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MUSCULAR AND VASCULAR ADAPTATIONS TO LOW-LOAD RESISTANCE EXERCISE WITH AND WITHOUT BLOOD FLOW RESTRICTION IN 40 TO 64 YEAR OLDS

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CHRISTOPHER ANTHONY FAHS
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MUSCULAR AND VASCULAR ADAPTATIONS TO LOW-LOAD RESISTANCE EXERCISE WITH AND WITHOUT BLOOD FLOW RESTRICTION IN 40 TO 64 YEAR OLDS

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

BY

____
Dr. Michael G. Bemben, Chair

____
Dr. Debra Bemben

____
Dr. Travis Beck

____
Dr. Daniel Feeback

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Dr. Howard Crowson

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Abstract

Low-load resistance training with blood flow restriction has been shown to enhance muscular adaptations compared to work-matched low-load resistance training. However, it is unclear if low-load resistance training performed to volitional fatigue can elicit similar muscular adaptations as low-load blood flow restricted (BFR) resistance training. The vascular adaptations to low-load resistance training with and without blood flow restriction are not well characterized in middle-aged individuals. PURPOSE: To determine the muscular (muscle thickness, strength, power, and endurance) and vascular (arterial stiffness, venous compliance, resistance vessel blood flow) effects of six weeks of low-load resistance training performed to volitional fatigue with and without blood flow restriction in middle aged individuals. METHODS: Twelve men and six women completed six-weeks of unilateral knee extensor resistance training performed to volitional fatigue with and without blood flow restriction. One limb trained under blood flow restriction (BFR) and the contralateral limb trained without blood flow restriction (free flow, FF). Twice before and once after the training, measures of arterial stiffness, calf blood flow, calf venous compliance, quadriceps muscle thickness, strength, power and endurance were assessed on each limb. RESULTS: No changes in vascular function were observed throughout the study. Quadriceps muscle strength, power, and endurance increased following the training in each limb with no differences between limbs. Quadriceps muscle thickness increased in both limbs following the training but lateral quadriceps muscle thickness increased more in the limb trained under blood flow restriction. CONCLUSION: Low-load resistance training performed to volitional fatigue with and without blood flow

restriction result in similar improvements in muscle function without changes in local vascular function. Low-load resistance training with blood flow restriction enhances muscle size more than low-load training without blood flow restriction.

Chapter I: Introduction

Low-load (20-50% 1RM) resistance training with blood flow restriction has been shown to enhance muscle size and function in a variety of populations [1-17]. Traditionally, resistance training with low-loads (without blood flow restriction) is thought of as ineffective for muscle hypertrophy. However, low-load (30% 1RM) knee extensor training to volitional fatigue without blood flow restriction has been shown to elicit comparable increases in muscle cross-sectional area and isometric strength as high-load (80% 1RM) training [18]. Most of the literature examining the training adaptations to blood flow restricted (BFR) resistance exercise has compared BFR resistance exercise to repetition-matched low-load resistance exercise. It is unclear if low-load resistance exercise performed to volitional fatigue can elicit similar muscular adaptations as BFR resistance exercise.

While most of the literature has focused on muscle mass and strength adaptations to BFR resistance training, fewer studies have characterized how this type of training may affect muscular power or endurance. Muscular power and endurance are two important components of muscular fitness and considerations for these attributes are made in resistance training recommendations [19]. Moreover, maintaining muscular power with age becomes important as muscular power can decline rapidly and is related to mobility and the ability to perform activities of daily living in older adults [20, 21]. Evidence suggests blood flow restriction enhances the metabolic adaptations to resistance training by increasing muscle glycogen storage [22]. In fact, BFR resistance training improves muscular endurance in athletes compared to work-matched low-load resistance training [12]. BFR resistance training may also improve muscular power in young individuals [1]. However, studies characterizing the effectiveness of BFR resistance training on muscular power and endurance in middle-aged or older adults are lacking.

Also of importance is the effect of BFR resistance training on vascular function. Low-load resistance training has been shown to reduce systemic arterial stiffness [23]. However, blood flow restriction causes venous pooling distal to the restrictive cuff and may increase retrograde arterial blood flow which can affect vascular function [24]. No changes in femoral artery stiffness occurred following 4-weeks of BFR knee extensor training in young individuals [3]. Although, arterial stiffness increases with age and the effects of conduit artery stiffness following BFR resistance training in older populations are unknown. Other conflicting evidence exists as BFR handgrip training may [25] or may not [26] reduce brachial artery flow mediated dilation, a measure of conduit artery endothelial function. More studies have observed beneficial vascular adaptations in resistance vessel function as BFR resistance training can increase calf filtration capacity [27] and enhance post-occlusive blood flow (i.e. reactive hyperemia) in both young [10] and old [11] populations.

The effect of BFR resistance exercise on venous compliance is also not well characterized. BFR treadmill walking may increase leg venous compliance in young men [28]. Although cross-sectional data suggest traditional resistance training may also increase venous compliance [29], the effect of BFR resistance exercise on venous compliance has not been studied.

Purpose

To determine the muscular (muscle thickness, muscular strength, power, and endurance) and vascular (arterial stiffness, venous compliance, resistance vessel blood flow) effects of six weeks of low-load resistance training performed to volitional fatigue with and without blood flow restriction in middle aged individuals.

Research Questions

1. Can low-load resistance training produce similar changes in muscle thickness, muscular strength, endurance, and power as low-load BFR resistance training when both are performed to volitional fatigue?
2. What is the effect of low-load resistance training with and without blood flow restriction on venous compliance, arterial stiffness, and calf blood flow in middle aged individuals?

Hypotheses

1. Low-load resistance training with and without blood flow restriction will increase muscle thickness, muscular strength, endurance, and muscular power; low-load resistance training with blood flow restriction will cause greater increases in muscle thickness and muscular endurance compared to training without blood flow restriction.
2. Low-load resistance training with blood flow restriction will decrease arterial stiffness and increase venous compliance and calf blood flow; low-load exercise without blood flow restriction will not alter arterial stiffness, venous compliance, or calf blood flow.

Significance

Both muscular fitness and vascular function are important for overall health and longevity. Thus, comparing the muscular and vascular responses to different forms of resistance exercise may help shape current resistance exercise guidelines. The findings will have implications primarily for individuals who are limited to perform low-load resistance exercise but aim to improve muscular fitness and vascular health.

Assumptions

1. Participants gave maximal effort for all muscular fitness testing.
2. Participants complied with the directions provided prior to testing including refraining from exercise, caffeine, and food.
3. Participants maintained their current level of outside physical activity and diet during the study.
4. Participants answered all questionnaires truthfully.

Delimitations

1. The findings of this study will only be applicable to middle-aged men and women.
2. These findings are specific to the quadriceps muscle group and lower body vasculature.

Limitations

1. The participants are willing volunteers and do not represent a true random sample.
2. There may be some cross-over effects from one limb to the other.

3. The influence of daily activity is assumed to be equal on both limbs but may affect training adaptations.

Operational Definitions

Blood flow restricted (BFR) resistance exercise – Resistance exercise performed while wearing a pneumatic restrictive cuff placed proximal to the exercising muscle.

Muscle endurance – The ability of a muscle or muscle group to perform repeated contractions against a submaximal resistance.

Muscle power – The ability of a muscle or muscle group to exert high force while contracting at high speed.

Muscle strength – The force a muscle or muscle group can exert in one maximal effort, quantified by the maximum load that can be lifted once (the one-repetition maximum; 1-RM).

Pulse Wave Velocity (PWV) – A measure of the speed (meters per second) of pulse wave propagation from one site used to assess regional arterial stiffness; greater pulse wave velocity indicates a stiffer vessel.

Venous compliance – The change in venous volume relative to venous pressure; low compliance is associated with risk of deep vein thrombosis while high venous compliance may lead to orthostatic intolerance.

Venous occlusion plethysmography – Technique used to measure volume changes in a limb which is used to determine blood flow into or out of a limb or digit.

Chapter II: Literature Review

Blood Flow Restricted Resistance Exercise

The idea of restricting blood flow during exercise to enhance skeletal muscle hypertrophy is credited to Yoshiaki Sato who developed this idea largely from personal experimentation in the mid 1960's in Japan [30]. Blood flow restricted (BFR) exercise training, coined "KAATSU Training", was first made available for public use in Japan in 1983 [30]. Since then, numerous studies have examined the effects of BFR exercise on skeletal muscle hypertrophy and strength gains, as well as on neural, endocrine, and cardiovascular responses. The novelty of BFR resistance exercise is that relatively low exercise intensities (e.g. 20% of one-repetition maximum, 1RM) can be utilized to elicit skeletal muscle adaptations once thought only possible with moderate- to high-intensity (60-80% 1RM) resistance exercise [31]. Even low-intensity aerobic exercise (e.g. walking), when combined with blood flow restriction, may be effective for increasing muscle strength and hypertrophy [32, 33]. Thus, this type of exercise has a wide range of practical applications, from performance enhancement in athletes to combating muscle atrophy in clinical populations.

The mechanics of restricting blood flow during exercise have been reviewed previously [31]. A tourniquet-like restrictive device, usually a pneumatic cuff, is placed on the most proximal portion of the exercising limb which reduces arterial blood inflow to the working muscle and occludes venous return resulting in the pooling of venous blood around the exercising muscle.

Although the exact mechanisms behind the efficacy of BFR exercise are complex and not fully understood, the build-up of local metabolites and/or muscle cell swelling may be the key factor in eliciting the muscular adaptations to BFR resistance exercise. This local accumulation of metabolites (lactate and hydrogen ions) during exercise may be critical for muscular adaptations following resistance training [34]. The buildup of local metabolites during BFR exercise alters motor unit recruitment [35, 36] and enhances the endocrine response [9, 37, 38]. The increase in neural activation may be due to a mismatch in energy supply and demand such that low-intensity BFR exercise causes a shift from oxidative metabolism to anaerobic metabolism as indicated by a depletion of phosphocreatine [39]. Additionally, decreased pH, and increased PCO_2 and lactate have been shown to alter sensory feedback from chemosensitive afferent fibers (group III and IV) which may facilitate large motor unit recruitment during low-load BFR exercise [40, 41]. Growth hormone, norepinephrine, and insulin-like growth factor-1 have been shown to increase following low-load BFR exercise [37, 42, 43] which is likely to due to simulation of the hypothalamic-pituitary axis via the metaboreflex [44]. Blood flow restriction alone or combined with exercise may also cause acute changes in muscle size (i.e. cell swelling) due to osmotic and hydrostatic pressure gradients from the blood flow restriction. Fluctuations in cell volume have been shown to influence metabolic pathways, with cell swelling inhibiting proteolysis [45]. This may, in part, explain how intermittent blood flow restriction has been shown to attenuate muscle atrophy during disuse [46].

Cardiovascular Effects of Blood Flow Restriction

Blood flow restriction can affect the cardiovascular system directly and indirectly through the autonomic nervous system. At rest, blood flow restriction has been shown to increase sympathetic nervous activity while decreasing parasympathetic nervous activity [47]. Under resting conditions, in the supine position, restriction of femoral blood flow (200 mmHg restrictive cuff pressure) has been shown to cause reductions in left ventricular diastolic volume, cardiac output, and diameter of the inferior vena cava with concomitant increases in heart rate, total peripheral resistance and mean arterial pressure, similar to an orthostatic stimulus (i.e. standing) [48]. Restricting blood flow to the legs results in a pooling of blood in the legs and thus, decreases venous return in a pressure dependent fashion [48]. In response to the reduced venous return, baroreceptors increase heart rate and total peripheral resistance. Iida et al. (2007) indicated that at low restrictive cuff pressures (50 mmHg), the cardiopulmonary baroreceptors respond to changes in central pressure whereas at high restrictive cuff pressures (200 mmHg) both the cardiopulmonary and arterial baroreceptors are activated. Additionally, increases in sympathetic nervous system activity are dependent on restrictive cuff pressure. During exercise, the BP response has been shown to be dependent on restrictive cuff pressure, with a pressure of 200 mmHg increasing BP to a greater extent than 160 mmHg [49].

The application of blood flow restriction to the limbs mimics the venous effects of lower-body negative pressure (LBNP) as well. LBNP causes decompression of the lower body and a footward fluid shift. LBP is a treatment used to treat orthostatic intolerance as well as a rehabilitation tool for astronauts to counteract post-flight orthostatic hypotension [50]. With LBNP, venous pooling increases proportionately with increasing levels of negative pressure which increases leg volume, systemic resistance, heart rate, and activate the renin-angiotensin system. Blood flow restriction to the limbs during exercise may have similar effects in a pressure-dependent fashion until the cuff pressure begins to exceed arterial blood pressure at which point blood flow into the limb becomes reduced.

Cardiovascular Adaptations to Resistance Exercise Training

It is thought exercise reduces cardiovascular disease risk in part by modifying traditional risk factors (i.e. lowering blood pressure, blood glucose, etc.) as well as altering both the structure and function of the vascular system [51]. The vascular adaptations may differ depending on the mode of exercise and the majority of research thus far has examined the impact of aerobic-type exercise on the cardiovascular system. Generally, the function of the vascular system may be measured by measuring the compliance of the vessels, defined as the change in diameter of a vessel for a given pressure step (change in pressure) [52], and/or by assessing blood flow via ultrasound or venous occlusion plethysmography. In individuals with cardiovascular disease, exercise training improves vasodilator function of both the conduit and resistance vessels primarily by improving endothelial function while smooth muscle function is not altered [53]. In contrast, in healthy individuals with normal endothelial function, the effects are less dramatic with most studies observing no changes in endothelial function [54].

With resistance training specifically, studies have shown both negative and positive effects on the vascular system. Cross-sectional studies have shown that, compared to endurance-trained males, resistance trained males have greater resting limb blood flow but slightly lower vasodilatory capacity [55]. Resistance-trained individuals also may have greater venous compliance compared to sedentary individuals [29]. However, arterial compliance has been shown to be lower in middle-aged (40-60 years) resistance-trained men relative to their sedentary peers [56]. This reduction in arterial compliance has been suggested to be caused by high arterial blood pressures during resistance exercise; an acute bout of resistance exercise (performed at 75% 1RM) has been shown to reduce arterial compliance in the post-exercise period [57]. Moreover, interventions utilizing high-intensity (80% 1RM) resistance training have documented chronic reductions in arterial compliance [58]. However, these are not universal findings as other acute [59] and chronic [60, 61] resistance exercise studies have found either no change or an increase in arterial compliance. Despite these discrepancies, if high-intensity resistance training does decrease arterial compliance, moderate- or low-intensity resistance training may be a suitable alternative. Moderate-intensity (70% 1RM) resistance training may not decrease arterial compliance in middle-aged or older adults [62] while low-intensity (50% 1RM) has been shown to decrease arterial stiffness [23]. Low-load BFR resistance exercise has been shown to acutely increase arterial compliance [59] although there does not appear to any changes in arterial compliance with short-term (3-6 week) low-load BFR training [60, 63].

Similar to arterial compliance, venous compliance declines with age but may be preserved with endurance training [64]. Reduced venous compliance may increase risk for deep vein thrombosis; on the other hand, abnormally high venous compliance may cause orthostatic intolerance. The effects of resistance training on venous compliance are not as well documented although resistance-trained individuals may have greater venous compliance compared to sedentary individuals [29]. However, it has also been suggested that muscle hypertrophy may limit expansion of the veins and reduce venous compliance [65]. With BFR exercise there is a greater hydrostatic force placed on the veins distal to the restrictive cuffs which may increase venous compliance. Venous compliance has been shown to increase following 6-weeks of BFR walk exercise [28]. However, the effects of low-load BFR resistance exercise are unknown.

Assessing arterial blood flow, including resting flow and peak blood flow in response to ischemia or exercise, has been used to assess both arterial caliber and arterial function. Assessment of conduit artery blood flow has indicated resistance training may attenuate the age-related reduction in limb blood flow [66]. Microvascular blood flow, assessed by venous occlusion plethysmography, may also be improved following resistance training. Six-weeks of traditional high-intensity resistance training can increase both resting forearm blood flow and peak hyperemia in young men [67]. Even shorter resistance training interventions (4 weeks) have been shown to increase vasodilatory capacity [68]. With low-load BFR resistance exercise, the blood flow adaptations may be unique since the arterial flow pattern may be disrupted (and hence shear stress) which has been shown to be important for exercise-induced changes in vascular function [69]. The acute calf blood flow response has been shown to be lower following acute low-load BFR resistance exercise compared to moderate intensity (70% 1RM) resistance exercise suggesting that higher intensity resistance training may be necessary to elicit increases in regional blood flow [59]. Despite this, 6-weeks of low-load BFR increased calf blood flow to a similar extent as low- (45% 1RM) and moderate-intensity (70% 1RM) lower body resistance training [60]. Other investigations have found an increase in calf microvascular capacity despite no change in resting calf blood flow following low-load BFR calf exercise [27]. The authors speculate that these changes are mediated by increased capillarization which was enhanced by the blood flow restriction

[27]. Although the exact mechanism is unknown, potential reasons for this adaptation include the capillary exposure to hypoxia from the blood flow restriction and/or the reactive hyperemia following the cuff release [27]. Two recent investigations also documented enhanced post-occlusive blood flow following low-load BFR resistance training in both young women [10] and in older individuals [11]. Again, the exact mechanism is not clear but it is thought that enhanced metabolic accumulation and/or fast twitch fiber recruitment during low-load BFR exercise stimulates an increase in capillarization [70].

Muscular Adaptations to Resistance Exercise Training

Trainable characteristics of skeletal muscle include muscular strength, muscular endurance, and muscular power. Muscular strength is the ability of a muscle to generate a maximal force; muscle endurance is the ability to perform repeated contractions against a submaximal resistance; muscle power is the ability of a muscle to exert high force while contracting at high speed. All three characteristics may be altered with resistance training and are important from a health perspective.

Increases in muscular strength with resistance training may be due to a combination of morphological and neurological factors. The morphological changes in skeletal muscle leading to increased muscle strength primarily are due to changes in whole muscle and individual fiber size [71]. Increases in muscle fiber number (hyperplasia), changes in fiber type and myosin heavy-chain composition, and changes in muscle architecture (increases in pennation angle) may also contribute to increased muscular strength, but evidence does not suggest these factors play a large role [71]. Current resistance exercise recommendations for improving muscular strength differ depending on the population. For experienced strength-trainers, a hard to very hard resistance exercise intensity (>80% 1RM) is recommended; for older individuals or for sedentary individuals beginning a resistance exercise program, a very light to light intensity (40-50% 1RM) is recommended for increasing strength [72]. With BFR resistance exercise, even lower exercise intensities may be capable of increasing muscular strength. BFR resistance exercise using 30% 1RM has been shown to increase muscle strength to a similar extent as high intensity (80% 1RM) resistance training in young males [3] and to a slightly lower extent in older males [7]. However, improvements in strength following low-load BFR resistance training may be more attributable morphological changes rather than neurological changes. BFR resistance training at an intensity of 20% 1RM did not change muscle specific tension or increase muscle activation as assessed by the twitch interpolation technique [73]. Furthermore, Yasuda et al. also showed relative dynamic strength (1RM divided by muscle cross-sectional area) was increased following high-intensity (75% 1RM) but not following low-load BFR training at 30% 1RM [74]. Moore et al. [75] did find BFR resistance training was capable of enhancing post-activation potentiation, but their training protocol consisted of a higher exercise intensity (50% 1RM) and the authors speculate this neural adaptation may have been driven by the load rather than the blood flow restriction per se.

As mentioned, increases in muscle size (hypertrophy) may also increase muscle strength. For increasing muscle size specifically, resistance exercise recommendations are to exercise at an intensity of 70-85% 1RM for novice and intermediate individuals and 70-100% 1RM for advanced trainers [72]. However, low-load resistance exercise combined with blood flow restriction has been shown to induce muscle hypertrophy in a relatively short period. Changes in quadriceps muscle cross sectional area have been documented in as little as seven days (training twice daily) of low-load BFR resistance exercise training [76]. Numerous other investigations have documented significant increases in muscle hypertrophy following low-load BFR resistance exercise compared to low-intensity resistance exercise without BFR [12, 13, 16, 77]. Total work, in addition to mechanical loading, may also play a large role in skeletal muscle hypertrophy [78]. Therefore, it is possible that the addition of blood flow restriction to low-intensity resistance exercise lowers the exercise volume threshold that is required to induce muscle hypertrophy. In fact, low-load, high-volume exercise appears to be superior to high-load, low-volume resistance exercise for inducing muscle hypertrophy. Previous work has shown small (~2.8% increase in CSA) increases in muscle hypertrophy following 9-weeks of elbow flexion exercise at an intensity of 35% 1RM but not 90% 1RM [78]. Theoretically, BFR exercise to volitional fatigue would lead to greater adaptations than exercise not performed to volitional fatigue. In fact, comparing studies in which participants performed BFR exercise training to volitional fatigue or not to fatigue, it appears that greater muscle hypertrophy may occur when the exercise is performed to volitional fatigue. Takarada et al. [14] observed a ~16% increase in quadriceps cross sectional area (CSA) when participants performed five sets of BFR knee extension to fatigue (16 training bouts) which is more than four times as large an increase as observed (3.5% increase in quadriceps CSA) in the study by Fujita et al. [4] in which participants performed four sets of knee extension short of fatigue (75 total repetitions), although this study only included 12 training bouts.

As mentioned, there are a number of potential mechanisms explaining the hypertrophic effects low-load BFR resistance exercise including acute increases in anabolic hormones, increased type II fiber recruitment, and muscle cell swelling. A few studies have examined levels of muscle protein synthesis to better understand the effects of BFR exercise on muscle hypertrophy. Fujita et al. [79] showed that muscle protein synthesis and phosphorylation of ribosomal S6 kinase 1 (S6K1), a downstream effector of the muscle protein synthesis pathway, was increased following low-load BFR resistance exercise but not following the same exercise protocol without blood flow restriction. This study also showed greater increases in lactate, growth hormone, and cortisol following low-load BFR exercise suggesting that the metabolic accumulation and acute hormonal response might be the key mechanism leading to increased muscle protein synthesis [79]. Similar findings have been shown in older men [80]. This same group also showed increases in several genes associated with muscle growth and remodeling following acute low-load BFR exercise which, surprisingly, were also increased following low-intensity resistance exercise [81]. In contrast, Manini et al. [82] did not find an increase in myogenic (i.e. muscle building) mRNA expression but did find a decrease proteolytic (i.e. muscle breakdown) mRNA expression following acute low-load BFR resistance exercise. Most recently, Laurentino et al. [8] found not only did low-load BFR and high-intensity resistance training produce comparable increases in muscle size and strength, but also that both protocols produced similar reductions in myostatin (a negative regulator of muscle mass) gene expression. The collective body of research supports the idea that low-load BFR resistance exercise can increase muscle protein synthesis and/or decrease muscle protein degradation leading to increases in muscle hypertrophy comparable to high-intensity resistance exercise. However, the exact mechanism (i.e. hypoxia, cell swelling, anabolic hormones, etc.) which trigger these pathways remains unclear.

For improving muscular endurance a resistance exercise intensity of <50% 1RM is recommended [72]. This exercise intensity is based on the idea of specificity of training; that is, performing resistance exercise with lighter loads for a greater number of repetitions per set (e.g.10-20) will improve muscular endurance to a greater extent than resistance exercise with higher loads and lower repetitions. Campos et al. [83] has shown that high-rep (20-28 repetitions per set) was superior to intermediate-rep (9-11 repetitions per set) and low-rep (3-5 reps per set) training for improving local muscle endurance. Since BFR resistance exercise is typically performed with low-loads and a higher number of repetitions per set (usually 15 to 30 reps per set), this type of exercise would be expected to improve muscular endurance. Cook et al. [84] showed that low-load BFR resistance exercise not only could combat muscle atrophy but also improve muscular endurance of the knee extensor when low-load BFR resistance exercise was performed during a period of 30 days of unloading. Kacin & Strazar [6] showed that BFR enhanced muscular endurance (measured by the number of repetitions performed at 15% MVC to fatigue) was improved to a greater extent following low-load BFR exercise (63% increase) compared to the same training without BFR (36% increase). Similar improvements in dynamic muscle endurance following low-load BFR exercise have been documented in trained athletes [12]. The mechanism for enhanced muscular endurance following BFR resistance exercise training is not entirely clear, but increases in the volume of the muscle microvasculature [85], mitochondria [86], and glycogen stores [87] have all been proposed. In fact, Burgomaster et al. [22] did find that blood flow restriction during resistance training increased resting muscle glycogen concentration and decreased resting ATP concentration compared to work-matched resistance training without blood flow restriction. They proposed that hypoxia-stimulated glucose uptake led to the increase in muscle glycogen stores following training but the reduction in ATP was primarily attributable to the previous exercise session (i.e. an acute reduction, not necessarily a training adaptation) [22]. Others have shown an increase in local (calf muscle) capillary filtration capacity following low-load BFR resistance training which may be an indication of exercise-induced capillary growth [27]. Hypoxia may induce vascular endothelial growth factor-1 (VEGF) expression. In fact, VEGF has been shown to increase following acute low-load BFR exercise [37].

Muscular power is the product of force and velocity; muscular power can be increased by performing the same amount of work in a shorter time or by increasing the amount of work performed during the same period of time. The age-related reduction in muscular power may be related to the age-related reduction in muscle mass (sarcopenia) and/or concomitant age-related reduction in strength (dynapenia) as well as alterations in neuromuscular function (reduced voluntary activation). There is some debate over the age-related changes that lead to reduced muscle power. When muscle power at submaximal loads (<70% 1RM) is expressed relative to body mass or cross-sectional area of the muscle, the difference in muscle power between middle-aged and elderly men are not apparent [88]. However, at maximal efforts (100% 1RM) relative muscular power is different between middle-aged and older men suggesting a decrease in maximal voluntary neural drive does occur with aging [88].

In older adults, muscle power has been associated with the ability to perform activities of daily living [20] and is a good predictor of risk of falling and functional dependency [89]. Thus, resistance training aimed at increasing muscular power is appropriate for a variety of population from young athletes to older adults. Current resistance training recommendations for increasing muscular power are to perform one to three sets of exercise using light to moderate loadings (30-60% 1RM for upper body exercise, 0-60% 1RM for lower body exercise) for three to six repetitions [72]. It is commonly thought that athletes should train with loads that maximize their power output to enhance muscular power [90]. However, de Vos et al. [91] showed that at a variety of resistance exercise intensities (20, 50, and 80% 1RM) can increase muscle power in older adults.

As mentioned, not only morphological (e.g. muscle hypertrophy) but also neurological adaptations may contribute to increased power output with resistance training. Increases in the rate of force development, force production at fast and slow velocities, stretch-shortening cycle performance, and coordination of movement pattern and skill all contribute to muscular power [72]. Explosive, high-intensity (50-80% 1RM) resistance training has been shown to increase agonist muscle activation, increase the rate of isometric force development, and decrease antagonist muscle activation in middle-aged and older men and women results in significant increase in muscle strength and power [92]. Although low-load BFR resistance exercise is not typically performed in an explosive manner, muscular power may be enhanced through this type of training due to increases in muscular strength. Blood flow restriction during low-load resistance exercise has been shown to increase muscle activation relative to non-BFR low-load resistance exercise [35, 36]. This increase in motor unit recruitment and type II fiber activation, is one of the proposed mechanisms behind the efficacy of low-load BFR resistance training [31]. However, thus far, few investigations have specifically examined the effect of low-load BFR resistance training on muscular power. Abe et al. [1] found that twice daily low-load BFR squat and leg curl exercise was effective in increasing both muscle strength and 30 meter dash time in college athletes after just 8 days of training (16 exercise sessions). The mechanism for this increase in power is not clear but may be due to the strength adaptations rather than neural adaptations per se. As mentioned, low-load BFR exercise has been shown to enhance post-activation potentiation and decrease resting twitch torque but may not affect either maximal voluntary activation or the rate of torque development [75]. The enhanced post-activation potentiation was attributed to the lower resting twitch torque which the authors speculate was due to an increased extensibility of the muscle-tendon complex or low-frequency fatigue in response to the training regimen [75].

Chapter III: Methodology

Participants

Fourteen men and eight women aged 40-64 years from Norman, Oklahoma and the surrounding area were recruited to participate in this study. Eighteen (12 men, 6 women) completed the entire study protocol. Two men were excluded because they could not obtain medical clearance from their physician; one woman dropped out after the initial screening visit due to an unexpected surgical procedure (unrelated to the study) and one woman dropped out during the resistance training because she felt uncomfortable with the exercise. An *a priori* analysis indicated that a sample size of 18 participants would be necessary to detect a significant limb by time interaction using (2x3, limb x time) repeated measures analysis of variance with an alpha level of 0.05, a power of 0.80, and an estimated effect size of 0.33 for calf venous compliance. All participants gave written informed consent and received medical clearance from their primary care physician before undergoing any testing and/or exercise training for the study.

Inclusion Criteria

1. Men and post-menopausal women between the ages of 40-64 years
2. Non-smokers or individuals who have quit smoking within last 6 months
3. No orthopedic problems preventing strength testing and/or training
4. Not currently engaged in a lower-body resistance training program
5. Normotensive (either with or without medication)
6. Ankle-brachial index >0.90
7. Free of overt clinical disease from health history questionnaire

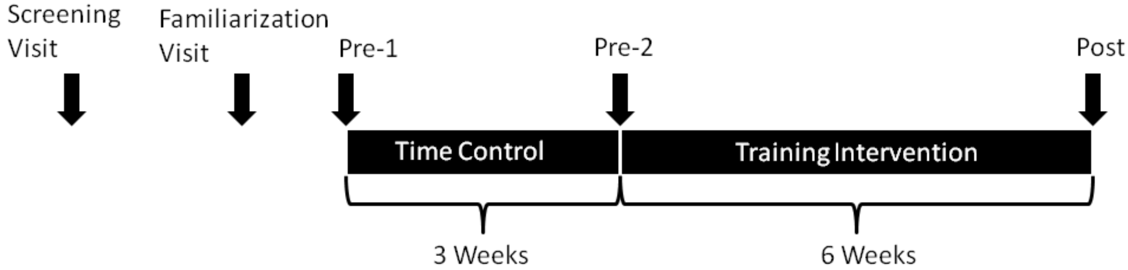
Exclusion Criteria

1. Men and women outside the age range and any pre-menopausal women
2. Smokers
3. Men on androgen replacement therapy
4. Women on non-oral hormone replacement therapy
5. Diabetes
6. Uncontrolled hypertension
7. Orthopedic problems preventing the completion of strength testing
8. Currently engaging in a lower body resistance exercise program
9. More than one risk factor for thromboembolism
    a. Obese (BMI > 30.0 kg/m^2)
    b. Diagnosed Crohn's or inflammatory bowel disease
    c. Past fracture of hip, pelvis, or femur
    d. Major surgery within the last 6 months
    e. Varicose veins
    f. Personal or family history of deep vein thrombosis or pulmonary embolism

Experimental Design

Participants visited the laboratory for a Screening Visit and Familiarization Visit followed by three testing sessions and 18 exercise training sessions (Figure 1). Testing took place approximately three weeks before the exercise training (Pre-1), within one week of the exercise training (Pre-2), and between 48-96 hours following the last training session (Post). Between the second and third testing sessions, each participant performed low-load unilateral knee extension exercise with blood flow restriction (BFR) while the contralateral limb performed the same exercise without blood flow restriction (free flow, FF) three times per week for six weeks (18 training sessions).

Figure 1. Study Design.



Screening Visit

On the initial visit to the laboratory (Screening Visit) each participant was screened to ensure all inclusion criteria and no exclusion criteria were met. Participants also completed a health history questionnaire and physical activity readiness questionnaire. Following completion of these forms, as part of the screening process, standing height and body mass were measured followed by measurements of brachial blood pressure (BP) and ankle brachial index (ABI) with the participant supine. Finally, each participant was given the physician clearance form to be signed by their primary care physician. Once screening was complete and informed consent was obtained, the lower limbs of each participant were assigned to the experimental conditions (BFR and FF).

Questionnaires

All participants filled out a health history questionnaire which included an assessment of how frequently (hours per week) each participant engaged in aerobic activity during the past six months.

Standing Height

Height was measured to the nearest 0.5 cm using a wall mounted stadiometer (Stadi-O-Meter, Novel Products Inc., Rockton, IL) with the participant unshod. The participant placed their heels together against the wall and was asked to stand up tall with back flat against the wall and their head aligned in the sagittal plane.

Body Mass and Body Mass Index

Body mass was measured to the nearest 0.1kg using a digital electronic scale (TANITA digital scale, TANITA, Japan) with the participant unshod and wearing light weight clothing. Body mass index (BMI) was calculated as body mass in kilograms divided by height in meters squared (kg/m^2).

Brachial Blood Pressure (BP)

Brachial systolic (SBP) and diastolic BP (DBP) were measured using an automatic blood pressure measuring device (Omron Healthcare Inc., Vernon Hills, IL). Two measurements were taken one minute apart on the left arm and averaged. If these measurements were not with 5 mmHg, a third measurement was taken and used for analysis. Mean arterial pressure (MAP) was calculated using the formula:

$$MAP = (2/3)\ DBP + (1/3)\ SBP$$

Ankle-brachial Index (ABI)

A vascular cuff was place on each upper arm 2-3 cm above the antecubital space and on each leg 1-2 cm above the malleolus and inflated with a manual handheld cuff inflator. To detect arterial blood flow, a Doppler probe (MD6 Bidirectional Doppler, D.E. Hokanson Inc., Bellevue, WA) was placed distal to the vascular cuff, over the brachial artery for brachial measurements and over the posterior tibial artery for ankle measurements. The vascular cuff was inflated to a pressure above which arterial blood flow could be detected and then slowly deflated (2-3 mmHg/sec). The highest pressure at which arterial flow could be detected during deflation was recorded as the systolic pressure in each limb. ABI was calculated as the lower ankle pressure divided by the higher brachial pressure.

