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Acute and chronic skeletal muscle response to very low load resistance exercise with and without the application of blood flow restriction in the upper body

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ACUTE AND CHRONIC SKELETAL MUSCLE RESPONSE TO VERY LOW LOAD RESISTANCE EXERCISE WITH AND WITHOUT THE APPLICATION OF BLOOD FLOW RESTRICTION IN THE UPPER BODY

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ABSTRACT

This study examined the acute and chronic effects of resistance exercise with and without blood flow restriction (BFR) on skeletal muscle. **Methods**: The acute study examined changes in torque, muscle thickness (MTH), and surface electromyography (EMG) in response to resistance exercise with high load [70% 1RM,(7000)], low load [15% 1RM,(1500)], low load with moderate (BRF) [15% 1RM+40%BFR(1540)], or low load with greater BFR [15% 1RM+80%BFR(1580)]. The chronic study investigated changes in MTH, strength, and endurance following 8-weeks. **Acute results:** Following exercise, the 7000 condition had lower ($p<0.05$) MTH [4.2(1.0) cm] compared to the 1500 [4.4 (1.1)cm], 1540 [4.4(1.1)cm], and 1580 [4.5(1.0cm] conditions. This continued 15 minutes post. Immediately following exercise torque was ($p<0.05$) lower in the 1500 [31.8 (20) Nm], 1540 [28.3(16.9) Nm] and 1580 [29.5 (17) Nm] conditions compared to the 7000 condition [40 (19) Nm]. 15 minutes post, 1500 and 1540 conditions demonstrated lower torque compared to the 7000 condition. For the first three repetitions of EMG the 7000 condition displayed greater amplitude compared to all low load conditions ($p<0.001$). For the last three repetitions percentage EMG was greater in the 7000 compared to the 1580 condition. **Chronic results:** 1RM strength changes were greater in the 7000 condition [2.09 (95% CI=1.35-2.83) kg] compared to all low load conditions. For isometric and isokinetic strength there were no changes. For endurance there was a main effect for time [mean pre to post change = 7.9 (4.3–11.6) repetitions]. At the 50% site, the mean change in MTH in the 7000 condition [0.16 (0.10-0.22) cm] was greater than all low load conditions. For the 60% site, the mean change in MTH [0.15 (0.08-0.22)] was greater than all low load conditions.

For the 70% site there was a main effect for time [mean pre to post change = 0.09 (0.5–0.14 cm].

Conclusions: Very load loads produce a similar acute response regardless of pressure. This response was greater than that observed in the 7000 group. Very low loads produce skeletal muscle growth. However, this response is not as robust as that observed following high load training.

DEDICATION

This dissertation is dedicated to all the individuals whom put up with my absence from their life for the past 4.5 years as I worked on this doctoral degree. It is difficult to be a good son, brother, or friend when spending countless hours in the lab, office and coffee shop.

LIST OF ABBREVIATIONS AND SYMBOLS

AIC	Akaike's Information Criterion
AOP	Arterial Occlusion Pressure
ANOVA	Analysis of Variance
BIC	Bayesian Information Criterion
BFR	Blood Flow Restriction
EMG	Electromyography
MTH	Muscle Thickness
MVC	Maximal Voluntary Contraction
1RM	One Repetition Maximum
1500	15% one repetition maximum with no blood flow restriction pressure
1540	15% one repetition maximum with 40% arterial occlusion pressure
1580	15% one repetition maximum with 80% arterial occlusion pressure
7000	70% one repetition maximum with no blood flow restriction pressure

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#OleMissMuscle for life……Boop, Boop!

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Thank you for the song "On the Nature of Daylight" to which I wrote many of my papers.

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Thank you for writing so many great works, which from time to time helped me clear my mind…and keep my life together.

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CHAPTER 1: INTRODUCTION

Skeletal muscle is a highly malleable tissue, subject to growth and adaptation in response to contractile activity (Coffey & Hawley, 2007; Ozaki, Loenneke, Buckner, & Abe, 2016). Specifically, the performance of resistance exercise often results in skeletal muscle hypertrophy; a complex process involving the conversion of mechanical signals to molecular cascades. These molecular cascades result in the activation or repression of pathways that stimulate gene expression (Drummond et al., 2008) and a protein synthetic response (Phillips, Tipton, Aarsland, Wolf, & Wolfe, 1997). Typically, resistance exercise results in a rate of protein synthesis that is greater than the rate of degradation, resulting in the production of contractile proteins which are added to existing myofibers (i.e., hypertrophy). The exploitation of these pathways through various resistance training protocols will most often result in skeletal muscle growth. Although the stimuli for these molecular pathways are not fully understood, it is believed that both mechanical and metabolic mechanisms play a role in the stimulation of compensatory skeletal muscle growth (Ozaki et al., 2016).

The past several years have greatly increased our understanding of skeletal muscle adaptations. For example, low load resistance training and low load resistance training in combination with blood flow restriction (BFR) have been shown to result in similar muscle hypertrophic changes when compared to traditional high load resistance training (Mitchell et al., 2012; Ogasawara, Loenneke, Thiebaud, & Abe, 2013). Recently, our laboratory has shown that maximally flexing

the elbow flexors throughout a range of motion (no external load) will result in similar skeletal muscle growth as traditional high load resistance training (Counts et al., 2016). Thus, contrary to textbook recommendations (Baechle & Earle, 2008), a variety of training loads (NO LOAD, low load, high load, low load + BFR) can be used to elicit a similar hypertrophic response in skeletal muscle. A recent review by Ozaki and colleagues (2016) discusses the potential of both metabolic and mechanical influence on skeletal muscle growth. For example, more traditional resistance exercise (i.e., 3-4 sets at or near 70% of one repetition maximum) is believed to rely primarily on mechanical mechanisms; whereas low load resistance exercise (i.e., 30% 1RM to failure) is believed to rely on both mechanical and metabolic mechanisms. Presumably, despite varying contribution from metabolic and mechanical stimuli, these protocols work through messengers to transduce this mechanical signal, resulting in the anabolic response. This response is thought to be multifaceted, involving: mechanical stretch; calcium flux, and changes in redox, as well as phosphorylation state within the muscle (Coffey & Hawley, 2007). However, despite our accumulating knowledge of skeletal muscle adaptation, many knowledge gaps still exist. On the forefront of this knowledge gap is blood blow restriction in combination with low load resistance training. Specifically, low load resistance training in combination with BFR has been shown to lead to similar adaptations as traditional high load resistance training (Laurentino et al., 2012; Martin-Hernandez, Marin, Menendez, Ferrero, et al., 2013; Takarada, Sato, & Ishii, 2002; Takarada, Takazawa, & Ishii, 2000), promotes a muscle hypertrophic response when combined with low intensity aerobic exercise (Abe, Kearns, & Sato, 2006), and has been shown to attenuate atrophy during prolonged skeletal muscle disuse (Takarada, Takazawa, & Ishii, 2000). Nonetheless, recent evidence has suggested that the addition of BFR to low load resistance exercise may provide little additional benefit, when exercise is performed to failure.

Counts et al. (2016) found that the application of 40% or 90% of arterial occlusion pressure in combination with low load resistance exercise at 30% of 1RM resulted in similar increases in muscle size and strength following 8 weeks of training in the elbow flexors. This suggested that increasing the restrictive pressure did not add to the anabolic response of BFR exercise. However, this study lacked a control group to compare low load exercise without BFR. Kim et al. (2017) showed that low load resistance exercise (30% of 1RM) with the addition of 50% of arterial occlusion pressure resulted in similar muscle growth as traditional high load resistance exercise (70% 1RM). More recently, it has been demonstrated that the acute skeletal muscle response to low load exercise at 30% of 1RM is not augmented by the application of BFR (Jessee et al., 2017). Specifically, acute muscle swelling, acute torque decrements, and electromyography activity did not change across different arterial occlusion pressures (AOP) of 0%, 10%, 20%, 30%, 50%, or 90% in a small group of trained individuals with fairly high levels of baseline strength. This lack of change in the acute response with the application of increasing pressures led us to question the efficacy of BFR as a tool for increasing skeletal muscle adaptation when exercise is performed to volitional failure. Specifically, does the addition of occlusion pressure provide any stimulus beyond that achieved through performing low load exercise to failure? And secondly, does the application of pressure become more important with very low training loads? In attempt to answer this question, we examined the acute response to *very* low load resistance exercise protocols (10, 15 or 20% of 1RM) with or without the application of BFR (Dankel et al., 2017). This may be an important application of BFR, as very low load resistance exercise may not produce a great level of fatigue on its own. Thus, metabolically induced motor unit recruitment or cell swelling mechanisms produced by BFR

may increase the robustness of this stimulus. The results of this study showed that, with very low loads (<20% 1RM), the application of BFR appeared to increase levels of fatigue as measured through acute torque decrements. These data suggest that BFR may have important applications, particularly when very low loads are utilized. This is supported by the results of Lixandrão et al. (2015) who found that that increasing the relative occlusion pressure from 40% to 80% augmented muscle growth when used with a 20% 1RM load, but had no greater effect when a 40% load was used Thus, restrictive pressures may be more important at lower intensities (i.e., ≥ 20% 1RM) that produce little fatigue on their own.

The mechanisms through which BFR works are not completely understood; however, it is believed that muscle cell swelling, and metabolically induced changes in motor unit recruitment are two of the primary contributors (Loenneke, Fahs, Rossow, Abe, & Bemben, 2012; Loenneke, Fahs, Wilson, & Bemben, 2011; Pearson & Hussain, 2015). Of course, the downstream pathways (e.g., mTORC1) involved in protein synthesis (Gundermann et al., 2014), as well as changes in gene expression involved in muscle function and plasticity (Ellefsen et al., 2015) are likely the same. However, the addition of the restrictive cuff leads to venous pooling within the limb and may influence how the anabolic pathways are stimulated. Recently, the notion that the accumulation of metabolites can stimulate anabolic signaling has been challenged. Specifically, Dankel et al. (2016) showed that 6 weeks of high load resistance exercise, followed by 3 minutes of post-exercise BFR appeared to attenuate skeletal muscle growth in the biceps. Notably, relative to a control performing only high load exercise, females appeared to have an attenuation of growth, and males saw no additional benefit when trapping metabolites in the muscle following high load resistance exercise. Although this does not definitively prove that

metabolites are not important, it provides evidence that they do not directly stimulate anabolic-signaling cascades. This leaves cell swelling and metabolically induced muscle activation as potential mechanisms through which BFR may exert its effects. The cell swelling hypothesis, proposed by Haussinger (1993), suggests that cellular hydration may act as an anabolic proliferative signal, resulting in a shift towards anabolism. However, much of the understanding of cell swelling is derived from research in hepatocyte cells, which demonstrated that blocking insulin-induced hepatocyte cell swelling resulted in a lack of anabolic response (Haussinger et al., 1993; Loenneke et al., 2012). The cell swelling mechanism helps to explain why BFR may attenuate skeletal muscle loss during periods of disuse and may ultimately play a role during all resistance type activities. However, much of this recommendation is still speculation, as this has not been definitively shown in human skeletal muscle. Nonetheless, if this mechanism is important, it may be of increasing importance with lower loads, where mechanical mechanisms are less prominent. Regarding metabolic induced motor unit recruitment, the application of BFR appears to produce high levels of muscle activation as measured through integrated electromyography (Moore et al., 2004; Takarada et al., 2000). However, high levels of activation can similarly be achieved with low load resistance exercise without the application of BFR (Wernbom, Järrebring, Andreasson, & Augustsson, 2009). Of course, it appears that BFR may decrease the number of repetitions necessary to reach failure (Farup et al., 2015); which, interestingly, may be the only unique contribution of BFR on skeletal muscle adaptation combined with low load resistance exercise.

Low load exercise performed to volitional failure appears to elicit a similar skeletal muscle response as low load exercise with the addition of BFR. Thus, it is not presently clear if there is a

point at which BFR is absolutely necessary to elicit an anabolic skeletal muscle response. Meaning, is there a point where the exercise load is too low to elicit an anabolic response without the application of BFR? Our recent acute work seems to suggest that there may be a point where the training load becomes too low to elicit a robust response, making it difficult to reach failure within a reasonable amount of time. This may occur when the load is too low or when an individual has a low level of baseline strength (relative exercise load becomes very low)(Dankel et al., 2017). Based on the current evidence, it appears that metabolically induced motor unit activation and cell swelling may be the sole mechanisms through which BFR exerts its effects. If this is true, BFR may be able to augment the response to very low load resistance training programs, which on their own may not present an anabolic stimulus.

Purpose

The purpose of this study was to compare the acute skeletal muscle response (i.e., acute muscle swelling, acute torque decrements and muscle activity) following a variety of resistance training protocols (i.e. different combinations of arterial occlusion pressure and load) in the upper body. In addition, long-term adaptations of skeletal muscle size, strength and endurance were examined following 8 weeks of these various resistance-training protocols.

Research Question (Acute)

Will the acute skeletal muscle response differ between traditional high load resistance exercise and very low load resistance exercise with and without the application of different blood flow restriction pressures?

Hypothesis

1. It was hypothesized that, acute changes in torque and muscle thickness would be similar across all resistance exercise protocols (15% 1RM; 15% 1RM + 40% AOP; 15% 1RM + 80% AOP; 70% 1RM).
2. It was hypothesized that electromyography amplitude, as measured through EMG would be higher in the high load resistance condition (70% 1RM) compared to all other conditions.

3. Research Question (Chronic)

Will the chronic skeletal muscle adaptations differ between traditional high load resistance exercise and very low load resistance exercise with and without the application of different blood flow restriction pressures?

Hypothesis (Chronic)

4. It was hypothesized that similar skeletal muscle growth would be observed amongst all resistance exercise conditions across the 8 week period.
5. It was hypothesized that isometric and isotonic strength adaptations would be greatest in the traditional high load training condition (70% 1RM), with strength adaptations being similar between all low load conditions (regardless of AOP).
6. It was hypothesized that muscular endurance would change similarly across exercise protocols.

Significance

Resistance exercise in combination with BFR allows less dependence on the external load lifted, providing a safe alternative through which low-load resistance training may be used as a means to elicit marked increases in muscle size and strength. As such, BFR appears to provide a useful

alternative for clinical populations, which may include: individuals recovering from injury (Ohta et al., 2003), individuals coming off bed rest (Cook, Brown, Deruisseau, Kanaley, & Ploutz-Snyder, 2010) or those limited by other musculoskeletal disorders, in whom the ability to perform traditional resistance exercise may be limited (Ohta et al., 2003). In addition to this, BFR has also shown to promote beneficial adaptations in healthy populations. Specifically, BFR has shown to improve strength in college athletes when added to their existing resistance-training program (Luebbers, Fry, Kriley, & Butler, 2014; Yamanaka, Farley, & Caputo, 2012) and stimulates muscle growth and strength in healthy, non-resistance trained individuals (Martin-Hernandez, Marin, Menendez, Ferrero, et al., 2013; Martin-Hernandez, Marin, Menendez, Loenneke, et al., 2013). However, the BFR literature has reached a contingency, as it has become unclear if the application of BFR actually augments the response to low load resistance exercise when performed to failure. Specifically, the recent work of our laboratory has shown that the application of pressure does not augment the acute response to resistance exercise performed at 30% of 1RM, but does appears to impact the acute responses at very low loads (<20% 1RM). Thus, it is currently unknown if there are any situations where the application of BFR would be absolutely necessary to elicit an anabolic response. This study will help to determine the efficacy of the addition of BFR to very low load resistance exercise.

Assumptions

1. Participants are honest during screening procedures, making them eligible for participation in this study.
2. Participants will follow pre-testing instructions (e.g., no exercise 24 hours prior to visit, no caffeine 8 hours prior, not food 2 hours prior, etc.…).

3. Participants will give a maximal effort during all muscular strength testing and training sessions.
4. Participants will maintain their current level of outside physical activity and current level of diet for the duration of the study.

Delimitations

1. The findings of our acute study may only be applicable to resistance trained men and women between the ages of 18-35.
2. The findings of our chronic study are only applicable to non-resistance trained men and women between the ages of 18-35.
3. Participants will be recruited through convenience-based sampling and will not represent a true random sample.

