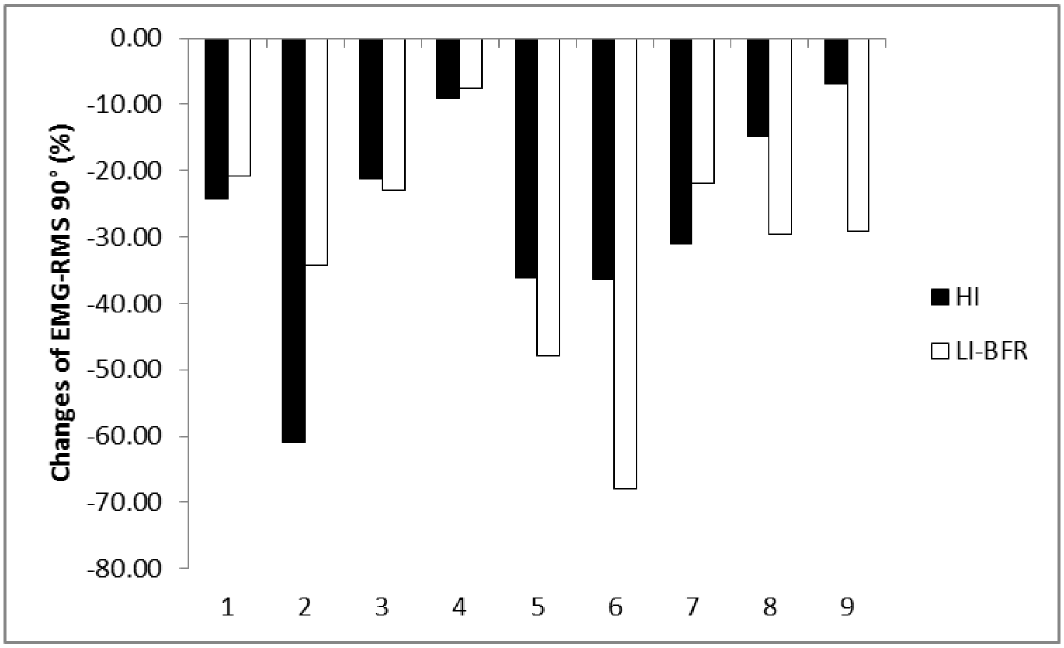

Figure 41. Individual Acute Changes of EMG-RMS 90 ° in Both HI and LI-BFR Groups.

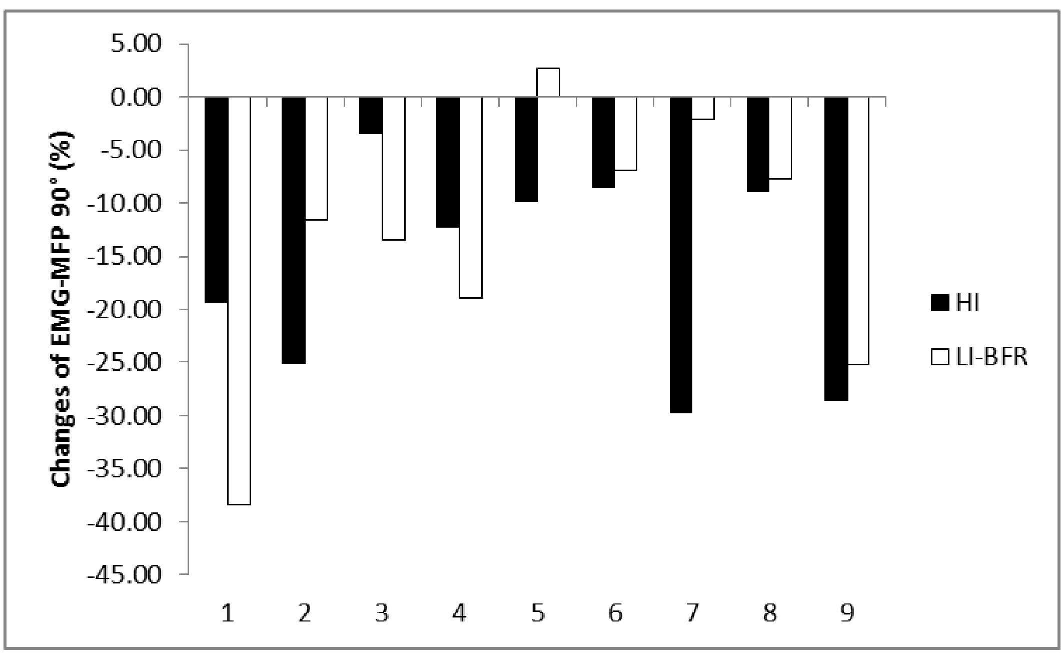

Figure 42. Individual Acute Changes of EMG-MPF 90 ° in Both HI and LI-BFR Groups.

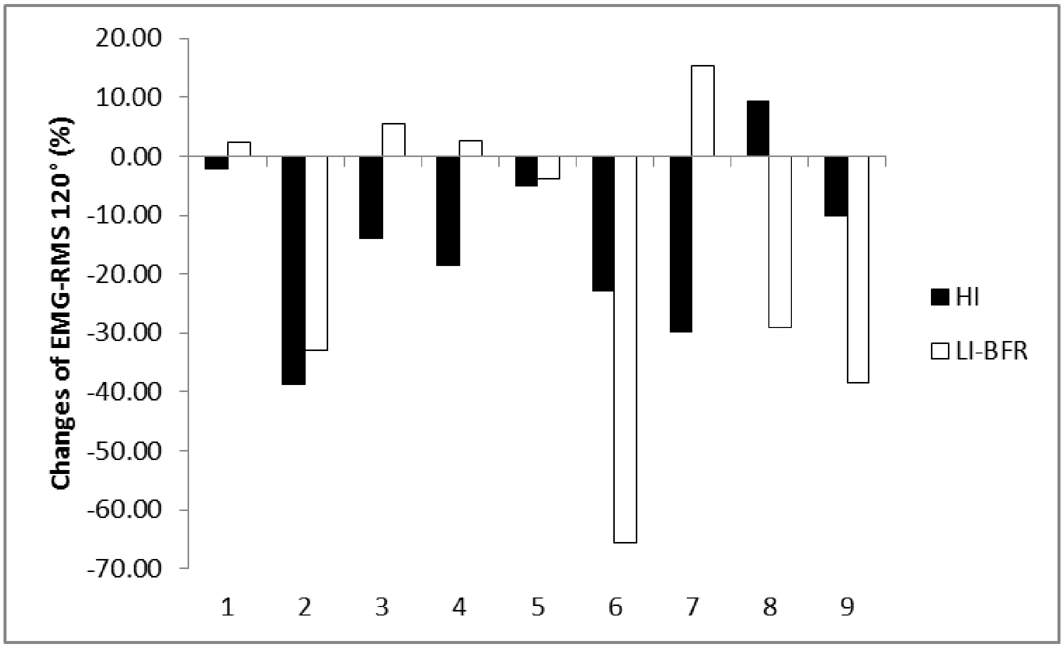

Figure 43. Individual Acute Changes of EMG-RMS 120 °in Both HI and LI-BFR Groups.

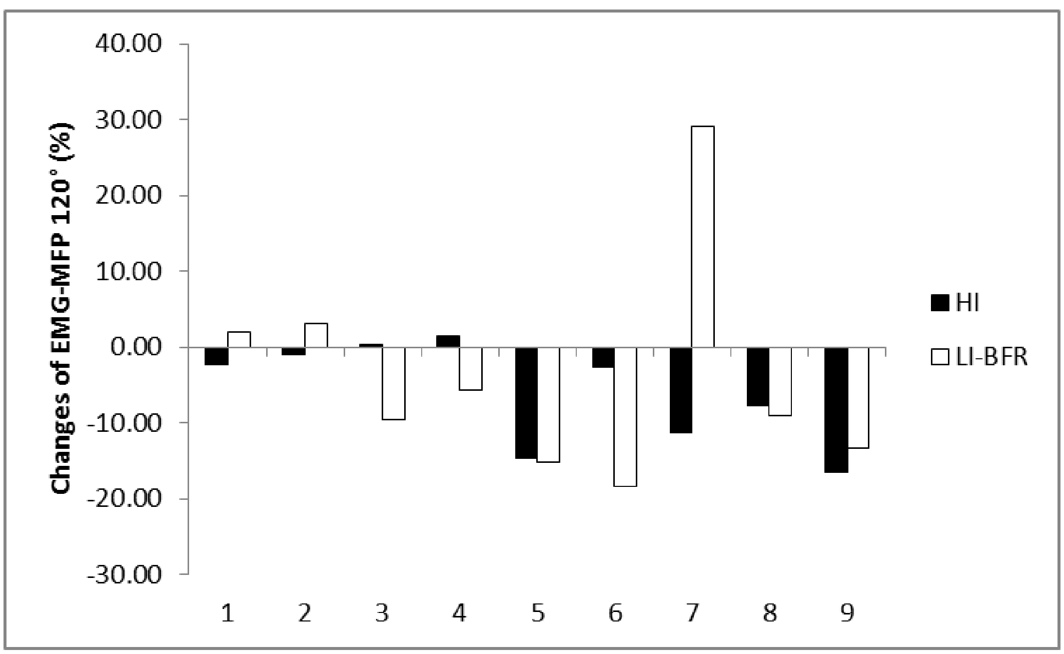

Figure 44. Individual Acute Changes of EMG-MPF 120 °in Both HI and LI-BFR Groups.

Exercise Training

Volume of Exercise

At baseline, the volume of exercise ($p = 0.451$) was not significantly different between groups. Also there were no group differences for the volume of exercise in each week. The volume of exercise during eight weeks of training for both groups is shown in Figure 46.

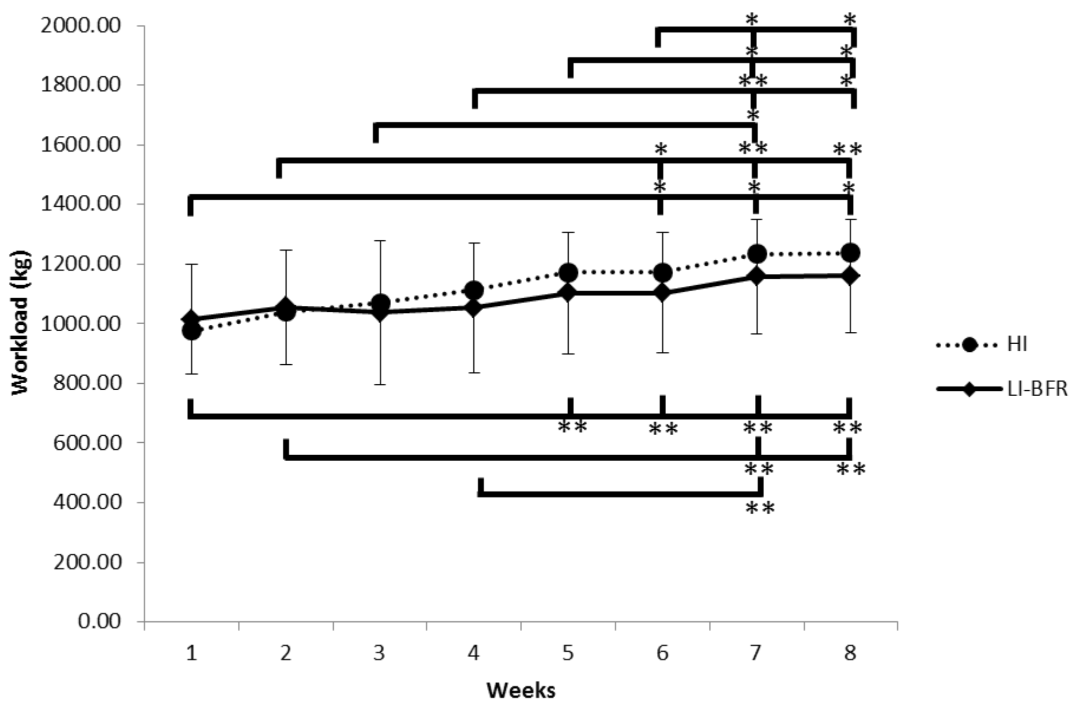

Figure 45. Volume of Exercise during Eight Weeks of Training for Both HI and LI-BFR Groups.
$^{*}p < 0.05$ time effect; $^{**}p < 0.01$time effect

For the volume of exercise, results from the two-way repeated measures ANOVA indicated there was significant time (p = 0.000) and group × time interaction (p = 0.017) effects, but no group effect (p = 0.379). The one-way ANOVA showed the volume of exercise in both HI (p = 0.000) and LI-BFR (p = 0.000) groups was significantly increased over time. The Bonferroni post-hoc test showed there were time effects from week 1 to week 6 (p = 0.041), week 7 (p = 0.025) and week 8 (p = 0.025), from week 2 to week 6 (p = 0.037), week 7 (p = 0.008) and week 8 (p = 0.008), from week 3 to week 7 (p = 0.038), from week 4 to week 7 (p = 0.009) and week 8 (p = 0.017), from week 5 to week 7 (p = 0.029) and week 8 (p = 0.027) and from week 6 to week 7 (p = 0.017) and week 8 (p = 0.027) in the HI group and from week 1 to week 5 (p = 0.006), week 6 (p = 0.006), week 7 (p = 0.001) and week 8 (p = 0.001), from week 2 to week 7 (p = 0.001) and week 8 (p = 0.002) and from week 4 to week 7 (p = 0.042) in the LI-BFR group, but there was no group difference at each time points (p = 0.451, p = 0.733, p = 0.565, p = 0.257, p = 0.157, p = 0.185, p = 0.169, and p = 0.152, respectively).

Rating of Perceived Exertion (RPE) and Discomfort

The RPE and discomfort during eight weeks of training for the HI and LI-BFR groups are shown in Figure 47, 48, 49 and 50, respectively.

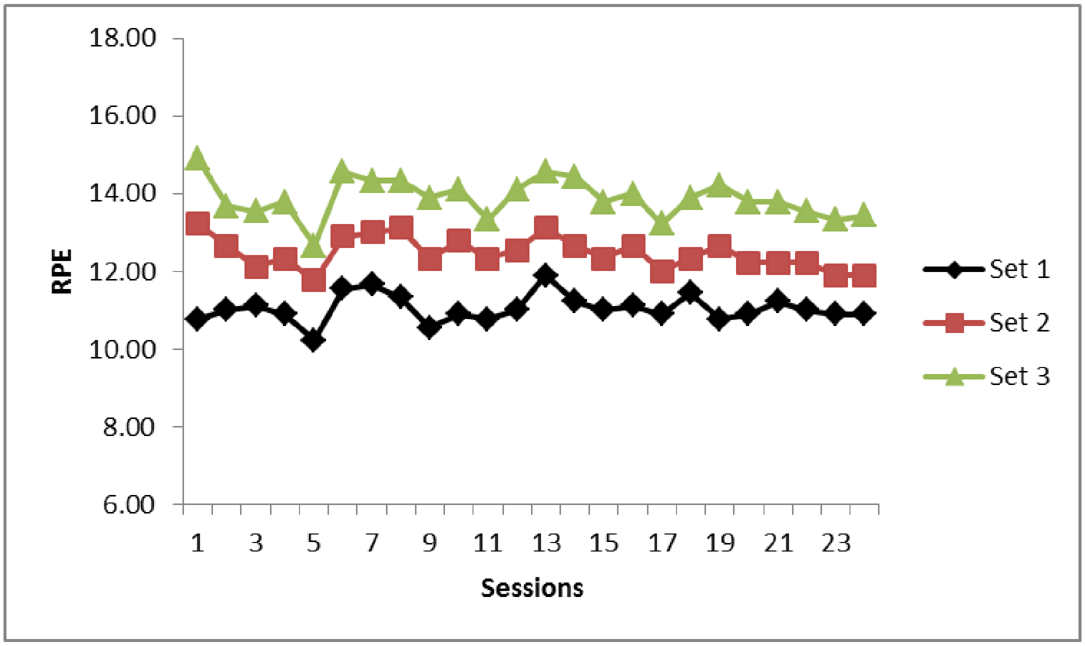

Figure 46. PRE during 8 Weeks of Training for the HI Group.