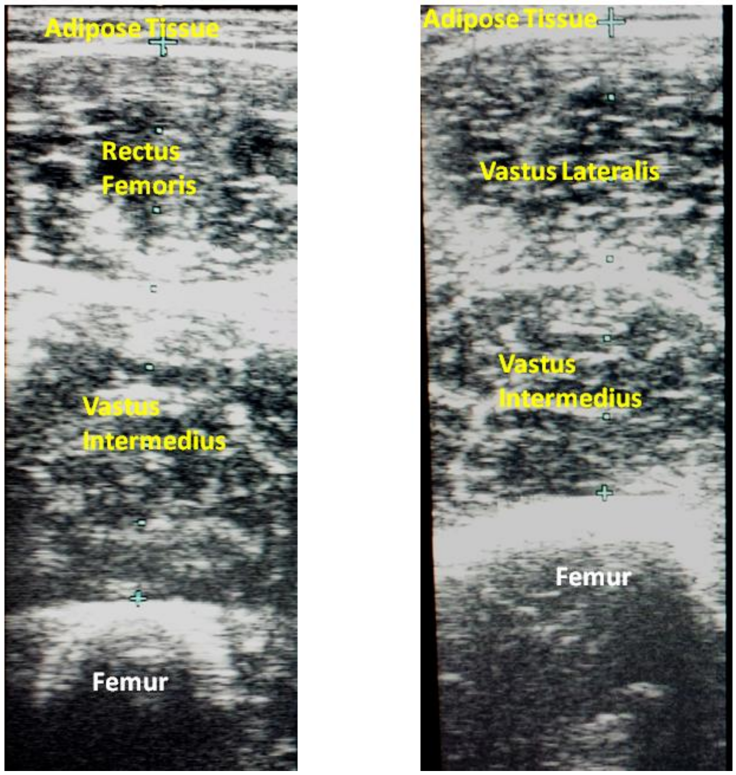
Familiarization Visit

On the second visit to the laboratory (Familiarization Visit), quadriceps muscle thickness (MTh) measurements were obtained on both thighs and the arterial occlusion pressure (AOP) was determined on the BFR limb. During this visit the participant was also familiarized with the knee extension machine and blood flow restriction apparatus; this included familiarization with the strength testing and power testing procedures and with the cadence of the metronome used for the exercise training.

Quadriceps Muscle Thickness (MTh)

B-mode ultrasound measurements of muscle thickness (MTh) were obtained at six anatomical sites on each thigh: on the lateral (LT) and anterior (AT) surface of the thigh at distance of 40% (40), 50% (50), and 60% (60) between the lateral epicondyle of the femur and the greater trochanter. Distances between bony landmarks were measured with a tape measure and marked with a pen. All ultrasound measurements were made using a Fukuda Denshi UF-750XT (Tokyo, Japan) ultrasound unit and a linear probe with an adjustable frequency of 6-9 MHz. For all measurements the probe frequency was 6 MHz and the depth and gain were adjusted to optimize the image. The probe was coated with transmission gel and placed perpendicular to the tissue interface at the marked sites without depressing the skin. MTh was determined as the distance from the adipose tissue-muscle interface to the muscle-bone interface and measured on-screen with electronic calipers to the nearest 0.01 cm. Representative images are shown in Figure 2.

Figure 2. Anterior Thigh (left) and Lateral Thigh (right) MTh Images.



Two measurements of MTh at each site were obtained and averaged. All muscle thickness measurements were taken with the participant standing with their legs fully extended [93]. Day-to-day coefficient of variation for the MTh measurements ranged from 3.40-6.64% for the various measurement sites.

Arterial Occlusion Pressure Determination (AOP)

With the participant supine, the blood flow restriction cuff (KaatsuMaster-mini, Sato Sports Plaza, Tokyo, Japan) was applied to the BFR limb at an initial pressure of 20-25 mmHg. The cuff was then inflated to 120 mmHg for 30 seconds and then deflated for 10 seconds while arterial blood flow at the posterior tibial artery was continuously assessed with a Doppler probe (MD6 Bidirectional Doppler, D.E. Hokanson Inc., Bellevue, WA). Cuff pressure was then increased incrementally by 40 mmHg (30 second inflation followed by a 10 second deflation) until arterial blood flow at the posterior tibial artery was no longer detected during cuff inflation. When arterial blood flow was no longer detected, cuff pressure was then decreased in increments of 10 mmHg units until flow was present during inflation. Arterial occlusion pressure was recorded, to the nearest 10 mmHg, as the lowest cuff pressure at which arterial flow was absent.

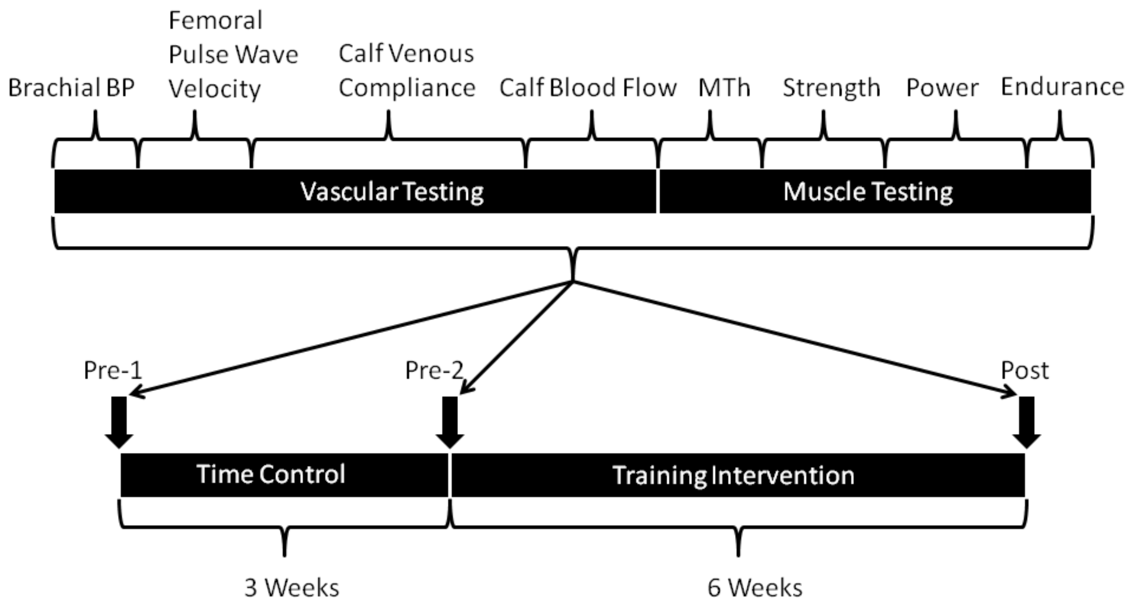
Familiarization

The knee extensor machine (NT 1220, Nautilus, Louisville, CO) seat back and shin pad were adjusted to fit the participant. These settings were recorded and remained the same for all testing and training sessions. The participant was instructed on proper form and breathing technique for the exercise. The participant completed unilateral knee extensor exercise with each limb starting at a low load (25-30% of estimated 1RM) for 8-10 repetitions and the load was progressively increased up (over 3-4 trials) to a high load (90% of estimated 1RM) for one repetition. The participant was then instructed on the procedures for the power measurement. Next, the blood flow restriction cuff was applied to the BFR limb and inflated to 50% AOP while the participant performed 8-10 repetitions with a low-load (25-30% estimated 1RM) through a full range of motion with a cadence of 1.5-sec concentric 1.5-sec eccentric. This was repeated with the FF limb without application of the blood flow restriction cuff.

Testing Visits

After the screening and familiarization visits, participants returned to the laboratory on three occasions for testing. During these testing visits, body mass, brachial blood pressure, thigh circumference, measures of vascular function, and quadriceps MTh and function measurements were obtained (Figure 3).

Figure 3. Overview of Testing Sessions.



All vascular and muscular measurements were performed on the right side of the body first. Since the BFR and FF assignment was randomized between the right and left limbs, this ensured that the testing order was randomized between the BFR and FF limbs. Participants were instructed to avoid caffeine (minimum 4 hours), food (minimum 3 hours), and strenuous activity (minimum 24 hours) before all testing visits. All testing sessions took place at the same time of day.

Body Mass

Body mass was measured as described above.

Brachial Blood Pressure (BP)

Brachial systolic and diastolic blood pressures were measured as described above.

Femoral Pulse Wave Velocity (PWV)

Femoral PWV was measured on both sides of the body in accordance with current guidelines [94]. The distance from the femoral artery pulse to the posterior tibial artery pulse was measured as a straight line with a tape measure. Using a high-fidelity strain-gauge transducer (SphygmoCor, AtCor Medical, Sydney, Australia), pressure waveforms were obtained at both pulse locations. During each pulse measurement, an electrocardiogram (ECG) was recorded to obtain heart rate and used as a timing marker. Femoral PWV was calculated from the distance between measurement points and the measured time delay between the proximal (femoral) and distal (posterior tibial) waveforms relative to the peak of the R-wave recorded from the ECG and expressed as meters per second (m/s).

Calf Venous Compliance (CVC)

Both legs were elevated (14 cm) above heart level and an appropriately-sized venous collecting cuff was placed on each thigh (4-5 cm above patella) and an appropriately-sized strain gauge (2-3 cm smaller than the maximum circumference of the calf) connected to the plethysmograph was placed around each calf at the point of maximum circumference. The venous collecting cuff was inflated to 20 mmHg for 45 seconds, followed by subsequent cuff inflation pressures of 20, 40, 60, and 80 mmHg which were sustained for 1, 2, 3, and 4 minutes, respectively, with 1 minute allotted between inflations to allow for new baseline formation and prevent edema formation [95].

Venous volume variation (VVV; ml/100 ml) was defined as the maximal volume change in the calf at each cuff pressure and recorded by the plethysmograph in the Noninvasive Vascular Program (NIVP3, D.E. Hokanson Inc., Bellevue, WA) . VVV was plotted across cuff pressures (20, 40, 60, 80 mmHg) to create a pressure-volume curve. Calf venous compliance (ml/100ml/mmHg) was calculated from the slope of the pressure-volume curve. Following each cuff inflation, maximum venous outflow (MVO; ml/100ml/min) was calculated as the slope of the line tangent to the curve 0.5 seconds after cuff release and also recorded in the NIVP3.

Calf Blood Flow (CBF)

Calf blood flow (CBF) measurements were obtained using strain gauge plethysmography. The participant’s legs remained in the same position and the setup was the same as described for the CVC measurement. The venous collecting cuff was inflated to 50 mmHg for 7 sec while the plethysmograph recorded the arterial inflow. Each inflation was followed by an 8 sec deflation. Six measurements were taken on each leg and recorded in the NIVP3. Calf vascular conductance was calculated as flow per unit pressure (mmHg) using the formula:

$$\text{Calf Vascular Conductance} = (\text{CBF} / \text{MAP}) * 1000$$

The average of the six measures was used for analysis.

Quadriceps Muscle Thickness (MTh)

Quadriceps MTh was measured as described above (Familiarization Visit).

Thigh Circumference

With the participant in the supine position and legs passively elevated, the circumference of the mid thigh (50% of the distance between the lateral epicondyle of the femur and the greater trochanter) was measured with a tape measure and recorded to the nearest 0.5 cm.

Knee Extensor Strength

The maximum load that could be lifted through a full range of motion with proper form during unilateral knee extension was assessed and recorded as the one-repetition maximum (1RM). For each limb, the 1RM was assessed following standard 1RM procedures [96]. The participant completed a warm-up of 8-10 repetitions with 40-50% of their estimated 1RM followed by a second warm-up using approximately 75% of their estimated 1RM for 2-5 repetitions. The participant then completed one repetition using 90% of their estimated 1RM and then the load was increased or decreased on subsequent attempts depending on whether or not the participant successfully lifted the load. All 1RMs were determined within 6 attempts and a minimum of 1 min rest was allotted between attempts.

Knee Extensor Power

Knee extensor power was assessed during unilateral knee extension at three relative loads (30%, 60%, and 90% 1RM). The loads used to assess power were relative to the 1RM measured during that same visit. The participant was instructed to complete the concentric portion of the repetition as fast as possible. Two trials were completed at each load, in ascending order, and separated by a minimum of 1 minute rest. A TENDO Fitrodyne Sports Powerlyzer unit was attached to the arm connecting the shin pad to the load which measured the mean velocity (m/s) during each trial. For each load, the greater of the two mean velocities was used for analysis. Mean power (watts) was calculated using the formula:

Mean power (watts) = [load (kg) x mean velocity (m/s)] / 0.10197

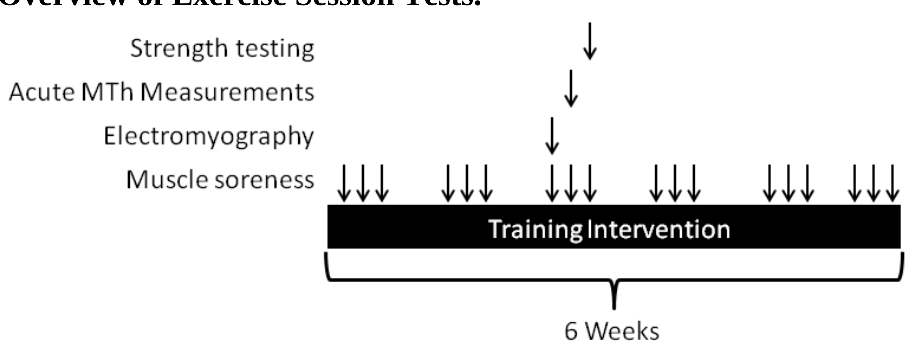
Knee Extensor Endurance

Following the knee extensor power test, the participant was given a minimum of 3 min of rest. The load was adjusted to 30% the 1RM measured on that visit. Participants completed one set of unilateral knee extension exercise to volitional fatigue at a pace of 20 repetitions per min (1.5 sec concentric and 1.5 sec eccentric). The number of repetitions completed through a full range of motion was recorded.

Exercise Training Visits

Between the second and third testing sessions, each participant performed low-load unilateral knee extension exercise three times per week for six weeks (18 training sessions) with each limb (BFR and FF). Surface electromyography (EMG) was used to record electrical activity of the vastus lateralis muscle during exercise during the seventh exercise session. Measurements of quadriceps MTh were obtained immediately before and immediately after exercise during the eighth exercise training session. Quadriceps muscle strength (1RM) was evaluated immediately before the ninth exercise session. Quadriceps muscle soreness (pressure-pain threshold) was measured prior to each exercise session (Figure 4).

Figure 4. Overview of Exercise Session Tests.



Quadriceps Muscle Soreness

Quadriceps muscle soreness was assessed on the vastus lateralis 20 cm distal to the lateral epicondyle. Up to 10 kg/cm^2 of pressure was applied to the site using an algometer (pain diagnostic force gauge, PFK 20, Wagner Instruments, Greenwich, CT). The participant was asked to verbally indicate when the pressure became “uncomfortable” and this force was recorded (pressure-pain threshold; kg/cm^2). If no indication of discomfort was given, soreness was considered not present. Each site was tested twice and the mean pressure reading was used for analysis. If the measurements differed by more than 1 kg/cm^2, a third measurement was taken and the median was used as the representative value [97].

Blood Flow Restriction Protocol

With the participant in the seated position, the blood flow restriction cuff was applied with an initial compressive force of 20-25 mmHg to the most proximal portion of the thigh. The cuff was then inflated to 40% of AOP (100-120 mmHg) for 30 seconds and then deflated for 10 seconds. The cycle of cuff inflation/deflation was repeated with cuff pressure increasing in increments of 20-40 mmHg until the target inflation pressure was reached. For the first week of training, target inflation pressure was 150 mmHg or 50% of AOP (whichever was lower); for the subsequent weeks (2-6) of training, target inflation pressure was 80% of AOP but no higher than 240 mmHg. The cuff was inflated to the target inflation pressure for ~15 seconds prior to the first set of exercise and was deflated and removed immediately following the final set of exercise.

Exercise Training Protocol

Resistance training consisted of unilateral knee extension performed to volitional fatigue using a load of 30% of 1RM performed three times per week for six weeks. If a participant had to miss a session, the session was rescheduled and the sessions proceeded sequentially. The BFR limb exercised with the blood flow restriction cuff (Sato Sports Plaza, Tokyo, Japan) placed on proximal portion of the thigh. The contralateral limb (FF) performed the same exercise without the blood flow restriction cuff. The order of training alternated each session with the BFR limb exercising first during the odd numbered sessions and the FF limb exercising first during the even numbered sessions. A metronome was employed to ensure each participant performed the concentric and eccentric portion of each repetition in 1.5 sec (20 repetitions per minute). One minute rest periods were allotted between all sets. During the first two weeks of training, participants completed two sets of exercise with each limb during each session. The training volume progressively increased with participants completing three sets of exercise each session for each limb during weeks 3 and 4 except the ninth exercise session during which knee extensor strength was assessed and only two sets of exercise were performed with each limb. Four sets of exercise were performed during each session for each limb during weeks 5 and 6. The number of repetitions performed during each set for each limb was recorded during each session. The total exercise volume (kg) for all training sessions combined was calculated as load (kg) x total repetitions.

Acute Exercise Responses

During the seventh exercise session, surface electromyography (EMG) of the vastus lateralis (VL) was recorded on each limb during the exercise session. During the eighth exercise session, MTh measurements were obtained immediately before (Pre) and after (Post) the exercise session. During the ninth exercise session, knee extensor strength (1RM) was assessed.

Surface Electromyography (EMG)

Surface electromyography (EMG) was recorded on the VL. A pen mark was placed on the muscle belly of the VL at 66% of the distance between the anterior-superior iliac crest and the superior edge of the lateral side of the patella. At the site, the skin was shaved, abraded, and cleaned with alcohol. Circular Ag/AgCl electrodes (recording area diameter 20 mm; ConMed Instatrace Electrode, ConMed) were placed in line with the estimated pennation angle (~5°) of the VL over the muscle belly in a bipolar configuration with an inter-electrode distance of 20 mm. The electrodes were fixed on the skin with athletic tape. The ground electrode was placed on the 7th cervical vertebrae at the neck. The electrodes were connected to an amplifier and digitized (Biopac System, Inc. Goleta, CA). The signal was filtered (low-pass filter 500Hz; high-pass filter 10 Hz), amplified (1000x) and sampled at a rate of 1 KHz. Before the exercise bout, the participant performed two 3-5 sec unilateral maximal isometric voluntary contractions (MVCs) with the knee extensors of each limb at a joint angle of 90° with 1 min rest between MVCs. All MVCs were performed on the knee extensor machine with the machine settings in the same configuration as used for the exercise training. The EMG signal was recorded during the MVCs and during each set of knee extensor exercise.

EMG Analysis

The computer software Labview 7.1 (National Instrument Corporation, Austin, TX) was used to analyze the raw EMG signal. EMG amplitude (root mean square, RMS) and mean power frequency (MPF) were analyzed from the signal. From the isometric MVC recordings, four 25 ms epochs were analyzed and averaged for each recording. For each limb, the MVC with the higher amplitude was used for normalization of the signal recorded during the exercise session. Normalization was performed by dividing the EMG signal from the dynamic contractions (i.e. exercise session) by the EMG signal from the MVC and expressed as a percentage. For the dynamic contractions, 1000 ms epochs from the concentric (CON) and eccentric (ECC) phase of the first three (first) and last three (last) repetitions of each set (S1, S2, and S3) of exercise for each limb (BFR and FF) were analyzed. Additionally, since the FF limb performed more repetitions than the BFR limb during the exercise session, the three repetitions during FF exercise that corresponded to the last three repetitions performed during the BFR exercise were also analyzed (repetition matched, RM).

Quadriceps Muscle Thickness (MTh)

Quadriceps MTh was measured as described above (Familiarization Visit). On this occasion, measurements were only made at AT50 and LT50 on each thigh. Measurements were taken immediately before the exercise session (Pre) and within 2 min following the exercise bout (Post). These measurements (mid-training, Mid) were taken before exercise were also included in the analysis of MTh over the course of the entire study.

Knee Extensor Strength

Knee extensor strength was assessed as described above (Testing Visits).This measurement (mid-training, Mid) was also included in the analysis of strength over the course of the entire study.

Statistical Analyses

All data were analyzed using PASW Statistics 18. All data are expressed as mean ± standard deviation (SD). For all statistical tests, an alpha level of 0.05 was used. Participant characteristics were compared between men and women with independent samples t-tests. Systemic hemodynamic variables were analyzed with repeated measures (RM) analysis of variance (ANOVA). All local hemodynamic variables, muscular power, endurance, thigh circumference, and MTh at AT 40, AT 60, LT 40, LT 60 were analyzed with a 2x3 (limb x time) RM ANOVA. Local hemodynamic variables were also analyzed with a 2x4x2 (limb x time x sex) RM ANOVA with a between-subjects factor of sex. Muscular strength and MTh at AT 50 and LT 50 were analyzed with a 2x4 (limb x time) RM ANOVA. The relationship between baseline strength and MTh (at Pre-2) and the magnitude of adaptation (Post – Pre-2 values) were examined with Pearson correlations. Muscular strength was also analyzed with RM analysis of covariance (ANCOVA) with baseline strength as the covariate. Muscular power was analyzed with a 2x3x3 (limb x load x time) RM ANOVA. Muscular strength and MTh were also analyzed with a 2x4x2 (limb x time x sex) RM ANOVA with a between-subjects factor of sex. Muscular strength, endurance, power, and MTh were also analyzed separately with RM ANOVA within each sex. EMG amplitude (RMS) and frequency (MPF) were analyzed with a 2x2x6 (limb x phase x time) RM ANOVA for both non repetition-matched (i.e. maximal BFR vs maximal FF) and repetition-matched (i.e. maximal BFR vs submaximal FF) data separately. Acute changes in MTh were analyzed with a 2x2 (limb x time) RM ANOVA. Exercise volume was analyzed over the first six and over the last six training sessions with a 2x6 (limb x session) RM ANOVA. Pressure-pain threshold readings were analyzed with a 2x18 (limb x session) RM ANOVA. Mauchly's test of sphericity was used to determine if sphericity was violated. When sphericity was violated, the Greenhouse-Geisser test statistic was used to test within-subject effects; when sphericity was not violated, the Sphericity Assumed test statistic was used. When significant main effects were present, Least Significant Difference (LSD) pairwise comparisons were made on the marginal means. When significant interactions were present, paired samples t-tests were used to compare means within each factor. For all muscle function measures, test-retest reliability between Pre-1 and Pre-2 was determined using the intraclass correlation coefficient ($ICC_{3,1}$) and precision was determined using the standard error of the measurement (SEM) as described by Weir et al. [98]. For thigh circumference and MTh measures, % coefficient of variation (% CV) was calculated using the formula:

$$\% \text{ CV} = [(\text{mean Pre-1} + \text{mean Pre-2}) / 2] / (\text{SD})$$

To compare the magnitude of each treatment effect across time, effect size (ES) was calculated using the formula [99]:

$$\text{ES} = (\text{test 2 mean} - \text{test 1 mean}) / (\text{test 1 SD})$$

Chapter IV: Results & Discussion

Purpose

The purpose of this study was to determine the muscular (muscle thickness, muscular strength, power, and endurance) and vascular (arterial stiffness, venous compliance, resistance vessel blood flow) effects of six weeks of low-load resistance training performed to volitional fatigue with and without blood flow restriction in middle aged individuals.

Results

Participant Characteristics

At enrollment, on average, participants were overweight and engaged in a few hours of self-reported aerobic activity per week. Men and women were similar in all characteristics except standing height (Table 1). Body mass did not change significantly over the course of the study (82.7 ± 16.5, 82.4 ± 16.3, 82.1 ± 16.1, 82.2 ± 16.0 kg; enrollment, Pre-1, Pre-2, Post).

Table 1. Participant Characteristics at Enrollment.

	Men n=12	Women n=6	Total N=18	Range Min-Max
Age (yrs)	54 (8)	58 (5)	55 (7)	42-62
Height (m)	1.81 (0.06)	1.65 (0.07)*	1.76 (0.10)	1.50-1.91
Body Mass (kg)	86.1 (14.1)	76.1 (20.1)	82.7 (16.5)	55.8-120.6
BMI (kg/m^2)	26.2 (4.3)	27.6 (5.7)	26.7 (4.7)	20.4-36.1
ABI	1.1 (0.1)	1.1 (0.1)	1.1 (0.1)	1.0-1.2
Aerobic Activity (hrs/wk)	2.4 (1.9)	2.2 (2.4)	2.3 (2.0)	0-6.5

Data presented as mean (SD); BMI, body mass index; ABI, ankle-brachial index; Min, minimum; Max, maximum; *p<0.05 from Men.

Arterial Occlusion Pressure

Arterial occlusion pressure (AOP) was either 300 mmHg or 300+ mmHg (i.e. no occlusion at 300 mmHg) for 17 of the 18 participants; the blood flow restriction target pressure was 150 mmHg and 240 mmHg during sessions 1-3 and 4-18 for these individuals, respectively. The AOP for the other participant was 230 mmHg; the blood flow restriction target pressure was 120 mmHg and 180 mmHg during sessions 1-3 and 4-18 for this individual, respectively.

Systemic Hemodynamics

Over the course of the study brachial BP did not change. Heart rate was significantly altered over the course of the study (p=0.036); Post heart rate was significantly greater (p=0.035) than Pre-1 heart rate (Table 2).

Table 2. Systemic Hemodynamics.

	Pre-1	Pre-2	Post
Systolic BP (mmHg)	120 (13)	118 (11)	119 (11)
Diastolic BP (mmHg)	76 (8)	75 (7)	75 (8)
Mean Arterial Pressure (mmHg)	91 (9)	89 (8)	89 (9)
Heart Rate (bpm) †	60 (7)	62 (7)	63 (9)*

Data presented as mean (SD); BP, blood pressure; †p<0.05 time effect; *p<0.05 from Pre-1.

Local Hemodynamics

Technical issues with the plethysmograph and involuntary muscle contractions of the calf during the venous compliance measurement resulted in missing data for three participants at one of the measurement timepoints. Therefore, calf venous compliance data are presented on 15 participants (n=15). No main effects or interaction effects of sex were observed for any local hemodynamic variable; therefore, data collapsed across sex. Femoral artery stiffness (PWV) and calf venous compliance were unaltered over the course of the study (Table 3). A significant limb x time interaction was observed for calf blood flow (p=0.047) and calf vascular conductance (p=0.035). However, pairwise comparisons did not reveal any significant differences between values compared within each limb across time or compared at each timepoint between limbs.

Table 3. Local Hemodynamics.

		Pre-1	Pre-2	Post
PWV (m/s)	BFR	8.9 (0.9)	9.0 (1.0)	9.4 (0.9)
	FF	9.1 (1.2)	8.8 (1.2)	9.0 (1.1)
Calf Blood Flow (ml/min/100ml)‡	BFR	2.77 (1.55)	2.53 (0.88)	2.55 (1.03)
	FF	2.41 (1.12)	2.27 (0.71)	2.73 (0.94)
Calf Vascular Conductance (flow/mmHg)‡	BFR	30.8 (17.1)	28.7 (10.6)	28.8 (10.8)
	FF	26.6 (12.4)	25.4 (7.9)	31.1 (11.4)
Calf Venous Compliance (ml/100ml/mmHg)	BFR	0.041 (0.012)	0.038 (0.011)	0.037 (0.012)
	FF	0.039 (0.013)	0.034 (0.012)	0.037 (0.009)
MVO20 (ml/min/100ml)	BFR	32.2 (11.8)	32.8 (16.0)	24.5 (11.7)
	FF	28.3 (14.6)	25.0 (13.4)	25.3 (15.8)
MVO40 (ml/min/100ml)	BFR	54.4 (17.4)	56.2 (24.9)	42.7 (15.6)
	FF	46.6 (21.9)	43.7 (16.5)	43.7 (27.4)
MVO60 (ml/min/100ml)	BFR	64.3 (22.1)	65.1 (25.6)	53.0 (18.9)
	FF	55.6 (25.3)	52.0 (17.8)	50.9 (27.6)
MVO80 (ml/min/100ml)	BFR	68.8 (23.6)	69.9 (23.9)	60.4 (21.8)
	FF	60.2 (21.8)	56.2 (18.9)	57.8 (26.8)

Data presented as mean (SD); PWV, pulse wave velocity; BFR, blood flow restricted limb; FF, free flow limb; MVO, maximum venous outflow; ‡$p<0.05$ limb x time interaction.

Knee Extensor Function

One participant injured his back (unrelated to the study) between the final training session and the post testing session and was unable to complete the knee extensor function tests at Post. Therefore, this participant was excluded from the RM ANOVA analyses and data are presented on 17 participants (n=17). A main effect of sex (p<0.001) was observed with men exhibiting greater strength than women regardless of limb or timepoint; no limb x sex, time x sex, or limb x time x sex interactions were observed for knee extensor strength. Knee extensor strength was altered significantly over time ($p<0.001$) with no statistically significant differences between BFR and FF. Analysis of knee extensor strength within each sex revealed similar main effects for time with no limb x time interactions (data not shown).For both sexes combined, knee extensor strength was greater than Pre-1 at every timepoint. Knee extensor strength was greater at Post compared to Mid and Pre-2 (Table 4). Individual strength responses across time for each limb are shown in Figures 5 and 6; individual changes in strength over the training intervention (Post - Pre-2) for each limb are shown in figures 7 and 8. The change in strength over the intervention was inversely correlated with strength at Pre-2 for each limb (BFR: $r=-0.51$, $p=0.037$; FF: $r=-0.635$, $p=0.006$; Figure 9). ANCOVA did not reveal any significant differences in strength between limbs after controlling for baseline strength. Mean power at 30% and at 60% 1RM were significantly ($p=0.006$ and $p<0.001$, respectively) altered over time with no statistically significant differences between BFR and FF. Mean power at 30% 1RM was significantly greater at Post compared to Pre-1 and Pre-2; mean power at 60% 1RM was significantly greater at Pre-2 and Post compared to Pre-1 (Table 4). Mean velocity at 90% 1RM was significantly ($p=0.003$) altered over time; mean velocity at 90% 1RM was significantly lower at Post compared to Pre-1 and Pre-2 (Table 4). Knee extensor endurance was significantly altered over time ($p<0.001$) with no statistically significant differences between BFR and FF. Endurance at Post was significantly greater compared to Pre-1 and Pre-2 (Table 4). The test-retest reliability ICCs calculated from Pre-1 to Pre-2 were relatively high for knee extensor strength (0.93-0.94), mean power (0.87-

0.96), and endurance (0.74-0.89) and relatively low for mean velocity (0.00-0.73) (Table 4).

Although no statistically significant differences in knee extensor function between BFR and FF were observed over the course of the study, the effect size (ES) calculated over time (Pre-2 to Post) was greater in the BFR limb for knee extensor strength (ES = 0.34 vs 0.24, BFR vs FF) and mean power at 30% 1RM (ES = 0.32 vs 0.24, BFR vs FF); the ES for muscular endurance was greater for the FF limb (ES = 0.69 vs 0.87, BFR vs FF) over the course of the training intervention (Post – Pre-2) (Table 5).

RM ANOVA revealed a significant (p=0.004) load x time interaction for knee extensor mean power (Figure 10). Mean power at 60% and 90% 1RM were significantly greater than mean power at 30% 1RM at all timepoints; mean power at 90% 1RM was significantly greater than mean power at 60% 1RM at Pre-1 and Pre-2 but not at Post (Figure 10).

Table 4. Knee Extensor Function.

		Pre-1	Pre-2	Mid	Post	ICC (3,1)	SEM (3,1)
1RM (kg)*	BFR	25.9 (8.3)	27.9 (9.1)[a]	29.6 (8.3)[a]	31.0 (8.0)[a,b,c]	0.93	3.3
	FF	26.8 (8.8)	28.9 (9.7)[a]	30.4 (8.3)[a]	31.2 (8.1)[a,b,c]	0.94	3.1
Mean Power 30% 1RM (watts)*	BFR	78.5 (28.8)	80.0 (28.3)		89.0 (28.3)[a,b]	0.87	14.3
	FF	78.5 (29.1)	81.3 (30.9)		88.6 (29.2)[a,b]	0.90	13.3
Mean Power 60% 1RM (watts)*	BFR	123.5 (45.9)	133.7 (53.0)[a]		142.7 (46.9)[a]	0.89	22.5
	FF	124.3 (50.2)	138.0 (54.7)[a]		142.0 (50.7)[a]	0.96	14.5
Mean Power 90% 1RM (watts)	BFR	137.2 (54.9)	144.7 (59.5)		143.3 (55.2)	0.95	17.6
	FF	141.7 (59.3)	141.3 (55.6)		147.6 (51.7)	0.95	17.0
Mean Velocity 30% 1RM (m/s)	BFR	1.00 (0.15)	0.95 (0.09)		0.95 (0.10)	0.36	0.14
	FF	0.97 (0.12)	0.92 (0.10)		0.95 (0.11)	0.00	0.16
Mean Velocity 60% 1RM (m/s)	BFR	0.81 (0.13)	0.79 (0.09)		0.76 (0.08)	0.44	0.11
	FF	0.77 (0.14)	0.79 (0.09)		0.76 (0.13)	0.73	0.09
Mean Velocity 90% 1RM (m/s)*	BFR	0.58 (0.12)	0.57 (0.11)		0.51 (0.11)[a,b]	0.70	0.08
	FF	0.58 (0.13)	0.54 (0.08)		0.52 (0.08)[a,b]	0.70	0.08
Muscular Endurance (repetitions)*	BFR	32 (14)	35 (13)		44 (13)[a,b]	0.89	7
	FF	31 (12)	32 (15)		45 (15)[a,b]	0.74	10

Data presented as mean (SD); N=17; BFR, blood flow restricted limb; FF, free flow limb; 1RM, one repetition maximum; *$p<0.05$ time effect; [a]$p<0.05$ from Pre-1; [b]$p<0.05$ from Pre-2; [c]$p<0.05$ from Mid.

Table 5. Calculated Effect Sizes for Knee Extensor Function Measurements.

		Pre-2-Pre-1	Mid-Pre-2	Post-Mid	Post-Pre-1	Post-Pre-2
1RM	BFR	0.24	0.19	0.17	0.61	0.34
	FF	0.22	0.15	0.10	0.50	0.24
Mean Power 30% 1RM	BFR	0.05			0.36	0.32
	FF	0.10			0.35	0.24
Mean Power 60% 1RM	BFR	0.22			0.42	0.17
	FF	0.27			0.35	0.07
Mean Power 90% 1RM	BFR	0.14			0.11	-0.02
	FF	-0.01			0.10	0.11
Mean Velocity 30% 1RM	BFR	-0.33			-0.33	0.00
	FF	-0.42			-0.17	0.30
Mean Velocity 60% 1RM	BFR	-0.15			-0.38	-0.33
	FF	0.14			-0.07	-0.33
Mean Velocity 90% 1RM	BFR	0.08			-0.58	-0.55
	FF	0.31			-0.46	-0.25
Muscular Endurance	BFR	0.21			0.86	0.69
	FF	0.08			1.17	0.87

Calculated effect sizes across time within each treatment; BFR, blood flow restricted limb; FF, free flow limb.