Limitations

1. The design allows the possibility of some cross-over occurrence on strength measures. However, since all limbs will be training, we believe this influence will be minimized.
2. We are inferring muscle cell swelling and chronic changes in muscle size from ultrasound muscle thickness measures. However, we are not able to actually measure if this fluid shift is occurring into the muscle cells or just into the interstitial space.
3. We are inferring muscle activation from EMG amplitude, as opposed to more sophisticated techniques (such as decomposition). Thus, we can get an idea of muscle activation; however, we cannot determine actual motor unit activation.

Operational Definitions

1. Blood flow restriction (BFR) resistance exercise – Resistance exercise performed with the application of a pneumatic cuff to the most proximal portion of the limb, with the intention of limiting arterial blood flow and blocking venous return.
2. One repetition maximum (1RM) – The most weight an individual can lift once throughout a complete range of motion on a given exercise.
3. Maximal voluntary contraction (MVC) – The peak torque produced by a muscle as it contracts while pulling against an immovable object.
4. Muscle Thickness (MTH) - An estimate of muscle size, derived through a one-dimensional B-mode ultrasound image. MTH is measured as the distance from the muscle-bone interface to the muscle-fat interface.
5. Muscle Swelling – An acute increase in muscle thickness as measured through B-mode ultrasound, expressed as the change in muscle thickness from before to after an exercise bout.
6. Electromyography (EMG) – A technique that uses surface electrodes, along with data acquisition hardware/software, to record signals of electrical activity from skeletal muscle.

CHAPTER 2: LITERATURE REVIEW

1. Skeletal Muscle Adaptation

Skeletal muscle is a highly malleable tissue, subject to growth and adaptation in response to contractile activity (Coffey & Hawley, 2007). In most cases, the performance of resistance exercise is used to elicit changes in muscle size and strength. For example, the performance of resistance exercise often results in skeletal muscle hypertrophy; a complex process involving the conversion of mechanical signals to molecular cascades. These molecular cascades then augment gene expression (Drummond et al., 2008) and protein synthesis (Phillips et al., 1997). Typically, resistance exercise results in a rate of protein synthesis that is greater than the rate of breakdown, resulting in the production of contractile proteins which are added to existing myofibers (i.e., hypertrophy). Simultaneous to hypertrophic adaptations, strength adaptations are also often achieved through resistance exercise. Interestingly the mechanisms behind strength adaptation are not well understood, but are believed to be highly influenced by how closely the strength test mimics the intensity and movements of the exercises performed in the resistance exercise program (i.e. specificity of the movement and intensity) (Buckner et al., 2017), and appears to be explained largely by neural adaptations (Gabriel, Kamen, & Frost, 2006). The literature has demonstrated that muscle growth can be achieved through a variety of modalities and intensities; whereas, strength is highly reliant on exercise intensity and specificity of the movement. Nonetheless, a variety of modalities and intensities have been utilized throughout the literature with the goal of augmenting muscle size and strength (Ozaki et al., 2016).

High-loads, low loads and low loads with the application of BFR are most commonly utilized within the resistance training literature and have been shown to result in similar changes in skeletal muscle size. Mitchell et al. (2012) showed that 10 weeks of low load resistance training resulted in a similar muscle hypertrophic response as traditional high load resistance training in the lower body. Similarly, Ogasawara et al. (2013) showed that 6-weeks of low-load bench press training to fatigue resulted in muscle hypertrophy similar to high-load bench press training. In addition to these, low load resistance exercise with the application of BFR also results in a comparable growth response. Low load exercise with BFR is a unique form of resistance exercise, where a pneumatic cuff is applied to the most proximal portion of the arms or legs with the intention of restricting arterial blood flow to the muscles and limiting venous return. This technique decreases the number of repetitions to volitional failure compared to regular low load training, presumably through a reduction in oxygen, and an accumilation of metabolites (Loenneke, Balapur, Thrower, Barnes, & Pujol, 2012). Interestingly, considering the effectiveness of low load exercise performed to failure, it is not presently clear if there is a point at which BFR is absolutely necessary to elicit an anabolic skeletal muscle response. As previously mentioned, recent acute work from our laboratory seems to suggest that there may be a point where the training load becomes too low for the individual to reach failure within a reasonable time. Dankel et al. (2017) showed that the application of BFR to very low loads (<20%1RM) appeared to increase levels of fatigue as measured through acute torque decrements, suggesting that blood flow restriction may have important applications when very low loads are used. Although it appears that BFR may be important when very low loads are used, additional research is necessary to better understand the potential utility of BFR with intensities less than 20% of 1RM.

Regarding strength, low load resistance training typically results in less robust changes in maximal strength measured by a 1RM when compared to traditional high load resistance training (Mitchell et al., 2012; Ogasawara et al., 2013). However, when strength is measured using a test to which both groups are "naive" (i.e., train dynamic and test isometric), differences in strength become less apparent (Martin-Hernandez et al., 2013; Mitchell et al., 2012; Ward & Fisk, 1964). The majority of the literature seems to suggest that strength will improve most on a skill or movement that closely resembles the training protocol. As such, low load resistance training will not produce robust increases in maximal strength unless the program also includes periodic practice of a 1RM. This was illustrated by Morton et al. (2016), who found that multiple exposures to a 1RM during a low load resistance training program can largely abolish the difference in 1RM strength typically observed between high load and low load training modalities. This was also observed by Kim et al. (2017) who found that performing a 1RM assessment every 2-weeks during an 8-week training study provided enough practice to largely negate the strength differences typically observed between high load exercise and low load exercise with the addition of BFR.

2. Mechanisms of Skeletal Muscle Growth

Although the mechanisms of growth are not completely understood, it has been suggested that mechanical and metabolic contributions are likely playing a role in exercise-induced muscle hypertrophy. Indeed, much of the early work performed was on cardiac muscle (as opposed to skeletal muscle); however, recent advances have greatly increased our understanding of skeletal

muscle adaptation. In short, muscle contraction stimulates transient increases in the quantity of messenger RNA (mRNA), which appears to peak 3-12 hours following exercise, returning near baseline within a 24-hour period (Bickel et al., 2005; Coffey & Hawley, 2007). This increase in mRNA is accompanied by a subsequent increase in protein synthesis (Coffey & Hawley, 2007). Thus, repeated stimulations over time results in an increase in skeletal muscle size (hypertrophy). The early work of Goldberg (1968) used animal models to identify the capacity of skeletal muscle to increase in size in response to overload, showing that compensatory hypertrophy of skeletal muscle is accompanied by increased incorporation of labeled amino acids into proteins. Although this study employed a rodent model, using synergistic ablation in hypophysectomized rats, it was the first study to observe the incorporation of labeled amino acids into skeletal muscle proteins. This has since been observed in human models (Burd et al., 2010; Phillips et al., 1997). With resistance exercise, mechanical signals trigger secondary messengers, to signal a molecular cascade, which involves both primary and secondary messengers. The precise mechanism that transduces the mechanical signal of skeletal muscle contraction remains poorly understood. This response is thought to be multifaceted, involving: mechanical stretch; calcium flux, and changes in redox, as well as phosphorylation state within the muscle (Coffey & Hawley, 2007). Although, it is not fully understood how mechanoreceptors, neuronal mechanisms, and biochemical events interact as primary messengers for anabolic processes, there are several candidates, which may play a role in the anabolic process.

Cell Swelling Hypothesis

Cell swelling is one of the hypothesized mechanisms through which resistance exercise is believed to exert its effects. It has been suggested that amino acids are taken up into cells by sodium-ion dependent transport systems, converting an electrochemical gradient into an

osmotically active amino acid gradient, which ultimately causes a fluid shift of water into the cell (Haussinger et al., 1993). This hypothesis comes from the work of Haussinger (Haussinger & Gerok, 1994; Haussinger et al., 1993), which was conducted primarily in liver cells. Haussinger suggests that cellular swelling may act as an anabolic signal. More specifically, cell swelling is believed to work through the activation of different mitogen activated protein kinases, which may stimulate protein synthesis through s6 kinase, and modulate gene expression through various pathways (Haussinger et al., 1993). Although cell swelling is only a hypothesized mechanism of skeletal muscle growth, it is a repeatable phenomenon which has been examined across a variety for resistance training protocols (Buckner et al., 2016; Counts et al., 2016) and is believed to play a role in the anabolic process observed with resistance exercise.

Our research group and others have previously noted similar acute muscle swelling in the upper body (Buckner et al., 2017; Counts et al., 2016; Yasuda, Loenneke, Thiebaud, & Abe, 2012), as well as across a variety of protocols in the lower body (Loenneke et al., 2016). Notably, this acute response is highly repeatable and (in line with the hypotheses of Haussinger (1993)), is believed to be an indicator of anabolic potential. To provide some support, Yasuda et al. (2012) observed that concentric exercise in combination with BFR resulted in both a greater acute muscle swelling response and greater increase in muscle size over a 6-week period compared to a group performing eccentric exercise in combination with BFR. Authors suggest that the greater growth response may be explained by the greater degree of acute swelling seen with the exercise protocol. It is not currently known if the observed swelling response was necessary to induce a hypertrophic stimulus. Notably, there were also differences in EMG amplitude between the groups. Nonetheless, it appears that the majority of resistance training protocols that produce

growth are accompanied by some level of acute swelling. For example, high load (Counts et al., 2016), low load, low load with BFR (Buckner et al., 2016; Counts et al., 2016) and NO-LOAD (Counts et al., 2016) exercise have all been shown to elicit an acute swelling response. In addition, our laboratory has observed the acute swelling response across several exercise bouts in a given training week, finding that a muscle appears to swell to a similar degree with each exercise bout when taken to volitional fatigue (Buckner et al., 2017). Although it is not known if the response itself is anabolic, it may provide important information on the robustness of an acute exercise bout.

Swelling and BFR

Although swelling is not a unique mechanism to BFR exercise, BFR by itself may cause a fluid shift into the muscle. For example, Kubota et al. (2011) showed that repetitive restriction of blood flow using an arbitrary pressure of 50 mmHg applied to the lower extremity reduced muscular weakness caused by chronic unloading. This same research group has also showed that BFR by itself attenuated decreases in strength to a greater degree than isometric training, which suggests that venous pooling may play a therapeutic role during periods of unloading (Kubota, Sakuraba, Sawaki, Sumide, & Tamura, 2008). Similarly, Takarada et al. (2000) found that the application of high pressures post ACL surgery attenuated muscle disuse atrophy relative to a control group in a small sample of individuals. However, this is not a universal finding, as Iversen et al. (2016) did not observe an attenuation of atrophy 14 days following ACL reconstruction surgery when using BFR combined with muscle contractions. Although speculative, it seems plausible that Iversen et al.'s (2016) findings may be explained by their utilization of an athletic sample. Meaning, athletes (who are more likely to have hypertrophied

muscles) may experience a return to baseline levels of muscle mass. If true, the application of BFR may help with the loss of baseline levels (the level of muscle and individual has following development without contributions from compensatory hypertrophy), of muscle mass, while not providing enough of a stimulus to maintain the mass of a hypertrophied muscle. The swelling phenomenon is supported by the findings of Loenneke et al. (2012) who showed that a protocol of inflations and deflations in the lower body resulted in an acute increase in muscle thickness and a decrease in plasma volume. This work demonstrated that the increase in muscle thickness was likely indicative if a fluid shift into the muscle since the increase in muscle thickness was maintained post-deflation. Although applying pressure by itself may not provide a robust anabolic stimulus for skeletal muscle growth, these data provide some evidence that this may be an important mechanism for maintaining baseline levels of muscle mass when there is an absence of skeletal muscle contraction.

Muscle Activation

It is believed that high levels of muscle activation may be necessary for a maximal hypertrophic response. Similar muscle protein synthetic responses have been observed independent of the exercise load (Burd et al., 2010; Fry et al., 2010), which are supported by similar long-term hypertrophic adaptations across various exercise intensities (Ozaki et al., 2016). This is likely as result of high levels of activation across exercise protocols, despite varying external loads. For example, integrated electromyography has been shown to increase with low load exercise and low load exercise with BFR (Moore et al., 2004; Takarada et al., 2000). High levels of activation achieved during lower intensities are likely a function of fatigue. Specifically, muscular activity that results in muscular fatigue appears to be compensated for by an increase in motor unit

activation, including the activation of higher threshold motor units that innervate more type II muscle fibers (Loscher, Cresswell, & Thorstensson, 1996). Moritani et al. (1992) examined motor unit recruitment and lactate concentrations during intermittent isometric contractions of hand grip muscles with or without blood flow. Authors found that there was an increase in motor unit recruitment and firing rate while under arterial occlusion, suggesting that the metabolic state may have played an important role in this increased recruitment (Moritani et al., 1992). Other studies have observed similar increases in muscle activation, (Moore et al., 2004; Takarada, Nakamura, et al., 2000; Takarada et al., 2000) attributing such increases to reduced oxygen and metabolic accumulation within the working muscle.

Training to failure

Training to failure has recently been suggested to be the best way to ensure a maximal hypertrophic stimulus within a resistance training program (Dankel et al., 2017). This is likely due to high levels of motor unit recruitment observed across different exercise intensities when resistance exercise is performed to volitional failure (Moritani et al., 1992). As such, low load exercise without BFR has been shown to result in similar muscle growth as high load and low load + BFR alternatives (Ozaki et al., 2016). This may question the utility of BFR; however, it is important to note that low load exercise without BFR would require significantly more repetitions in order to stimulate a similar increase in myofibril muscle protein synthesis (Wernbom, Augustsson, & Thomee, 2006; Wernbom et al., 2009). In addition, acute work from our research group seems to suggest that there may be a point where the training load becomes too low to reach failure. This may occur when the load is too low or when an individual has a low level of baseline strength. Thus, training with very low loads may require BFR in order to

achieve high levels of muscle activation and elicit an anabolic response. Nevertheless, training to (or near) volitional failure appears important to ensure a high level of muscle activation is achieved.

Metabolites

Metabolites are likely playing some role in skeletal muscle adaptation during resistance exercise. Although their role is not completely understood, metabolites likely play an important role with regards to increasing muscle activation during low load exercise (Loenneke et al., 2011; Moritani et al., 1992). Specifically, metabolites are believed to increase muscle activation through the stimulation of group III and group IV afferents, which may inhibit the alpha motor neurons supplying slow-twitch fibers, resulting in an increased fast-twitch fiber recruitment (Yasuda et al., 2010). In addition, metabolites have also been hypothesized to act as anabolic signals themselves (Ozaki et al., 2016; Pierce, Clark, Ploutz-Snyder, & Kanaley, 2006). For example, Pierce et al. (2006) has suggested that a lack of blood flow in conjunction with muscle contraction may stimulate adaptation through growth hormone. Although changes in growth hormone being mechanistically important does not seem likely, metabolites have remained a primary hypothesized mechanism to explain the benefits of BFR. However, Dankel et al. (2016) demonstrated that trapping metabolites within the muscle following a resistance exercise bout provided no anabolic benefits over a 6-week period. Notably, relative to a control performing only high load exercise, females appeared to have an attenuation of growth, and males saw no additional benefit when trapping metabolites in the muscle following high load resistance exercise. Although this one study cannot definitively prove that metabolites are not important, it provides evidence that metabolites may not directly stimulate anabolic-signaling cascades.

3. Muscle strength

What is strength?

Attempts to measure the force producing capabilities of the musculature are often assessed through different performance measures. Specifically, isometric (Mitchell et al., 2012), isokinetic (Martin-Hernandez et al., 2013) and 1RM tests (Martin-Hernandez et al., 2013; Mitchell et al., 2012; Ogasawara et al., 2013) are all used to assess strength adaptation. We have recently challenged how we think about strength adaptation, as it appears that strength is a highly specific adaptation, explained primarily by the specificity of a movement (Buckner et al., 2017). In our recent perspective, we make a case for taking multiple measures of strength to assess "strength" adaptation to a resistance training, particularly when comparing different resistance training protocols/programs (Buckner et al., 2017). To illustrate, low load resistance training results in similar muscle hypertrophic changes as traditional high load resistance training, with less robust changes typically observed with maximal strength measured by a 1RM (Mitchell et al., 2012; Ogasawara et al., 2013). However, when strength is measured using a test to which both groups are "naive" (i.e. train dynamic and test isometric), differences in strength become less apparent (Martin-Hernandez et al., 2013; Mitchell et al., 2012; Ward & Fisk, 1964). This demonstrates how important the concept of specificity is when examining changes in strength. Moreover, it helps to illustrate how fundamental the concept of specificity is in facilitating a "strength" adaptation. We would suggest that strength would increase the most when the training procedures closely resemble the testing procedures. This was illustrated by Morton et al. (2016) who showed that including 1RM practice into a low load resistance training program largely eliminated the strength difference that is typically observed between high load and low load

resistance exercise. In addition, Hernandez et al. (2013) found comparable increases in isokinetic peak torque at 60° and 180°/sec between 5 weeks of traditional high load resistance exercise or 5 weeks of low load resistance exercise with BFR; with greater increases observed in 1RM strength for the high load training group. This suggests that the group that trained near a 1RM performed better at the 1RM test, which may be due to specificity and the fact that the low load training group had never been exposed to lifting maximally through a range of motion.