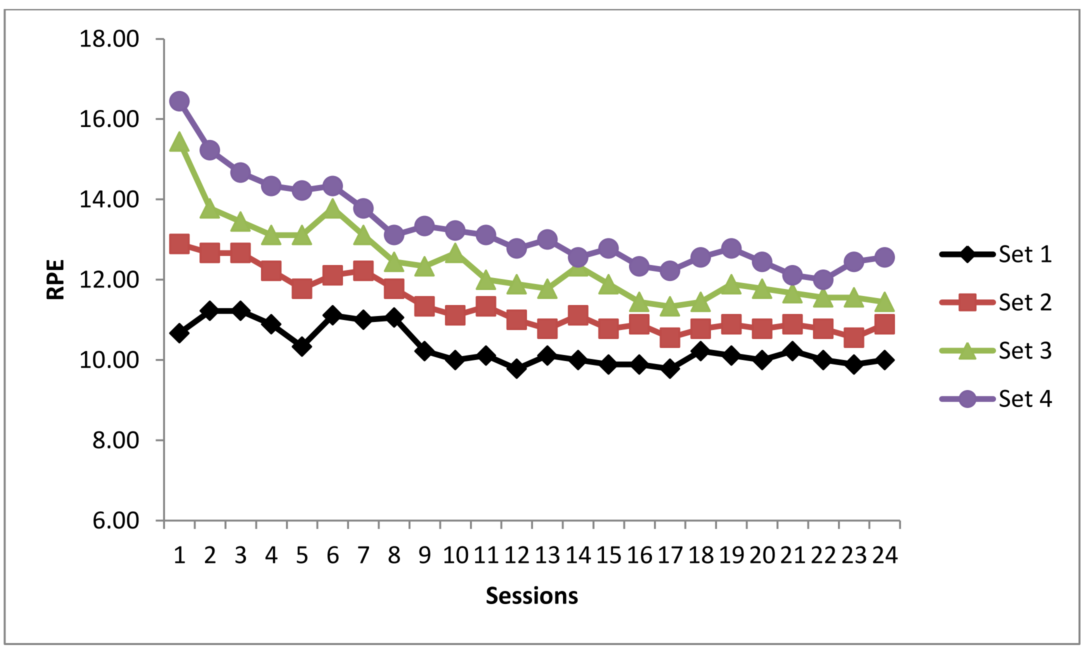

Figure 47. PRE during 8 Weeks of Training for the LI-BFR Group.

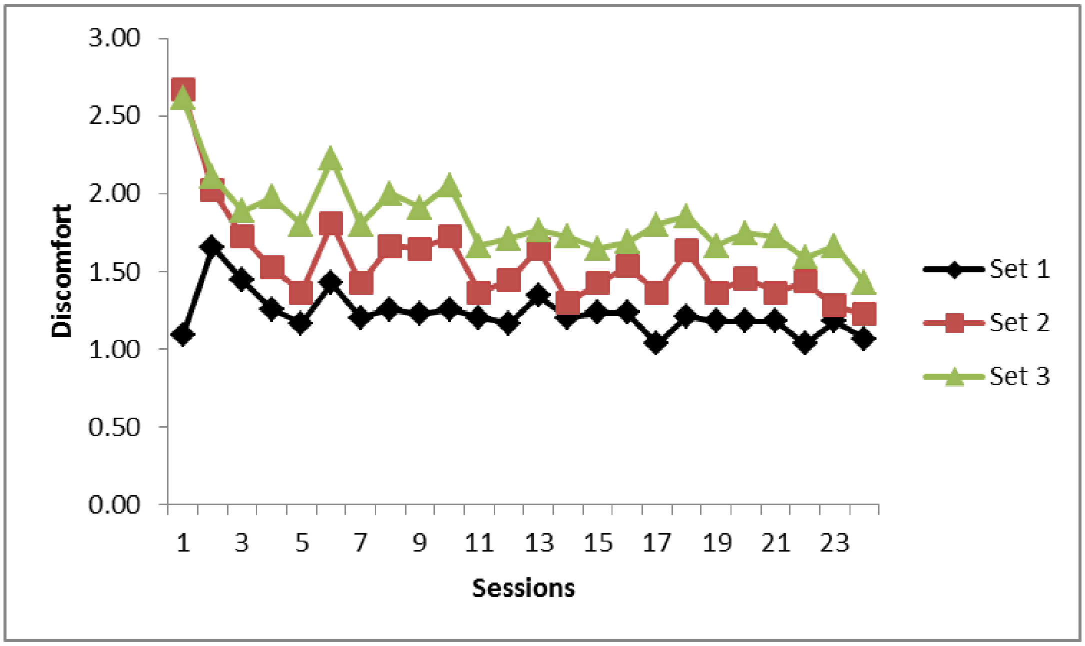

Figure 48. Discomfort during 8 Weeks of Training for the HI Group.

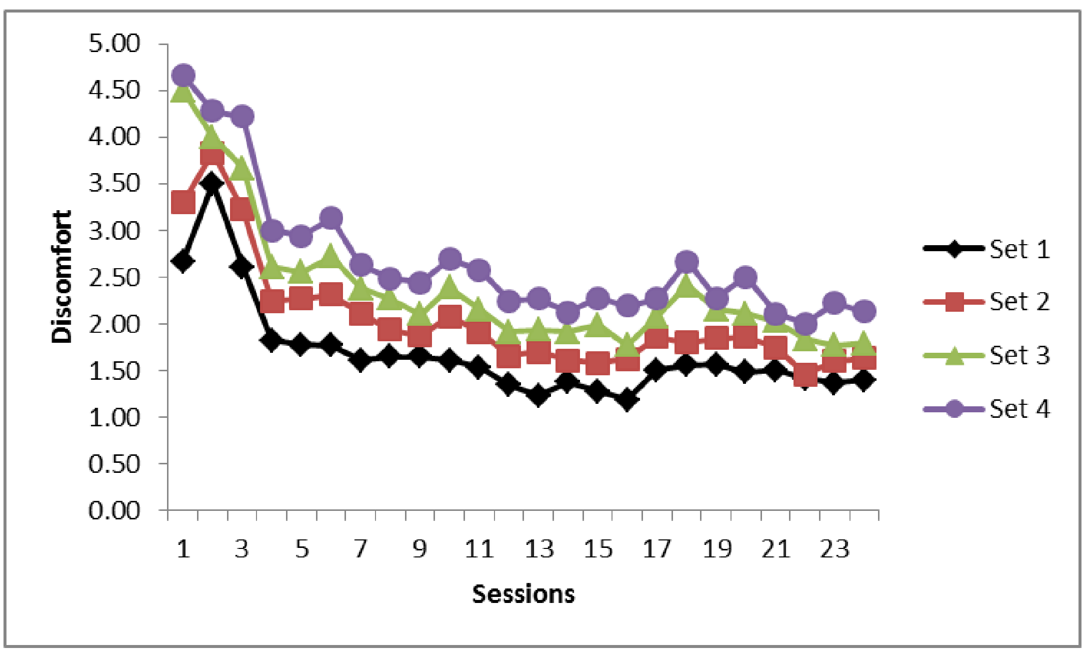

Figure 49. Discomfort during 8 Weeks of Training for the LI-BFR Group.

Discussion

Main Findings

1) Eight weeks of low-load (30% of 1-RM) unilateral elbow flexor training combined with BFR (50% of arterial occlusion pressure) resulted in similar muscle hypertrophy as the traditional high-load (75% of 1-RM) training, while the control group remained unchanged.

2) Eight weeks of low-load (30% of 1-RM) unilateral elbow flexor training combined with BFR (50% of arterial occlusion pressure) resulted in similar muscle strength gains as the traditional high-load (75% of 1-RM) training, while the control group remained unchanged.

3) Peripheral arterial stiffness and forearm blood flow did not change for the low-load with BFR training, high-load training and control groups.

4) EMG amplitude and mean power frequency did not change for the low-load with BFR training, high-load training and control groups.

5) A single bout of low-load unilateral elbow flexor exercise with BFR resulted in similar acute muscular responses as a bout of traditional high-load unilateral elbow flexor exercise.

6) A single bout of low-load unilateral elbow flexor exercise with BFR resulted in similar acute whole body lactate and hematocrit responses as a bout of traditional high-load unilateral elbow flexor exercise.

7) A single bout of low-load unilateral elbow flexor exercise with BFR resulted in similar acute muscle strength response as a bout of traditional high-load unilateral elbow flexor exercise.

8) A single bout of low-load unilateral elbow flexor exercise with BFR resulted in similar acute EMG responses as a bout of traditional high-load unilateral elbow flexor exercise.

Muscle Hypertrophy Responses

Both the low-load combined with BFR and the high-load unilateral elbow flexor training groups had significant increases in muscle thickness and arm circumferences at the 50, 60 and 70% sites of the biceps brachii with no changes in the control group which supported our hypothesis.

In the present study, even though individualized BFR pressures (72.0 $\pm$10.9) were much lower than the BFR pressures (~110 mmHg (87) and 100 to 160 mmHg (69, 103)) used in other BFR studies, muscle hypertrophy and increases in strength in the LI-BFR group were still similar to the HI group. This indicates that higher BFR pressures may not be required to induce muscle hypertrophy and strength gains, thus decreasing the perceived effort associated with BFR exercise.

Generally, previous LI-BFR resistance training studies compared their findings to work-matched low-load without BFR training and results always indicated that muscle hypertrophy in the LI-BFR training groups were greater than the non-BFR training groups (LI, work-matched with the LI-BFR protocol, but non-occlusion) (1, 66, 94). Only a few studies (19, 97) used ultrasound (B-mode) to measure muscle thickness between pre and post testing. These studies reported that the MTH at 60% of the triceps brachii and pectoralis major in the LI-BFR group was increased 8% and 16%, respectively, after 2 weeks (two times daily, 6 times per week, total 24 sessions) of bench press training (30% 1-RM and 75 reps with 100 to 160 mmHg occlusion pressure) in young males but not in the LI group (-1% and 2 %, respectively) (97). These MTH data were similar to the findings of the present study. Other BFR resistance training studies compared their results with non-work-matched low-load without BFR training (LFF, low-load free flow). Even though the volume of work in the LFF group was much greater than the BFR group, lateral quadriceps MTH in the BFR group was greater than the LFF group after 6 weeks (3 times per week) of unilateral knee extensor training (30% 1-RM, and 2 - 4 sets to failure with and without 50% AOP (150 to 240 mmHg)) in middle-aged males and females (aged 42 to 62 years) (19). In another study, changes of muscle volume by assessed MRI were similar between BFR and LFF (40% 1-RM and 4 sets to failure with and without 100 mmHg occlusion pressure) groups after unilateral elbow flexor dumbbell curl training for 6 weeks (3 time per week) in young males and females even though the work volume in the LFF group was three times higher than the BFR group (23).

Consistent with the results of the present study, Takarada et al. (87) reported that the muscle cross sessional area (CSA) at the mid-point of biceps brachii was significantly increased after 16 weeks of unilateral elbow flexor training (two times per week, 3 sets to failure protocols for LI-BFR and HI, and work-matched with LI-BFR for LI) at low-load with BFR (LI-BFR, ~50% 1-RM and 3 sets to failure with ~100 mmHg occlusion pressure) and high-load (HI, 80% 1-RM and 3 sets to failure) groups in old females (aged 47 to 67 years), but not at low-load group (LI, ~50% 1-RM and work-matched with the LI-BFR without occlusion). Additionally, muscle CSA for the biceps brachii in both HI and LI-BFR groups (18.4% and 20.3%, respectively) was greater than the LI group (6.9%) (87). Yasuada et al. (103) compared the LI-BFR (30% 1-RM and

75 reps (30, 15, 15 and 15) with 100 to 160 mmHg occlusion pressure) and HI (75% 1-RM and 30 reps) groups following 6 weeks of bench press training (3 times per week) in young males and reported that muscle CSA for the triceps brachii and pectoralis major was significantly increased 8.6% and 17.6% in the HI group and 4.9% and 8.8% in the LI-BFR group, respectively, but not in the CON group (no exercise training). Ozaki et al. (69) reported that 6 weeks of bench press training (3 time per week) for a HI group (75% 1-RM and 30 reps) and a LI-BFR group (30% 1-RM and 75 reps with 100 to 160 mmHg occlusion pressure) in young males resulted in significant increases in muscle CSA (sum of triceps brachii and pactoralis major) 11.8 % and 6.9%, respectively. In another study, Yasuda et al. (104) indicated that muscle CSA for the triceps brachii and pectoralis major was significantly increased after 6 weeks of bench press training (3 times per week) in young males for HI (75% 1-RM and 30 reps), LI-BFR (30% 1-RM and 75 reps (30, 15, 15 and 15) with 100 to 160 mmHg occlusion pressure), and CB (both protocols combined - two times per week with the LI-BFR protocol and once a week with the HI protocol), but not in the CON group (no exercise training). Additionally, muscle CSA for the triceps brachii and pactoralis major in the HI (8.6%, 17.6%), CB (7.2%, 10.5%), and LI-BFR (4.4%, 8.3%) groups were significantly increased but not in the CON group (-1.1%, 0.0%).

In the Takarada et al. study (87), the magnitude of muscle hypertrophy in the HI and LI-BFR groups were similar to findings in our study, but slightly different from Yasuda et al. and Ozaki et al. studies (69, 103, 104). These studies showed that the changes of muscle CSA in the LI-BFR group were slightly lower than the HI group but greater than the CON group (69, 103, 104). Discrepancies in these findings might be influenced by different intensities (~50% 1-RM vs 30% 1-RM), exercise modality (elbow flexor vs bench press), protocols (to failure vs 75 reps) or training periods (16 week vs 6 weeks).

Both HI and LI-BFR training elicited muscle hypertrophy, however the mechanism may be different between the two protocols. The eccentric portion of exercise in HI training contributes to muscle hypertrophy whereas the concentric portion of exercise in LI-BFR training has a beneficial influence on muscle hypertrophy (101).

This mechanism is supported by several studies. Vikne et al. (90) reported muscle CSA as well as individual Type I and IIA fibers were significantly increased after 12 weeks of high-load eccentric elbow flexor training (3 times per week, 4 to 8 RM and 3 to 5 sets) but not in concentric elbow flexor training. Yasuda et al. (101) showed changes in muscle CSA and muscle volume for concentric training was greater than for eccentric training after LI-BFR training (30% 1-RM and 75 reps with 100 to 160 mmHg occlusion pressure) for 6 weeks (3 times per week) in young males. Moreover, Yasuda et al. (102) indicated that 6 weeks of the concentric elbow flexor BFR training (3 times per week, 30% 1-RM and 75 reps with 100 to 160 mmHg occlusion pressure) in young males had greater muscle CSA increases compared to the eccentric BFR training, and muscle CSA in the concentric BFR group was well maintained and still greater than the eccentric BFR group after 6 weeks of detraining indicating that the concentric portion of BFR exercise may provide the important stimulus for muscle hypertrophy.

Muscle Strength Responses

In the present study, both LI-BFR and HI groups were able to statistically increase 1-RM's and MVC 90° and 120°. The 1-RM increase for the HI group was significantly greater than the CON group at the POST testing but LI-BFR and CON values were similar. Thus, this data supported our hypothesis.

Additionally, there were no strength differences between the three groups from PRE1 to PRE2, perhaps due to the familiarization session, which may have prevented a learning effect. The 1-RM values for both LI-BFR and HI groups gradually increased during the training period and there were no group differences at week 2, week 4, week 6 and POST testing.