Figure 5. Individual Strength Responses for the BFR limb.

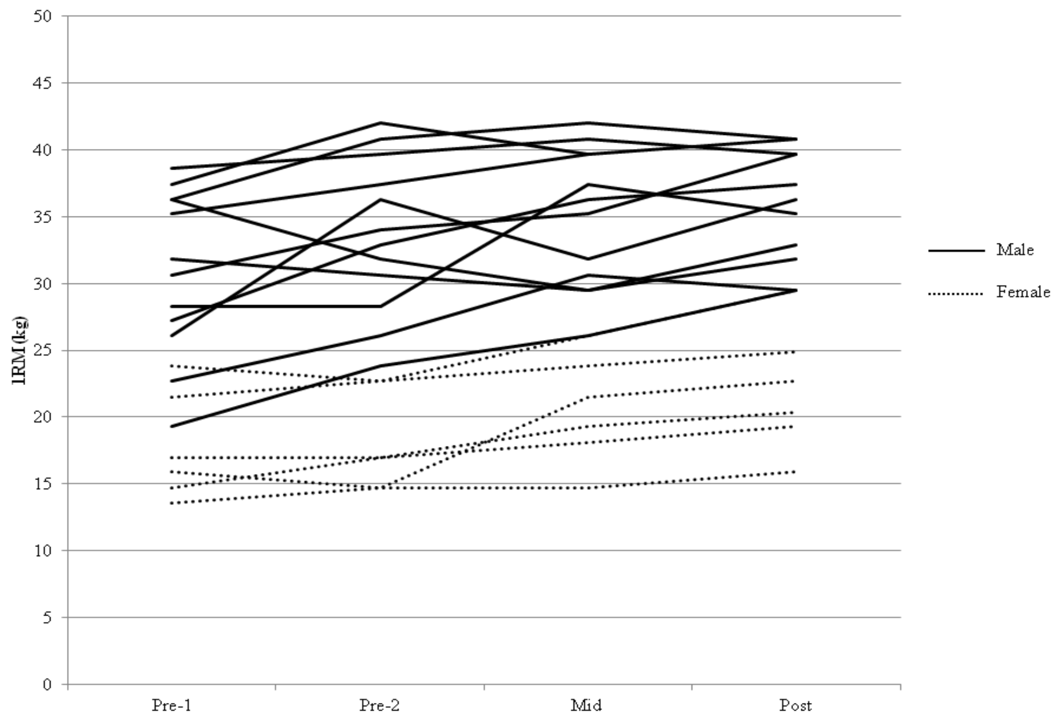


Figure 6. Individual Strength Responses for the FF limb.

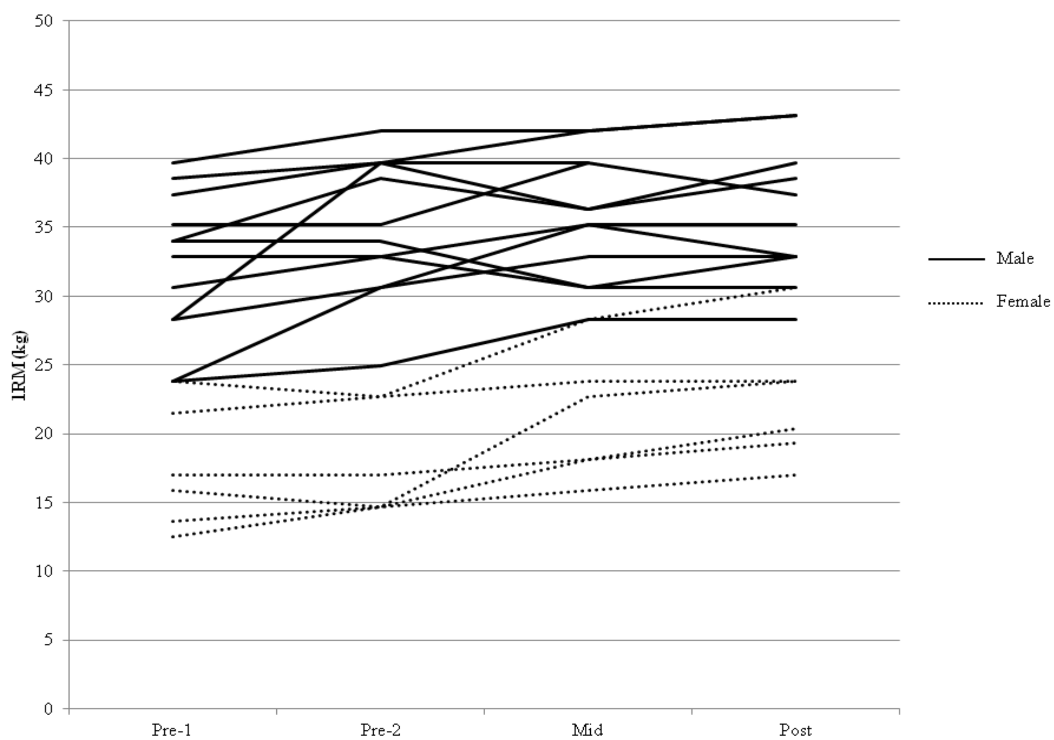


Figure 7. Individuals Changes (Post - Pre-2) in Strength for the BFR Limb.

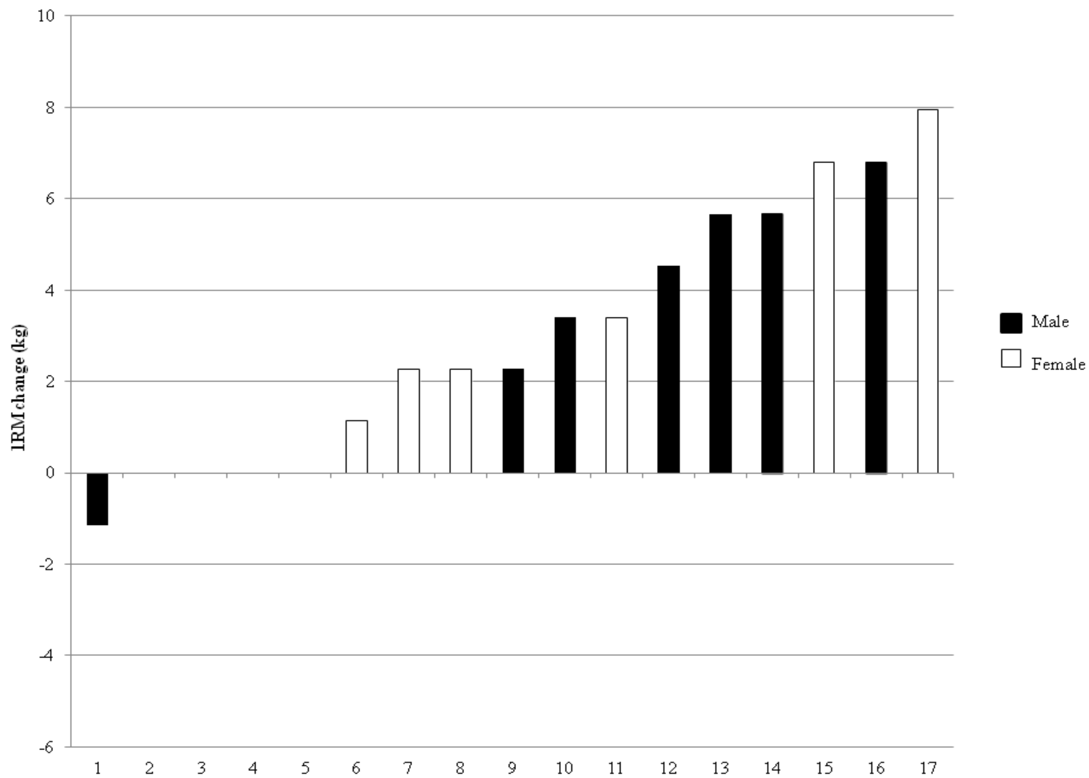


Figure 8. Individual Changes (Post - Pre-2) in Strength for the FF Limb.

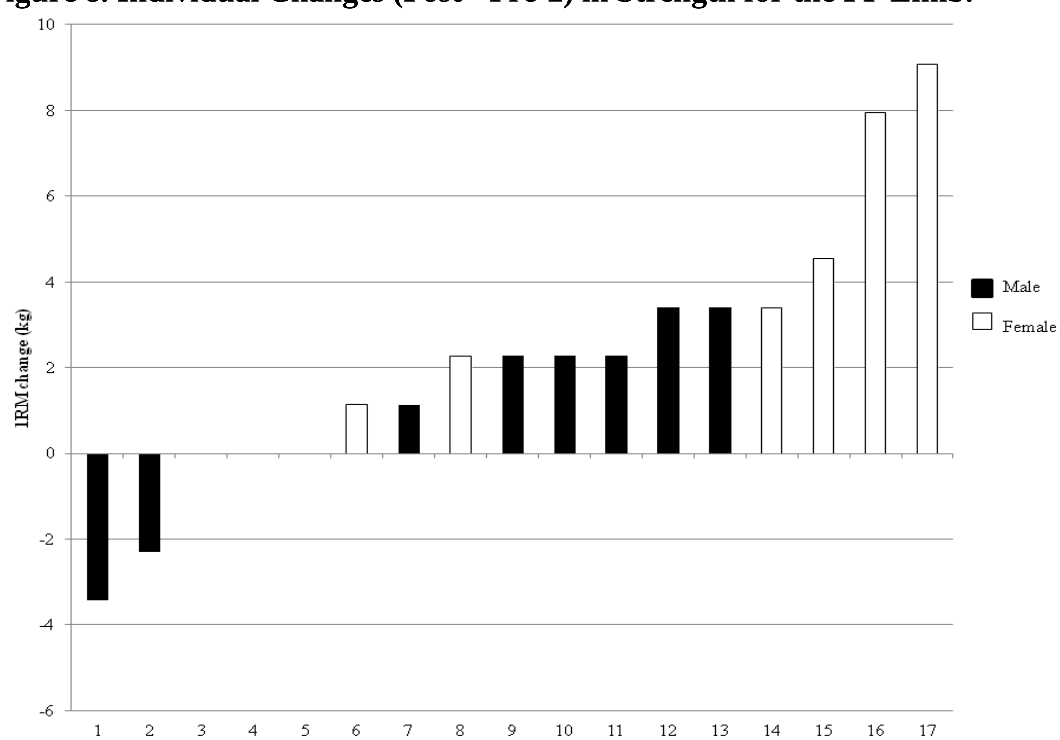


Figure 9. Correlation Between Pre-training Strength and Strength Adaptation.

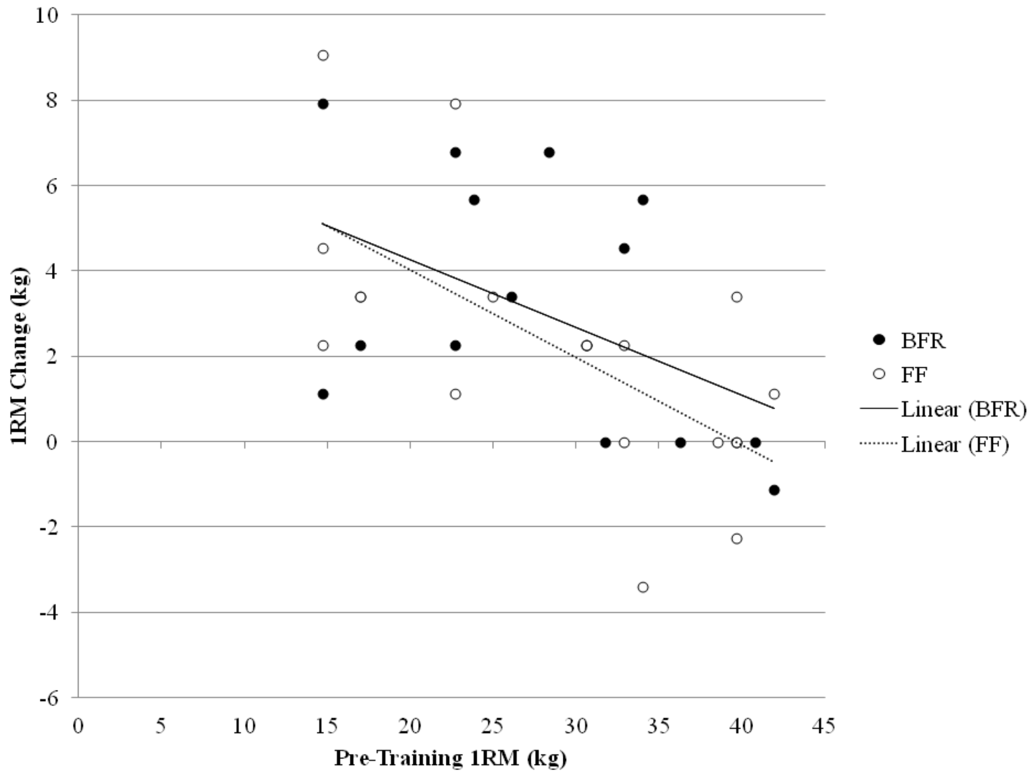
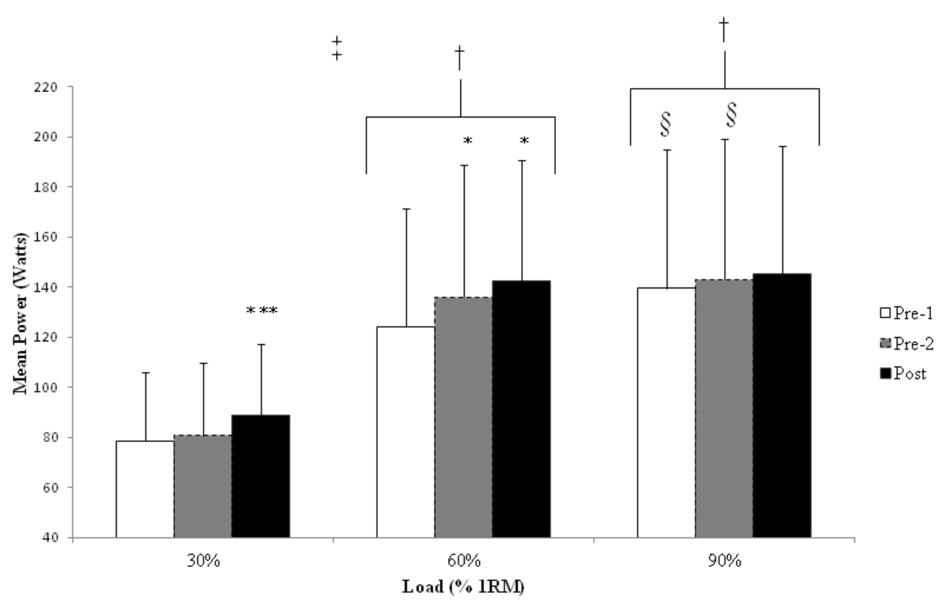


Figure 10. Knee Extensor Mean Power Collapsed Across Limbs Compared Between Loads and Timepoints.



Data presented as mean (SD); ‡p<0.05 load x time interaction; *p<0.05 from Pre-1; **p<0.05 from Pre-2; †p<0.05 from 30% 1RM; §p<0.05 from 60% 1RM

Thigh Circumference and MTh

Thigh circumference was unaltered over the course of the study (Table 6). MTh measurements were unobtainable on one participant because of excessive adipose tissue; therefore, MTh data are presented on 17 participants (n=17). Individual changes in MTh for AT 50 and LT 50 for each limb and shown in figures 11-14. A main effect of sex was present for MTh at all sites (p=0.028) with men exhibiting greater MTh in both limbs at all timepoints compared to women; no limb x sex, time x sex, or limb x time x sex interactions were observed for MTh at any site. For both sexes combined, main effects for time were observed for AT 40 (p=0.002), AT 50 (p=0.015), and AT 60 (p=0.001) with no differences between BFR and FF (Table 6). AT 40, AT 50, and AT60 were significantly greater at Post compared to Pre-1 and Pre-2 with no differences between Pre-1 and Pre-2 (Table 6). AT 50 was also significantly greater at Mid compared to Pre-1 and Pre-2 but not different between Mid and Post (Table 6). Significant limb x time interactions were observed for LT 40 (p=0.029), LT 50 (p=0.044), and LT 60 (p=0.024) (Table 6). LT 40, 50, and 60 were significantly greater at Post compared to Pre-1 and Pre-2 for BFR only; LT 60 was also significantly greater for BFR compared to FF at Post. LT 50 was significantly greater at Mid compared to Pre-1 and Pre-2 for BFR only; LT 50 was also significantly greater for BFR compared to FF at Mid (Table 6). Analysis of MTh within each sex revealed similar main effects for time with no limb x time interaction for women alone; similar main effects of time and limb x time interactions were observed for the men alone (data not shown). Individual changes in MTh are shown in Figures 11-14. The change in MTh over the intervention was not related to MTh at Pre-2 at either site for either limb (BFR: AT50, r=0.12, p=0.636; LT50, r=0.023, p=0.928; FF: AT50, r=-0.072, p=0.777; LT50, r=-0.146, p=0.563; Figures 15-16).

Table 6. Thigh Circumference and MTh Measurements.

		Pre-1	Pre-2	Mid	Post	CV%
Thigh Circumference (cm)	BFR	53.3 (5.8)	53.1 (5.0)		53.8 (4.7)	2.42%
	FF	53.3 (6.0)	53.3 (4.9)		53.9 (5.0)	1.87%
AT 40 (cm)*	BFR	5.61 (0.78)	5.56 (0.62)		5.87 (0.70)^{a,b}	3.40%
	FF	5.65 (0.67)	5.62 (0.72)		5.79 (0.78)^{a,b}	3.91%
AT 50 (cm)*	BFR	5.10 (0.83)	5.13 (0.69)	5.40 (0.66)^{a,b}	5.39 (0.72)^{a,b}	5.22%
	FF	5.21 (0.68)	5.16 (0.72)	5.39 (0.68)^{a,b}	5.36 (0.75)^{a,b}	5.73%
AT 60 (cm)*	BFR	4.47 (0.83)	4.48 (0.69)		4.81 (0.78)^{a,b}	6.55%
	FF	4.55 (0.69)	4.53 (0.67)		4.79 (0.70)^{a,b}	6.64%
LT 40 (cm)‡	BFR	3.56 (0.60)	3.54 (0.65)		3.71 (0.66)^{a,b}	4.97%
	FF	3.53 (0.74)	3.47 (0.74)		3.43 (0.76)	3.78%
LT 50 (cm)‡	BFR	3.54 (0.62)	3.50 (0.61)	3.62 (0.69)^{a,b,c}	3.67 (0.62)^{a,b}	4.85%
	FF	3.57 (0.72)	3.49 (0.73)	3.45 (0.72)	3.56 (0.70)	4.42%
LT 60 (cm)‡	BFR	3.37 (0.66)	3.38 (0.64)		3.57 (0.58)^{a,b,c}	4.34%
	FF	3.43 (0.67)	3.37 (0.71)		3.44 (0.63)	4.91%

Data presented as mean (SD); AT, anterior thigh; LT, lateral thigh; *$p<0.05$ time effect; ‡$p<0.05$ limb x time interaction; $^{a}p<0.05$ from Pre-1; $^{b}p<0.05$ from Pre-2; $^{c}p<0.05$ from FF.

Effect sizes calculated between Post and Pre-2 revealed greater effects for BFR on MTh at all sites (Table 7). For AT 50, the ESs calculated between Mid and Pre-2 (ES = 0.31, 0.39) were larger than between Post and Mid (ES = -0.04, -0.02). For LT 50, a greater ES for BFR was observed between Mid and Pre-2 (ES = 0.20) whereas a greater ES for FF was observed between Post and Mid (ES = 0.15) (Table 7).

Table 7. Calculated Effect Sizes for Thigh Circumference and MTh Measurements.

		Pre-2-Pre-1	Mid-Pre-2	Post-Mid	Post-Pre-2
Thigh Circumference	BFR	-0.03			0.14
	FF	0.00			0.12
AT 40	BFR	-0.06			0.50
	FF	-0.04			0.24
AT 50	BFR	0.04	0.39	-0.02	0.38
	FF	-0.07	0.31	-0.04	0.28
AT 60	BFR	0.01			0.48
	FF	-0.03			0.39
LT 40	BFR	-0.03			0.26
	FF	-0.08			-0.05
LT 50	BFR	-0.06	0.20	0.07	0.28
	FF	-0.11	-0.05	0.15	0.10
LT 60	BFR	0.02			0.30
	FF	-0.09			0.10

Calculated effect sizes across time within each limb; BFR, blood flow restricted limb; FF, free flow limb.

Figure 11. Individual Changes (Post - Pre-2) in AT 50 MTh for the BFR Limb.

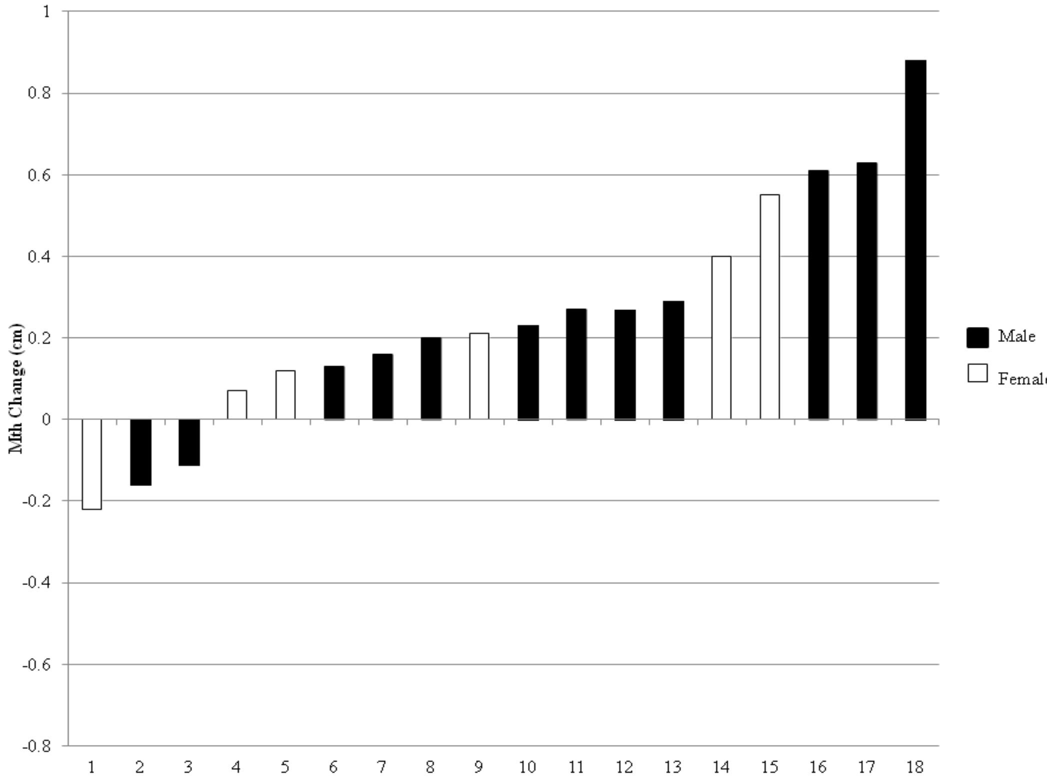


Figure 12. Individual Changes (Post - Pre-2) in AT 50 MTh for the FF Limb.

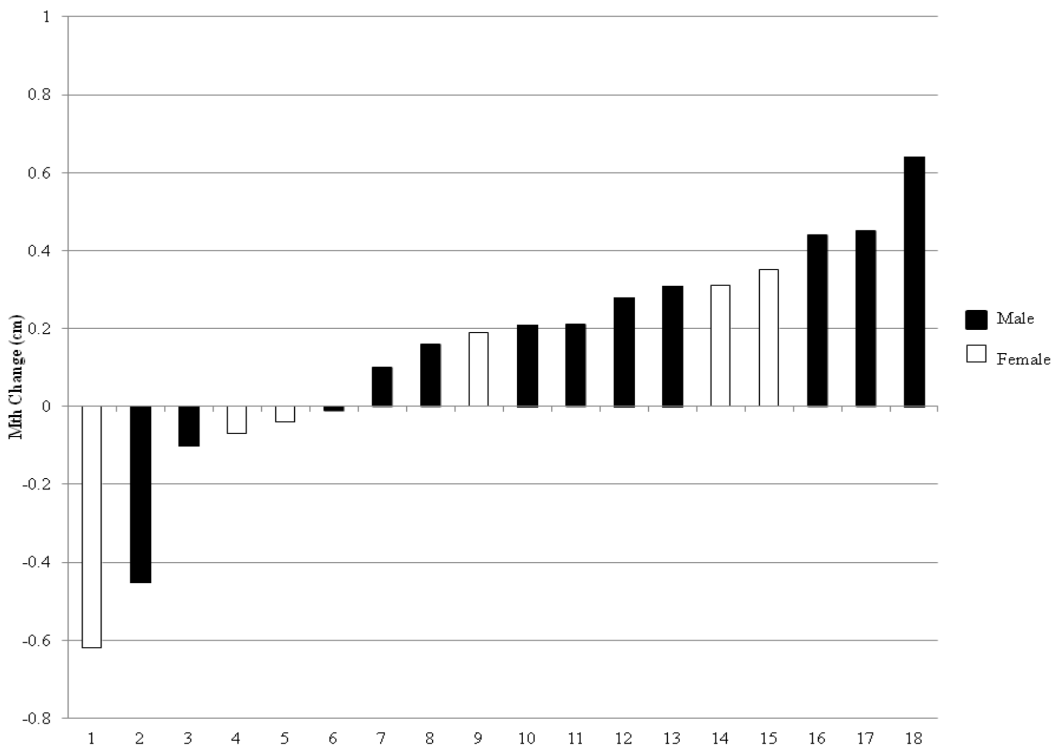


Figure 13. Individual Changes (Post - Pre-2) in LT 50 MTh for the BFR Limb.

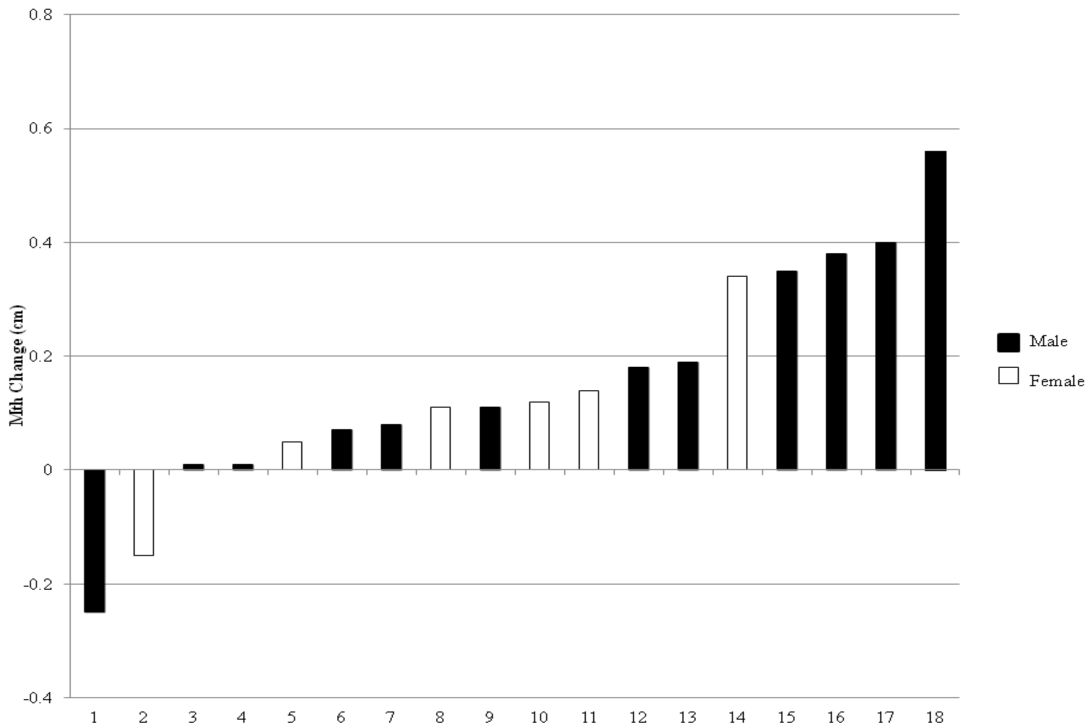


Figure 14. Individual Changes (Post - Pre-2) in LT 50 MTh for the FF Limb.

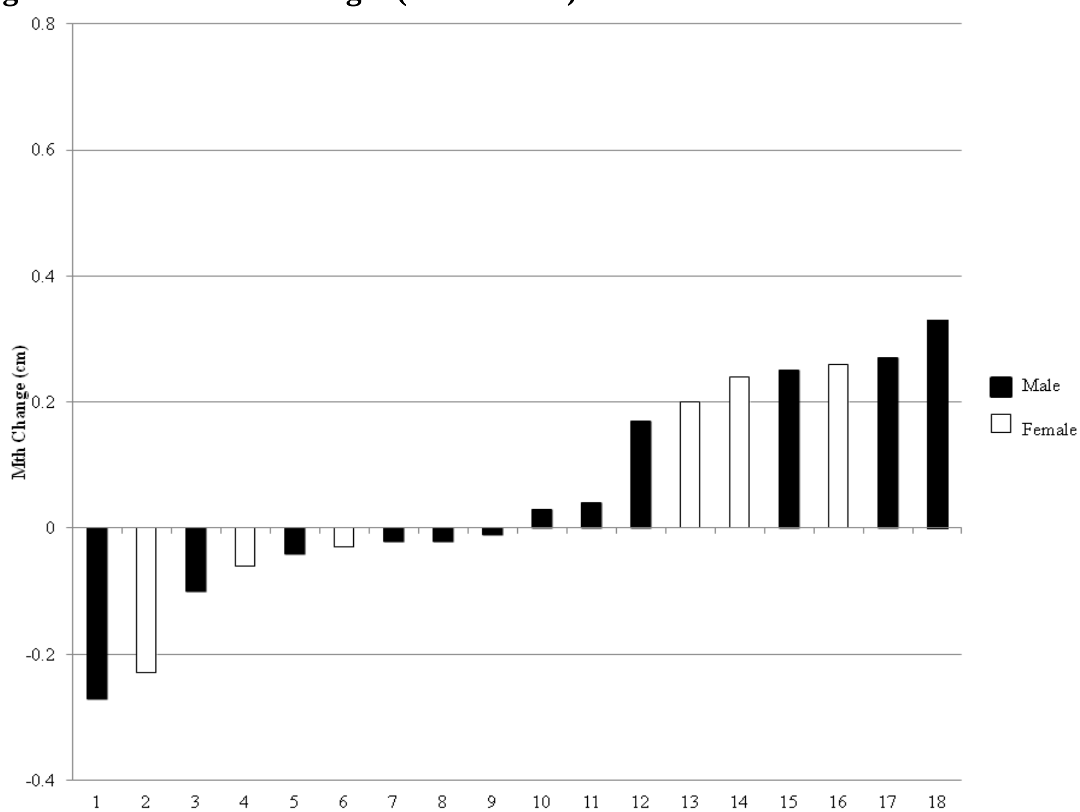


Figure 15. Correlation Between Pre-training Anterior Thigh MTh and change in MTh.

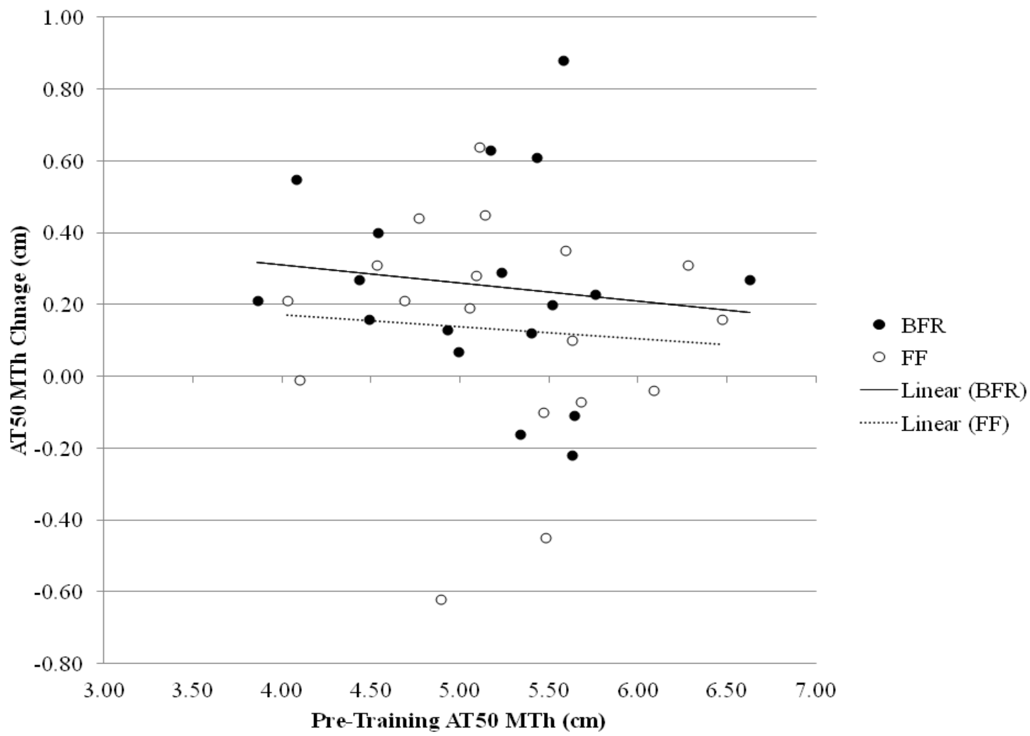
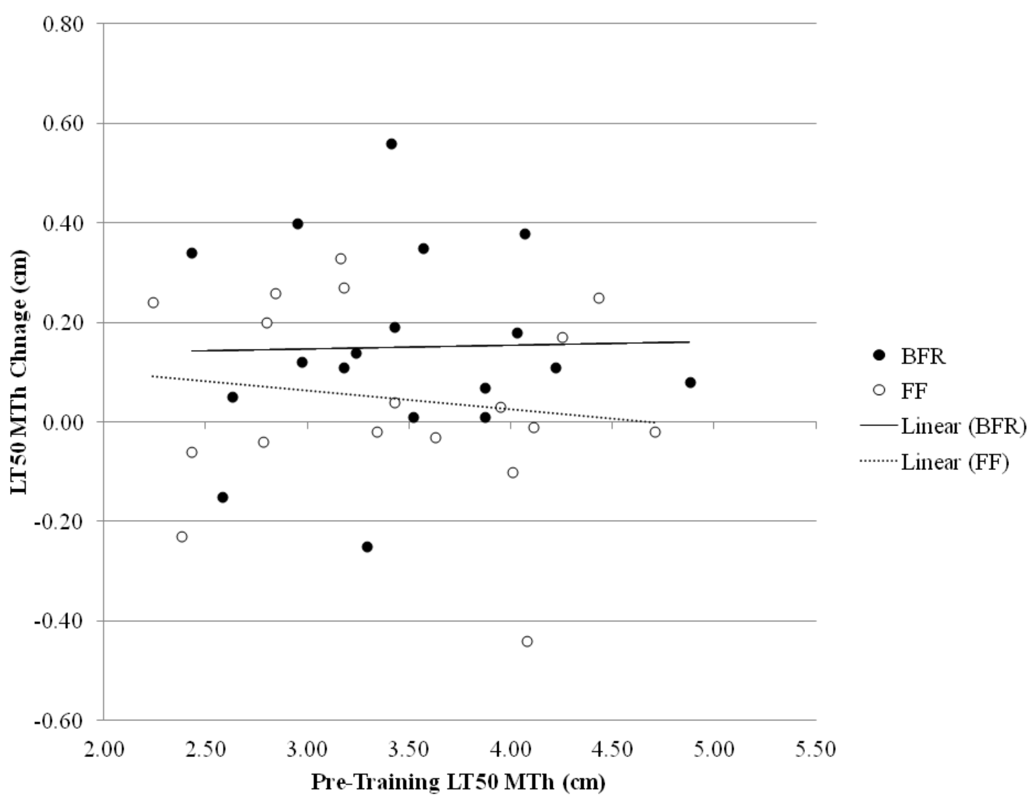


Figure 16. Correlation Between Pre-training Lateral Thigh MTh and change in MTh.