Mechanisms of strength

Classically, strength is believed to be a function of neural and hypertrophic adaptations (Moritani & deVries, 1979). However, our research group has recently challenged the causative relationship between the change in muscle size and the change seen in strength (Buckner et al., 2016), suggesting that these are separate and unrelated adaptations. If correct, the model proposed by Moritani and Devries (1979), would be invalid. The increase in strength following resistance exercise is likely a function of neural adaptations, and/or changes at the muscle level that do not result in a change in muscle size. For example, alterations in agonist-antagonist co-activation, increases in motor unit firing rates, and changes in descending drive to the motor neurons may explain a large portion of increases in strength observed with resistance exercise (Gabriel et al., 2006). However, even studies investigating neural adaptations provide conflicting results, as Jenkins et al. (2016) observed similar changes in voluntary activation between high-load and low-load resistance exercise, despite divergent strength adaptations. This illustrates that divergent neural adaptations assessed through twitch interpolation may not explain a large portion (if any) of the strength differences observed following high load or low load resistance

exercise. We would suggest that there is an evolving and limited understanding of the mechanisms that explain resistance exercise induced strength adaptations.

4. Time course of skeletal muscle growth

The time course of skeletal muscle growth is currently an area of contention. The early and influential work of Moritani and Devries (1979) suggested that skeletal muscle growth is a rather slow process. Specifically, authors suggest that strength adaptation is explained by neural adaptations for the first 3-5 weeks, with hypertrophy becoming a prominent mechanism in the later portions of a resistance training program. Although there are likely issues with using muscle size to explain strength, the majority of recent work has suggested that muscle growth may occur relatively early in a resistance training program (Counts et al., 2016; DeFreitas, Beck, Stock, Dillon, & Kasishke, 2011; Stock et al., 2017). Defreitas et al. (2011) conducted an 8 week resistance training study, where measurements of both muscle size and strength were taken weekly throughout the resistance training program. Although both measures (muscle size and strength) appeared to increase throughout the study period, authors used muscle quality to confirm that *actual* skeletal muscle growth had occurred. Thus, growth was considered real when muscle quality has exceeded the ratio (muscle strength/muscle size) seen at baseline. Once again, the time course of skeletal muscle growth was limited by the assumption that muscle size and strength are intrinsically linked. Inspired by the work of Defreitas and colleagues, Damas et al. (2015) suggested that it was not possible to differentiate between edema induced muscle swelling and actual skeletal muscle growth during the early portions of a resistance training program. In their work (Damas et al., 2015), they observed an increase in echo intensity during the early portions of a resistance training program. The authors suggest that an increase in echo

intensity is indicative of swelling, rendering an inability to differentiate between skeletal muscle growth and edema induced increases in muscle size. However, the work of Buckner et al. (2017) showed that swelling/edema does not appear to accumulate over time, suggesting that swelling does not likely contribute greatly to changes in muscle size beyond what occurs following the first exposure to resistance exercise. Specifically, authors suggest that a baseline shift occurs following the first resistance training session (degree of about 1 cm), and that anything beyond this baseline shift is likely real growth. This is supported by the letter written by Defreitas et al. (2016) in response to criticism by Damas and colleagues. In his original work, Defreitas suggested that skeletal muscle growth can be measured with confidence by week 3. However, in his letter, Defreitas suggests that real growth likely occurred by week 1. In addition, several more recent studies (Abe, DeHoyos, Pollock, & Garzarella, 2000; Alway, Grumbt, Stray-Gundersen, & Gonyea, 1992; Dankel et al., 2016; Ikai & Fukunaga, 1970; R. Ogasawara, Thiebaud, Loenneke, Loftin, & Abe, 2012) have reported skeletal muscle growth at earlier time points than what has been proposed by the original model presented by Moritani and Devries (1979). The discrepancies between the early work of Moritani and Devries other studies may be due to the crude techniques employed to measure muscle size. Specifically, authors used circumference and skinfold measures to calculate muscle size, as opposed to more sophisticated imaging (i.e., ultrasound; CT scan) techniques (Moritani & deVries, 1979). Thus, we would suggest that it is likely that measureable skeletal muscle growth can occur as early as one week into a resistance training program.

Confirming growth with swelling

The recent work of Buckner et al. (2017) proposed a technique to confirm skeletal muscle growth, although this has not yet been experimentally tested. Specifically, authors suggest that the acute swelling response itself can be exploited to confirm that skeletal muscle growth has occurred. This implementation of such a technique is quite simple. In short, the acute swelling response should be stimulated during the first and last measurement period. In doing so, the change in baseline (non-swollen) muscle thickness values can be compared to the changes in "swollen" muscle thickness values. If there is a similar change between the two time points real growth has likely occurred. In addition, Buckner et al. (2017) has suggested that the swelling response itself may demonstrate that real growth (as opposed to swelling or edema as suggested by Damas et al (2015) has occurred. Specifically, authors suggest that since a muscle can only swell a finite amount (i.e., a swollen muscle cannot elicit a swelling response) that the acute swelling response itself may help to indicate the presence of previous swelling within the muscle. In other words, stimulating a swelling response on the final visit may serve as a confirmation that real skeletal muscle growth has occurred.

5. The application of blood flow restriction

Relative pressure and cuff size

Although there are no official standards through which to apply BFR, recent methodological studies have provided some guidance on how to apply, and what factors should be considered when applying the blood flow restriction stimulus. Early research on tourniquet application has suggested that pressures should be applied relative to the width of the cuff, as well as the size of the limb in which the cuff is applied (Crenshaw, Hargens, Gershuni, & Rydevik, 1988; McEwen, Kelly, Jardanowski, & Inkpen, 2002; Shaw & Murray, 1982). Similar findings have been shown

within the BFR literature. For example, Loenneke et al. (Loenneke, et al., 2012) compared arterial occlusion pressures between a 13.5 cm and 5 cm wide cuff in the lower body, finding that the wide cuff occluded blood flow at a lower pressure compared to the narrow cuff. In addition, results showed that limb circumference explained the greatest amount of variance in arterial occlusion pressure following regression analysis. Similar to this, Jesse et al. (2016) examined differences in arterial occlusion pressure across three different size cuffs in the upper body (5 cm, 10 cm, 12 cm), finding (similar to findings in the lower body) that greatest variance was explained by limb circumference and that there was an inverse relationship between cuff width and arterial occlusion pressure. These findings suggest that the restrictive pressure should be applied relative to the cuff width and limb size of the individual.

Cuff Material

In addition to cuff size, it has also been suggested that the cuff type (material of cuff/type of equipment) may influence the stimulus when applying BFR. For example, Buckner et al. (2016) found that there was over a 100 mmHg difference in arterial occlusion pressure between nylon and elastic cuffs [nylon 139 (14) mmHg vs. elastic 246 (71) mmHg] in the upper body. However, despite these drastic differences the acute swelling and fatigue response to exercise were similar when pressures were applied relative to each cuffs respective arterial occlusion pressure. Similarly, Loenneke et al. (2014) examined the influence of cuff type in the lower body, finding that there were no differences in the repetitions to fatigue or perceptual response between different type cuffs (nylon vs. elastic) when the pressure was made relative to the arterial occlusion pressure of the cuff used. These studies demonstrate the importance of applying the pressure as a percentage of arterial occlusion pressure measured with the cuff of interest.

However, if individuals are not able to measure arterial occlusion pressures, the cuff type (or material) should be taken into consideration.

Although a relative pressure is recommended, it is not uncommon for the same restrictive pressure to be applied to all individuals within a study (Christopher A Fahs, Loenneke, Rossow, Tiebaud, & Bemben, 2012). As discussed, cuff size, limb circumference and cuff material all have an influence on the stimulus an individual is receiving when the cuff is inflated to an arbitrary pressure. To illustrate, Fujita et al. (2007) and Gundermann et al. (2012) both applied BFR using an arbitrary pressure of 200 mmHg. However, these studies cannot necessarily be compared since Fujita utilized a 5cm cuff; whereas, Gundermann used an 11 cm wide cuff. In addition, these are further confounded by the fact that Gundermann utilized a nylon cuff whereas Fujita utilized a nylon cuff. Such methodological issues are common within the BFR literature. However, recent methodological advances have shown that applying a restrictive stimulus relative to the individual and the cuff used appears to correct many of these issues and helps do deliver a more universal stimulus across individuals (Buckner et al., 2016; Loenneke et al., 2014).

Safety of BFR

The application of BFR appears to be a safe stimulus across a variety of populations when applied correctly (Loenneke, Wilson, Wilson, Pujol, & Bemben, 2011). Perhaps the greatest concern, regarding safety and BFR is an increased risk of blood clot, particularly as complete vascular occlusion can cause the formation of a thrombus even after reperfusion (Blaisdell, 2002). Within the BFR literature, Clark et al. (2011) found that a single bout of low load

exercise with blood flow restriction increased fibrinolytic activity without altering selected markers of coagulation or inflammation in healthy individuals. Additionally, Fry et al. (2010) found that an acute bout of low load exercise with BFR did not augment D-dimer protein content in the blood. This is further supported by a pilot study by Madarame et al. (2013) examining the hemostatic and inflammatory responses to blood flow restriction exercise in individuals with ischemic heart disease, which found that the application of BFR did not augment the hemostatic or inflammatory response to low load training. Although limited, the current evidence seems to suggest that there is not an increase in coagulation activity following acute or prolonged appropriate use of BFR.

Another common concern with blood flow restricted exercise, is the amount of muscle damage occurring, relative to more traditional protocols. Although muscle soreness is commonly experienced following BFR exercise (Cuthbertson et al., 2005; Thiebaud et al., 2014; Thiebaud, Yasuda, Loenneke, & Abe, 2013), there does not appear to be prolonged swelling (Thiebaud et al., 2013; Umbel et al., 2009; Wilson, Lowery, Joy, Loenneke, & Naimo, 2013) or prolonged decrements in torque (Loenneke et al., 2013; Thiebaud et al., 2013; Umbel et al., 2009) following blood flow restricted exercise. In addition, there appears to be little to no change in blood biomarkers following BFR exercise protocols (Clark et al., 2011; Cuthbertson et al., 2005; Madarame et al., 2013; Takarada, Nakamura, et al., 2000). Together, these data would suggest that the damage response to BFR exercise is minimal.

CHAPTER 3: METHODOLOGY

Study 1 – Acute Study

Participants

The aims of study 1 were: 1) to examine if the acute muscle response following resistance exercise at very low loads (15% 1RM) is improved with BFR; and 2) determine how this compares to that observed with high load resistance exercise (70% 1RM). In order to answer this research question, 10 males and 10 females between the ages of 18-35 were recruited for this study. Resistance trained males and females were recruited through word of mouth, fliers posted on campus, and class announcements. Resistance trained individuals were recruited in order to examine the acute response without being confounded by potential muscle damage from the resistance training protocols.

Inclusion Criteria	***Exclusion Criteria***
Between the ages of 18-35 years.	Outside the age range of 18-35 years.
Resistance trained in biceps curls for at least 6 months, with a frequency of 2x/week	Not resistance trained in the biceps curl
Participants should be ambulatory and have no disabilities or hemodynamic disorders preventing them from sustaining short bouts of limb compression.	Regular use of tobacco products (cigarettes, cigars, chew/snuff, etc.).
No orthopedic problems preventing strength testing/exercise.	Having more than one risk factor for thromboembolisms (Motykie et al., 2000) 2000): a. Diagnosed Crohns or Inflammatory Bowel Disease; b. Past fracture of a hip, pelvis, or femur; c. Major surgery within the last 6 months; d. Varicose veins; or e. Family history of deep vein thrombosis or pulmonary embolism.
Body Mass index between < 30 kg/m^2	
Non-smokers or those who had quit ≥6 months prior to participation.	BMI ≥ 30 kg/m^2
	On hypertensive medication

Study design

Participants reported to the laboratory on five separate occasions. If the participant consented and did not meet any exclusion criteria, their standing height, and body mass were measured. Arterial

occlusion pressure was also determined in both arms (visit 1). To illustrate, in random order, participants had a 5 cm nylon cuff placed at the top of each arm (one at a time). Pressure was increased by inflating the cuff until there is a cessation of blood flow to the distal portion of the limb as detected by a Doppler probe. The cuff was then removed and participants rested for 5 minutes at which point the cuff was put on the next arm to undergo the same procedure. Following this, the participant performed a 1RM test to measure elbow flexion strength in both arms. Next, participants underwent one set of familiarization to BFR exercise in each arm performed to a metronome followed by familiarization with dynamometer strength testing. Although not part of the present dissertation, the lower body (legs) also underwent the same procedures as the upper body in sequence. Although these measures are not relevant to the present dissertation, they are briefly mentioned as they have some influence on the number and length of visits. This first visit will last approximately 90-120 minutes.

For visits 2, 3, 4, and 5 (each approximately 5 days apart from one another) participants completed one of the four possible conditions per visit either in the upper body (and lower body) for a total of 4 conditions (plus an additional 4 in the lower body). Conditions consisted of four sets of elbow flexion exercise to failure using a traditional high load (70% 1RM), very low load (15% 1RM), very low load with moderate BFR (40%), or very low load with greater BFR (80%). Arterial occlusion pressure was measured prior to each exercise bout. Torque and muscle thickness were measured prior to exercise as well as immediately post, and 15 minutes post exercise. Further, electromyographic (EMG) amplitude was measured throughout the 4 sets of exercise. The difference between visits 2, 3, and 4 was be the limbs used and the conditions applied. Each visit lasted approximately 90 minutes, with 2 randomized conditions completed

during each visit (randomization of a total of 8 conditions collectively from upper and lower body).

Specific Procedures

1) Consent Form and Questionnaires:

Informed consent was obtained prior to completion of all questionnaires and any testing. Participants were also asked to complete a Physical Activity Readiness Questionnaire (PAR-Q). If participants qualified for this study after these assessments they completed all of the procedures listed below.

2) Height/Body Mass:

Participant height and body mass were measured using a stadiometer and a digital scale.

3) Arterial occlusion determination:

Participants were standing while we applied a narrow, nylon (5 cm wide) blood pressure cuff to the upper most portion of the participants arm to measure the inflation pressure at which blood flow to their wrist is no longer present. We began the inflation at 50 mmHg and then slowly increased it until we no longer could detect the participants pulse while the cuff is inflated. The cuff was then deflated and removed. Following this, the opposite arm underwent the same procedure to determine arterial occlusion pressure. The arterial occlusion pressure measurement was completed prior to each exercise condition.

4) One Repetition Maximum (1-RM):

The strength of the participants' elbow flexors was tested using a dumbbell. We assessed the 1RM of both arms (1-RM; the heaviest weight that can be lifted one time with good form). Participants were supervised by trained personnel during all strength testing.

5) Standardized Exercise Training:

For visits 2, 3, 4, and 5 participants exercised one limb with either a traditional high load (70% 1RM), or a very low load combined with no, moderate, or high restriction pressure. Participants completed a total of 4 different conditions over visits 2-5. For the high load exercise, the protocol consisted of 4 sets of elbow flexion exercise performed to failure. For low load training, exercise was performed until volitional failure or until 90 repetitions were completed, whichever occurred first. In the high load condition sets were separated by 90s rest and in the other conditions, sets were separated by 30 second rest periods.

6) Isometric Torque:

Isometric torque was tested on a dynamometer (Biodex Quickset System 4). The chair was adjusted for each individual, with the settings recorded to ensure the same testing conditions for each experimental visit. For testing, participants were asked to flex their arm against an immovable object as hard as possible to determine their isometric strength. All isometric testing was performed at 60° of elbow flexion. Each contraction lasted approximately 3-8 seconds.