1-RM strength for the HI, LI-BFR and CON groups of the present study increased 24.1%, 15.6% and -2.9%, respectively. Similar to our findings, Takarada et al. (87) reported that the 1-RM strength values for HI, LI-BFR, and LI groups were increased 22.6%, 18.4%, and 1%, respectively after 16 weeks of elbow flexor training in old females (aged 47 to 67 years). The magnitude of changes in the present study were very similar to results from the study of Takarada et al. (87) even though the training period, work-loads, and occlusion pressures in the present study were smaller. In other studies, the 1-RM for HI and LI-BFR groups were increased 17.7% and 8.7%, respectively, after 6 weeks of bench press training (69). Similarly, the 1-RM for HI, LI-BFR, and CON groups was increased 19.9%, 8.7% and 1.6%, respectively, after the bench press training for 6 weeks (103) in young males. In addition, Yasuda et al. (104) showed the 1-RM for HI, LI-BFR, and CB groups was significantly increased after 6 weeks of bench press training in young males, but not for the CON group. In these studies, the HI group had slightly greater 1-RM responses than the LI-BFR group, but there was no statistical group difference (69, 87, 103).

Contrary to the results from the present study, Burgomaster et al. (12) reported 1-RM strength increases in the LI-BFR (22%) and LI (23%) groups were not different following unilateral elbow flexor training (50% 1-RM with and without 100 mmHg occlusion pressure and 3 – 6 sets of 10 reps with to failure for the last set) for 8 weeks (2 times per week) in young males. Although this study utilized heavier work-loads and a greater number of sets and repetitions during each training session compared to the present study, neither group had strength increases (both 1-RM and isokinetic strength) (12). Hunt et al. (34) reported the 1-RM strength increases in both LI-BFR and LFF groups were significantly increased after 4 weeks (3 times per week) of unilateral handgrip training (40% 1-RM and 3 sets to failure with and without 80 mmHg occlusion pressure) in young males and still well maintained after 2 weeks of detraining, but there were no statistical group differences.

The MVC at 90 ° and 120 ° in the HI (13.0% and 12.3%) and LI-BFR (10.0% and 8.6%) groups of the present study were increased but not in the CON (-6.8% and 8.6%) group, respectively. Consistent with the results of the present study, Clark et al. (13) reported after 4 weeks (3 times per week) of knee extension training (80% 1-RM and 30% 1-RM with 1.3 times systolic blood pressure of occlusion pressure, and 3 sets to failure) in young males that the MVC strength in both HI (16%) and LI-BFR (8%) groups was increased. Similarly, Credeur et al. (16) showed MVC handgrip strength in the LI-BFR (16.2%) and LI (8%) groups were significantly increased following 4 week (3 times per week) of unilateral handgrip training (15 times per min for 20 minutes with and without

80 mmHg occlusion pressure) in young males. Patterson and Ferguson (72) reported after 4 weeks (3 times per week) of unilateral plantar-flexion training (25% 1-RM and 3 sets to failure with and without 110 mmHg occlusion pressure) in elderly (males and females, aged 62 to 73 years), that plantar-flexion MVC in the LI-BFR group was significantly increased but not in the LI group.

In contrast to our findings, Yasuda et al. (104) reported that MVC strength for HI and CB groups were significantly increased but not for LI-BFR and CON groups after the bench press training for 6 weeks .

In previous BFR studies, LI-BFR training has consistently demonstrated greater muscle hypertrophy and muscle strength gains compared to LI training and the magnitude of changes in muscle hypertrophy and muscle strength gains in the LI-BFR training groups have been similar as or slightly lower than HI training. Generally, high-load resistance training recruits a higher proportion of type II fibers which results in greater muscle hypertrophy and muscle strength gains compared to the lower proportion of type II fibers recruited during low-load exercise (27). However, LI-BFR exercise, as in the present study, may recruit additional type II fibers caused by changes in intramuscular metabolites and pH (37) leading to stimulation of chemosensitive group III and IV afferents (58).

Cardiovascular Responses

Contrary to our hypothesis, PWV (arterial stiffness) and forearm blood flow (FBF) in both HI and LI-BFR groups were not changed after unilateral elbow flexor training. The average values of PWV and FBF in the HI group were only slightly increased but were not statistically significant. The fact that the PWV was significantly different between PRE 1 and PRE 2 and that there were significant group differences for PWV and FBF at baseline may have been due to the age difference between experimental and control groups (21.8 $\pm$2.5 and 27.6 $\pm$6.4, respectively) although this difference was not statistically significant.

The hypothesis in the present study was that PWV in the HI group would increase, but decrease or remain unchanged in the LI-BFR group, and that FBF in both HI and LI-BFR groups would increase. This hypothesis was based on the fact that altered vascular smooth muscle tone during high-load resistance exercise might be caused by the sympathetic nervous system activation and enhanced norepinephrine release resulting in acute elevated blood pressure and ultimately increased arterial stiffness (67).

Consistent with the results of the present study, Clark et al. (13) reported that after 4 weeks of knee extension training (3 times per week and 3 sets to failure) in young males, peripheral PWV for both HI (80% 1-RM) and LI-BFR (30% 1-RM with 1.3 times SBP) groups were unaltered. Rossow et al. (75) reported that both central and peripheral PWV were not changed after 8 weeks (3 times per week) of high-load resistance training (6 exercises, 80% 1-RM and 3 sets of 8 – 10 reps) in both young (aged 18 to 25 years) and old (aged 50 to 64 years) females. Fahs et al. (20) reported arterial compliance (inverse relationship with arterial stiffness) was not altered following HI (70% 1-RM and 3 sets of 10 reps), MI (moderate intensity, 45% of 1-RM and 3 sets of 15 reps) and LI-BFR (20% 1-RM and 75 reps with 160 to 180 mmHg occlusion pressure) resistance training (6 exercises) for 6 weeks (3 times per week) in young males. Yasuda et al. (99) indicated that arterial stiffness was not changed after 12 weeks (2 times per week) of knee extension and leg press training (20 – 30% 1-RM and 75 reps with 120 to 270 mmHg occlusion pressure) in the elderly (males and females, aged 64 to 81 years).

Contrary to the results of the present study, Fahs et al. (22) showed peripheral PWV in both LI-BFR and LFF (low-load free flow) groups was increased after 6 weeks (3 times per week) of unilateral knee extensor training (30% 1-RM, and 2 - 4 sets to failure with and without 50% AOP (150 to 240 mmHg)) in middle-aged males and females. Also, Miyachi et al. (62) reported central arterial compliance was decreased following 4 months (3 times per week) of high-load resistance training (6 exercises, 80% 1-RM and 3 sets of 8 – 12 reps) in young males and returned back to baseline values following 4 months of detraining, but remained unchanged in the CON group during training and detraining. Ozaki et al. (69) reported central arterial compliance was decreased after 6 weeks of bench press training (3 time per week) in young males for the HI group (75% 1-RM and 30 reps) but was unaltered in the LI-BFR group (30% 1-RM and 75 reps with 100 to 160 mmHg occlusion pressure).

In the previous studies mentioned, there were no consistent findings related to arterial stiffness for both HI and LI-BFR training. Also, there were no reasonable explanations for the findings. Many factors, such as sympathetic nervous system activity and endothelial-derived vasoactive substance, influence arterial stiffness (22). A prior study indicated that the acute response of arterial blood pressure during high-load resistance might be strongly related to arterial stiffness (69) however, other studies showed arterial stiffness might not be altered following a single bout of high-load resistance exercise due to increased vasodilation after the exercise is terminated (29).

Further research is required to investigate the effect of HI and LI-BFR training on arterial stiffness.

Factors such as angiogenesis, i.e., increased capillaries and vascular endothelial growth factor (VEGF), have been related to changes in blood flow following exercise. A study that used an acute bout of knee extension resistance exercise (60-80% 1-RM and 3sets of 10 reps) reported an increase in VEGF messenger RNA (mRNA) in untrained young males (25). Also, VEGF mRNA has been shown to increase after inducing ischemia in human epithelial cells in vitro (80) as well as following 45 minutes of unilateral leg cycling with restricted blood flow (50 mmHg above atmospheric pressure) (26). Additionally, VEGF hormone has been shown to increase after acute knee extension resistance exercise (20% 1-RM and 30 reps with 3 sets to failure with 160 – 180 mmHg occlusion pressure) in untrained young males (84). These results indicate that capillary growth may occur after both HI and LI-BFR training.

Thus, the hypothesis in the present study was that the FBF in both HI and LI-BFR groups would increase. However, our findings indicated that FBF in both groups was not significantly changed.

Consistent with the results of the present study, Fahs et al. (22) reported calf blood flow was not altered after 6 weeks of knee extension training in both LI-BFR and LFF in middle-aged males and females. Moreover, Rossow et al. (75) showed resting forearm blood flow was not increased after 8 weeks of HI resistance training (6 exercises) in both young and old females. Patterson and Ferguson (71) indicated that resting calf blood flow was not changed after low-load unilateral plantar flexion training

(25% and 50% 1-RM and 3 sets to failure with and without 110 mmHg occlusion pressure) for 4 weeks (3 times per week) in young females. In addition, Patterson and Ferguson (72) showed that resting blood flow was not increased after 4 weeks of unilateral plantar flexion training (25% 1-RM with and without BFR) in elderly.

Contrary to the results of the present study, Evans et al. (17) showed calf filtration capacity was increased after unilateral calf raise training (30% MVC and 4 sets of 50 reps with 150 mmHg occlusion pressure) for 4 weeks (3 times per week) but not in a LI training group. Also, Hunt et al. (33) reported calf capillary filtration was increased after 6 weeks (3 times per week) of unilateral plantar flexion training with BFR (30% 1-RM and 3 sets to failure with 110 mmHg occlusion pressure) in young males but not in a CON group and Fahs et al. (20) reported that calf blood flow was increased after 6 weeks of HI, MI and LI-BFR resistance training (6 exercises) in young males.

Following LI-BFR exercise, microvascular function may be stimulated by hyperemia following deflation of the restrictive pressure, resulting in a large increase in blood flow (17). Therefore studies that have utilized higher restrictive pressures to restrict blood flow for longer periods of time and over a greater muscle mass like the lower limbs may show greater vascular responses compared to lower restrictive pressures used for upper limb training. More research is needed to elucidate these findings.

Acute Exercise Testing Responses

Acute Muscular Responses

Both MTH and AC at 50%, 60% and 70% in both HI and LI-BFR group were increased over time and % changes and ES in the LI-BFR group were slightly greater than the HI group, but there were no group differences.

The mechanism of muscle hypertrophy after LI-BFR exercise is not certain. Previous BFR studies have reported potential mechanisms include: 1) additional recruitment of type II fibers induced by local accumulation of metabolites (95), 2) elevation of anabolic hormone concentration (85), 3) decline of myostatin gene expression (45), 4) reactive hyperemia (enhanced blood flow after releasing occlusion pressure) (17) , and 5) cell swelling (49).

Cell swelling (cellular hydration), which is blood plasma movement into cells induced by changes of intracellular to extracellular pressure gradients, results in the membrane being stretched, which they could stimulate a volume sensor, leading to an enhanced anabolic response including stimulation of protein synthesis, inhibition of proteolysis (78) and the stimulation of muscle hypertrophy pathways such as mammalian target of repamycin (mTOR) and mitogen-activated protein-kinase (MAPK) (47).

Generally, resistance exercise is related to cell swelling (78) and enhanced intracellular metabolites induced by restricted blood flow also result in cell swelling during BFR exercise or BFR alone (51). Thus, the LI-BFR resistance exercise used in the current study might have promoted the cell swelling response.

Acute increases in muscle size are strongly related to a decrease in plasma volume (fluids shifting into cells) (6). Thus, measuring MTH and AC before and after an acute exercise session may be good indicators for cell swelling.

Consistent with the results of the present study, Yasuda et al. (100) showed that the MTH for the biceps brachii in both LI-BFR and LFF groups were increased after acute arm curl exercise (20% 1-RM and 4 sets to failure with and without 160 mmHg occlusion pressure) in young males. Fahs et al. (19) reported that the MTH in the lateral quadriceps was increased in both LI-BFR and LFF groups after acute unilateral knee extension exercise (8^{th} of 18 sessions) in middle-aged males and females and was only increased in the LI-BFR group after 6 weeks of training, but not in the LFF group. Yasuda et al. (101) reported that the MTH at 10 cm from the elbow joint and at the mid-point of the biceps brichii (measured by Ultrasound, one per week - total 6 times and averaged values) were increased after both concentric (CON-BFR) and eccentric (ECC-BFR) unilateral elbow flexor exercise (30% 1-RM and 75 reps with 100 to 160 mmHg occlusion pressure) in young males but the magnitude of change in the CON-BFR group was greater than the ECC-BFR group and only the CON-BFR group had muscle hypertrophy (measured by MRI) after 6 weeks of training.

Results in previous studies (19, 101) and the present study indicate that increased MTH after acute LI-BFR exercise (cell swelling) is related to the muscle hypertrophy observed after the exercise session and may represent the best explanation of a mechanism for BFR related muscle hypertrophy.

Acute Whole Blood Lactate and Hematocrit Responses

Consistent with our hypothesis, whole blood lactate was significantly increased in both HI and LI-BFR groups after a bout of unilateral elbow flexor exercise; however, hematocrit increased significantly for only the HI group.

The accumulation of lactate, which is strongly related with 60 to 80% 1-RM resistance exercise, may directly stimulate one of the muscle hypertrophy pathways (mTOR) (79). In addition, the lactate accumulated from LI-BFR training due to the hypoxic status of the limb results in an increase in intracellular hydration, also leading to cell swelling (79) and the reduction of blood plasma volume (inversely related with hematocrit). Furthermore, the acidic and hypoxic intramuscular environment created with BFR training can also stimulate chemosensitive group III and IV afferents leading to the recruitment of additional type II fibers (58).

Consistent with the results of the present study, Yasuda et al. (100) showed after acute arm curl exercise with BFR in young males, lactate and hematocrit were significantly increased. However, the lactate and hematocrit return to baseline 15 minutes post-testing whereas cell swelling was maintained until 60 minutes post-testing. Madarame et al. (57) reported that the blood lactate was increased immediately post and 15 and 30 minutes post-testing following a bout of upper limb (UL, biceps curl and triceps press down) and lower limb (LL, leg extension and flexion) exercise (30% 1-RM and 30 reps with 2 sets to failure with 130 mmHg (for the upper limbs) and 200 mmHg (for the lower limbs) occlusion pressure) in young males, and that there were no group differences at each time point even though mean values of lactate concentration in the LL group were greater than in the UL group. Yasuda et al. (93) reported that lactate concentrations were increased following a bout of unilateral elbow flexor exercise (20% 1-RM and 75 reps with and without occlusion peruse (100 and 160 mmHg, and 70% 1-RM and 3 sets to failure) in young males, and that the magnitude of change for lactate increased from low to high intensity (LI to LI-BFR (100 mmHg) to LI-BFR (160 mmHg) to HI); however, hematocrit did not change in any group. Manini et al. (59) reported the concentrations of lactate in young and elderly males were increased after acute knee extension exercise (20% 1-RM and 4 sets to failure with 1.5 times the SBP (135-186 mmHg) occlusion pressure and 80% 1-RM and 4 sets to failure), and that both LI-BFR and HI groups in the young and older men showed similar peak patterns. However, the lactate response for the LI-BFR group in the young males had a slight delay reaching peak values compared to the HI group and the peak lactate values for the LI-BFR group in the elderly males were slightly lower than for the HI group (59). Kim et al. (36) reported increased blood lactate concentrations in college-aged women after acute knee extension and leg press exercises (20% 1-RM and 60 reps with 200 mmHg occlusion pressure and 80% 1-RM and 3 sets of 10 reps), and the magnitude if changes for the HI group was significantly greater than for the LI-BFR group. Additionally, hematocrit in both HI and LI-BFR groups were increased with no group difference (36).

In these aforementioned studies (36, 57, 93), the changes in lactate concentrations for HI groups were greater than for LI-BFR groups most likely due to the higher volume of exercise in the HI groups compared to LI-BFR groups.

