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PHYSIOLOGICAL RESPONSES TO A SINGLE BOUT OF RESISTANCE EXERCISE: PRACTICAL VS CONTROLLED BLOOD FLOW RESTRICTION

A THESIS APPROVED FOR THE
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BY

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"Face your fears, and live your dreams."

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Abstract

Blood flow restriction (BFR) exercise has been used to induce increases in muscle size and strength at relatively low exercise intensities. The technique requires the application of a restriction device to reduce blood flow to the exercising limb, which causes unique physiological responses. The technique can be done using an inflatable cuff or knee wraps. However, people are more likely to use the knee wraps compared to the inflatable cuffs on daily basis. **PURPOSE:** The aim of this study was to compare the effects of a single bout of practical blood flow restriction, controlled blood flow restriction, high intensity, and low-intensity with no blood flow restriction resistance exercise on muscle activation, muscle swelling, and lactate responses in college-aged females. Most studies have examined metabolic responses to BFR separately, and to our knowledge, no one has examined the issue of limb symmetry following controlled and practical implementation of blood flow restriction. **METHODS:** Fifteen recreationally active females (20.3 ± 1.6 years old) were recruited for this research. The participants performed 4 different exercising protocols in a random order: 1) low intensity with controlled blood flow restriction (cBFR): pressure set at 50% of total occlusion pressure, intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 2) Practical blood flow restriction exercise (pBFR): pressure set at 7 based on a perceived pressure scale of 0 (no pressure, no pain) to 10 (extreme pressure with pain), intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 3) High intensity (HI): intensity set at 80% of 1RM, with 3 sets of 10 repetitions, without any blood flow restriction; 4) Control (CON): intensity set at 30% of 1RM, 4 sets of 30-15-15-15 repetitions, without any blood flow restriction. Subjects had muscle thickness, thigh circumference, muscle activation

(Electromyography [EMG]), blood lactate, and hematocrit assessed at rest, immediately post-exercise, and 5 and 15 min post-exercise. Strength was assessed using one maximum repetition (1RM) test for leg-press and knee extension. **RESULTS:** Muscle swelling significantly increased from pre-exercise measures to 15 post for all conditions, as represented by thigh circumference ($p \leq 0.05$) and muscle thickness ($p \leq 0.05$). Hematocrit decreased from pre-exercise to 15P ($p \leq 0.05$) and percent of plasma volume changes (%PVC) increased from IP to 15P ($p \leq 0.05$). No differences between conditions were reported among the variables associated to muscle swelling ($p \geq 0.05$). Lactate increased over time for all testing conditions ($p \leq 0.05$), with HI having higher levels than cBFR, and cBFR being higher than pBFR and LI ($p \leq 0.05$). Muscle activation also significantly changed across time for all conditions with both exercises ($p \leq 0.05$), where HI showed greater muscle activation than cBFR, and cBFR greater than pBFR and LI ($p \leq 0.05$). **CONCLUSION:** Muscle swelling seems to increase overtime to a similar extent for HI, cBFR, pBFR, and LI. Increases in thigh circumference and muscle thickness were highly correlated between legs, demonstrating no asymmetrical responses. However, lactate and muscle activation demonstrated greater responses for HI and cBFR than pBFR and LI, leading to the conclusion that cBFR might induce greater muscular stress than pBFR, which can possibly promote larger adaptations.

Chapter I: Introduction

A relatively new method of training has shown positive results for promoting muscle hypertrophy and increasing strength. “Kaatsu” or blood flow restriction (BFR) training has been used to provide muscle adaptations at relatively low exercise intensities (20% to 50% of 1 maximum repetition [1RM]). These positive adaptations are equivalent to those observed with traditional resistance exercise at high intensity (65% to 85% of 1RM) (Loenneke, et al., 2009; Takarada et al., 2000). The process is based upon the application of a restriction device to reduce blood flow to an exercising limb, which can be done with an inflatable cuff (controlled blood flow restriction, cBFR) or knee wraps (practical blood flow restriction, pBFR) on the proximal area around the limb. In this way, there is a limitation on blood delivery to and from the working tissue (Loenneke et al., 2009).

Although all the mechanisms that determine the BFR physiological responses have not yet been completely understood, this method has been very effective with elderly (Yasuda et al., 2016), clinical populations, and even enhancing athletes’ performance (Scott et al., 2015; Luebbers et al., 2014; Takarada et al., 2002). Nevertheless, no consistent protocol has been defined for the use of BFR exercise, and the wrong application could have negative effects; like subcutaneous hemorrhage, and numbness. Blood flow restriction training is also not recommended for populations with vascular issues, such as peripheral artery disease. Therefore, the best way to implement this technique would be to follow scientifically-based protocols and instructions (Fahs et al., 2012).

Blood flow restriction promotes hypertrophy because it causes an ischemic muscle environment during training, which leads to responses such as an early fast twitch fiber recruitment and the accumulation of metabolites, like lactic acid, even with low load exercises (Loenneke et al., 2009). Cellular swelling is one of the proposed mechanisms linked to muscle hypertrophy when using BFR. This response is due to the plasma shift that occurs during exercise, which can influence cellular swelling and induce hypertrophy by stimulating protein synthesis (Freitas et al. 2017; Yasuda et al., 2015). Also, the unique muscular environment caused by BFR application has shown increases in type II fiber recruitment due to a metabolic "overload", where the lack of oxygen and subsequent metabolic accumulation increases fiber recruitment (Loenneke et al., 2014; Yasuda et al., 2008; Wilson et al., 2013).

Wilson et al. (2013) demonstrated that pBFR influenced muscle swelling and muscle activation to a greater extent than a workload match control condition, which indicates that a bout of low-load pBFR might be effective in stimulating hypertrophy by cell swelling mechanism as well as type II fiber recruitment. Freitas et al. (2017) showed that muscle swelling lasts for approximately 75 min post exercise, similar to high intensity responses. Loenneke et al. (2012b) also investigated the effects of BFR on muscle swelling in the absence of exercise. Using inflatable cuffs, the study showed that there was an increase in muscle thickness after 3 min of 5 cycles of inflation/deflation without an addition of an exercise stimulus. This response indicates that BFR might influence muscle hypertrophy even in the absence of exercise, which may be important for some populations.

Loenneke et al. (2015) investigated the muscle activation of the vastus lateralis (dominant leg) using inflatable cuffs at different pressures. Electromyography (EMG) amplitude showed an augmentation at 40% and 50% of maximal occlusion, but no further increase was observed at 60%. Yasuda et al. (2008) also investigated muscle activation of the biceps brachii at different limb compression pressures, and reported that iEMG signals progressively increased and were significantly greater at 147 mmHg compression compared to other conditions. Although studies have shown increases in muscle activation for both pBFR and cBFR, there is a lack of information comparing the differences between the two devices.

Evidence has shown improvements in muscle size and strength with pneumatic cuffs (Abe et al.,2005; Luebbers et al., 2014; Takarada et al., 2002) as well as with knee wraps, also known as practical BFR training (pBFR) (Lowery et al., 2014; Yasuda et al., 2016; Takarada et al., 2000). The inflatable cuffs, such as Kaatsu and Hokanson, allow the practitioner to control the applied pressure, while the knee wraps are applied with a pressure according to the subject's perception of discomfort. Based on practicality, people are much more likely to use the knee wraps compared to the inflatable cuffs on a daily basis. Although several studies have shown positive muscle adaptations with different types of cuff material (Abe et al.,2005; Lowery et al., 2014), knee wraps are difficult to quantify in terms of the pressure that is being applied, meaning that the pressure applied in one limb might not be the same in the other limb. This raises the concern that muscular activation and metabolic responses may not happen at the same degree for both limbs.

Purpose of the Study

The purpose of this study was to compare the effects of a single bout of practical blood flow restriction, controlled blood flow restriction, high intensity and low-intensity with no blood flow restriction resistance exercise on muscle activation, muscle swelling, and lactate responses in college-aged females. Most studies have examined metabolic responses to BFR separately, and to our knowledge, no one has examined the issue of limb symmetry following controlled and practical implementation of blood flow restriction.

First Research Question

Do the physiological responses differ from a bout of practical BFR, controlled BFR, high intensity and low-intensity with no blood flow restriction restriction resistance exercise?

First Research Hypothesis

High intensity and controlled BFR resistance exercise will promote greater muscle activation, muscle swelling, and lactate production in comparison to practical BFR exercise because the applied pressure is controlled and known to be equal on both limbs.

Second Research Question

Does controlled BFR produce more symmetrical responses between legs for muscle swelling, thigh circumference, and muscle activation than practical BFR?

Second Research Hypothesis

Controlled BFR resistance exercise will promote more symmetrical responses between legs for muscle swelling, thigh circumference, and muscle activation than practical BFR.

Significance of The Study

Studies have reported gains in muscle size and strength using blood flow restriction with different techniques (inflatable, knee wraps and elastic bands) (Abe et al.,2005; Lowery et al., 2014; Yasuda et al., 2016; Luebbers et al., 2014; Takarada et al., 2002; Takarada et al., 2000; Fujita et al., 2008), however, there are very few studies that compare physiological responses between a bout of controlled BFR and practical BFR resistance exercise.

Wilson et al. (2013) investigated the physiological responses to a bout of pBFR and found that there was an increase in muscle swelling and muscle activation without showing any muscle damage responses, while no response was identified in the workload match control group other than a lower muscle activation than pBFR. Blood lactate was also higher when compared to control. Loenneke et al. (2010) used practical BFR to evaluate whole-body lactate changes during and after a bout of resistance exercise. When compared to control, lactate did not have significantly higher responses, which might be related to the intermittent pBFR protocol. This suggests that pBFR might have similar responses as cBFR, but there is yet to be a comparison to evaluate whether cBFR promote greater adaptations.

Freitas et al. (2017) evaluated time-course changes in muscle swelling after a bout of resistance exercise using controlled blood flow restriction. The results showed that

muscle thickness remained above baseline values until 30 min post exercise, while muscle cross-sectional area and thigh circumference were significantly higher until 75 min post exercise with BFR. Loenneke et al. (2012) investigated muscle swelling responses with controlled BFR in the absence of exercise. The study reported that after 5 bouts of inflation/deflation during rest, there was a significant muscle thickness increase when comparing 3 min post inflation/deflation periods with baseline values. However, there were no significant changes in blood lactate and muscle activation, which suggests that plasma volume changes and cellular swelling are strong determinants in muscle hypertrophy when using the blood flow restriction technique, since BFR training in the absence of exercise has shown to attenuate muscle atrophy (Kubota et al., 2008; Takarada et al., 2000).

Muscle activation was recorded at different pressures using cBFR by Yasuda et al. (2008) and Loenneke et al. (2015). Yasuda et al. (2008) investigated biceps brachii activation without BFR and with BFR at 98, 121, and 147 mmHg during a bout of unilateral elbow flexion, while Loenneke et al. (2015) compared the activation of the vastus lateralis at 50% and 60% of total occlusion pressures. Yasuda et al. (2008) registered peak muscle activation during 147 mmHg, and Loenneke et al. (2015) registered peak muscle activation at 50% of total occlusion. Loenneke et al. (2015) also demonstrated that at 60% occlusion there was no greater muscle activation when compared to 50%, suggesting that higher pressures are likely not needed to induce adaptations.

It is important to note that practical BFR and controlled BFR applications have provided increased physiological responses; however, no study has compared the

difference between practical and controlled BFR exercise responses. Also, there has yet to be a study that has considered the possibility of practical BFR to be less effective than controlled. Additionally, considering that the applied pressure might be different between limbs for practical BFR, it is unclear whether or not the exercise would induce similar responses between legs. To the best of our knowledge, no study has compared the differences between the two BFR methods on limb symmetry following controlled and practical implementation of blood flow restriction. Therefore, the aim of this study is to investigate whether the physiological responses differ between practical BFR (pBFR) and controlled BFR (cBFR) resistance exercise in muscle swelling, lactate, and muscle activation in college-aged women.

Delimitations

The delimitations of this study are:

1. Healthy females aged 18-30 years.
2. People who are recreationally active.
3. Participants with a Body Mass Index (BMI) ≤ 30 kg/m^2
4. Participants with an Ankle-Brachial Index ≥ 0.9 or ≤ 1.4.
5. Participants with no knee or hip injuries or cardiovascular diseases that can compromise the study.
6. Females taking hormonal contraceptives.
7. Non-pregnant females.

Limitations

The limitations are:

1. All subjects were asked to maintain their normal daily diet; however, this matter was not controlled by the study.
2. The outcome variables might differ for different age groups and training status.

Assumptions

The assumptions are:

1. All subjects performed maximal effort during testing sessions.
2. All subjects provided true information about medical and health history.
3. All subjects kept their daily diet normal.
4. All subjects did not perform lower body resistance exercise prior to the tests.
5. Ultrasound is a valid and reliable method to determine muscle thickness.
6. Lactate Plus Analyzer is a valid and reliable method to determine lactate.

Operational Definitions

1. **Blood flow restriction (BFR):** Technique based upon the application of a restriction device to reduce blood flow to an exercising limb, typically done with a pneumatic cuff or an elastic knee wrap (Loenneke et al., 2012b).
2. **Pneumatic cuff:** Blood pressure-like device that allows an inflation of up to 300 mmHg (Loenneke et al., 2013).

3. **Controlled BFR (cBFR):** Condition that used a pneumatic cuff to partially restrict blood flow during exercise (Loenneke et al., 2013).
4. **Practical BFR (pBFR):** Condition that used an elastic knee wrap-like device to restrict blood flow during exercise (Loenneke et al., 2013).
5. **Hematocrit (Hct):** Percentage of red blood cells in the blood (Plowman et al., 2013).
6. **Lactate (L):** A product of glycolysis, which represents the cellular glucose metabolism (Plowman et al., 2013).
7. **One Maximum Repetition (1RM):** Highest weight an individual can lift in one repetition (Plowman et al., 2013).
8. **Electromyography (EMG):** Technique that involves the development, recording and analysis of muscular electrical activity (Plowman et al., 2013).
9. **Muscle Thickness:** The distance between the tissue-muscle to the muscle bone tissue (Loenneke et al., 2012b).
10. **Ankle-Brachial Index (ABI):** Noninvasive test to evaluate risk of peripheral artery disease (PAD) (Aboyans et al., 2012).

Chapter II: Literature Review

The purpose of this study was to investigate the different responses between practical, controlled blood flow restriction, high intensity, and low-intensity with no blood flow restriction resistance exercise on muscle activation, blood lactate, and muscle swelling. Additionally, to the best of our knowledge, this was the first study to compare the differences between the two BFR methods as well as examine the issue of limb symmetry following controlled and practical implementation of blood flow restriction. Therefore, this section talks about the physiological mechanisms of hypertrophy for blood flow restriction.

Methodological Considerations

Blood flow restriction training varies depending on several factors, such as cuff type and width, time under pressure, and applied pressure. Loenneke et al. (2013) examined the differences between similar sized elastic and nylon cuffs on repetitions to fatigue, perceptual ratings of exertion (RPE) and discomfort after 3 sets of BFR knee extension exercises. Sixteen males and females participated in a cross-over design using either elastic or nylon BFR devices. There were no differences between the cuffs for any of the variables, suggesting that elastic and nylon cuffs of the same width produce similar repetitions to fatigue, RPE and discomfort.

Rossow et al. (2012) investigated the cardiovascular responses to acute BFR resistance training and the influence of cuff type. In a cross-over design, 30 young men and women performed 4 sets of knee extension at 20% of 1RM wearing either a narrow elastic cuff (5.0 cm) or a wide nylon cuff (13.5 cm). Brachial and central blood pressures (BP) were measured using an automatic BP device and from radial BP waveforms using

a generalized transfer function. Pulse wave velocity (PWV) was measured using applanation tonometry and a high-fidelity strain-gauge transducer. All measurements were taken before and after the restrictive cuffs were applied, after the second and fourth sets of resistance exercise, and 5 and 15 min after the last set. The results showed a greater increase in brachial and central BP, heart rate, perceived effort and pain for wider cuffs. Also, the augmentation index had a greater decrease during BFR exercise with the wide cuff when compared to the narrow ones. In summary, this study suggests that cuff width affects cardiovascular responses during resistance exercise.

Fifth-three males and 63 females were evaluated to test the differences in cuff pressure for two types of BFR cuffs and to determine the factors that influence the pressure prescription (Loenneke et al., 2012a). Mid-thigh muscle and fat cross-sectional (mCSA and fCSA, respectively) area of the right thigh were measured using a peripheral quantitative computed tomography (pQCT). Leg circumference, ankle-brachial index, and brachial blood pressure were measured using a standard tape measure, segmental cuff and bidirectional Doppler, and automatic blood pressure, respectively. The arterial occlusion pressure determination was assessed using two types of devices, the Hokanson 13.5cm x 83 cm cuff (wide cuff), and the Kaatsu Master 5cm x 135cm (narrow cuff). The authors observed differences between cuff types and arterial occlusion, while thigh circumference and mCSA/fCSA explained the most variance in the occlusion pressures. The results suggest that wide cuffs restrict arterial blood flow at a lower pressure than narrow cuffs, implying that further studies should take cuff width and limb circumference into consideration (Loenneke et al., 2012a).

Time under pressure (continuous or intermittent) also seems to influence BFR training responses. Fitschen et al. (2014) published an article describing two studies. For the first one, the investigators recruited 5 men and 6 women who had not performed resistance training 6 months prior to the study. The authors investigated the pain responses to a bout of resistance training for three conditions: (i) continuous BFR (maintain the pressure throughout all exercises and rest periods); (ii) intermittent BFR (releasing the pressure during rest periods); (iii) control (exercise without BFR). The subjects performed 4 sets to fatigue for the non-dominant knee extension exercise at 30% of 1RM with 90 seconds rest between sets. The pressure was set at a constant 160 mmHg and a Kaatsu Master cuff was used. Pain measurement was assessed with a scale of 1-10 (0 – no pain, 10 – extreme pain). The results found a significantly greater pain response to continuous BFR when compared to the intermittent protocol. This suggests that an acute bout of intermittent BFR produces the same muscle stress as continuous BFR, but with less pain.

Fitschen et al. (2014) also examined the strength and lean mass after 5 weeks of BFR training for (i) continuous BFR (maintain the pressure throughout all exercises); (ii) intermittent BFR (releasing the pressure during rest periods); (iii) control (exercise without BFR). Thirty subjects (5 males and 25 females) performed one set of 30 repetitions, two sets of 30 and 15 repetitions and four sets of 30-15-15-15 repetitions during the 3 training sessions, respectively. Weeks 4 and 5 were followed by four sets of 30-20-20-20. Leg press, leg extension, and seated hamstring curls were performed at 30% of 1RM with 1-minute rest between sets. Lean mass was measured using a dual energy X-ray absorptiometry (DXA) and strength with an isokinetic dynamometer. There were

no significant differences for strength and lean mass between the groups, suggesting that intermittent and continuous BFR training increases muscle size and strength to a similar extent.

Blood Flow Restriction Mechanisms and Physiology

According to the American College of Sports and Medicine, muscular hypertrophy is more likely to happen at an intensity of at least 65% of 1 repetition maximum (1RM) for 6-12 repetitions (ACSM, 2010). However, blood flow restriction training has demonstrated increases in muscle size at intensities of 20%, 30%, and 50% of 1RM. Physiologically, this adaptation is due to the ischemic muscular environment provided by the vascular occlusion (Loenneke et al., 2009).

Muscle swelling is an important mechanism that influences protein synthesis, and therefore, muscle hypertrophy. Although the mechanisms that drive protein synthesis with BFR are not restricted to cell swelling, the plasma shifts seem to play an important role in the process to increase muscle mass. It is believed that venous blood flow restriction can increase the intracellular to extracellular pressure gradient, and increase the water flux into the cell. The hypoxic environment caused by BFR produces an increase in intracellular metabolites, which might lead the cell to increase its water volume to equilibrate the osmotic gradient and activate signaling cascades for protein synthesis. In addition, the activation of fluid shifts may lead to a G-protein-mediated activation, which might lead to an activation of mammalian target of rapamycin (mTOR), and mitogen-activated protein-kinase (MAPK) pathways, known as important networks regulating skeletal muscle growth (Loenneke et al., 2011).

Loenneke et al. (2012b) investigated the effects of blood flow restriction on muscle swelling in the absence of exercise. Ten subjects (5 females and 5 males) aged 25 ± 3 years were first asked to rest in a supine position for 10 min. This was followed by baseline measurements of muscle thickness (MTH), rating of discomfort (RD), whole body lactate (WBL), hematocrit (Hct), EMG, and heart rate (HR). Afterward, subjects were asked to rest for another 10 mintues (time-control) followed by another set of data collection. Then, five cycles of blood flow restriction were performed at the supine position. The cycles were characterized by inflating the cuffs for 5 min and deflating for 3 min. Then, EMG, HR, MTH, and RD were taken approximately 4 min following each inflation period and again 2 min following each deflation period. Lactate and Hct were taken 4 min into the 5^{th} inflation period and again 3 min post BFR along with EMG, HR, MTH, and RD. There were no changes in muscle activation, lactate, and HR. However, significant changes were found for muscle thickness and plasma volume changes, suggesting that muscle swelling might be an important mechanism related to muscle hypertrophy and atrophy attenuation when applying a BFR protocol.

Blood flow restriction exercise has been shown to promote significant muscle swelling responses, similar to high intensity responses. Freitas et al. (2017) compared the time course change in muscle swelling in 10 male participants (22.1 ± 3.0 yrs). There were three conditions: 1) single bout of high intensity resistance exercise (3 sets of 8 to 10 reps at 80% of 1RM); 2) blood flow restriction (1 set of 30 reps, plus 3 sets of 15 reps at 20% of 1RM with occlusion set at 160 mmHg); 3) control (no exercise). The study measured muscle cross-sectional area (mCSA) using pQCT, muscle thickness (ultrasound), and thigh circumference. The exercise testing conditions included a two-leg

press, knee extension, and knee flexion. Muscle thickness and plasma volume changes were measured at baseline, immediately post-exercise with the BFR device, and 30 min and 1 hour after exercise with the BFR device removed. Muscle cross-sectional area and thigh circumference were measured at baseline as well as 15 min, 75 min, 24h, 48h, 72h, and 96h after exercise. The results identified that the changes in muscle swelling are similar between high intensity and blood flow restriction, which tends to return to baseline after 75 min of rest.

Yasuda et al. (2015) compared muscle swelling between a bout of resistance exercise to fatigue with and without blood flow restriction. Ten males (27 ± 5 yrs) were recruited to perform 3 sets to fatigue at 20% of 1RM for the blood flow restriction protocol (Kaatsu master set at 160 mmHg), and the Non-BFR protocol (no pressure). The two protocols had different resting periods, 30s between sets for the BFR condition, and 3 min for Non-BFR. The study measured muscle thickness (ultrasound), eEMG, hematocrit (plasma volume changes), and lactate. The muscle thickness measurements were taken at rest, between sets during exercise, at 0, 15, 30, and 60 min post exercise. Blood samples were taken at rest, and 0, 15, 30, and 60 min post exercise. EMG and heart rate were recorded during exercise. The results did not express significant differences between groups for muscle swelling and muscle activation. Also, the time-course of muscle swelling response was similar between conditions, and the low-load resistance exercise to fatigue induced muscle swelling because of muscle damage and inflammation responses regardless of BFR. Therefore, exercising to fatigue seemed to be efficient even at low-loads.