7) EMG Amplitude:

Surface electromyography (EMG) for the biceps brachii was measured during exercise visits. Biceps brachii electrodes were placed on the line between the medial acromion (shoulder area)

and the antecubital fossa (elbow joint) at a distance of 1/3 from the antecubital fossa. A reference electrode was placed on the 7th cervical vertebrae (bony part of back of neck). The skin was prepared for electrode placement by lightly shaving the electrode placement area to remove excess body hair, using a roughing pad to remove dead skin, and then cleaning area with a sterile alcohol wipe. Electrodes were placed in accordance with the Seniam guidelines for EMG (Hermens et al., 1999).

8) Muscle Thickness:

Ultrasound measurements of muscle thickness was made on the anterior aspect of the participant's upper arm at 70 % of the distance from the acromion process to the olecranon process. Muscle thickness was measured as the distance between the muscle-bone and muscle-adipose interface. The probe was coated with gel and held lightly against their skin. This measurement was made before exercise, immediately after and 15 minutes after exercise.

Study 2 – Chronic Study

Participants

The aim of study 2 was to determine differences in muscle growth in the upper body (elbow flexors) in response to 8 weeks of resistance exercise under four specific conditions: (1) low load resistance training (15% 1RM), (2) low load resistance training in combination with low levels of BFR (15% 1RM + 40% arterial occlusion pressure), (3) low load resistance training in combination with high levels of BFR (15% 1RM + 80% arterial occlusion pressure), and (4) traditional high load resistance training (70% 1RM, 8-12RM). In order to answer this research question, a total of 42 untrained (21 individuals per group), healthy men and women (ages 18-35) will report to the laboratory for a total of 22 visits.

Inclusion Criteria	***Exclusion Criteria***
Between the ages of 18-35 years.	Outside the age range of 18-35 years.
Not resistance trained in biceps curls for at least 6 months, with a frequency of 2x/week	Resistance trained in the biceps curl
Participants should be ambulatory and have no disabilities or hemodynamic disorders preventing them from sustaining short bouts of limb compression.	Regular use of tobacco products (cigarettes, cigars, chew/snuff, etc.).
No orthopedic problems preventing strength testing/exercise.	Having more than one risk factor for thromboembolisms (Motykie et al., 2000): a. Diagnosed Crohns or Inflammatory Bowel Disease; b. Past fracture of a hip, pelvis, or femur; c. Major surgery within the last 6 months; d. Varicose veins; or e. Family history of deep vein thrombosis or pulmonary embolism.

Non-smokers or those who had quit ≥6 months prior to participation.	Body Mass Index > 30
Body Mass index between < 30	On hypertensive medication

Study design

Participants had both of their arms assigned to a condition in a random counter-balanced fashion so that each arm completed 1 of the following 4 conditions: (1) very low load training; (2) very low load training with low levels of BFR; (3) very low load training with high levels of BFR pressure; and (4) traditional high load resistance training. Although not a part of the present dissertation, the legs were also randomized into one of the previously mentioned conditions (undergoing the same procedures as in the upper body for testing and training). However, since the lower body was not part of the present dissertation, it will only be mentioned in the context of study design and the duration of visits. On the initial pre visit, we determined if the participant meets the inclusion criteria, and if so, they proceeded to complete an informed consent document, PAR-Q, and have their height and body mass measured. Participants then had their muscle thickness measured in their arms. Next, participants were familiarized with the unilateral elbow flexion exercise by practicing the movement with no external load. On the second pre visit, participants were tested for their unilateral one repetition maximum (1RM) test in both arms followed by a test of muscular endurance on each arm. In addition, participants were familiarized with isokinetic and isometric testing in the upper body. A third pre visit, was be completed, during which individuals performed isokinetic and isometric testing for each arm.

Finally, participants completed strength and performance testing in the lower body (not relevant to the present dissertation). The following week, the participants began the eight-week training protocol consisting of two training sessions per week with at least 24h separating each visit. Both arms trained each day in a counter-balanced fashion (Although not part of the present dissertation, the legs were also training during each visit). Measures of muscle thickness was taken at the midpoint of the training study (beginning of week 4). Finally, in order to implement the aforementioned swelling technique to confirm skeletal muscle growth, muscle thickness measures were taken before and after exercise on the first, middle (visit 9) and on visit 15. At least 48 hours following the last training session, post measurements were taken over three separate days, similar to the pre-visits.

Specific Procedures

1) Very Low Load Training:

Very low load training consisted of unilateral elbow flexion exercise completed to volitional failure at 15% 1RM or 90 reps per set, whichever occurs first. Each participant completed four sets with 30s of rest between sets. Ninety repetitions represents 3 minutes of continuous exercise and we chose this based off of previous acute data showing that with increased time under tension there is an increase in mitochondrial and sarcoplasmic muscle protein synthesis as opposed to myofibrillar protein synthesis (Burd et al., 2012). Thus, the 3 minute cut-off is intended to limit a transition into primarily oxidative energy production. The concentric and eccentric portions of the lift were 1s each for a total of a 2s repetition.

2) Very Low Load Training with BFR:

The same protocol used for very low load training was employed with the addition of a cuff at the top of the limb which was inflated to 40% or 80% of the individual's resting arterial occlusion pressure. The cuff remained inflated for the duration of the protocol including rest periods. A 5 cm wide nylon cuff was used. The cuff was deflated and removed upon completion of the final set.

3) High Load Resistance Training:

The high load resistance training condition consisted of unilateral elbow flexion and knee extension exercise. Participants attempted to complete 4 sets of 8-12 repetitions at 70% 1RM with 90s of rest between sets. The concentric and eccentric portions of the lift were each set for 1s for a total of a 2s repetitions. The load was progressed if participants completed at least 12 repetitions across all 4 sets of exercise, to ensure they are maintaining approximately 70% of their 1RM.

4) Exercise Progression

Given the large volume of exercise associated with the low load protocols, we gradually increased the number of sets performed for all exercise conditions. Specifically, all groups performed 1 set of exercise on the first training session, 2 sets of exercise on the second training session, 3 sets of exercise on the third and fourth exercise sessions and 4 sets for all training sessions thereafter.

5) Muscle Thickness

B-mode ultrasound (GE Healthcare NextGen LOGIQ e, Little Chalfont, Buckinghamshire, UK) was used to measure the distance between the muscle-bone and muscle-adipose interface. Three different measurement locations were taken on the anterior upper arm of both arms at 50%, 60% and 70% the distance from the acromion process to the lateral epicondyle. An additional measurement was also taken at the 60% site of the posterior right arm to serve as a within subject control, given that the triceps were not directly trained. Muscle thickness measurements were taken at the first pre and post visits as well as the midpoint of training by the same tester with 2 images taken and stored on an external drive to be analyzed later. During analysis, the tester was blinded to each condition.

6) Acute muscle swelling

In order to use swelling as a confirmatory measure of skeletal muscle growth, the acute swelling response was measured at the 70% muscle thickness site before and after training (on each arm) during visit 1, visit 9, and visit 15. Following the muscle thickness procedures outlined above, muscle thickness measures were taken on each arm prior to and immediately after the completion of all 4 sets of exercise.

7) One repetition maximum

We tested the unilateral strength of the participant's arms using the elbow flexion exercise. We assessed the 1RM on both arms (1-RM; the heaviest weight they can lift one time with good form). Participants performed each attempt with their back against the wall. To ensure the full range of motion was completed, the investigator handed the participant the weight while the arm

is fully extended. Participants were supervised by trained personnel during all strength testing. Participants completed 1RM testing on the second pre visit and the second post visit.

8) Isokinetic and Isometric Strength:

Isokinetic and isometric maximal voluntary contractions (MVC) was tested on a dynamometer (Biodex Quickset System 4). Each participant was seated in the dynamometer with the chair adjusted for each individual and the settings were recorded to ensure the same testing conditions for both the pre and post measures. For isokinetic testing, the participant were given 2 attempts at 60 and 180°/s, with 60s of rest between each attempt. Next, the participant completed two 3-8s isometric MVC's at 60° of elbow flexion with 60s rest between attempts. Participants were provided with visual feedback for the duration of the MVC. This was done on each arm. Testing was completed on the third pre visit and the third post training visit.

9) Muscle Endurance:

The participants completed as many repetitions as possible on the elbow flexion exercise using 42.5% of their pre-test 1RM, to a metronome of 1 second for the concentric and 1 second for the eccentric portion of the lift; totaling 2s per repetition. The test was terminated if they were not able to keep pace to the metronome or could not lift the load through a full range of motion. The last successful repetition completed was used for analysis. Participants rested for 5 minutes between each arm. Endurance testing took place during the second pre visit and second post training visit.

10) Arterial Occlusion:

Upon arrival for their scheduled training session, if the participant had an arm randomized into a BFR condition, arterial occlusion was determined. Participants were standing with a 5cm (Hokanson, Bellevue, WA, USA) cuff placed at the top of the arm. The pressure was determined by placing an MD6 Doppler probe (Hokanson, Bellevue, WA, USA) at the radial or artery to detect a pulse. The pressure cuff was then inflated and was increased by 1 mmHg increments until a pulse is no longer present. The pressure to the nearest 1 mmHg at which blood flow is ceased was deemed the arterial occlusion pressure. This occurred prior to start of each training session to account for any variation in the arterial occlusion pressure that might happen over multiple visits. This pressure was then set to 40% of the resting arterial occlusion pressure for the low pressure condition and 80% of the resting arterial occlusion pressure for the high pressure condition.

STATISTICAL ANALYSIS

Acute Statistics

Using the SPSS 24.0 statistical software package (SPSS Inc., Chicago, IL), a 4x3 (condition x time) repeated measure ANOVA was used to determine any differences in muscle thickness and torque between conditions in the upper body. To determine any differences in EMG amplitude for the first three and last three repetitions for each of the exercise sets across conditions, two separate 4x4 (condition x reps) repeated measures ANOVA were used. If there were interactions, we ran one-way ANOVAs across time within each condition, as well as across conditions within each time point. Statistical significance for all tests will be set at an alpha level of 0.05.

Chronic Statistics

In order to examine changes in all strength and muscle thickness values across time between groups, while accounting for our within/between subject design, all strength and muscle thickness measures were analyzed using a linear mixed model approach. Prior to analysis, two models were examined for each variable. In one model, the variance structure was set as compound symmetry. In the second model, the variance structure was set as unstructured, with random effects and individual intercepts for each participant. Akaike's Information Criterion (AIC) and Schwaiz's Bayesian Criterion (BIC) values were compared to determine the most appropriate model. For triceps (control) muscle thickness, a repeated measured analysis of variance (ANOVA) was used to examined changes in muscle thickness across time. If there was an interaction ($p < 0.05$) we examined simple effects. Otherwise, main effects of time and condition were examined.

CHAPTER IV: RESULTS

Acute Results

Demographics

A total of 22 resistance-trained males (n = 12) and females (n = 10) [mean (SD); age 22 (2) years; height: 174.7 (10.4) cm; body mass: 76 (17) kg; RA 1RM: 20.1 (8.9) kg; LA 1RM: 19.7 (8.9) kg] were recruited to participate in this study.

Repetitions

For repetitions there was a condition x set interaction ($p<0.001$). For set 1, the 1500 condition completed more repetitions than the 1580 [mean difference 14.5(23),$p=0.009$] and 7000 [mean difference 78.4 (9), $p<0.001$] conditions. In addition, the 1540 condition completed more repetitions during the first set compared to the 1580 [mean difference 9.9 (15),$p=0.005$] and 7000 [mean difference = 73.8(14.5), $p<0.001$] conditions. During the first set, the 1580 condition also completed more repetitions compared to the 7000 condition [mean difference 63.9 (22), $p<0.001$]. During the second set, the 7000 condition completed less repetitions than the 1500 [mean difference = 49 (29.5), $p <0.001$] ,1540 [mean difference = 48.4 (30.4), $p <0.001$] and 1580 [mean difference = 24 (24.8), $p <0.001$] conditions. In addition, the 1580 condition completed less repetition than the 1500 [mean difference 24(24.3), $p <0.001$] and 1540 conditions [mean difference = 24.0 (22.9) during set 2. During the third set, the 1580 condition performed less repetitions compared to the 1500 [mean difference = 23 (22.5), $p < 0.001$)] and

1540 conditions [mean difference = 17 (20.6), $p < 0.001$). The 1580 condition also performed more repetitions compared to the 7000 condition during the third set [mean difference = 17.5 (23.9), $p < 0.001$). During the fourth set, the 1580 condition performed less repetitions compared to the 1500 [mean difference = 20.1 (15.4), $p < 0.001$)] and 1540 conditions [mean difference = 16.5 (22.3), $p = 0.002$). The 1580 condition also performed more repetitions compared to the 7000 condition during the fourth set [mean difference = 18.0 (27.6), $p < 0.001$). The 7000 condition completed less repetitions than all low load conditions across all sets ($p < 0.001$)(Table 1).

Table 1: Repetitions for each condition across sets

	Set1	Set2	Set3	Set4	Time
1500	87(7)[a]	54(30)[a]	45(31)[a]	42(32)[a]	1 v 2,3,4; 2 v 3,4; 3 v 4
1540	82(14)[a]	54(31)[a]	39(29)[a]	38(31)[a]	1 v 2,3,4; 2 v 3,4
1580	72(21)[b]	30(26)[b]	22(25)[b]	22(28)[b]	1 v 2,3,4; 2 v 3,4
7000	8(2)[c]	5(2)[c]	5(3)[c]	4(1)[c]	1 v 2,3,4; 2 v 4

Letters indicate conditions within a given set were not significantly different ($p>0.05$). In additions, the "Time" column displays significant differences ($p < 0.05$) across sets within each condition.

Muscle Thickness

For muscle thickness, there was a group x time interaction ($p<0.001$). At baseline, there were statistically significant differences between the 1500 [3.8 (0.97cm)] and 7000 [3.9 (1.0cm)] condition ($p = 0.029$), as well as the 1500 [3.8 (0.97cm)] and 1540 [3.9 (1.0cm)] conditions. Immediately following exercise, the 7000 condition had lower muscle thickness values [4.2 (1.0) cm] compared to the 1500 [4.4 (1.1) cm, $p = 0.001$], 1540 [4.4(1.1) cm, $p = 0.001$], and 1580 [4.5 (1.0) cm, $p = 0.001$] conditions. There were no significant differences between any of the low load conditions at this time point. This continued 15 minutes post exercise, with the high load condition having lower muscle thickness values [4.1(1.0) cm], compared to 1500 [4.2 (1.0)

cm, p = 0.019], 1540 [4.3 (1.0) cm, p=0.003] and 1580 [4.3 (1.0) cm, p<0.001] conditions. There were no significant differences between any of the low load conditions at this time point. For all conditions, muscle thickness increased from pre to post exercise (p<0.001), remaining elevated above baseline 15 minutes post exercise (p<0.001, Figure 1, table 2).

Table 2: Acute Muscle Thickness Values

	1500	1540	1580	7000
Pre	3.8 (0.9)^{a}	4 (1.0)^{b}	3.9 (1.0)^{a,b}	4 (1.1)b
0 Min Post	4.4 (1.1)^{a*}	4.5 (1.1)^{a*}	4.5 (1.0)^{a*}	4.2 (1.1)^{b*}
15 Min Post	4.3 (1.1)^{a*}	4.3 (1.1)^{a*}	4.4 (1.1)^{a*}	4.2 (1.1)^{b*}

Mean (SD) values for muscle thickness before exercise (pre), immediately following exercise (0 Min Post) and 15 min following exercise (15 Min Post). There was a group x time interaction (p < 0.001). For a given time point (i.e., pre, 0 Min Post, 15 Min Post) conditions with the same letter indicates similar muscle thickness at that time point. An asterisks* denotes a given value is significantly different from pre (p < 0.05) within a given condition.