Contrary to the results in the present study, Takarada et al. (87) reported that after acute unilateral elbow flexor exercise (40% 1-RM and 20 reps with 100 mmHg occlusion pressure and 80% 1-RM and 10 reps) in young males that lactate concentrations for the LI-BFR group were significantly higher than for the HI group.

Acute Maximal Voluntary Contraction Responses

Consistent with our hypothesis, the MVC at 90 ° and 120 ° in both HI and LI-BFR groups were significantly decreased after acute elbow flexor exercise, but the MVC at 90 ° and 120 ° in the LI-BFR group was significantly lower than the HI group. Moreover, EMG amplitude and MFP at 90 ° in both HI and LI-BFR groups were significantly decreased with no group difference at acute POST, but only EMG amplitude and MFP at 120 ° in the HI group was significantly decreased.

Central or peripheral fatigue influenced by intense muscle performance (MVC) is related with lactate accumulation and EMG activity (46). Muscular fatigue induced by acidic intracellular environments can result in lower movement and sensitivity of Ca^{++} thereby reducing muscle force production (43).

Consistent with the results in the present study, Cook et al. (15) reported that MVC was significantly decreased after unilateral knee extension (20% and 40% MVC, 3 sets to failure with 160 and 300 mmHg occlusion pressure and 80% MVC, 3 sets to failure) in young males and females, and that MVC in the 20% MVC with 300 mmHg BFR group was significantly lower than for the HI group. In fact, the MVC in most LI-BFR protocols are reported to be slightly lower than the HI group without significant group differences (15). Yasuda et al. (95) reported the MVC (at 90 °) and EMG (MPF) were decreased after a bout of unilateral elbow flexion (20% 1-RM and 30 reps, 3 sets of 10 reps, and 3 sets of 15 reps with 160 and 300 mmHg occlusion pressure) in young males but not in the LI group, and MVC and EMG in the LI-BFR (300 mmHg) group was lower than in the LI-BFR (160 mmHg) group. Additionally, the MVC measured after one of minute rest following the POST test was still significantly lower than baseline, but EMG activity was not different between groups (95). Similarly, in the present study, the MVC in the LI-BFR group at both 90 ° and 120 ° was significantly lower than baseline, but EMG at 120 ° was not different from baseline since the MVC 120 ° was measured following 30 seconds of rest after the EMG 90 ° measurement. There results indicate that the decreases in MVC and EMG after LI-BFR exercise are caused by muscle fatigue and not muscle damage.

Only one BFR study (92) suggested that the dramatic decrease in MVC after LI-BFR exercise was due to muscle damage. However, Loenneke et al. (50) was able to demonstrated that the dramatic decrease in MVC for the LI-BFR group was measured immediately post exercise while the BFR cuffs were still inflated and that MVC returned to baseline all other time points (4, 24, 48, 72, 96 hours after exercise).

Exercise Training

Volume of Exercise, RPE and Discomfort Responses

The volume of exercise in both HI and LI-BFR groups were gradually increased during the 8 week training period without any significant differences although the volume for the HI group was slightly greater than the LI-BFR group. The RPE and discomfort for both HI and LI-BFR groups increased from set 1 to set 3 or set 4 consistently during each training day.

Chapter V: Conclusions

Purpose of the Study

The purpose of this study was to compare the skeletal muscle (arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) and vascular responses (forearm blood flow and peripheral arterial stiffness) following eight weeks of unilateral elbow flexor resistance exercise with either a traditional high-load without BFR or a low-load with BFR (50% of arterial blood flow occlusion) in untrained college-aged males.

A secondary purpose of this study was to compare the acute skeletal muscle responses (muscle thickness, muscle activity, isometric strength, hematocrit and blood lactate) between traditional high-load and low-load with BFR unilateral elbow flexor resistance exercise in college-aged males.

Research Hypotheses

1. **Low-load elbow flexor resistance training with BFR will produce skeletal muscle responses (increases in arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) similar to traditional high-load elbow flexor resistance training.**

   Low-load elbow flexor resistance training with BFR was able to increase arm circumference, muscle thickness, muscle activity and strength (isometric and isotonic) similar to traditional high-load elbow flexor resistance training, therefore this hypothesis was accepted.

2. **Low-load elbow flexor resistance training with BFR will produce increased forearm blood flow response similar to traditional high-load elbow flexor resistance training but unchanged or decreased peripheral arterial stiffness response different from traditional high-load elbow flexor resistance training.**

   Both low-load combined with BFR and traditional high-load elbow flexor resistance training did not alter forearm blood flow and peripheral arterial stiffness, therefore this hypothesis was not supported.

3. **High-load elbow flexor resistance training will produce vascular responses (increases in forearm blood flow and peripheral arterial stiffness) different from a control (non-exercise) group and the low-load elbow flexor resistance training with BFR will produce vascular responses (increase in forearm blood flow and unchanged or decreased peripheral arterial stiffness) different from a control (non-exercise) group.**

   At the baseline, peripheral arterial stiffness and forearm blood flow were significantly different among groups and arterial stiffness in all groups was unaltered after training, therefore this hypothesis was not supported.

Subhypothese

1. **Low-load elbow flexor resistance exercise with BFR will produce acute skeletal muscle responses (increases in muscle thickness, hematocrit and blood lactate and decrease in isometric strength and muscle activity) similar to traditional high-load elbow flexor resistance exercise.**

   Low-load elbow flexor resistance exercise with BFR was able to increases in muscle thickness, hematocrit and blood lactate and decreases in isometric strength and muscle activity similar to traditional high-load elbow flexor resistance exercise, therefore this hypothesis was accepted.

Limitations

The results of the present study are limited to healthy college-aged male population and may be different from other age populations or gender. Also, the results from unilateral high-load or low load with BFR elbow flexor resistance training may be different from other types of exercise protocols or other muscle groups. Another limitation was the lack of daily diet and physical activity monitoring during the training period which could influence the results of muscle hypertrophy, muscle strength gain or cardiovascular measurements. Also, the results of the cardiovascular responses are from a small muscle group (biceps brachii) and a short training period (8 weeks) in the present study and may be different if used large muscle groups and longer training periods were used. In addition, the small sample size used in this study may have underpowered our statistical analysis.

Significance

Low-load resistance training combined with blood flow restriction is able to increase muscle size and muscle strength without increasing arterial stiffness similar to high-load resistance training. Thus, this type of exercise may be appropriate for some populations who are not able to perform high-load resistance exercise due to cardiac or joint problems such as the elderly, clinical patients, or individuals undergoing rehabilitation.

Additionally, the muscle hypertrophy and strength gains that were elicited in the present study were done with lower BFR pressure than many previous BFR studies indicating that lower restrictive pressures may be as effective as higher pressures that have been used in the past.

Future Research

Future studies should investigate this type of exercise with different muscle groups, varying protocols (to failure), training durations, and occlusion pressures while using robust measurements for muscle hypertrophy such as magnetic resonance imaging (MRI), peripheral quantitative computed tomography, and mRNA expression.

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Appendix A: IRB Approval Letter, Consent Form, and HIPPA

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Initial Submission – Board Approval

Date: August 08, 2014

To: Michael G Bemben, PHD

IRB#: 4309
Meeting Date: 08/04/2014
Approval Date: 08/08/2014
Expiration Date: 07/31/2015

Study Title: Comparison of Upper Limb Muscular and Vascular Responses Following Traditional High-load and Low-load Resistance Training _with or without Blood Flow Restriction in College-aged Males

Reference Number: 595707
Study Status: Active - Open
Collection/Use of PHI: Yes

At its regularly scheduled meeting the IRB reviewed the above-referenced research study. Study documents (e.g. protocol, consent, survey, etc.) associated with this submission are listed on page 2 of this letter. To review and/or access the submission forms (e.g. application) as well as the study documents approved for this submission, open this study from the *My Studies* option, click to open this study, look under Protocol Items to click on the current *Application*, *Informed Consent* and *Other Study Documents*.

If this study required routing through the Office of Research Administration (ORA), you may *not begin your study yet*, as per OUHSC Institutional policy, until the contract through ORA is finalized and signed.

As principal investigator of this research study, it is your responsibility to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations at 45 CFR 46 and/or 21 CFR 50 and 56.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB Policy.
- Maintain accurate and complete study records for evaluation by the HRPP quality improvement program and if applicable, inspection by regulatory agencies and/or the study sponsor.
- Promptly submit continuing review documents to the IRB upon notification approximately 60 days prior to the expiration date indicated above.

In addition, it is your responsibility to obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.

If you have questions about this notification or using iRIS, contact the IRB @ 405-271-2045 or irb@ouhsc.edu.

Sincerely,

Karen Beckman, MD
Chairperson, Institutional Review Board

Consent Form
University of Oklahoma Health Sciences Center (OUHSC)

Comparison Of Upper Limb Muscular And Vascular Responses Following Traditional High-Load And Low-Load Resistance Training With or Without Blood Flow Restriction In College-Aged Males

Sponsor: Department of Health & Exercise Science
University of Oklahoma
Norman, OK 73019

Principal Investigator: **Michael Bemben, PhD**
University of Oklahoma
405-325-2717

This is a research study. Research studies involve only individuals who choose to participate. Please take your time to make your decision. Discuss this with your family and friends.

Why Have I Been Asked To Participate In This Study?
You are being asked to take part in this study because you are a healthy young male between the ages of 18 and 35 who exercises no more than twice a week.

Why Is This Study Being Done?
The purpose of this study is to see how blood flow restriction (BFR) with low intensity exercise affects arm circumference, muscle thickness, muscle activity, strength, forearm blood flow, and peripheral arterial stiffness as compared with traditional high intensity exercise without blood flow restriction in untrained 18-35yo males.

How Many People Will Take Part In The Study?
About 60 young men (30 control and 30 research subjects) will take part in this study, all at this location.

What Is Involved In The Study?
You will be in the study for a total of 10 weeks, including one week of pre outcome testing (PRE 1 and PRE 2 to establish reliability of the measurements) and one week of post outcome (POST) testing. You will be randomized to either the exercise or the control group. Randomization means you have a 50/50 chance (like flipping a coin) of being in either group. Subjects in the experimental group will train for eight weeks with each arm individually performing elbow flexor training using either a traditional high load protocol or a low load with BFR protocol (three times per week, total 24 sessions), and then post outcome testing will be completed. The subjects in the control (non-exercise, CON) group will maintain their current activity levels and will then complete the post outcome testing.

The initial portion of the study will include screening, a familiarization session, and pre outcome testing. At least 48 hours and within 10 days after the first pre outcome testing, the second pre outcome testing will be completed. In the first and second sessions of fourth week, acute response measurements will be assessed for the exercise group.

All initial consenting and inclusion/exclusion visits as well as any follow up visits will take place inside the Health and Exercise Science building located at 1401 Asp Avenue HHC # 104, Norman, OK 73019. All testing sessions will take place in the Neuromuscular Research (HHC # 06) laboratory and Diagnostic Ultrasound laboratory (HHC # 02) located in the Department of Health and Exercise Science at the aforementioned address.

Visit #1 Initial screening (90-100 minutes)

Questionnaires
You will be asked to sign a consent form, a Health Information Privacy (HIPAA) form, a Physical Activity Readiness Questionnaire (PAR-Q), and health status questionnaires.

Body Mass and Height
A digital scale will measure your body mass, and a wall stadiometer will measure your height. Your body mass index (BMI (kg/m^2)) will be calculated: weight (kg) divided by height (m^2).

Brachial Blood Pressure
You will lay flat on a bed for 10 minutes of rest, then your blood pressure will be measured two times with an automatic blood pressure cuff and the values will be averaged.

Ankle Brachial Index (ABI)
A blood pressure cuff will be applied on your right arm and inflated, and blood flow will be determined by a probe. Following the measurement on the right arm, the blood pressure cuff will be placed on your right ankle and inflated. This measurement will be repeated on the left ankle and left arm.

Forearm Circumference
While you are lying flat on a bed, a tape measure will be applied to measure forearm circumference of both arms at the largest circumference site. The same procedure will be completed on the other arm.

Familiarization Session

Rating of Perceived Exertion and Discomfort
The Rating of Perceived Exertion and Discomfort scales will be explained to you.

Maximal Isometric Voluntary Contraction
You will be seated on an isokinetic dynamometer and one of your arms will perform isometric elbow flexion for 3 seconds to measure the highest torque. Three submaximal contractions will be performed as a warm up followed by two maximal contractions. After that your arm will then be moved to a 120 degree angle and you will complete two additional maximal contractions. The same procedures will be completed by the other arm.

One-Repetition Maximum (1-RM)
1-RM testing will be performed to determine the maximum strength for the elbow flexors of each arm. After you will complete a standard warm-up, you will begin the 1-RM procedure. Weight will be incrementally increased until the maximum weight that can be lifted in one repetition with correct form is reached.

Blood flow restriction
When you are standing, a specialized blood pressure cuff will be worn at the most proximal end of one of the arms, and arterial occlusion pressure will be determined. After determining the arterial occlusion pressure, you will perform single arm dumbbell curl for 2 sets of 15 repetitions at 30% 1-RM combined with blood flow restriction. Following low intensity protocol, you will rest for 5 minutes and will perform single arm dumbbell curl with other arm for 2 sets of 5 repetitions at 75% 1-RM.

Visits # 2 & 3 (80 – 90 minutes each)

Pre Outcome Testing (PRE 1 and PRE 2)
After finishing the initial screening and familiarization, first pre outcome testing (PRE 1) will be completed. A second pre outcome testing (PRE 2) session will take place at least 48 hours after PRE 1, but before the end of 10 days to assess measurement reliability. You will do the following tests for both PRE 1 and PRE 2:

Body Mass and Height

Muscle Thickness
You will stand with your arms fully extended downward at their side and relaxed. Muscle thickness at 50%, 60% and 70% sites of biceps brachii for both arms will be determined by an ultrasound. Three scans will be taken at each marked site for each arm.

Upper Arm Circumference
While you are standing with your arms at your side, a tape measure will be applied to measure arm circumference at 50%, 60% and 70% sites of the upper arm. Both arms will be assessed.

Brachial Blood Pressure
You will be lay flat on a bed for 10 minutes of rest, then your blood pressure will be measured two times with an automatic blood pressure cuff.

Pulse Wave Velocity (PWV)
The stiffness of your blood vessels will be determined by measuring pulse wave velocity for both arms. Electrocardiography (ECG) sites will be placed below the right and left clavicles and below the left rib cage and the speed of blood flow through your blood vessels will be measured a probe.

Forearm Blood Flow

Your forearm will be placed on a foam pad and a blood pressure cuff will be placed on your wrist and upper arm. A strain gauge (similar to a rubber band) will be placed around your forearm and the blood pressure cuff on the upper arm will be inflated to 50 mmHg for 7 seconds and then deflated for 8 seconds to measure blood flow. Both arms will be assessed.

One-Repetition Maximum (1-RM)
1-RM testing will be performed to determine the maximum strength for the elbow flexors of each arm. After you will complete a standard warm-up, you will begin the 1-RM procedure. Weight will be incrementally increased until the maximum weight that can be lifted in one repetition with correct form is reached.

Maximal Isometric Voluntary Contraction
You will be seated on a machine that measures your muscle power and one of your arms will perform isometric elbow flexion for 3 seconds to measure the highest torque. Three submaximal contractions will be performed as a warm up followed by two maximal contractions. After that your arm will then be moved to a 120 degree angle and you will complete two additional maximal contractions. The same procedures will be completed by the other arm.

Electromyography
During the maximal isometric voluntary contraction test, muscle activity will be measured by electrodes placed on the upper arms and on the back of your neck.

Visits # 4 - 28 (about 25 minutes each, except Visit # 10 and 11)

Exercise Training Protocols
If you are in the exercise group, you will complete 24 exercise sessions. Your arm will be randomly assigned to perform one of two exercise protocols with a dumbbell at traditional high intensity (75% 1-RM, HI) with 10 repetitions of 3 sets or low intensity (30% 1-RM) with blood flow restriction (LI-BFR)) with 30 repetitions followed by three sets of 15 repetitions. During each training session, the starting order for each arm will be randomized. For example, if you perform the high intensity protocol first, you will complete low intensity protocol later and vice versa. The control group will not perform any exercise sessions.