Practical blood flow restriction has also been shown to induce muscle swelling responses. Wilson et al. (2013) investigated the effects of moderate pBFR on metabolic stress, muscle swelling, muscle activation, and indices of muscle damage. The researchers recruited twelve trained males (21 ± 3 yrs) to complete 4 sets of 30-15-15-15 repetitions at 30% of their 1RM wearing the knee wrap device (LI-BFR). The knee wrap tensions were set at 7 based on a scale of 0 (no pressure and no pain) to 10 (extreme pressure with pain). In the control trial, the wraps were applied without pressure. Muscle thickness was recorded at baseline, immediately post exercise with the device, immediately post exercise without the device, and 5 and 15 min post exercise without the wraps. Muscle activation was recorded during warm up and during the last 15 repetitions of the last set. Muscle thickness increased significantly immediately post exercise with wraps, and 5 min post exercise without the wraps. No changes were identified for the control trial. Also, LI-BFR had greater muscle activation when compared to the control. There was no time effect for muscle damage, which indicates that practical BFR increases muscle activation and muscle swelling without increasing indices of muscle damage.

Traditional resistance training protocols have been studied and reported to improve muscular size because of the metabolic stress caused by moderate-to-high intensity training (Wernbom, et al., 2007). This stress could be described as the depletion of phosphocreatine (PCr), increase in inorganic phosphate, decrease in muscle pH, and lactate accumulation. Suga et al. (2009) investigated the levels of intramuscular PCr, and deprotonated phosphate (H_2PO_4) as well as intramuscular pH at rest and during exercise. A P-magnetic resonance spectroscopy (MRS) was used to assess metabolite levels after a bout of resistance exercise with and without blood flow restriction. There were three

groups, the low-intensity (20% 1RM) with blood flow restriction (LR), low-intensity without BFR (L) and high-intensity (H) (65% 1RM). All three groups performed the same exercise and protocol, which corresponds to 30 repetitions per minute of unilateral plantar flexion (2 min total). The results showed that LR metabolic accumulation was higher than L, but lower than H. This suggests that exercises with blood flow restriction may not have similar responses to high intensity resistance training. The authors discussed the possibility of a lack of consistency between BFR protocols, the muscle receiving occlusion, and gender differences (Suga et al., 2009).

On the other hand, Takarada et al. (2000) analyzed the acute changes on integrated electromyography (iEMG), vascular resistive index, and plasma lactate concentration following a single-arm dumbbell exercise, either at low-intensity (40% 1RM) without BFR, low intensity (40% 1RM) with BFR (~110 mmHg) or high intensity (80% 1RM) without BFR. The results demonstrated an elevated mean iEMG, post-exercise hyperemia, and plasma lactate concentration for all the conditions compared to baseline. However, low intensity without BFR demonstrated much lower responses when compared to the other conditions.

Blood flow restriction training studies have also shown to stimulate great hormonal responses after low-intensity training. Abe et al. (2005) investigated the effects of Kaatsu training on muscle size and circulating insulin-like factor-1 (IGF-1). The researchers recruited sixteen young men (23.6±6.5 yrs) and divided them into two groups: low-intensity Kaatsu (LIT-Kaatsu) and low-intensity (LIT) (20% 1RM). The subjects trained two times a day, six days a week for 2 weeks. Squat and leg curl exercises were performed. Muscle CSA and volume was measured by magnetic resonance imaging

(MRI) at baseline and 3 days after the last training session. Serum IGF-1 concentration was measured at baseline, mid-post and post testing. The study showed that there was a significant gradual increase in circulating IGF-1 for LIT-Kaatsu after 2 weeks of training, while LIT group had no significant changes. The increase in this hormone is an indication of potential muscle hypertrophy because it stimulates muscle protein synthesis.

Takano et al. (2005) examined the hemodynamic and hormonal responses to BFR training. The investigators examined the serum concentrations of growth hormone (GH), vascular endothelial growth factor (VEGF), noradrenaline (NE), IGF-1, ghrelin, and lactate. Eleven untrained men (34±6 yrs) performed a bout of bilateral leg extension at low-intensity (20% 1RM) with BFR (4 sets of 30-failure-failure-failure repetitions with 20 seconds of rest). Nine men came back for a second visit after 2-4 weeks to perform the same exercise and intensity without BFR. The results showed a significant increase in GH, IGF-1, and VEGF in the groups with BFR when compared to the control condition. These hormones are strongly related to hypertrophy responses, indicating that low-intensity Kaatsu training can induce muscle growth. The authors also suggest that the stimulation of these substances and the reduction of cardiac preload could make Kaatsu training a unique technique to support patients with cardiovascular diseases.

Mammalian target of rapamycin complex 1 (mTORC1) is also a molecular signal that induce protein synthesis, which also contributes to the process of muscle hypertrophy. Fry et al. (2010) studied the mTORC1 and protein synthesis (MPS) responses to blood flow restriction exercise in seven older men (70±2 yrs) before and after exercise. The subjects were submitted to bilateral leg extension exercise in two sessions: low-intensity (20% 1RM) with and without blood flow restriction. MPS and

phosphorylation of signaling proteins were determined through muscle biopsies. The results showed an increase of 56% in MPS from baseline for BFR exercise, while there were no changes for the control condition. In addition, mTORC1, ribosomal S6 kinase 1 (S6K1) phosphorylation and ribosomal protein S6 (rpS6) phosphorylation had a significant increase following BFR exercise when compared to low-intensity without the occlusion pressure. Therefore, the study concluded that resistance exercise with BFR enhances mTORC1 and MPS in older men, providing possible stimulus for muscle hypertrophy even in older populations.

Nielsen et al. (2012) investigated the effects of BFR training on proliferation of myogenic stem cells (MSC) after 23 training sessions. The study included 18 male participants, of which 10 (22.8±2.3 yrs) performed four sets of knee extensor exercises (20% 1RM) to concentric failure with blood flow restriction, and 8 (21.9±3.0 yrs) work-matched controls that trained without BFR. Muscle biopsies were used to analyze changes in the myofiber area (MFA), MSC and myonuclei number. A muscle biopsy sample was collected at baseline (pre), after 8 days of intervention (mid8) and 3 (post3) and 10 days (post10) post training. The results indicated a significant increase in type I and II MFA of 38% (Mid8), 35-37% (post3) and 31-32% (post10) for the BFR condition. Also, MSC per myofiber increased significantly from pre to mid8, post3 and post 10. Myonuclei per myofiber increased from pre to mid8, post 3 and post 10 when compared to the control.

Strength and Hypertrophy

Several studies have shown positive adaptations to resistance training with occlusion using knee wraps and elastic bands as an alternative to the pneumatic cuffs used to induce blood flow occlusion. For example, Luebbers et al. (2014) investigated the

effects of practical BFR training in American college football athletes. The study design had four groups, which consisted of one group that performed traditional high-intensity training and supplemental 1RM lifting protocols (H/S/R) with BFR; one that performed only high-intensity training (H); another one with high-intensity and supplemental 1RM lifting without BFR (H/S); and a modified training program (M/S/R), which also had supplemental 1RM lifting with BFR. The purpose was to examine the effects of 7-weeks of training in muscular size and strength. The dependent variables were analyzed using the arm, chest and thigh circumferences for muscle size, and bench press and squat 1 RM pre-and post-test to assess strength. Significant differences were found for the squat 1RM test, indicating an increase in strength for all groups. However, H/S/R group experienced greater gains, suggesting that high-intensity training with a supplemental bout of pBFR exercise can improve strength (Luebbers et al., 2014).

Another study examined the effects of a periodized program of pBFR resistance training on muscle hypertrophy in twenty college-aged males. The program consisted of 8 weeks of training, with two groups either applying occlusion with knee wraps in the first 4 weeks or in the second 4 weeks. The subjects performed biceps training twice a week. Directed ultrasound was used to determine muscle thickness and was assessed at the end of weeks 0, 4 and 8. The training protocol during pBFR period included three sets of 30 repetitions with 30% 1RM, while the traditional resistance training without pBFR included 3 sets of 15 repetitions at 60% of 1RM. The results showed that both groups increased muscle thickness after 4 and 8 weeks, suggesting that pBFR is as effective for increasing thickness as traditional resistance training (Lowery et al., 2014).

Resistance training can also be applied with other instruments besides dumbbells and machines. In a 2016 study, Yasuda et al. (2016) submitted 30 older women to 12 weeks of elastic band training. They were divided into three groups: low-intensity elastic band training with BFR (BFR-Tr); middle-to high intensity elastic band training (MH-Tr), and no training (Ctrl). Cross-sectional area at mid-thigh was measured with MRI, while maximum voluntary contractions (1RM) for knee extensions was measured with a dynamometer machine (Biodex). The results demonstrated a significant increase in muscle CSA of 6.9% and strength of 13.7% in BFR-Tr, but not for MH-Tr and Ctrl groups. This investigation presented muscle adaptations to cBFR after a different type of resistance training, implying that blood flow occlusion can be beneficial for different kinds of resistance training modalities.

Controlled BFR training is known as the application of a pneumatic cuff on the exercising limb to restrict blood flow. This method allows the practitioner to set and control and maintain the desired pressure. Takarada et al. (2000) also analyzed the long-term effects of cBFR. The sample was composed of 24 older women. There was a 16-week training of elbow flexion at low-intensity (50-30% 1RM) using occlusion pressures around 110 mmHg (LIO), low-intensity without occlusion (LI), and high-to medium intensity (80-50% 1RM) without occlusion (HI). Muscular strength and muscular hypertrophy were assessed with isokinetic dynamometer and magnetic resonance imaging (MRI), respectively.

Each protocol resulted in significant increase in muscle cross-sectional area (CSA). LIO had a significant larger CSA increase than LI. Although not significant, LIO showed a tendency of greater adaptation than HI. Strength responses also increased in all

groups, where LIO had a significant higher improvement than LI. This investigation suggests that exercises at low intensities can induce gains in muscle size and strength similar to high intensity without occlusion when controlled blood flow restriction is applied (Takarada et al., 2000).

Another study by Takarada et al. (2002) had a similar approach applied to seventeen elite rugby athletes. There were three groups: low-intensity (50% 1RM) with occlusion (200 mmHg) (LIO); low-intensity without occlusion (LI) and control group (no exercise training). Improvements in knee extensors CSA and strength were analyzed using MRI, and an isokinetic dynamometer, respectively. LIO increased muscle CSA by about 15% compared to pretest values, indicating that controlled BFR training could enhance muscle size, strength and endurance even in highly trained athletes (Takarada, et al., 2002).

In summary, BFR training is an overall safe method to improve muscle strength and promote hypertrophy. Also, different approaches have shown to induce positive muscular adaptations, whether performed with inflatable cuffs or elastic wraps.

Chapter III: Methodology

The aim of this study was to compare the effects of a single bout of practical blood flow restriction, controlled blood flow restriction, high intensity and low-intensity with no restriction resistance exercise on muscle activation, muscle swelling, and lactate responses in college-aged females. Additionally, to the best of our knowledge, this was the first study to compare the differences between the two BFR methods as well as examine the issue of limb symmetry following controlled and practical implementation of blood flow restriction.

Participants

An a priori sample size calculation using G-power (version 3.1.9.2) indicated that a sample of 15 participants would be required, based on a repeated measures Analysis of Variance (ANOVA) crossover design and an alpha $\alpha = 0.05$, ß = 0.8, and an effect size = 0.3. Sixteen recreationally active females were recruited from the University of Oklahoma, and surrounding areas to participate in this study. Out of the initial participants, fifteen completed the study (20.3 ± 1.6 years old). All females met the inclusion criteria, which includes being 18 to 30 years old, having a body mass index (BMI) less than 30 kg/m², and Ankle-Brachial Index (ABI) higher than 0.9 and lower than 1.4. Also, the subjects declared themselves physically active through the PAR-Q and health status questionnaire. No knee or hip injuries as well as no cardiovascular diseases were reported. Each subject performed four different protocols: 1) Controlled blood flow restriction exercise (cBFR): pressure set at 50% of total occlusion pressure, intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 2) Practical blood flow restriction exercise (pBFR): pressure set at 7 based on a perceived pressure scale of 0 (no pressure,

no pain) to 10 (extreme pressure with pain), intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 3) High intensity (HI): intensity set at 80% of 1RM, with 3 sets of 8 to 10 repetitions, without any blood flow restriction; 4) Control (CON): intensity set at 30% of 1RM, 4 sets of 30-15-15-15 repetitions, without any blood flow restriction. The conditions were performed in a random order for each subject and were at least 3 days apart.

Inclusion Criteria

1. Females aged between 18-30 years old.
2. Ankle Brachial Index > 0.9 and <1.4.
3. Recreationally active females.
4. Normotensive.
5. Participants taking hormonal contraceptive.
6. Healthy and able to participate in the study according to the consent forms, such as Health Insurance Portability and Accountability act (HIPAA) form, physical activity readiness questionnaire (PAR-Q), health status questionnaire, and menstrual history questionnaire.

Exclusion Criteria

1. Subjects with Body Mass Index (BMI) above 30 kg/m^2.
2. Females who are not recreationally active.
3. Pregnant females.
4. Females with cardiovascular or metabolic diseases.
5. Females with hip or knee injuries from the past 6 months.
6. Participants with high blood pressure (>140/90mm Hg).

7. Ankle Brachial Index < 0.9 or > 1.4.

Experimental Design

Sixteen recreationally active females were recruited from the University of Oklahoma, and surrounding areas to participate in this study. Out of the initial participants, fifteen completed the study (20.3 ± 1.6 years old). In a crossover design, subjects performed 4 different exercise protocols in random order. The protocols were: 1) low intensity with controlled blood flow restriction (cBFR): pressure set at 50% of total occlusion pressure, intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 2) Practical blood flow restriction exercise (pBFR): pressure set at 7 based on a perceived pressure scale of 0 (no pressure, no pain) to 10 (extreme pressure with pain), intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 3) High intensity (HI): intensity set at 80% of 1RM, with 3 sets of 8 to 10 repetitions, without any blood flow restriction; 4) Low Intensity (LI): intensity set at 30% of 1RM, 4 sets of 30-15-15-15 repetitions, without any blood flow restriction. The study included 6 visits total for all the participants. On the first visit (approximately 1 hour), all participants completed the consent form, health insurance portability and accountability act (HIPAA) form, physical activity readiness questionnaire (PAR-Q), health status questionnaire, and a menstrual questionnaire. Also, height, weight, brachial blood pressure, and ankle-brachial index were measured. Finally, the participants participated in a 1 maximum repetition (1RM) familiarization with the two-leg press and knee extension exercises. On the second visit (approximately 1.5 hour), the total occlusion pressure was measured, and the participants were tested for the 1RM on two-leg press and knee extension (Clayton et al., 2015). After finding their 1RM, subjects were familiarized with exercising while wearing the BFR

devices (2 sets of 15 and 10 reps for each exercise: two-leg press and knee extension). The 3rd, 4th, 5th, and 6th visits consisted of 4 different exercise sessions (approximately 1 hour each). At the beginning of each session, the EMG and muscle thickness site were marked, and the EMG electrodes were placed on the surface of the vastus lateralis. The participants performed 10 repetitions at 50% of their 1RM in order to warm up, then they performed 1 lift of their previously determined 1RM for the two-leg press and knee extension in order to record the reference EMG signal that was used to normalize EMG activity. After collecting the EMG activity at 1RM, the participants rested for 5 min before the baseline measurements of lactate, hematocrit, muscle thickness, and thigh circumference were obtained. Subjects then completed one of the four possible exercise bouts. Immediately post exercise, 5 min post exercise, and 15 min post exercise the measurements for muscle thickness, thigh circumference, hematocrit, and blood lactate were again assessed. Muscle activation was recorded during each set of each exercise protocol. EMG signals were measured from the Vastus Lateralis (VL) for both legs. Each testing visit were at least 3 days apart.

Standing Height & Body Mass

Standing height was measured with a calibrated stadiometer (Stadiometer, Novel Products, Inc., Rockton, Illinois, USA), where the subject was standing straight against the stadiometer, keeping both ankles together. Body mass was assessed with a calibrated scale (Tanita, Digital Scale, Model BWB-800A, Japan). Height and weight were registered as the nearest 0.5 cm, and 1 kg, respectively. The subjects were asked to wear the minimum amount of clothing to participate in both assessments.

Brachial Blood Pressure

The participant was asked to rest in the supine position for 5 min before the measurements. Blood pressure was assessed with an automatic blood pressure cuff (Omron Healthcare Inc. Vernon Hills, IL, Model HEM-773). There were measurements and the average was used. The measurements should not be more than 5 mmHg different, if so, a third measure was performed.

Ankle Brachial Index

According to the American Heart Association (2013), ankle-brachial index is the ratio resulted by the division of the highest blood pressure in the ankle by the highest blood pressure in the arms for both sides of the body. Subjects rested in the supine position for 5 min. Left brachial blood pressure was assessed with a MV10 segmental cuff and the blood flow with a hand-held bidirectional Doppler (MD4, Hokanson, Bellevue, WA). The Doppler was placed at a 45-60-degree angle on the brachial artery and the cuff was placed on the left arm. The cuff was inflated until the Doppler signal disappears, then deflated slowly until the first sound was heard. The first sound was recorded as the systolic blood pressure. The procedure was repeated for the right arm. To assess the ankle systolic blood pressure, the cuff was placed 2 cm above the malleoli and the Doppler on the posterior tibial artery. The same procedure was repeated on the right ankle. The ABI was calculated dividing the highest systolic blood pressure in the ankles by the highest systolic blood pressure in the arms (Lambert, M., 2013).

Arterial Occlusion Pressure Determination

To determine the arterial occlusion pressure, the Hokanson (13.5cm x 84cm Hokanson, SC12, Bellevue, WA) was used with a Doppler probe to assess the blood flow

at the anterior tibial artery. The cuff was placed on the most proximal portion of the thigh. The protocol consisted in inflating the cuff progressively until the blood flow signal could not be detected through the probe. The first increase on the cuffs pressure was to 50mm Hg and it lasted for 30s, then it was deflated for 10s. The pressures values were monitored on the equipment's screen. Next, the cuff was inflated to the participants' systolic pressure for 30s, and deflated for 10s. Then, following the same time frame of inflation/deflation, incremental increases of 40 mmHg were done until the complete occlusion was reached. After finding the occlusion pressure by verifying no pulse signal coming from the Doppler, the pressure was decreased to the nearest 10mm HG until the signal reappeared. Arterial occlusion was determined as the lowest pressure where the pulse was not detected. The process was done for both right and left legs. The pressure was not increased above 300 mmHg. The same device was used during the controlled BFR exercise session, where the pressure was set at 50% of the average of the total occlusion pressure.

One Repetition Maximum (1RM)

Each participant warmed-up on each exercise machine with a load that allowed the individual to perform easily 8 to 10 repetitions. Participants were asked to evaluate their ratings of perceived effort (RPE) through a 0 (no effort) to 10 (maximum effort) scale after each set during the test, allowing the tester to estimate the next load. After 1-minute rest, the load was increased to an estimated resistance (around 1.5 or 2 plates) that allowed the participant to perform 3 to 5 repetitions. Then, the load was increased following 2-4 min rest until the subject could attempt to one maximum repetition. If the subject was successful, another rest period was given and the load was increased (1.5 or

2 plates). If the subject failed, small load decreases were made until 1RM was reached, spaced out by 2-4 min resting periods. The test was performed on a two-leg press and knee extension machine (Clayton et al., 2015).

Resistance Exercise

At first, the participants performed 10 repetitions at 50% of their previously found 1RM in order to warm up. Following the warm up, exercises were performed in the following order for all protocols: two-leg press and knee extension (Cybex International Inc., Medway, MA, USA). The conditions consisted of: 1) low intensity with controlled blood flow restriction (cBFR): pressure set at 50% of total occlusion pressure, intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 2) Practical blood flow restriction exercise (pBFR): pressure set at 7 based on a perceived pressure scale of 0 (no pressure, no pain) to 10 (extreme pressure with pain), intensity set at 30% of 1RM, and 4 sets of 30-15-15-15 repetitions; 3) High intensity (HI): intensity set at 80% of 1RM, with 3 sets of 8 to 10 repetitions, without any blood flow restriction; 4) Low Intensity (LI): intensity set at 30% of 1RM, 4 sets of 30-15-15-15 repetitions, without any blood flow restriction. All sessions had 1 min resting period between sets and 3 min between exercises. The BFR pressure was released between exercises. Each testing visit was at least 3 days apart.

Metronome

A digital metronome (SEIKO DM-11) was used to ensure that the subjects kept a contraction cadence of one and half seconds for the concentric and eccentric phases during all exercises.

Thigh Circumference

Femur length was measured as the distance between the greater trochanter and the femoral condyle with a standard measuring tape, where 50% was calculated and marked. Limb circumference was measured at the 50% site after 5 min of seated rest, immediately post, 5 and 15 min post exercise without the BFR device.

Muscle Thickness

An ultrasound machine (Fukuda Denshi UF-4500, Tokyo, Japan) and a 5 MHz linear probe was used to assess muscle thickness on both legs. The probe surface was covered with transmission gel and gently placed perpendicular to the tissue on the 50% mark of femur length. The measurement was done with the subject in the standing position with feet apart. They were asked to maintain equal weight distribution between legs and keep the arms relaxed. The distance between the tissue-muscle to the muscle-bone tissue was determined as the muscle thickness. The site was measured after 5 min of seated rest prior to exercise, immediately post, 5 and 15 min post exercise without the BFR device. The ultrasound machine accounts on *in vivo* precision (CV%) for right and left leg, respectively, of 4.28% and 4.10% for muscle.

Lactate

A reliable and valid (Hart et al., 2013) Lactate Plus analyzer (Nova Biomedical) was used to collect lactate measurements. Two solutions (control 1 – low and control 2 – high) were utilized to calibrate the analyzer, comparing the results to the solution's label. If the results did not match the values on control solution vial, the procedure was repeated. Lactate samples were taken through finger prick after 5 min of seated rest prior to the exercise, immediately post, 5 and 15 min post exercise without the BFR device. The

fingertip was wiped with alcohol, punctured with a lancet device, and the first drop of blood was discarded.

Hematocrit

Hematocrits (Hct) was collected after 5 min of seated rest prior to exercise, immediately post, 5 and 15 min post exercise without the BFR device in the same lactate puncture point, collected with capillary tube, then analyzed with a CritSpin (micro-hematocrit centrifuge) that was centrifuged for 120 seconds. Hematocrits were taken in duplicate and the values were read with a micro-capillary reader (Damon /IEC Division). The average was taken and the plasma volume change was calculated with the formula below (Van Beaumont et al., 1972):

*% Change Plasma Volume = (100/(100 – Hct pre)) * 100 ((Hct pre – Hct post) / Hct post)*

Electromyography (EMG)

Electromyography (EMG) signals using bipolar electrodes placed 20mm apart were recorded from the vastus lateralis (VL) of both right and left legs. The electrodes were placed at 66% on the line from anterior spina iliaca superior to the lateral side of the patella (SENIAM). The skin was market at the site with a permanent marker to avoid variability. The ground electrode was placed on the left patella. The electrodes were connected to an amplifier and digitized (Biopac System, Inc. Goleta, CA). The signal was filtered (low-pass filter 500 Hz; high-pass filter 10 Hz), amplified (1000x) and sampled at a rate of 1 KHz. The EMG was registered continuously from both right and left Vastus Lateralis during each set of two-leg press and knee extension protocols using the AcqKnowlege software (version 3.8.1). EMG amplitude (root mean square, RMS) and mean power frequency (MPF) were analyzed for the 3 lasts concentric contractions of

each set of each exercise. The highest RMS of the concentric portion of the last 3 repetitions were averaged for each set. The highest RMS of EMG signal within half of a second (0.5s) during the 1RM replication was used as reference to normalize the EMG activity for each set of each exercise (%1RM).

Perceived Pressure Scale (PP)

On the pBFR condition, the occlusion pressure was based on a Perceived Pressure Scale that ranges from 0, meaning no pressure, to 10, meaning extreme pressure with pain. The subject was asked to tighten the elastic wrap around the proximal area of the thigh at a perceived pressure scale of 7, meaning moderate pressure with no pain (Wilson et al., 2013).