Figure 1: Acute Change in Muscle Thickness

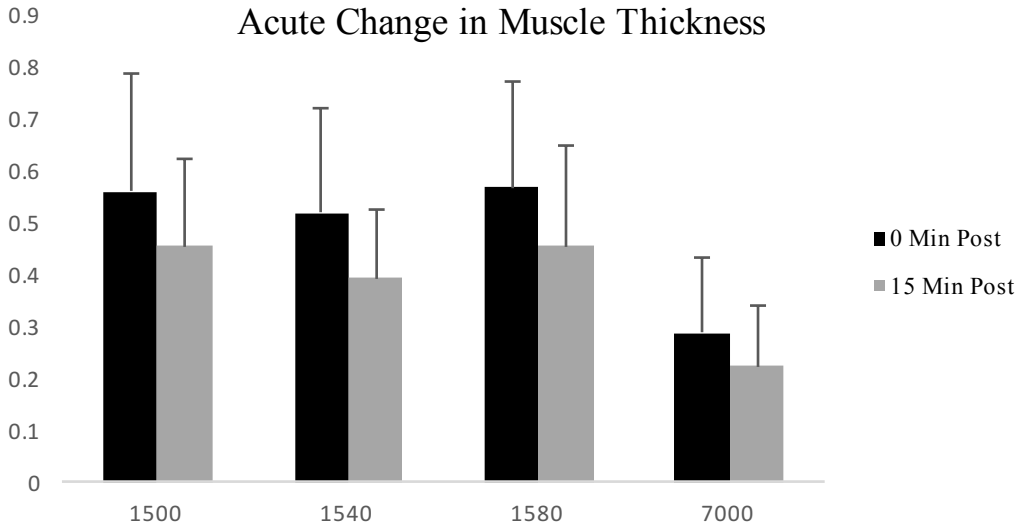


Figure 1 displays acute changes in muscle thickness relative to pre-values for 0 min post exercise and 15 min post exercise.

Isometric Torque

For Isometric torque, there was a condition x time interaction ($p<0.001$). Immediately following exercise torque values were significantly lower in the 1500 [31.8 (20) Nm, $p=0.004$], 1540 [28.3(16.9) Nm, $p<0.001$] and 1580 [29.5 (17) Nm, $p=0.002$] conditions compared to the 7000 condition [40 (19) Nm]. There were no significant differences between any of the low load conditions at this time point. At 15 minutes post exercise, 1500 [39.9 (23) Nm, $p= 0.007$) and 1540 [38.6(18) Nm, $p= 0.001$] conditions demonstrated lower torque values compared to the 7000 [47 (23) Nm] condition. There were no other significant differences between conditions at this time point. For all conditions, torque decreased immediately following exercise ($p<0.001$), increasing towards baseline, but remaining depressed 15 minutes following the exercise bout ($p<0.001$) (Figure 2, table 3).

Table 3: Acute Isometric Torque Values

	1500	**1540**	**1580**	**7000**
Pre	51.5 (25)	51.5 (25)	55.9 (25)	54.9 (26)
0 Min Post	31.8 (21)[a]	28.4 (17)[a]	29.5 (17)[a]	40 (19)[b]
15 Min Post	40 (23)[a]	38.7 (19)[a]	44.4 (24)[a]	47.6 (24)[b]

Mean (SD) values for isometric torque values before exercise (pre), immediately following exercise (0 Min Post) and 15 min following exercise (15 Min Post). There was a group x time interaction ($p < 0.001$). For a given time point (i.e., pre, 0 Min Post, 15 Min Post) conditions with the same letter indicates similar isometric torque values at that time point. Within each condition, all time points are significantly different from one another ($p < 0.001$).

Figure 2: Acute Change in Isometric Torque

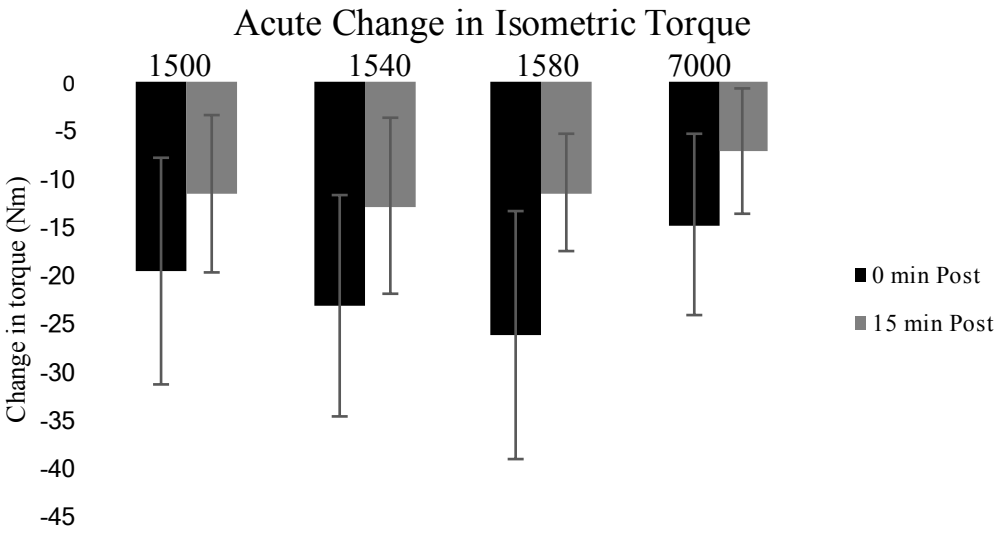


Figure 2 displays acute changes isometric torque relative to pre-values for 0 min post exercise and 15 min post exercise.

Electromyography

Two individuals failed to complete repetitions on at least one set of exercise and were excluded from analysis of EMG. Thus, 20 individuals were included in the final analysis. For the first three repetitions, there was a condition x set interaction ($p<0.001$). Follow up analysis showed that the high load condition tended to display greater EMG amplitude compared to all low load conditions across all sets ($p<0.001$, Table 4). In addition, the 1580 condition displayed greater activation compared to the 1500 condition during the first set. For the 1500 and 1540 conditions, there was a general trend for increased muscle activation across the first 3 sets, with muscle activation remaining similar between sets 3 and 4 ($p<0.05$). The 1580 condition displayed increased activation from sets 1 to sets 2, with activation remaining similar thereafter ($p<0.001$)

Within the 7000 condition activation was only significantly different between sets 1 and sets 4 (p =0.04, table 2).

Table 4: EMG First 3 Repetitions

	Set1	Set2	Set3	Set4	Across Sets:
1500	33(16)[a]	45(19)[a]	48(18)[a]	48(17)[a]	1v2, 1v3, 1v4, 2v3
1540	28(11)[a,b]	41(14)[a]	45(15)[a]	46(13)[a]	1v2, 1v3, 1v4, 2v3, 2v4
1580	24(11)[b]	41(12)[a]	42(13)[a]	46(18)[a]	1v2, 1v3, 1v4
7000	71(34)[c]	67(26)[b]	66(27)[b]	65(27)[b]	NA

EMG amplitude for the fisrt three repetitions across sets for each condition. Conditions with the same letter indicates similar EMG amplitude during a given set. Within each condition, significant differences ($p < 0.001$) are indicated in the right most column.

For the last three repetition There was no condition x set interaction ($p = 0.35$), however, there were main effects of condition ($p = 0.03$) and set ($p= 0.001$) Percentage EMG amplitude (relative to an isometric MVC) was greater in the high load condition compared to the 1580 condition ($p=0.007$). There were no other significant differences between conditions. Across sets, relative EMG amplitude was greater in set 1 [66.7(21.8)] compared to set 4 [62.9(21.400] ($p=0.032$), in set 2 [69.1 (24.4)] compared to set 3 [64.2(20.2)] and in set 2 [69.1(24.4)] compared to set 4 [62.9(21.400] ($p<0.001$). EMG values across sets for conditions are displayed in table 5.

Table 5: EMG Last3 repetitions

	Set1[a,b]	Set2[a]	Set3[b,c]	Set4[c]
1500[a,b]	65(30)	66(28)	62(24)	61(22)
1540[a,b]	62(23)	67(27)	64(20)	62(24)
1580[a]	58(27)	63(39)	56(33)	54(32)
7000[b]	81(31)	77(30)	73(25)	73(27)

EMG amplitude for the last three repetitions across sets for each condition. Conditions with the same letter indicates similar EMG within those conditions ($p > 0.05$). Sets with the same letter indicates similar EMG across those sets ($p > 0.05$).

Chronic Results

Demographics

All data are displayed as means (95%CI), with the exception of repetitions, which are displayed as means (SD). A total of 40 individuals (males=20; [mean (95% CI) Age 21.8 (20.5, 23) yrs; Height: 178.3 (175, 181) cm; Body mass: 75.8 (71.2, 80.3) kg; BMI: 23.8 (22.6, 25.1)]) (females=20; [mean (95% CI) Age: 21.2 (20.2, 22.2) yrs; Height: 164.8 (162.2, 167.4) cm; Body mass: 61 (57.3, 64.6) kg; BMI: 22.2 (20.9, 23.6)]) completed the study. Participant characteristics are displayed in table 6.

Table 6: Chronic Study Demographics

	Male (n=20)	Female (n=20)
Age	21.8 (20.5, 23)	21.2 (20.2, 22.2)
Height (cm)	178.3 (175, 181)	164.8 (162.2, 167.4)
Body Mass (kg)	75.8 (71.2, 80.3)	61 (57.3, 64.6)
BMI (kg/m^2)	23.8 (22.6, 25.1)	22.2 (20.9, 23.6)

All values are presented as means (95% CI)

Repetitions

Repetitions for each condition across weeks are displayed in table 7.

Table 7: Repetitions for Conditions Across Weeks

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
1500	244 (27)	455 (106)	622 (146)	644 (131)	665 (99)	701 (44)	691 (76)	685 (100)
1540	218 (40)	399 (120)	541 (176)	573 (160)	576 (140)	625 (136)	638 (118)	644 (144)
1580	163 (45)	250 (120)	356 (182)	341 (157)	391 (185)	390 (196)	406 (209)	461 (204)
7000	34 (9)	60 (14)	74 (20)	82 (19)	85 (23)	93 (25)	100 (26)	105 (32)

Total repetitions displayed as means (SD)

1RM Strength

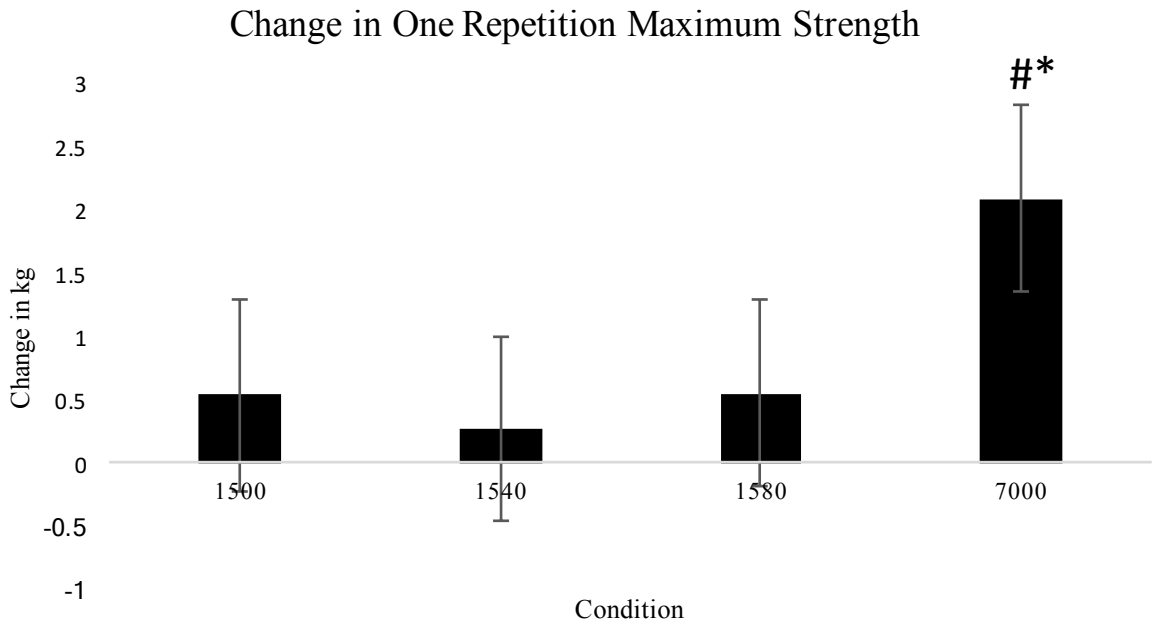
It was determined that the compound symmetry variance structure was most appropriate for the analysis of 1RM data. There was a condition x time interaction ($p = 0.003$). Follow up test showed that the change in strength was greater in the high load condition [2.09 (95% CI = 1.35-

2.83)kg,] compared to the 1500 condition [0.537 (95% CI = 0.219-1.294)kg, p = 0.004], 1540 [0.269 (95% CI = 0.449-0.99)kg, p = 0.001], and 1580 conditions [0.55 (95% CI = 0.182-1.294)kg, p = 0.004]. There were no statistically significant increases in strength for any of the low load conditions (1500, 1540 and 1580) from pre to post training ($p > 0.05$) (Table 8). However, strength did increase in the high load condition ($p < 0.001$). The pre-post change in 1RM strength is displayed in figure 3. Additionally, 1RM strength values are displayed in figure 4.

Table 8: Mean change (95% CI) for 1RM strength across conditions

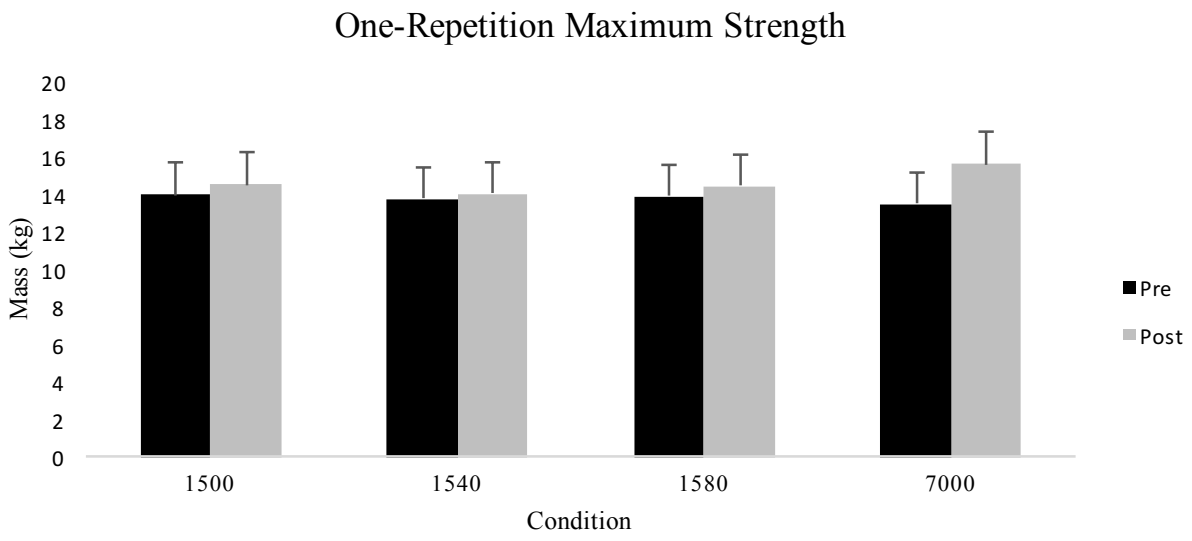
		95% CI For Difference	
Condition	**Mean Change (kg)**	**Lower**	**Upper**
1500	0.53	-0.21	1.29
1540	0.26	-0.44	0.99
1580	0.55	-0.18	1.29
7000	2.09	1.35	2.82

Figure 3: Change in 1RM Strength



Mean change (95% CI) for 1RM strength across conditions. There was a condition x time interaction ($p = 0.003$). An asterisks* indicates significantly different from 1500, 1540 and 1580 conditions. # indicates a significant change within a condition.

Figure 4: One-Repetition Maximum Strength



Mean values (95% CI) for 1RM strength across conditions. There was a condition x time interaction (p = 0.003). An asterisks* indicates significantly different from 1500, 1540 and 1580 conditions. # indicates a significant change within a condition.