Surface Electromyography

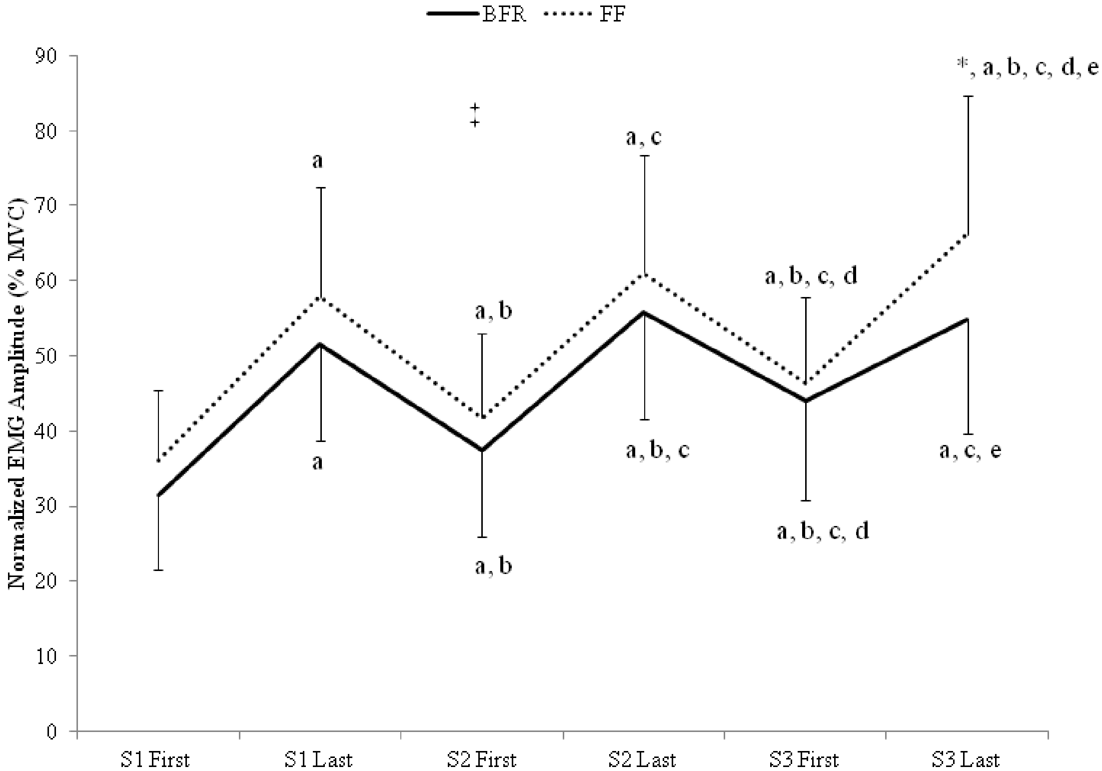
One participant could not complete six full repetitions during the third set of exercise with BFR. Therefore, EMG data were not available from this participant at all measurement timepoints and the statistical analyses were performed on 17 participants (n=17). RM ANOVA revealed a significant limb x time (p=0.044) and a significant phase x time (p<0.001) interaction for normalized EMG amplitude (RMS) for the non repetition-matched data (Table 8). RMS was significantly greater for FF compared to BFR at S3 Last (Figure 17); significant pairwise differences across time within each limb are shown in Figure 17. RMS was significantly greater for CON compared to ECC at all timepoints (Figure 18); significant pairwise differences across time within each phase are shown in Figure 18.

Table 8. Normalized EMG Amplitude (% MVC) Compared Under Non Repetition-matched Conditions.

‡ §		BFR		FF	
		CON	ECC	CON	ECC
S1	First	42.3 (14.6)	20.8 (7.6)	48.5 (12.9)	23.5 (7.5)
	Last	72.6 (19.1)	30.4 (7.8)	83.6 (23.0)	32.2 (9.9)
S2	First	55.3 (16.9)	19.6 (7.3)	61.6 (16.5)	22.0 (8.5)
	Last	79.6 (20.5)	31.9 (10.6)	85.8 (22.9)	36.3 (12.0)
S3	First	64.0 (19.3)	24.0 (8.1)	67.2 (17.1)	25.3 (8.1)
	Last	75.4 (20.1)	34.2 (12.7)	87.8 (25.4)	44.5 (14.1)

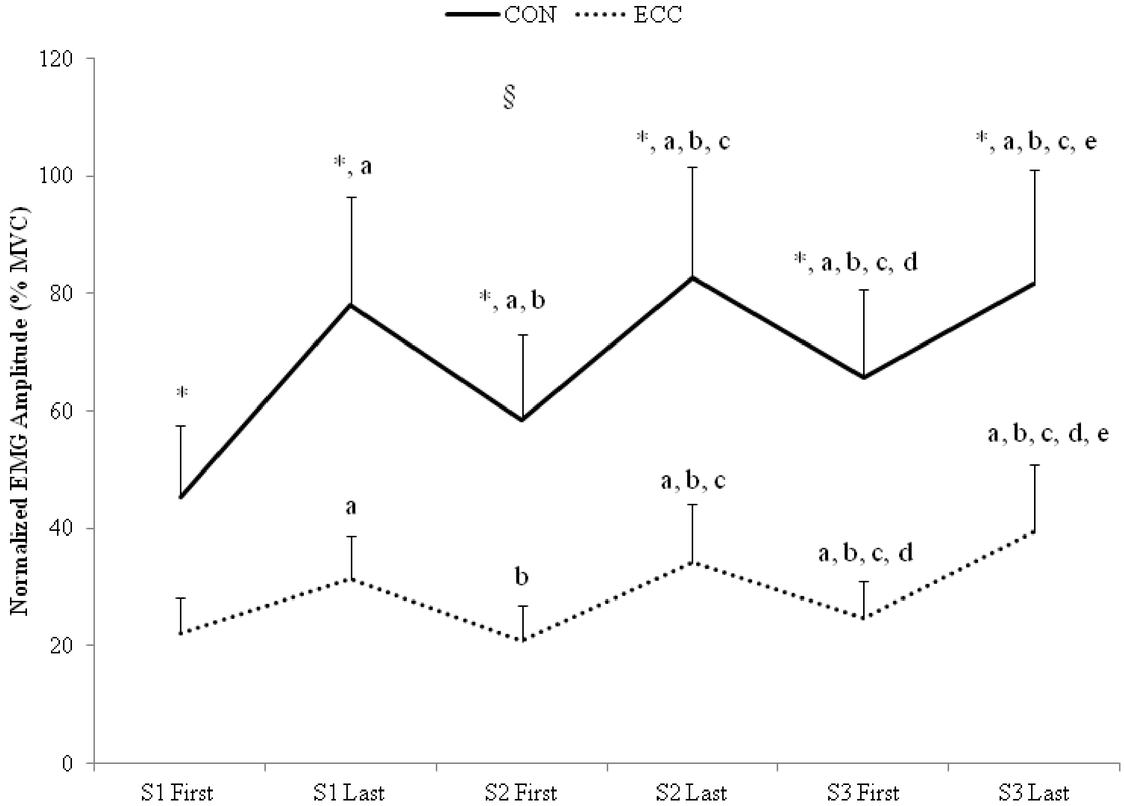
Data presented as mean (SD); ‡p<0.05 limb x time interaction; § p<0.05 phase x time interaction; BFR, blood flow restricted limb; FF, free flow limb; S1, set 1; S2, set 2; S3, set 3; First, first three repetitions; Last, last three repetitions.

Figure 17. Normalized EMG Amplitude Collapsed Across Phase Compared Under Non Repetition-matched Conditions.



Data presented as mean (SD); ‡ $p<0.05$ limb x time interaction; [a]$p<0.05$ from S1 First; [b]$p<0.05$ from S1 Last; [c]$p<0.05$ from S2 First; [d]$p<0.05$ from S2 Last; [e]$p<0.05$ from S3 First; *$p<0.05$ from BFR.

Figure 18. Normalized EMG Amplitude Collapsed Across Limbs Compared Under Non Repetition-matched Conditions.



Data presented as mean (SD); § p<0.05 phase x time interaction; [a]p<0.05 from S1 First; [b]p<0.05 from S1 Last; [c]p<0.05 from S2 First; [d]p<0.05 from S2 Last; [e]p<0.05 from S3 First; *p<0.05 from ECC.

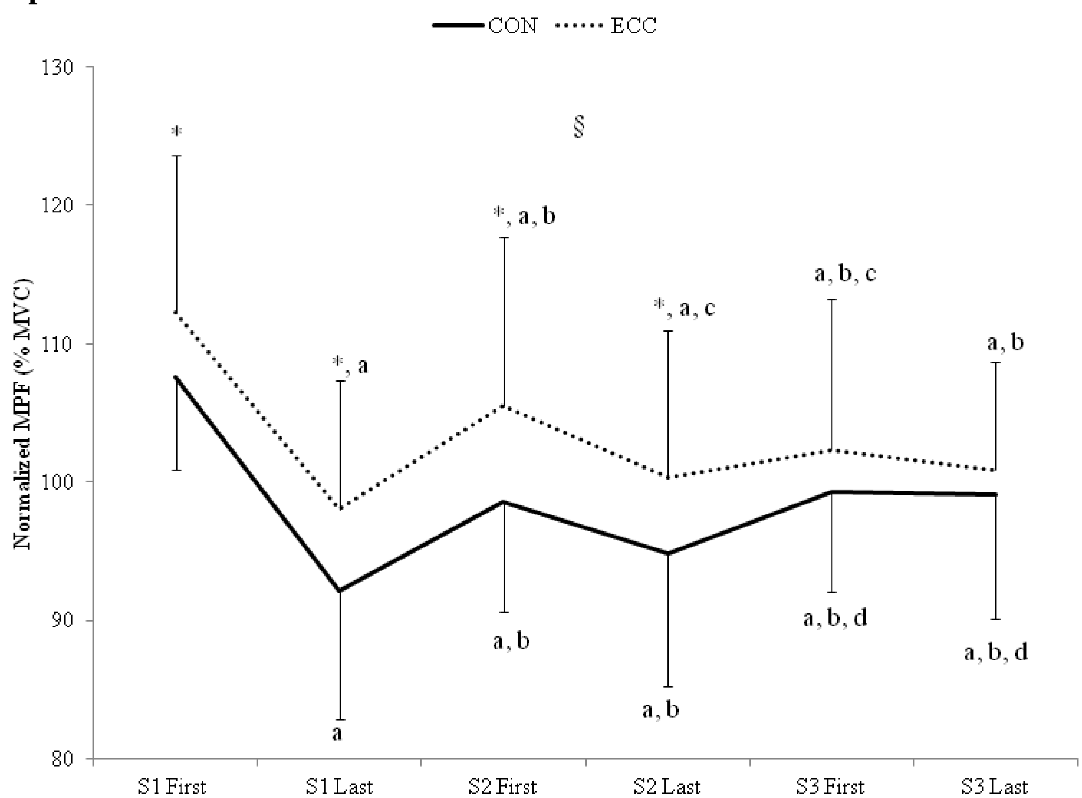
RM ANOVA revealed a significant phase x time (p=0.05) interaction for normalized MPF for the non repetition-matched data (Table 9). Normalized MPF was significantly greater for ECC compared to CON at S1 First, S1 Last, S2 First, and S2 Last (Figure 19); significant pairwise differences across time within each phase are shown in Figure 19.

Table 9. Normalized MPF (% MVC) Compared Under Non Repetition-matched Conditions.

§		BFR		FF	
		CON	ECC	CON	ECC
S1	First	103.3 (9.4)	108.3 (9.6)	111.8 (11.3)	116.2 (18.5)
	Last	91.1 (12.0)	96.4 (7.1)	93.1 (9.6)	99.7 (14.0)
S2	First	96.7 (8.2)	103.1 (10.6)	100.4 (11.8)	107.9 (16.8)
	Last	93.5 (10.8)	99.1 (9.9)	96.1 (11.7)	101.6 (14.4)
S3	First	97.1 (10.3)	100.4 (9.4)	101.5 (10.7)	104.3 (15.5)
	Last	98.5 (11.3)	100.0 (8.4)	99.7 (11.1)	101.7 (12.9)

Data presented as mean (SD); § $p<0.05$ phase x time interaction; BFR, blood flow restricted limb; FF, free flow limb; S1, set 1; S2, set 2; S3, set 3; First, first three repetitions; Last, last three repetitions.

Figure 19. Normalized MPF Collapsed Across Limbs Compared Under Non Repetition-matched Conditions.



Data presented as mean (SD); § $p<0.05$ phase x time interaction; [a]$p<0.05$ from S1 First; [b]$p<0.05$ from S1 Last; [c]$p<0.05$ from S2 First; [d]$p<0.05$ from S2 Last; [e]$p<0.05$ from S3 First; *$p<0.05$ from CON.

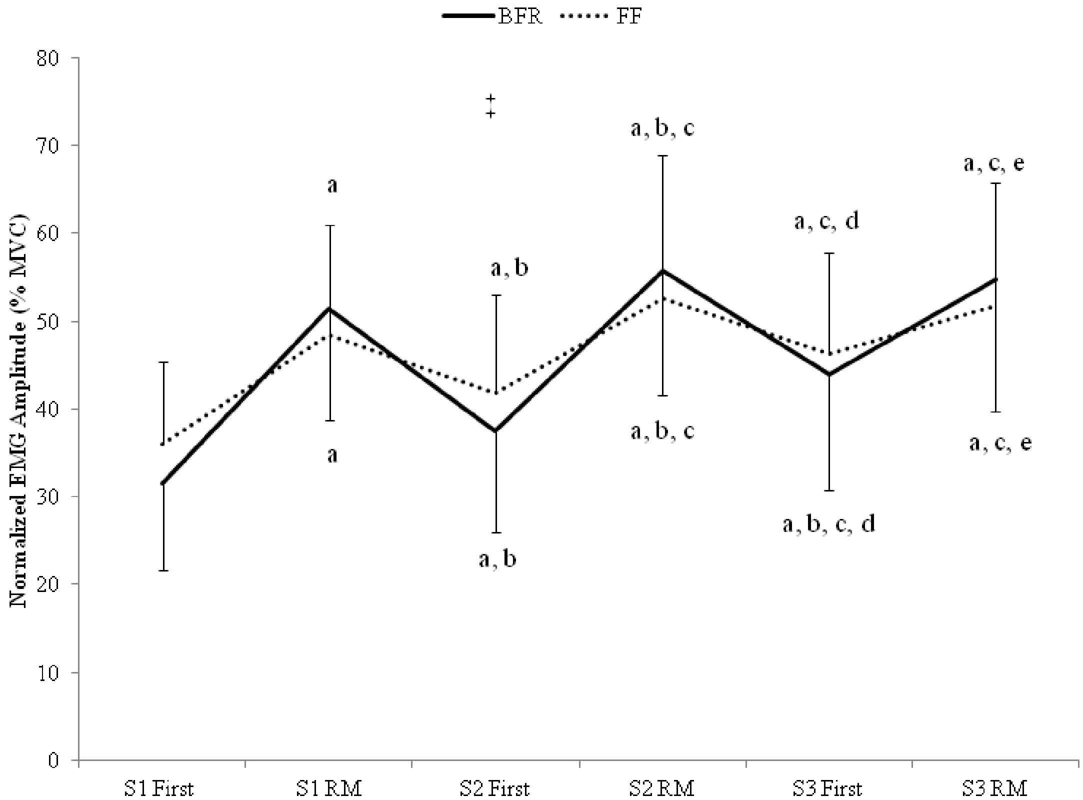
RM ANOVA revealed a significant limb x time ($p<0.001$) and a significant phase x time ($p<0.001$) interaction for normalized EMG amplitude (RMS) for the repetition-matched data (Table 10). RMS was not significantly different between FF and BFR at any timepoint (Figure 20); significant pairwise differences across time within each limb are shown in Figure 20. Normalized RMS was significantly greater for CON compared to ECC at all timepoints (Figure 21); significant pairwise differences across time within each phase are shown in Figure 21.

Table 10. Normalized EMG Amplitude (% MVC) Compared Under Repetition-matched Conditions.

‡ §		BFR		FF	
		CON	ECC	CON	ECC
S1	First	42.3 (14.6)	20.8 (7.6)	48.5 (12.9)	23.5 (7.5)
	RM	72.6 (19.1)	30.4 (7.8)	70.2 (19.5)	26.8 (8.1)
S2	First	55.3 (16.9)	19.6 (7.3)	61.6 (16.5)	22.0 (8.5)
	RM	79.6 (20.5)	31.9 (10.6)	75.5 (22.7)	29.7 (12.4)
S3	First	64.0 (19.3)	24.0 (8.1)	67.2 (17.1)	25.3 (8.1)
	RM	75.4 (20.1)	34.2 (12.7)	72.2 (19.0)	31. 2 (11.2)

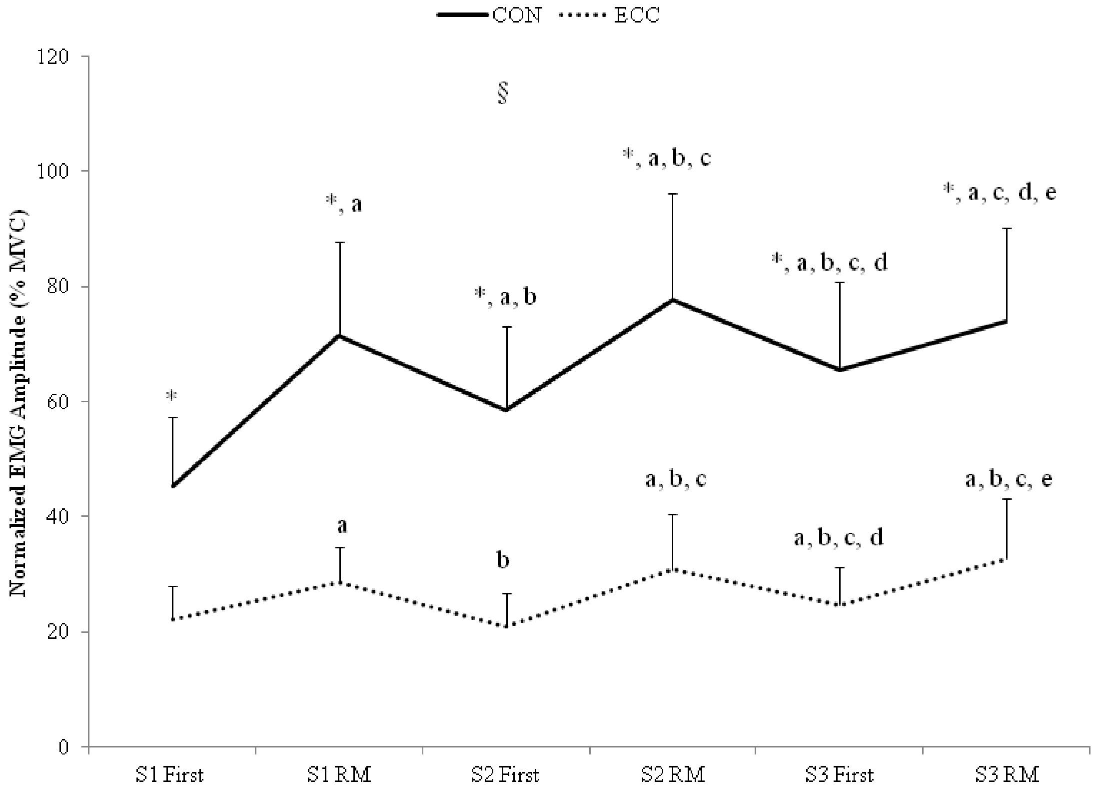
Data presented as mean (SD); ‡$p<0.05$ limb x time interaction; § $p<0.05$ phase x time interaction; BFR, blood flow restricted limb; FF, free flow limb; S1, set 1; S2, set 2; S3, set 3; First, first three repetitions; RM, repetition-matched.

Figure 20. Normalized EMG Amplitude Collapsed Across Phase Compared Under Repetition-matched Conditions.



Data presented as mean (SD); ‡ $p<0.05$ limb x time interaction; [a]$p<0.05$ from S1 First; [b]$p<0.05$ from S1 RM; [c]$p<0.05$ from S2 First; [d]$p<0.05$ from S2 RM; [e]$p<0.05$ from S3 First.

Figure 21. Normalized EMG Amplitude Collapsed Across Limbs Compared Under Repetition-matched Conditions.



Data presented as mean (SD); § p<0.05 phase x time interaction; [a]p<0.05 from S1 First; [b]p<0.05 from S1 RM; [c]p<0.05 from S2 First; [d]p<0.05 from S2 RM; [e]p<0.05 from S3 First; *p<0.05 from ECC.

RM ANOVA revealed significant main effects for time (p<0.001) and phase (p=0.039) for normalized MPF for the repetition-matched data (Table 11). Normalized MPF was significantly greater for ECC compared to CON (Table 11); significant pairwise differences across time are shown in Table 11.

Table 11. Normalized MPF (% MVC) Compared Under Repetition-matched Conditions.

	†¢	BFR		FF	
		CON	ECC	CON	ECC
S1	First	103.3 (9.4)	108.3 (9.6)	111.8 (11.3)	116.2 (18.5)
	RM[a]	91.1 (12.0)	96.4 (7.1)	96.1 (10.8)	98.4 (12.3)
S2	First[a,b]	96.7 (8.2)	103.1 (10.6)	100.4 (11.8)	107.9 (16.8)
	RM[a,b,c]	93.5 (10.8)	99.1 (9.9)	98.6 (11.9)	99.4 (14.0)
S3	First[a,b,d]	97.1 (10.3)	100.4 (9.4)	101.5 (10.7)	104.3 (15.5)
	RM[a,b,d]	98.5 (11.3)	100.0 (8.4)	102.7 (9.9)	104.1 (13.2)

Data presented as mean (SD); †$p<0.05$ time effect; ¢$p<0.05$ phase effect; [a]$p<0.05$ from S1 First; [b]$p<0.05$ from S1 RM; [c]$p<0.05$ from S2 First; [d]$p<0.05$ from S2 RM; BFR, blood flow restricted limb; FF, free flow limb; S1, set 1; S2, set 2; S3, set 3; First, first three repetitions; RM, repetition-matched.

Acute MTh Measurements

AT 50 significantly (main effect for time; $p<0.001$) increased following acute exercise for both BFR and FF (Table 12). RM ANOVA revealed a significant limb x time interaction ($p=0.009$) for LT 50 (Table 12). LT 50 at Pre was greater for BFR compared to FF; LT 50 increased from Pre to Post for BFR and FF with no differences between BFR and FF at Post (Table 12). Calculated effect sizes revealed a slightly larger effect size for FF compared to BFR at AT 50 and LT 50 (Table 12). The number of repetitions completed during the acute exercise bout was significantly ($p<0.001$) greater for FF compared to BFR (Table 12).

Table 12. MTh Measurements, Exercise Volume, and Calculated Effect Sizes for MTh During Acute Exercise.

		Pre	Post	Effect Size
AT 50 (cm)*	BFR	5.40 (0.66)	5.73 (0.64)[a]	0.50
	FF	5.39 (0.68)	5.81 (0.80)[a]	0.62
LT 50 (cm)‡	BFR	3.62 (0.69)[b]	3.80 (0.70)[a]	0.26
	FF	3.45 (0.72)	3.73 (0.72)[a]	0.39
Repetitions	BFR	53 (12)[b]		
	FF	91 (38)		

Data presented as mean (SD); *p<0.05 time effect; ‡p<0.05 limb x time interaction, [a]p<0.05 from Pre; [b]p<0.05 from FF; BFR, blood flow restricted limb; FF, free flow limb.

Exercise Training Volume

RM ANOVA revealed a significant limb x session interaction for exercise training volume for Sessions 1-6 (p=0.005) and Sessions 13-18 (p<0.001; Table 13). Exercise training volume was greater for FF compared to BFR during all sessions (Table 13); pairwise comparisons between sessions are shown in Table 13.

Table 13. Number of Repetitions Per Session and Total Exercise Training Volume.

†	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
BFR	40 (12)	42 (10)	43 (13)	42 (12)	44 (12)	43 (11)
FF	58 (25)*	59 (29)*	62 (24)*	66 (32)^{*,a,b}	66 (28)^{*,a,b,c}	70 (29)^{*,a,b,c}

	Session 7	Session 8	Session 9	Session 10	Session 11	Session 12
BFR	53 (12)	51 (11)	46 (10)	51 (14)	53 (13)	52 (11)
FF	90 (41)	91 (39)	73 (36)	84 (38)	78 (24)	81 (23)

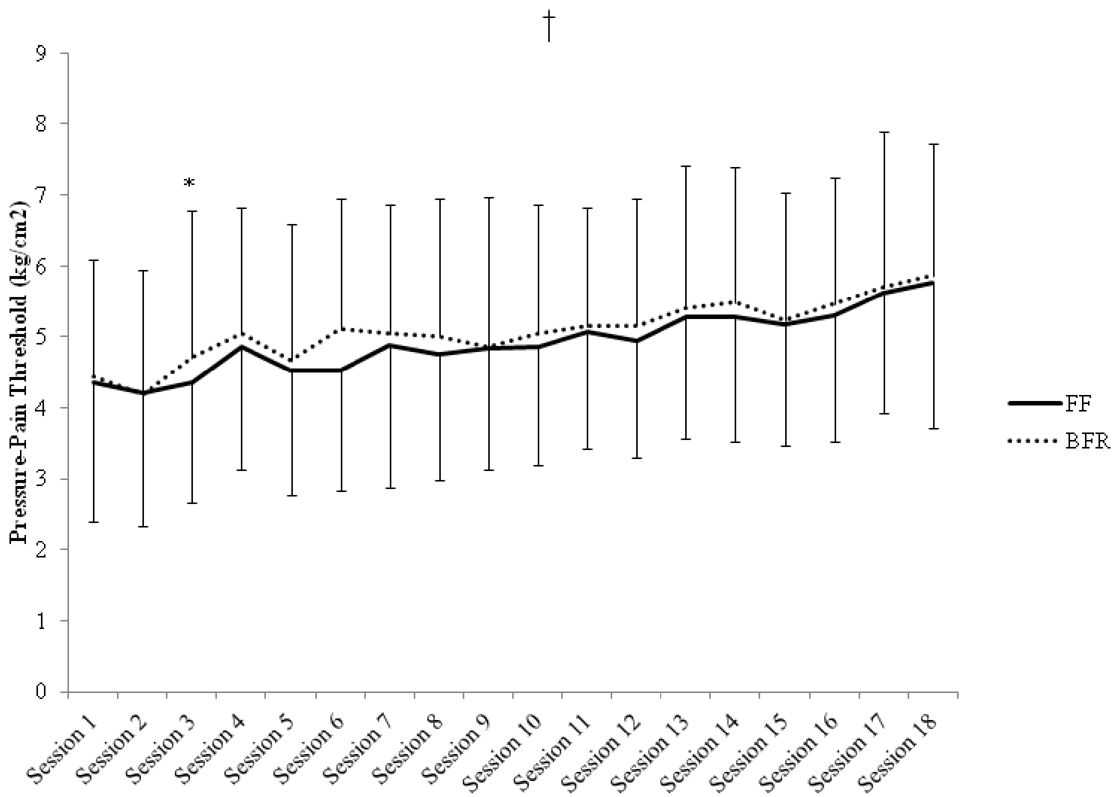
†	Session 13	Session 14	Session 15	Session 16	Session 17	Session 18	Total Volume (kg)
BFR	64 (13)	62 (15)	65 (15)	67 (15)^{e}	71 (14)^{d,e,f,g}	67 (15)^{e}	8844 (3704)
FF	93 (25)*	95 (27)*	96 (27)*	102 (28)^{*,d,e,f}	102 (31)^{*,d,e,f}	109 (33)^{*,d,e,f,g}	13857 (7030)*

Data presented as mean (SD); BFR, blood flow restricted limb; FF, free flow limb; †$p<0.05$ limbx session interaction; *$p<0.05$ from BFR; $^{a}p<0.05$ from Session 1; $^{b}p<0.05$ from Session 2; $^{c}p<0.05$ from Session 3; $^{d}p<0.05$ from Session 13; $^{e}p<0.05$ from Session 14; $^{f}p<0.05$ from Session 15; $^{g}p<0.05$ from Session 16.

Quadriceps Muscle Soreness

RM ANOVA revealed a main effect for time ($p<0.001$) for pressure-pain threshold (Figure 22). Pairwise comparisons between adjacent sessions indicated a significant increase in pressure-pain threshold from Session 2 to Session 3 (Figure 22).

Figure 22. Quadriceps Muscle Soreness Recorded During Each Exercise Session.



Data presented as mean (SD); † $p<0.05$ time effect; *$p<0.05$ from Session 2.

Discussion

Main Findings

The main findings of this study are as follows:

1) Short-term low-load BFR and FF knee extensor exercise training performed to volitional fatigue result in similar increases in muscular strength, power, and endurance despite a significantly lower exercise volume performed with the limb under blood flow restriction.

2) Short-term low-load BFR and FF knee extensor exercise training performed to volitional fatigue result in similar increases in muscle thickness of the anterior thigh but BFR resistance exercise training resulted in greater increases in muscle thickness of the lateral thigh despite a significantly lower exercise volume.

3) Neither short-term BFR nor FF knee extensor exercise training altered femoral artery stiffness, calf venous compliance, or calf blood flow.

4) Neither BFR nor FF knee extensor exercise cause significant muscle soreness.

5) Compared to BFR, FF knee extensor exercise elicits greater vastus lateralis activation during multiple sets of low load knee extensor exercise performed to volitional fatigue.

6) BFR and FF knee extensor exercise performed to volitional fatigue cause similar acute increases in muscle thickness of the knee extensors.

Systemic Hemodynamics

Resting heart rate unexpectedly increased following the training intervention. Although statistically significant, this change (60 to 63 bpm) was relatively small. As expected, brachial blood pressure was unaltered over the course of the study.

Local Hemodynamics

Contrary to our hypothesis, we did not observe any changes in femoral artery stiffness or calf venous compliance following low-load BFR knee extensor training. Although calf blood flow was altered between limbs over time, pairwise comparisons did not reveal any significant changes over time or between limbs. In agreement with our hypothesis, we also did not observe any vascular changes in the limb trained without BFR.

We expected femoral artery stiffness to decease because pulse wave velocity is inversely related to arterial diameter and previous work has shown an increase in brachial artery diameter following unilateral BFR hand grip training [26] and also because low intensity whole body resistance training has been shown to reduce systemic arterial stiffness (brachial-ankle pulse wave velocity) [23]. To our knowledge only one other study has investigated the effect of low-load BFR resistance training on local (i.e. femoral) arterial stiffness [3]; similar to our findings, these authors observed no changes in femoral artery stiffness following BFR knee extensor exercise [3]. However, this study was shorter in duration (4 weeks, 12 training sessions) and used a younger (~24 yrs) sample compared to the present investigation. Thus, our observation of no change in arterial stiffness following low-load BFR resistance training extends previous work in that our training intervention was longer (6 weeks, 18 sessions) and our sample was older (~55 yrs). Our results suggest that low-load resistance training performed to fatigue with or without BFR does not alter femoral artery stiffness. Future studies should investigate changes in brachial artery stiffness following upper body BFR resistance exercise as BFR handgrip training may [25] or may not [26] reduce brachial artery flow mediated dilation, a measure of conduit artery function.

Resting calf blood flow was altered differently between limbs over time. Although not statistically significant, it appears calf blood flow was higher in the BFR limb before training (Pre-1 and Pre-2) compared to the FF limb whereas calf blood flow increased in the FF limb following training and was blood flow was greater in the FF limb compared to the BFR limb after training. Of note, a relative high degree of variation in calf blood flow was observed over the time control period. The variability in resting blood flow has been reported previously [100] and occurs despite attempts to control for external factors including nutrition, environment, and time of testing. Thus, it is difficult to determine if the alterations in calf blood flow observed are due to an effect of the training or simply day-to-day variation. However, the changes in calf blood flow were relatively small over the control period (between 0.14 and 0.24 ml/100ml/min) whereas the increase in calf blood flow in the FF limb following training was more substantial (0.48 ml/100ml/min). Thus, it is possible that the observed increase in calf blood flow was a result of the FF training itself.

Femoral artery blood flow has been shown to increase following traditional high-intensity resistance training [66] and even slow-movement low-intensity resistance training [101] while resting calf blood flow has been shown to increase similarly following high, moderate, or BFR low intensity lower body resistance training [60]. Post occlusive calf blood flow [10, 11], calf microvascular filtration capacity [27], and peak brachial artery blood flow [26] have been shown to increase following short-term (4 weeks) unilateral BFR resistance training. However, these studies [10, 11, 26, 27] did not observe changes in resting blood flow following BFR resistance training. It appears that regional, as opposed to whole body, resistance training does not increase resting limb blood flow. Because of discomfort associated with post occlusive calf blood flow measurements, this measurement was not included in the present study. The discomfort of post occlusive blood flow measurement may be lesser in the arm. Therefore, future studies should investigate the effect of upper arm BFR resistance exercise on post occlusive forearm blood flow to clarify the effect of proximal BFR training on downstream (i.e. distal) resistance vessel adaptations.