OMNI-Resistance Exercise Scale (RPE)

OMNI-Resistance Exercise Scale (RPE) is based on a scale of 0-10, where 0 means extremely easy, and 10 extreme hard. The OMNI was used to measure the perceived intensity of each condition. RPE was recorded before exercise, and after each set of each exercise (Robertson et al., 2003).

Borg Discomfort Scale (RD)

Rating of discomfort (RD) was assessed with the Borg Discomfort Scale of 0-10, where 0 means no discomfort, and 10 as the worst discomfort experienced by the participant (Hollander et al., 2003). If the discomfort related to the exercise was higher than 10, the subject was instructed to evaluated as 11 or 12. If the discomfort is extremely higher than its worst discomfort, the participant was instructed to say 15. Ranting of Discomfort was taken before exercise, and after each set of each exercise.

Statistical Analyses

Data analyses were performed using IBM SPSS Statistics 23 software and a level of significance of $p \leq 0.05$ was set. A within-within two-way [condition (cBFR, pBFR, HI, and LI) x time (pre, immediately, 5 and 15-minutes post)] repeated measures analysis of variance (ANOVA) with Bonferroni *post hoc* correction was used to compare main effects and interactions for lactate, hematocrit and plasma volume change. Also, a within-within [condition (cBFR, pBFR, HI, and LI) x time (pre, immediately, 5 and 15-minutes post) x legs (Right and left legs)] 3-way repeated measures ANOVA with Bonferroni *post hoc* correction was used to compare main effects and interactions for muscle thickness, thigh circumference, and muscle activation. If there were a significant condition by time, condition by leg, time by leg interaction, individual one-way ANOVAs were used to decompose the model and test for simple effects. Also, Pearson's correlation coefficients were used to correlate both legs for muscle swelling, thigh circumference, and muscle activation for each condition. For the effort and discomfort evaluations, a Friedmans's non-parametric test was used to analyze the responses across condition and time. For the pairwise comparisons, a paired Wilcoxon non-parametric tests with Bonferroni correction were used. Mean ± standard deviation [SD] was used to present the data, unless otherwise indicated.

Chapter IV: Results and Discussion

Results

The purpose of this study was to compare the effects of a single bout of controlled blood flow restriction (cBFR), practical blood flow restriction (pBFR), high intensity (HI) and low intensity (LI) with no restriction resistance exercise on muscle activation, muscle swelling, and lactate responses in college-aged females. Also, assuming that controlled BFR provides an exact applied pressure and practical BFR relies on the participants' perception of pressure, this study aims to evaluate the symmetry between right and left legs on muscle swelling and muscle activation.

Subjects

Sixteen recreationally active females were recruited from the University of Oklahoma, and surrounding areas to participate in this study. Out of the initial participants, 15 completed the study (20.3 ± 1.6 years old). The participant's characteristics are described in Table 1 (Mean ± Standard Deviation [SD]). All females met the inclusion criteria, which includes being within 18 to 30 years of age, having a body mass index (BMI) less than 30 kg/m^2, and an Ankle-Brachial Index (ABI) within the range of 0.9 to 1.4. Also, the subjects declared themselves physically active through the PAR-Q and health status questionnaire. Fourteen participants were self-described right leg dominant. No knee or hip injury as well as no cardiovascular diseases were reported.

Table 1. Participant Characteristics (*n* = 15) (Mean ± SD).

Variable	Mean ± SD
Age (y)	20.3 ± 1.6
Weight (kg)	63.7 ± 7.5
Height (cm)	1.6 ± 0.1
BMI (kg/m^2)	23.4 ± 2
SBP (mmHg)	113.7 ± 8.8
DBP (mmHg)	70.6 ± 7.3
ABI	1.1 ± 0.1
TOP (mmHg)	135 ± 14.5
50% TOP (mmHg)	67.7 ± 7.3

BMI = Body Mass Index; SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; ABI = Ankle-Brachial Index; TOP = Total Occlusion Pressure;

Table 2 includes the results of the maximal strength tests and the intensities used for both exercise conditions.

Table 2. Maximal strength and exercise intensities (*n* = 15) (Mean ± SD).

Exercise	1RM (kg)	30% 1RM	80% 1RM
Leg Press	117.3 ± 23.2	35.2 ± 7	93.8 ± 18.6
Knee Extension	64.2 ± 2	19.3 ± 3.8	51.4 ± 10.2

1RM = One Maximum Repetition.

Table 3 presents the mean ± SD for the number of repetitions performed on each set during leg press and knee extension. Additionally, the total work load (TWL) for each condition and exercise (leg press and knee extension) was also calculated and it was determined that the HI condition resulted in a significantly greater TWL being lifted compared to the other 3 conditions (cBFR, pBFR, and LI) for leg press. However, TWL lifted for HI was significantly lower than the other 3 conditions for knee extension.

Table 3. Repetitions per set and exercise, and total work load (n = 15)(Mean ± SD).

		Condition			
Time	**Exercise**	**cBFR**	**pBFR**	**HI**	**LI**
Set 1	**Leg Press**	30 ± 0.00	30 ± 0.00	10 ± 0.00	30 ± 0.00
	Knee Extension	29.6 ± 1.55	30 ± 0.00	8.87 ± 1.73	30 ± 0.00
Set 2	**Leg Press**	15 ± 0.00	15 ± 0.00	10 ± 0.00	15 ± 0.00
	Knee Extension	14.2 ± 2.24	15 ± 0.00	8.07 ± 1.67	15 ± 0.00
Set 3	**Leg Press**	15 ± 0.00	15 ± 0.00	10 ± 0.00	15 ± 0.00
	Knee Extension	14.6 ± 1.30	15 ± 0.00	7.53 ± 2.20	14.73 ± 0.63
Set 4	**Leg Press**	15 ± 0.00	15 ± 0.00	N/A	15 ± 0.00
	Knee Extension	14.67 ± 1.29	15 ± 0.00		14.8 ± 0.77
TWL	**Leg Press**	2639.06 ± 522.4	2639.06 ± 522.4	2814.99 ± 557.23**	2639.06 ± 522.4
	Knee Extension	1401.19 ± 260.99	1444.25 ± 287.95	1240.63 ± 213.82*	1433.54 ± 279.79

*TWL: Total work load (kg); cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity. **$p \leq 0.01$: significantly greater than cBFR, pBFR, and LI. *$p \leq 0.05$: significantly lower than cBFR, pBFR, and LI.*

Lactate

A 2-way repeated measures ANOVA (Condition [4] x Time [4]) analysis revealed significant condition ($p \leq 0.001$), and time ($p \leq 0.001$) main effects as well as a significant condition by time interaction ($p \leq 0.001$) for total body lactate (Table 5).

As illustrated in Table 4 and Figure 1, lactate levels for the cBFR, pBFR, and LI conditions significantly increased from pre-exercise to immediately post-exercise (IP) ($p \leq 0.001$), 5 min post-exercise (5P) ($p \leq 0.001$), and 15 min post-exercise (15P) ($p \leq 0.001$). Additionally, 5P measurements were significantly lower than IP ($p \leq 0.05$). At 15P, lactate levels were significantly lower than 5P ($p \leq 0.001$). HI showed significantly higher levels of lactate than pre-exercise at time points of IP ($p \leq 0.001$), 5P ($p \leq 0.001$), and 15P ($p \leq 0.001$). IP lactate measures were also significantly higher than 15P ($p \leq 0.001$), however, IP measures were not significantly different than 5P ($p = 0.101$).

No significant differences were observed across conditions for pre-exercise measures of lactate ($p = 0.370$). However, significantly greater lactate levels were observed for HI and cBFR when compared to pBFR and LI for measurements at IP, 5P,

and 15P ($p \leq 0.001$). Finally, pBFR lactate levels were significantly higher than LI at IP, 5P, and 15P ($p \leq 0.001$).

Table 4. Lactate changes across the different testing conditions and time points (n = 15) (Mean ± SD).

	cBFR	pBFR	HI	LI
Pre- Exercise	1.45 ± 0.5	1.52 ± 0.74	1.24 ± 0.39	1.33 ± 0.5
IP	5.93 ± 1.70[a*]	5.62 ± 1.97[a†]	7.74 ± 1.99[a#*]	5.85 ± 1.36[a]
5P	5.54 ± 1.81[ab*]	4.96 ± 2.31[ab†]	7.25 ± 1.96[a#*]	5.19 ± 1.67[ab]
15P	3.39 ± 1.21[ac*]	3.12 ± 1.36[ac†]	4.85 ± 1.56[ab#*]	3.15 ± 1.11[ac]

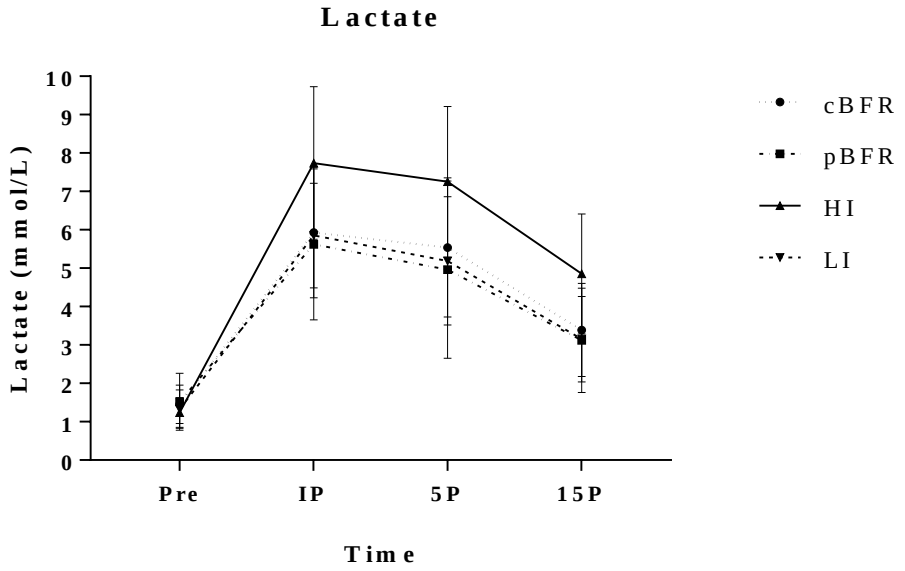
*Values are expressed in mmol/L. Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity. a: significantly different than pre ($p \leq 0.001$); b: significantly different than IP ($p \leq 0.001$); c: significantly different than 5P ($p \leq 0.001$); *significantly different than pBFR and LI ($p \leq 0.001$); # significantly different than cBFR † significantly different than LI ($p \leq 0.001$).*

Table 5. Main Effects and interactions for lactate measurements (n = 15).

	F	p	η2	Power
****Condition**	13.001	0.001	0.482	1.000
****Time**	133.028	0.001	0.905	1.000
****Condition*Time**	14.084	0.001	0.502	1.000

*F: Ratio of mean squares; p: Probability, *p ≤0.05 and **p ≤0.01 for statistical significance; η2: Eta Squared, effect Size.*

Figure 1. Lactate changes across different testing conditions and time points.



Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Hematocrit & Percent Plasma Volume Change

Table 6 demonstrates that hematocrit values generally increased from pre-exercise to IP and 5P, then returned to near pre-exercise values for each condition. While percent plasma volume changes (%PVC) generally decreased from pre-exercise to IP and 5P, but increased from pre-exercise to 15P. Statistical analysis for hematocrit values demonstrated that there was no significant condition main effect ($p = 0.312$) or condition by time interaction ($p = 0.066$); however, there was a significant time main effect ($p \leq 0.001$), as illustrated on Table 7 and Figure 2. Post-hoc comparisons identified a significant difference between measurements at pre-exercise and 15P ($p \leq 0.001$) as well as IP to 15P ($p = 0.005$), and 5P to 15P ($p \leq 0.001$).

Table 6. Hematocrit values expressed as percent of blood volume and plasma volume percent changes expressed relative to baseline values. (*n* = 13) (Mean ± SD).

	cBFR	pBFR	HI	LI
Hematocrit (%)				
Pre- Exercise	42.62 ± 2.11	41.62 ± 2.62	42.35 ± 2.9	42.7 ± 4.11
IP	43.08 ± 2.75	42.31 ± 2.05	43.19 ± 2.95	41.89 ± 3.47
5P	43.19 ± 2.12	42.12 ± 2.59	43.62 ± 2.98	42.69 ± 3.41
15P	41.15 ± 2.59 [abc]	41.12 ± 2.29 [abc]	41.89 ± 3.06 [abc]	41.12 ± 3.11 [abc]
%PVC				
Pre to IP	-1.70 ± 5.31	-2.62 ± 6.56	-3.27 ± 5.53	3.47 ± 5.56
Pre to 5P	-2.17 ± 6.03	-1.65 ± 8.86	-4.89 ± 5.92	0.085 ± 5.54
Pre to 15P	6.49 ± 7.81[bc]	0.66 ± 9.32[bc]	2.08 ± 5.93[bc]	6.89 ± 7.42[bc]

Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity. a: significantly different than pre ($p \leq 0.001$); b: significantly different than IP ($p \leq 0.001$); c: significantly different than 5P ($p \leq 0.001$);

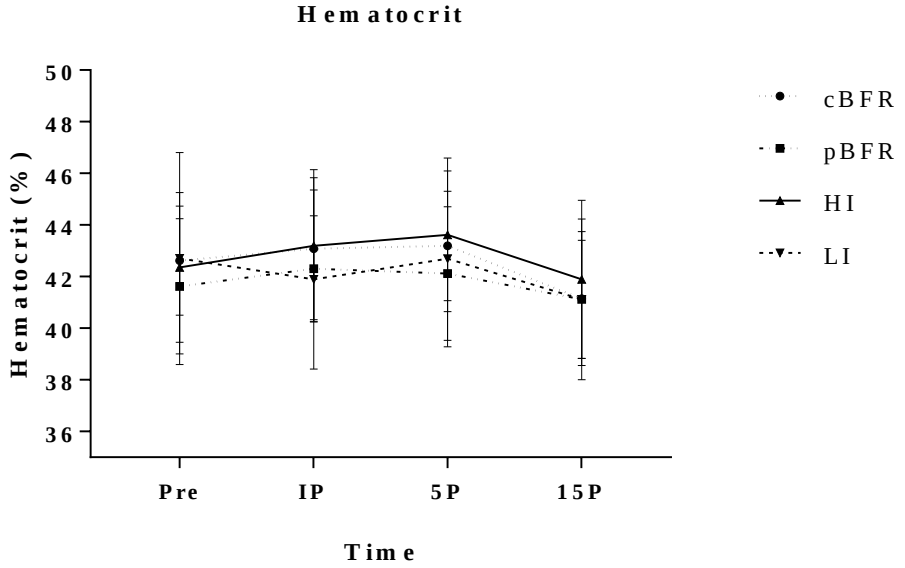
A 2-way ANOVA analysis revealed no significant condition main effect (p = 0.071) or condition by time interaction (p = 0.198) for plasma volume changes. However, Table 6 displays that there was a significant time main effect ($p \leq 0.001$), where a post hoc comparison demonstrated that percent of plasma volume change (%PVC) from pre-exercise to IP was significantly different than changes from pre-exercise to 15P ($p \leq 0.001$), as well as from pre-exercise to 5P and pre-exercise to 15P ($p \leq 0.001$). However, no significant difference was observed between %PVC pre-exercise to IP and %PVC Pre to 5P (p = 0.781), as illustrated on Table 6 and Figure 3.

Table 7. Hematocrit and % Plasma Volume Change Main Effects (*n* = 13).

Hematocrit (%)	F	p	η2	Power
Condition	1.232	0.312	0.093	0.302
****Time**	14.618	0.001	0.549	1.000
Condition*Time	1.861	0.066	0.134	0.796
%PVC				
Condition	2.545	0.071	0.175	0.579
****Time**	22.164	0.001	0.649	1.000
Condition*Time	1.477	0.198	0.11	0.539

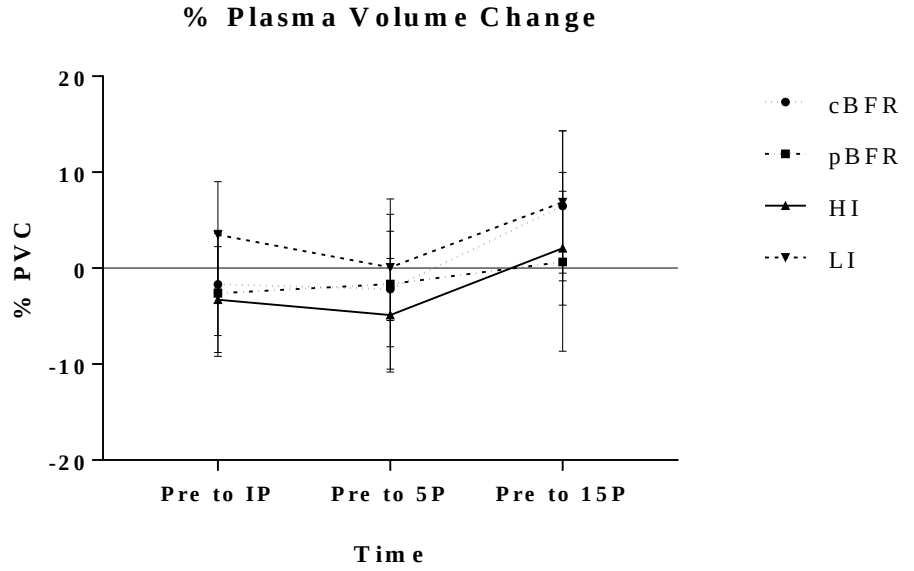
*F: Ratio of mean squares; p: Probability, *p ≤0.05 and **p ≤0.01 for statistical significance; η2: Eta Squared, effect Size.*

Figure 2. Hematocrit changes across different testing conditions and time points.



Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Figure 3. Percent of plasma volume change (%PVC) across different testing conditions and time points.



Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Thigh Circumference

As presented in Table 9, there were no significant condition ($p = 0.746$) or leg ($p = 0.361$) main effects, but there was a significant time main effect ($p \leq 0.001$) for thigh circumference. Additionally, no significant condition by time ($p = 0.725$), condition by leg ($p = 0.585$), or time by leg ($p = 0.112$), or condition by time by leg ($p = 0.603$) interactions were observed.

Table 8. Thigh circumference changes across the different testing conditions and time points (*n* = 15) (Mean ± SD).

		Condition			
Time	**Leg**	**cBFR**	**pBFR**	**HI**	**LI**
Pre	**Left**	54.06 ± 4.31	54.1 ± 4.49	54.13 ± 3.93	54 ± 4.24
	Right	54.08 ± 4.39	54.26 ± 4.64	54.19 ± 3.91	54.23 ± 4.05
IP	**Left**	54.91 ± 4.4[a]	54.85 ± 4.49[a]	54.96 ± 4.31[a]	54.58 ± 4.35[a]
	Right	54.95 ± 4.46[a]	55.19 ± 4.89[a]	55.04 ± 4.17[a]	54.89 ± 4.11[a]
5P	**Left**	54.73 ± 4.29[ab]	54.68 ± 4.53[ab]	54.72 ± 4.31[ab]	54.48 ± 4.31[ab]
	Right	54.73 ± 4.32[ab]	54.95 ± 4.73[ab]	54.88 ± 4.07[ab]	54.79 ± 4.11[ab]
15P	**Left**	54.43 ± 4.25[abc]	54.53 ± 4.39[abc]	54.51 ± 4.29[abc]	54.3 ± 4.34[abc]
	Right	54.42 ± 4.30[abc]	54.61 ± 4.47[abc]	54.59 ± 4.01[abc]	54.47 ± 4.19[abc]

Values are expressed in centimeters (cm). Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity. a: significantly different than pre ($p \leq 0.001$); b: significantly different than IP ($p \leq 0.001$); c: significantly different than 5P ($p \leq 0.001$);

The post hoc pairwise comparison showed that thigh circumference was significantly greater for IP ($p \leq 0.001$), 5P ($p \leq 0.001$), and 15P ($p \leq 0.001$) than pre-exercise measures for all conditions, as presented on Table 8 and Figures 4 and 5. IP measurements also demonstrated higher values when compared to 5P ($p = 0.017$) and 15P ($p \leq 0.001$) as well as 5P was significantly greater than 15P ($p \leq 0.001$).

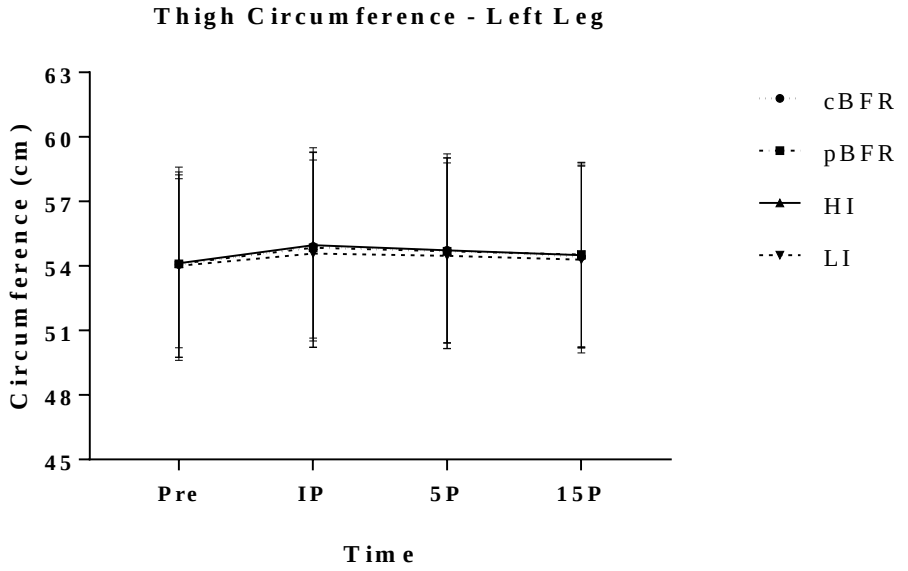
Table 9. Main effects and interactions for thigh circumference measurements (*n* = 15).

	F	p	η2	Power
Condition	0.41	0.746	0.028	0.125
****Time**	72.94	0.001	0.839	1.000
Leg	0.892	0.361	0.06	0.142
Condition*Time	0.681	0.619	0.046	0.216
Condition*Leg	0.653	0.585	0.045	0.175
Time*Leg	2.12	0.112	0.132	0.503
Condition*Time*Leg	0.721	0.603	0.049	0.239

*F: Ratio of mean squares; p: Probability, *p ≤0.05 and **p ≤0.01 for statistical significance; η2: Eta Squared, effect Size.*

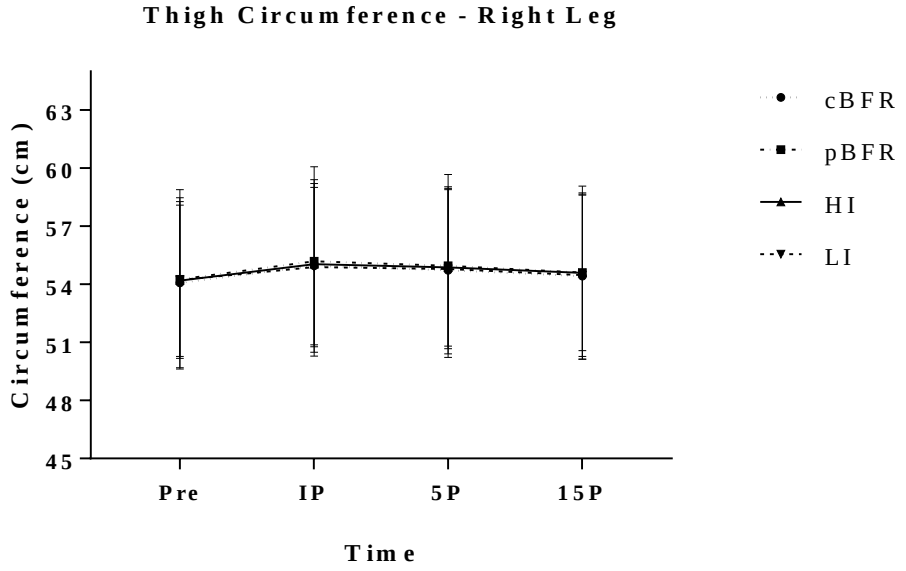
Pearson's correlation coefficients demonstrated that there was a strong positive correlation between left and right legs for thigh circumference at pre-exercise ($p \leq 0.001$, $r = 0.980$), IP ($p \leq 0.001$, $r = 0.980$), 5P ($p \leq 0.001$, $r = 0.979$), and 15P measurements ($p \leq 0.001$, $r = 0.984$) for the cBFR condition. The pBFR condition revealed a strong positive correlation for both legs at pre-exercise ($p \leq 0.001$, $r = 0.991$), IP ($p \leq 0.001$, $r = 0.989$), 5P ($p \leq 0.001$, $r = 0.989$), and 15P ($p \leq 0.001$, $r = 0.994$). The HI condition demonstrated a strong positive correlation between legs at pre-exercise ($p \leq 0.001$, $r = 0.984$), IP ($p \leq 0.001$, $r = 0.976$), 5P ($p \leq 0.001$, $r = 0.973$), and 15P ($p \leq 0.001$, $r = 0.978$). Also, LI showed a strong positive relationship between legs for pre-exercise ($p \leq 0.001$, $r = 0.982$), IP ($p \leq 0.001$, $r = 0.989$), 5P ($p \leq 0.001$, $r = 0.990$), and 15P ($p \leq 0.001$, $r = 0.991$).