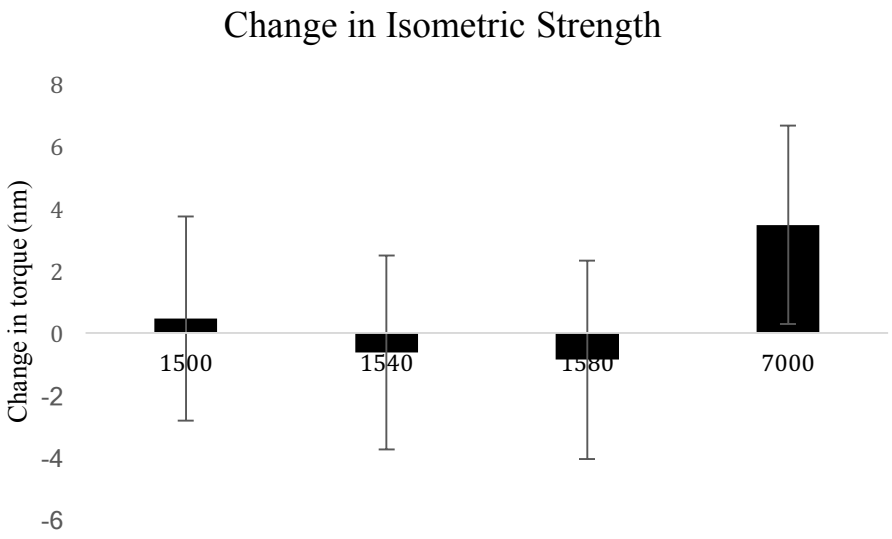
Isometric Strength

It was determined that the compound symmetry variance structure was most appropriate for the analysis of isometric strength data. For isometric strength there was no condition x time interaction (p = 0.207). In addition, there were no main effects for time (p= 0.456) or condition (p = 0.470). Mean change scores are displayed in table 9. In addition, isometric strength change scores are displayed in figure 5 and values are displayed in figure 6.

Table 9: Mean change (95% CI) for isometric strength across conditions

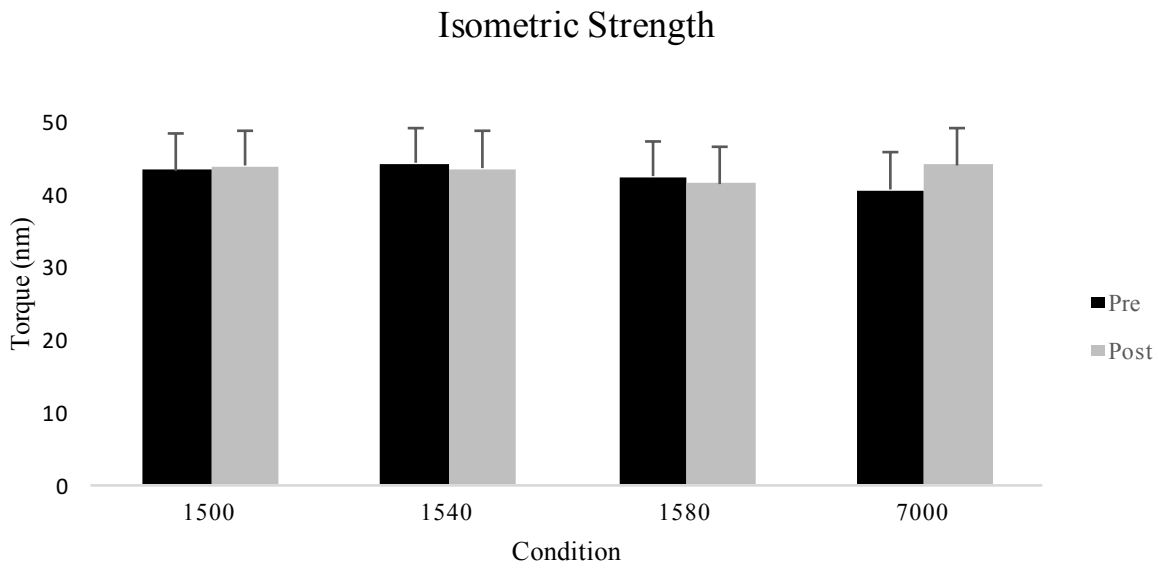
		95% CI For Difference	
	Mean Change (Nm)	**Lower**	**Upper**
1500	0.453	-2.829	3.735
1540	-0.638	-3.76	2.484
1580	-0.875	-4.074	2.324
7000	3.475	0.276	6.674

Figure 5: Change in Isometric Strength



Mean change (95% CI) for isometric strength across conditions

Figure 6: Isometric Strength



Mean values (95% CI) for isometric strength across conditions pre and post training intervention.

Isokinetic Strength

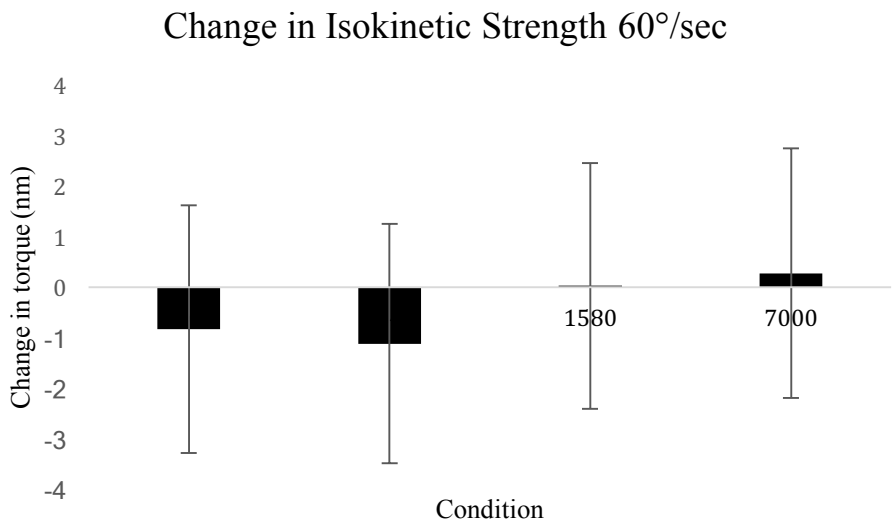
60°/sec

It was determined that the unstructured variance approach was most appropriate for the analysis of isokinetic data at 60°/sec. For isokinetic strength at *60°/sec* there was no condition x time interaction (p = 0.704). In addition, there were no main effects for time (p= 0.649) or condition (p = 0.954). Isokinetic strength change scores are displayed in table 10 and figure 7. Additionally, values at each time point are displayed in figure 8.

Table 10: Mean change (95% CI) for isokinetic strength 60°/sec across conditions

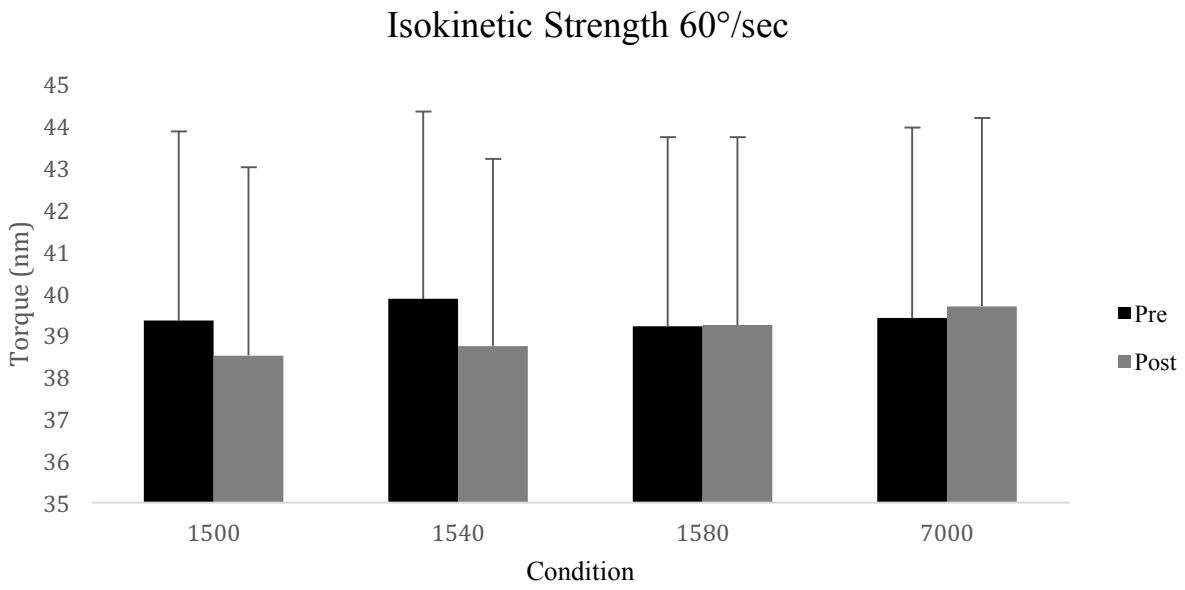
		95% CI For Difference	
	Mean Change (Nm)	**Lower**	**Upper**
1500	-0.832	-3.289	1.625
1540	-1.12	-3.491	1.252
1580	0.032	-2.403	2.466
7000	0.276	-2.198	2.75

Figure 7: Change in Isokinetic Strength 60°/sec



Mean change (95% CI) for isokinetic strength 60°/sec across conditions

Figure 8: Isokinetic Strength 60°/sec



Mean values (95% CI) for isokinetic strength 60°/sec across conditions pre and post training intervention.

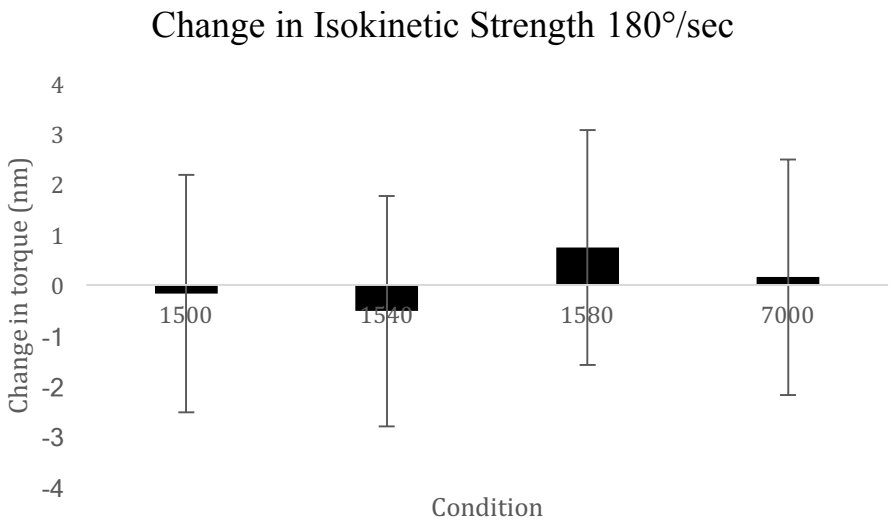
180°/sec

It was determined that the unstructured variance approach was most appropriate for the analysis of isokinetic data at 180°/sec. There was no condition x time interaction ($p = 0.739$). In addition, there were no main effects for time ($p= 0.951$) or condition ($p = 0.792$). Isokinetic strength change scores are displayed in table 11 and figure 9. Additionally, values at each time point are displayed in figure 10.

Table 11: Mean change (95% CI) for isokinetic strength 180°/sec across conditions

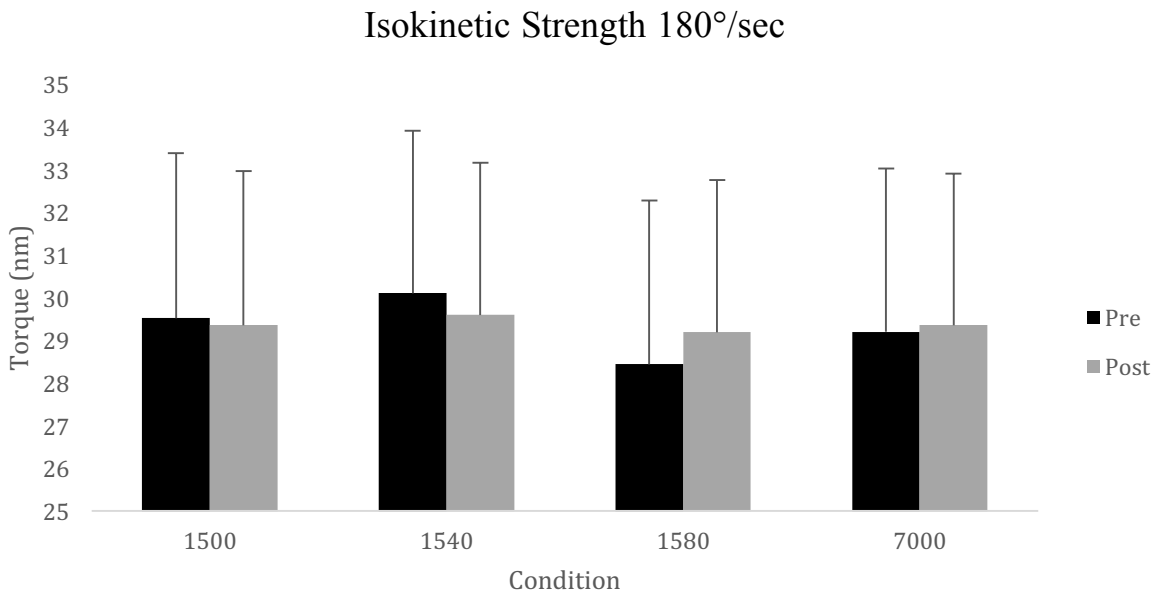
		95% CI For Difference	
	Mean Change (Nm)	**Lower**	**Upper**
1500	-0.165	-2.522	2.192
1540	-0.513	-2.803	1.776
1580	0.748	-1.58	3.076
7000	0.161	-2.178	2.5

Figure 9: Change in Isokinetic Strength 180°/sec



Mean change (95% CI) for isokinetic strength 180°/sec across conditions

Figure 10: Isokinetic Strength 180°/sec

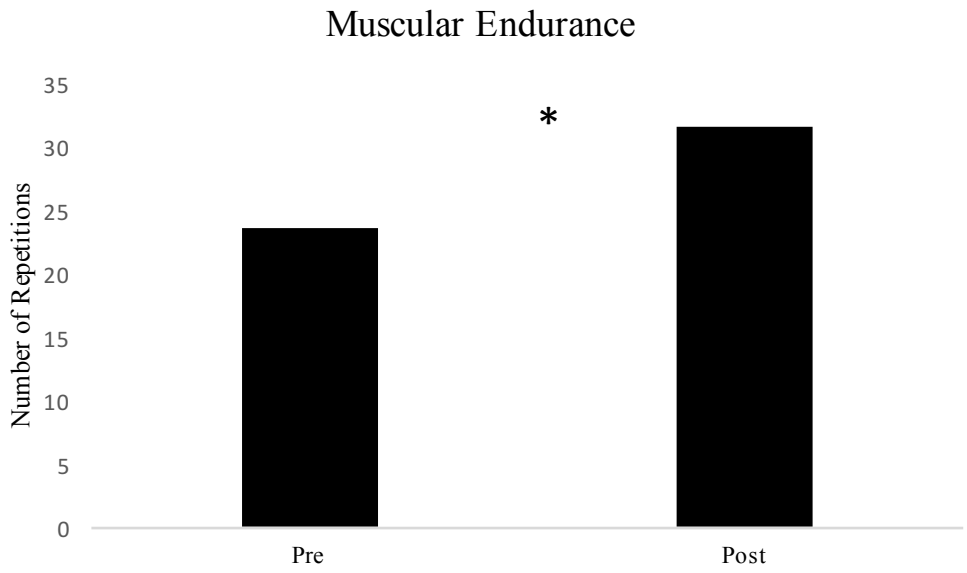


Mean values (95% CI) for isokinetic strength 180°/sec across conditions pre and post training intervention.

Muscular Endurance

It was determined that the unstructured variance approach was most appropriate for the analysis of muscular endurance data. For muscular endurance, there was no condition x time interaction ($p = 0.375$). In addition, there was no main effect for condition ($p = 0.914$). However, there was a main effect for time ($p < 0.001$). The number of repetitions performed increased from pre to post-training [Mean change = 7.9 (4.3 – 11.6) repetitions, $p < 0.001$]. Results are visually displayed in figure 11 and provided in table 12.

Figure 11: Muscular Endurance



Repetitions completes for muscular endurance pre and post intervention. The Asterisks* denotes a main effect for time ($p < 0.001$)

Table 12: Muscular Endurance Repetitions Pre and Post

	1500	1540	1580	7000
Pre	23 (21-26)	23 (21-26)	23(20-25)	22 (18-27)
Post	31 (25-36)	30 (25-35)	33 (27-38)	31 (26-36)

Repetitions pre and post training across conditions. Data are presented as means (95%CI).

Muscle Thickness

For all muscle thickness sites, it was determined that the unstructured variance approach was most appropriate.