Calf venous compliance was also unaltered following the training intervention. Relatively few studies have examined the impact of resistance exercise on limb venous compliance. Cross-sectional data suggest resistance-trained individuals have greater forearm venous compliance compared to age-matched sedentary individuals [29].

Structural remodeling of the vessels is the likely mechanism behind increased venous compliance in resistance trained individuals [29]. We hypothesized that BFR resistance exercise would increase calf venous compliance due to the venous pooling that occurs during the BFR resistance exercise. Additionally, venous function is related to musculoskeletal fitness [100]; thus, we expected if quadriceps muscle function improved this may also increase calf venous compliance and maximum venous outflow. Short-term (6 week) blood flow restricted walk training increased calf venous compliance and maximum venous outflow at 80 mmHg in elderly (~67 yrs) women [28]. However, contrary to our hypothesis, BFR knee extensor resistance training did not alter calf venous compliance. It is possible that the number of training sessions was insufficient (18 sessions) and/or the duration of blood flow restriction during each training session was too short (~3.5 to ~7.5 min) in the present study to induce changes in venous compliance. The aforementioned study [28] involved 30 training sessions in which participants were under blood flow restriction for ~20 min/session. Since venous compliance was also unaltered in the FF limb, our results suggest that low-load lower body resistance exercise does not affect lower body venous compliance. While this appears to contradict the findings of Kawano et al. [29], which observed greater forearm venous compliance in resistance-trained individuals, it is important to note that calf and forearm venous compliance may be affected by different factors. For instance, muscle mass appears to be negatively related to calf venous compliance [64] whereas it appears to be positively related to forearm venous compliance [29]. Another possibility is that changes in venous compliance were confounded by daily physical activity of the lower limbs as many of the participants in the present study did some moderate aerobic exercise. Future studies should investigate the effect of upper body resistance exercise on forearm venous compliance.

Knee Extensor Function

Low-load knee extensor training to fatigue with or without BFR was able to increase quadriceps muscle strength, mean power at low and moderate loads, and muscular endurance.

Significant increases in knee extensor strength were observed during the time control period (Pre-1 to Pre-2) with subsequent increases in strength occurring during the latter portion (weeks 4-6) of the training intervention (Mid to Post). In agreement with our hypothesis, low-load knee extensor training with or without BFR was able to increase muscular strength. Most [1, 2, 4, 10-14, 27] but not all [6, 22, 75, 102] previous investigations have found that low-load resistance training with BFR increases muscular strength to a greater extent than work-matched low-load exercise without BFR. To our knowledge this is the first study to compare muscular adaptations to low-load resistance training with and without BFR under non work-matched conditions; our results suggest that low-load resistance training without BFR performed to volitional fatigue can elicit similar increases in strength as a lower volume of BFR resistance training.

Although all participants underwent familiarization with the strength testing procedure before testing, there was still a significant increase in muscular strength over the time control period (Pre-1 to Pre-2) suggesting that a learning effect was responsible for this increase. Consistent with our findings, knee extensor strength increased over two strength testing sessions in untrained older (>60 yrs) women [103]. These authors also observed that strength did not change from the second to third testing session; this finding supports the idea that the subsequent increases in strength observed in the present study (from Mid to Post) likely reflect a true training adaptation. The calculated effect sizes (ES = 0.24 FF, 0.34 BFR) over the training intervention (Pre-2 to Post) are considered trivial according to proposed guidelines [99]. However, the effect size calculated over the entire intervention (Pre-1 to Post) are larger (ES = 0.61 BFR, 0.50 FF) and are consistent with a meta-analysis [104] on the effect of BFR exercise on muscular strength which indicate a small effect size (average ES = 0.58). The effect size for muscular strength in the FF limb over the training intervention (ES = 0.24) is larger than reported for low-load training without BFR (average ES = 0.00) and this is likely because the low-load exercise performed by the FF limb in the present study was performed to volitional fatigue. Interestingly, although not statistically different, the effect size for muscular strength was greater for the BFR limb compared to the FF limb despite a substantially lower of exercise volume performed. Furthermore, it appears that those individuals with lower levels of strength before training exhibited a greater increase in strength during the intervention as an inverse correlation was found between pre-training strength and strength adaptation.

The similar increases in muscular strength over the training intervention for the BFR and FF limb may be partially due to a cross-education effect. However, although unilateral training with a high-load with one limb has been shown to increase strength in the untrained, contralateral limb [105], many studies [10, 11, 27] have shown superior muscular strength adaptations in one limb compared to the contralateral limb using a mixed-limb design similar to the present study. This suggests that the increases in muscular strength observed in the FF limb may be attributable to the training itself and not necessarily to a cross-education effect.

The increases in strength observed are likely due to a combination of neural (i.e. greater activation) and structural (i.e. changes in pennation angle and/or muscle fiber hypertrophy) adaptations. Traditionally, neural adaptations causing increases in muscular strength are thought to occur in the early phases (i.e. 2-4 weeks) of resistance training programs whereas increases in muscle size are thought to occur later (i.e. >4 weeks) in the training program [106]. The present data suggest that, with low-load resistance training, the opposite may be observed as increases in muscle thickness occurred during the first three weeks of training (Pre-2 to Mid) while increases in strength occurred later (weeks 4-6; Mid to Post). This has also be proposed in meta-analysis of blood flow restricted exercise training [104].

As expected, men exhibited greater strength compared to women. However, no sex x limb, sex x time, or sex x limb x time interactions were observed for muscular strength. Moreover, analysis of muscle strength changes within each sex revealed similar main effects for time. This suggests that the training elicited similar increases in strength in men and women. In examining the individual strength changes by sex, it is clear that the absolute increase in strength was greater in many of the women compared to the men regardless of limb (BFR or FF). In contrast to our findings, muscle strength has been shown to increase to a greater extent in older men compared to older women following heavy resistance training [107, 108] although this is not a universal finding [109]. There are many possibilities for these conflicting findings. Compared to the present study, the study by Bamman et al. [108] utilized a much longer resistance training program

(26 weeks), the training loads were higher (65-80% 1RM), multiple exercises were utilized (knee extension and leg press or squat) and the sample was older (61-77 years). It appears that the sex differences in strength adaptation are not apparent early in training, but manifest later in training. Bamman et al. [108] observed similar increases in strength in men and women in the early phases of resistance training (25 days) but men exhibited greater increases in strength during the later portion of the training (days 50-175). Since the present study was only 6 weeks (42 days), the duration may have been inadequate to observe sex differences in strength adaptations to low-load resistance training. Similar to our findings however, Hakkinen et al. did not observe sex differences in knee extensor strength following high-load training in middle-aged or older adults [109]; their training program was also longer in duration (26 weeks) than the present study. However, their participants only trained two days per week and some of the training was performed with lighter loads (50-60% 1RM). Thus, it is possible that the lack of sex differences in strength adaptation observed in the present study could also be attributed to the low-loads utilized. However, future studies utilizing longer training protocols (8+ weeks) are needed to clarify if sex difference may be apparent in the strength adaptation to low-load resistance training.

Irrespective of limb (BFR or FF), mean muscular power at a low load (30% 1RM) increased following the training intervention (Pre-2 to Post) whereas mean muscular power at a moderate load (60% 1RM) increased following the time control period (Pre-1 to Pre-2) only. Other studies have also found that resistance training with low-loads (20% 1RM) is capable of increasing muscular power in older (~69 yrs) adults [91]. Of note, these results also confirm previous findings [110] which suggest that the greatest increase in power are observed at similar loads to that which is used during the resistance training (in this case 30% 1RM). It appears that the increase in muscular strength was primarily responsible for the increase in mean power at 30% 1RM as the mean velocity at 30% 1RM was unaltered over the course of the study and the mean velocity at 60% and 90% 1RM actually decreased slightly from Pre-2 to Post (although only a statistically significant decrease in mean velocity was observed at 90% 1RM). This is consistent with the idea that increases in muscular power from traditional, low velocity resistance training (similar to the present study), are attributable primarily to increases in muscular strength whereas changes in muscle shortening velocity and neural recruitment would be more likely to be elicited by high velocity resistance training [111]. Furthermore, it is interesting to note that the calculated effect sizes over the course of the training intervention (Pre-2 to Post) are very similar for muscular strength and mean power at 30% 1RM.

The increase in mean power at 60% during the control period (Pre-1 to Pre-2) can likely be attributed to a learning effect since the absolute load lifted was slightly greater while the participants, on average, were able to move that load at the same velocity (i.e. mean velocity at 60% 1RM did not change from Pre-1 to Pre-2 whereas the load, 60% 1RM, increased). However, examination of the power-load relationship (collapsed across limbs) revealed that mean power at 60% 1RM was statistically lower than mean power at 90% 1RM before training (Pre-1 and Pre-2) but after training mean power at 60% and 90% were no longer statistically different. This suggests that low-load resistance training may shift the load-power curve slightly up and to the left.

Previous studies have shown conflicting results as to the effect of low-load BFR resistance training on muscular power. Low-load BFR resistance training has been shown to improve sprint performance in male athletes [1] but not jump performance in untrained young men [112]. Our results suggest that low-load training with or without BFR can increase muscular power at a low-load only.

The most robust effect of the low-load training was on muscular endurance which increased following the training intervention (Pre-2 to Post) but, contrary to our hypothesis, did not increase to a greater extent in the BFR limb. Compared to repetition-matched resistance training, BFR resistance training has been shown to augment resting levels of muscle glycogen and ATP [22] and also enhance muscular endurance in both athletes [12] and non-athletes [6]. Our results suggest that a higher volume of non-BFR resistance exercise can elicit similar increases in muscular endurance as BFR resistance exercise. Since both limbs performed knee extensor exercise in a no-relaxation manner (i.e. no rest between repetitions) it is possible that the metabolic stress, and ultimately the metabolic adaptations, in the quadriceps were similar between limbs. However, the mechanisms behind the adaptations observed are beyond the scope of this study; future studies are needed to clarify these mechanisms.

In comparing the effect sizes between the changes in muscular strength and endurance over the course of training (Pre-2 to Post), our results are in line with previous findings that high-repetition, low-load resistance training elicits greater adaptations in muscular endurance relative to muscular strength [83].

Knee Extensor Size

The most interesting finding of the present study is the observed changes in MTh following the training intervention. No statistically significant changes in thigh circumference were observed in either limb and this is likely due to the fact that the training only involved one muscle group of the thigh (quadriceps) and the effect of quadriceps muscle hypertrophy on thigh circumference is likely small (observed effect size over the training intervention for thigh circumference for each limb was small). In contrast, measurements of MTh suggest significant hypertrophy of the anterior quadriceps occurred in both limbs whereas only BFR training induced significant hypertrophy of the lateral quadriceps muscles. This partially supports our hypothesis that BFR resistance training would elicit greater increase in MTh compared to FF resistance training. Previous studies have observed muscle hypertrophy following low-load resistance training [18, 113] however most studies comparing repetition-matched low-load BFR and non-BFR resistance training have observed greater hypertrophy following BFR resistance training [1, 4, 6, 12-14, 114]. Our findings extend previous work by comparing non-repetition matched BFR and non-BFR resistance training and suggest that, even with a lower volume of exercise, BFR resistance training can elicit greater increases in MTh of at least some regions of the quadriceps compared to non-BFR resistance training.

Since many previous studies have not observed significant muscle hypertrophy following low-load resistance training without BFR [1, 2, 4, 14, 17], it is tempting to speculate that the increase in MTh observed in the FF limb may be due to a cross-transfer effect. However, although lower body BFR resistance training has been shown to augment resistance training-induced muscle hypertrophy of the elbow flexors [9], it is unlikely that the observed increases in MTh in the FF limb are attributable to a cross-transfer effect from the BFR limb. The proposed mechanism of cross-transfer muscle hypertrophy is an exercise-induced increase in systemic anabolic hormones [9]. However, the effect of acute increases in systemic anabolic hormones on muscle hypertrophy is controversial as both cross-sectional studies [115] as well as resistance training intervention studies [116] have failed to support a link between exercise-induced increases in systemic anabolic hormones and muscle hypertrophy. Moreover, even if exercise-induced increases in systemic anabolic hormones were responsible for muscle hypertrophy, unilateral lower body resistance exercise does not induce a rise in such hormones [117]. Additionally, many resistance training studies using a mixed-limb design have shown unequal degrees of muscle hypertrophy between two limbs [6, 18, 117-120]. Therefore, it is likely that the increases in anterior thigh MTh observed in the FF limb are attributable to the local training stimulus and not a cross-transfer effect.

Interestingly, lateral MTh only increased in the BFR limb suggesting that BFR and FF resistance training may induce different degrees of muscle hypertrophy between the components of a muscle group. The lateral MTh measurement included the thickness of the vastus lateralis and the vastus intermedius whereas the anterior MTh measurement included thickness of the rectus femoris and the vastus intermedius. Thus, it could be assumed that BFR resistance training induces greater increases in MTh of the vastus lateralis since the vastus lateralis was part of the lateral MTh measurement, which increased in the BFR but not FF limb, only. Several studies have observed not only different degrees of hypertrophy along the length of the quadriceps muscles following knee extensor training, but also different degrees of hypertrophy between the individual muscles of the quadriceps [118, 119, 121, 122]. Greater muscle activation during exercise is one proposed mechanism to explain the heterogeneous hypertrophy observed [118, 122]. Our acute EMG data would suggest that vastus lateralis activation (as indicated by EMG amplitude) was actually lower during the third set of low-load resistance exercise for the BFR limb compared to the FF limb. This suggests that another mechanism may be responsible for the greater increase in lateral thigh MTh observed following BFR resistance training. Regardless of the mechanism, our data suggest that, when performed to volitional fatigue, low-load BFR and FF resistance training may elicit similar increases in rectus femoris muscle hypertrophy whereas BFR resistance training may elicit greater increases in vastus lateralis muscle hypertrophy. In agreement with our findings, a study also using a mixed limb design also found that vastus lateralis muscle hypertrophy only occurred in the limb which performed ischemic knee extensor exercise whereas no hypertrophy was observed in the contralateral limb which trained without ischemia [6].

Also of note is that the majority of changes in MTh that occurred over the training intervention occurred during the first three weeks of training (i.e. significant increase in MTh were observed from Pre-2 to Mid). This suggests that muscle hypertrophy can occur following a short duration of training and is consistent with previous observations which have shown muscle hypertrophy can occur with just 2-3 weeks of BFR resistance training [1, 2, 4, 17].

One of the proposed mechanisms behind BFR-induced muscle hypertrophy is acute changes in muscle cell swelling [123]. In support of this idea, BFR concentric only resistance exercise was able to induce acute changes in MTh, and index of muscle cell swelling, as well as chronic training-induced increases in muscle cross-sectional area whereas BFR eccentric only resistance exercise induced smaller acute changes in MTh and no significant training-induced changes in muscle cross-sectional area; this suggests that acute changes in muscle size may be important for inducing BFR training-induced muscle hypertrophy [124]. The present results suggest that the acute changes in MTh may not induce chronic changes in MTh, at least with non-BFR exercise, as lateral thigh MTh acutely increased in the FF limb with exercise yet no chronic changes in lateral thigh MTh were observed. Furthermore, correlational analyses did not reveal any significant correlations between acute changes in MTh and chronic changes in MTh for either site for either limb (data not shown). It is possible that only a certain threshold of cell swelling may be needed to elicit muscle hypertrophy and the effect may not be dose-dependent.

The BFR limb experienced a greater increase in lateral thigh MTh compared to the FF limb whereas changes in muscle function were statistically similar between the limbs. One would expect if greater hypertrophy occurred in one limb that muscle function would also be enhanced to a greater extent. There are several possibilities for this result. First, although it is unlikely that a cross-education effect occurred, we cannot completely rule out the possibility that some of the changes in muscle strength were influenced by the mixed-limb training design whereas, for reasons outlined above, changes in MTh were exclusively driven by the local training stimulus. Another possibility is that the effect of the training was more robust on MTh whereas the effects of low-load training on muscle function are more subtle and the effect was too small to detect with our sample. Although not statistically different, training-induced changes in muscle strength were greater for the BFR limb as indicated by the effect size. Finally, it should be noted that the changes in MTh may be influenced by increases in fluid and/or non-contractile elements the muscle (i.e. sarcoplamic hypertrophy). Thus, it is possible that the increases in MTh do not actually correspond to increases in myofibrillar hypertrophy although this is unlikely since we did observe increases in quadriceps muscle function.

The calculated effect sizes for MTh over the training intervention for each limb support the idea that a lower volume of BFR resistance training elicits greater increases in muscle hypertrophy than non-BFR resistance training. For all MTh measurement sites, the effect size was greater for the BFR limb compared to the FF limb over the course of the training intervention (Pre-2 to Post). Because the MTh measurements are a one-dimensional measure, it is difficult to compare these observed effect sizes with previous studies which have used muscle cross-sectional area, a two dimensional measurement, as a measure of muscle hypertrophy. It is expected that the magnitude of change observed in MTh would be less than what would be observed in muscle cross-sectional area. Fewer studies have used ultrasound MTh as a measure of limb muscle hypertrophy; however, the results of one of study which measured triceps brachii MTh over the course of BFR bench press exercise observed ~3 mm increases in MTh over the course of 24 training sessions [17]. This is in line with the training-induces changes in MTh observed in the present study of 1.5-3.0 mm over 18 training sessions.

Interestingly, although a main effect of sex was present in the analyses of MTh, training-induced changes in MTh were not different between sexes. Analysis of MTh changes for men alone revealed similar main effects for time for AT MTh and similar limb x time interactions for LT MTh; in contrast, analysis of MTh changes for women alone only revealed main effects for time and no limb x time interactions. However, this is likely due to a very small sample of women for MTh measures (N=5). Literature is conflicting as to whether sex differences exist in resistance-training induced muscle hypertrophy in older adults as studies have shown either no sex difference [107], a greater increase in hypertrophy in men [108], or a greater increase in hypertrophy in women [109]. In comparing the resistance training protocols utilized in the aforementioned studies, it appears that resistance training with lower loads (50-60% 1RM) may be more beneficial for muscle hypertrophy in older women. In line with this idea, we observed no sex differences in low-load resistance training-induced changes of MTh.

Surface Electromyography

The amplitude of the EMG signal recorded from the vastus lateralis, a measure of muscle activation, increased over time during each of the three sets of exercise and was greater in the FF limb compared to the BFR limb at the end of the third set of exercise (under non repetition-matched conditions). As expected, EMG amplitude increased from the beginning to the end of each set which suggests that more muscle activation was required to lift the load as the exercise progressed toward volitional fatigue. Also, EMG amplitude was greater during the concentric compared to the eccentric portion of each repetition (regardless of limb) which suggests that, as expected, more muscle activation was required to lift the load (i.e. the concentric portion) than to lower the load (i.e. the eccentric portion). The finding of greater EMG amplitude during low-load exercise performed to fatigue without BFR compared to with

BFR is in agreement with previous work which noted greater EMG amplitude of the vastus medialis and vastus lateralis during the eccentric portion of low-load knee exercise without BFR compared to exercise with BFR performed to fatigue [125]. Interestingly, although high levels of muscle activation are thought to be one of the major factors in exercise-induced muscle hypertrophy, our results would suggest that low-load resistance exercise without BFR can elicit high levels of muscle activation and yet fail to induce muscle hypertrophy (as indicated by changes in lateral MTh). It is unclear why changes in MTh of anterior thigh but not lateral thigh were observed in the FF limb since clearly a moderate level of activation of the vastus lateralis took place during the exercise training.

On the other hand, EMG amplitude was similar between the limbs when the exercise was matched for volume (i.e. repetition-matched). This is in contrast to previous observations of higher muscle activation recorded during BFR resistance exercise compared to repetition-matched non-BFR resistance exercise [35, 36, 42]. Previous studies indicate that the degree of blood flow restriction (restrictive cuff pressure) influences EMG amplitude during BFR exercise; EMG amplitude recorded during exercise differs little between conditions of no restriction and moderate blood flow restriction whereas substantial differences in EMG amplitude are apparent between condition of no restriction and high levels of blood flow restriction [35, 36]. Thus, since arterial occlusion pressure was measured to ensure cuff pressure during exercise would not cause complete arterial occlusion, the degree of blood flow restriction may not have been great enough to cause substantial differences in EMG amplitude between limbs during exercise. Additionally, although EMG amplitude was not statistically different between the limbs at any timepoint under repetition-matched conditions, it appears that there was a greater increase in EMG amplitude during each set with the BFR limb (as indicated by the significant limb x time interaction for EMG amplitude under repetition-matched conditions).

Analysis of the mean power frequency of the EMG signal showed that mean power frequency was reduced during the first set of fatiguing exercise (regardless of limb or phase of contraction) and it also was reduced during the second set of exercise during the eccentric phase of exercise only. Additionally, mean power frequency was lower during the concentric phase compared to the eccentric phase at the beginning and end of the first two sets of exercise. Mean power frequency is influenced by many factors including, most notably, muscle fiber conduction velocity. The decrease in mean power frequency observed during exercise is consistent with other literature which suggests that fatigue will cause a decrease in muscle fiber conduction velocity manifested by a decrease in mean power frequency [126, 127].

To our knowledge only one other study [36] has assessed EMG mean power frequency during BFR resistance exercise and, in contrast to our findings, found that mean power frequency decreased to a greater extent during BFR elbow flexor exercise compared to non-BFR exercise. The fact that mean power frequency was not different between limbs suggests that similar reductions in conduction velocity occurred during exercise in each limb. During exercise a build-up of hydrogen ions (decrease in pH), accumulation of lactate, a decrease in the ATP/ADP ratio, and a decrease in creatine phosphate levels may all contribute to the decrease in muscle fiber conduction velocity; these metabolic changes that occur during exercise are exaggerated with blood flow restriction [39, 41]. Therefore, it is somewhat surprising that mean power frequency did not decrease to a greater extent in the BFR limb. One possible explanation for the similar responses in each limb is that, during fatiguing exercise, some muscles exhibit more substantial changes in mean power frequency than others. For instance, during 50 consecutive maximal knee extensor contractions, decreases in EMG mean power frequency in the rectus femoris are greater than the decreases observed in either the vastus medialis or vastus lateralis [128]. Thus, it may be that differences in EMG mean power frequency between limbs were not observed because the muscle studied, the vastus lateralis, exhibits relatively small changes in mean power frequency with fatigue. Alternatively, it may be that since the exercise was performed in a no-relaxation manner (i.e. no rest between repetitions) that the metabolic accumulation was similar in each limb during exercise. Future studies should examine changes EMG mean power frequency in other muscles during exercise with and without blood flow restriction. EMG mean power frequency was lower during the concentric phase at the beginning and end of the first and second set of exercise whereas mean power frequency was not different between phases during the third set (regardless of limb). It appears that EMG mean power frequency reaches a point during fatigue at which decreases are no longer apparent which is similar to previous observations [128].

Other work has shown heterogeneous recruitment of the quadriceps muscles during knee extensor exercise with greater activation of the rectus femoris compared to the vastus medialis or vastus lateralis [40]. EMG signals recorded from the rectus femoris during exercise would provide more insight into the degree of activation of that muscle during FF and BFR resistance exercise and could provide a possible explanation for similar increases in MTh observed on the anterior thigh.

Acute MTh Changes

Both anterior and lateral thigh MTh increased following acute exercise in each limb. Acute changes in muscle cell swelling during BFR exercise have been hypothesized to play a role in BFR-induced muscle hypertrophy [123]. It appears that both FF and BFR exercise performed to fatigue elicit similar acute increases in anterior thigh MTh whereas FF exercise can elicit greater acute increases in MTh of the lateral thigh. However, it appears that part of the reason why FF exercise induced greater acute changes in lateral thigh MTh is because the BFR limb had a larger initial (pre-exercise) MTh. The effect sizes for each limb indicate a slightly larger effect for the FF limb which may be expected since the total exercise volume was substantially higher. It appears that other factors in addition to acute changes in MTh influence the chronic changes in MTh as no relationship was found between acute and chronic changes in MTh. Moreover, acute changes in lateral thigh MTh occurred whereas chronic FF exercise training did not increase lateral thigh MTh. One limitation of using MTh as a surrogate to muscle cell swelling is that other fluid shifts outside of the muscle may also influence the MTh measurement.

Exercise Training Volume

As expected, the FF limb performed more repetitions during each exercise session and the total exercise volume of the training intervention was substantially higher. Thus, the higher exercise volume needed to elicit muscle adaptations should be considered when comparing the changes in muscle size and function between limbs.

Blood flow restriction results in a reduction in muscle endurance during acute exercise [125, 129]. Interestingly, the progression of muscle endurance during training appears to be greater in the FF limb compared to the BFR limb during the initial (first 6 sessions) and final (last 6 sessions) training phases. Similarly, the increase in muscle endurance (measured without blood flow restriction) was greater in the FF limb (based on effect size) following the training intervention. Total exercise volume is a consideration in any resistance training program and may be a very important concern for individuals who are undergoing rehabilitation and are limited to low-load resistance training. Thus, our results would suggest that low-load BFR resistance training would be optimal for individuals aiming to maximize muscular adaptations with a lower total exercise volume.

Quadriceps Muscle Soreness

Our results suggest that neither BFR nor FF low-load resistance exercise performed to volitional fatigue result in significant quadriceps muscle soreness. In contrast to our results previous investigations have suggested that BFR exercise, especially when performed to fatigue, results in muscle damage [130, 131] although other investigations have suggested otherwise [132]. One factor that may play a role on the perceptual responses to BFR exercise is the size and pressure of the restrictive cuff as well as the exercise protocol itself [133]. Thus, although the exercise was performed to volitional fatigue, the exercise volume progressed slowly (starting with two sets of exercise) and the cuff pressure (restrictive cuff pressure started at 50% AOP during the first week) was carefully selected to ensure protocol adherence and minimize muscle soreness. It should be noted that despite the lack of muscle soreness from the protocol, many participants indicated high levels of exertion during the exercise with each limb (as expected when exercising to volitional fatigue). Despite this, compliance to the protocol was excellent and no adverse events occurred during the training.

Chapter V: Conclusions

Purpose

The purpose of this study was to determine the muscular (muscle thickness, muscular strength, power, and endurance) and vascular (arterial stiffness, venous compliance, resistance vessel blood flow) effects of six weeks of low-load resistance training performed to volitional fatigue with and without blood flow restriction in middle aged individuals.

Hypotheses

1. Low-load resistance training with and without blood flow restriction will increase muscle thickness, muscular strength, endurance, and power; low-load resistance training with blood flow restriction will cause greater increases in muscle thickness and muscular endurance.

Low-load resistance training with and without blood flow restriction was able to increase muscle thickness, muscular strength, endurance, and power. Low-load resistance training with blood flow restriction did cause greater increases in muscle thickness but did not cause greater increases in muscular endurance compared to training without blood flow restriction.

2. Low-load resistance training with blood flow restriction will decrease arterial stiffness and increase venous compliance and calf blood flow; low-load exercise without blood flow restriction will not alter arterial stiffness, venous compliance, or calf blood flow.

Low-load resistance training with blood flow restriction did not alter arterial stiffness or venous compliance. Calf blood flow was altered differently between limbs over time. Low-load exercise without blood flow restriction did not alter arterial stiffness, venous compliance, or calf blood flow.

Strengths and Limitations

The results of this study may be limited to healthy middle-aged individuals and the effects observed may be different in individuals with vascular disease or significant muscle/joint impairments. The participants were physically active and other lower body activities may have influenced the adaptations observed. Finally, the results from unilateral resistance training with and without BFR may or may not reflect adaptations to bilateral or whole-body resistance training.

This is one of the first studies to examine the effects of BFR resistance training on muscle size and function in middle-aged men and women. Additionally, this is the first study to examine changes in venous compliance and mean muscular power following BFR resistance training. The mixed-limb study design allowed comparisons to be made within-individuals and increased sample size and statistical power.

Significance

Low-load resistance training with or without blood flow restriction is a viable option for middle-aged individuals who are unable to perform resistance training with high loads. However, the magnitude of training-induced strength adaptation appears to be less compared with other high-load training protocols. The magnitude of strength and hypertrophy adaptation may be slightly greater when low-load training is combined with blood flow restriction. Low-load training-induced muscle hypertrophy and strength adaptations appear to be similar for men and women; thus, this mode of training may be beneficial for both sexes.

Conclusions

The results of this study indicate that low-load resistance exercise with or without BFR can enhance muscle size and function without altering local vascular function or causing muscle soreness. Acute changes in MTh and/or muscle activation during low-load exercise may be part of the mechanisms by which BFR exercise induces muscle hypertrophy.

Future Research Directions

Future studies should examine similar outcomes following upper body and/or multi-joint BFR resistance exercise. Additionally, further exploration of the effects of BFR on muscle activation and fatigue in other muscles groups is warranted.

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Appendix A: IRB Approval Letter, Consent Form, and Research Privacy Form

The University of Oklahoma®
Health Sciences Center
INSTITUTIONAL REVIEW BOARD

IRB Number: 16379
Amendment Approval Date: April 25, 2012

April 25, 2012

Michael Bemben, Ph.D.
Univ of Oklahoma, Dept of Health & Exercise Sci
1401 Asp Avenue
Norman, OK 73019

RE: IRB No. 16379: Muscular and Vascular Adaptations to Blood Flow Restricted Resistance Exercise

Dear Dr. Bemben:

On behalf of the Institutional Review Board (IRB), I have reviewed your protocol modification form. It is my judgement that this modification allows for the rights and welfare of the research subjects to be respected. Further, it has been determined that the study will continue to be conducted in a manner consistent with the requirements of 45 CFR 46 or 21CFR 50 56 as amended; and that the potential benefits to subjects and others warrant the risks subjects may choose to incur.

This letter documents approval to conduct the research as described in:

Amend Form Dated: April 24, 2012
Consent form - Subject Dated: September 08, 2010
Priv - Research Auth 1 Dated: January 04, 2012
Protocol Dated: April 24, 2012
Other Dated: April 24, 2012 Verbal Recruitment Script & Email Message

Amendment Summary:
Changing the title of the project to the same title as the grant application.

This letter covers only the approval of the above referenced modification. All other conditions, including the original expiration date, from the approval granted April 08, 2012 are still effective.

Any proposed change in approved research including the protocol, consent document, or other recruitment materials cannot be initiated without IRB approval except when necessary to eliminate immediate hazards to participants. Changes in approved research initiated without IRB approval to eliminate immediate hazards to the participant must be promptly reported to the IRB. Completion of approved research must be reported to the IRB.

If consent form revisions are a part of this modification, you will be provided with a new stamped copy of your consent form. Please use this stamped copy for all future consent documentation. Please discontinue use of all outdated versions of this consent form.

If you have any questions about these procedures or need additional assistance, please do not hesitate to call the IRB office at (405) 271-2045 or send an email to irb@ouhsc.edu.

Sincerely yours,

M Jelley

Martina Jelley, M.D., M.S.P.H.
Chair, Institutional Review Board

Post Office Box 26901 • 1000 S.L. Young Blvd., Room 176
Oklahoma City, Oklahoma 73126-0901 • (405) 271-2045 • FAX: (405) 271-1677

Ltr_Amend_Final_Appv_Exp

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CONSENT FORM

Version 09/08/10 ***IRB No: 16379***

Consent Form
University of Oklahoma Health Sciences Center (OUHSC)
University of Oklahoma – Norman Campus
Muscular and vascular adaptations to blood flow restricted resistance exercise
Sponsor: Department of Health & Exercise Science

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

There is no benefit in participating in this research project. This includes any affect on your grades in any classes. You will be compensated for your time. 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 trial/study because you are a male or female between the ages of 40-64 years.

Why Is This Study Being Done?
The purpose of this study is to compare the effects (good and bad) of low-intensity resistance exercise with and without blood flow restriction on you and other people between 40 and 64 years of age.

What is the Status of the Drugs (Devices or Procedures) involved in this study?
No experimental devices or procedures will be used in this research study.

How Many People Will Take Part In The Study?
About 30 people will take part in this study at this location.

What Is Involved In The Study?
If you take part in this study, you will have the following tests and procedures:

First Visit
Consent Form, Questionnaires, and Screening
Informed consent will be obtained prior to completion of all questionnaires and any testing. You will be asked to complete a Health Status Questionnaire and Physical Activitiy Readiness Questionaire (PAR-Q). If there are no reasons why you cannot participate as determined from the completed questionnaires, we will measure your blood pressure in your arm and in your leg as well as your height and weight to ensure you meet all inclusion criteria. If you meet all inclusion criteria and none of the exclusion criteria,

you will be asked to obtain medical clearance from your primary care physician. This visit will take about 1 hour.

Second Visit

During the second visit to the laboratory we will familiarize you with the testing equipment including the knee extension machine and vascular restriction cuffs. We will also measure the thickness of your thigh muscles on each leg with an ultrasound. We will ask you to indicate which leg is your dominant limb. We will place the blood flow restriction cuff on your leg and progressive inflate it while we measure the pulse at your ankle. This will be done to ensure that we do not completely restrict your blood flow during the blood flow restricted exercise training. We will also have you perform some exercise to obtain an estimate of your strength (which will be formally assessed during the subsequent visits). This will take about one hour.

Testing Visits

Circulatory function and muscle size and function tests

We will take measures of your circulatory system and muscles on both legs on three occasions. The first two of these testing visits will be approximately 3 weeks apart, both before the exercise training begins. The third testing visit will be after the exercise training is complete (~6 weeks after the second testing visit). Each of these visits will be in the morning and we will ask you to avoid exercise, caffeine, food, and any beverages except water on the day of testing before coming to the lab. On each of these visits we will take measurements of the arteries, veins, and blood flow in each leg as well as the strength, power, endurance and size of the muscles on each thigh. Each of these testing visits will take about 2 hours and 15 minutes.