Figure 4. Thigh circumference for left leg across different testing conditions and time points.



Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Figure 5. Thigh circumference for right leg across different testing conditions and time points.



Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Muscle Thickness

As displayed in Table 11, a 3-way ANOVA revealed significant time ($p \leq 0.001$) and leg ($p \leq 0.001$) main effects, but no condition main effect ($p = 0.161$) for muscle thickness. No significant condition by time ($p = 0.608$), condition by leg ($p = 0.279$), or time by leg ($p = 0.832$), or condition by time by leg ($p = 0.253$) interaction were found.

The pairwise comparison for the time main effect demonstrated that muscle thickness was significantly different at IP ($p \leq 0.001$), 5min post-exercise ($p \leq 0.001$), and 15min post-exercise ($p \leq 0.001$) when compared to pre-exercise measures for all conditions. IP measurements also demonstrated higher values when compared to 5P ($p = 0.017$) and 15P ($p \leq 0.001$) as well as 5P was significantly greater than 15P ($p \leq 0.001$) for muscle thickness. Additionally, as illustrated on Table 10, the comparison between legs revealed that right leg was significantly different than the left leg ($p = 0.007$).

Table 10. **Muscle Thickness changes across the different testing conditions, time points, and right and left legs (*n* = 15) (Mean ± SD).**

		Condition			
Time	**Leg**	**cBFR**	**pBFR**	**HI**	**LI**
Pre	**Left**	4.73 ± 0.65	4.8 ± 0.66	4.91 ± 0.75	4.8 ± 0.61
	Right	4.91 ± 0.65*	4.89 ± 0.67*	5.03 ± 0.75*	4.8 ± 0.64*
IP	**Left**	5.06 ± 0.66^{a}	5.08 ± 0.7^{a}	5.25 ± 0.79^{a}	5.07 ± 0.63^{a}
	Right	5.19 ± 0.65^{a*}	5.17 ± 0.68^{a*}	5.33 ± 0.8^{a*}	5.16 ± 0.66^{a*}
5P	**Left**	4.97 ± 0.65^{ab}	5.0 ± 0.71^{ab}	5.21 ± 0.82^{ab}	4.97 ± 0.65^{ab}
	Right	5.13 ± 0.66^{ab*}	5.12 ± 0.65^{ab*}	5.27 ± 0.83^{ab*}	5.11 ± 0.63^{ab*}
15P	**Left**	4.96 ± 0.66^{abc}	4.95 ± 0.69^{abc}	5.12 ± 0.77^{abc}	4.93 ± 0.65^{abc}
	Right	5.09 ± 0.66^{abc*}	5.04 ± 0.64^{abc*}	5.23 ± 0.84^{abc*}	5.03 ± 0.62^{abc*}

*Values are expressed in centimeters (cm). Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity. a: significantly different than pre ($p \leq 0.001$); b: significantly different than IP ($p \leq 0.001$); c: significantly different than 5P ($p \leq 0.001$); *Significantly different than left leg ($p \leq 0.05$).*

Table 11. Main effects and interaction for muscle thickness measurements (*n* = 15).

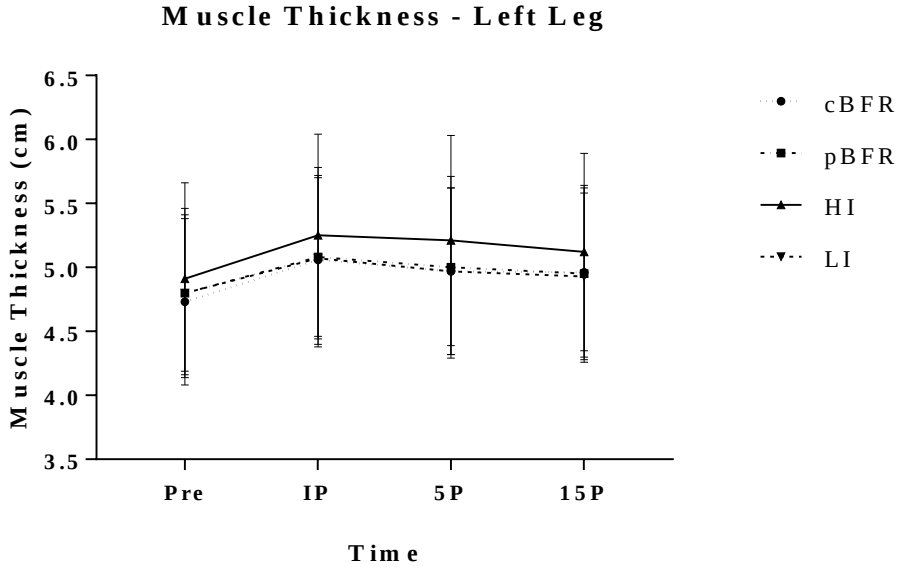
	F	p	η2	Power
Condition	1.804	0.2	0.114	0.248
****Time**	80.046	0.001	0.851	1.000
****Leg**	10.077	0.007	0.419	0.839
Condition*Time	0.81	0.50	0.055	0.214
Condition*Leg	1.324	0.279	0.086	0.327
Time*Leg	0.29	0.832	0.02	0.101
Condition*Time*Leg	1.282	0.253	0.084	0.605

*F: Ratio of mean squares; p: Probability, *p ≤0.05 and **p ≤0.01 for statistical significance; η2: Eta Squared, effect Size.*

Nevertheless, Pearson's correlation coefficients demonstrated a strong positive correlation for cBFR when comparing right and left legs for pre-exercise ($p \leq 0.001$, $r = 0.969$), IP ($p \leq 0.001$, $r = 0.969$), 5min post-exercise ($p \leq 0.001$, $r = 0.974$), and 15min post-exercise measurements ($p \leq 0.001$, $r = 0.971$). For pBFR, there was a strong positive association between legs at pre-exercise ($p \leq 0.001$, $r = 0.986$), IP ($p \leq 0.001$, $r = 0.965$), 5P ($p \leq 0.001$, $r = 0.972$), and 15P ($p \leq 0.001$, $r = 0.977$). The HI condition demonstrated

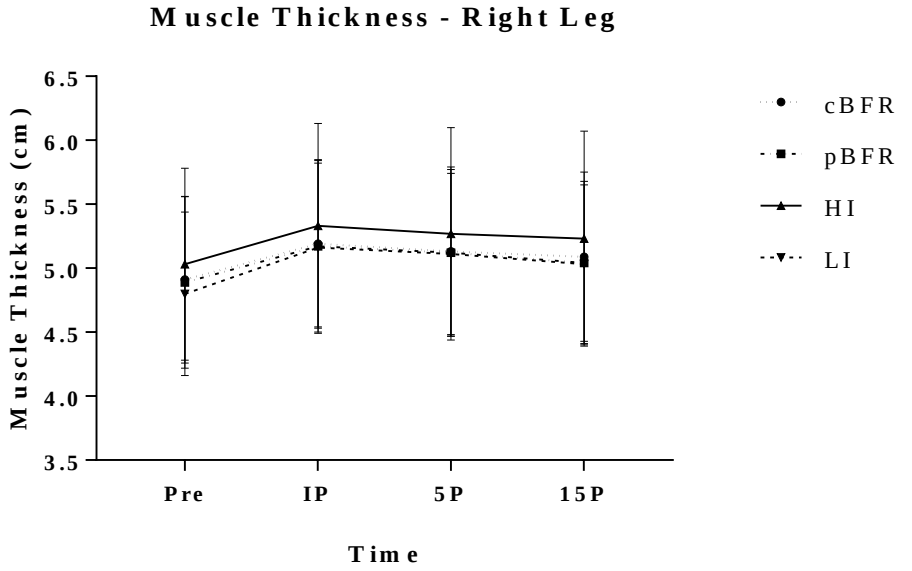
strong positive correlation between legs at pre-exercise ($p \leq 0.001$, $r = 0.983$), IP ($p \leq 0.001$, $r = 0.971$), 5P ($p \leq 0.001$, $r = 0.964$), and 15P ($p \leq 0.001$, $r = 0.975$). Also, LI showed a strong positive relationship between legs for pre-exercise ($p \leq 0.001$, $r = 0.951$), IP ($p \leq 0.001$, $r = 0.969$), 5P ($p \leq 0.001$, $r = 0.951$), and 15P ($p \leq 0.001$, $r = 0.967$).

Figure 6. Muscle thickness for left leg across different testing conditions and time points.



Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Figure 7. Muscle thickness for left leg across different testing conditions and time points.



Pre: Baseline measurements, IP: Immediately post-exercise, 5P: 5 minutes post-exercise, 15P: 15 minutes post exercise; cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Muscle Activation (%Max-RMS)

Two-Leg Press

A 3-way ANOVA compared the first 3 sets of cBFR, pBFR, HI, and LI, and indicated a significant main effect for condition ($p \leq 0.001$) and time ($p \leq 0.001$), as well as a significant condition by time interaction ($p = 0.039$). However, no significant leg main effect was found ($p = 0.481$). Additionally, no significant condition by leg ($p = 0.183$) or time by leg ($p = 0.325$) or condition by time by leg ($p = 0.664$) interactions were reported for muscle activation on leg press (Table 13).

Table 12. Muscle activation changes across 4 sets, different testing conditions, and both right and left legs on two-leg press exercise (n = 15) (Mean ± SD).

		Condition			
Time	**Leg**	**cBFR**	**pBFR**	**HI**	**LI**
1st Set	**Left**	35.8 ± 8.31	38.94 ± 24.2*	88.74 ± 18.18$^{*\#}$	33.5 ± 8.35
	Right	33.13 ± 9.09	32.64 ± 8.31*	93.65 ± 19.39$^{*\#}$	30.96 ± 9.1
2nd Set	**Left**	31.74 ± 9.34^{a}	38.49 ± 23.88*	86.68 ± 13.53$^{*\#}$	33.13 ± 9.21
	Right	30.52 ± 9.9^{a}	29.94 ± 8.69*	90.26 ± 20.08$^{*\#}$	28.94 ± 6.55
3rd Set	**Left**	28.76 ± 7.43^{a†}	37.7 ± 21.1*	83.37 ± 14.4$^{a\#}$	33.56 ± 7.92
	Right	38.94 ± 10.37^{a†}	30.82 ± 9.43*	88.63 ± 16.73$^{a\#}$	30.05 ± 7.57
4th Set	**Left**	29.56 ± 7.29^{a}	36.68 ± 21.83^{a}	N/A	34.14 ± 8.12
	Right	28.54 ± 10.13^{a}	30.41 ± 7.96^{a}		29.57 ± 6.1

*Values are expressed as %Max-RMS (percent of muscle activation relative to the highest RMS on 1RM). cBFR: Control blood flow restriction, pBFR: Practical blood flow restriction, HI: High intensity, LI: Low Intensity. a: significantly different than 1st set ($p \leq 0.001$); b: significantly different than 2nd set ($p \leq 0.001$); c: significantly different than 3rd set ($p \leq 0.001$); *significantly different than cBFR and LI ($p \leq 0.001$); # Significantly different than pBFR; † significantly different than LI ($p \leq 0.001$).*

Further analysis revealed that during cBFR, muscle activation was significantly greater during the 1st set when compared to 2nd and 3rd sets ($p \leq 0.001$). However, no significant difference was observed between 2nd and 3rd sets (p = 0.053). Also, no significant difference was observed in muscle activation across the time points for the pBFR condition (p = 0.078). For the HI protocol, a significant increase in muscle activation was observed from 1st to 3rd set (p = 0.020), but no change occurred from first to the second set (p = 0.166), and second to third set (p = 0.293). Additionally, no significant changes were revealed across time for the LI protocol (p = 0.283). For the pairwise comparisons between time (set 1, set 2, and set 3), across conditions (cBFR, pBFR, HI, and LI), cBFR protocol displayed a significant lower muscle activation when compared to HI and pBFR ($p \leq 0.001$) on 1st and 2nd set, while it showed a significantly higher muscle activation than LI on the 3rd set ($p \leq 0.001$). HI demonstrated greater muscle activation compared to pBFR, cBFR, and LI for all sets ($p \leq 0.001$). pBFR resulted in

significantly higher muscle activation than cBFR and LI for all sets ($p \leq 0.001$), and LI was significantly lower than cBFR, HI, and pBFR on 1st and 2nd sets, and significantly higher than cBFR on the 3rd set, as it shows on Table 12, and Figures 8 and 9.

Table 13. Main effects and interactions for muscle activation on Leg Press (n = 15).

3 Sets	F	p	η2	Power
****Condition**	170.264	0.001	0.924	1.000
****Time**	13.457	0.001	0.49	0.995
Leg	0.525	0.481	0.036	0.104
***Condition*Time**	2.338	0.039	0.143	0.779
Condition*Leg	1.694	0.204	0.108	0.318
Time*Leg	1.169	0.325	0.077	0.235
Condition*Time*Leg	0.683	0.664	0.047	0.257
4 Sets				
Condition	1.204	0.302	0.079	0.195
****Time**	11.215	0.001	0.445	0.98
Leg	2.791	0.117	0.166	0.344
****Condition*Time**	4.38	0.001	0.238	0.977
Condition*Leg	0.558	0.488	0.038	0.111
Time*Leg	0.698	0.521	0.047	0.163
Condition*Time*Leg	1.231	0.299	0.081	0.459

*F: Ratio of mean squares; p: Probability, *p ≤0.05 and **p ≤0.01 for statistical significance; η2: Eta Squared, effect Size.*

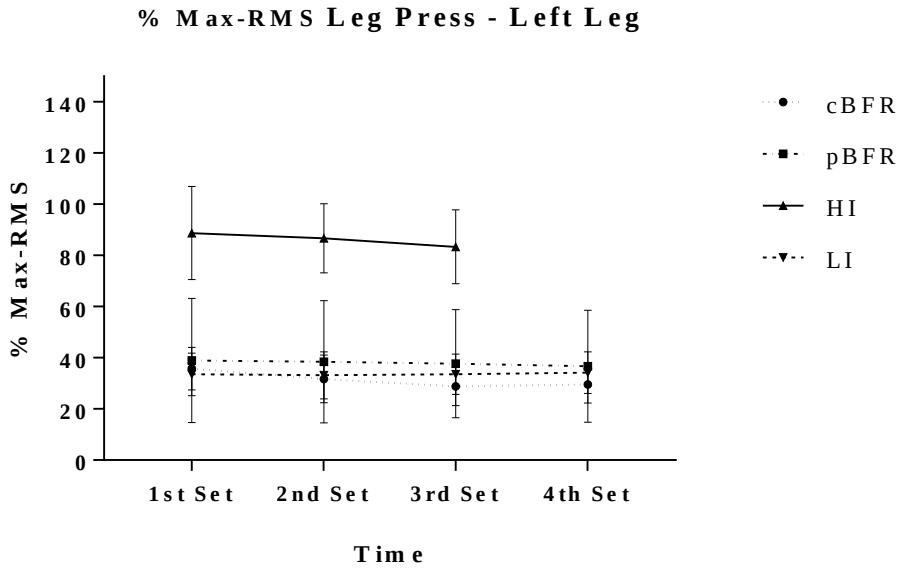
Comparing all four sets of cBFR, pBFR, and LI on leg press, the analysis demonstrated that there was no significant main effect for condition (p = 0.302) or leg (p = 0.117). However, there was a significant time main effect ($p \leq 0.001$) as well as a significant condition by time (p = 0.001) interaction. No condition by time by leg interaction was reported (p = 0.299) (Table 13).

Further analysis revealed that 1st set on cBFR was significantly greater than all sets ($p \leq 0.05$). No significant change was found between the 2nd set, and 3rd (p = 0.107) and 4th sets (p = 0.429) as well as no significant difference was found between 3rd and 4th sets (p = 1.00). pBFR showed a significantly greater muscle activation for 1st set compared to the 4th set (p = 0.004). However, no differences were found between other

sets ($p > 0.05$). No significant differences were found across sets for LI ($p = 0.404$). Looking at the pairwise comparisons between time (set 1, set 2, set 3, and set 4) across conditions (cBFR, pBFR, and LI), there was no significant differences between conditions across sets ($p > 0.05$).

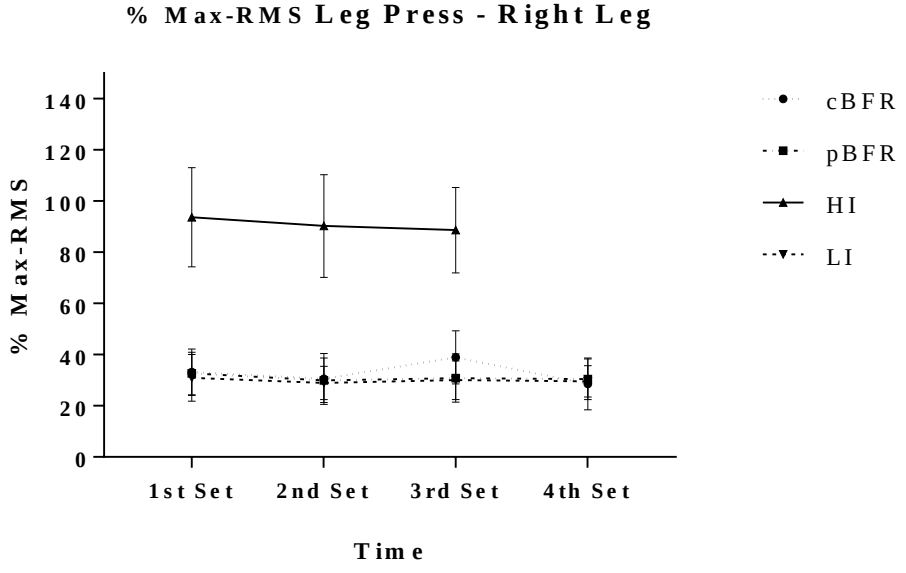
Pearson's coefficient correlations showed a significantly low positive correlation between right and left legs for cBFR on the first set ($p = 0.019$, $r = 0.595$), and 2nd set ($p = 0.023$, $r = 0.580$). However, there was no significant relationship between legs for 3rd ($p = 0.348$, $r = 0.260$), and 4th set ($p = 0.132$, $r = 0.407$). For pBFR, no significant correlations were found between legs for set 1 ($p = 0.750$, $r = 0.090$), set 2 ($p = 0.814$, $r = 0.067$), set 3 ($p = 0.649$, $r = 0.128$), and set 4 ($p = 0.879$, $r = 0.043$). Also, HI showed a significant low positive relationship between legs for set 1 ($p = 0.035$, $r = 0.547$), although no significant relationship between legs were found for set 2 ($p = 0.144$, $r = 0.396$), and set 3 ($p = 0.393$, $r = 0.238$).

Figure 8. Percent of muscle activation relative to the highest RMS on 1RM for left leg across different testing conditions and time points.



%Max-RMS: Percent of muscle activation relative to the highest RMS on 1RM. cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Figure 9. Percent of muscle activation relative to the highest RMS on 1RM for right leg across different testing conditions and time points.



%Max-RMS: Percent of muscle activation relative to the highest RMS on 1RM. cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Knee Extension

The statistical analysis between the first 3 sets of cBFR, pBFR HI, and LI demonstrated no main effect for time (p = 0.852) or leg (p = 0.051). However, as presented on Table 15, a significant condition main effect detected ($p \leq 0.001$), where cBFR showed a significantly higher muscle activation when compared to pBFR (p = 0.026) and LI (p = 0.002), and significantly lower than HI ($p \leq 0.001$). pBFR muscle activation was significantly lower than HI ($p \leq 0.001$) and did not show significant differences when compared to LI (p = 1.00). HI was significantly higher than all conditions ($p \leq 0.05$), and LI was significantly lower than cBFR (p = 0.002) and HI ($p \leq 0.001$). Table 14 and Figures 10 and 11 represents the results for muscle activation across sets and conditions on knee extension.

Table 14. **Muscle Activation changes across sets, different testing conditions, and both right and left legs on knee extension exercise (n = 15) (Mean ± SD).**

		Condition			
Time	**Leg**	**cBFR**	**pBFR**	**HI**	**LI**
1st Set	**Left**	63.59 ± 12.76*	53.02 ± 11.38	101.23 ± 23.01$^{*\#}$	54.58 ± 10.35
	Right	67.32 ± 20.4*	60.3 ± 15.33	103.47 ± 30.55$^{*\#}$	56.8 ± 15.01
2nd Set	**Left**	63.31 ± 12.41*	54.21 ± 11.98	103.71 ± 20.45$^{*\#}$	54.16 ± 12.89
	Right	62.88 ± 12.41*	57.74 ± 14.4	103.43 ± 27.21$^{*\#}$	55.33± 11.13
3rd Set	**Left**	67.56 ± 12.88*	56.92 ± 13.38	97.18 ± 25.01$^{*\#}$	52.83 ± 10.53
	Right	68.97 ± 14.2*	61.21 ± 15.94	101.39 ± 23.41$^{*\#}$	53.92 ± 11.14
4th Set	**Left**	72 ± 12.03^{*bc}	59.28 ± 17.98^{bc}	N/A	58.63 ± 11.14^{bc}
	Right	74.37 ± 16.34^{*bc}	63.77 ± 17.98^{bc}		57.75 ± 11.45^{bc}

*Values are expressed as %Max-RMS (percent of muscle activation relative to the highest RMS on 1RM). cBFR: Control blood flow restriction, pBFR: Practical blood flow restriction, HI: High intensity, LI: Low Intensity. a: significantly different than 1st set ($p \leq 0.05$); b: significantly different than 2nd set ($p \leq 0.05$); c: significantly different than 3rd set ($p \leq 0.05$); *Significantly different than pBFR and LI ($p \leq 0.001$); # Significantly different than pBFR ($p \leq 0.001$); † significantly different than LI ($p \leq 0.001$).*

When comparing all four sets of cBFR, pBFR, and LI, a significant condition main effect was found ($p \leq 0.001$), as well as a time main effect (p = 0.004). However, there was no leg main effect (p = 0.372). No condition by time (p = 0.148), condition by

leg ($p = 0.462$), and time by leg ($p = 0.126$) interactions were found. The post hoc pairwise comparison demonstrated that cBFR had a significantly different muscle activation when compared to pBFR ($p = 0.002$), and LI ($p = 0.001$). Also, pBFR was not significantly different than LI ($p = 1.00$). Studying the time points, pairwise comparisons showed that muscle activation was not significantly different between the 1st set and 2nd, 3rd, and 4th sets ($p > 0.05$). However, the 2nd set showed a significantly different muscle activation when compared to 4th set ($p = 0.009$), although no differences were found between 2nd set and 3rd set ($p > 0.05$). The 3rd set demonstrated a significantly different muscle activation when compared to the 4th set ($p = 0.002$).