Biceps 50% Site

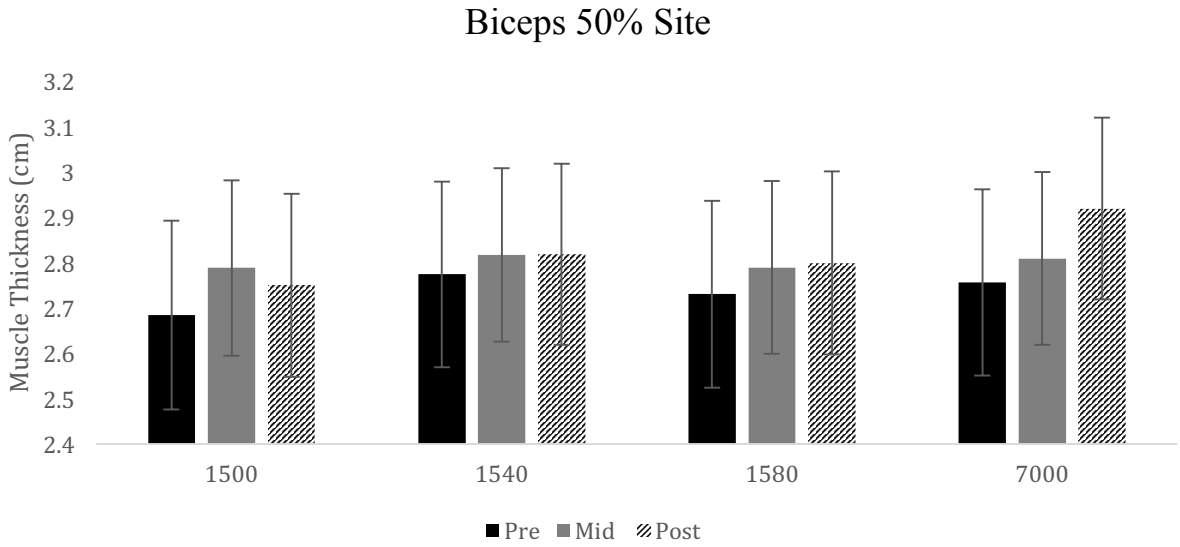
For the 50% site, there was a condition x time interaction ($p = 0.004$). The mean change in muscle thickness from pre to post training in the 7000 condition was greater than that observed in the 1500 [mean difference = 0.09 (0.01 - 0.18), $p = 0.022$], 1540 [mean difference = 0.11 (-0.03 - 0.20), $p = 0.005$] and 1580 [mean difference = 0.09 (0.12 - 0.17), $p = 0.024$] conditions. Similarly, the mean change in muscle thickness from mid to post training in the 7000 condition [0.11 (0.058 - 0.162)] was greater than that observed in the 1500 [mean difference = -0.14 (0.07 - 0.22), $p < 0.001$], 1540 [mean difference = 0.10 (0.03 - 0.17), $p = 0.003$] and 1580 [mean difference = 0.09 (-0.28 - 0.16), $p = 0.007$] conditions. There were no differences between conditions in the change in muscle thickness from the pre to mid time points ($p > 0.05$). Muscle thickness mean differences scores are provided in table 13. In addition, muscle thickness values at each time point are displayed in figure 12.

Table 13: 50% Site: Mean differences (95% CI) for changes in Muscle Thickness

	Pre vs. Mid	Mid vs. Post	Pre vs. Post
1500	0.104 (0.041-0.167)*[a]	-0.038' (-0.092 - 0.015)[a]	0.066 (0.003 - 0.128)*[a]
1540	0.043 (-0.043 - 0.103)[a]	0.001 (-0.05 - 0.052)[a]	0.044 (-0.016 - 0.103)[a]
1580	0.058 (-0.003 - 0.12)[a]	0.011 (-0.041 - 0.063)[a]	0.069 (0.008 - 0.13)*[a]
7000	0.053 (-0.009 - 0.115)[a]	0.11 (0.058 - 0.162)*[b]	0.163 (0.101 - 0.225)*[b]

An asterisks* denotes a significant change within each condition. For a given time point (i.e., pre vs. mid, mid vs. post) conditions with the same letter indicates a similar change in muscle thickness.

Figure 12: Biceps 50% Site



Mean values (95% CI) for muscle thickness values at the 50% site across conditions for pre mid and post training intervention.

Biceps 60% Site

For the 60% site, there was a condition x time interaction ($p = 0.014$). The mean change in muscle thickness from pre to post training in the 7000 condition was greater than that observed in the 1500 [mean difference = 0.10 (0.01 - 0.18) cm, $p = 0.026$], 1540 [mean difference = 0.09 (0.004 - 0.17) cm, $p = 0.04$] and 1580 [mean difference = 0.09 (0.01 - 0.18) cm, $p = 0.025$] conditions. Similarly, the mean change in muscle thickness from mid to post training in the 7000 condition was greater than that observed in the 1500 [mean difference = 0.09 (0.02 - 0.16)] cm, $p = 0.006$], 1540 [mean difference = 0.11 (-0.05 - 0.18) cm, $p = 0.001$] and 1580 [mean difference = 0.11 (0.04 - 0.17) cm, $p = 0.001$] conditions. There were no differences between conditions in the change in muscle thickness from the pre to mid time points ($p > 0.05$). Muscle thickness

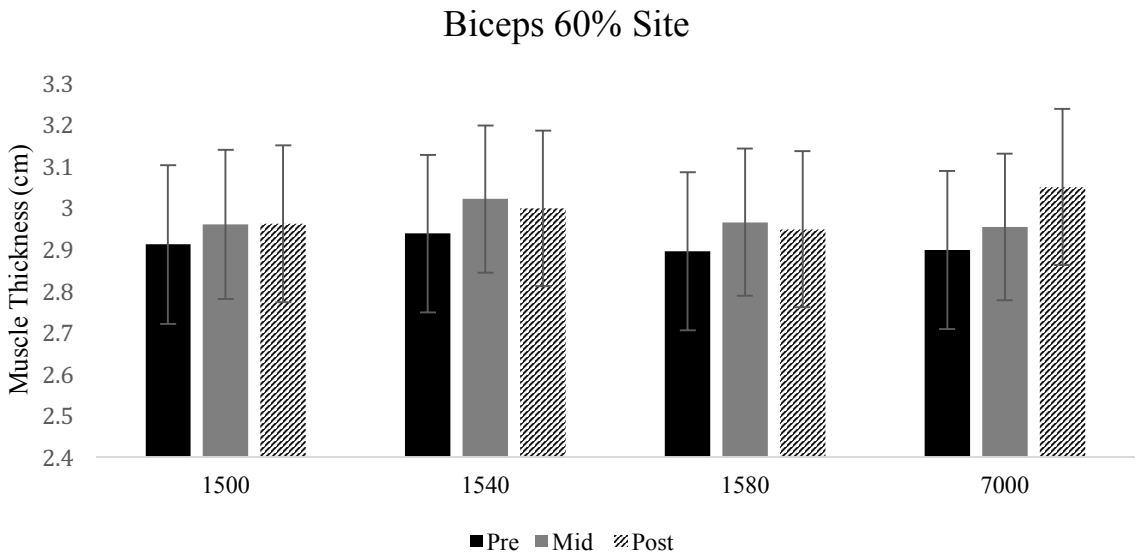
mean differences scores are provided in table 14. In addition, muscle thickness values at each time point are displayed in figure 13.

Table 14: 60% Site: Mean differences (95% CI) for changes in Muscle Thickness

	Pre vs. Mid	Mid vs. Post	Pre vs. Post
1500	0.048 (-0.012-0.108)[a]	0.002 (-0.046 - 0.05)[a]	0.05 (-0.02 - 0.12)[a]
1540	0.083 (0.026 - 0.141)*[a]	-0.023 (-0.069 - 0.023)[a]	0.061 (-0.006 - 0.127)[a]
1580	0.068 (0.01 - 0.127)*[a]	-0.016 (-0.064 - 0.031)[a]	0.052 (-0.017 - 0.12)[a]
7000	0.055 (-0.003 - 0.113)[a]	0.096 (0.048 - 0.144)*[b]	0.151 (0.082 - 0.22)*[b]

An asterisks* denotes a significant change within each condition. For a given time point (i.e., pre vs. mid, mid vs. post) conditions with the same letter indicates a similar change in muscle thickness.

Figure 13: Biceps 60% Site



Mean values (95% CI) for muscle thickness values at the 60% site across conditions for pre mid and post training intervention.

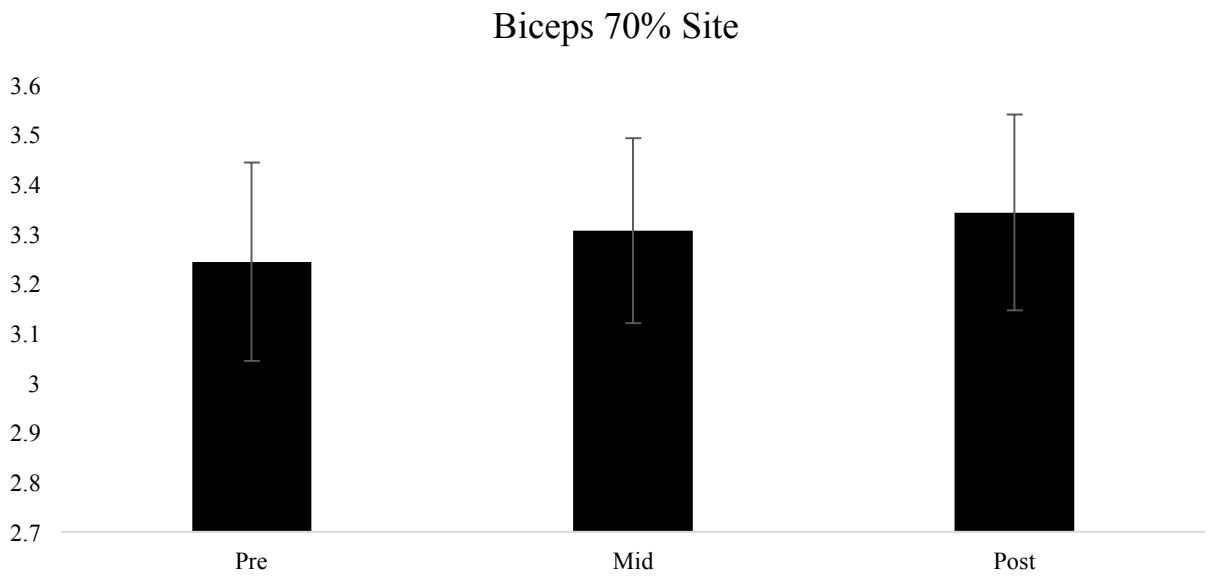
Biceps 70% Site

For the 70% site, there was no condition x time interaction (p = 0.308). In addition there was no main effect for condition (p = 0.958). However, there was a main effect for time (p = 0.001). Muscle thickness increased from pre-testing to the midpoint [mean change = 0.06 (0.01– 0.10) cm, p = 0.005] and remained elevated above baseline at post-testing [mean change = 0.09 (0.5 – 0.14 cm, p < 0.001]. Muscle size also increased from the midpoint to the post-testing time point [mean change = 0.03 (0.003 – 0.06) cm, p < 0.035]. Muscle thickness values across conditions are provided in table 15, and collapsed across conditions in figure 14.

Table 15: 70% Site: Mean Values (95% CI) for Muscle Thickness

	1500	1540	1580	7000
Pre	3.26 (3.05- 3.42)	3.24 (3.04 - 3.45)	3.24 (3.03 - 3.45)	3.21 (3.01 - 3.42)
Mid	3.31 (3.11 - 3.50)	3.32 (3.12 - 3.51)	3.31 (3.12 - 3.51)	3.28 (3.08 - 3.47)
Post	3.33 (3.12 - 3.54)	3.32 (3.11 - 3.52)	3.35 (3.15 - 3.56)	3.35 (3.14 - 3.56)

Figure 14: Biceps 70% Site

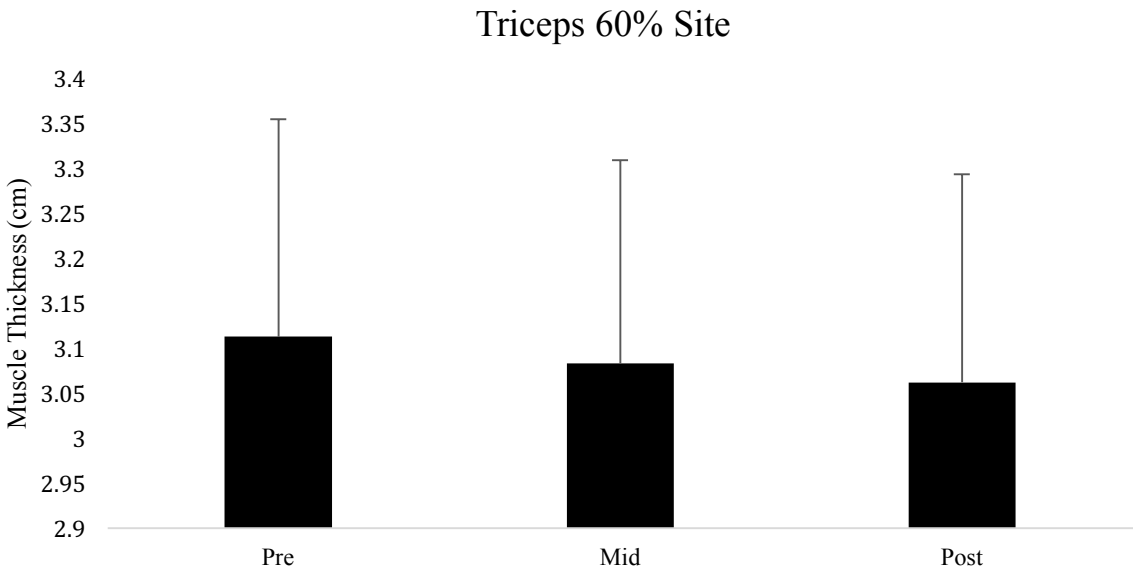


Mean values (95% CI) for muscle thickness values at the 70% site across conditions for pre mid and post training intervention.

Triceps 60% Site

For the triceps 60% site, there was not main effect of time (p = 0.092). Triceps muscle thickness remained constant from pre [3.113 (2.871 – 3.354) cm] to mid [3.083 (2.857 – 3.309) cm] to post training [3.062 (2.830 – 3.293) cm]. Results are displayed in figure 15.

Figure 15: Triceps 60% Site



Mean values (95% CI) for muscle thickness at the 60% site of the triceps collapsed across conditions for pre mid and post training intervention.

Acute Swelling

It was determined that the compound symmetry variance approach was most appropriate for the analysis of muscle swelling data. For the change in acute swelling there was a condition x time interaction (p = 0.047). Follow up analysis revealed that the change in acute muscle swelling was

less in the high load condition compared to all low load conditions across all time point comparisons ($p<0.05$). In addition, the change in the swelling response from pre to mid was significant ($p < 0.05$) for all conditions. From pre to post, the change in the swelling response was significant ($p < 0.05$) for the 1540, 1580 and 7000 conditions. The change in muscle thickness from mid to post was not significant for any condition ($P > 0.05$). Acute changes in muscle thickness for each condition for pre, mid and post are displayed in table 16. Table 17 displays the changes in the acute swelling response between the respective time points (pre vs. mid, pre vs. post and mid vs. post).

Table 16: Change in muscle thickness following an acute training bout

	Pre	Mid	Post
1500	0.352 (0.286-0.418)	0.434 (0.368-0.500)	0.380 (0.314-0.446)
1540	0.339 (0.276-0.403)	0.441 (0.378-0.504)	0.438 (0.375-0.501)
1580	0.360 (0.295-0.424)	0.512 (0.447-0.576)	0.496 (0.431-0.560)
7000	0.141 (0.076-0.205)	0.361 (0.297-0.426)	0.363 (0.298-0.427)

Values are displayed across conditions for pre, mid and post training study. All values are presented as means (95% CI)

Table 17: The change in the acute muscle swelling response

	Pre vs. Mid	Pre vs. Post	Mid vs. Post
1500	0.082 (0.00-0.164)[a*]	.028 (-0.054-0.110)[a]	-0.054 (-0.136-0.028)[a]
1540	0.102 (0.024-0.180)[a*]	0.099 (0.020-0.177)[a*]	-0.003 (-0.082-0.075)[a]
1580	0.152 (0.072-0.232)[a,b*]	0.136 (0.056-0.216)[a,b*]	-0.016 (-0.096-0.064)[a]
7000	0.220 (0.140-0.300)[b*]	0.222 (0.142-0.302)[b*]	0.002 (-0.078-0.082)[a]

The change in the acute muscle swelling response from "pre to mid", "pre to post" and "mid to post" training study. Values are displayed across all conditions. The same letter indicates that conditions within a given time points were not different from one another ($p > 0.05$). In addition, an asterisks* indicates that the change between time points within each condition was significant ($p > 0.05$). All values are presented as means (95% CI)

CHAPTER V: DISCUSSION

Acute Study

The primary findings of the acute portion of the study were as follows: 1) Blood flow restriction (BFR) decreased the number of repetitions performed in the low load conditions, with high pressure completing less repetitions compared to low pressure; 2) All groups displayed an acute muscle swelling response (low loads producing greatest change), with the swelling being greatest immediately post exercise, decreasing towards baseline 15 minutes post exercise; 3) Torque decreased in all groups from pre to post exercise (low loads producing greatest change), increasing towards baseline 15 minutes post; and 4) EMG amplitude (relative to an isometric MVC) was greatest in the high load condition compared to the very low load conditions.