First we will measure your height and weight. Then we will have you lie down on a table for about 10 minutes. After 10 minutes, while you are still lying down, we will measure your blood pressure and place three electrodes (stickers) on your torso. We will also measure the circumference of your thigh and calf with a tape measure at this time. Next we will measure the pulse waves (the pulse of blood flowing through your arteries) at the top and bottom of each leg with a small pen-shaped sensor. This is measuring the stiffness of the arteries in your leg. Next we will elevate both of your legs about 6 inches, place blood pressure-like cuffs around both of your thighs, and place a rubber-band like sensor around each calf. We will then inflate the cuff on one thigh while we measure the blood flow in and out of the calf with the rubber band. The cuff will be inflated for 1, 1, 2, 3, and then 4 minutes with one minute deflation in between each inflation. This is measuring how much your veins can stretch. Next we will measure the blood flow to your calf with the same instrument but the cuff will only inflate for a few seconds (~7 seconds) and the deflate the cuff for a few seconds (~8 seconds) between measurements. We will take 6 of these blood flow measurements on each leg.

We will then have you stand up and measure the thickness of your thigh muscles (muscle size) by placing an ultrasound probe with some gel over your thigh. This will also be performed on both legs.

Following the muscle size measurements, we will provide you with a breakfast bar or shake prior to the muscle function tests. For the muscle function tests, we will have you sit in the knee extension machine and warm-up with a light weight with each leg, one leg at a time. After you warm-up will we progressive add more weight to the machine to determine the maximum amount of weight that you can lift once with each leg. Next, we test how quickly you can move a light (30% of the maximum weight you can lift), a medium (60% of the maximum weight you can lift), and a heavy (90% of the maximum weight you can lift) weight with each leg. Finally, we will test how many repetitions you can perform before fatigue using a light (30% of the maximum weight you can lift) weight with each leg.

Exercise Training Visits (18 exercise sessions)
Between the second and third testing session you will complete three exercise training sessions each week for six weeks, for a total of 18 exercise training sessions. For each training session, you will perform knee extension exercise with each leg individually. For each leg, the weight will be 30% of the maximum weight you can lift for one repetition. One leg will exercise under normal conditions and the other leg will be exercised while a blood pressure like cuff is inflated around the top the thigh. For the first two weeks of training you will complete two sets of exercise with each leg. For the second two weeks of training you will complete three sets of exercise with each leg. For the last two weeks of training you will complete four sets of exercise with each leg. Each set of exercise will be performed at a pace controlled by a metronome (20 repetitions per minute) until fatigue (until you cannot complete another repetition). One minute rest periods will be allotted between each set of exercise. Each of these training sessions will last between 20 and 30 minutes.

Before each exercise session we will assess the muscle soreness in each of your legs by applying a small probe against your thigh and applying force until you indicate that the force is "uncomfortable".

During the 3rd week of training we will also reassess your strength in each leg by determining the maximum weight you can lift. During this week we will measure the acute change in muscle size that occurs with exercise in each leg using the same ultrasound procedure as above. We will also measure the electrical activity in your muscle during exercise during one training session. For this we will first clean, abrade, and shave a small amount of skin on each thigh and on the back of your neck. Then we will place two stickers on each of your thighs and one on the back of your neck.

How Long Will I Be In The Study?

We think that you will be in the study for 10 weeks.

There may be anticipated circumstances under which your participation may be terminated by the investigator without regard to your consent. Reasons of termination include: 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 and your regular doctor first.

What Are The Risks of The Study?

While on the study, you are at risk for these side effects. You should discuss these with the researcher and/or your regular doctor.

Risks and side effects related to blood flow restriction:
- Feelings of faintness, fatigue, or lightheadedness
- Bruising and discomfort caused by the restrictive cuff
- Numbness (slight tingling that typically goes away upon release of the cuff)
- There is a theoretical risk that restricting blood flow in the leg could increase the risk of developing a blood clot in one of the veins but this has not been observed to date

Risks and side effects related exercise testing and training
- Feelings of fatigue and/or soreness in the muscle

Are There Benefits to Taking Part in The Study?

If you agree to take part in this study, there may or may not be direct medical benefit to you. We hope that the information learned from this study will benefit other individuals in the future.

What Other Options Are There?

There are no alternative procedures for this investigation; your alternative is to not 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 US Food & Drug Administration, 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 is no cost to you for participating in this study.

Will I Be Paid For Participating in This Study?
Yes, you will be paid up to a total of $150.00 for this study. The payments will be based on the number of completed visits, not contingent on completion of the entire study. For the second (familiarization) visit and each of the three testing visits you will be paid $15 per visit ($60 total). For each of the 18 exercise sessions you will be paid $5 per session ($90 total).

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 is 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 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, at certain times during the treatment, it may be dangerous for you to withdraw, so please be sure to discuss leaving the study with the principal investigator or your regular physician. You may discontinue your participation at any time without penalty or loss of benefits, to which you are otherwise entitled.

We will provide you with any significant new findings developed during the course of the research that may affect your health, welfare or willingness to continue your participation in this study.

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 at 405-325-5211 or Chris Fahs at 405-551-1222.

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 Office Version Date: 09/08/2010

APPROVAL
APR 2 5 2012
OUHSC IRB

APPROVAL EXPIRES
FEB 2 8 2013
OUHSC IRB

IRB No.: 16379

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: **Muscular and vascular adaptations to blood flow restricted resistance exercise**

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

Address: **115 HHC, 1401 Asp Avenue, Norman OK**

Phone Number: **1-405-325-2717**

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 analyze the data from the project and present the information.

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) and the Department of Health and Human Services (HHS). The researchers may also share your PHI with all researchers collaborating on this project.

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 end when all data from the project has been analyzed and all reports have been published. 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 Bemben, permission to share your PHI for the research project called Muscular and Vascular Adaptations to Low Load Resistance Training with and without Blood Flow Restriction

Patient/Participant Name: ______________________

______________________________ ______________

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

Or

IRB Office Use Only
Version 01/04/12

APPROVAL
APR 2 5 2012
OUHSC IRB

APPROVAL EXPIRES
FEB 2 8 2013
OUHSC IRB

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.

IRB No.: 16379

Appendix B: Medical Clearance Form, PAR-Q, and Health History Questionnaire

Subject Medical Clearance Form

University of Oklahoma Neuromuscular Laboratory

To the Attending Physician of: ____

The above-named individual has indicated that he/she wishes to participate in a research study investigating the effects of low load resistance exercise combined with blood flow restriction on muscle size, strength, power, endurance, and vascular function in middle aged men and women. Prior to participation, participants are required to obtain medical clearance from their personal physician(s). This study is comprised of three testing sessions that involve: (1) completion of an informed consent form and a participant screening questionnaire, (2) completion of health-related questionnaires, (3) familiarization with knee extensor (quadriceps) resistance exercise, (5) maximal strength, power, and endurance testing for the quadriceps, (6) arterial stiffness measurements, (7) limb blood flow measurements, (8) venous compliance measurements, and (8) muscle thickness measurements with ultrasound. The exercise training will happen 3 times a week for 6 weeks and will involve: (1) low load unilateral knee extension exercise (2) blood flow restriction on one leg during knee extension exercise. Blood flow restriction involves placing a narrow cuff above the muscle causing a pooling of blood in the working muscle. Specific inclusion and exclusion criteria apply to the subjects recruited for this study. Below are the exclusion criteria. Please check any boxes that apply to the above-named individual.

☐ Orthopedic disability or injury
☐ Crohn's disease
☐ Inflammatory bowel disease
☐ Major surgery within the last 6 months
☐ Thrombosis
☐ Diabetes (Type 1 or 2)
☐ Uncontrolled hypertension
☐ Other: _______________
☐ I recommend that the above-named individual be allowed to participate in the study.
☐ I **do not** recommend that the above-named individual be allowed to participate in the study.

MEDICATIONS/NOTES: ____

____

Physician Name: ________________________ Contact Number: ________________
(please print)
Physician Signature: ______________________ Date: ________________________

This study has been approved by the University of Oklahoma Health Science Center Institutional Review Board
For questions, please contact Michael G. Bemben, Ph.D. at (405) 325-2717 or mgbemben@ou.edu.

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 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 their doctor before they start becoming much more physically active.

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 and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**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?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all 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 professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for 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)

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 ________

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: ____________

9. Circle operations you have had:

Back (SLA) Heart (MC) Kidney (SLA) Eyes (SLA) Joint (SLA) 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

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

13. Do any of the following apply:

– A sudden death in your biological father or brother, or mother or sister prior to age 55 or 65, respectively?	Yes	No
– Current smoker or have you quit smoking within the past 6 months?	Yes	No
– Do you take hypertensive medication or have a confirmed systolic or diastolic blood pressure $\geq$140 or 90 mmHg, respectively?	Yes	No
– Take lipid lowering medication or have high blood cholesterol?	Yes	No
– You have a confirmed fasting blood glucose of $\geq$100 mg/dL?	Yes	No
– Diagnosed as clinically obese (BMI > 30)?	Yes	No
– Are you sedentary?	Yes	No
– Diagnosed Crohn's or inflammatory bowel disease	Yes	No
– Past fracture of a hip, pelvis, or femur	Yes	No
– Major Surgery within the last 6 months	Yes	No
– Have been diagnosed with varicose veins	Yes	No
– Family history of deep vein thrombosis or pulmonary embolism	Yes	No
– Personal history of deep vein thrombosis or pulmonary embolism	Yes	No

Part 3. Health-related behavior

14. (RF) Do you now smoke or chew tobacco? Yes No

15. 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	

16. Weight now: ________lb. One year ago: ________lb

17. 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

18. 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

19. Do you regularly engage in aerobic (such as running, walking, biking, swimming) exercise?

1. Yes 2. No

20. If you answered "yes" to question #19, how frequently (hours per week) have you engaged in aerobic activities during the past 6 months?

____

21. Do you regularly engage in strength-training exercise for your lower body such as lifting weights, using weight-machines or therabands?

1. Yes 2. No

22. If you answered "yes" to question #21, how frequently (times per week) have you engaged in strength-training exercise during the past 6 months?

____

Appendix C: Sample Data Collection Forms

Participant ID:_____________ Screening Date:______________

Height: __________cm Weight: ______________kg BMI:________________________

Brachial Blood Pressure

Reading 1:__________________mmHg

Reading 2:__________________mmHg

Reading 3: _________________mmHg

Ankle Brachial Index

Left arm: ___________mmHg Right arm: __________mmHg

Left leg: ___________mmHg Right leg: ____________mmHg

ABI (highest leg/arm BP):________________

Familiarization Data Sheet

ID: __________ Date:____________

Length of left lateral thigh: _____________cm Length of right lateral thigh: ____________cm

Length of left anterior thigh: ___________cm Length of right anterior thigh: ___________cm

Distance From Hip	Left	Right
40% Anterior Thigh		
50% Anterior Thigh		
60% Anterior Thigh		
40% Lateral Thigh		
50% Lateral Thigh		
60% Lateral Thigh		

Dominant limb: Right Left

BFR limb: Right Left

Arterial Occlusion Pressure: _______________mmHg

Familiarization with knee extension machine

Estimated 1-RM right leg: __________lbs

Estimated 1-RM left leg: ___________lbs

Practice Power measurement with moderate (50-60% estimated 1-RM) load ________

Familiarization with cadence of metronome ___________

Data Sheet

Subject ID:___________ Date:____________ Time of Day: ________ Visit: Pre-1 Pre-2 Post

Date of Birth:____________

Dominant leg: Right Left

BFR leg: Right Left

Height: _________ cm Weight: ___________ kg

*Place electrodes for PWV

Anthropometric Measures

Left thigh circumference (50%): _________cm Right thigh circumference (50%): ___________cm

Left calf circumference: __________cm Right calf circumference: ___________cm

Automatic BP (left arm)

Reading 1: __________________ mmHg Reading 2: __________________mmHg

Average: ___________________mmHg

Femoral Pulse Wave Velocity (Femoral-distal)

Left leg distance: ______________cm Right leg distance: _____________cm

Calf Venous Compliance & Resting Blood Flow Measurement

Left calf strain gauge size: ____________cm Right calf strain gauge size: ___________cm

Thigh length: Distance from greater trochanter to lateral condyle of femur

Length of left lateral thigh: ______________cm Length of right lateral thigh: _____________cm

Length of left anterior thigh: ____________cm Length of right anterior thigh: ____________cm

Muscle Thickness Measurements

Distance From Hip	Left	Right
40% Anterior Thigh		
50% Anterior Thigh		
60% Anterior Thigh		
40% Lateral Thigh		
50% Lateral Thigh		
60% Lateral Thigh		

Knee Extension 1-RM (1 min rest between each attempt)

	Left	Right
Estimated 50% 1-RM (8-10 reps)		
Estimated 75% 1-RM (2-3 reps)		
1^{st} attempt		
2^{nd} attempt		
3^{rd} attempt		
4^{th} attempt		
5^{th} attempt		

Muscle Power (2 trials at each load, 1 min rest)

Data Sheet

Subject ID:___________ Visit: Pre-1 Pre-2 Post Date:____________

Pulse Wave Velocity (m/s)

Left	Right

Venous Compliance

	Left				Right			
	MVO	Cap	MVO2	T1/2	MVO	Cap	MVO2	T1/2
20								
40								
60								
80								

Calf Blood Flow

	Left	Right
1		
2		
3		
4		
5		
6		
Mean		

Participant ID: _______________

BFR Limb: Left Right

Load (lbs)

	Left	Right
Load (lbs)		

BFR Pressure (week 1) :___________ mmHg

BFR Pressure (week 2-6):___________ mmHg

Session 1 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		

Session 2 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		

Session 3 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		

Session 4 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		

Session 5 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		

Session 6 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		

Old Load (lbs)		

Session 7 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		

****EMG Testing**

Set 1 Reps		
Set 2 Reps		
Set 3 Reps		

Session 8 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		

**** US MTh Pre/Post**

Set 1 Reps		
Set 2 Reps		
Set 3 Reps		

Session 9 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		

New 1-RM		
Set 1 Reps		
Set 2 Reps		

New Load (lbs)		

Start using new load session 10*

Session 10 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		

Set 1 Reps		
Set 2 Reps		
Set 3 Reps		

Session 11 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		

Set 1 Reps		
Set 2 Reps		
Set 3 Reps		

Session 12 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		

Set 1 Reps		
Set 2 Reps		
Set 3 Reps		

BFR Limb: Left Right BFR Pressure:_______________ mmHg

	Left	Right
Load (lbs)		

Session 13 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		
Set 3 Reps		
Set 4 Reps		

Session 14 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		
Set 3 Reps		
Set 4 Reps		

Session 15 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		
Set 3 Reps		
Set 4 Reps		

Session 16 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		
Set 3 Reps		
Set 4 Reps		

Session 17 Date:____________ (BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		
Set 3 Reps		
Set 4 Reps		

Session 18 Date:____________ (non-BFR first)

	Left leg	Right leg
Pressure Reading 1		
Pressure Reading 2		
Pressure Reading 3		
Set 1 Reps		
Set 2 Reps		
Set 3 Reps		
Set 4 Reps		

Acute EMG Testing Session (Session 7) **BFR Limb Trained First**

ID:____________________

	Left Thigh	Right Thigh
Distance from ASIS to lateral condyle of patella (cm)		
66% Site mark (cm)		

-Mark 66% site on both thighs

-Shave area (including C7)

-Abrade area

-Alcohol

-Place electrodes

-Check Signal

-Record 2 isometric MVCs

-Perform exercise protocol

Acute Muscle Thickness Measurements (Session 8) **FF Limb Trained First**

ID:____________________

Length of left lateral thigh: ______________cm

Length of right lateral thigh: ______________cm

Length of left anterior thigh: ____________cm

Length of right anterior thigh: ____________cm

Pre

	Left	Right
50% Anterior Thigh		
50% Lateral Thigh		

Post

	Left	Right
50% Anterior Thigh		
50% Lateral Thigh		

Appendix D: Raw Data

ID	M/F	Age	Height (m)	Body Mass (kg)	Pre-1 Mass (kg)	Pre-2 Mass (kg)
1	M	45	1.9	74.5	74.2	73.1
2	F	58	1.59	55.8	55.7	56
3	M	45	1.82	86.5	86.2	86.5
4	M	59	1.85	97.1	95.8	94.5
5	M	62	1.8	79.3	77.4	77.1
6	M	47	1.685	91.1		
7	F	60	1.625	64.5	64.4	63.3
8	F	48	1.615	87.1	86.4	85.5
9	F	60	1.725	75.2	75.2	76.2
10	M	62	1.79	74.8	74.9	74.9
11	M	58	1.78	89.3	89.7	90.9
12	F	59	1.61	63.1	63.5	62.9
13	F	60	1.75	110.6	109.2	109
14	M	59	1.905	90.5	90.1	89
15	M	55	1.76	95.7	95	94.7
16	F	60	1.625	76.1		
17	F	60	1.73	79.4	78.6	77.6
18	M	59	1.86	70.6	71.3	71.3
19	M	58	1.71	97.6		
20	M	58	1.77	80.7	79.3	78.9
21	M	42	1.83	120.6	121	120.1
22	M	43	1.685	73	73.6	73.7
MEAN		55	1.75	83.3	82.2	81.9
SD		7	0.10	15.4	15.8	15.7

Post Mass (kg)	BMI (kg/m^2)	ABI	AOP (mmHg)	Dominant Limb (R/L)	BFR Limb (R/L)
74.5	20.6	1.05	300+	L	L
55.5	22.1	1.08	300+	R	R
85	26.1	1.13	300+	R	L
94.1	28.4	1.16	300+	R	R
78.5	24.5	1.15	300+	L	L
	32.1	1.18	300+	R	R
64.7	24.4	1.14	300	R	L
83.4	33.4	1.04	300+	R	R
77.3	25.3	1.22	300+	R	L
75.3	23.3	1.21	300+	L	R
90.3	28.2	1.04	300+	R	L
63.9	24.3	1.24	300+	R	R
109.7	36.1	1.07	300+	R	L
90.4	24.9	1.11	300+	R	R
95.3	30.9	1.1	300+	R	L
	28.8	1.03			R
	26.5	1.13	300+	R	L
70.9	20.4	1.11	230	R	R
	33.4	1.00			L
78.5	25.8	1.12	300+	R	R
119.6	36.0	1.07	300+	R	L
73.5	25.7	1.00	300+	R	R
82.2	27.3	1.11		10 Dominant BFR	
16.0	4.6	0.07		9 Non-dominant BFR	

Aerobic Activity (h/wk)	Upper Body Resistance (h/wk)
3	0
2	0
4.5	1.5
3.5	0
6	0
4	0
6.5	0
2	2
0	0
0	0
3	0
0	0
2.5	0
2	0
0	0
3	0
4	0
0	0
0	0
3	0
2.5	0
1	0
2.4	0.2
2.1	0.6

ID	Pre-1	SBP	DBP	MAP	HR	BFR Limb	PWV (m/s)
1		123	78	93	58		9.7
2		104	70	81	63		8.1
3		131	81	98	68		9.4
4		117	73	88	58		8.6
5		103	63	76	59		7.5
6		142	98	113	50		12.0
7		114	68	83	59		7.8
8		125	80	95	56		9.8
9		124	83	97	65		9.4
10		141	85	104	68		8.9
11		128	76	93	55		9.9
12		132	87	102	52		8.2
13		114	75	88	60		7.7
14		131	74	93	54		9.6
15		129	77	94	78		9.1
16							
17		108	65	79	52		8.5
18		99	62	74	55		9.1
19							
20		110	75	87	53		9.2
21		138	93	108	56		10.7
22		103	70	81	61		8.2
23							
24							
25							
MEAN		121	77	91	59		9.1
SD		13	9	10	7		1.1

CBF (ml/min/100ml)	CVC (flow/mmHg)	MVO_20	MVO_40	MVO_60	MVO_80	Cap_20
1.49	16.02	23.8	40.0	40.0	45.0	1.1
2.43	29.88	31.3	58.8	75.0	82.5	1.9
2.26	23.14	23.8	37.5	45.0	46.3	1.3
2.08	23.73	50.0	66.3	81.3	92.5	2.5
1.76	23.06	32.5	46.3	52.5	53.8	1.6
2.42	21.48	17.5	38.8	50.0	58.8	0.9
2.65	31.80	32.5	52.5	63.8	66.3	1.5
6.59	69.37	53.8	87.5	105.0	111.0	1.9
1.32	13.66	18.8	35.0	43.8	46.3	0.9
1.63	15.72	35.0	50.0	60.0	61.3	1.9
1.51	16.18	32.5	93.8	115.0	121.0	1.2
4.79	46.96	42.5	53.8	57.5	63.8	2.1
5.59	63.52	23.8	41.3	56.3		1.1
1.00	10.75	21.3	37.5	38.8	47.5	0.8
2.38	25.23	16.3	43.8	57.5	48.8	1.0
2.83	35.67	38.8	60.0	62.5	65.0	2.1
4.05	54.48	45.0	63.8	68.8	76.3	2.5
2.24	25.85	11.3	25.0	37.5	43.8	0.6
3.34	30.93	31.3	48.8	52.5	60.0	1.3
2.81	34.69	16.3	38.8	52.5	56.3	0.9
2.76	30.61	29.9	51.0	60.8	65.6	1.5
1.47	16.36	11.9	17.2	20.5	22.2	0.6

Cap_40	Cap_60	Cap_80	VVV Slope	FF Limb	PWV (m/s)	CBF (ml/min/100ml)
2.1	2.7	3.6	0.041		8.8	1.75
3.1	4.2	4.8	0.049		8.4	1.8
2.0	2.6	3.1	0.030		10.1	2.32
3.9	4.8	5.7	0.053		8.8	2.23
2.4	2.8	3.2	0.026		8.1	2.35
1.8	2.5	3.2	0.038		9.2	1.9
2.5	3.4	4.3	0.047		10.9	2.58
3.6	4.4	4.8	0.048		10.0	4.32
1.7	2.2	2.9	0.033		9.1	1.58
2.8	3.4	3.9	0.033		10.4	1.94
3.5	4.6	5.5	0.070		10.5	2.13
3.0	3.5	4.2	0.034		7.7	2.55
1.9	2.8		0.043		8.4	5.25
1.6	2.0	2.4	0.026		10.4	0.85
2.2	3.0	3.8	0.046		9.4	2.68
3.4	4.1	4.5	0.040		8.2	3.2
3.5	3.9	4.8	0.037		6.3	2.81
1.8	2.6	3.3	0.045		9.0	1.13
2.3	2.8	3.3	0.033		9.0	3.85
1.9	2.7	3.7	0.046		8.1	1.2
2.6	3.3	3.9	0.041		9.0	2.42
0.7	0.8	0.9	0.010		1.1	1.08

CVC (flow/mmHg)	MVO_20	MVO_40	MVO_60	MVO_80	Cap_20	Cap_40	Cap_60	Cap_80
18.82	5.0	13.8	16.3	18.8	0.5	1.2	2.0	2.7
22.13	13.8	48.8	58.8	60.0	1.1	2.0	3.1	3.9
23.75	16.3	43.8	57.5	58.8	1.2	2.3	3.1	3.5
25.44	38.8	61.3	73.9	81.3	1.8	3.4	4.1	4.6
30.79	30.0	46.3	51.3	58.8	1.4	2.3	2.7	3.2
16.86	21.3	41.3	46.3	50.0	1.0	1.9	2.3	2.8
30.96	35.0	52.5	68.8	76.3	1.6	2.8	3.8	4.8
45.47	47.5	72.5	83.8	91.3	1.5	3.4	4.1	4.5
16.34	16.3	30.0	36.3	42.5	0.9	1.4	2.5	2.8
18.71	28.8	43.8	48.8	53.8	1.4	2.3	2.9	3.2
22.82	50.0	95.0	116.0	126.0	2.2	4.0	5.4	6.3
25.00	30.0	40.0	43.8	43.8	1.3	2.2	2.5	2.9
59.66	11.3	33.8	46.3	70.0	1.3	1.6	3.8	4.3
9.14	15.0	26.3	36.3	42.5	0.8	1.4	2.0	2.4
28.41	27.5	58.8	71.3	58.8	1.4	2.9	3.8	4.5
40.34	33.8	52.5	57.5	63.8	1.9	2.8	3.4	3.9
37.80	46.3	61.3	62.5	70.0	2.1	3.1	3.4	4.1
13.04	8.8	16.3	23.8	30.0	0.8	1.5	1.9	2.6
35.65	35.0	36.3	43.8	52.5	1.9	3.2	2.9	3.2
14.81	5.0	12.5	22.5	26.3	0.3	1.0	1.4	2.4
26.80	25.8	44.3	53.3	58.8	1.3	2.3	3.1	3.6
12.31	14.1	20.2	23.0	24.1	0.5	0.8	1.0	1.0

VVV Slope	Pre-2	SBP	DBP	MAP	HR	BFR Limb	PWV (m/s)
0.037		126	86	99	70		10.8
0.048		102	64	77	67		6.6
0.039		126	82	97	74		10.1
0.046		110	71	84	54		8.6
0.029		102	62	75	56		8.4
0.029							
0.053		113	71	85	53		9.4
0.049		124	84	97	58		8.4
0.034		118	79	92	73		8.9
0.030		127	79	95	68		9.7
0.069		130	79	96	57		10.5
0.026		125	73	90	55		7.9
0.056		106	74	85	58		9.6
0.027		137	77	97	60		9.6
0.051		122	76	91	72		8.6
0.033		112	75	87	55		8.4
0.032		102	68	79	57		9.0
0.029		122	76	91	55		9.2
0.018		124	81	95	54		9.3
0.034		113	69	84	66		7.4
0.038		118	75	89	61		9.0
0.013		10	6	7	7		1.0

CBF (ml/min/100ml)	CVC (flow/mmHg)	MVO_20	MVO_40	MVO_60	MVO_80	Cap_20
1.53	15.40	15.0	35.0	41.3	46.3	1.1
2.39	31.17	45.0	56.3	62.5	63.8	2.3
1.23	12.72	11.3	32.5	33.8	50.0	1.1
1.29	15.36	53.8	107.0	113.0	113.0	2.1
3.08	40.88	55.0	97.5	112.0	111.0	2.4
3.06	36.00	40.0	62.5	75.0	83.8	1.9
3.8	39.04	51.3	77.5	82.5	86.3	2.5
1.96	21.30	20.0	33.8	41.3	43.8	1.0
2.27	23.89	33.8	53.8	61.3	61.3	1.9
2.05	21.35	33.8	71.3	86.3	95.0	1.5
3.28	36.31	30.0	43.8	52.5	57.5	1.7
3.78	44.65	25.0	40.0	52.5	66.3	1.1
1.27	13.09	23.8	38.8	42.5	47.5	1.1
3.89	42.59	47.5	68.8	77.5	82.5	1.8
3.58	40.99	41.3	55.0	60.0	61.3	2.1
2.38	30.00	27.5	41.3	50.0	56.3	1.5
2.72	29.78	36.3	46.8	56.3	62.5	2.2
2.42	25.38	5.0	17.5	27.5	40.0	0.4
3.12	37.29	10.0	37.5	51.3	60.0	0.6
2.58	29.33	31.9	53.5	62.1	67.8	1.6
0.88	10.64	15.2	22.9	23.8	21.6	0.6

Cap_40	Cap_60	Cap_80	VVV Slope	FF Limb	PWV (m/s)	CBF (ml/min/100ml)
1.9	2.9	3.3	0.038		9.5	1.75
3.1	3.5	4.1	0.029		5.8	2.04
1.9	2.3	3.2	0.034		9.4	1.98
4.3	5.3	6.1	0.065		7.4	1.24
4.1	4.8	5.2	0.046		8.7	2.12
3.0	4.1	4.8	0.049		10.2	3.04
3.6	3.8	4.6	0.033		9.8	2.92
1.6	2.3	2.5	0.026		9.2	2.73
3.1	3.8	4.1	0.037		9.3	1.9
3.0	3.8	4.4	0.048		10.3	1.57
2.5	3.2	3.5	0.031		8.4	3.1
1.7	2.8	4.0	0.049		7.8	2.94
1.8	2.3	2.5	0.024		10.9	2
2.8	3.4	4.3	0.041		9.1	3.8
2.8	3.5	3.8	0.029		9.4	3.31
2.3	2.7	3.4	0.031		7.7	1.25
2.8	3.4	4.2	0.033		7.9	2.21
1.0	1.5	2.3	0.031		8.9	2.64
1.8	2.6	3.4	0.046		8.3	1.59
2.6	3.3	3.9	0.038		8.8	2.32
0.9	0.9	1.0	0.010		1.2	0.73

CVC (flow/mmHg)	MVO_20	MVO_40	MVO_60	MVO_80	Cap_20	Cap_40	Cap_60	Cap_80
17.62	5.0	11.3	15.0	17.5	0.6	1.2	1.9	2.8
26.61	33.8	46.3	46.3	48.8	1.7	2.6	3.0	3.2
20.48								
14.76	11.3	35.0	58.8	53.8	0.7	1.9	3.8	3.3
28.14	47.5	66.3	73.8	77.5	2.1	3.0	3.6	4.0
35.76	43.8	67.5	77.5	86.3	2.3	3.6	4.4	5.2
30.00	32.5	47.5	60.0	63.8	1.7	2.5	3.1	3.0
29.67	20.0	33.8	41.3	45.0	0.9	1.5	2.1	2.8
20.00	28.8	43.8	47.5	51.3	1.1	2.4	2.9	3.5
16.35	12.5	65.0	75.0	85.0	1.5	2.8	3.8	4.8
34.32	32.5	45.0	47.5	48.8	1.7	2.4	2.7	2.5
34.72	23.8	38.8	50.0	60.0	1.0	1.7	2.8	3.7
20.62	31.3	46.3	53.8	58.8	1.4	2.3	2.8	3.1
41.61	37.5	61.3	72.5	77.5	1.7	2.9	3.8	4.6
37.90	41.3	55.0	60.0	61.3	2.1	2.8	3.5	3.8
15.76	16.3	32.5	40.0	46.3	0.8	1.3	1.9	2.3
24.20	23.8	37.5	43.8	47.5	1.5	2.3	2.8	3.4
27.69	15.0	30.0	33.8	38.8	0.8	1.5	1.8	2.5
19.00	7.5	23.8	37.5	43.8	0.5	1.4	2.1	2.8
26.06	25.8	43.7	51.9	56.2	1.3	2.2	2.9	3.4
8.18	12.8	15.3	16.4	17.4	0.6	0.7	0.8	0.8

VVV Slope	Post	SBP	DBP	MAP	HR	BFR Limb	PWV (m/s)
0.0365		119	75	90	66		8.1
0.0245		102	64	77	69		9.6
		121	79	93	81		10.0
0.0485		102	66	78	59		7.7
0.0315		108	63	78	56		9.1
0.0475		117	76	90	52		9.2
0.0225		128	86	100	65		8.2
0.0315		115	84	94	75		9.8
0.0385		126	73	91	69		9.8
0.0545		125	76	92	58		10.9
0.0135		136	73	94	55		9.0
0.046		136	89	105	50		9.5
0.028		135	81	99	58		10.1
0.048		124	75	91	75		10.0
0.029				0			
0.0255		103	69	80	67		9.4
0.031		123	69	87	58		10.2
0.027		120	54	76	57		10.1
0.038		108	71	83	70		8.2
0.035		119	74	84	63		9.4
0.011		11	9	22	9		0.9

CBF (ml/min/100ml)	CVC (flow/mmHg)	MVO_20	MVO_40	MVO_60	MVO_80	Cap_20
2.94	32.79	25.0	42.5	56.3	55.0	1.4
2.76	36.00	37.5	53.8	60.0	68.8	2.0
2.59	27.85	30.0	43.8	63.8	62.5	1.9
1.85	23.72	51.3	86.3	107.0	120.0	2.7
2.16	27.69	41.3	55.0	66.3	67.5	1.8
2.71	30.22	25.0	40.0	48.8	56.3	1.3
5.91	59.10	26.3	50.0	68.8	95.0	1.4
1.57	16.64	20.0	36.3	37.5	46.3	2.1
1.92	21.18	30.0	46.3	51.3	55.0	1.2
1.31	14.19	16.3	35.0	48.8	56.3	0.9
1.87	19.89	6.3	17.5	27.5	33.8	0.4
2.82	26.94	16.3	28.8	40.0	48.8	0.8
1.47	14.85	13.8	26.3	31.3	37.5	0.9
2.71	29.67	15.0	40.0	46.3	51.3	1.0
3.05	37.97	21.3	38.8	50.0	56.3	1.0
2.17	24.94	21.3	40.0	50.0	56.3	1.1
2.6	34.21	15.0	31.3	41.3	47.5	0.8
3.44	41.28	23.8	41.3	53.8	60.0	1.3
2.55	28.84	24.2	41.8	52.7	59.7	1.3
1.03	10.84	10.9	14.5	17.6	20.0	0.6

Cap_40	Cap_60	Cap_80	VVV Slope	FF Limb	PWV (m/s)	CBF (ml/min/100ml)
2.5	3.5	4.6	0.053		7.5	2.19
2.8	3.5	4.5	0.041		6.0	2.39
2.7	3.5	4.2	0.039		8.6	2.33
4.3	5.6	6.4	0.062		8.8	2.14
2.4	3.1	3.9	0.035		8.0	4.22
2.1	2.8	3.9	0.043		8.9	2.26
2.6	2.7	4.3	0.044		11.5	5.13
2.3	1.9	2.8	0.009		9.4	2.31
2.1	2.8	3.4	0.037		8.9	2.13
1.8	2.5	3.1	0.037		10.1	1.81
1.0	1.7	2.4	0.034		9.4	2.46
1.5	2.2	3.2	0.040		9.2	2.74
1.3	1.6	2.2	0.021		9.8	1.92
1.9	2.7	3.3	0.039		9.0	3.01
1.5	2.2	2.9	0.032		9.0	2.39
1.8	2.9	3.8	0.046		9.3	1.86
1.5	2.2	2.8	0.034		8.9	3.47
2.3	3.1	3.9	0.043		9.0	4.31
2.1	2.8	3.6	0.038		9.0	2.73
0.7	0.9	1.0	0.011		1.1	0.95