Table 15. Main Effects and Interaction for muscle activation on Knee Extension (n = 15).

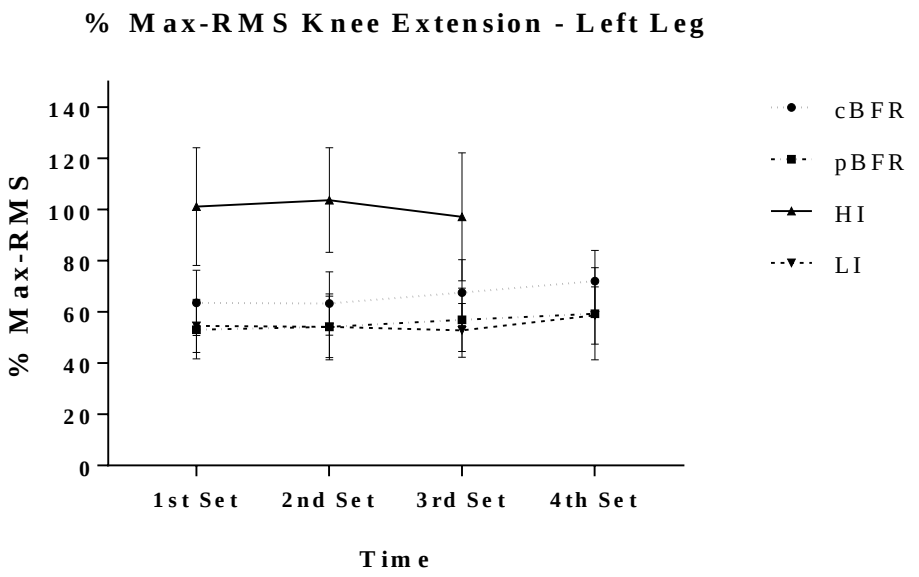
3 Sets	**F**	**p**	**η2**	**Power**
****Condition**	47.648	0.001	0.773	1.00
Time	0.093	0.852	0.007	0.061
Leg	0.745	0.402	0.051	0.127
Condition*Time	2.022	0.127	0.126	0.475
Condition*Leg	0.25	0.750	0.018	0.083
Time*Leg	2.078	0.144	0.129	0.391
Condition*Time*Leg	0.428	0.858	0.03	0.169
4 Sets				
****Condition**	10.291	0.002	0.424	0.927
***Time**	0.15	0.016	0.269	0.744
Leg	0.85	0.372	0.057	0.850
Condition*Time	1.909	0.148	0.12	0.437
Condition*Leg	0.794	0.462	0.054	0.172
Time*Leg	2.021	0.126	0.126	0.482
Condition*Time*Leg	0.394	0.792	0.027	0.09

*F: Ratio of mean squares; p: Probability, *p ≤0.05 and **p ≤0.01 for statistical significance; η2: Eta Squared, effect Size.*

Pearson's correlations coefficient showed a significantly low positive relationship between legs for cBFR at the 2nd set ($p = 0.022$, $r = 0.587$). However, no significant correlation was found between legs for set 1 ($p = 0.187$, $r = 0.361$), set 3 ($p = 0.169$, $r =$

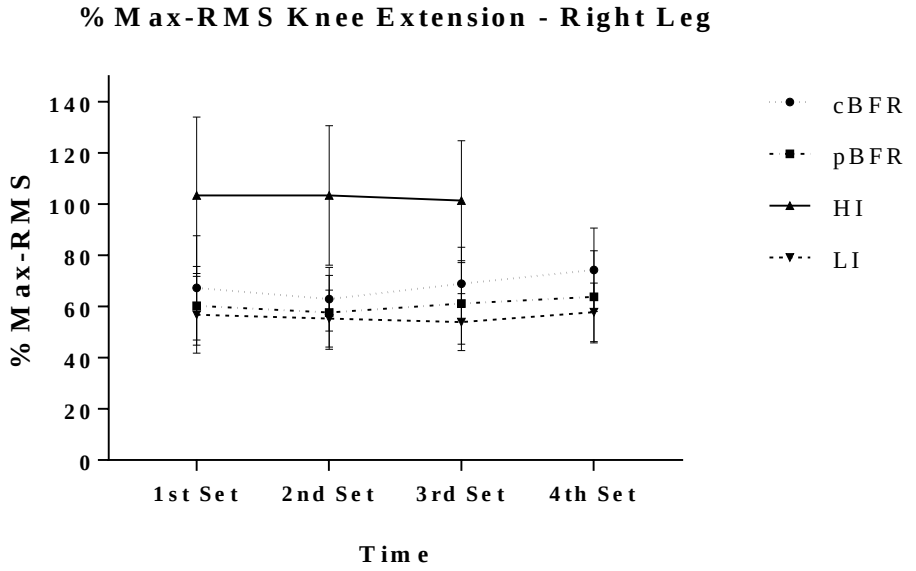
0.374), and set 4 (p = 0.106, r = 0.434). For pBFR, a significant moderate positive relationship was found between legs for 1st (p = 0.002, r = 0.743) and 2nd sets (p = 0.004, r = 0.690). On the other hand, no significant correlation between legs were revealed for 3rd (p = 0.083, r = 0.461) and 4th sets (p = 0.075, r = 0.473). For HI, a significant moderate positive relationship between legs was found for the 1st (p = 0.040, r = 0.534) and 3rd sets (p = 0.030, r = 0.561). However, no significant relationship was identified for the 2nd set (p = 0.078, r = 0.468). LI did not show any significant correlation between legs for set 1 (p = 0.136, r = 0.403), set 2 (p = 0.135, r = 0.405), set 3 (p = 0.109, r = 0.431), and set 4 (p = 0.182, r = 0.364).

Figure 10. Percent of muscle activation relative to the highest RMS on 1RM for left leg across different testing conditions and time points.



%Max-RMS: Percent of muscle activation relative to the highest RMS on 1RM. cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Figure 11. Percent of muscle activation relative to the highest RMS on 1RM for right leg across different testing conditions and time points.



%Max-RMS: Percent of muscle activation relative to the highest RMS on 1RM. cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity.

Rate of Perceived Exertion (RPE)

Leg Press

A Friedman's non-parametric test revealed a significant RPE increase over time for all 4 conditions (cBFR, pBFR, HI, LI) on leg press ($p \leq 0.001$). For cBFR, all sets demonstrated an increase when compared to the 1st set ($p \leq 0.005$), although no difference was found from the 2nd set to the 4th set ($p > 0.005$). For pBFR, there was no difference between the 1st set to the 4th set ($p > 0.005$). HI demonstrated a significant increase from pre-exercise to all sets, as well as from 1st set to 3rd set ($p \leq 0.008$). Additionally, no difference was reported between sets for LI ($p > 0.005$).

A Wilcoxon's correction revealed that there was no significant difference between conditions for pre-exercise value ($p > 0.05$), although a significant difference between conditions was reported for all sets ($p \leq 0.05$). For the 1st and 2nd sets, HI demonstrated higher RPE ratings when compared to pBFR ($p \leq 0.005$), and LI ($p \leq 0.005$), as well as

cBFR was greater than LI ($p \leq 0.005$). No significant difference was reported between cBFR and pBFR, as well as between pBFR and LI for the first 2 sets ($p > 0.005$). However, HI had significantly greater RPE ratings than cBFR, pBFR, and LI for the 3rd set ($p \leq 0.005$). Additionally, cBFR demonstrated higher RPE rating than pBFR and LI ($p = 0.001$), although no difference was reported between pBFR and LI ($p = 0.023$). On the 4th set, cBFR was significantly greater than pBFR and LI ($p = 0.001$), but pBFR was not significantly different than LI ($p = 0.011$).

Knee Extension

A Friedman's non-parametric test showed a significant increase of RPE across time for cBFR, pBFR, and HI on knee extension ($p \leq 0.05$), although no significant difference was reported for LI across time ($p = 0.292$). As illustrated on Table 16, further analysis revealed that no significant time changes were observed for cBFR and pBFR ($p > 0.005$). However, HI demonstrated a significant increase from 1st set to 3rd set ($p = 0.002$), and from 2nd to 3rd set ($p = 0.002$). Analyzing the differences between conditions over time, HI demonstrated significantly higher RPE than pBFR and LI on the 1st set. No differences were reported across other conditions on the 1st set ($p > 0.008$). For the 2nd and 3rd sets, HI indicated a significantly greater RPE than cBFR, pBFR, and LI ($p \leq 0.008$). However, no differences were found between other conditions ($p > 0.008$). Additionally, no significant difference was observed on the 4th set across conditions (cBFR, pBFR, and LI).

Table 16. Ratings of perceived exertion (RPE) across the different testing conditions and time points (n = 15) (Mean ± SD).

	cBFR	pBFR	HI	LI
Leg Press				
Rest	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Set 1	3.80 ± 1.61[a†]	3.00 ± 1.20[a]	5.07 ± 1.79[a*]	2.13 ± 0.92
Set 2	4.90 ± 1.56[a†]	3.00 ± 1.00[a]	6.00 ± 1.25[a*]	2.13 ± 1.19
Set 3	5.30 ± 1.67[a*]	3.33 ± 1.29[a]	6.93 ± 1.22[a*#]	2.33 ± 1.18
Set 4	5.57 ± 1.80[a*]	3.60 ± 1.76[a]		2.40 ± 1.24
Knee Extension				
Set 1	5.93 ± 1.83	5.53 ± 1.85	7.33 ± 1.40[*]	5.60 ± 1.76
Set 2	6.37 ± 1.82	5.63 ± 1.91	8.00 ± 1.07[*#]	5.33 ± 1.50
Set 3	6.67 ± 1.95	5.93 ± 2.09	8.87 ± 1.23[bc*#]	5.73 ± 1.98
Set 4	7.13 ± 2.26	6.33 ± 2.23		5.90 ± 2.14

cBFR: *Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity. a: significantly different than pre-exercise ($p \leq 0.005$); b: significantly different than 1st set ($p \leq 0.005$); c: significantly different than 2nd set ($p \leq 0.005$); d: significantly different than 3rd set ($p \leq 0.005$); *significantly different than pBFR and LI ($p \leq 0.005$); # Significantly different than cBFR ($p \leq 0.005$); † significantly different than LI ($p \leq 0.005$).*

Ratings of Discomfort (RD)

Leg Press

A Friedman's non-parametric test indicated that ratings of discomfort significantly increased across time for all conditions ($p \leq 0.05$) when compared to baseline values for leg press. Further analysis revealed that there was a significant difference between sets 1 and 2, 1 and 3, and 1 and 4 for cBFR ($p \leq 0.005$). Also, the RD was significantly different from 2nd and 3rd sets, as well as 2nd and 4th sets ($p \leq 0.005$). However, no difference was reported between 3rd and 4th sets ($p = 0.022$). For pBFR, there was a significant increase in RD from the 2nd to 3rd set ($p \leq 0.005$), although no differences were identified between other sets ($p > 0.005$). For HI, RD was significantly greater for the 3rd set than the 1st and 2nd sets ($p \leq 0.008$), as well as the 2nd set was significantly greater than 1st set ($p = 0.003$). Additionally, no significant difference was identified between sets for LI ($p > 0.005$).

Examining the differences between conditions across time, a Friedman's analysis demonstrated a significant difference at pre-exercise, where cBFR had a significantly higher RD at rest when compared to HI and LI ($p \leq 0.008$). No differences were identified across other conditions at rest ($p > 0.008$). On the 1st, 2nd, and 3rd sets, cBFR and pBFR demonstrated significantly greater RD when compared to LI ($p \leq 0.008$). Although no significant differences were reported across other conditions for the 1st set ($p > 0.008$), HI was significantly higher than LI on the 2nd and 3rd sets ($p = 0.005$). Comparing cBFR, pBFR, and LI on the 4th set, cBFR RD was significantly greater than pBFR and LI ($p = 0.001$) as well as pBFR was significantly higher than LI ($p = 0.001$).

Knee Extension

For knee extension RD, a Friedman's test revealed a significantly increase from the 1st set to all sets for cBFR, pBFR, and HI ($p \leq 0.05$), although no significant difference was reported between sets for LI ($p = 0.379$). However, further analyses indicated that there was no significant difference between sets for cBFR and LI ($p > 0.008$). For pBFR, there was a significant increase in RD from 2nd to 3rd set, and 2nd to 4th set ($p \leq 0.008$), while no differences were reported between other sets for cBFR, HI, and LI ($p > 0.008$). HI demonstrated significantly greater RD for the 3rd set when compared to 1st and 2nd sets ($p \leq 0.008$), as well as 2nd set RD was significantly higher than 1st set ($p = 0.002$) as illustrated on Table 17.

No differences between conditions across time were reported on the 1st set of knee extension ($p = 0.226$). cBFR demonstrated significantly greater RD than pBFR and LI ($p \leq 0.008$) for the 2nd set, 3rd, and 4th sets. However, no other significant difference was reported between conditions within sets ($p > 0.008$).

Table 17. Ratings of discomfort across the different testing conditions and time points (n = 15) (Mean ± SD).

	cBFR	pBFR	HI	LI
Leg Press				
Rest	0.73 ± 0.75*†	0.49 ± 0.70	0.00 ± 0.00	0.00 ± 0.00
Set 1	2.13 ± 1.23^{a†}	1.44 ± 0.87^{a†}	1.73 ± 2.06^{a}	0.62 ± 0.53
Set 2	3.09 ± 1.57^{a†}	1.32 ± 1.02^{a†}	2.47 ± 2.10^{a†}	0.63 ± 0.51
Set 3	3.79 ± 2.02^{ac†}	1.71 ± 1.32^{ac†}	3.22 ± 2.38^{ac†}	0.73 ± 0.68
Set 4	4.39 ± 2.26^{ac*}	2.01 ± 1.59^{a†}		0.86 ± 0.94
Knee Extension				
Set 1	4.09 ± 2.42	3.07 ± 1.56	2.92 ± 2.54	2.87 ± 1.51
Set 2	4.75 ± 2.45	3.20 ± 1.97^{b}	4.10 ± 2.92^{bc}	2.69 ± 1.34
Set 3	4.95 ± 2.51	3.77 ± 2.37^{bc}	4.89 ± 2.99^{b}	3.14 ± 1.88
Set 4	5.62 ± 2.86	4.17 ± 2.81^{bc}		3.47 ± 2.34

*cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity. a: significantly different than pre-exercise ($p \leq 0.005$); b: significantly different than 1st set ($p \leq 0.005$); c: significantly different than 2nd set ($p \leq 0.005$); d: significantly different than 3rd set ($p \leq 0.005$); *significantly different than pBFR and LI ($p \leq 0.005$); # Significantly different than HI ($p \leq 0.005$); † significantly different than LI ($p \leq 0.005$).*

Total Work Load (TWL)

Analyzing the differences between total workload (TWL) across conditions on leg press exercise, an ANOVA demonstrated a significant time main effect ($p < 0.001$), where pairwise comparisons indicated that HI TWL on leg press was significantly greater than cBFR, pBFR, and LI. However, no significant difference was observed between cBFR, pBFR, and LI on leg press ($p \geq 0.05$). Comparing the TWL across conditions on knee extension exercise, a significant time main effect was found ($p < 0.001$), where HI demonstrated lower TWL than cBFR, pBFR, and LI ($p < 0.001$). However, no significant differences were observed between cBFR, pBFR, and LI on knee extension ($p \geq 0.05$). Total work load values are expressed as kilograms (kg) on Table 3.

A Pearson's correlation coefficient was used to analyze the relationship between TWL on both exercises and percent change for thigh circumference, muscle thickness, lactate, hematocrit, and muscle activation (set 1). Percent changes were calculated as *((IP*

– *pre)/pre) *100.* Table 18 express the *r* values identified in the correlations between TWL and the percent changes.

Table 18. Correlations between total work load (kg) and percent changes (*n* = 15).

		Condition			
Variable	**Exercise**	**cBFR**	**pBFR**	**HI**	**LI**
%TC	**Leg Press**	-0.058	0.487	0.316	-0.05
	Knee Extension	0.236	0.736**	0.449	0.077
%MT	**Leg Press**	-0.045	-0.346	-0.502	-0.284
	Knee Extension	-0.028	-0.121	-0.479	-0.103
%LA	**Leg Press**	0.031	0.659**	0.368	0.54*
	Knee Extension	0.078	0.708**	0.478	0.457
%Hct	**Leg Press**	-0.055	0.618*	0.165	0.304
	Knee Extension	0.217	0.547*	0.347	0.348
%MA	**Leg Press**	0.144	-0.418	-0.17	0.15
	Knee Extension	0.43	0.412	-0.014	0.525*

*Values expressed as absolute r values. **p ≤ 0.01; *p ≤ 0.05. cBFR: Controlled blood flow restriction; pBFR: Practical blood flow restriction; HI: High intensity; LI: Low Intensity; %TC: Percent change from pre to immediately post exercise for thigh circumference on right leg; %MT: Percent change from pre to immediately post exercise for muscle thickness on right leg; %LA: Percent change from pre to immediately post exercise for lactate; %Hct: Percent change from pre to immediately post exercise for hematocrit; %MA: Percent of muscle activation on set 1.*

Discussion

The purpose of this study was to compare the effects of a single bout of controlled blood flow restriction (cBFR), practical blood flow restriction (pBFR), high intensity (HI), and low-intensity (LI) with no restriction resistance exercise on muscle swelling, and lactate responses, and muscle activation in college-aged females. To the best of our knowledge, this was the first study to compare the differences between the two BFR methods as well as examine the issue of limb symmetry following controlled and practical implementation of blood flow restriction.

Muscle Swelling

The results of this study demonstrated an increase in muscle swelling after exercise, based on thigh circumference and muscle thickness for all testing conditions.

There was no difference between conditions for muscle swelling, hematocrit, and %PVC, which partially contradicted our original hypothesis that high intensity (HI) and controlled blood flow restriction (cBFR) would stimulate greater physiological responses than practical blood flow restriction (pBFR) and low-intensity (LI). However, it is important to noticed that percent changes in muscle thickness were greater the coefficients of variation (4.28% for right leg) for all conditions, implying true increases in muscle swelling.

Although no differences were reported between conditions, the results are in agreement with Freitas et al. (2017), which indicated that exercising with blood flow restriction stimulates an increase in muscle swelling for up to 15 min post-exercise for both cBFR and HI conditions in males. Since no differences between HI and cBFR were reported in the present study and for Freitas et al. (2017), it can be implied that both exercise protocols are capable of inducing similar physiological responses that ultimately lead to muscle swelling to a similar extent. Practical BFR also showed a similar muscle swelling responses as HI in the present study, which was also demonstrated by Wilson et al. (2013). Using a similar protocol, the authors observed that after pBFR exercise, muscle thickness remained higher than baseline values for about 15 min post-exercise. However, in contrast to the present investigation, Wilson et al. (2013) observed greater muscle swelling during the pBFR protocol than the control trial. Differences in findings may be explained by variations in protocol, where the present study protocol implemented two exercises and Wilson et al. (2013) only one.

The low-intensity (LI) protocol demonstrated similar muscle swelling response as the HI and both BFR protocols. This result could be related to muscle fatigue. Although

no restriction was applied for this condition, the exercise volume might have been enough to cause a muscular stress equivalent to those observed in the HI and BFR conditions, as demonstrated by increased lactate levels. Yasuda et al. (2015) analyzed the differences between BFR and non-BFR LI exercise to volitional fatigue and reported that BFR exercise achieved the same metabolic responses as LI, but at a much lower volume.

Hematocrit levels did not increase over time and, consequently, %PVC did not decrease over time in this study. Blood flow restriction exercise is known to induce muscle swelling, which is commonly associated with increased hematocrit levels and decreased percent plasma volume change. These responses have been generally associated with an acute accumulation of metabolites and a reduced oxygen availability within the muscle, leading to a change in the pressure gradient and a fluid shit from the extracellular to the intracellular space (Freitas et al, 2017; Loenneke et al., 2012b; Wilson et al., 2013; Yasuda et al., 2015; Suda et al., 2009).

The responses of hematocrit and %PVC in the current research might be related to the fact that subjects had a variety of posture changes over the exercise session and during post exercise data collection. Leg press exercise was performed in the supine position whereas knee extension was performed in the seated position, and the post measurements were taken while participants were standing, unless feeling faint and allowed to sit between post-exercise measures. Therefore, changes in posture may have impacted hematocrit variables, leading to a misrepresentation of plasma volume shifts, since significant increases in thigh circumference and muscle thickness were reported (Jacob et al., 2005). Additionally, it is important to notice that some of our participants demonstrated pre-exercise hematocrit values higher (51%) than the expected average for

females, which normally range between 35% to 45% (Zeng et al., 2001). Above average hematocrit levels might be related to the fact that some of the participants might have been dehydrated during the study or due to possible errors in measurements.

Loenneke et al. (2012b) hypothesized that as the muscle cells increase water volume and equilibrate the osmotic gradient, they may potentially activate molecular signaling pathways that may ultimately induce protein synthesis and consequent muscle hypertrophy. These mechanisms involving fluid shifts within the muscle cells might stimulate the activation of a G-protein, leading to an activation of mammalian target of rapamycin (mTOR), and mitogen-activated protein-kinase (MAPK) pathways, known to play a key role in the regulation of muscle growth (Fry et al., 2010).

In the present investigation, the right leg demonstrated greater muscle thickness than the left leg at all-time points. The majority of the participants (93%) in this study declared themselves right leg dominant and no limb differences in muscle thickness were found across all testing conditions. Therefore, the variations in limb size might be related to the fact that dominant leg knee extensors were stronger than the ones in the non-dominant leg in females, potentially indicating differences in muscle size (Lanshammar et al., 2011). Even though a difference was reported between legs, muscle swelling appears to happen to the same extent in both legs, as indicated by the Person's coefficient correlation. The results demonstrated that the right and left legs were highly correlated at all-time points for muscle thickness and thigh circumference, indicating that they responded in a similar fashion across all time points.

Metabolic Stress

According to the results of this research, lactate responses were larger for HI and cBFR when compared to pBFR and LI conditions, with HI inducing greater increases than all conditions. Also, statistical analysis demonstrated that for HI, lactate levels decreased at a much slower rate, as it did not show differences from IP to 5P (Figure 1). The lactate responses in this study are not in agreement with the results from Takarada et al. (2000b), which observed greater lactate levels with cBFR exercise than for HI exercise. The authors speculated that this response was due to the fact that BFR exercise usually involves greater volumes (about 75 repetitions) in comparison to HI exercise (about 30 repetitions).

Additionally, Loenneke et al. (2010) showed that lactate levels were similar between pBFR and LI protocols, while in this study, pBFR demonstrated higher lactate levels than the LI condition. These discrepancies might be related to the fact that lactate might have been diffused more efficiently during the LI, since no blood flow restriction was applied. On the other hand, congruent with this study, Kim et al. (2014) demonstrated significantly higher lactate levels for a traditional high intensity exercise compared to cBFR in young women. The authors intentionally developed a protocol that allowed HI to have a greater total work load (TWL) than cBFR, therefore explaining the greater lactate levels. In the current research, TWL was significantly higher for HI on leg press, but significantly lower on knee extension, when compared to cBFR, pBFR, and LI. The lower TWL for HI on knee extension could be related to the fact that the subjects might have not finished all the repetitions due to the greater muscular stress as demonstrated by the higher lactate levels and increased RPE.