Visits #10 - 11 (about 50 - 60 minutes each)

Acute Response Testing
Acute response measurements (muscle thickness and upper arm circumference, whole blood lactate, hematocrit, maximal isometric voluntary contraction and electromyography) will be obtained before (Acute PRE) and after one of the exercise protocols (Acute POST) in the first and second sessions of fourth week. In the Visit #10, you will perform one of exercise protocols (high intensity or low intensity with blood flow restriction with PRE and POST Acute Response Testing, and then you will complete other protocol as a normal exercise session. In the Visit #11, you will perform untested exercise protocol in the Visit #10 with Acute Response Testing, and then you will complete other protocol as a normal exercise session. You will do the following tests both before and after the exercise sessions. After post testing one arm, you will rest 5

minutes, and then you will complete the exercise protocol for the untested arm as a normal exercise session.

Muscle Thickness
You will stand with your arms fully extended downward at their side and relaxed. Muscle thickness at 50%, 60% and 70% sites of biceps brachii for both arms will be determined by an ultrasound. Three scans will be taken at each marked site for each arm.

Upper Arm Circumference
While you are standing with your arms at your side, a tape measure will be applied to measure arm circumference at 50%, 60% and 70% sites of the upper arm. Both arms will be assessed.

Whole Blood Lactate
Fingertip blood lactate samples will be obtained before and after exercise protocols. A finger will be pricked by a lancet and then will be lightly pressed to form a drop of blood for determining blood lactate.

Hematocrit (HCT)
Following blood lactate measurements, hematocrit will be measured by filling two small tubes with blood. We will try to get the blood from the same finger prick used for the lactate measure, however, we may have to do another finger prick for the hematocrit measurement.

Maximal Isometric Voluntary Contraction
You will be seated on an isokinetic dynamometer and one of your arms will perform isometric elbow flexion for 3 seconds to measure the highest torque. Three submaximal contractions will be performed as a warm up followed by two maximal contractions. After that your arm will then be moved to a 120 degree angle and you will complete two additional maximal contractions. The same procedures will be completed by the other arm.

Electromyography
During the maximal isometric voluntary contraction test, muscle activity will be measured by electrodes placed on the upper arms and on the back of your neck.

Visit #29 (about 80 – 90 minutes)

POST Outcome Testing (POST)
If you are in the exercise group, you will undergo the same tests that you did in the PRE outcome testing (Visit #2) the week after completing the eight weeks of training. If you are in the control group, your Visit #4 will occur eight weeks following the PRE 2 testing (Visit #3) and you will undergo the same tests that you did in the PRE outcome testing.

How Long Will I Be In The Study?
You will be in this study for approximately 10 weeks. Visits #1, 2, 3 and 29 (#4 for the control group) take approximately 90 minutes each. If you are in the exercise group, you will complete 8 weeks of training 3 times per week with each session taking approximately 25 minutes each. Exercise sessions with acute response testing in the first and second sessions of 4th week of

training period will take approximately 60 minutes each. If you are in the control group, you will complete Visits #1, 2, 3, and the post testing.

There may be circumstances under which your participation may be terminated by the investigator without regard to your consent. For reasons such as not adhering to all study guidelines, for health concerns observed by the investigators, or if the study is terminated by the investigators.

You can stop participating in this study at any time. However, if you decide to stop participating in the study, we encourage you to talk to the researcher.

What Are The Risks of The Study?
While in the study, you are at risk for these side effects. There may also be risks that are currently unforeseeable. You should discuss these with the researcher and/or your regular doctor prior to providing your consent to participate.

Risks and side effects related to blood flow restriction:

- Feeling faint, fatigued, lightheaded and possibility of passing out (rare).
- Bruising and discomfort caused by the strap (rare).
- Numbness (slight tingling that typically goes away upon release of the cuff)[possible]
- There is a theoretical risk that restricting blood flow in the arm could increase the risk of developing a blood clot in one of the veins but this has not been observed to date (rare).

Risks and side effects related to exercise:

- Feeling faint, fatigued, lightheaded and possibility of passing out due to physical exertion (rare).
- Muscle soreness and/or stiffness beginning within 24 hours post-exercise and lasting for several days (possible).
- Muscle fatigue, shortness of breath, and elevated heart rate during and trouble walking immediately following maximal exercise tests (possible).

Risks and side effects related to having a Finger Stick:

- Bleeding at the sight of puncture (possible)
- Pain at the sight of puncture (possible)
- Feeling lightheaded or faint (rare)
- A slight possibility of infection which can occur anytime the skin is broken (possible-rare)

Are There Benefits to Taking Part in The Study?
There are no direct benefits to taking part in this study.

What Other Options Are There?
You may choose not to participate.

What About Confidentiality?

Efforts will be made to keep your personal information confidential. You will not be identifiable by name or description in any reports or publications about this study. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. You will be asked to sign a separate authorization form for use or sharing of your protected health information.

There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include the faculty members and graduate students appointed to this protocol from the Department of Health & Exercise Science at the University of Oklahoma, and the OUHSC Institutional Review Board

What Are the Costs?
There are no costs to you for participating in this study.

Will I Be Paid For Participating in This Study?
If you are in the exercise group, you will receive $5.00 for completing the PRE1 and PRE2 testing ($10.00 total), $10.00 for completing the POST testing, and $25.00 for completing at least 21/24 exercise sessions. If you are in the control group, you will receive $5.00 for completing the PRE1 and PRE2 testing ($10.00 total) and $10.00 for completing the POST testing.

What if I am Injured or Become Ill While Participating in this Study?
In the case of injury or illness resulting from this study, emergency medical treatment will be available. If injury occurs as a result of participation, you should consult with your personal physician to obtain treatment. However, you or your insurance company will be responsible for the costs of this treatment. No funds have been set aside by The University of Oklahoma Health Sciences Center or the Department of Health & Exercise Science to compensate you or pay for the costs associated with treatment in the event of injury.

What Are My Rights As a Participant?
Taking part in this study is voluntary. You may choose not to participate. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. If you agree to participate and then decide against it, you can withdraw for any reason and leave the study at any time. However, please be sure to discuss leaving the study with the principal investigator. You may discontinue your participation at any time without penalty or loss of benefits, to which you are otherwise entitled.

You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study has completely finished and you consent to this temporary restriction.

Whom Do I Call If I have Questions or Problems?
If you have questions, concerns, or complaints about the study or have a research-related injury, contact Michael Bemben, PhD at 405-325-2717 or Daeyeol Kim at 405-325-5211.

If you cannot reach the Investigator or wish to speak to someone other than the investigator, contact the OUHSC Director, Office of Human Research Participant Protection at 405-271-2045.

For questions about your rights as a research participant, contact the OUHSC Director, Office of Human Research Participant Protection at 405-271-2045.

Signature:
By signing this form, you are agreeing to participate in this research study under the conditions described. You have not given up any of your legal rights or released any individual or entity from liability for negligence. You have been given an opportunity to ask questions. You will be given a copy of this consent document.

I agree to participate in this study:

PARTICIPANT SIGNATURE (age ≥18) *(Or Legally Authorized Representative)*	Printed Name	Date
SIGNATURE OF PERSON OBTAINING CONSENT	Printed Name	Date

IRB No.: 4309

AUTHORIZATION TO USE or DISCLOSE
PROTECTED HEALTH INFORMATION FOR RESEARCH

An Informed Consent Document for Research Participation may also be required.
Form 2 must be used for research involving psychotherapy notes.

Title of Research Project: **Comparison Of Upper Limb Muscular And Vascular Responses Following Traditional High-Load And Low-Load Resistance Training With or Without Blood Flow Restriction In College-Aged Males**

Leader of Research Team: **Michael G. Bemben**

Address: **Huston Hufman Center # 115, Norman, OK 73019**

Phone Number: **405-325-2717**

If you decide to join this research project, University of Oklahoma Health Sciences Center (OUHSC) researchers may use or share (disclose) information about you that is considered to be protected health information for their research. Protected health information is information about past, present, and future medical treatment or condition that is identifiable to you. It will be called PHI in this Authorization.

PHI To Be Used or Shared. Federal law requires that researchers get your permission (authorization) to use or share your PHI. If you give permission, the researchers may use or share with the people identified in this Authorization any PHI related to this research from your medical records and from any test results. Information used or shared may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form; medical records and charts; name, address, telephone number, date of birth, race, and government-issued identification numbers.

Purposes for Using or Sharing PHI. If you give permission, the researchers may use your PHI to compare the skeletal muscle (arm circumference, muscle thickness, muscle activity, and isometric and isotonic strength) and vascular responses (forearm blood flow and peripheral arterial stiffness) following 8 weeks of unilateral elbow flexor resistance exercise with a traditional high-load intensity without blood flow restriction (BFR) and a low-load intensity with BFR (50% of arterial blood flow occlusion) in untrained college-aged males. A secondary purpose of this study is to compare the acute skeletal muscle responses (muscle thickness, muscle activity, isometric strength, hematocrit and blood lactate) between traditional high-load and low-load with BFR unilateral elbow flexor resistance exercise in college-aged males.

Other Use and Sharing of PHI. If you give permission, the researchers may also use your PHI to develop new procedures or commercial products. They may share your PHI with other researchers, the research sponsor, and its agents, the OUHSC Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Food and Drug Administration (FDA)

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and the Department of Health and Human Services (HHS). The researchers may also share your PHI with no one else.

Confidentiality. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information confidential, but confidentiality is not guaranteed. The law does not require everyone receiving the information based on this authorization to keep it confidential, so they could release it to others, and federal law may no longer protect it.

YOU UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING A COMMUNICABLE OR NONCOMMUNICABLE DISEASE.

Voluntary Choice. The choice to give OUHSC researchers permission to use or share your PHI for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OUHSC researchers to use or share your PHI if you want to participate in the research and, if you cancel your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care from OUHSC.

Cancelling Permission. If you give the OUHSC researchers permission to use or share your PHI, you have a right to cancel your permission whenever you want. However, cancelling your permission will not apply to information that the researchers have already used, relied on, or shared.

End of Permission. Unless you cancel it, permission for OUHSC researchers to use or share your PHI for their research will never end You may cancel your permission at any time by writing to:

Privacy Official
University of Oklahoma Health Sciences Center
PO Box 26901
Oklahoma City, OK 73190

or

Privacy Board
University of Oklahoma Health Sciences Center
PO Box 26901
Oklahoma City, OK 73190

If you have questions, call: (405) 271-2511 or (405) 271-2045.

Access to Information. You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study is completely finished. You consent to this temporary restriction.

Giving Permission. By signing this form, you give OUHSC and OUHSC's researchers led by Michael G. Bemben, permission to share your PHI for the research project called Comparison Of Upper Limb Muscular And Vascular Responses Following Traditional High-Load And Low-Load Resistance Training With Blood Flow Restriction In College-Aged Males.

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Patient/Participant Name: ______________________

_______________________________________ ______________

Signature of Patient-Participant Date
or Parent if Participant is a minor

Or

_______________________________________ ______________

Signature of Legal Representative** Date

**If signed by a Legal Representative of the Patient-Participant, provide a description of the relationship to the Patient-Participant and the Authority to Act as Legal Representative:

____

OUHSC may ask you to produce evidence of your relationship.

A signed copy of this form must be given to the Patient-Participant or the Legal Representative at the time this signed form is provided to the researcher or his representative.

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Appendix B: Other Forms

PAR-Q & YOU

(A questionnaire for People Aged 15-69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with your doctor before you start.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the **PAR-Q** will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check **YES** or **NO**

YES ☐	NO ☐	**1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
YES ☐	NO ☐	**2. Do you feel pain in your chest when you do physical activity?**
YES ☐	NO ☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
YES ☐	NO ☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
YES ☐	NO ☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
YES ☐	NO ☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
YES ☐	NO ☐	**7. Do you have a diabetes or thyroid condition?**
YES ☐	NO ☐	**8. Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered "Yes":

YES to one or more questions

A medical clearance form is required of all participants who answer 'yes' to any of the eight **PAR-Q** questions.
Note: Personal training staff reserve the right to require medical clearance from any client they feel may be at risk.

- Discuss with your personal doctor any conditions that may affect your exercise program.
- All precautions must be documented on the medical clearance form by your personal doctor.

NO to all questions

If you answered **NO** honestly to <u>all</u> **PAR-Q** questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professionals. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q:</u> The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability to persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME______________________________

SIGNATURE______________________________ **DATE**____________________

SIGNATURE OF PARENT________________________ **WITNESS**____________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP SCPE

Supported by: Health Canada Santé Canada

Physical Activity Readiness Questionnaire – PAR-Q (revised 2008 by CW)

IRB APPROVED
IRB NUMBER: 4309
IRB APPROVAL DATE: 08/08/2014

Neuromuscular Research Laboratory
OU Department of Health and Exercise Science
Health Status Questionnaire

Instructions: Complete each question accurately. All information provided is confidential.

(NOTE: The following codes are for office use only: RF; MC; SLA; SEP)

Part 1. Information about the individual

1.____

Date

2. ____

Legal name Nickname

3.____

Mailing address

____

Home phone Business phone

4.Gender (circle one): Female Male (RF)

5. Year of birth: ____________________ Age ________ Dominant Arm: (Right or Left)

6. Number of hours worked per week: Less than 20 20-40 41-60 Over 60

(SLA) More than 25% of time spent on job (circle all that apply)

Sitting at desk Lifting or carrying loads Standing Walking Driving

Part 2. Medical history

7. (RF) Circle any who died of heart attack before age 50:

Father Mother Brother Sister Grandparent

8.Date of: Last medical physical exam: ____________ Last physical fitness test: ____________

Year Year

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9. Circle operations you have had:

Back (SLA)	Heart (MC)	Kidney (SLA)	Eyes (SLA)	Joint (SLA, Wrist, Elbow and Shoulder)
Neck (SLA)	Ears (SLA)	Hernia (SLA)	Lung (SLA)	Other____________________

10. Please circle any of the following for which you have been diagnosed or treated by a physician or health professional:

Alcoholism (SEP)	Diabetes (SEP)	Kidney problem (MC)
Anemia, sickle cell (SEP)	Emphysema (SEP)	Mental illness (SEP)
Anemia, other (SEP)	Epilepsy (SEP)	Neck strain (SLA)
Asthma (SEP)	Eye problems (SLA)	Obesity (RF)
Back strain (SLA)	Gout (SLA)	Osteoporosis
Bleeding trait (SEP)	Hearing loss (SLA)	Phlebitis (MC)
Bronchitis, chronic (SEP)	Heart problems (SLA)	Rheumatoid arthritis (SLA)
Cancer (SEP)	High blood pressure (RF)	Stroke (MC)
Cirrhosis, liver (MC)	Hypoglycemia (SEP)	Thyroid problem (SEP)
Concussion (MC)	Hyperlipidemia (RF)	Ulcer (SEP)
Congenital defect (SEP)	Infectious mononucleosis (MC)	Other ____________________

11. Circle all medicine taken in last 6 months:

Blood thinner (MC)	Epilepsy medication (SEP)	Nitroglycerin (MC)
Diabetic pill (SEP)	Heart-rhythm medication (MC)	Estrogen
Digitalis (MC)	High-blood-pressure medication (MC)	Thyroid
Diuretic (MC)	Insulin (MC)	Corticosteroids
Asthma	Other ____________________	

12. Any of these health symptoms that occurs frequently is the basis for medical attention. Circle the number indicating how often you have each of the following:

1 = Practically never 2 = Infrequently 3 = Sometimes 4 = Fairly often 5 = Very often

a. Cough up blood (MC)	d. Leg pain (MC)	g. Swollen joints (MC)
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
b. Abdominal pain (MC)	e. Arm or shoulder pain (MC)	h. Feel faint (MC)
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
c. Low back pain (SLA)	f. Chest pain (RF) (MC)	I. Dizziness (MC)
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
j. Breathless with slight exertion (MC)		
1 2 3 4 5		

Part 3. Health-related behavior

13. (RF) Do you now smoke? Yes No

14. If you are a smoker, indicate number smoked per day:

Cigarettes:	40 or more	20-39	10-19	1-9
Cigars or pipes only:	5 or more or any inhaled		Less than 5, none inhaled	

15. Weight now: ________lb. One year ago: ________lb.. Age 21: ________lb.

16. Thinking about the things you do at work, how would you rate yourself as to the amount of physical activity you get compared with others of your age and sex?