CVC (flow/mmHg)	MVO_20	MVO_40	MVO_60	MVO_80	Cap_20	Cap_40	Cap_60	Cap_80
24.42	6.3	12.5	13.8	17.5	0.5	1.0	1.9	2.8
31.17	26.3	42.5	45.0	51.3	1.3	2.1	2.8	3.3
25.05	30.0	43.8	58.8	62.5	1.9	2.7	3.5	3.7
27.44	57.5	86.3	93.8	97.5	2.5	3.9	4.7	5.2
54.10	63.8	123.0	128.0	128.0	3.4	4.9	5.8	6.7
25.20	12.5	28.8	42.5	55.0	0.7	1.7	2.7	3.6
51.30	27.5	50.0	57.5	78.8	1.3	2.2	2.9	3.5
24.49	21.3	33.8	42.5	40.0	0.9	1.5	2.1	2.5
23.49	22.5	35.0	41.3	45.0	1.3	2.0	2.6	3.1
19.60	21.3	40.0	50.0	57.5	1.2	2.2	3.0	3.8
26.17	11.3	22.5	31.3	37.5	0.5	1.1	1.6	2.4
26.18	16.3	27.5	42.5	50.0	0.6	1.0	2.1	2.8
19.39	15.0	25.0	31.3	37.5	1.2	1.6	2.0	2.2
32.96	26.3	43.8	56.3	56.3	1.3	2.3	3.1	3.7
29.75	20.0	36.3	45.0	58.8	1.0	1.7	2.5	3.0
21.38	26.3	38.8	45.0	45.0	1.6	2.6	3.2	3.8
45.66	17.5	32.5	32.5	47.5	1.2	1.9	2.7	2.9
51.72	30.0	43.8	52.5	58.8	1.8	2.8	3.7	4.4
31.08	25.1	42.6	50.5	56.9	1.3	2.2	2.9	3.5
11.43	14.6	25.2	25.2	24.6	0.7	1.0	1.0	1.1

VVV Slope
0.039
0.034
0.031
0.045
0.054
0.049
0.037
0.027
0.030
0.043
0.031
0.039
0.017
0.040
0.034
0.036
0.030
0.044
0.036
0.009

ID	Pre-1	BFR Limb	1-RM (lbs)	1-RM (kgs)	30%_1RM (kgs)	30%_Vel (m/s)	30%_Power
1			82.5	37.4	11.3	1.02	113.4
2			30	13.6	4.5	0.86	38.3
3			60	27.2	7.9	0.86	66.9
4			57.5	26.1	7.9	0.9	70.1
5			50	22.7	6.8	1.44	96.1
6			82.5	37.4	11.3	0.86	95.6
7			32.5	14.7	4.5	0.82	36.5
8			52.5	23.8	6.8	1.04	69.4
9			35	15.9	4.5	0.94	41.8
10			80	36.3	11.3	1.02	113.4
11			85	38.6	12.5	0.98	119.9
12			37.5	17.0	5.7	0.9	50.0
13			47.5	21.5	6.8	1.08	72.1
14			62.5	28.3	9.1	1.08	96.1
15			42.5	19.3	5.7	0.9	50.0
16							
17			45	20.4	5.7	0.92	51.2
18			70	31.8	9.1	0.96	85.4
19							
20			77.5	35.2	10.2	0.92	92.1
21			80	36.3	11.3	0.98	109.0
22			67.5	30.6	9.1	1.2	106.8
23							
24							
25							
MEAN			58.9	26.7	8.1	0.98	78.7
SD			18.5	8.4	2.6	0.14	27.6

60%_1RM (kgs)	60%_Vel (m/s)	60%_Power	90%_1RM (kgs)	90%_Vel (m/s)	90%_Power
22.7	0.92	204.6	34.0	0.64	213.5
7.9	0.72	56.0	12.5	0.54	66.1
15.9	0.82	127.7	24.9	0.58	141.9
15.9	0.74	115.2	23.8	0.64	149.5
13.6	0.98	130.8	20.4	0.76	152.1
22.7	0.78	173.5	34.0	0.48	160.1
9.1	0.6	53.4	13.6	0.44	58.7
13.6	0.7	93.4	20.4	0.46	92.1
9.1	0.82	73.0	14.7	0.42	60.7
21.5	0.76	160.6	32.9	0.58	187.0
23.8	0.62	144.8	36.3	0.48	170.8
10.2	0.66	66.1	15.9	0.44	68.5
12.5	0.88	107.6	19.3	0.6	113.4
17.0	1	166.8	26.1	0.76	194.4
11.3	0.96	106.8	17.0	0.7	116.8
12.5	0.82	100.3	18.1	0.54	96.1
19.3	0.72	136.1	28.3	0.48	133.4
21.5	0.74	156.4	31.8	0.58	180.6
21.5	0.9	190.2	32.9	0.7	225.7
18.1	0.94	167.3	27.2	0.7	186.8
16.0	0.80	126.5	24.2	0.58	138.4
5.2	0.12	44.5	7.7	0.11	52.5

Endurance (reps)	FF Limb	1-RM (lbs)	1-RM (kgs)	30%_1RM (kgs)	30%_Vel (m/s)	30%_Power
61		82.5	37.4	11.3	1.14	126.8
22		30	13.6	4.5	0.9	40.0
30		62.5	28.3	9.1	1	89.0
		75	34.0	10.2	1.04	104.1
59		52.5	23.8	6.8	0.84	56.0
18		75	34.0	10.2	0.94	94.1
28		27.5	12.5	3.4	0.92	30.7
22		52.5	23.8	6.8	0.92	61.4
23		35	15.9	4.5	0.96	42.7
23		75	34.0	10.2	0.86	86.1
25		85	38.6	12.5	0.92	112.5
23		37.5	17.0	5.7	0.78	43.4
26		47.5	21.5	6.8	1.12	74.7
37		62.5	28.3	9.1	1	89.0
41		52.5	23.8	6.8	1.08	72.1
14		50	22.7	6.8	1	66.7
16		72.5	32.9	10.2	0.88	88.1
58		77.5	35.2	10.2	0.9	90.1
24		87.5	39.7	12.5	0.9	110.1
34		67.5	30.6	9.1	1.22	108.5
31		60.4	27.4	8.3	0.97	79.3
14		18.6	8.5	2.7	0.11	27.2

60%_1RM (kgs)	60%_Vel (m/s)	60%_Power	90%_1RM (kgs)	90%_Vel (m/s)	90%_Power
22.7	0.82	182.4	34.0	0.64	213.5
7.9	0.68	52.9	12.5	0.44	53.8
17.0	0.82	136.8	26.1	0.66	168.8
20.4	0.78	156.1	30.6	0.7	210.2
14.7	0.86	124.3	21.5	0.68	143.7
20.4	0.72	144.1	32.9	0.4	129.0
7.9	0.5	38.9	11.3	0.46	51.2
14.7	0.6	86.7	21.5	0.34	71.8
9.1	0.72	64.1	14.7	0.48	69.4
20.4	0.78	156.1	30.6	0.5	150.1
23.8	0.66	154.1	36.3	0.5	177.9
10.2	0.5	50.0	15.9	0.38	59.2
12.5	0.84	102.8	19.3	0.62	117.2
17.0	0.94	156.8	26.1	0.7	179.0
14.7	0.98	141.7	21.5	0.82	173.3
13.6	0.8	106.8	20.4	0.5	100.1
19.3	0.74	139.9	29.5	0.6	173.5
21.5	0.76	160.6	31.8	0.58	180.6
23.8	0.9	210.2	36.3	0.62	220.6
18.1	0.92	163.7	27.2	0.66	176.2
16.5	0.77	126.5	25.0	0.56	141.0
5.1	0.13	47.2	7.8	0.13	56.0

Endurance (reps)	Pre-2	BFR Limb	1-RM (lbs)	1-RM (kgs)	30%_1RM (kgs)	30%_Vel (m/s)
45			92.5	42.0	12.5	0.94
22			32.5	14.7	4.5	0.92
38			72.5	32.9	10.2	0.82
			80	36.3	11.3	0.94
37			57.5	26.1	7.9	1.08
18						
30			37.5	17.0	5.7	1
23			50	22.7	6.8	0.9
24			32.5	14.7	4.5	0.84
25			70	31.8	9.1	1.08
25			87.5	39.7	12.5	1.1
20			37.5	17.0	5.7	0.84
29			50	22.7	6.8	0.94
37			62.5	28.3	9.1	0.84
50			52.5	23.8	6.8	0.92
12			45	20.4	5.7	1.26
15			67.5	30.6	9.1	1.02
58			82.5	37.4	11.3	0.96
20			90	40.8	12.5	0.92
32			75	34.0	10.2	1
29			61.8	28.1	8.5	0.96
12			19.9	9.0	2.7	0.11

30%_Power	60%_1RM (kgs)	60%_Vel (m/s)	60%_Power	90%_1RM (kgs)	90%_Vel (m/s)	90%_Power
115.0	24.9	0.8	195.7	37.4	0.58	212.8
40.9	9.1	0.74	65.8	13.6	0.5	66.7
82.1	19.3	0.78	147.5	29.5	0.62	179.3
104.5	21.5	0.72	152.1	31.8	0.48	149.5
84.1	15.9	0.84	130.8	23.8	0.68	158.8
55.6	10.2	0.72	72.1	15.9	0.5	77.8
60.1	13.6	0.76	101.4	20.4	0.52	104.1
37.4	9.1	0.72	64.1	13.6	0.28	37.4
96.1	19.3	0.78	147.5	28.3	0.64	177.9
134.6	26.1	0.86	220.0	36.3	0.6	213.5
46.7	10.2	0.64	64.1	15.9	0.44	68.5
62.7	13.6	0.7	93.4	20.4	0.56	112.1
74.7	17.0	0.92	153.5	26.1	0.7	179.0
61.4	14.7	0.74	107.0	21.5	0.56	118.3
			0.0			
70.1	12.5	0.82	100.3	18.1	0.66	117.4
90.7	18.1	0.82	145.9	27.2	0.6	160.1
			0.0			
106.8	22.7	0.78	173.5	34.0	0.56	186.8
112.5	24.9	0.9	220.2	36.3	0.64	227.8
100.1	20.4	0.96	192.2	30.6	0.72	216.2
80.8	17.0	0.79	134.0	25.3	0.57	145.5
27.5	5.5	0.08	63.3	7.9	0.10	57.3

Endurance (reps)	FF Limb	1-RM (lbs)	1-RM (kgs)	30%_1RM (kgs)	30%_Vel (m/s)	30%_Power
68		87.5	39.7	12.5	0.86	105.2
31		32.5	14.7	4.5	0.9	40.0
37		87.5	39.7	12.5	0.96	117.4
48		85	38.6	11.3	1.02	113.4
46		55	24.9	7.9	0.96	74.7
22		32.5	14.7	4.5	0.9	40.0
18		50	22.7	6.8	0.9	60.1
26		32.5	14.7	4.5	1	44.5
37		75	34.0	10.2	1.06	106.1
32		87.5	39.7	12.5	1.02	124.8
29		37.5	17.0	5.7	0.74	41.1
29		50	22.7	6.8	0.9	60.1
35		67.5	30.6	9.1	0.84	74.7
43		67.5	30.6	9.1	0.7	62.3
23		55	24.9	7.9	1.04	81.0
18		72.5	32.9	10.2	0.98	98.1
57		77.5	35.2	10.2	0.96	96.1
24		92.5	42.0	12.5	0.98	119.9
44		72.5	32.9	10.2	1	100.1
35		64.1	29.1	8.9	0.93	82.1
13		20.6	9.3	2.8	0.10	29.3

60%_1RM (kgs)	60%_Vel (m/s)	60%_Power	90%_1RM (kgs)	90%_Vel (m/s)	90%_Power
23.8	0.84	196.2	36.3	0.54	192.2
9.1	0.68	60.5	13.6	0.48	64.1
23.8	0.8	186.8	36.3	0.58	206.4
22.7	0.82	182.4	35.2	0.58	199.9
14.7	0.84	121.4	22.7	0.68	151.2
9.1	0.72	64.1	13.6	0.52	69.4
13.6	0.68	90.7	20.4	0.44	88.1
9.1	0.74	65.8	13.6	0.42	56.0
20.4	0.8	160.1	30.6	0.54	162.1
26.1	0.74	189.3	36.3	0.46	163.7
10.2	0.6	60.1	15.9	0.4	62.3
13.6	0.72	96.1	20.4	0.48	96.1
19.3	0.84	158.8	28.3	0.58	161.2
18.1	0.84	149.5	27.2	0.6	160.1
14.7	0.8	115.7	22.7	0.58	129.0
19.3	0.84	158.8	29.5	0.58	167.7
21.5	0.78	164.8	31.8	0.56	174.4
24.9	0.9	220.2	37.4	0.56	205.5
19.3	0.98	185.3	29.5	0.68	196.6
17.5	0.79	138.2	26.4	0.54	142.4
5.7	0.09	52.2	8.4	0.08	53.1

Endurance (reps)	Post	BFR Limb	1-RM (lbs)	1-RM (kgs)	30%_1RM (kgs)	30%_Vel (m/s)
71			90	40.8	12.5	1.02
32			35	15.9	4.5	0.9
28			82.5	37.4	11.3	0.98
69			80	36.3	11.3	0.98
35			65	29.5	9.1	1.04
27			42.5	19.3	5.7	0.88
16			55	24.9	7.9	0.7
20			50	22.7	6.8	0.84
25			70	31.8	9.1	1.02
30			87.5	39.7	12.5	0.92
25			45	20.4	5.7	0.88
34			65	29.5	9.1	1
40			77.5	35.2	10.2	1.1
30			65	29.5	9.1	1.02
19						
16			72.5	32.9	10.2	1.02
63						
23			90	40.8	12.5	1
37			87.5	39.7	12.5	0.92
34			68.2	31.0	9.4	0.95
17			17.7	8.0	2.6	0.10

30%_Power	60%_1RM (kgs)	60%_Vel (m/s)	60%_Power	90%_1RM (kgs)	90%_Vel (m/s)	90%_Power
124.8	24.9	0.78	190.8	36.3	0.52	185.0
40.0	9.1	0.76	67.6	14.7	0.46	66.5
109.0	22.7	0.78	173.5	34.0	0.48	160.1
109.0	21.5	0.72	152.1	32.9	0.32	103.2
92.5	18.1	0.84	149.5	26.1	0.66	168.8
48.9	11.3	0.6	66.7	17.0	0.4	66.7
54.5	14.7	0.68	98.3	22.7	0.42	93.4
56.0	13.6	0.64	85.4	20.4	0.34	68.1
90.7	19.3	0.84	158.8	28.3	0.6	166.8
112.5	23.8	0.74	172.8	36.3	0.5	177.9
48.9	12.5	0.7	85.6	18.1	0.48	85.4
89.0	18.1	0.72	128.1	26.1	0.44	112.5
110.1	21.5	0.88	185.9	32.9	0.66	212.8
90.7	19.8	0.76	147.2	26.1	0.58	148.3
102.1	19.3	0.78	147.5	29.5	0.62	179.3
122.3	24.9	0.86	210.4	36.3	0.58	206.4
112.5	23.8	0.88	205.5	36.3	0.66	234.9
89.0	18.8	0.76	142.7	27.9	0.51	143.3
28.3	4.9	0.08	46.9	7.3	0.11	55.2

Endurance (reps)	FF Limb	1-RM (lbs)	1-RM (kgs)	30%_1RM (kgs)	30%_Vel (m/s)	30%_Power
70		82.5	37.4	11.3	1.04	115.7
49		37.5	17.0	5.7	0.78	43.4
53		95	43.1	12.5	0.98	119.9
50		85	38.6	11.3	1.06	117.9
55		62.5	28.3	9.1	0.92	81.8
38		42.5	19.3	5.7	0.94	52.3
18		52.5	23.8	6.8	0.74	49.4
44		52.5	23.8	6.8	0.88	58.7
47		67.5	30.6	9.1	1	89.0
47		87.5	39.7	12.5	0.9	110.1
42		45	20.4	5.7	0.8	44.5
34		67.5	30.6	9.1	0.92	81.8
39		72.5	32.9	10.2	1.02	102.1
59		72.5	32.9	10.2	0.96	96.1
36		72.5	32.9	10.2	0.98	98.1
59						
30		95	43.1	12.5	1.06	129.7
36		77.5	35.2	10.2	1.16	116.1
45		68.7	31.2	9.3	0.95	88.6
12		17.9	8.1	2.4	0.11	29.2

60%_1RM (kgs)	60%_Vel (m/s)	60%_Power	90%_1RM (kgs)	90%_Vel (m/s)	90%_Power
22.7	0.84	186.8	34.0	0.56	186.8
10.2	0.64	64.1	15.9	0.44	68.5
26.1	0.76	194.4	38.6	0.58	219.3
22.7	0.86	191.3	35.2	0.58	199.9
17.0	0.92	153.5	26.1	0.6	153.5
11.3	0.68	75.6	17.0	0.46	76.7
14.7	0.64	92.5	21.5	0.42	88.7
14.7	0.44	63.6	21.5	0.38	80.3
18.1	0.8	142.3	27.2	0.58	154.8
23.8	0.76	177.5	36.3	0.44	156.6
12.5	0.58	70.9	18.1	0.48	85.4
18.1	0.72	128.1	27.2	0.48	128.1
19.3	0.84	158.8	29.5	0.62	179.3
19.3	0.82	155.0	29.5	0.54	156.1
19.3	0.82	155.0	29.5	0.52	150.4
26.1	0.84	214.9	38.6	0.58	219.3
21.5	0.9	190.2	31.8	0.66	205.5
18.7	0.76	142.0	28.1	0.52	147.6
4.8	0.13	50.7	7.3	0.08	51.7

Endurance (reps)
87
28
45
70
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16

ID	Fam	BFR Limb	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60
1			5.84	5.24	4.73	3.54	3.76	3.62
2			4.80	4.30	3.62	3.15	3.43	3.23
3			5.59	5.38	5.05	4.91	4.64	4.14
4			6.04	5.47	5.00	3.80	3.80	3.70
5			5.41	5.17	4.97	4.68	4.43	3.87
6			7.31	7.23	6.95	3.76	3.93	3.86
7			4.39	4.14	3.97	3.13	2.88	2.64
8					5.59	2.73	3.04	2.99
9			4.88	4.47	3.63	2.60	2.73	2.65
10			4.96	4.83	4.05	3.54	3.47	3.23
11			6.20	5.89	5.45	3.81	3.80	3.75
12			5.47	5.03	4.49	2.67	2.66	2.53
13			5.57	4.93	4.76	3.31	3.33	3.35
14			5.96	5.58	4.77	3.78	3.61	3.49
15			6.48	5.82	5.20	2.86	3.04	3.14
16								
17			5.97	5.27	4.58	3.03	3.26	3.25
18			5.01	4.44	3.93	3.40	3.30	2.99
19								
20			5.79	5.14	4.60	4.07	3.97	3.84
21			7.12	6.54	5.73	4.32	4.78	4.88
22			5.96	5.54	5.07	4.42	4.37	4.15
23								
24								
25								
MEAN			5.72	5.28	4.81	3.58	3.61	3.47
SD			0.75	0.76	0.79	0.67	0.62	0.58

FF Limb	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60	Pre-1	BFR Limb
	6.03	5.44	4.73	3.23	3.31	3.33		
	5.02	4.41	4.19	2.63	2.73	2.74		
	6.22	6.06	5.71	4.29	3.87	3.50		
	6.28	6.08	5.65	4.32	4.18	4.10		
	5.53	4.69	4.23	4.24	4.05	3.77		
	6.91	6.69	6.63	3.73	3.83	3.88		
	4.66	4.43	3.63	2.95	2.83	2.83		
			5.34	2.55	2.75	2.95		
	5.19	4.54	3.73	2.18	2.38	2.54		
	5.47	5.09	4.40	2.65	2.60	2.50		
	6.14	5.63	5.20	3.47	3.66	3.73		
	5.67	5.06	4.54	2.20	2.15	2.18		
	5.87	5.75	5.16	3.57	3.68	3.57		
	5.67	5.19	4.58	3.48	3.38	3.23		
	6.08	5.83	5.21	3.22	3.28	3.19		
	5.93	5.34	4.84	3.19	3.30	3.25		
	5.42	4.82	4.15	3.34	3.29	3.01		
	6.16	5.93	5.37	3.95	3.85	3.83		
	7.07	6.42	5.18	4.32	4.75	4.66		
	5.94	5.58	5.09	4.74	4.54	4.24		
	5.86	5.42	4.88	3.41	3.42	3.35		
	0.59	0.67	0.73	0.75	0.70	0.64		

Thigh Circ. (cm)	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60	FF Limb
49.5	6.15	5.49	4.82	3.39	3.54	3.45	
52.0	4.80	3.90	3.37	3.01	3.03	3.17	
49.0	5.10	4.51	4.01	4.07	3.84	3.42	
53.0	6.28	5.69	5.14	3.77	3.84	3.67	
51.0	5.38	5.26	4.96	4.43	4.14	3.71	
55.0	7.59	7.51	6.87	4.48	4.53	4.14	
49.5	4.84	4.10	3.13	3.17	2.87	2.56	
64.0			5.64	2.20	2.49	2.84	
49.0	4.74	4.37	3.69	2.50	2.60	2.64	
46.0	4.85	4.24	3.57	3.44	3.33	2.82	
56.0	6.32	6.22	5.64	3.44	3.87	3.96	
50.0	4.98	4.36	3.82	2.72	2.52	2.22	
66.0	5.68	5.50	4.62	3.23	3.29	3.35	
56.0	6.08	5.76	5.07	3.99	3.81	3.55	
56.0	6.48	5.79	4.90	3.09	3.21	3.12	
52.0	5.94	5.34	4.79	3.00	3.38	3.35	
48.5	5.00	4.51	4.06	3.27	3.14	2.80	
49.5	5.32	4.73	4.22	4.18	4.09	3.96	
63.0	7.53	6.82	6.11	4.44	4.77	4.89	
52.0	5.86	5.40	4.88	4.35	4.29	4.08	
53.4	5.73	5.24	4.67	3.51	3.53	3.39	
5.5	0.87	0.96	0.96	0.68	0.66	0.64	

Thigh Circ. (cm)	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60	Pre-2	BFR Limb
48.5	6.08	5.09	4.43	3.52	3.57	3.46		
51.0	4.60	4.20	3.38	2.97	3.19	3.20		
51.0	5.44	5.16	5.08	4.52	4.28	3.88		
54.0	6.42	6.11	5.65	4.04	3.91	3.65		
51.0	5.49	5.09	4.43	4.19	4.22	3.68		
55.0	7.26	7.08	6.65	3.89	4.17	4.09		
48.5	4.59	4.16	3.27	2.90	2.78	2.52		
63.0			5.55	2.30	2.38	2.63		
48.5	4.94	4.36	3.86	2.12	2.36	2.44		
47.0	5.55	5.36	4.52	3.08	3.01	2.93		
54.0	6.29	6.09	5.32	3.42	3.81	3.84		
50.0	5.33	4.71	4.14	2.22	2.25	2.22		
65.5	5.81	5.83	5.24	3.39	3.53	3.56		
55.0	5.82	5.50	4.88	3.57	3.40	3.37		
55.5	5.57	4.89	4.17	3.41	3.33	3.24		
52.0	5.91	5.33	4.72	3.17	3.37	3.31		
48.5	5.37	4.77	4.18	3.54	3.59	3.30		
50.5	5.45	5.05	4.52	3.97	3.97	3.82		
67.0	7.34	6.56	5.48	4.42	4.87	4.84		
51.0	5.94	5.59	4.87	4.75	4.59	4.35		
53.3	5.75	5.31	4.72	3.47	3.53	3.42		
5.7	0.73	0.77	0.81	0.74	0.73	0.66		

Thigh Circ. (cm)	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60	FF Limb
50.0	6.02	5.43	4.77	3.46	3.57	3.54	
52.5	4.52	3.86	3.36	3.07	3.18	3.07	
52.0	5.71	5.52	4.99	4.21	3.87	3.81	
53.0	5.83	5.58	4.98	3.48	3.52	3.44	
51.0	5.38	5.23	4.90	4.32	4.07	3.70	
49.5	5.02	4.08	3.06	3.18	2.97	2.85	
62.0	6.06	5.40	4.58	2.41	2.58	2.63	
51.0	4.75	4.54	3.75	2.43	2.63	2.68	
47.0	5.09	4.43	4.06	3.58	3.43	3.15	
54.0	6.28	5.76	5.30	3.90	3.87	3.80	
50.5	5.42	4.99	4.37	2.45	2.43	2.23	
62.0	5.74	5.63	4.94	3.31	3.24	3.10	
52.5	5.79	5.34	4.48	3.59	3.41	3.20	
55.5	5.91	5.64	4.81	2.84	2.95	2.83	
51.0	5.73	5.02	4.60	3.39	3.49	3.48	
49.0	4.93	4.49	4.02	3.19	3.29	3.02	
49.5	5.35	4.93	4.15	4.11	4.03	3.94	
65.0	7.07	6.63	5.70	4.54	4.88	4.98	
50.0	5.67	5.17	4.45	4.45	4.22	4.07	
53.0	5.59	5.14	4.49	3.47	3.45	3.34	
4.9	0.59	0.66	0.65	0.67	0.62	0.63	

Thigh Circ. (cm)	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60	Post	BFR Limb
48.5	6.34	5.68	4.95	3.38	3.43	3.30		
53.0	4.39	4.03	3.69	2.49	2.84	2.92		
52.0	6.25	6.09	5.31	4.42	4.25	3.62		
55.0	6.44	6.28	5.69	3.95	4.08	3.91		
51.0	5.38	4.89	4.39	4.13	4.01	3.67		
49.5	4.72	4.10	3.36	2.92	2.80	2.64		
61.5	5.53	5.09	4.60	2.20	2.38	2.51		
51.0	4.89	4.53	3.66	2.32	2.43	2.50		
48.0	5.93	5.48	4.95	2.92	2.78	2.65		
55.0	5.98	5.47	5.06	3.64	3.95	3.84		
49.5	5.29	4.69	4.22	2.23	2.24	2.20		
63.0	5.80	5.63	4.98	3.52	3.63	3.59		
53.0	5.46	5.14	4.49	3.37	3.18	3.09		
54.5	5.61	5.11	4.52	3.19	3.16	3.09		
51.0	5.93	5.14	4.44	3.33	3.32	3.28		
49.0	5.24	4.77	4.04	3.45	3.34	3.01		
51.0	5.32	5.05	4.59	4.03	4.11	4.07		
64.5	7.34	6.47	5.34	4.33	4.71	5.00		
51.0	5.19	4.39	3.83	4.70	4.43	4.12		
53.2	5.63	5.16	4.53	3.40	3.42	3.32		
4.8	0.68	0.68	0.63	0.75	0.73	0.70		

Thigh Circ. (cm)	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60	FF Limb
51.0	6.43	6.04	5.52	3.88	3.92	3.83	
53.5	4.72	4.07	3.47	3.13	3.29	3.47	
51.5	5.98	5.72	5.28	4.33	3.88	3.89	
53.5	6.74	6.46	5.70	3.48	3.53	3.45	
52.5	5.71	5.52	5.37	4.62	4.45	4.17	
50.0	5.19	4.63	3.56	3.24	3.09	2.98	
61.5	5.79	5.52	4.96	2.07	2.43	2.63	
52.5	5.21	4.94	4.22	2.36	2.68	2.74	
48.0	5.21	4.70	4.10	3.72	3.62	3.28	
56.0	6.42	5.99	5.66	3.93	3.94	3.84	
51.5	5.49	5.06	4.73	2.75	2.77	2.67	
64.5	5.72	5.41	4.92	3.29	3.38	3.34	
54.0	5.80	5.18	4.40	4.19	3.97	3.83	
56.0	6.24	5.53	4.70	3.43	3.35	3.27	
47.0	5.17	4.65	4.07	3.30	3.04	2.92	
50.0	5.98	5.06	4.69	4.19	4.21	4.00	
62.0	7.53	6.90	6.21	4.70	4.96	4.92	
53.0	6.33	5.80	5.19	4.45	4.33	4.09	
53.8	5.87	5.40	4.82	3.61	3.60	3.52	
4.7	0.68	0.70	0.75	0.75	0.67	0.61	

Thigh Circ. (cm)	AT_40	AT_50	AT_60	LT_40	LT_50	LT_60
49.5	6.30	5.61	4.94	3.38	3.47	3.39
52.5	4.63	4.24	3.88	2.72	3.10	3.31
52.5	6.29	6.05	5.58	4.62	4.42	3.94
54.5	6.71	6.59	6.05	3.72	3.64	3.58
52.5	4.62	4.27	3.85	4.33	3.91	3.71
50.5	4.72	4.09	3.52	3.07	3.00	2.81
62.0	5.82	5.37	5.01	2.38	2.15	2.27
52.0	5.39	4.84	4.35	2.08	2.37	2.49
48.0	5.43	5.03	4.37	2.84	2.74	2.63
53.5	5.78	5.37	4.71	3.59	3.98	3.91
50.5	5.39	4.90	4.58	2.47	2.48	2.47
65.5	5.89	5.73	5.32	3.43	3.60	3.46
54.5	6.18	5.59	5.04	3.71	3.45	3.33
57.5	6.00	5.75	5.33	3.45	3.49	3.40
48.5	5.62	5.21	4.56	3.42	3.32	3.03
50.0	5.57	5.24	4.38	4.17	4.10	3.97
63.0	7.66	6.63	5.55	4.25	4.69	4.64
54.0	6.24	5.93	5.41	4.83	4.68	4.42
53.9	5.79	5.36	4.80	3.47	3.48	3.38
5.0	0.75	0.73	0.68	0.78	0.75	0.67

ID	Wk1_P (mmHg)	Week2-6_P (mmHg)	BFR Limb	Pre_1RM (kgs)	Week1-3_Load (kgs)	Mid_1RM (kgs)	Week4-6_Load (kgs)
1	150	240		42.0	12.5	39.7	12.5
2	150	240		14.7	4.5	14.7	4.5
3	150	240		32.9	10.2	36.3	11.3
4	150	240		36.3	11.3	31.8	9.1
5	150	240		26.1	7.9	30.6	9.1
6							
7	150	240		17.0	5.7	18.1	5.7
8	150	240		22.7	6.8	23.8	6.8
9	150	240		14.7	4.5	21.5	6.8
10	150	240		31.8	9.1	29.5	9.1
11	150	240		39.7	12.5	40.8	12.5
12	150	240		17.0	5.7	19.3	5.7
13	150	240		22.7	6.8	26.1	7.9
14	150	240		28.3	9.1	37.4	11.3
15	150	240		23.8	6.8	26.1	7.9
16							
17	150	240		20.4	5.7		
18	120	180		30.6	9.1	29.5	9.1
19							
20	150	240		37.4	11.3	39.7	12.5
21	150	240		40.8	12.5	42.0	12.5
22	150	240		34.0	10.2	35.2	10.2

Session 1	Set 1	Set 2	Session 2	Set 1	Set 2	Session 3	Set 1	Set 2
	35	23		48	18		55	18
	31	19		26	10		26	15
	21	11		26	12		25	11
	27	15		26	16		27	10
	34	0		28	7		30	12
	20	9		22	11		21	9
	22	13		20	13		23	12
	26	10		31	15		33	12
	27	12		31	16		30	21
	23	11		27	14		31	8
	23	9		22	8		23	10
	30	16		27	17		25	13
	23	13		25	15		29	16
	34	21		31	17		33	13
	21	7		24	13		26	14
	16	10		17	21		19	11
	48	26		43	21		49	24
	27	11		20	13		25	15
	30	12		30	11		34	13

Session 4	Set 1	Set 2	Session 5	Set 1	Set 2	Session 6	Set 1	Set 2
	51	22		57	17		49	18
	25	12		26	6		26	6
	27	10		30	17		26	10
	32	12		33	17		33	17
	24	8		30	16		28	18
	25	10		24	7		26	7
	22	12		21	13		22	12
	37	15		33	12		39	14
	28	15		38	13		36	18
	25	15		27	11		28	12
	22	9		27	10		25	9
	30	12		30	14		26	15
	32	23		31	19		31	16
	27	10		41	17		33	16
	21	8		20	10		22	7
	19	11		19	12		19	9
	41	17		37	22		43	14
	22	10		20	10		25	11
	29	11		35	13		35	14

Session 7	Set 1	Set 2	Set 3	Session 8	Set 1	Set 2	Set 3	Session 9
	39	9	8		46	16	15	
	29	20	13		29	12	12	
	27	11	6		32	15	12	
	38	14	13		21	15	8	
	32	21	9		28	14	14	
	21	7	4		23	7	6	
	22	10	10		21	10	10	
	34	10	6		39	9	6	
	26	9	10		33	12	13	
	28	12	10		33	9	6	
	27	8	4		27	8	7	
	26	17	13		25	11	13	
	32	16	12		30	16	13	
	35	15	0		36	18	12	
	23	19	10		23	13	14	
	41	22	18		39	14	0	
	24	12	9		22	9	0	
	34	13	10		37	15	10	

Set 1	Set 2	1-9 Tot Reps	1-9 Tot Vol.	Session 10	Set 1	Set 2	Set 3	Session 11
50	18	612	7634.0		42	17	18	
34	24	401	1818.9		31	19	17	
32	15	376	3837.4		31	15	13	
29	15	418	4740.1		33	14	11	
31	14	398	3159.3		24	11	8	
28	12	299	1695.3		23	6	6	
21	10	319	2170.5		19	9	10	
37	15	433	1964.1		23	8	5	
35	22	445	4037.0		36	14	17	
27	12	369	4602.9		34	10	9	
29	10	317	1797.4		28	10	7	
27	11	398	2708.0		20	11	10	
31	16	439	3982.6		24	11	9	
49	19	477	3245.5		39	13	10	
		193	1094.3					
22	16	323	2930.2		26	10	9	
41	17	577	6543.1		40	20	16	
23	10	318	3964.9		22	9	0	
31	14	431	4398.8		36	14	9	

Set 1	Set 2	Set 3	Session 12	Set 1	Set 2	Set 3	Session 13	Set 1
45	18	18		42	16	15		48
31	7	4		33	20	12		31
30	12	13		29	7	5		25
34	14	11		31	16	13		31
28	14	6		25	15	6		30
26	9	4		22	10	8		25
19	11	11		20	13	11		20
28	8	9		28	10	11		29
29	18	13		26	12	15		32
38	12	9		36	14	10		29
27	8	5		29	8	5		29
22	12	11		25	11	11		29
28	16	12		24	12	11		26
41	17	0		49	15	11		39
26	14	11		24	10	13		25
44	19	17		40	15	15		39
25	12	6		23	12	6		28
37	15	12		38	13	12		33

Set 2	Set 3	Set 4	Session 14	Set 1	Set 2	Set 3	Set 4	Session 15
17	12	16		44	17	19	18	
15	11	11		31	18	15	13	
18	13	13		29	14	12	13	
15	10	8		33	18	11	12	
20	12	7		25	16	10	7	
10	5	5		25	11	7	9	
10	10	9		20	9	11	11	
10	10	9		27	12	12	9	
22	13	14		26	14	13	11	
12	9	0		36	11	9	8	
8	6	6		24	8	5	5	
12	9	10		27	10	10	6	
15	11	10		22	12	9	8	
11	12	15		39	16	13	0	
16	12	12		24	13	12	11	
18	17	13		36	16	15	14	
13	11	6		22	11	3	0	
15	11	10		34	16	11	10	