Previously literature suggested that blood flow restriction exercise caused a slower lactate diffusion from the exercising muscles into the bloodstream (Loenneke et al., 2010), which along with other metabolites, might stimulate Insulin Growth Factor-1 (IGF-1) synthesis and secretion. Abe et al. (2005) demonstrated that after 2 weeks of BFR training, serum IGF-1 concentration showed a significant gradual increase, whereas no differences were found for LI. Additionally, Takano et al. (2005) reported that after a single bout of BFR exercise, levels of growth hormone (GH), IGF-1, and vascular endothelial growth factor (VEGF) significantly increased when compared to the control condition. Kim et al. (2014) indicated that GH levels increased to a similar extent for cBFR and HI after a bout of leg press and knee extension exercise, using similar protocols as this study. Although the hormonal responses to exercise are not the only mechanism that accounts for stimulating muscle hypertrophy, it is well documented that these hormones are strongly related to increases in muscle size (Spiering et al., 2008). In this study, cBFR tended to induce greater lactate responses than pBFR, which could potentially lead to greater hormonal responses, ultimately resulting in a greater muscular hypertrophy.

Muscle Activation

Analyzing the electromyography (EMG) results for leg press, HI demonstrated a higher muscle activation than cBFR, pBFR, and LI. This study indicated that muscle activation was higher at set 1 than at any other set for all conditions on leg press, and that there was a trend to decrease for the subsequent sets. For knee extension exercise, no differences across time on the 3 first sets and all 4 conditions were identified, indicating that muscle activation remained similar throughout the exercise. While comparing the 4

sets between cBFR, pBFR, and LI, set 4 demonstrated a greater muscle activation than the previous sets.

The decrease in muscle activation from the 1st to the last set on leg press might be related to the fact that set 1 involved a greater number of repetitions, which could have caused greater increases in lactate levels as well as the decrease in intramuscular pH and decline of phosphocreatine availability, known as factors that may influence early recruitment of fast-twitch fibers (Yasuda et al., 2010; Wernbom et al., 2007). An additional speculation regarding the lower muscle activation during leg press following the first set could be related to the fact that absolute 1RM weights could have been too low to induce muscular fatigue. Additionally, hips and ankle extensor are known to be activated during leg press, potentially leading to a lower activation of vastus lateralis (VL) (Alkner et al., 2000).

When comparing across all 4 conditions, pBFR and HI demonstrated greater muscle activation than cBFR and LI for leg press exercise. However, when comparing cBFR, pBFR, and LI, no differences among conditions were reported. Nevertheless, on the knee extension exercise, HI and cBFR presented a greater overall muscle activation than pBFR and LI, where pBFR had no differences when compared to LI. Practical and controlled BFR have shown to increase muscle activation to greater levels than LI, by inducing neural adaptations to produce greater motor unit recruitment and synchronization after 8 weeks of training (Wilson et al., 2013; Takarada et al., 2000; Yasuda et al., 2015; Yasuda et al., 2008; Takarada et al., 2002).

Congruent with the present data, Wilson et al. (2013) reported that pBFR induced a greater muscle activation than LI after a bout of 4 sets of 30-15-15-15 repetitions on leg

press exercise. Yasuda et al. (2008) tested the changes in muscle activation at different cBFR pressure levels and verified that EMG activity progressively increased throughout the contraction bout at a similar protocol as the present study, demonstrating greater muscle activation at 147mmHg. Yasuda et al. (2015) had subjects perform cBFR exercise to fatigue, showing increases in muscle activation as well. Although these studies demonstrated similarities to the current study, it is important to notice that Yasuda et al. (2015) and Yasuda et al. (2008) performed the cBFR protocols for elbow flexors instead of the quadriceps.

Both BFR conditions demonstrated significant increases in muscle activation during knee extension only, but cBFR appeared to be more effective. Exercising with BFR alters the relationship between energy supply and demand during contractions, where the lack of oxygen, glucose, and free fatty acids caused by the restricted blood flow seems to induce a compensation mechanism, in which additional muscle fibers are recruited (Yasuda et al., 2015). However, cBFR demonstrated a higher blood lactate concentration than pBFR, which could partially explain a greater energy mismatch, therefore increasing the recruitment of type II fibers as well as stimulating group III and IV afferent fibers (Yasuda et al., 2010). Another probable reason could be related to the differences in occlusion pressure during exercise. Finally, differences in cuff size might have also influenced the outcome variables. Loenneke et al. (2012a) demonstrated that wider cuffs (13.5 x 83 cm) restrict arterial blood flow at a lower pressure than narrow cuffs (5 x 135 cm). However, cBFR and pBFR appeareds to indicate similar ratings of exertion (RPE) and ratings of discomfort (RD), which can potentially indicate that pBFR was effective at mimicking the occlusion pressure applied on cBFR. It is important to

notice that both BFR devices used by Loenneke et al. (2012a) were inflatable, which was not the case for the current research. It has been reported that difering levels of compression may alter the metabolite accumulation, and therefore induced greater muscle activation (Yasuda et al., 2008).

Perceptual Response

Overall, rating of perceived exertion (RPE) and rating of discomfort (RD) increased overtime for all testing conditions and exercises. HI demonstrated higher ratings than cBFR, pBFR and LI, especially on knee extension. Although non-parametric analysis was performed separately for leg press and knee extension RPE and RD, knee extension seems to cause greater ratings than leg press. These findings might be a result of the increases in muscle activation and accumulation of metabolites reported in this study, which are known to cause perceived discomfort (Rossow et al., 2012; Wilson et al., 2013). Additionally, an application of a restrictive device may have caused more discomfort during exercise when compared to LI, as demonstrated by higher ratings for cBFR and pBFR. Finally, it is important to mention that the participants in this study seemed to prefer the narrow elastic cuff (pBFR) when compared to the wide inflated cuff (cBFR).

Limitations

This study has several limitations. First, although the participants were instructed to avoid heavy exercises 24h prior to the testing visits, as well as caffeine, alcohol intake 6h prior, and stay hydrated before testing, there is no guarantee these guidelines were followed. Also, even though the technicians strictly followed the 1RM familiarization and testing protocol, participants might have provided poor effort during tests, which

could have directly affected exercises intensities and muscle activation readings. Likewise, strength tests and exercises should be performed unilaterally in order to provide true symmetrical comparisons.

In the present study, leg press and knee extension exercises were used, which are supine and seated exercises, respectively. Posture may have affected some of the collected variables, such as lactate and hematocrit. Another limiting factor involve the contraction time, where some subjects were not able to follow the metronome for their contraction times perfectly. Additionally, perhaps a fixed time frame between testing visits would have provided a more consistent and reliable intensity, by avoiding neurological adaptations on strength, and enhancing the quality of our measurements. The results of this study can only be applied to college-aged recreationally trained females for leg press and knee extension machines. Gender differences in BFR exercise are yet to be investigated. At last, the pBFR device was based upon a perceived pressure, therefore we did not have precise control of the pressure that was being applied to each individual participant.

Chapter V: Conclusion

A single bout of controlled blood flow restriction (cBFR), practical blood flow restriction (pBFR), high intensity (HI), and low-intensity (LI) resistance exercise demonstrated significant increases in muscle swelling, lactate levels, and muscle activation overtime. However, the overall magnitude of these responses was higher for HI and cBFR than pBFR and LI in females. Muscle swelling increased to a similar extent for all conditions, therefore, muscle swelling seems to occur regardless of condition. On the other hand, lactate levels showed higher values for HI and cBFR, demonstrating a possible greater muscular stress than pBFR and LI. Muscle activation was also higher for HI and cBFR on both exercises, indicating that cBFR might be more effective than pBFR on inducing greater fiber recruitment during exercise.

Regarding the symmetrical issue, the exercising condition did not interfere the differences found between legs, which leads to the conclusion that muscle swelling and muscle activation happen to a similar extent for both legs. Therefore, this investigation concluded that HI and cBFR are more likely to induce greater physiological responses when compared to pBFR and LI in college-aged females.

Research Questions

First Research Question

Do the physiological responses differ from a bout of practical BFR, controlled BFR, and no restriction resistance exercise?

Muscle thickness, thigh circumference, hematocrit, and percent of plasma volume changes (%PVC) did not differ between conditions. However, lactate levels and muscle activation were greater for HI and cBFR.

First Hypothesis

Controlled BFR resistance exercise will promote greater muscle activation, muscle swelling, and lactate production in comparison to practical BFR exercise because the applied pressure is controlled and known to be equal on both limbs.

Controlled BFR promoted greater muscle activation and lactate levels than pBFR, however muscle swelling did not differ between conditions, therefore this hypothesis was partially accepted.

Second Research Question

Does controlled BFR produce more symmetrical responses between legs for muscle swelling, thigh circumference, and muscle activation than practical BFR?

No differences were reported between the right and left legs for any of the conditions on thigh circumference and muscle activation. However, muscle swelling demonstrated greater values for left leg regardless of conditions.

Second Hypothesis

Controlled BFR resistance exercise will promote more symmetrical responses between legs for muscle swelling, thigh circumference, and muscle activation than practical BFR.

No differences were observed between legs for thigh circumference and muscle activation. Greater muscle thickness was reported for the right leg at all-time points, although no differences were identified between conditions. Therefore, this hypothesis was not accepted.

Practical Significance

The purpose of this study was to compare the physiological differences of a single bout of cBFR, pBFR, HI, and LI resistance exercise on muscle swelling, lactate, and muscle activation. Along with the main goal of this study, investigators addressed that because of the differences in the pressure application on cBFR and pBFR conditions, there was a potential for an asymmetrical response between legs for muscle swelling and muscle activation. This study demonstrated that the conditions did not influence asymmetrical responses between legs. In practice, this result indicates that BFR application during exercise will provide similar adaptations between limbs.

Additionally, this investigation enforces that cBFR, pBFR, and HI produce similar muscle swelling responses, which could possibly induce muscle hypertrophy. This finding could be beneficial to people with limitations, such as elderly and patients in a rehabilitation process, who are not capable of exercising at high intensity levels. However, it is important to noticed that although pBFR might offer a better practicability on a daily setting, cBFR is more likely to promote greater muscle adaptations as demonstrated by higher lactate levels and muscle activation.

Future Research Directions

Future research should investigate the symmetrical question by analyzing strength and muscle activation at unilateral exercises. Another study should also make comparisons between cBFR and pBFR on males, since males tend to demonstrate higher physiological responses than females. At last, future studies should compare physiological responses between cBFR and pBFR using similar cuff size, as the size might affect the magnitude of the outcome variables.

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Appendix A: Study Documents

701A Consent Version: IRB Number: 8715

Consent Form
University of Oklahoma Health Sciences Center (OUHSC)

Physiological Responses to a Single Bout of Resistance Exercise: Practical vs Controlled Blood Flow Restriction
Principal Investigator: Michael Bemben, PhD

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

Why Have I Been Asked To Participate In This Study?
You are being asked to take part in this study because you are a recreationally active female or a male between the ages of 18 and 30 years old and have met the inclusion criteria.

Why Is This Study Being Done?
The purpose of this study is to compare the differences between gender on the physiological responses of a single bout of practical blood flow restriction and controlled blood flow restriction resistance exercise.

How Many People Will Take Part In The Study?
About 40 people will take part in this study, all at the University of Oklahoma – Norman campus.

What Is Involved In The Study?
If you agree to be in this research study, you will be asked to participate in a total of 6 (six) visits, 2 (two) of those being screening visits and 4 (four) randomized testing sessions.

The first visit will consist of screening tests, consent, questionnaires, and a strength test familiarization (approximately 1.5 hour):

- Physical Activity Readiness Questionnaire (PAR-Q).
- International Physical Activity Questionnaire – will assess your physical activity status
- Menstrual Questionnaire – will assess the participant's menstrual history.
- Body weight and height.
- Brachial blood pressure measurement – You will rest for 5 minutes and your blood pressure will be measured twice using a non-invasive electronic device.

- Ankle-brachial Index – It is a non-invasive procedure that will measure the blood pressure of both arms and legs.

- You will perform two sub maximal strength testing protocols on the following exercises: two-leg press and knee extension. You will begin testing at very light loads and progress to higher loads.

The second visit will consist of one non-invasive blood flow assessment, a 1 Maximum Repetition test (1RM or the maximal amount of weight that a person can successfully lift while maintain proper form) for two-leg press and knee extension, and a familiarization of exercising while wearing the blood flow restriction devices (approximately 1.5 hour):

- Occlusion Pressure Assessment: You will lay supine on the testing table and blood flow restriction cuffs will be placed on both legs. The device will be inflated and deflated several times until the occlusion pressure is reached.

- You will be instructed to inflate the blood flow restriction band around your leg at a pressure of 7, on a scale of 0 to 10, where 0 means no pressure and no pain, and 10 means high pressure with pain.

- You will perform two maximal strength testing protocols on the following exercises: two-leg press and knee extension. You will begin testing at very light loads and progress to your one repetition maximum (1RM) after six to eight total sets.

- You will perform 2 sets of repetitions (15 repetitions then a 1 minute rest followed by 10 repetitions) for two exercises (leg press and knee extension) at 30% of your 1RM wearing the blood flow restriction devices.

The third, fourth, fifth, and sixth visits will be randomized and you will have 3 to 7 days of rest in between. No alcohol or heavy exercise 24 hours prior to each testing visit as well as no caffeine for 6 hours prior to each visit. In these sessions, you will perform a bout of two-leg press and knee extension exercises at four different conditions. Measurements of muscle activation, lactate, hematocrit, thigh circumference, and ultrasound will be taken before and after the exercises (approximately 1.5 hour each):

- Condition 1 (controlled blood flow restriction): You will perform 4 sets of 30-15-15-15 repetitions at 30% of your 1RM wearing an inflatable blood pressure cuff with a minute of rest between sets

- Condition 2 (practical blood flow restriction): You will perform 4 sets of 30-15-15-15 repetitions at 30% of your 1RM wearing the knee wrap with a minute of rest between sets.

- Condition 3 (high intensity without restriction): You will perform 3 sets of 8 to 10 repetitions at 80% of your 1RM with a minute of rest between sets.

- Condition 4 (Control day without restriction): You will perform 4 sets of 30-15-15-15 repetitions at 30% of 1RM without wearing any blood flow restriction device with a minute of rest between sets.

- Muscle activation measurement: Superficial electrodes will be placed on both legs to record the electrical activity of the muscles.

- Blood sample: One of your fingers will be punctured with a lancet device to expose a small drop of blood in order to collect blood lactate and hematocrit samples four times during each session.

- You are going to have two ultrasounds (one for each leg) and two thigh circumference measurements, which will assess muscle thickness and circumference, respectively, of your lower limbs. This will be performed four times during each session.

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 first.

What Are The Risks of The Study?
While participating in this study, there may be some risks involved with performing the maximal strength tests. These risks include musculoskeletal injury during the activity or muscular soreness following the activity. You might experience short term numbness and minor bruising due to the blood flow restriction training; however, it is very unlikely. There may also be unforeseeable risks with participation. You should discuss these with the researcher prior to providing your consent.

Risks and side effects related to the strength testing and blood flow restriction exercise include:

- Muscle numbness;
- Bruising;
- Muscle soreness;

Are There Benefits to Taking Part in The Study?
You may or may not benefit from participation in this study. The possible benefits are being able to determine your maximal strength on two-leg press and knee extension.

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

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 outside the OUHSC that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include the US Food & Drug Administration and other regulatory agencies.. The OUHSC Human Research Participant Program office, the OUHSC Institutional Review Board, and the OUHSC Office of Compliance may also inspect and/or copy your research records for these purposes.

What Are the Costs?
There is no cost to you if you participate in this study.

Will I Be Paid For Participating in This Study?
You will not be reimbursed for your time and participation in this research. You will receive a $15 gift card for completing the study.

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 you are injured during your participation, report this to a researcher immediately. You or your insurance company will be expected to pay the usual charge from this treatment. The University of Oklahoma Norman Campus and the University of Oklahoma Health Sciences Center have set aside no funds 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. 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. 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 Dr. Michael Bemben at 405-325-5211 or mgbemben@ou.edu during the hours of 7:00 am – 6:00 pm and at 405-364-7030 during the hours of 6:00 pm – 7:00 am.

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)	Printed Name	Date
SIGNATURE OF PERSON OBTAINING CONSENT	Printed Name	Date

IRB Office Version Date: 09/21/2016

AUTHORIZATION TO USE or SHARE
HEALTH INFORMATION[1] THAT IDENTIFIES YOU 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: **Physiological Responses of a Single Bout of Resistance Exercise: Practical vs Controlled Blood Flow Restricton**

Leader of Research Team: **Michael Bemben, PhD.**

Address: **1401 Asp Avenue, Norman, OK, 73019**

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

If you decide to sign this document, University of Oklahoma Health Sciences Center (OUHSC) researchers may use or share information that identifies you (protected health information) for their research. Protected health information will be called PHI in this document.

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, government-issued identification numbers, and blood pressure, height, weight, two-leg press strength test, knee extension strength test, electromiography (EMG), blood lactate, hematocrit, ultrasound measures of thigh muscle, and the results of the following questionnaires International Physical Activity Questionnaire (IPAQ), Physical Activity Readiness Questionnaire (PAR-Q), and the menstrual hisory questionnaire.

Purposes for Using or Sharing PHI. If you give permission, the researchers may use your PHI to compare the differences between gender on the physiological responses of a single bout of practical blood flow restriction and controlled blood flow restriction resistance exercise.

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), and when required by law. The researchers may also share your PHI with no one else.

[1] **Protected Health Information includes all identifiable information relating to any aspect of an individual's health whether past, present or future, created or maintained by a Covered Entity.**

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 covered by this document 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 unrelated to this study from OUHSC.

Canceling 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, canceling your permission will not apply to information that the researchers have already used, relied on, or shared or to information necessary to maintain the reliability or integrity of this research.

End of Permission. Unless you cancel it, permission for OUHSC researchers to use or share your PHI for their research will never end.

Contacting OUHSC: You may find out if your PHI has been shared, get a copy of your PHI, or 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 the Research Team Leader permission to share your PHI for the research project listed at the top of this form.

Patient/Participant Name (Print): _____

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

Or

_____ _____
Signature of Legal Representative** Date

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

_____
OUHSC may ask you to produce evidence of your relationship.

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

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE
(October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ
The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ
Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation
Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ
International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information
More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

   ☐ Yes

   ☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

   _____ **days per week**

   ☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

   _____ **hours per day**
   _____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

   _____ **days per week**

   ☐ No moderate job-related physical activity → ***Skip to question 6***

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**
_____ **minutes per day**

This is the end of the questionnaire, thank you for participating.

Subject ID:_____Date:_____

Bone Density Research Laboratory
Department of Health and Exercise Science
University of Oklahoma

MENSTRUAL HISTORY QUESTIONNAIRE

We are asking you to give us as complete a menstrual history as possible. All information is strictly confidential.

Are you pregnant (circle your response)

YES- Do not complete the rest of this form
NO- Continue to section A.

SECTION A: CURRENT MENSTRUAL STATUS

1. Approximately how many menstrual periods have you had during the past 12 months?
(please circle what months you have had a period. This means from this time last year to the present month)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

2. What is the usual length of your menstrual cycle (first day of your period to the next onset of your period)?

_____days. Today is day _____ of your present menstrual cycle.

3. What was the date of the onset of your last period?

4. When do you expect you next period?

5. What is the average length (number of days) of your menstrual flow? _____ days

How many of these days do you consider "heavy"?_____days

6. Do you experience cramps during menstruation (dysmenorrheal)? If yes, how many days does this last?

7. Do you experience symptoms of premenstrual syndrome (i.e., weight gain, increased eating, depression, headaches, anxiety, breast tenderness)? If yes, please list the symptoms.

8. Do you take oral contraceptives or any other medication that includes estrogen and/or progesterone?

   If yes, how long have you been taking this medication?_____

   What is the brand name and dosage of this mediation?_____

Has this medication affected your menstrual cycle (regularity, length and amount of flow)? If yes, indicate changes.

9. Have you taken oral contraceptives in the past? If no, skip to SECTION B.

   If yes, what was the brand name and dosage?_____

   When did you start taking the pill; for how long; and when did you stop taking it?

10. If you answered yes to 9 or 10, did you experience a weight gain and/or a change in appetite as a result of oral contraceptive use? If so, please indicate amount of weight gained. _____lbs

SECTION B: PAST MENSTRUAL HISTORY

1. At what age did you experience your first menstrual period?

2. Were your periods regular (occurring monthly) during the first two years after menstruation began? If not, at what age did your period become regular?

3. Has there been any time in the past where your periods were irregular or absent? If no, skip to question 4. If yes, did these periods coincide with unusual bouts of training, or with a period of stress?

4. If you have had an irregular period due to training please describe (i.e., you have a period in the offseason but only irregular menstruation during preseason and season)?

5. Have you ever consulted a doctor about menstrual problems (specifically, about irregular or missing periods)? If no, skip to question 6.

   Have you ever been diagnosed as having a shortened luteal phase (the time in between periods)?

6. Have you ever consulted a doctor about any problems relating to your hormonal system? If so, please explain.

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.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

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 or GUARDIAN (for participants under the age of majority) _____ WITNESS _____

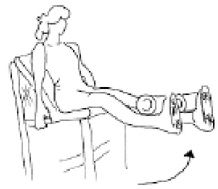
Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

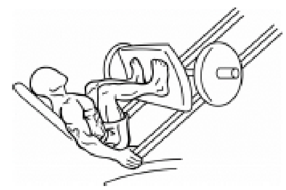
Supported by: Health Canada Santé Canada

continued on other side...

Interested in testing your lower body strength?

Physiological Responses to a Single Bout of Resistance Exercise: Practical vs Controlled Blood Flow Restriction





To Participate

- Males and Females 18 – 30 years old
- Recreationally trained.
- Females taking Hormonal Contraceptives.
- No hip or knee injuries for the past year.

Compensation will be given for the completion of the study.