1. Much more active
2. Somewhat more active
3. About the same
4. Somewhat less active
5. Much less active
6. Not applicable

17. Now, thinking about the things you do outside of work, how would you rate yourself as to the amount of physical activity you get compared with others of your age and sex?

1. Much more active
2. Somewhat more active
3. About the same
4. Somewhat less active
5. Much less active
6. Not applicable

18. Do you regularly engage in strenuous exercise or hard physical labor?

1. Yes (answer question # 19) 2. No (stop)

19. Do you exercise or labor at least three times a week?

1. Yes 2. No

Appendix C: Data Collection Forms

Subject ID: _______________ Date of Birth: _____/_____/________ Group:

<u>Exercise or CON</u>

Visit #1 (Initial Screening)

- Questionnaires
  - Consent form
  - HIPPA
  - PAR-Q
  - Health Status Qustionnaires

- Weight: _______________kg, Height: ______________cm, BMI: ____________kg/m^2

- Blood pressure (patient lie down on a bed for 10 minutes)
  - BP 1: __________/____________ BP 2: ___________/___________ mmHg
  - Average BP _____________/_____________ mmHg

- Ankle Brachial Index (ABI) – if < 0.9, exclude
  - Right Arm: ______________ Right Leg: ____________ ABI:_______________
  - Left Leg: ______________ Left Arm: ____________ ABI: ______________

- Forearm Circumference
  - Right Arm: _____________cm Left Arm: ________________cm

- **Familiarization Session**
  - RPE and Discomfort Scales
  - 1 RM

1. Light warm – up (8 – 10 repetitions)	Right	Left
2. Heavy warm – up (3 – 5 repetitions)	Right	Left
Attempt 1		
Attempt 2		
Attempt 3		
Attempt 4		
Attempt 5		

- Blood flow restriction
    - Arterial Occlusion Pressure (AOP)
        - Right Arm: __________mmHg – 50% AOP: __________mmHg
        - Left Arm: __________mmHg– 50% AOP: ___________mmHg
    - Dumbbell Curls
        - 30% of 1RM with 50% AOP
            - 2 set of 15 repetitions (30 seconds rest)
        - 75% of 1RM
            - 2 set of 5 repetitions (1 minute rest)
- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
    - Check Positions

	Right	Left
1		
2		
3		
4		

- 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
- 2 all-out at 90 degree

        - 2 all-out at 120 degree

- **Schedule Next Visit**
    - Reminders for next visit #2
        - Wear shorts and a t-short
        - Overnight fasting before visit #2
        - Hydrated (no Alcohol and caffeine)

Visit #2 (PRE 1 testing)

- Weight: ________________kg, Height: _______________cm, BMI: _____________kg/m^2
- Muscle Thickness
    - Marks at 50, 60 and 70% of Biceps brachii on Right and Left Arms
        - Total distance (medial acromion process and lateral epicondyle)
            - Right Arm: __________cm Left Arm: __________cm
        - Distance form later epicondyle to 50% of biceps brachii
            - Right Arm: __________cm Left Arm: __________cm
    - Marks at 33% of Biceps brachii on Right and Left Arms
        - Total distance (medial acromion process and antecubital fossa)
            - Right Arm: __________cm Left Arm: __________cm
    - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right	Left
50% BB		
60% BB		
70% BB		

- Arm Circumferences
    - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right	Left
50% BB		
60% BB		
70% BB		

- Blood pressure (patient lie down on a bed for 10 minutes)
    - BP 1: ___________/_____________ BP 2: ____________/____________ mmHg
    - Average BP ______________/______________ mmHg
- Pulse Wave Velocity (PWV)
    - Sphygmacor: **Stiffness**
        1. Last name: Dissertation
        2. First name: DK
        3. ID: DKD_ _
        4. Birthdate: ____/____/_______
    - Measure Distance from Carotid pulse to Sternal notch:
        - Right______________ cm Left: ______________cm
    - Measure Distance from Sternal notch to Radial pulse:
        - Right______________ cm Left: ______________cm
        - Sternal to Radial – Carotid to Sternal (Right) _______________ cm
        - Sternal to Radial – Carotid to Sternal (Left) _______________ cm
    - Measure Largest forearm circumference
        - Right______________ cm Left: ______________cm

        - Largest forearm circumference – 3 or 4 cm = **Right** strain gauge:

          ___________cm

        - Largest forearm circumference – 3 or 4 cm = **Left** strain gauge:

          ____________cm

    - Clean ECG sites
        - At lateral sites below the right and left clavicles and below the left rib cage
        - Place Electrodes
    - Open the program
        - Put in blood pressure
        - Put visit # with Right or Left
        - Put distance of Carotid to Sternal (Right or Left)
    - Measure at Carotid and Radial Pulse

        - Right_____________ Left: _____________

- Forearm Blood Flow

    - Hokanson: **blood**
        1. Last name: Dissertation
        2. First name: DK
        3. ID: 1100-00-0__ __
        4. Birthdate: ____/____/_______

    - Open the Hokanson program
        - Place one pad under shoulder
        - Place two pads in shape of square and with wrist holder pad on the top at the area of the wrist
        - Place 10 cm cuff with pressure inflator on wrist
        - Pleace 12 cm cuff over upper arm
        - Place string gauge over forearm at marked site
        - Inflate wrist cuff to 200 mmHg for 1 minute
        - After hit start and take 6 measures

	Right	Left
1		
2		
3		
4		
5		
6		

- 1 RM

1. Light warm – up (8 – 10 repetitions)	Right	Left
2. Heavy warm – up (3 – 5 repetitions)	Right	Left
Attempt 1		
Attempt 2		
Attempt 3		
Attempt 4		
Attempt 5		

- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
    - At the 33% of BB on both Arms and the 7th cervical vertebrae of the neck
        - shaved by a razor
        - abraded to remove dead skin
        - cleaned with an alcohol prep pad
        - Place bipolar electrode at 33% of BB on both arms and an

          electrode at C7
    - Check Positions

	Right	Left
1		
2		
3		
4		

- Right Arm
  - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
  - 2 all-out at 90 degree (Peak Torque ________________Nm)
  - 2 all-out at 120 degree (Peak Torque ________________Nm)
- Left Arm (after 5 minutes rest)
  - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
  - 2 all-out at 90 degree (Peak Torque ________________Nm)
  - 2 all-out at 120 degree (Peak Torque ________________Nm)

- **Schedule Next Visit**
  - Reminders for next visit #3
    - Wear shorts and a t-short
    - Overnight fasting before visit #3
    - Hydrated (no Alcohol and caffeine)

Visit #3 (PRE 2 testing)

- Weight: _______________kg, Height: ______________cm, BMI: ____________kg/m^2
- Muscle Thickness
  - Marks at 50, 60 and 70% of Biceps brachii on Right and Left Arms
    - Total distance (medial acromion process and lateral epicondyle)
      - Right Arm: _________cm Left Arm: _________cm
    - Distance form later epicondyle to 50% of biceps brachii

- Right Arm: _________cm Left Arm: _________cm

- Marks at 33% of Biceps brachii on Right and Left Arms
  - Total distance (medial acromion process and antecubital fossa)
    - Right Arm: _________cm Left Arm: _________cm
- Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right	Left
50% BB		
60% BB		
70% BB		

- Arm Circumferences
  - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right	Left
50% BB		
60% BB		
70% BB		

- Blood pressure (patient lie down on a bed for 10 minutes)
  - BP 1: __________/____________ BP 2: ___________/___________

    mmHg
  - Average BP _____________/_____________ mmHg
- Pulse Wave Velocity (PWV)
  - Sphygmacor: **Stiffness**
    5. Last name: Dissertation
    6. First name: DK
    7. ID: DKD_ _
    8. Birthdate: ____/____/_______
  - Measure Distance from Carotid pulse to Sternal notch:
    - Right_____________ cm Left: _____________cm

- Measure Distance from Sternal notch to Radial pulse:
    - Right_____________ cm Left: _____________cm
    - Sternal to Radial – Carotid to Sternal (Right) ______________ cm
    - Sternal to Radial – Carotid to Sternal (Left) ______________ cm
- Measure Largest forearm circumference
    - Right_____________ cm Left: _____________cm
    - Largest forearm circumference – 3 or 4 cm = **Right** strain gauge: ___________cm
    - Largest forearm circumference – 3 or 4 cm = **Left** strain gauge: ____________cm
- Clean ECG sites
    - At lateral sites below the right and left clavicles and below the left rib cage
    - Place Electrodes
- Open the program
    - Put in blood pressure
    - Put visit # with Right or Left
    - Put distance of Carotid to Sternal (Right or Left)
- Measure at Carotid and Radial Pulse
    - Right_____________ Left: _____________

- Forearm Blood Flow
    - Hokanson: **blood**
        5. Last name: Dissertation
        6. First name: DK
        7. ID: 1100-00-0__ __
        8. Birthdate: ____/____/_______
    - Open the Hokanson program
        - Place one pad under shoulder

- Place two pads in shape of square and with wrist holder pad on the top at the area of the wrist
- Place 10 cm cuff with pressure inflator on wrist
- Pleace 12 cm cuff over upper arm
- Place string gauge over forearm at marked site
- Inflate wrist cuff to 200 mmHg for 1 minute
- After hit start and take 6 measures

	Right	Left
1		
2		
3		
4		
5		
6		

- 1 RM

1. Light warm – up (8 – 10 repetitions)	Right	Left
2. Heavy warm – up (3 – 5 repetitions)	Right	Left
Attempt 1		
Attempt 2		
Attempt 3		
Attempt 4		
Attempt 5		

- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
  - At the 33% of BB on both Arms and the 7th cervical vertebrae of the neck
    - shaved by a razor
    - abraded to remove dead skin
    - cleaned with an alcohol prep pad
    - Place bipolar electrode at 33% of BB on both arms and an electrode at C7

- Check Positions

	Right	Left
1		
2		
3		
4		

- Right Arm
    - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
    - 2 all-out at 90 degree (Peak Torque ________________Nm)
    - 2 all-out at 120 degree (Peak Torque ________________Nm)
- Left Arm (after 5 minutes rest)
    - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
    - 2 all-out at 90 degree (Peak Torque ________________Nm)
    - 2 all-out at 120 degree (Peak Torque ________________Nm)

- **Schedule Next Visit**
    - Reminders for next visit # 4 - 27
        - Wear a t-short for exercise

Visit # 4 – 28 (Exercise sessions)

- Visit # 4 – 7 (LI-BFR : ____________Arm and HI: _______________Arm)
    - LI-BFR - 30% of 1RM: _____________kg and 50% AOP: ______________mmHg - 30 repetitions followed by three sets of 15 repetitions
    - HI – 75% of 1RM: _______________kg - 10 repetitions of 3 sets

	Visit # 4		Visit # 5		Visit # 6	
	LIBFR	**HI**	**LIBFR**	**HI**	**LIBFR**	**HI**
Set 1						
RPE						
Disc						
Set 2						
RPE						
Disc						
Set 3						
RPE						
Disc						
Set 4						
RPE						
Disc						

- Visit # 7 – 9 (Visit #9 – **1RM testing**)

	Visit # 7		**Visit # 8**		**Visit # 9 – 1RM**	
	LIBFR	**HI**	**LIBFR**	**HI**	**LIBFR**	**HI**
Set 1						
RPE						
Disc						
Set 2						
RPE						
Disc						
Set 3						
RPE						
Disc						
Set 4						
RPE						
Disc						

- **Visit #9 - 1 RM**

1. Light warm – up (8 – 10 repetitions)	Right	Left
2. Heavy warm – up (3 – 5 repetitions)	Right	Left
Attempt 1		
Attempt 2		
Attempt 3		
Attempt 4		
Attempt 5		

Visit # 10 – 15 (Acute Response Testing)

- Visit # 10 – 12 (LI-BFR : ___________Arm and HI: ______________Arm)
  - LI-BFR - 30% of 1RM: ____________kg and 50% AOP: _____________mmHg - 30 repetitions followed by three sets of 15 repetitions
  - HI – 75% of 1RM: ______________kg - 10 repetitions of 3 sets

	Visit # 10		**Visit # 11**		**Visit # 12**	
	LIBFR	**HI**	**LIBFR**	**HI**	**LIBFR**	**HI**
Set 1						
RPE						
Disc						
Set 2						
RPE						
Disc						
Set 3						
RPE						
Disc						
Set 4						
RPE						
Disc						

- **Visit # 13**
- **Acute PRE Testing (LI-BFR or HI)**
- Muscle Thickness
  - Marks at 50, 60 and 70% of Biceps brachii on Right or Left Arms
    - Total distance (medial acromion process and lateral epicondyle)
      - Arm: _________cm
    - Distance form later epicondyle to 50% of biceps brachii
      - Arm: _________cm
  - Marks at 33% of Biceps brachii on Right or Left Arms

- Total distance (medial acromion process and antecubital fossa)
  - Arm: _________cm

- Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- Arm Circumferences
  - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- Whole Blood Lactate (WBL)- PRE
  - Clean a finger with an alcohol pad and Kimwipes
  - Lance it ________________ mmol/L
- Hematocrit (HCT)- PRE
  - Fill two Capillary tubes, sill it and centrifuge it
  - 1. ______________________ 2. ____________________
- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
  - At the 33% of BB on both Arms and the 7th cervical vertebrae of the neck
    - shaved by a razor
    - abraded to remove dead skin
    - cleaned with an alcohol prep pad
    - Place bipolar electrode at 33% of BB on both arms and an electrode at C7

- Check Positions

	Right	Left
1		
2		
3		
4		

- Right or Left Arm
  - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
  - 2 all-out at 90 degree (Peak Torque ________________Nm)
  - 2 all-out at 120 degree (Peak Torque ________________Nm)

- **Exercise (LI-BFR or HI) – 30% 1RM ___________kg or 75%1RM ______________kg**

	LIBFR or HI	RPE	Discomfort
Set 1			
Set 2			
Set 3			
Set 4			

- **Acute POST testing**
- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
  - Right or Left Arm
    - 2 all-out at 90 degree (Peak Torque ________________Nm)
    - 2 all-out at 120 degree (Peak Torque ________________Nm)
- Arm Circumferences
  - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- **Muscle Thickness**
    - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- Whole Blood Lactate (WBL)- POST
    - Clean a finger with an alcohol pad and Kimwipes
    - Lance it ________________ mmol/L
- Hematocrit (HCT)- POST
    - Fill two Capillary tubes, sill it and centrifuge it
    - 1. ______________________ 2. ____________________
- **Take 5 minutes rest**
- **Exercise (LI-BFR or HI) – Untested Protocol**
- **30% 1RM ___________kg or 75%1RM ______________kg**

	LIBFR or HI	RPE	Discomfort
Set 1			
Set 2			
Set 3			
Set 4			

- **Visit # 14**
- **Acute PRE Testing (LI-BFR or HI)**
- Muscle Thickness
    - Marks at 50, 60 and 70% of Biceps brachii on Right or Left Arms
        - Total distance (medial acromion process and lateral epicondyle)
            - Arm: _________cm

        - Distance form later epicondyle to 50% of biceps brachii
            - Arm: _________cm
    - Marks at 33% of Biceps brachii on Right or Left Arms
        - Total distance (medial acromion process and antecubital fossa)
            - Arm: _________cm
    - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- Arm Circumferences
    - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- Whole Blood Lactate (WBL)- PRE
    - Clean a finger with an alcohol pad and Kimwipes
    - Lance it ________________ mmol/L
- Hematocrit (HCT)- PRE
    - Fill two Capillary tubes, sill it and centrifuge it
    - 1. ______________________ 2. ____________________
- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
    - At the 33% of BB on both Arms and the 7th cervical vertebrae of the neck
        - shaved by a razor
        - abraded to remove dead skin
        - cleaned with an alcohol prep pad