Set 1	Set 2	Set 3	Set 4	Session 16	Set 1	Set 2	Set 3	Set 4
38	17	18	13		42	18	17	18
33	16	14	10		41	21	15	18
33	13	12	12		35	9	10	10
35	18	14	13		47	19	14	16
29	17	10	7		30	17	4	4
23	11	7	3		25	12	8	6
20	12	11	9		22	12	11	11
26	10	6	10		26	10	7	11
35	13	12	16		31	13	13	10
36	14	9	11		37	12	10	10
27	10	7	5		28	9	7	6
34	15	14	13		29	13	12	15
25	10	9	8		25	11	8	8
43	16	16	10		44	16	12	11
33	16	13	13		26	11	13	12
38	17	15	15		32	16	14	12
21	6	0	0		21	13	13	10
37	14	11	11		39	13	11	10

Session 17	Set 1	Set 2	Set 3	Set 4	Session 18	Set 1	Set 2	Set 3
	44	19	19	13		42	20	14
	40	23	16	15		30	17	13
	35	17	13	12		32	15	8
	37	18	14	15		39	15	17
	29	17	19	0		30	13	0
	25	12	10	8		22	11	7
	22	14	11	11		21	9	15
	31	12	8	7		30	11	12
	40	10	13	10		35	25	15
	40	13	13	10		40	14	12
	28	9	7	5		27	8	5
	32	15	15	14		26	11	6
	26	12	10	10		27	15	12
	48	15	11	11		53	16	11
	33	14	12	11		28	14	15
	42	15	14	13		35	18	15
	22	14	10	11		23	15	10
	41	14	10	11		41	14	11

Set 4	10-18 Tot reps	10-18 Tot Vol.	1-18 Tot Vol.	FF Limb	Pre_1RM (kgs)	Week1-3_Load (kgs)
15	789	9841.9	17476.0		39.7	12.5
10	651	2952.9	4771.8		14.7	4.5
8	566	6418.4	10255.8		39.7	12.5
11	657	5960.3	10700.4		38.6	11.3
0	490	4445.3	7604.6		24.9	7.7
6	407	2307.7	4003.0		14.7	4.5
12	446	3034.6	5205.0		22.7	6.8
14	479	3259.1	5223.2		14.7	4.5
11	627	5688.1	9725.1		34.0	10.2
11	578	7209.9	11812.7		39.7	12.5
5	411	2330.4	4127.7		17.0	5.7
12	522	4143.6	6851.6		22.7	6.8
12	488	5533.9	9516.5		30.6	9.1
13	686	5445.4	8690.9		30.6	9.1
	0	0.0	1094.3		24.9	7.9
13	545	4944.2	7874.4		32.9	10.2
14	719	8968.7	15511.9		35.2	10.2
11	409	5101.8	9066.7		42.0	12.5
11	625	6378.7	10777.5		32.9	10.2

Mid_1RM (kgs)	Week4-6_Load (kgs)	Session 1	Set 1	Set 2	Session 2	Set 1	Set 2	Session 3
39.7	12.5		58	27		72	27	
15.9	4.5		35	19		32	18	
42.0	12.5		25	18		25	15	
36.3	11.3		64	28		69	46	
28.3	9.1		52	37		52	50	
18.1	5.7		25	19		26	17	
23.8	6.8		26	16		20	14	
22.7	6.8		23	23		31	17	
30.6	9.1		31	15		32	17	
36.3	11.3		26	14		24	14	
18.1	5.7		22	13		23	13	
28.3	9.1		47	24		36	17	
35.2	10.2		41	22		35	28	
32.9	10.2		50	19		16	23	
			20	18		22	13	
30.6	9.1		15	12		16	11	
39.7	12.5		72	46		58	53	
42.0	12.5		25	12		25	13	
35.2	10.2		30	17		40	13	

Set 1	Set 2	Session 4	Set 1	Set 2	Session 5	Set 1	Set 2	Session 6
71	29		100	27		85	26	
26	24		36	19		37	17	
27	16		29	18		33	15	
69	44		76	27		72	54	
49	34		49	34		53	42	
31	25		33	26		33	24	
24	15		23	12		22	12	
41	20		50	18		52	16	
38	25		33	20		30	26	
27	11		30	11		28	14	
26	12		24	12		28	13	
35	15		31	24		39	28	
43	23		50	30		52	26	
33	31		44	27		52	21	
24	16		27	15		21	16	
22	17		23	13		26	18	
71	26		93	52		72	30	
27	17		32	20		21	15	
50	18		38	16		45	16	

Set 1	Set 2	Session 7	Set 1	Set 2	Set 3	Session 8	Set 1	Set 2
72	48		71	31	26		100	28
37	26		40	20	17		45	25
27	16		32	16	12		34	14
80	41		90	39	28		89	41
60	50		73	58	62		76	42
43	19		43	19	17		44	21
25	16		24	11	13		23	13
59	18		59	17	20		61	17
36	26		47	33	20		43	24
34	10		29	13	9		30	11
26	13		30	11	10		30	11
40	20		38	23	21		40	19
49	25		52	24	19		38	24
54	21		52	17	13		50	18
25	14		21	20	14		26	28
73	42		82	22	23		88	20
44	15		27	17	13		30	15
36	21		39	16	12		41	19

Set 3	Session 9	Set 1	Set 2	1-9 Tot Reps	1-9 Tot Vol.	Session 10	Set 1	Set 2
30		119	31	1078	13446.9		70	27
20		47	23	563	2553.8		37	25
13		33	16	434	5413.7		32	16
24		94	49	1124	12746.1		107	69
41		75	47	1036	7988.8		49	37
20		49	27	561	2544.7		37	22
13		19	14	355	2415.4		23	12
17		53	27	639	2898.5		30	14
20		40	21	577	5888.8		45	33
11		29	11	386	4814.9		36	13
10		30	11	368	2086.5		31	14
20		33	21	571	3885.1		27	11
18		41	30	670	6078.2		28	19
13		49	22	625	5670.0		48	19
				192	1524.1			
12		25	14	372	3796.6		31	22
40		63	32	1058	10797.9		58	15
15		28	17	428	5338.8		37	16
14		48	19	548	5592.9		44	21

Set 3	Session 11	Set 1	Set 2	Set 3	Session 12	Set 1	Set 2	Set 3
24		61	27	22		64	27	25
24		35	26	16		43	27	15
18		36	16	17		38	18	14
29		48	31	26		59	32	19
29		56	41	31		57	36	31
15		41	20	17		35	21	13
14		18	15	11		23	14	14
11		34	13	13		37	14	13
25		57	25	20		38	24	20
12		41	14	13		43	16	13
10		32	12	9		32	13	10
15		28	14	15		30	14	15
16		32	21	16		33	18	18
15		52	20	17		53	19	17
15		30	19	15		41	22	20
32		60	21	24		66	32	22
17		27	14	15		28	18	16
14		45	18	14		47	21	12

Session 13	Set 1	Set 2	Set 3	Set 4	Session 14	Set 1	Set 2	Set 3
	63	31	20	25		67	28	22
	39	18	20	14		41	20	14
	35	16	16	16		36	18	17
	50	32	21	26		46	25	27
	48	33	34	29		52	37	37
	36	15	15	15		50	22	16
	20	13	12	12		21	13	13
	39	14	14	15		40	13	14
	28	27	20	23		39	21	12
	41	14	12	11		44	14	13
	34	12	10	9		29	10	9
	34	14	14	12		30	21	16
	30	21	19	16		33	22	17
	40	22	18	16		53	24	16
	36	20	14	12		31	25	14
	56	23	25	20		61	29	24
	36	17	14	14		28	17	15
	46	17	14	14		48	17	13

Set 4	Session 15	Set 1	Set 2	Set 3	Set 4	Session 16	Set 1	Set 2
22		61	28	25	24		64	33
17		36	20	18	15		43	22
13		35	20	15	19		44	20
23		58	28	20	32		67	35
28		50	42	35	32		49	43
13		35	20	22	18		42	25
14		22	13	12	13		25	11
15		42	16	15	13		46	19
14		40	30	19	18		41	28
11		41	15	13	12		45	18
9		31	12	9	9		31	10
14		42	19	15	13		34	19
15		34	21	15	12		33	19
15		56	17	17	15		55	25
18		38	20	15	16		43	21
18		50	19	22	18		52	22
14		22	17	16	13		36	24
13		45	20	12	13		51	17

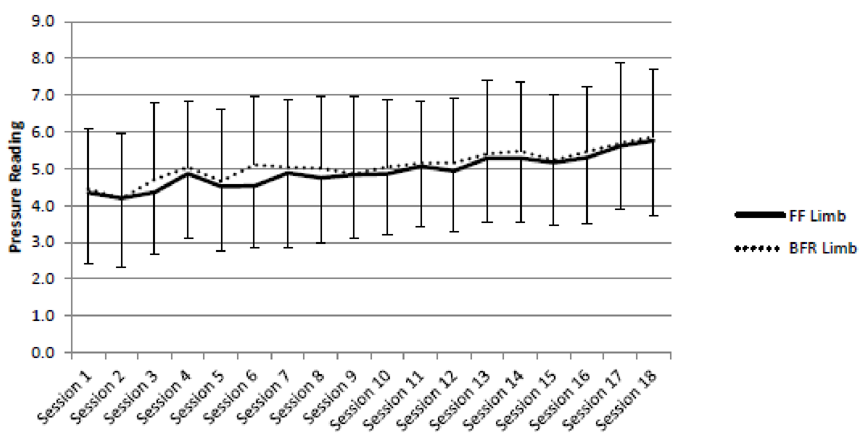
Set 3	Set 4	Session 17	Set 1	Set 2	Set 3	Set 4	Session 18	Set 1
22	21		71	31	32	28		76
15	12		41	24	21	20		37
17	14		44	22	16	17		50
28	24		62	29	28	31		72
34	33		52	45	36	34		55
20	20		42	41	19	15		31
15	14		28	11	12	15		28
16	16		47	18	19	14		44
28	23		32	21	16	17		71
13	10		51	17	13	12		49
10	9		31	11	9	9		30
18	14		27	24	19	14		35
18	16		34	22	17	19		36
17	16		0	0	0	0		63
16	18		35	25	16	17		46
24	14		45	27	17	17		57
16	16		26	15	14	17		36
14	12		48	14	12	12		52

Set 2	Set 3	Set 4	10-18 Tot reps	10-18 Tot Vol.	1-18 Tot Vol.
33	21	30	1225	15280.5	28727.4
21	18	15	809	3669.6	6223.4
24	18	16	763	9517.6	14931.3
37	27	29	1277	14481.0	27227.0
46	38	36	1325	12020.3	20009.1
26	27	19	825	4677.7	7222.4
13	13	12	519	3531.3	5946.7
19	21	23	731	4973.7	7872.2
19	20	25	919	8337.1	14225.9
19	15	13	717	8130.7	12945.6
11	9	9	525	2976.7	5063.3
22	15	15	669	6069.1	9954.2
24	19	18	731	7457.2	13535.4
28	17	17	807	8236.2	13906.2
			0	0.0	1524.1
23	17	17	768	6967.3	10763.9
24	26	16	1036	12923.0	23720.9
20	17	14	662	8257.7	13596.6
15	13	12	780	7960.6	13553.5

ID	BFR Limb	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
1		3.3	3.7	4.7	5.0	3.7	4.9
2		2.6	1.9	1.9	2.7	1.8	2.4
3		7.7	7.9	10.0	10.0	10.0	10.0
4		5.3	4.7	4.8	4.0	5.5	4.4
5		4.8	4.0	4.6	4.1	4.3	4.0
6							
7		3.7	4.2	5.0	6.4	5.0	5.4
8		5.7	3.4	3.3	4.6	3.6	3.8
9		1.1	1.7	2.4	3.3	3.1	3.8
10		5.0	8.1	9.3	6.1	7.6	7.9
11		4.4	4.6	5.3	5.2	5.1	5.4
12		3.4	1.9	3.5	2.2	2.4	2.4
13		5.8	5.2	4.3	5.6	5.6	5.3
14		3.1	3.9	3.7	4.7	3.0	6.0
15		2.8	1.8	1.9	2.7	2.4	2.7
16							
17		4.7	4.9	4.7	6.4	5.5	5.6
18		4.9	5.0	5.3	6.4	5.1	6.3
19							
20		4.3	3.9	4.2	5.5	5.7	4.9
21		7.8	4.4	5.8	5.7	5.2	6.2
22		4.0	4.4	4.8	5.2	4.0	5.6
23							
24							
25							
AVERAGE		4.4	4.2	4.7	5.0	4.7	5.1
		1.6	1.8	2.1	1.8	1.9	1.8

2 Days rest

Session 7	Session 8	Session 9	Session 10	Session 11	Session 12	Session 13	Session 14
4.3	5.0	2.6	4.6	4.9	5.4	4.5	4.8
2.3	2.2	1.8	1.9	2.4	2.4	3.5	2.7
10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
5.2	4.7	5.7	5.1	4.8	4.5	5.0	6.5
5.1	4.8	4.8	4.8	4.1	5.2	4.7	5.1
6.5	6.2	6.3	5.4	4.6	4.7	5.7	5.2
4.6	4.1	3.6	4.2	5.2	3.6	3.1	4.0
2.7	2.4	2.5	3.0	4.3	4.4	4.9	3.7
7.4	7.6	8.3	6.7	7.5	7.0	9.6	8.1
5.9	6.0	6.4	5.9	5.9	6.1	6.0	7.1
3.2	2.3	2.5	2.8	3.4	3.2	2.4	3.5
4.5	6.3	4.0	5.9	5.7	5.3	5.2	4.4
4.5	4.5	5.7	7.0	5.2	6.9	6.6	7.5
2.8	2.9	3.4	3.3	3.2	2.6	3.0	2.9
4.8	5.4	5.3	5.3	5.8	4.6	5.3	5.8
5.6	5.2	4.3	5.4	5.4	5.9	6.7	5.7
5.5	5.1	5.6	4.4	4.9	5.7	5.2	5.4
5.8	5.5	4.6	5.2	5.4	5.4	5.9	6.3
5.0	5.0	4.9	5.1	5.2	5.2	5.4	5.5
1.8	1.9	2.1	1.8	1.7	1.8	2.0	1.9



Session 15	Session 16	Session 17	Session 18	FF Limb	Session 1	Session 2	Session 3
4.4	4.1	4.4	5.4		3.2	4.0	4.6
3.0	3.0	2.0	2.4		2.1	2.4	1.8
10.0	10.0	10.0	10.0		9.7	10.0	10.0
5.1	6.8	8.0	6.0		3.2	4.7	5.0
4.8	5.0	5.1	3.8		5.3	3.8	3.7
5.9	5.9	6.7	6.1		4.0	3.7	4.6
5.3	6.4	5.7	7.3		4.7	3.2	3.7
4.1	4.8	3.8	4.8		1.4	1.3	3.0
7.8	6.9	8.2	8.3		6.5	5.8	6.3
7.3	5.7	8.4	6.5		4.4	5.1	4.8
3.1	2.9	3.4	3.9		3.5	3.0	3.8
4.7	5.1	5.3	5.5		3.8	3.8	3.5
5.9	7.2	7.2	7.7		2.0	4.0	3.1
2.7	3.0	2.3	3.7		2.7	1.4	2.7
					4.9	5.6	4.4
4.6	4.4	4.5	5.1		4.1	3.9	4.1
5.0	4.7	5.5	6.4		5.8	5.0	4.0
6.1	6.9	7.2	7.2		6.9	5.0	5.1
4.3	5.5	4.8	5.5		4.4	4.1	4.7
5.2	5.5	5.7	5.9		4.3	4.2	4.4
1.8	1.8	2.2	1.8		2.0	1.9	1.7

Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session 10	Session 11
5.9	4.5	5.0	4.2	4.0	5.1	4.6	4.3
2.6	1.9	2.5	2.3	2.3	2.6	2.4	2.6
10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
5.0	5.7	4.6	7.3	6.4	5.4	6.1	6.7
4.5	4.7	4.2	5.1	4.5	4.8	4.5	5.9
5.3	4.2	4.7	5.6	4.5	3.8	4.2	4.3
5.0	3.6	4.2	4.4	4.5	5.8	4.3	4.9
3.2	3.0	2.6	2.1	2.7	3.3	4.2	5.6
5.5	6.3	5.1	8.2	6.5	6.6	5.5	6.1
4.9	4.5	5.1	4.9	5.1	5.6	5.0	5.1
3.0	2.7	2.5	3.5	3.7	3.2	3.2	3.6
3.9	4.8	3.8	3.5	3.4	3.7	5.1	3.7
3.6	3.2	3.6	3.8	4.1	5.3	4.4	5.4
2.8	2.8	2.6	3.0	2.7	2.9	3.4	2.8
5.4	5.2	5.4					
4.1	4.5	4.9	4.3	4.7	4.4	3.6	5.0
4.5	5.2	4.2	4.6	5.2	4.4	4.5	4.7
7.2	5.1	4.9	5.1	5.8	4.4	5.5	4.7
6.1	3.9	6.1	6.0	5.4	5.8	7.0	5.8
4.9	4.5	4.5	4.9	4.8	4.8	4.9	5.1
1.7	1.7	1.7	2.0	1.8	1.7	1.7	1.7

Session 12	Session 13	Session 14	Session 15	Session 16	Session 17	Session 18
6.0	4.9	4.9	4.2	4.5	4.8	5.9
2.2	4.2	2.9	3.0	3.3	3.4	3.0
10.0	10.0	10.0	10.0	10.0	8.7	10.0
5.5	6.6	7.7	5.8	7.1	8.0	7.6
6.1	5.4	6.4	5.8	4.9	5.0	5.6
3.8	4.5	4.0	4.5	5.6	4.0	4.3
4.5	3.6	5.6	5.6	6.4	7.5	10.0
3.7	4.8	4.3	3.2	4.4	4.8	4.6
4.9	7.2	5.8	6.2	7.0	7.4	7.3
5.9	5.5	6.7	6.5	6.9	7.3	6.6
4.1	3.0	3.6	3.6	3.3	3.5	4.3
4.4	4.6	3.5	4.1	4.2	4.6	4.1
4.5	6.3	5.5	5.8	4.2	7.4	4.5
2.9	2.5	3.0	2.7	3.2	3.7	3.6
4.3	5.1	4.9	5.3	3.9	4.4	3.8
5.4	4.6	6.1	4.6	4.9	4.8	6.3
5.1	7.0	5.2	6.0	7.0	6.3	7.1
5.6	5.4	5.1	6.1	4.6	5.5	5.2
4.9	5.3	5.3	5.2	5.3	5.6	5.8
1.7	1.7	1.8	1.7	1.8	1.7	2.0

ID	Pre	BFR Limb	AT_50	LT_50	FF Limb	AT_50	LT_50	Post
1			5.84	3.4		5.97	3.32	
2			4.15	3.47		4.45	3.29	
3			5.67	3.94		5.31	4.19	
4			5.98	3.71		6.26	4.08	
5			5.42	4.62		4.48	3.95	
6								
7			4.95	3.18		4.73	2.94	
8			6.04	2.49		5.74	2.15	
9			4.83	2.7		4.75	2.47	
10			4.61	3.47		4.94	2.81	
11			5.99	4		5.72	3.87	
12			4.73	2.53		4.7	2.29	
13			5.45	3.49		5.55	3.55	
14			5.27	4.18		5.6	3.42	
15			5.82	3.33		5.73	3.45	
16								
17								
18			4.88	3.26		4.93	3.29	
19								
20			5.09	4.09		5.75	4.05	
21			6.88	5.03		7.08	4.78	
22			5.63	4.26		5.31	4.27	
			5.40	3.62		5.39	3.45	

BFR Limb	AT_50	LT_50	FF Limb	AT_50	LT_50	BFR Volume (Total Reps)
	6.08	3.69		6.39	3.69	77
	4.65	3.53		4.58	3.42	53
	5.91	4.73		6.14	4.95	59
	6.49	3.87		6.95	4.39	44
	5.62	4.59		5.34	4.06	56
	4.95	3.36		5.1	3.37	36
	6.09	2.53		5.73	2.57	41
	5.07	2.86		5.12	2.68	54
	5.06	3.65		5.06	2.99	67
	6.26	4.14		6.04	4.04	48
	5.35	2.85		4.94	2.63	42
	5.66	3.65		5.78	3.92	49
	6.06	4.15		6.09	3.68	59
	6.06	3.47		6.65	3.85	66
	4.98	3.35		5.13	3.44	50
	5.69	4.42		5.85	4.18	53
	7.22	5.14		7.77	4.85	31
	6.01	4.44		5.92	4.49	62
	5.73	3.80		5.81	3.73	53

FF Volume (Total Reps)	BFR	Δ AT	Δ LT	FF	Δ AT	Δ LT
158		0.24	0.29		0.42	0.37
90		0.5	0.06		0.13	0.13
61		0.24	0.79		0.83	0.76
154		0.51	0.16		0.69	0.31
159		0.2	-0.03		0.86	0.11
		0	0		0	0
85		0	0.18		0.37	0.43
49		0.05	0.04		-0.01	0.42
95		0.24	0.16		0.37	0.21
103		0.45	0.18		0.12	0.18
52		0.27	0.14		0.32	0.17
51		0.62	0.32		0.24	0.34
79		0.21	0.16		0.23	0.37
80		0.79	-0.03		0.49	0.26
81		0.24	0.14		0.92	0.4
		0	0		0	0
		0	0		0	0
66		0.1	0.09		0.2	0.15
		0	0		0	0
148		0.6	0.33		0.1	0.13
60		0.34	0.11		0.69	0.07
74		0.38	0.18		0.61	0.22
91		0.27	0.15		0.34	0.23

ID	BFR Limb	Concentric	S1_first_RMS	S1_last_RMS	S1_first_MPF	S1_last_MPF	S2_first_RMS
1			32.78	69.17	85.25	65.68	55.16
2			57.57	112.80	110.08	78.00	85.02
3			52.98	63.84	93.86	80.22	63.30
4			39.48	64.14	110.46	97.92	55.64
5			24.29	49.84	94.51	97.37	26.64
6			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
7			71.46	105.08	99.11	100.84	85.12
8			63.07	100.91	100.97	84.60	75.25
9			45.45	78.66	108.77	86.84	57.41
10			40.02	72.34	96.39	96.03	59.33
11			21.96	51.09	120.45	105.91	44.46
12			34.20	77.94	107.19	89.04	62.93
13			58.10	80.49	95.11	88.70	53.91
14			42.46	53.75	96.05	85.50	49.39
15			27.28	64.83	82.95	84.56	43.60
16			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
17			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
18			24.55	64.67	105.73	84.15	31.98
19			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
20			47.29	79.59	102.15	91.66	61.81
21			34.80	56.83	116.80	118.45	36.71
22			27.79	53.58	114.06	97.38	36.25
23							
24							
25							
AVG			41.42	72.20	102.22	90.72	54.66
SD							

S2_last_RMS	S2_first_MPF	S2_last_MPF	S3_first_RMS	S3_last_RMS	S3_first_MPF	S3_last_MPF
70.54	85.15	82.64	60.36	65.77	77.75	84.88
118.87	98.96	77.82	85.99	107.96	91.74	84.08
71.76	91.94	86.93	67.60	73.26	89.59	90.25
71.10	115.17	104.41	66.36	66.34	120.10	108.00
41.70	91.99	98.92	32.13	38.85	96.52	93.57
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
107.63	108.38	97.90	94.15	95.36	102.84	106.10
98.45	93.91	92.50	73.98	97.39	87.76	93.09
78.18	99.85	90.97	54.77	69.03	99.26	103.48
75.70	94.80	97.41	65.49	81.56	89.17	99.96
64.53	103.95	99.27	50.70	60.60	111.15	109.75
79.75	91.55	81.83	85.91	91.37	99.13	90.66
107.12	92.07	80.64	58.51	92.98	94.72	85.30
59.27	90.53	88.63	56.52	53.59	87.82	93.40
68.29	86.46	82.71	0.00	0.00	0.00	0.00
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
74.79	89.96	93.97	52.65	67.32	100.76	104.90
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
101.89	89.55	90.92	100.69	105.87	99.89	92.96
59.90	109.78	122.27	39.42	54.66	110.45	126.79
72.58	96.83	102.34	41.98	60.20	92.86	108.04
79.00	96.16	92.89	63.95	75.42	97.15	98.54

Eccentric	S1_first_RMS	S1_last_RMS	S1_first_MPF	S1_last_MPF	S2_first_RMS	S2_last_RMS
	26.08	33.62	113.57	84.46	21.60	30.67
	33.60	44.29	127.24	95.77	28.72	41.91
	13.58	27.27	93.57	88.33	14.83	26.18
	13.65	18.04	109.12	94.33	12.02	16.24
	13.45	33.96	101.84	88.84	8.52	32.84
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	27.81	43.09	112.68	104.90	34.89	51.27
	35.24	44.28	113.97	91.80	30.06	50.05
	15.34	27.09	114.01	93.17	15.05	18.49
	15.67	28.76	99.02	108.99	15.95	32.01
	14.49	25.39	114.73	106.37	13.99	25.21
	18.79	27.27	105.91	91.84	22.11	28.32
	19.07	29.06	103.87	98.19	21.42	41.77
	27.54	28.50	100.64	102.01	22.94	32.95
	13.60	40.40	91.01	93.32	15.27	47.23
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	20.47	31.21	118.13	94.10	19.28	39.04
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	28.35	32.06	88.71	92.45	25.40	36.27
	11.00	18.28	115.23	106.87	10.39	20.22
	18.84	23.81	109.36	95.70	16.07	19.16
	20.36	30.91	107.37	96.19	19.36	32.77

S2_first_MPF	S2_last_MPF	S3_first_RMS	S3_last_RMS	S3_first_MPF	S3_last_MPF	FF Limb
88.90	83.68	26.53	31.91	83.70	86.50	
111.89	91.74	37.23	53.21	101.58	96.02	
85.66	85.83	16.48	23.16	82.97	87.40	
101.73	98.14	20.96	30.76	97.02	100.60	
108.71	97.56	14.43	20.79	99.64	93.92	
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
114.41	120.44	33.26	35.93	112.50	115.57	
102.29	103.36	35.01	58.22	99.08	99.87	
102.02	99.92	17.22	22.63	107.70	109.89	
99.08	108.99	27.36	33.81	102.60	101.89	
110.07	97.65	16.35	22.81	110.70	110.24	
103.35	101.75	28.07	37.98	104.63	99.17	
105.58	100.40	25.12	55.49	103.68	100.41	
100.43	86.60	23.12	45.90	93.42	88.76	
93.57	95.98	0.00	0.00	0.00	0.00	
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
123.70	104.60	20.70	34.73	115.79	99.80	
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
82.29	88.30	36.52	35.93	86.97	97.68	
112.95	113.87	11.53	19.39	103.98	112.90	
99.35	101.07	17.96	18.65	100.91	99.39	
102.55	98.88	23.99	34.19	100.40	100.00	

Concentric	S1_first_RMS	S1_mid_RMS	S1_last_RMS	S1_first_MPF	S1_mid_MPF	S1_last_MPF
	45.22	69.47	105.91	108.40	92.43	92.61
	53.61	89.42	112.36	106.51	80.51	73.50
	63.24	67.20	81.37	131.28	94.72	96.01
	35.11	50.19	63.28	103.47	99.29	98.45
	61.50	52.04	58.02	94.05	87.28	89.17
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	54.78	73.71	97.76	130.86	121.97	103.29
	56.96	64.37	71.40	97.41	81.36	76.79
	53.15	84.37	94.09	115.30	92.77	84.79
	30.40	56.92	67.15	125.42	114.64	110.66
	40.61	91.85	91.85	111.09	92.64	92.64
	50.86	106.58	124.80	102.64	94.12	93.67
	69.88	105.47	119.58	119.41	99.44	89.50
	44.48	49.29	64.01	114.45	101.65	101.81
	34.57	54.11	82.53	138.42	121.69	112.90
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	31.67	54.99	54.99	121.39	87.91	87.91
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	65.27	75.97	89.23	96.87	87.28	88.47
	27.49	45.68	54.98	109.53	102.77	100.22
	41.11	55.21	69.76	112.88	102.37	103.26
	47.77		83.50	113.30		94.20

S2_first_RMS	S2_mid_RMS	S2_last_RMS	S2_first_MPF	S2_mid_MPF	S2_last_MPF	S3_first_RMS
86.80	77.05	115.76	101.25	96.21	98.63	87.03
71.35	109.43	109.43	92.34	75.37	75.37	71.20
63.38	76.15	89.96	106.88	112.09	107.74	80.82
49.31	49.16	63.01	105.09	110.91	108.34	51.70
56.07	53.43	49.10	89.39	90.76	93.72	60.32
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
66.90	74.98	106.45	115.44	109.40	101.19	71.51
58.97	66.47	77.66	88.14	81.99	84.19	63.02
73.08	86.94	96.55	108.76	102.73	88.38	74.21
51.91	41.88	67.63	127.11	122.15	123.60	52.65
66.36	92.62	92.62	87.96	87.99	87.99	81.51
92.86	124.58	133.21	97.03	100.43	88.01	105.19
74.64	105.57	103.19	104.35	97.48	93.90	76.45
52.50	66.63	75.60	100.82	105.66	101.68	68.53
48.66	71.89	75.00	116.33	122.47	131.96	61.84
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
34.19	71.82	79.47	106.00	88.36	82.71	40.58
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
70.43	76.09	76.09	76.88	92.37	92.37	66.92
31.86	48.09	55.49	103.97	104.79	107.42	39.51
46.79	63.31	66.96	95.79	97.90	98.79	50.78
60.89		85.18	101.31		98.11	66.88

S3_mid_RMS	S3_last_RMS	S3_first_MPF	S3_mid_MPF	S3_last_MPF	Eccentric	S1_first_RMS
97.18	120.16	106.04	112.13	98.63		27.25
88.73	100.97	88.13	91.78	79.83		24.04
70.10	89.75	107.11	109.81	112.06		16.80
47.72	58.28	106.86	119.13	107.31		15.84
54.04	58.54	88.36	91.99	93.02		36.86
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!
84.37	127.04	112.02	110.26	105.13		25.32
75.11	85.69	95.51	90.56	91.97		21.71
75.73	101.84	103.36	103.42	82.56		19.43
53.88	58.15	126.57	117.61	122.28		12.39
100.31	100.31	90.77	88.86	88.86		23.94
86.57	122.96	96.85	94.54	101.05		31.18
106.17	125.40	111.93	99.29	97.61		38.38
63.91	73.72	101.17	109.36	107.02		27.23
0.00	75.26	116.95	0.00	122.74		11.71
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!
60.68	72.14	99.42	93.42	92.12		21.96
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!
63.55	71.31	85.66	99.23	96.99		27.84
51.02	63.08	110.62	112.12	112.41		13.90
49.02	62.82	95.09	102.41	105.60		15.78
	87.08	102.36		100.95		22.86

S1_mid_RMS	S1_last_RMS	S1_first_MPF	S1_mid_MPF	S1_last_MPF	S2_first_RMS	S2_mid_RMS
25.00	46.68	115.40	93.57	89.12	27.64	21.11
24.24	33.75	115.76	83.52	88.27	25.24	44.81
25.50	25.71	115.76	100.22	106.25	12.82	22.52
17.67	18.61	98.89	96.31	103.25	12.82	14.39
39.02	49.29	93.25	93.22	95.17	35.00	40.05
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
26.75	35.58	165.26	126.94	133.47	23.31	21.31
24.60	27.55	96.70	86.40	90.70	15.02	28.73
25.91	30.50	119.08	98.49	83.00	19.20	27.24
17.47	28.04	125.55	121.55	120.11	12.62	12.57
36.48	36.48	130.90	94.21	94.21	25.06	44.02
34.06	34.27	103.65	96.49	97.92	32.91	37.26
44.51	53.61	144.44	116.06	123.39	39.54	57.92
29.54	29.65	108.76	98.92	91.28	25.36	30.11
23.32	45.29	145.08	124.15	129.40	15.12	38.62
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
28.91	28.91	124.88	89.68	89.68	20.21	35.34
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
23.35	27.60	97.59	88.12	87.55	21.50	32.58
19.01	20.89	112.01	101.35	100.56	11.79	18.76
14.18	20.25	106.96	86.95	100.14	13.34	16.59
	32.93	117.77		101.30	21.58	

S2_last_RMS	S2_first_MPF	S2_mid_MFP	S2_last_MPF	S3_first_RMS	S3_mid_RMS	S3_last_RMS
57.43	97.45	96.08	98.08	36.35	32.25	67.31
44.81	99.73	84.99	84.99	28.98	35.41	45.32
26.56	106.00	99.76	110.99	16.08	19.92	32.54
17.14	101.55	99.16	106.42	14.53	14.73	22.74
46.72	94.59	91.88	95.44	35.31	36.71	52.85
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
46.43	147.85	130.01	132.43	23.95	27.90	55.02
34.19	95.54	82.24	88.14	22.23	37.56	44.38
27.93	109.12	95.65	96.32	23.49	25.20	47.54
34.46	119.38	127.36	129.26	19.12	20.17	38.66
44.02	116.18	88.84	88.84	26.74	45.26	45.26
46.18	101.77	94.27	102.84	36.73	37.02	53.11
48.35	135.07	120.24	119.16	39.26	60.15	71.30
35.97	102.48	99.40	99.96	29.43	28.93	44.53
43.27	132.32	127.14	122.49	18.26	0.00	50.29
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
37.76	124.18	89.48	90.78	23.70	33.60	48.19
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
32.58	77.36	87.22	87.22	25.12	34.94	40.21
23.40	109.89	102.93	106.92	13.85	19.83	33.31
13.02	96.18	101.11	89.90	15.67	20.66	14.84
36.68	109.26		102.79	24.93		44.86

S3_first_MPF	S3_mid_MPF	S3_last_MPF
95.50	101.32	101.99
87.10	87.30	84.69
99.50	108.24	113.74
99.78	105.14	104.35
93.36	91.49	94.36
#DIV/0!	#DIV/0!	#DIV/0!
135.67	134.59	117.03
96.73	97.41	97.82
101.98	101.95	80.44
132.32	132.47	132.01
103.81	94.93	94.93
97.70	89.10	97.38
132.65	111.87	117.01
103.32	105.52	105.21
119.29	0.00	147.59
#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!
112.03	103.14	88.01
#DIV/0!	#DIV/0!	#DIV/0!
82.17	91.73	97.92
103.68	106.05	106.38
95.19	107.35	96.20
105.10		104.28