6 visits required
Total time commitment about 9 hours
Tests will take place at Health and Exercise Science Neuromuscular Lab, University of Oklahoma

If you are eligible and interested, please contact:
Bianca Galletti, biancagalletti@ou.edu or Karolina Koziol, karolina@ou.edu
Department of Health and Exercise Science
Principal Investigator: Michael Bemben, PhD

The University of Oklahoma is an equal opportunity institution. IRB 8715

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Appendix B: Raw Data

	ID	Age	DominantLeg	Weightkg	Heightcm	BMI	SBP	DBP	ABI	Ave_Ocp	@50_Ocp	@1RM_LP
1	BK 05	22.0	1.0	67.0	1.61	25.847768218818715	120.0	68.5	1.10	136.0	68.0	154.20
2	BK 06	22.0	1.0	54.4	1.53	23.238925199709513	114.0	76.5	1.05	129.0	65.0	81.65
3	BK 09	18.0	1.0	68.7	1.64	25.542831647828677	121.5	63.0	1.19	143.0	72.0	157.12
4	BK 12	20.0	1.0	71.9	1.74	23.748183379574580	131.0	78.5	.95	151.0	76.0	104.05
5	BK 14	18.0	1.0	61.1	1.67	21.908279249883467	107.0	62.0	1.12	133.5	67.0	104.14
6	BK15	18.0	1.0	50.0	1.60	19.531249999999996	96.0	59.5	1.18	98.0	49.0	84.50
7	BK20	20.0	1.0	70.3	1.69	24.613984104198035	106.5	75.5	1.15	160.0	80.0	140.05
8	BK 21	20.0	1.0	63.2	1.68	22.392290249433110	114.5	72.5	1.17	132.0	66.0	99.79
9	BK 22	21.0	1.0	65.0	1.57	26.370238143535232	107.0	70.5	1.14	123.5	62.0	108.86
10	BK 24	22.0	1.0	61.2	1.60	23.906249999999996	113.0	64.0	1.15	142.0	71.0	113.22
11	BK 25	23.0	1.0	49.9	1.55	20.770031217481787	118.5	76.5	1.14	131.0	66.0	104.14
12	BK 28	22.0	1.0	72.8	1.74	24.045448540097766	124.0	78.5	1.07	151.0	76.0	108.86
13	BK 29	19.0	1.0	71.9	1.69	25.174188578831277	115.5	82.5	1.03	131.0	66.0	131.36
14	BK 30	20.0	1.0	64.6	1.75	21.093877551020405	112.0	68.5	1.21	124.5	62.0	136.07
15	BK 32	20.0	2.0	63.1	1.66	22.898824212512704	104.5	62.5	1.09	139.5	70.0	131.36

@30_LP	@80_LP	@1RM_KE	@30_KE	@80_KE	Tcpre_L_cBFR	Tcpre_R_cBFR	TCIP_L_cBFR	TCIP_R_cBFR	TC5P_L_cBFR	TC5P_R_cBFR	TC15P_L_cBFR
46.260000000000000	123.36000000000000	90.70	27.210000000000000	72.560000000000000	58.0	59.0	59.0	60.0	58.0	59.0	57.7
24.495000000000000	65.32000000000001	53.93	16.179000000000000	43.144000000000005	50.3	50.5	51.8	52.3	51.2	52.0	50.7
47.136000000000000	125.69600000000001	85.05	25.514999999999997	68.040000000000000	60.9	60.3	62.1	61.5	61.5	60.9	61.3
31.214999999999996	83.24000000000001	56.70	17.010000000000000	45.360000000000010	54.2	54.0	55.3	54.5	55.1	54.4	54.3
31.241999999999997	83.31200000000001	56.70	17.010000000000000	45.360000000000010	52.2	50.0	52.5	50.5	52.5	50.4	52.1
25.349999999999998	67.60000000000001	45.40	13.620000000000000	36.320000000000000	46.5	46.0	47.1	46.3	47.0	46.3	46.7
42.015000000000000	112.04000000000002	76.60	22.979999999999997	61.280000000000000	59.8	59.3	60.7	60.9	60.7	60.9	60.2
29.937000000000000	79.83200000000001	55.38	16.614000000000000	44.304000000000000	51.3	52.0	52.1	52.6	52.1	52.4	51.9
32.658000000000000	87.08800000000001	53.93	16.179000000000000	43.144000000000005	54.6	56.0	55.4	56.8	55.3	56.6	54.8
33.966000000000000	90.57600000000001	56.70	17.010000000000000	45.360000000000010	54.8	54.9	55.6	55.7	55.2	55.2	55.0
31.241999999999997	83.31200000000001	76.50	22.950000000000000	61.200000000000000	48.1	47.8	48.9	49.5	49.0	49.4	49.1
32.658000000000000	87.08800000000001	62.37	18.711000000000000	49.896000000000000	56.0	56.4	56.9	57.0	56.9	56.7	56.6
39.408000000000000	105.08800000000002	65.27	19.581000000000000	52.216000000000000	59.9	59.3	60.7	59.8	60.7	59.7	60.5
40.821000000000000	108.85600000000000	68.00	20.400000000000000	54.400000000000006	51.6	52.2	52.2	52.8	52.3	52.9	52.1
39.408000000000000	105.08800000000002	59.60	17.880000000000000	47.680000000000010	52.7	53.5	53.3	54.0	53.5	54.1	53.5

TC15P_R_cBFR	Mtpre_L_cBFR	Mtpre_R_cBFR	MTIP_L_cBFR	MTIP_R_cBFR	MT5P_L_cBFR	MT5P_R_cBFR	MT15P_L_cBFR	MT15P_R_cBFR	LApre_cBFR	LAIP_cBFR	LA5P_cBFR	LA15P_cBFR
58.0	6.1	6.3	6.7	6.8	6.6	6.8	6.5	6.7	2.2	8.6	8.7	5.8
51.7	4.2	4.5	4.5	4.7	4.4	4.6	4.4	4.5	1.7	8.5	7.9	4.1
60.6	5.7	5.7	5.9	6.0	5.8	5.9	5.8	5.9	1.3	7.9	7.3	3.7
54.0	4.1	4.4	4.6	5.0	4.5	4.9	4.4	4.8	1.5	4.9	5.3	3.8
50.4	4.3	4.2	4.7	4.5	4.6	4.5	4.5	4.4	.9	5.8	5.2	3.7
46.0	4.2	4.3	4.3	4.4	4.2	4.2	4.2	4.2	2.1	4.1	4.1	2.4
60.3	5.5	5.8	5.6	5.9	5.5	5.8	5.6	5.8	1.3	6.4	5.8	3.9
52.3	4.1	4.6	4.6	4.8	4.6	4.7	4.5	4.7	1.3	4.4	3.7	2.1
56.0	4.7	5.0	4.9	5.2	4.8	5.1	4.7	5.1	.8	4.2	3.6	1.9
54.7	4.3	4.5	4.6	4.7	4.6	4.8	4.5	4.7	1.1	5.6	4.0	2.8
48.7	4.2	4.2	4.6	4.8	4.5	4.7	4.6	4.7	1.4	8.4	8.4	5.9
56.7	4.7	4.8	5.0	4.9	4.9	4.9	4.9	4.9	.9	5.5	4.9	2.8
60.0	5.4	5.4	5.7	5.6	5.6	5.5	5.6	5.5	2.2	6.1	6.2	2.8
52.8	5.0	5.3	5.3	5.4	5.2	5.4	5.3	5.3	2.1	3.5	3.1	2.3
54.1	4.5	4.6	4.9	5.1	4.8	5.1	4.9	5.2	1.0	5.1	4.9	2.9

Hctpre_cBFR	HctIP_cBFR	Hct5P_cBFR	Hct15P_cBFR	PVIP_cBFR	PV5P_cBFR	PV15P_cBFR	RepsLP_1S_cBFR	RepsLP_2S_cBFR	RepsLP_3S_cBFR	RepsLP_4S_cBFR	RepKE_1S_cBFR
46.0	47.5	46.0	46.0	-5.8479532163742690	.0000000000000000	.0000000000000000	30.0	15.0	15.0	15.0	30.0
41.0	44.5	44.0	43.5	-13.3307941344505800	-11.5562403697996900	-9.7408922657315400	30.0	15.0	15.0	15.0	30.0
41.0	44.0	42.5	38.5	-11.5562403697996900	-5.9820538384845460	11.0059432093330380	30.0	15.0	15.0	15.0	30.0
43.0	44.5	44.5	43.0	-5.9136605558840920	-5.9136605558840920	.0000000000000000	30.0	15.0	15.0	15.0	30.0
45.0	45.5	46.0	44.5	-1.9980019980019980	-3.9525691699604740	2.0429009193054140	30.0	15.0	15.0	15.0	30.0
43.0	42.0	42.0	37.5	4.1771094402673340	4.1771094402673340	25.7309941520467800	30.0	15.0	15.0	15.0	30.0
39.0	39.0	41.5	40.0	.0000000000000000	-9.8755678451510980	-4.0983606557377055	30.0	15.0	15.0	15.0	30.0
42.0	42.0	43.5	41.0	.0000000000000000	-5.9453032104637330	4.2052144659377630	30.0	15.0	15.0	15.0	30.0
43.5	44.5	43.0	42.0	-3.9773292234264694	2.0580366330520685	6.3211125158027810	30.0	15.0	15.0	15.0	30.0
39.0	38.0	40.0	37.5	4.3140638481449525	-4.0983606557377055	6.5573770491803280	30.0	15.0	15.0	15.0	30.0
44.5	47.0	47.0	45.5	-9.5840521372436260	-9.5840521372436260	-3.9600039600039603	30.0	15.0	15.0	15.0	30.0
45.0	46.5	42.5	43.0	-5.8651026392961870	10.6951871657754000	8.4566596194503170	30.0	15.0	15.0	15.0	30.0
43.0	42.5	42.0	40.0	2.0639834881320950	4.1771094402673340	13.1578947368421040	30.0	15.0	15.0	15.0	30.0
45.0	44.0	46.0	43.0	4.1322314049586780	-3.9525691699604740	8.4566596194503170	30.0	15.0	15.0	15.0	30.0
41.0	40.5	41.0	39.5	2.0924879681941830	.0000000000000000	6.4363870414074230	30.0	15.0	15.0	15.0	24.0

RepKE_2S_cBFR	RepKE_3S_cBFR	RepKE_4S_cBFR	Dis_RestLP_cBFR	Dis_1sLP_cBFR	Dis_2sLP_cBFR	Dis_3sLP_cBFR	Dis_4sLP_cBFR	Eff_Rest_LP_cBFR	Eff_1s_LP_cBFR	Eff_2s_LP_cBFR	Eff_3s_LP_cBFR	Eff_4s_LP_cBFR
15.0	15.0	15.0	.0	3.0	3.0	4.0	6.0	.0	5.0	5.0	6.0	6.0
15.0	15.0	15.0	2.0	2.5	3.0	3.0	3.0	.0	4.0	5.5	5.5	5.5
7.0	15.0	15.0	.0	.5	1.0	2.0	2.0	.0	2.0	3.0	3.0	4.0
15.0	15.0	15.0	1.0	2.5	3.0	5.0	4.0	.0	4.0	5.0	6.0	5.0
15.0	15.0	15.0	1.0	2.0	4.0	4.0	6.0	.0	4.0	6.0	7.0	8.0
15.0	14.0	15.0	1.0	3.0	5.0	6.0	6.0	.0	6.0	7.0	7.0	7.0
15.0	15.0	15.0	.5	2.5	4.0	6.0	7.0	.0	2.0	5.0	5.0	6.0
15.0	15.0	15.0	.0	.5	2.0	3.0	4.0	.0	2.0	4.0	5.0	5.0
15.0	15.0	15.0	.5	2.0	2.5	1.0	1.5	.0	3.0	3.0	3.0	3.0
15.0	15.0	15.0	2.5	5.0	7.0	8.0	9.0	.0	7.0	8.0	8.0	9.0
11.0	10.0	10.0	.0	2.0	2.5	2.5	3.0	.0	4.0	4.0	4.0	5.0
15.0	15.0	15.0	.5	1.5	3.0	5.0	5.0	.0	2.0	5.0	6.0	7.0
15.0	15.0	15.0	1.0	2.0	3.0	3.0	4.0	.0	2.0	2.0	2.0	2.0
15.0	15.0	15.0	.0	.0	.3	.3	.3	.0	5.0	5.0	6.0	5.0
15.0	15.0	15.0	1.0	3.0	3.0	4.0	5.0	.0	5.0	6.0	6.0	6.0

Dis_1sKE_cBFR	Dis_2sKE_cBFR	Dis_3sKE_cBFR	Dis_4sKE_cBFR	Eff_1s_KE_cBFR	Eff_2s_KE_cBFR	Eff_3s_KE_cBFR	Eff_4s_KE_cBFR	MVC_1sLP_L_cBFR	MVC_2sLP_L_cBFR	MVC_3sLP_L_cBFR	MVC_4sLP_L_cBFR	MVC_1sLP_R_cBFR
9.0	10.0	10.0	10.0	8.0	8.0	8.0	9.0	32.80	27.51	26.46	26.98	31.31
3.0	4.0	4.0	4.0	7.0	7.5	8.0	9.0	29.49	26.92	28.21	32.05	25.23
3.0	7.0	7.0	7.0	5.0	7.0	8.0	8.0	31.03	29.89	22.99	28.74	16.67
6.0	6.0	7.0	10.0	7.0	7.0	8.0	10.0	31.43	29.52	32.38	30.48	24.44
7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	45.83	37.50	32.29	30.21	41.23
3.0	3.0	3.0	3.0	8.0	8.0	7.0	8.0	25.40	18.25	14.29	15.08	27.08
2.5	4.0	6.0	8.0	4.0	5.0	7.0	8.0	25.83	25.00	23.33	24.17	38.38
2.0	2.0	2.0	2.0	4.0	4.0	4.0	4.0	33.33	22.58	24.73	26.88	36.23
8.0	5.0	4.0	6.0	7.0	6.0	5.0	5.0	24.56	14.91	16.67	20.18	25.71
4.0	6.0	6.0	7.0	5.0	6.0	7.0	7.0	41.94	36.56	35.48	25.81	42.86
5.0	7.0	6.0	6.0	8.0	9.0	9.0	9.0	40.00	40.00	34.44	33.33	33.33
3.0	4.0	4.0	6.0	5.0	7.0	7.0	8.0	40.00	37.78	40.00	40.00	23.33
2.5	3.0	4.0	4.0	2.0	2.0	2.0	2.0	40.00	41.11	32.22	37.78	47.62
.3	.3	.3	.3	5.0	5.0	5.0	5.0	53.33	41.67	38.33	43.33	42.22
3.0	3.0	3.0	3.0	6.0	6.0	6.0	6.0	41.98	46.91	29.63	28.40	41.38

MVC_2sLP_R_cBFR	MVC_3sLP_R_cBFR	MVC_4sLP_R_cBFR	MVC_1sKE_L_cBFR	MVC_2sKE_L_cBFR	MVC_3sKE_L_cBFR	MVC_4sKE_L_cBFR	MVC_1sKE_R_cBFR	MVC_2sKE_R_cBFR	MVC_3sKE_R_cBFR	MVC_4sKE_R_cBFR	Tcpre_L_pBFR	Tcpre_R_pBFR
27.27	26.26	27.78	63.27	53.74	74.83	85.71	64.91	46.20	69.59	78.95	56.5	56.8
25.23	25.23	25.23	53.76	60.22	60.22	72.04	61.76	60.78	72.55	87.25	50.5	51.5
15.28	13.89	14.81	75.83	51.67	59.17	63.33	128.33	57.50	80.00	79.17	62.4	63.4
21.11	16.67	22.22	57.29	57.29	61.46	78.13	55.56	59.26	64.20	75.31	54.0	54.0
45.61	37.72	42.11	45.33	53.33	54.67	58.67	60.26	66.67	79.49	92.31	51.5	50.3
23.96	27.08	20.83	49.07	61.11	63.89	62.96	61.29	69.89	67.74	70.97	46.9	46.4
26.26	26.26	28.28	71.79	88.46	88.46	91.03	73.91	76.81	92.75	85.51	60.8	60.7
28.99	27.54	30.43	56.41	51.28	50.43	55.56	62.07	59.77	59.77	57.47	51.6	52.0
24.76	23.81	20.00	53.15	53.15	66.67	66.67	43.90	50.41	53.66	57.72	54.5	55.4
46.03	34.92	31.75	69.23	61.54	62.82	64.10	56.19	55.24	48.57	48.57	54.6	54.2
32.72	32.72	32.72	52.56	51.92	54.49	58.97	64.20	54.32	62.96	65.43	47.5	47.5
20.00	18.33	18.33	60.00	70.00	67.78	74.44	72.84	77.78	80.25	90.12	56.1	56.3
46.03	57.14	53.97	78.21	76.92	80.77	84.62	93.59	87.18	84.62	101.28	59.7	59.3
36.67	34.44	36.67	81.67	76.67	71.67	71.67	48.89	45.56	41.11	46.67	52.0	52.4
37.93	26.44	22.99	86.27	82.35	96.08	92.16	62.12	75.76	77.27	78.79	52.9	53.7

TCIP_L_pBFR	TCIP_R_pBFR	TC5P_L_pBFR	TC5P_R_pBFR	TC15P_L_pBFR	TC15P_R_pBFR	Mtpre_L_pBFR	Mtpre_R_pBFR	MTIP_L_pBFR	MTIP_R_pBFR	MT5P_L_pBFR	MT5P_R_pBFR	MT15P_L_pBFR
57.8	59.0	57.1	57.8	57.0	57.4	6.3	6.5	6.7	6.8	6.6	6.5	6.5
51.5	52.0	50.7	52.0	51.2	51.9	3.9	4.0	4.6	4.7	4.4	4.6	4.4
63.7	65.4	63.5	64.5	63.3	63.7	5.6	5.7	6.2	6.3	6.1	6.3	6.0
55.2	55.0	55.0	54.7	55.0	54.6	4.3	4.5	4.6	5.1	4.5	5.0	4.5
52.5	51.2	52.5	51.2	52.2	51.5	4.5	4.5	4.6	4.5	4.5	4.5	4.3
47.6	47.0	47.0	46.7	47.1	46.7	4.2	4.2	4.4	4.5	4.2	4.3	4.2
61.4	62.0	61.2	61.7	60.3	60.4	5.4	5.6	5.7	5.8	5.7	5.7	5.7
51.9	52.2	52.0	52.1	51.7	51.9	4.3	4.6	4.4	4.8	4.3	4.7	4.4
55.1	56.5	54.9	56.3	55.0	55.4	4.8	4.8	4.9	5.2	4.9	5.2	4.7
55.1	54.9	55.0	54.9	54.8	54.1	4.3	4.4	4.6	4.6	4.5	4.6	4.4
48.7	49.0	48.7	48.7	48.6	48.6	4.2	4.4	4.7	4.7	4.7	4.7	4.7
56.7	56.6	56.8	56.7	56.4	56.4	4.8	4.8	4.9	4.9	4.9	4.9	4.8
59.8	59.6	59.9	59.6	59.8	59.7	5.3	5.4	5.7	5.5	5.5	5.5	5.4
52.5	53.0	52.6	53.3	52.3	53.1	5.3	5.2	5.3	5.3	5.3	5.4	5.3
53.2	54.4	53.3	54.1	53.2	53.8	4.8	4.8	4.9	4.9	4.9	4.9	4.9

MT15P_R_pBFR	LApre_pBFR	LAIP_pBFR	LA5P_pBFR	LA15P_pBFR	Hctpre_pBFR	HctIP_pBFR	Hct5P_pBFR	Hct15P_pBFR	PVIP_pBFR	PV5P_pBFR	PV15P_pBFR
6.5	1.1	5.9	5.4	2.7	41.0	43.0	41.5	40.5	-7.8833267638943630	-2.0420665713702270	2.0924879681941830
4.5	2.9	8.2	7.9	4.4	42.0	42.5	44.0	.	-2.0283975659229210	-7.8369905956112860	.
6.1	1.2	8.9	8.7	5.4	36.5	41.5	43.0	39.0	-18.9735319229674640	-23.8051638893975440	-10.0948919846557640
4.9	3.0	6.4	6.9	3.5	41.0	44.0	42.0	42.0	-11.5562403697996900	-4.0355125100887810	-4.0355125100887810
4.5	1.2	5.2	4.6	4.1	45.0	45.0	44.0	42.0	.0000000000000000	4.1322314049586780	12.9870129870129850
4.2	1.7	3.7	3.1	2.3	38.5	38.0	38.0	40.0	2.1394950791613176	2.1394950791613176	-6.0975609756097560
5.7	1.3	7.0	5.9	3.9	41.5	43.5	41.5	41.0	-7.8593182041457890	.0000000000000000	2.0846362309776945
4.6	.9	3.7	2.5	1.9	41.5	41.5	42.5	42.0	.0000000000000000	-4.0221216691804930	-2.0350020350020350
5.1	1.1	4.4	3.4	1.9	45.0	44.5	43.5	46.0	2.0429009193054140	6.2695924764890270	-3.9525691699604740
4.5	.9	4.8	3.1	2.6	40.0	40.0	38.5	41.0	.0000000000000000	6.4935064935064934	-4.0650406504065040
4.7	1.9	9.0	9.1	5.8	45.5	44.5	47.5	45.5	4.1232862591485420	-7.7257363592467400	.0000000000000000
4.8	1.2	3.7	3.0	2.0	43.0	42.5	40.5	37.5	2.0639834881320950	10.8295429932856830	25.7309941520467800
5.3	2.5	6.1	5.1	3.1	41.0	41.0	41.0	41.0	.0000000000000000	.0000000000000000	.0000000000000000
5.3	.6	2.8	1.9	1.3	42.5	43.0	45.0	42.0	-2.0222446916076846	-9.6618357487922700	2.0703933747412010
4.9	1.3	4.5	3.8	1.9	40.0	41.0	40.5	41.0	-4.0650406504065040	-2.0576131687242800	-4.0650406504065040

RepsLP_1S_pBFR	RepsLP_2S_pBFR	RepsLP_3S_pBFR	RepsLP_4S_pBFR	RepKE_1S_pBFR	RepKE_2S_pBFR	RepKE_3S_pBFR	RepKE_4S_pBFR	Dis_RestLP_pBFR	Dis_1sLP_pBFR	Dis_2sLP_pBFR	Dis_3sLP_pBFR	Dis_4sLP_pBFR
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.3	2.0	2.0	3.0	3.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	1.0	1.0	1.0	1.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.3	2.0	.5	1.0	1.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	1.0	1.5	1.5	1.5	1.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	1.0	2.0	2.0	2.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	2.0	3.0	2.5	3.0	3.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.5	1.0	1.0	3.0	4.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.3	.3	.3	.3
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	1.0	.5	.5	.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	2.0	3.0	4.0	5.0	6.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.5	.5	.5	.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.3	2.0	1.5	2.0	2.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	2.0	1.5	1.5	2.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.3	.0	.3	.3
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	1.0	1.0	1.0	1.0	1.0

Eff_Rest_LP_pBFR	Eff_1s_LP_pBFR	Eff_2s_LP_pBFR	Eff_3s_LP_pBFR	Eff_4s_LP_pBFR	Dis_1sKE_pBFR	Dis_2sKE_pBFR	Dis_3sKE_pBFR	Dis_4sKE_pBFR	Eff_1s_KE_pBFR	Eff_2s_KE_pBFR	Eff_3s_KE_pBFR	Eff_4s_KE_pBFR
.0	3.0	3.0	4.0	4.0	5.0	6.0	6.5	7.5	6.0	6.0	7.0	8.0
.0	3.0	3.0	3.0	3.0	2.0	2.0	2.5	3.0	5.0	5.5	6.0	6.0
.0	4.0	2.0	3.0	3.0	5.0	6.0	8.0	9.0	7.0	8.0	8.0	9.0
.0	2.0	2.0	2.0	2.0	5.0	5.0	5.0	8.0	7.0	7.0	6.0	7.0
.0	3.0	4.0	4.0	5.0	4.0	6.0	7.0	7.0	7.0	7.0	8.0	8.0
.0	5.0	4.0	5.0	6.0	2.5	2.5	2.5	2.5	8.0	7.0	7.0	8.0
.0	1.0	3.0	3.0	5.0	2.0	3.0	4.0	4.0	3.0	5.0	6.0	7.0
.0	2.0	2.0	2.0	2.0	.7	.7	.7	.7	4.0	3.0	3.0	4.0
.0	2.0	2.0	2.0	2.0	2.5	1.5	2.0	2.0	4.0	3.0	3.0	3.0
.0	4.0	5.0	6.0	8.0	5.0	5.0	6.0	7.0	7.0	6.0	6.0	7.0
.0	2.0	2.0	2.0	2.0	3.0	3.0	4.0	4.0	8.0	9.0	10.0	10.0
.0	3.0	3.0	3.0	3.0	3.0	3.0	4.0	3.0	4.0	5.0	6.0	6.0
.0	2.0	2.0	2.0	2.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0
.0	4.0	4.0	5.0	4.0	.3	.3	.3	.3	5.0	5.0	5.0	5.0
.0	5.0	4.0	4.0	3.0	2.0	1.0	1.0	1.5	6.0	6.0	6.0	5.0