- Place bipolar electrode at 33% of BB on both arms and an electrode at C7

  - Check Positions

	Right	Left
1		
2		
3		
4		

  - Right or Left Arm
    - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
    - 2 all-out at 90 degree (Peak Torque ________________Nm)
    - 2 all-out at 120 degree (Peak Torque ________________Nm)

- **Exercise (LI-BFR or HI) – 30% 1RM ___________kg or 75%1RM ______________kg**

	LIBFR or HI	RPE	Discomfort
Set 1			
Set 2			
Set 3			
Set 4			

- **Acute POST testing**
- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
  - Right or Left Arm
    - 2 all-out at 90 degree (Peak Torque ________________Nm)
    - 2 all-out at 120 degree (Peak Torque ________________Nm)
- Arm Circumferences
  - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- **Muscle Thickness**
    - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right or Left
50% BB	
60% BB	
70% BB	

- Whole Blood Lactate (WBL)- POST
    - Clean a finger with an alcohol pad and Kimwipes
    - Lance it ________________ mmol/L
- Hematocrit (HCT)- POST
    - Fill two Capillary tubes, sill it and centrifuge it
    - 1. ______________________ 2. ____________________
- **Take 5 minutes rest**
- **Exercise (LI-BFR or HI) – Untested Protocol**
- **30% 1RM ___________kg or 75%1RM ______________kg**

	LIBFR or HI	RPE	Discomfort
Set 1			
Set 2			
Set 3			
Set 4			

- **Visit # 15**
- **Exercise (LI-BFR and HI) – 30% 1RM ___________kg or 75%1RM ______________kg**

	LIBFR	HI
Set 1		
RPE		
Disc		
Set 2		
RPE		
Disc		
Set 3		
RPE		
Disc		
Set 4		
RPE		
Disc		

- **Visit #15 - 1 RM**

1. Light warm – up (8 – 10 repetitions)	Right	Left
2. Heavy warm – up (3 – 5 repetitions)	Right	Left
Attempt 1		
Attempt 2		
Attempt 3		
Attempt 4		
Attempt 5		

- Visit # 16 – 18 (LI-BFR : ____________Arm and HI: _______________Arm)
    - LI-BFR - 30% of 1RM: _____________kg and 50% AOP: ______________mmHg - 30 repetitions followed by three sets of 15 repetitions
    - HI – 75% of 1RM: _______________kg - 10 repetitions of 3 sets

	Visit # 16		**Visit # 17**		**Visit # 18**	
	LIBFR	**HI**	**LIBFR**	**HI**	**LIBFR**	**HI**
Set 1						
RPE						
Disc						
Set 2						
RPE						
Disc						
Set 3						
RPE						
Disc						
Set 4						
RPE						
Disc						

- Visit # 19 – 21 (Visit #21 – **1RM testing**)

	Visit # 19		**Visit # 20**		**Visit # 21 - 1RM**	
	LIBFR	**HI**	**LIBFR**	**HI**	**LIBFR**	**HI**
Set 1						
RPE						
Disc						
Set 2						
RPE						
Disc						
Set 3						
RPE						
Disc						
Set 4						
RPE						
Disc						

- **Visit # 21 - 1 RM**

1. Light warm – up (8 – 10 repetitions)	Right	Left
2. Heavy warm – up (3 – 5 repetitions)	Right	Left
Attempt 1		
Attempt 2		
Attempt 3		
Attempt 4		
Attempt 5		

- Visit # 22 – 24 (LI-BFR : ____________Arm and HI: _______________Arm)
    - LI-BFR - 30% of 1RM: _____________kg and 50% AOP: ______________mmHg - 30 repetitions followed by three sets of 15 repetitions
    - HI – 75% of 1RM: _______________kg - 10 repetitions of 3 sets

	Visit # 22		**Visit # 23**		**Visit # 24**	
	LIBFR	**HI**	**LIBFR**	**HI**	**LIBFR**	**HI**
Set 1						
RPE						
Disc						
Set 2						
RPE						
Disc						
Set 3						
RPE						
Disc						
Set 4						
RPE						
Disc						

- Visit # 25 – 27 (Visit #27 – **NO 1RM testing**)

	Visit # 25		**Visit # 26**		**Visit # 27**	
	LIBFR	**HI**	**LIBFR**	**HI**	**LIBFR**	**HI**
Set 1						
RPE						
Disc						
Set 2						
RPE						
Disc						
Set 3						
RPE						
Disc						
Set 4						
RPE						
Disc						

Visit #28 (POST testing)

- Weight: _______________kg, Height: ______________cm, BMI: ____________kg/m^2
- Muscle Thickness
  - Marks at 50, 60 and 70% of Biceps brachii on Right and Left Arms
    - Total distance (medial acromion process and lateral epicondyle)
      - Right Arm: _________cm   Left Arm: _________cm
    - Distance form later epicondyle to 50% of biceps brachii
      - Right Arm: _________cm   Left Arm: _________cm
  - Marks at 33% of Biceps brachii on Right and Left Arms
    - Total distance (medial acromion process and antecubital fossa)
      - Right Arm: _________cm   Left Arm: _________cm

- Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right	Left
50% BB		
60% BB		
70% BB		

- Arm Circumferences
  - Measure at 50, 60 and 70% of Beceps brachii by Ultrasound

Sites	Right	Left
50% BB		
60% BB		
70% BB		

- Blood pressure (patient lie down on a bed for 10 minutes)
  - BP 1: ___________/_____________ BP 2: ____________/____________ mmHg
  - Average BP ______________/______________ mmHg
- Pulse Wave Velocity (PWV)
  - Sphygmacor: **Stiffness**
    9. Last name: Dissertation
    10. First name: DK
    11. ID: DKD_ _
    12. Birthdate: ____/____/_______
  - Measure Distance from Carotid pulse to Sternal notch:
    - Right______________ cm Left: ______________cm
  - Measure Distance from Sternal notch to Radial pulse:
    - Right______________ cm Left: ______________cm
    - Sternal to Radial – Carotid to Sternal (Right) _______________ cm
    - Sternal to Radial – Carotid to Sternal (Left) _______________ cm

- Measure Largest forearm circumference
    - Right_____________ cm Left: _____________cm
    - Largest forearm circumference – 3 or 4 cm = **Right** strain gauge: ___________cm
    - Largest forearm circumference – 3 or 4 cm = **Left** strain gauge: ____________cm
- Clean ECG sites
    - At lateral sites below the right and left clavicles and below the left rib cage
    - Place Electrodes
- Open the program
    - Put in blood pressure
    - Put visit # with Right or Left
    - Put distance of Carotid to Sternal (Right or Left)
- Measure at Carotid and Radial Pulse
    - Right_____________ Left: _____________

- Forearm Blood Flow
    - Hokanson: **blood**
        9. Last name: Dissertation
        10. First name: DK
        11. ID: 1100-00-0__ __
        12. Birthdate: ____/____/_______
    - Open the Hokanson program
        - Place one pad under shoulder
        - Place two pads in shape of square and with wrist holder pad on the top at the area of the wrist
        - Place 10 cm cuff with pressure inflator on wrist
        - Pleace 12 cm cuff over upper arm
        - Place string gauge over forearm at marked site
        - Inflate wrist cuff to 200 mmHg for 1 minute
        - After hit start and take 6 measures

	Right	Left
1		
2		
3		
4		
5		
6		

- 1 RM

1. Light warm – up (8 – 10 repetitions)	Right	Left
2. Heavy warm – up (3 – 5 repetitions)	Right	Left
Attempt 1		
Attempt 2		
Attempt 3		
Attempt 4		
Attempt 5		

- Maximal Isometric Voluntary Contraction – (Right arm and Left Arm)
  - At the 33% of BB on both Arms and the 7th cervical vertebrae of the neck
    - shaved by a razor
    - abraded to remove dead skin
    - cleaned with an alcohol prep pad
    - Place bipolar electrode at 33% of BB on both arms and an

      electrode at C7
  - Check Positions

	Right	Left
1		
2		
3		
4		

- Right Arm
  - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
  - 2 all-out at 90 degree (Peak Torque ________________Nm)
  - 2 all-out at 120 degree (Peak Torque ________________Nm)
- Left Arm (after 5 minutes rest)
  - 3 warm-ups at 90 degree (30, 50 and 70% of estimated maximal effort)
  - 2 all-out at 90 degree (Peak Torque ________________Nm)
  - 2 all-out at 120 degree (Peak Torque ________________Nm)

Appendix D: Data

Subject	Arm	group	GROUP	Age	height	weight	AOP	Weight 1
1	right	CON	3	31	176	73.3	140	75
1	left	CON	3				141	
2	right	LIBFR	2	18	166.5	60.6	126	60.5
2	left	HI	1				123	
4	right	HI	1	18	185.5	75.8	141	75.3
4	left	LIBFR	2				127	
6	right	HI	1	31	182	78	161	78.5
6	left	LIBFR	2				155	
7	right	HI	1	18	180	65.3	133	64.6
7	left	LIBFR	2				129	
8	right	LIBFR	2	25	181	76.4	124	76.8
8	left	HI	1				123	
9	right	CON	3	18	171	53.3	116	52.9
9	left	CON	3				93	
10	right	LIBFR	2	20	165.5	84.9	190	83.6
10	left	HI	1				180	
11	right	CON	3	33	171	61.9	120	61.6
11	left	CON	3				124	
13	right	HI	1	25	183.5	91.9	154	90.9
13	left	LIBFR	2				160	
14	right	LIBFR	2	23	178	75.6	147	76.6
14	left	HI	1				149	
15	right	LIBFR	2	18	179	75.3	138	73.9
15	left	HI	1				138	
17	right	CON	3	32	174	78.4	143	76.8
17	left	CON	3				138	
18	right	CON	3	24	184	101.7	185	103.8
18	left	CON	3				186	

P1-MTH50	P1-MTH60	P1-MTH70	P1-AC50	P1-AC60	P1-AC70	P1-SBP	P1-DBP	P1-FAC	P1-PWV	P1-FBF	P1-1RM	P1-1RM(kg)	P1-MVC90	P1-MVC120
2.75	3.22	3.766	30.5	29.5	27.4	127	83	26.2	9.4	2.554	32.5	14.77	47.6	50.8
2.36	3.16	3.76	28.9	28.8	26.7			25.8	8.3	2.48	30	13.64	38.6	42.4
2.97	3.48	3.73	28	26.5	25.5	103	59	26	6.9	2.94	30	13.64	31.7	35.3
2.78	3.24	3.51	27.2	26.6	25.9			25	7.3	3.588	27.5	12.50	27.7	40.3
3.346	3.383	3.886	30.4	30.1	29.9	115	64	29	6.8	2.94	32.5	14.77	37.3	48
3.246	3.126	3.326	30.3	29.6	29.2			28.5	7.2	3.31	30	13.64	40.5	51.2
3.253	3.373	3.653	31.7	30.8	29.4	118	77	29	7	2.068	32.5	14.77	48.9	59.7
3.096	3.143	3.426	31.2	30.6	29.3			28.9	8.1	3.498	25	11.36	45.1	53
2.503	3.05	3.82	28.1	26.5	25.7	120	67	26.5	6.4	2.42	33.75	15.34	54.8	59
2.535	3.086	3.6	27.5	26.2	25.5			25.8	6.3	2.01	31.35	14.25	55.5	59.9
1.87	3	3.593	32.5	31.8	30.9	117	72	26.8	7	2.276	31.5	14.32	53.4	57.4
2.65	3.386	3.916	32.2	31.1	30.1			26.1	8.4	2.03	30	13.64	42.8	52.9
2.37	2.74	3.2	24.7	24.5	23.9	102	70	25	9	1.206	30	13.64	37.2	39.8
2.346	2.61	3.066	24.2	24	23.5			25	9.1	1.69	29.425	13.38	34.4	42.1
3.52	3.78	4.07	36.5	34.5	32.8	120	69	27.1	8.1	3.055	36.25	16.48	33.2	53.2
3.33	3.75	3.86	34.5	33	31			26	7.4	3.59	31.925	14.51	33.5	49
2.8	3.02	3.34	27.7	26.6	25.5	115	79	25.2	7.4	0.66	25.675	11.67	29	40.3
2.76	3.03	3.3	27	25.8	25			25.3	8.1	1.5	25	11.36	26	37.2
4.02	4.39	4.82	37.2	37	35.6	112	63	30.6	7.9	1.99	50	22.73	88.8	107.5
3.94	4.32	4.85	35.1	34.6	33.5			29	7.9	2.15	47.5	21.59	77.8	88.7
3.06	3.42	3.76	31.6	30.8	29.5	121	76	27	7.1	1.992	35	15.91	52.1	58.4
2.79	2.92	3.35	31.5	29.8	28.5			26	6.4	2.468	35	15.91	39.9	47.9
2.59	2.82	3.21	31	30	29	117	71	25.7	7.5	2.625	30	13.64	26.8	41.6
2.77	3.02	3.46	31	29.9	28.5			25.5	7.6	1.945	35	15.91	31.9	42.1
2.96	3.45	3.8	31.5	31	30.5	116	86	27.4	8.5	1.06	32.5	14.77	50.6	57.3
2.91	3.21	3.46	32	31.5	30.5			26.9	10.1	1.6	32.5	14.77	50.5	54.7
3.78	4.17	4.48	36	35.2	33.4	127	88	30.5	8.9	2.93	42.5	19.32	57.4	78.4
4.09	4.55	4.91	36.9	36.1	33.9			31.2	9	2.58	45	20.45	59.2	73.2

Weight 2	P2-MTH50	P2-MTH60	P2-MTH70	P2-AC50	P2-AC60	P2-AC70	P2-SBP	P2-DBP	P2-FAC	P2-PWV	P2-FBF	P2-1RM	P2-1RM (kg)	P2-MVC90	P2-MVC120
75.2	2.76	3.41	3.946	30.5	29.6	27.7	129	87	26.5	8	1.71	32.5	14.77	47.5	53.6
	2.42	2.99	3.57	29.1	28.3	27.3			25.9	7.7	2.21	30	13.64	39.8	52.9
60.1	2.88	3.07	3.36	27.8	25.5	24.9	104	63	26	6.6	3.39	32.5	14.77	30.1	41.2
	2.48	2.996	3.44	27.7	25.7	24.8			25	7.5	3.73	27.5	12.50	24.7	37.5
75.1	3.346	3.333	3.86	30.8	30.6	30.1	118	67	28.6	6.9	2.225	33.75	15.34	45	51.6
	3.345	3.253	3.706	30.4	30	29.5			28.6	7.2	2.546	30	13.64	39.1	49.5
78.7	3.176	3.39	3.653	32.2	30.6	29.6	114	76	29.2	7.3	1.8875	31.5	14.32	51.7	65.1
	3.1	3.14	3.42	31.8	30.8	29.1			29.2	7.7	2.432	27.5	12.50	45.2	53.9
64.8	2.84	3.21	3.67	27.5	26.3	25.5	118	66	26.5	6.5	2.628	33.75	15.34	56.3	60.3
	2.81	3.09	3.5	27.5	26.2	25.5			26	5.6	2.184	31.25	14.20	54.3	66.4
77	1.91	2.91	3.513	32.6	32.2	30.9	116	73	27.2	6.8	3.02	33.75	15.34	50.6	53.7
	2.373	3.136	3.726	32.4	30.7	29.7			26.4	7.7	1.84	32.5	14.77	47.2	52.9
52.9	2.38	2.67	3.2575	24.7	24.7	24	98	64	25	8.9	1.755	30	13.64	43.9	45
	2.37	2.56	2.96	24	24.2	23.5			25.1	9	1.96	27.5	12.50	37.1	44.1
82	3.48	3.82	4.12	36.2	34.9	32.7	118	64	27.2	7.4	2.94	37.5	17.05	33.5	54.8
	3.33	3.75	3.96	34.8	32.5	30.5			26.2	7.1	2.45	31.925	14.51	36.6	53.8
63.1	2.73	3.04	3.37	27.2	26.8	26	103	72	25.5	7.3	2.56	25	11.36	23.8	35.3
	2.76	3.05	3.31	26.5	26.1	25.6			25.4	7.6	3.16	25	11.36	32.9	35.8
92.3	3.91	4.19	4.7	36.5	36.8	35.5	120	67	30.6	7.7	2.254	50	22.73	88.3	96.5
	3.9	4.17	4.7	34.9	34.9	33.5			29.2	8.2	3.22	47.5	21.59	84.8	79.7
76.4	3.14	3.38	3.86	31.8	31	30	120	72	27.1	6.9	2.594	36.25	16.48	54.7	57.6
	2.83	2.98	3.43	32	30.5	29			26	6.4	2.54	32.5	14.77	40.7	49.8
74.4	2.59	2.92	3.38	30.9	29.9	28.9	118	73	25.8	7.6	2.448	32.5	14.77	26.8	44.1
	2.81	3.14	3.59	31	30	28.8			25.6	7.5	2.854	35	15.91	24.9	45.2
77.9	2.96	3.39	3.76	31.5	31	30.5	112	77	27.5	8.3	1.66	31.25	14.20	48	46
	2.95	3.33	3.56	32.3	31.8	30.6			26.9	9.9	2.58	32.5	14.77	46.9	54.5
103.2	3.72	4.07	4.41	36	35.2	33.7	135	90	30.5	9.1	2.82	42.5	19.32	51	49.9
	4.07	4.47	4.88	36.8	35.8	34			31	8.3	3.14	45	20.45	67.8	70.5

Weight 3	PT-MTH50	PT-MTH60	PT-MTH70	PT-AC50	PT-AC60	PT-AC70	PT-SBP	PT-DBP	PT-FAC	PT-PWV	PT-FBF	PT-1RM	PT-1RM (kg)	PT-MVC90	PT-MVC120
74.8	2.81	3.346	3.78	30	28.7	27.5	125	85	26.1	9.1	3.64	31.25	14.20	45.8	62.8
	2.76	2.99	3.42	29.4	28.3	27.2			25.6	9.1	2.52	30	13.64	41.6	52.9
61.8	2.81	3.056	3.366	29	28.1	27.5	97	57	25.8	6.1	2.7144	32.5	14.77	29.7	39.7
	3.09	3.37	3.63	28.8	28	27			25.6	7.4	2.4621	35	15.91	34	44.5
75.3	3.58	3.93	4.486	31.2	31.2	30.9	113	64	29	6.5	3.53	36.5	16.59	49.7	62.8
	3.696	3.54	3.94	30.5	30.4	30			29	7.1	2.85	35	15.91	40.7	52.4
82.5	3.49	3.91	4.406	33.6	32.5	31.3	120	69	29.7	9.1	3.79	38.75	17.61	47.6	58.9
	3.606	3.846	4.35	33	32.1	31			29.9	7.4	4.52	35	15.91	44.3	56.1
64.9	3.0075	3.27	4.04	29.5	28.6	27.6	120	71	26.9	7.6	2.75	40	18.18	55.7	63.7
	3.03	3.27	3.7475	28	27	26.2			26.5	7.2	2.44	33.75	15.34	49.2	52.4
75.9	2.91	3.19	3.84	32.9	32.1	31.4	120	70	26.8	7.9	2.88	35	15.91	55.4	62.5
	2.846	3.156	3.72	32	31.5	30.8			26.5	8.2	4.12	40	18.18	54.3	61.7
54.1	2.296	2.69	3.27	25.2	25.3	24.5	104	73	25	8.7	1.2	27.5	12.50	34.8	41.1
	2.466	2.776	3.246	24.3	24.2	23.4			25.2	8.8	1.552	25	11.36	33.5	43.5
84.1	3.67	3.93	4.11	37	35	32.5	117	69	27.5	7.6	2.24	42.5	19.32	50.6	62.1
	3.28	3.51	3.87	35	33	31.6			26.5	6.5	2.16	40	18.18	48	70
60.3	2.71	2.96	3.27	27	26.5	26	115	73	25.1	6.8	2.89	25	11.36	30.2	43.1
	2.81	2.74	3.08	26.5	26	25.5			25	8.1	1.72	22.5	10.23	27.3	43.1
91.5	4.29	4.6	5.15	37.2	37.5	36.5	108	61	30.7	7.8	1.965	70	31.82	82.2	104.6
	4.19	4.5	5.09	35	35.1	34			29.5	7.7	2.11	55	25.00	93.2	102.6
80.2	3.37	3.63	3.95	33	31.8	30.5	120	71	27.7	6.6	2.248	43.75	19.89	60.9	69
	3.19	3.3	3.82	32.8	31.5	30.2			27	6.9	2.36	42.5	19.32	47.8	53.8
75.8	2.82	3.07	3.55	31	30	29	123	72	26	7.6	3.57	37.5	17.05	35.4	45.7
	3	3.3	3.71	32	30.5	29.5			26	8	4.865	40	18.18	44.5	52
80.1	2.98	3.42	3.74	31.5	31.2	30.7	117	85	27.6	9	1.35	32.5	14.77	43.4	58.6
	2.86	3.25	3.51	32.5	31.6	30.5			27.1	10	2.52	32.5	14.77	46.3	54.9
105.9	3.76	4.1	4.44	36	35	33.5	139	88	30.6	8.9	2.96	42.5	19.32	57.2	76.2
	4.06	4.41	4.82	37	36	34			31	8.4	2.67	45	20.45	45	67.2

APRE MTH50	APRE MTH60	APRE MTH70	APRE AC50	APRE AC60	APRE AC70	APRE SBP	APRE DBP	APRE FAC	APRE PWV	APRE FBF	APRE 1RM	APRE 1RM kg	APRE MVC90	APRE MVC 120
2.76	3.32	3.86	30.50	29.55	27.55	128.00	85.00	26.35	8.70	2.13	32.50	14.77	47.55	52.20
2.39	3.08	3.67	29.00	28.55	27.00	0.00	0.00	25.85	8.00	2.35	30.00	13.64	39.20	47.65
2.93	3.28	3.55	27.90	26.00	25.20	103.50	61.00	26.00	6.75	3.17	31.25	14.20	30.90	38.25
2.63	3.12	3.48	27.45	26.15	25.35	0.00	0.00	25.00	7.40	3.66	27.50	12.50	26.20	38.90
3.35	3.36	3.87	30.60	30.35	30.00	116.50	65.50	28.80	6.85	2.58	33.13	15.06	41.15	49.80
3.30	3.19	3.52	30.35	29.80	29.35	0.00	0.00	28.55	7.20	2.93	30.00	13.64	39.80	50.35
3.21	3.38	3.65	31.95	30.70	29.50	116.00	76.50	29.10	7.15	1.98	32.00	14.55	50.30	62.40
3.10	3.14	3.42	31.50	30.70	29.20	0.00	0.00	29.05	7.90	2.97	26.25	11.93	45.15	53.45
2.67	3.13	3.75	27.80	26.40	25.60	119.00	66.50	26.50	6.45	2.52	33.75	15.34	55.55	59.65
2.67	3.09	3.55	27.50	26.20	25.50	0.00	0.00	25.90	5.95	2.10	31.30	14.23	54.90	63.15
1.89	2.96	3.55	32.55	32.00	30.90	116.50	72.50	27.00	6.90	2.65	32.63	14.83	52.00	55.55
2.51	3.26	3.82	32.30	30.90	29.90	0.00	0.00	26.25	8.05	1.94	31.25	14.20	45.00	52.90
2.38	2.71	3.23	24.70	24.60	23.95	100.00	67.00	25.00	8.95	1.48	30.00	13.64	40.55	42.40
2.36	2.59	3.01	24.10	24.10	23.50	0.00	0.00	25.05	9.05	1.83	28.46	12.94	35.75	43.10
3.50	3.80	4.10	36.35	34.70	32.75	119.00	66.50	27.15	7.75	3.00	36.88	16.76	33.35	54.00
3.33	3.75	3.91	34.65	32.75	30.75	0.00	0.00	26.10	7.25	3.02	31.93	14.51	35.05	51.40
2.77	3.03	3.36	27.45	26.70	25.75	109.00	75.50	25.35	7.35	1.61	25.34	11.52	26.40	37.80
2.76	3.04	3.31	26.75	25.95	25.30	0.00	0.00	25.35	7.85	2.33	25.00	11.36	29.45	36.50
3.97	4.29	4.76	36.85	36.90	35.55	116.00	65.00	30.60	7.80	2.12	50.00	22.73	88.55	102.00
3.92	4.25	4.78	35.00	34.75	33.50	0.00	0.00	29.10	8.05	2.69	47.50	21.59	81.30	84.20
3.10	3.40	3.81	31.70	30.90	29.75	120.50	74.00	27.05	7.00	2.29	35.63	16.19	53.40	58.00
2.81	2.95	3.39	31.75	30.15	28.75	0.00	0.00	26.00	6.40	2.50	33.75	15.34	40.30	48.85
2.59	2.87	3.30	30.95	29.95	28.95	117.50	72.00	25.75	7.55	2.54	31.25	14.20	26.80	42.85
2.79	3.08	3.53	31.00	29.95	28.65	0.00	0.00	25.55	7.55	2.40	35.00	15.91	28.40	43.65
2.96	3.42	3.78	31.50	31.00	30.50	114.00	81.50	27.45	8.40	1.36	31.88	14.49	49.30	51.65
2.93	3.27	3.51	32.15	31.65	30.55	0.00	0.00	26.90	10.00	2.09	32.50	14.77	48.70	54.60
3.75	4.12	4.45	36.00	35.20	33.55	131.00	89.00	30.50	9.00	2.88	42.50	19.32	54.20	64.15
4.08	4.51	4.90	36.85	35.95	33.95	0.00	0.00	31.10	8.65	2.86	45.00	20.45	63.50	71.85

Subject	Arm	group	GROUP	PRE1 90 AM	PRE1 90 MPF	PRE1 120 AM	PRE1 120 MPF	PRE2 90 AM	PRE2 90 MPF	PRE2 120 AM	PRE2 120 MPF
1	right	CON	3	806.7	85.21	482	85.99	391.9	92.22	298.7	85.55
1	left	CON	3	650.3	86.6	509.4	93.77	693.8	80.7	938.4	77.64
2	right	LIBFR	2	893.2	85.36	931.1	77.83	944.5	81.93	1136	85.17
2	left	HI	1	540.1	91.02	608.2	76.37	603.9	76.27	828.3	74.47
4	right	HI	1	548.1	91.15	991.3	87.71	556.2	80.45	606.5	82.86
4	left	LIBFR	2	732	65.87	996.9	72.76	630	63.32	1241.1	60.44
6	right	HI	1	655.1	69.17	578.5	72.48	730.2	60.5	625.6	63.61
6	left	LIBFR	2	539.8	66.99	586.4	64.73	938.7	72.37	778.7	64.98
7	right	HI	1	759.2	103.2	684.2	89.59	814.8	104.3	1036.7	98.83
7	left	LIBFR	2	1261.3	74.88	760.3	68.93	811	97.13	1239.7	68.7
8	right	LIBFR	2	612.4	79.38	255.2	87.05	272	88.73	315.2	88.63
8	left	HI	1	182.4	84.11	393	74.77	170	64.43	330.2	100.6
9	right	CON	3	1047.3	87.47	504.9	77.99	1157.5	73.36	623.3	63.34
9	left	CON	3	1001.4	75.77	1112.2	68.34	1250.9	73.07	1186.3	70.15
10	right	LIBFR	2	331.4	75.15	365.5	77.2	510.7	91.7	438.1	84.79
10	left	HI	1	751.1	72.37	610.3	72.45	656	78.38	668.9	74.71
11	right	CON	3	483.9	82.7	354.6	82.14	479.6	96.34	339.5	82.38
11	left	CON	3	660.7	78.13	518.5	64.83	447.1	71.09	417.2	80.67
13	right	HI	1	801.9	118.4	1216	85.93	845	93.23	737	86.28
13	left	LIBFR	2	934.6	110.8	974.5	95.7	1036.4	102	640	95.02
14	right	LIBFR	2	963.9	79.98	1030.8	72.02	843.5	81.61	710.6	72.32
14	left	HI	1	473.7	67.1	533.5	62.32	481.8	64.58	483.5	60.57
15	right	LIBFR	2	1015.9	92.26	944.9	88.69	522.6	99.96	617.2	83.36
15	left	HI	1	745.8	121.7	731.7	105.1	763.8	89.33	884.4	81.84
17	right	CON	3	629.9	65.69	627.3	59.87	647.2	68.64	571.6	64.2
17	left	CON	3	574.3	75.44	546.3	65.07	595.1	72.81	489	60.52
18	right	CON	3	424.3	75.48	433.8	70.23	331.3	84.81	281.9	75.93
18	left	CON	3	760.6	75.28	816.1	78.19	647.1	81.66	672.9	70.46

POST 90 AM	POST 90 MPF	POST 120 AM	POST 120 MPF
408.7	80.59	336.7	83.52
893.4	67.3	806.5	63.51
741.3	91.01	816	100.8
731.7	76.74	929.1	73.11
581.8	78.05	651.7	80.56
838.2	75.48	1123.4	70.21
771.7	71.02	730.9	76.09
575.1	69.63	662.6	68.73
1599.9	69.29	1305.6	73.14
1395.7	68.74	957.2	70.89
672.5	65.57	680.5	65.58
687.3	74.5	631.6	81.67
748.5	74.92	484.8	70.5
1101.9	78.44	1064.2	72.08
590.5	79.65	519.4	69.03
540.6	79	708.7	66.49
730.1	79.74	531	80.55
663.6	80.31	605.6	71.02
778.6	80	986.1	101.2
962.5	108.9	815	89.18
1027.2	70.24	945.8	68.54
655.4	63.69	609.6	62.73
560.6	85.77	625.1	80.08
686.5	75.51	538.6	68.5
561.9	68.4	498.7	62.5
433.9	74.28	420.68	68.05
380.1	82.35	392.2	77.35
717.3	80.4	759.3	80.6

Acute 90 PRE AM	Acute 90 PRE MPF	Acute 120 PRE AM	Acute 120 PRE MPF	Acute 90 POST AM	Acute 90 POST MPF	Acute 120 POST AM	Acute 120 POST MPF
893.5	100.6	895.6	81.83	707.1	61.89	916.4	83.52
877.2	80.02	683.8	70.08	664.5	64.53	669.4	68.49
590	102.8	527.7	100.2	230.7	77.04	323.4	99.21
761.4	80.25	968.7	73.35	500	70.92	650.3	75.67
761.1	60.09	648.5	66.58	599.5	58.04	557.7	66.82
867.3	62.83	609.3	65.79	669	54.39	642.2	59.51
1602.8	69.9	1851	65.83	1457	61.31	1506.4	66.8
1629.3	63.79	1113.1	57.46	1507.3	51.74	1142.4	54.18
971	58.26	614	75.56	504.8	59.81	589.6	64.1
635.4	68.21	544.4	71.76	405	61.45	517.3	61.31
538.6	75.37	503.4	76.52	172.5	70.12	173.7	62.52
681.8	79.47	721.7	71.68	433.6	72.72	556.3	69.71
884.6	99.15	986.4	79.47	609.3	69.69	693.2	70.47
1258.2	84.13	847.6	75.87	984	82.37	977.3	97.9
783.9	79.14	797.6	77.03	553.1	73.04	566.1	70.05
554	74.65	527.4	70.56	472.2	67.98	576.1	65.18
665.6	77.9	669.7	72.87	471.1	58.26	411.6	63.1
1009	84.82	923.4	72.88	939	60.56	829.5	60.8