MVC_1sLP_L_pBFR	MVC_2sLP_L_pBFR	MVC_3sLP_L_pBFR	MVC_4sLP_L_pBFR	MVC_1sLP_R_pBFR	MVC_2sLP_R_pBFR	MVC_3sLP_R_pBFR	MVC_4sLP_R_pBFR	MVC_1sKE_L_pBFR	MVC_2sKE_L_pBFR	MVC_3sKE_L_pBFR	MVC_4sKE_L_pBFR	MVC_1sKE_R_pBFR
30.46	32.76	29.89	32.76	26.77	27.27	28.79	29.80	56.03	53.90	53.90	64.54	68.33
34.85	36.36	34.85	31.82	37.68	30.43	33.33	33.33	62.04	63.89	68.52	67.59	63.89
22.48	22.48	26.36	24.03	12.88	14.39	15.15	14.02	51.28	48.08	48.72	58.33	80.95
24.24	30.30	30.30	25.25	50.00	56.25	56.25	50.00	57.26	53.85	64.96	73.50	54.55
48.72	45.30	47.01	39.32	34.75	34.04	34.75	30.50	66.67	63.19	67.36	58.33	74.31
23.93	24.79	23.08	23.93	33.33	27.27	29.29	29.29	44.14	45.05	54.05	60.36	59.38
27.21	23.13	23.81	27.89	34.31	27.45	24.51	28.43	65.56	77.78	74.44	78.89	72.00
31.18	30.11	32.26	27.96	31.88	26.09	31.88	28.99	41.50	37.41	38.10	42.18	54.44
25.93	28.70	21.30	21.30	25.19	24.44	18.52	20.74	25.93	39.81	50.93	59.26	21.38
121.43	121.43	109.52	111.90	32.32	29.29	30.30	29.29	48.48	47.47	44.44	47.47	49.61
29.73	29.73	34.23	27.93	29.24	26.90	28.07	30.41	51.19	52.98	45.24	40.48	63.81
36.78	39.08	36.78	35.63	31.31	27.27	29.29	29.29	54.76	65.48	64.29	58.33	76.81
43.70	34.07	38.52	37.78	44.19	33.33	36.43	40.31	51.16	58.91	62.79	66.67	54.76
43.06	41.67	36.11	40.28	31.37	31.37	26.47	27.45	47.47	37.37	35.35	36.36	41.23
40.40	37.37	41.41	42.42	34.31	33.33	39.22	34.31	71.79	67.95	80.77	76.92	69.05

MVC_2sKE_R_pBFR	MVC_3sKE_R_pBFR	MVC_4sKE_R_pBFR	Tcpre_L_HI	Tcpre_R_HI	TCIP_L_HI	TCIP_R_HI	TC5P_L_HI	TC5P_R_HI	TC15P_L_HI	TC15P_R_HI	Mtpre_L_HI	Mtpre_R_HI
61.11	68.33	73.89	55.5	56.0	56.9	57.8	56.5	57.5	56.3	56.8	6.1	6.3
72.22	73.15	83.33	51.5	52.4	52.6	53.5	52.2	53.2	51.5	52.8	4.2	4.2
74.29	96.19	104.76	61.7	60.8	63.0	61.4	62.7	61.0	62.4	60.7	5.8	6.0
61.62	51.52	61.62	54.3	54.5	54.6	55.4	54.4	55.2	54.5	54.6	4.2	4.5
64.58	61.11	67.36	51.0	50.5	52.3	51.0	52.3	50.6	51.6	50.3	4.4	4.2
53.13	65.63	63.54	47.4	46.7	47.4	47.0	47.0	47.1	46.9	46.9	4.2	4.2
68.00	73.33	80.00	58.8	59.1	60.0	60.3	59.9	60.0	59.6	59.7	5.4	5.5
48.89	54.44	54.44	52.1	52.0	53.0	52.9	52.6	52.7	52.4	52.6	4.4	4.6
28.30	38.99	40.25	55.4	55.4	56.4	56.2	55.9	56.1	55.7	55.8	6.4	6.7
43.41	44.96	45.74	54.8	54.2	54.9	54.6	54.5	54.5	54.5	54.3	4.4	4.5
61.90	50.00	43.33	48.9	49.0	49.3	49.5	49.3	49.6	49.1	49.5	4.3	4.4
81.16	76.81	78.26	56.1	57.7	56.7	58.5	56.4	58.2	56.4	58.0	4.7	5.0
50.00	58.73	58.73	59.6	58.7	61.7	60.5	61.6	60.4	61.2	60.0	5.5	5.4
36.84	35.96	42.98	51.9	52.4	52.3	53.0	52.1	53.1	52.0	52.8	5.2	5.2
60.71	69.05	58.33	53.0	53.5	53.3	54.0	53.4	54.0	53.5	54.1	4.5	4.7

MTIP_L_HI	MTIP_R_HI	MT5P_L_HI	MT5P_R_HI	MT15P_L_HI	MT15P_R_HI	LApre_HI	LAIP_HI	LA5P_HI	LA15P_HI	Hctpre_HI	HctIP_HI	Hct5P_HI
6.6	6.8	6.6	6.7	6.4	6.7	1.7	8.1	7.3	6.0	40.0	42.0	41.5
4.6	4.7	4.3	4.5	4.3	4.4	1.1	9.2	9.2	5.3	40.5	43.5	45.0
6.0	6.1	6.0	6.1	5.8	6.0	1.0	11.2	9.4	7.8	40.5	43.5	42.5
4.5	5.1	4.5	5.0	4.6	5.0	1.3	7.1	6.9	4.9	44.5	44.0	43.5
4.7	4.6	4.7	4.3	4.6	4.4	1.4	7.2	7.0	5.8	44.0	46.0	48.0
4.4	4.5	4.4	4.3	4.4	4.2	1.9	7.1	5.5	4.3	38.0	39.0	37.5
5.7	5.8	5.7	5.8	5.7	5.8	.8	8.8	9.3	6.2	40.5	41.0	41.5
4.6	4.9	4.5	4.8	4.5	4.7	.9	5.6	5.9	2.9	44.0	43.0	46.0
6.9	7.0	6.9	7.0	6.8	7.0	1.1	4.2	3.8	1.8	44.0	43.0	44.0
4.7	4.6	4.7	4.6	4.6	4.6	1.3	9.8	8.7	5.1	37.0	39.5	41.0
4.8	4.7	4.7	4.7	4.7	4.7	1.6	10.0	9.7	6.3	45.5	47.0	46.0
5.1	5.2	5.0	5.2	4.8	5.1	.8	6.2	5.4	4.1	42.0	42.5	42.5
5.8	5.6	5.8	5.5	5.7	5.5	1.0	7.9	8.5	4.8	42.5	44.0	43.0
5.4	5.5	5.3	5.4	5.1	5.3	1.9	8.9	8.1	4.8	47.0	49.0	48.5
4.9	4.9	5.0	5.1	4.8	5.0	.8	4.8	4.0	2.6	41.0	40.0	43.0

Hct15P_HI	PVIP_HI	PV5P_HI	PV15P_HI	RepsLP_1S_HI	RepsLP_2S_HI	RepsLP_3S_HI	RepKE_1S_HI	RepKE_2S_HI	RepKE_3S_HI	Dis_RestLP_HI	Dis_1sLP_HI
40.5	-7.9365079365079370	-6.0240963855421680	-2.0576131687242800	10.0	10.0	10.0	7.0	8.0	5.0	.0	1.0
42.5	-11.5908432338452610	-16.8067226890756300	-7.9090459713297090	10.0	10.0	10.0	10.0	7.0	7.0	.0	.0
40.5	-11.5908432338452610	-7.9090459713297090	.0000000000000000	10.0	10.0	10.0	10.0	8.0	4.0	.0	3.0
42.0	2.0475020475020480	4.1420731075903490	10.7250107250107240	10.0	10.0	10.0	10.0	8.0	4.0	.0	.7
45.0	-7.7639751552795030	-14.8809523809523800	-3.9682539682539690	10.0	10.0	10.0	10.0	6.0	10.0	.0	6.0
38.0	-4.1356492969396190	2.1505376344086025	.0000000000000000	10.0	10.0	10.0	10.0	10.0	8.0	.0	2.0
41.0	-2.0496003279360524	-4.0498126961628030	-2.0496003279360524	10.0	10.0	10.0	10.0	5.0	9.0	.0	.7
40.5	4.1528239202657815	-7.7639751552795030	15.4320987654320980	10.0	10.0	10.0	7.0	10.0	7.0	.0	.3
43.0	4.1528239202657815	.0000000000000000	4.1528239202657815	10.0	10.0	10.0	6.0	10.0	10.0	.0	.5
37.0	-10.0462125778581480	-15.4858691444057300	.0000000000000000	10.0	10.0	10.0	9.0	8.0	8.0	.0	.5
46.0	-5.8559437829396840	-1.9944156362185879	-1.9944156362185879	10.0	10.0	10.0	5.0	7.0	7.0	.0	1.0
42.0	-2.0283975659229210	-2.0283975659229210	.0000000000000000	10.0	10.0	10.0	10.0	10.0	10.0	.0	6.0
43.0	-5.9288537549407110	-2.0222446916076846	-2.0222446916076846	10.0	10.0	10.0	10.0	10.0	10.0	.0	.0
47.5	-7.7011936850211780	-5.8354405757634710	-1.9860973187686195	10.0	10.0	10.0	9.0	8.0	9.0	.0	.3
39.0	4.2372881355932200	-7.8833267638943630	8.6918730986527580	10.0	10.0	10.0	10.0	6.0	5.0	.0	4.0

Dis_2sLP_HI	Dis_3sLP_HI	Eff_Rest_LP_HI	Eff_1s_LP_HI	Eff_2s_LP_HI	Eff_3s_LP_HI	Dis_1sKE_HI	Dis_2sKE_HI	Dis_3sKE_HI	Eff_1s_KE_HI	Eff_2s_KE_HI	Eff_3s_KE_HI	MVC_1sLP_L_HI
3.0	3.0	.0	5.0	7.0	7.0	3.0	7.0	7.0	6.0	8.0	8.0	79.89
.5	1.0	.0	2.0	5.0	6.0	2.0	2.0	5.0	7.0	8.0	10.0	84.44
4.0	6.0	.0	6.0	7.0	8.0	7.0	9.0	10.0	8.0	9.0	10.0	89.52
1.0	1.5	.0	5.0	6.0	7.0	1.5	2.0	3.0	8.0	9.0	10.0	68.57
7.0	8.0	.0	7.0	8.0	8.0	10.0	10.0	10.0	9.0	9.0	10.0	128.89
3.0	4.0	.0	7.0	7.0	8.0	2.0	2.5	3.0	8.0	9.0	9.0	67.36
2.0	2.5	.0	4.0	5.0	7.0	2.0	4.0	5.0	5.0	8.0	9.0	92.75
.7	2.0	.0	2.0	4.0	5.0	2.0	3.0	5.0	5.0	6.0	7.0	82.83
3.0	3.0	.0	3.0	4.0	5.0	3.0	4.0	4.0	9.0	7.0	8.0	64.04
1.0	3.0	.0	5.0	6.0	8.0	2.0	4.0	6.0	8.0	9.0	9.0	78.89
1.5	2.0	.0	6.0	6.0	7.0	2.0	3.0	3.0	8.0	9.0	10.0	94.62
6.0	7.0	.0	8.0	8.0	9.0	4.0	7.0	8.0	6.0	7.0	8.0	90.48
.0	.0	.0	4.0	5.0	5.0	.0	.0	.0	6.0	6.0	7.0	115.05
.3	.3	.0	6.0	6.0	7.0	.3	.5	.3	8.0	8.0	8.0	111.59
4.0	5.0	.0	6.0	6.0	7.0	3.0	3.5	4.0	9.0	8.0	10.0	82.14

MVC_2sLP_L_HI	MVC_3sLP_L_HI	MVC_1sLP_R_HI	MVC_2sLP_R_HI	MVC_3sLP_R_HI	MVC_1sKE_L_HI	MVC_2sKE_L_HI	MVC_3sKE_L_HI	MVC_1sKE_R_HI	MVC_2sKE_R_HI	MVC_3sKE_R_HI	Tcpre_L_LI	Tcpre_R_LI
80.46	72.99	78.11	73.13	75.62	108.16	106.12	102.72	88.89	82.22	81.67	56.2	57.8
80.00	95.56	78.16	60.92	77.01	133.33	128.33	118.33	189.74	191.03	150.00	51.4	51.7
83.81	81.90	66.67	59.42	65.70	111.11	96.91	69.75	152.27	126.52	110.61	60.6	60.0
68.57	58.57	90.91	93.94	96.97	68.57	68.57	60.00	90.91	93.94	96.97	54.8	54.4
108.89	101.11	116.67	102.50	94.17	94.70	93.94	84.85	106.67	98.00	114.00	50.1	50.3
62.50	58.33	91.67	92.86	83.33	72.92	83.33	75.69	92.16	87.25	88.24	47.1	47.0
81.16	73.91	103.85	98.72	80.77	133.33	112.50	110.42	93.10	93.10	116.09	59.9	60.2
84.85	79.80	120.63	114.29	115.87	141.44	140.54	142.34	104.30	103.23	112.90	52.0	52.7
76.32	74.56	75.31	77.78	71.60	77.54	87.68	90.58	75.93	96.30	87.04	54.5	55.0
83.33	83.33	75.00	73.96	72.92	106.25	104.17	112.50	108.15	97.04	91.85	54.5	54.7
95.70	84.95	82.10	84.57	83.33	75.15	70.91	50.91	66.23	74.12	44.74	47.9	48.1
95.24	84.13	124.24	130.30	116.67	82.14	120.24	110.71	94.87	107.69	117.95	57.3	55.8
101.08	102.15	117.28	107.41	112.35	102.02	114.14	107.07	107.78	112.22	116.67	60.0	59.4
110.14	102.90	105.56	105.56	102.22	105.75	120.69	121.84	86.67	97.14	101.90	51.2	52.3
88.10	96.43	78.57	78.57	80.95	106.06	107.58	100.00	94.44	91.67	90.28	52.5	54.0

TCIP_L_LI	TCIP_R_LI	TC5P_L_LI	TC5P_R_LI	TC15P_L_LI	TC15P_R_LI	Mtpre_L_LI	Mtpre_R_LI	MTIP_L_LI	MTIP_R_LI	MT5P_L_LI	MT5P_R_LI	MT15P_L_LI
56.8	57.9	56.5	57.8	56.4	57.4	6.2	6.3	6.6	6.8	6.5	6.7	6.4
51.5	52.4	51.4	52.1	51.3	51.4	4.2	4.1	4.5	4.7	4.3	4.6	4.3
61.9	61.5	61.8	61.5	61.9	61.4	5.7	5.7	6.0	6.1	5.9	5.9	5.9
55.2	54.7	55.3	55.0	55.1	54.5	4.1	4.4	4.5	4.9	4.3	4.9	4.3
50.9	51.0	50.8	50.9	50.6	50.7	4.4	4.3	4.6	4.4	4.6	4.4	4.6
47.4	47.5	47.4	47.4	47.3	47.2	4.2	4.3	4.5	4.6	4.3	4.5	4.3
60.5	61.0	60.4	60.7	60.2	60.4	5.2	5.7	5.5	5.8	5.4	5.8	5.4
52.4	52.8	52.3	52.6	52.2	52.6	4.3	4.7	4.6	4.7	4.7	4.7	4.4
56.0	56.5	55.5	56.2	55.3	55.8	4.8	4.8	5.1	5.3	5.0	5.2	5.0
55.2	55.0	54.8	54.8	54.6	54.2	4.4	4.5	4.5	4.7	4.4	4.6	4.3
48.4	49.4	48.4	49.3	48.0	48.4	4.4	4.3	4.7	4.7	4.5	4.7	4.5
57.6	56.7	57.2	56.4	56.9	56.3	4.8	4.7	5.0	4.9	4.9	4.9	4.9
60.2	59.9	60.4	60.0	60.1	59.9	5.3	5.3	5.5	5.5	5.5	5.4	5.5
51.7	52.7	52.0	52.9	51.8	52.8	5.2	5.2	5.4	5.4	5.4	5.4	5.3
53.0	54.4	53.0	54.3	52.8	54.1	4.8	4.6	5.0	4.9	4.9	5.0	4.9

MT15P_R_LI	LApre_LI	LAIP_LI	LA5P_LI	LA15P_LI	Hctpre_LI	HctIP_LI	Hct5P_LI	Hct15P_LI	PVIP_LI	PV5P_LI	PV15P_LI
6.5	1.3	8.1	6.7	3.9	41.0	43.0	.	39.5	-7.8833267638943630	.	6.4363870414074230
4.6	1.3	6.5	5.6	2.9	42.5	42.5	43.0	41.0	.0000000000000000	-2.0222446916076846	6.3626723223753970
5.9	1.0	7.6	7.1	4.5	36.5	37.0	37.0	35.0	-2.1281123643328370	-2.1281123643328370	6.7491563554555680
4.7	1.7	6.0	6.3	3.9	43.5	44.5	43.5	42.5	-3.9773292234264694	.0000000000000000	4.1644976574700680
4.5	1.3	4.8	3.8	2.8	45.0	45.0	45.5	44.0	.0000000000000000	-1.9980019980019980	4.1322314049586780
4.3	2.2	5.4	4.4	3.1	36.5	36.0	38.5	39.5	2.1872265966754156	-8.1807955823703860	-11.9605302501744260
5.7	1.3	6.4	6.2	3.5	40.5	40.0	39.5	39.0	2.1008403361344540	4.2548665035634510	6.4641241111829350
4.7	1.7	6.0	6.3	3.9	43.0	41.5	43.5	41.5	6.3411540900443875	-2.0165355918531960	6.3411540900443875
5.0	1.1	4.6	3.7	2.0	45.5	43.5	46.0	44.0	8.4361488980280500	-1.9944156362185879	6.2552126772310250
4.5	.8	5.1	3.8	2.1	39.0	39.0	39.0	38.0	.0000000000000000	.0000000000000000	4.3140638481449525
4.6	2.2	8.0	7.9	5.5	51.0	47.0	49.0	46.0	17.3686495874945730	8.3298625572678060	22.1827861579414400
4.8	.9	3.6	2.6	1.7	42.0	42.0	43.0	39.5	.0000000000000000	-4.0096230954290295	10.9122653862941950
5.4	1.7	6.5	6.7	3.7	42.0	40.5	42.0	40.0	6.3856960408684540	.0000000000000000	8.6206896551724130
5.3	.4	4.9	3.5	2.1	47.5	47.0	44.5	45.0	2.0263424518743665	12.8410914927768850	10.5820105820105800
4.9	1.1	4.2	3.3	1.7	43.0	41.5	44.0	40.5	6.3411540900443875	-3.9872408293460926	10.8295429932856830

RepsLP_1S_LI	RepsLP_2S_LI	RepsLP_3S_LI	RepsLP_4S_LI	RepKE_1S_LI	RepKE_2S_LI	RepKE_3S_LI	RepKE_4S_LI	Dis_RestLP_LI	Dis_1sLP_LI	Dis_2sLP_LI	Dis_3sLP_LI	Dis_4sLP_LI
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.5	.5	.5	.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.0	.0	.0	.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.7	1.0	1.0	1.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	1.0	.7	.7	.7
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	1.0	1.5	2.0	2.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	1.0	1.0	1.0	1.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	1.0	1.0	2.0	2.5
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.3	.3	.3	.3
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.5	.3	.3	.3
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	2.0	1.5	1.5	3.0
30.0	15.0	15.0	15.0	30.0	15.0	11.0	12.0	.0	.0	.3	.3	.3
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.3	.3	.3	.3
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.7	1.0	1.0	1.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.3	.0	.0	.0
30.0	15.0	15.0	15.0	30.0	15.0	15.0	15.0	.0	.0	.0	.0	.0

Eff_Rest_LP_LI	Eff_1s_LP_LI	Eff_2s_LP_LI	Eff_3s_LP_LI	Eff_4s_LP_LI	Dis_1sKE_LI	Dis_2sKE_LI	Dis_3sKE_LI	Dis_4sKE_LI	Eff_1s_KE_LI	Eff_2s_KE_LI	Eff_3s_KE_LI	Eff_4s_KE_LI
.0	1.0	1.0	1.0	1.0	3.0	4.0	5.0	6.0	5.0	5.0	7.0	8.0
.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	4.0	4.0	4.5
.0	1.0	1.0	2.0	2.0	2.0	2.5	3.0	3.0	4.0	4.0	4.0	4.0
.0	2.0	2.0	3.0	3.0	4.0	4.0	5.0	7.0	7.0	7.0	8.0	8.0
.0	4.0	5.0	5.0	5.0	4.0	4.0	4.0	5.0	7.0	8.0	8.0	8.0
.0	2.0	2.0	2.0	2.0	3.0	2.0	3.0	3.0	5.0	4.0	5.0	5.0
.0	3.0	4.0	4.0	4.0	4.0	4.0	7.0	8.0	6.0	7.0	8.0	9.0
.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.5	5.0	4.0	4.0	4.0
.0	2.0	1.0	1.0	1.0	5.0	3.0	3.0	2.5	9.0	6.0	5.0	5.0
.0	3.0	2.0	3.0	4.0	5.0	3.0	4.0	3.0	7.0	5.0	4.0	5.0
.0	2.0	2.0	2.0	2.0	1.5	2.0	1.5	1.5	8.0	8.0	10.0	10.0
.0	1.0	1.0	1.0	1.0	2.5	4.0	4.0	4.0	5.0	5.0	6.0	6.0
.0	2.0	2.0	2.0	2.0	4.0	4.0	4.0	5.0	3.0	4.0	4.0	4.0
.0	3.0	3.0	3.0	3.0	.5	.3	.3	.3	6.0	5.0	5.0	5.0
.0	3.0	3.0	3.0	3.0	.5	.5	.3	.3	4.0	4.0	4.0	3.0

MVC_1sLP_L_LI	MVC_2sLP_L_LI	MVC_3sLP_L_LI	MVC_4sLP_L_LI	MVC_1sLP_R_LI	MVC_2sLP_R_LI	MVC_3sLP_R_LI	MVC_4sLP_R_LI	MVC_1sKE_L_LI	MVC_2sKE_L_LI	MVC_3sKE_L_LI	MVC_4sKE_L_LI	MVC_1sKE_R_LI
34.64	35.29	35.29	38.56	32.29	25.00	27.60	27.60	52.05	55.56	54.97	61.40	48.96
39.39	36.36	37.88	39.39	21.14	23.58	21.95	24.39	53.33	54.44	52.22	66.67	32.73
25.81	27.96	31.18	32.26	20.00	18.79	23.03	28.48	51.92	44.23	42.95	46.79	81.82
30.00	25.00	22.50	25.83	24.56	25.44	26.32	23.68	51.35	66.67	64.86	69.37	46.51
45.45	51.52	48.48	49.49	39.88	36.90	38.69	35.71	45.68	36.42	47.53	45.06	57.31
21.97	18.18	21.97	21.97	37.18	33.33	32.05	34.62	37.78	35.56	39.26	40.74	52.63
31.88	33.33	35.51	32.61	31.82	34.85	30.30	27.27	76.77	74.75	75.76	80.81	70.97
34.17	32.50	32.50	34.17	27.08	28.13	30.21	26.04	46.78	45.03	43.27	57.31	45.93
18.30	18.95	22.88	20.26	23.66	27.96	25.81	27.96	45.53	43.09	48.78	59.35	39.17
41.03	30.77	33.33	33.33	34.52	29.76	33.33	33.33	62.96	49.38	49.38	51.85	61.26
33.33	31.25	28.13	32.29	24.86	20.90	25.99	24.29	72.09	70.54	48.84	61.24	71.84
26.85	33.33	33.33	34.26	22.92	21.53	22.22	22.22	51.52	42.42	39.39	45.45	47.75
34.41	39.78	36.56	31.18	52.00	40.00	52.00	45.33	52.25	62.16	61.26	71.17	64.10
35.90	33.33	35.90	38.46	29.17	30.21	31.25	28.13	54.76	65.48	64.29	58.33	82.80
49.33	49.33	48.00	48.00	43.33	37.78	30.00	34.44	63.89	66.67	59.72	63.89	48.15

MVC_2sKE_R_LI	MVC_3sKE_R_LI	MVC_4sKE_R_LI
46.88	48.96	54.69
36.36	35.15	41.82
62.88	62.12	68.94
57.36	58.14	64.34
56.14	54.39	49.71
57.89	60.53	57.89
66.67	73.12	78.49
42.96	46.67	55.56
45.83	44.17	49.17
55.86	52.25	60.36
67.82	47.13	51.15
45.05	47.75	50.45
78.63	76.92	81.20
60.22	56.99	58.06
49.38	44.44	44.44