Fatigue and Electromyography

In the present study, we observed greater torque decrements in all low load conditions (regardless of pressure) compared to the traditional high load condition. The torque decrements observed were of a greater magnitude than what has previously been reported, with decreases of 40, 46 and 48% observed for the 1500, 1540 and 1580 conditions respectively. This is nearly twice the 26% decrease that was observed in the traditional high load condition. The decrements in the present study were also greater than those observed by Dankel et al. (2017), who found decreases of 15% and 20% for 1540 and 1580 conditions respectively when exercise was not performed to volitional failure (performed 1 set of 30 repetitions followed by 3 sets of 15). Considering that changes in isometric torque are considered a surrogate for fatigue, it is not

surprising that the torque decrements were so large in the low load conditions. For example, the amount of fatigue necessary to render an individual incapable of overcoming a load of 15% 1RM is much greater than the level of fatigue needed to render them incapable of overcoming a load of 70% of 1RM. Taken into consideration with the EMG data, it seems likely that the protocol was able to increase motor unit recruitment despite the low load used, with no differences noted with or without the application of restrictive pressure. This is similar to the findings of Kacin and Strazar (2011) who observed similar EMG activity between legs exercising at 15% MVC with or without the application of ischemic pressure. Authors suggests that "differences in muscle activation between ischemic and control exercise disappear when exercises are performed at maximal efforts"(Kacin & Strazar, 2011). Fahs et. al (2015) noted lower EMG amplitude when comparing blood flow restricted and free flow unilateral knee extension exercise. However, differences were subtle (~10% difference) compared to those observed between low load and traditional resistance exercise. Thus, performing exercise to volitional failure may be particularly important when employing loads as low as 15% 1RM. This may alter recruitment patterns, facilitating the involvement of higher threshold motor units which may not be involved without the presence of fatigue (Fallentin, Jorgensen, & Simonsen, 1993). When more fibers are stressed, this may act as a signal for molecular events leading to a hypertrophic response. The present study also observed higher relative EMG amplitudes (~54 - 67% MVC during the last three repetitions of each set) compared to those observed by Dankel et al.(2017) whilst employing loads of 15% 1RM not to volitional failure (~36-43% of MVC during the last 3 repetitions of each set). It appears that higher level of EMG amplitude can be accomplished with lower loads if individuals train to failure/fatigue; however, these values are still lower than those observed with high load resistance training.

Acute Changes in Muscle Thickness

Haussinger (1993) has been suggested that cellular hydration may act as an anabolic proliferative signal, resulting in a shift towards anabolism. Although much of the understanding of cell swelling is derived from research in hepatocyte cells (Haussinger et al., 1993; Loenneke et al., 2012), it is still postulated as a mechanism to explain why BFR may attenuate skeletal muscle loss during periods of disuse and may ultimately play a role during all resistance type activities (Loenneke et al., 2012). Although it is unclear if cell swelling is a "mechanism" for muscle growth, a similar swelling response has been documented following a number of resistance training protocols. If not anabolic on its own, the presence of a swelling response may be indicative that a sufficient stimulus was achieved with the resistance training protocol. Our lab has observed a remarkably similar acute swelling response across a number of different resistance exercise protocols in the upper (Buckner et al., 2016, Counts et al., 2016) and lower body (Loenneke et al., 2016). Dankel et al. (2017) noted subtle differences in the acute swelling response, with acute swelling tending to be greater with increasing pressure and intensity when comparing the responses to 10, 15 and 20% 1RM with moderate (40% AOP) and high (80% AOP) restrictive pressures. The acute swelling response in the present study was greater than values previously observe in the literature for the low load training groups. Specifically, we observed acute changes of 0.55 (0.22) cm, 0.51 (0.19) cm, and 0.56 (0.20) cm immediately following exercise for the 1500, 1540 and 1580 training groups respectively. Following traditional high load resistance training we observed a more typical acute swelling response of 0.27 (0.14) cm. We believe this larger swelling response is likely driven by the volume or work

performed in the very low load conditions. Specifically, many of the participants were performing several sets of exercise for a duration of 3 min.

Repetitions

Blood flow restriction decreases the number of repetitions to volitional failure compared to regular low load training, presumably through a reduction in oxygen, and an accumilation of metabolites (Loenneke et al., 2012). For example, Jessee et al. (2017) found that higher pressures typically resulted in fewer repetition completed compared to lower pressures when employing a standardized exercise protocol (30 repetitions on set 1, followed by 3 sets of 15) with 30% of 1RM. Nonetheless, across a wide range of restrictive pressures (0%, 10%, 20%, 30%, 50%, or 90% AOP) all groups appeared to reach volitional failure as demonstrated by individuals' inability to perform all of the goal repetitions. When implementing this same protocol with lower loads (10, 15 or 20% of 1RM) together with moderate (40% AOP) or high (80% AOP) restrictive pressure, our research group found that individuals in the 15% 1RM condition completed all repetitions regardless of the pressure applied. These results suggest that a standardized exercise protocol may not be appropriate when using very low loads since volitional failure appears necessary for achieving a similar stimulus across individuals (Dankel et al., 2017). For example, It has been demonstrated that females are more resistant to fatigue than males (Clark, Collier, Manini, & Ploutz-Snyder, 2005), and that endurance athletes are more fatigue-resistant than weight-trained individuals (Richens & Cleather, 2014). Thus when performing an arbitrary number of repetitions, an individual's ability to reach failure may be dependent on their local muscular endurance. The present results also brought into question the ability to reach volitional failure when using such light loads. The present study found that the majority of individuals,

regardless of pressure, reached volitional failure by the first or second set of exercise with 15% of their 1RM. There were only 6, 5, and 3 individuals to complete all repetitions during the final set for the 1500, 1540 and 1580 conditions respectively. Although BFR does not appear to augment the acute muscular response to very low loads, it does decrease the repetitions necessary to reach volitional failure.

Chronic Study

1RM strength

Increases in 1RM strength were only observed in the high load training condition in the present study. These strength adaptations occurred despite muscle growth in all conditions, albeit growth was typically less in all low load conditions. Previous literature examining strength adaptations between high load and low load resistance exercise have often observed greater 1RM strength increases in high load training conditions, despite similar increases in muscle size (Martin-Hernandez et al., 2013; Ogasawara et al., 2013). Mitchell et al. (2012) found that low load training (30% 1RM) increased dynamic muscle strength but not to the same extent as a condition that had repeated practice lifting a heavy load (80% 1RM). In a follow up study, Morton et al. (2016) found that strength differences could be largely eliminated through practice of a 1RM every three weeks throughout the duration of the study. Thus, when allowing the participants to practice the strength test periodically, the differences in dynamic strength between low loads and high loads were eliminated in each of the simple machine based strength skills (i.e., machine guided shoulder press, machine guided knee extension, and leg press). However, when assessing strength in a more complex skill (barbell bench press 1RM) the strength differences between

loading schemes was not completely abolished. This suggests that specificity is important for the acquirement of strength, and that a greater volume of practice is necessary as the complexity of the skill increases. The results of the present study suggest that loads as low as 15% of 1RM do not facilitate adaptations in 1RM strength. This is similar to the findings of Kacin and Strazar (2011), who observed increases in muscle size with no change in performance measures when examining adaptations to 4 weeks of knee extension exercise performed at 15% of MVC with the application of restrictive pressure. Conversely, Lixandrao (2015) observed increases in knee extension 1RM strength following 12 weeks of lower body resistance exercise performed with 20% 1RM with moderate (40% AOP) and high (80% AOP) restrictive pressures; however, strength increases were not as great as those observed in a group training with 80% 1RM. Holm et al. (2008) observed increases in 1RM strength following 12 weeks of unilateral knee extension exercise performed using 15.5% of 1RM. However, the observed increase (19 $\pm$ 2%) was much less that that observed in the contralateral leg performing traditional high load (70% 1RM) resistance exercise (36 $\pm$ 5%). In addition, investigators assessed 1RM strength on 4 separate occasions over the course of the study. Thus, the 1RM strength adaptations observed by Holm et al. (2008) may be explained through their practice of the 1RM test itself as opposed to an adaptation facilitated through the training program. Altogether, it appears that lower loads are capable of augmenting 1RM strength; however, the lower the loads become the less likely it appears that strength adaptations will be observed.

Isometric and Isokinetic Strength

Our laboratory group has previously suggested that multiple strength tests (i.e., isometric, isokinetic) should be utilized in order to better capture any strength adaptation that may result

from a resistance training program (Buckner et al., 2017). This suggestion was largely influenced by our observations that low load training did not always result in similar strength adaptations as high load training, despite similar muscle growth. Naturally, our thinking on this has evolved as we have come to suspect that exercise induced increases in muscle size play little role with exercise induced increases in muscle strength (Buckner et al., 2016) Results of the present study would support this assertion. Specifically, no measures of isometric or isokinetic strength were augmented in any of the training groups. Likewise, 1RM strength increased in the high load training group, who's training largely resembled the 1RM strength assessment. Although strength mechanisms are poorly understood, it has been previously demonstrated that isometric and isokinetic strength measures can increase following isotonic training programs. However, others have questioned the assertion that there is a "generality" of strength adaptation. Specifically, Baker et al. (1994) examined the relationship between isometric and dynamic measures of muscular function to determine the existence of "generality or specificity". Authors noted moderate correlations between dynamic and isometric strength at baseline of a resistance training program ($r = 0.57 – 0.61$), but found that the changes in strength measures following a heavy resistance training program were unrelated ($r = 0.12$ to 0.15) (Baker et al., 1994). Although their study design and analysis were not adequate to draw definitive conclusions on strength adaptation, authors suggested that "a generality of muscular function does not occur across differing testing conditions and it would appear imprudent to extrapolate the results of one form of testing to another". This suggestion is more properly illustrated by Rasch and Morehouse (1957), whom found that strength in the elbow flexors increased more when participants were tested in a position (erect vs. supine) and manner (dynamic vs. modified Martin technique) more similar to how they had trained. They ultimately concluded that strength adaptations likely

reflect the acquisition of skill. We believe that this lack of a "generic" strength highlights the importance of specificity when training for a desired strength outcome. Although we have previously suggested that multiple strength assessments may better capture strength adaptation following a resistance training protocol (Buckner et al., 2017), it seems that these changes may just be reflecting skill acquisition resulting from more than one exposure to the test coupled with some a potential crossover of strength adaptation from the training program itself. Results of the present study suggest that 2 exposures in combination with our training protocols was not a sufficient enough stimulus to augment strength outcomes on these tests (i.e., isometric and isokinetic testing). In addition, the movement patters of biceps curls performed with heavy and very low loads appear to facilitate no skill acquisition for maximal isometric or isokinetic strength. Overall, it seems the farther a performance or strength task deviates from the training program, the more difficult it is to estimate what adaptations will be observed. In addition, strength increases that are believed to be indicative of "generality" appear largely dependent on the number of exposures an individual has performing that specific strength skill.

Mechanisms of Strength Adaptation

Although the widely accepted model of strength adaptation would suggest that strength is driven by both neural and hypertrophic adaptations (Moritani & deVries, 1979), mechanisms of strength adaptation remain largely elusive. For example, our research group has examined statistically equivalent strength adaptations between a group performing a one-repetition maximum attempt twice a week for 8-weeks and a group performing traditional high load training (8-12 repetition maximum) to volitional failure in the knee extension and chest press (machine) exercises (Mattocks et al., 2017). Interestingly, the model proposed by Moritani and Devries (Moritani &

deVries, 1979) can very seldom explain strength adaptations observed following a resistance training protocol. For example, this model would suggest that trained individuals would require muscle growth for continued strength adaptation, which does not appear to be the case (Dankel et al., 2017; Zourdos et al., 2015). It seems that the increase in strength following resistance exercise is likely a function of neural adaptations, and/or changes at the muscle level that do not result in a change in muscle size (i.e., changes in composition of the myosin motors, pattern of calcium release, and/or changes in components involved in the excitation contraction coupling process). As previously stated, alterations in agonist-antagonist co-activation, increases in motor unit firing rates, and changes in descending drive to the motor neurons may explain a large portion of increases in strength observed with resistance exercise (Gabriel et al., 2006). However, even studies investigating neural adaptations provide conflicting results. Jenkins et al. (2016), observed similar changes in voluntary activation between high-load and low-load resistance exercise, which would predict similar strength adaptations. However, high load training still elicited greater increases in 1RM strength compared to the low load condition. This illustrates that divergent neural adaptations assessed through twitch interpolation may not explain a large portion (if any) of the strength differences observed following high load or low load resistance exercise. Although the exact mechanisms of strength are presently unknown, our results reiterate the importance of specificity for strength adaptation and underscore the need for future work aimed to better understand mechanisms of strength adaption.

Skeletal Muscle Growth

In the present study, all conditions increased muscle thickness. However, the overall growth response appeared most robust in the 7000 condition compared to all low load conditions. The

1540 and 1580 conditions increased muscle size at the 50% site; however, these changes were not as great as those observed in the 7000 condition. In addition, only the high load condition observed increases in muscle thickness at the 60% site from pre to post. Despite these differences, all groups increased muscle similarly at the 70% site. Although high-loads, low loads and low loads with the application of BFR are have been shown to result in similar changes in skeletal muscle size (Mitchell et al., 2012; Ogasawara et al., 2013), results of the present study would suggest that loads as low as 15% of 1RM may not be as effective as high loads at producing a homogenous growth response across the muscle. This is similar to the findings of Holm et al. (2008), whom compared muscle size adaptations following 12 weeks of either unilateral knee extension performed at 15.5% (10 sets of 36 repetitions) or 70% (10 sets of 8 repetitions) of 1RM, finding that increases in quadriceps muscle cross-sectional area were much greater in the high load (70% 1RM, increase of 7.4 $\pm$ 1.4%) training group compared to the lower load (15.5% 1RM increase of 2.6 $\pm$ 0.8%) training group. Interestingly, Lixandrão et al. (2015) compared muscle size and strength adaptations across a variety of intensities and pressures and found that intensities as low as 20% 1RM with moderate pressure applied (40% AOP) produced no muscle growth. Authors observed greater increases in muscle size with increasing exercise intensity (20% 1RM < 40% < 80%), with higher pressures (80% AOP) appearing more important for growth when lower loads are used (20% 1RM). For example, authors found that increasing the relative occlusion pressure from 40% to 80% of augmented muscle growth when using a load of 20% 1RM load, but had no greater effect when a 40% load was used (Lixandrao et al., 2015). Authors ultimately suggested that "occlusion pressures seem secondary to exercise intensity". However, it is important to note that Lixandrão et al. (2015) used a standardized exercise protocol (2-3 sets of 15 repetitions) that did not induce failure like

the present study, or produce a high level of fatigue as seen in the Holm investigation (2008). Had all individuals performed exercise to volitional failure, it seems reasonable to suggest that investigators may have observed a more homogeneous growth response across conditions. Nonetheless, authors provided some evidence regarding the potential importance of restrictive pressure when lower loads are used. In contrast, Counts et al.(2016) found that the application of 40% or 90% of arterial occlusion pressure in combination with low load resistance exercise at 30% of 1RM resulted in similar increases in muscle size and strength following 8 weeks of training in the elbow flexors. Although the difference in exercise load could explain why Lixandrão et al.(2015) found pressure to be important with lower loads, it seems that the conservative exercise protocol employed (similar to the previous suggestion) by Lixandrão et al.(2015) may ultimately explain the lack of hypertrophy observed in their 20% 1RM condition with moderate pressure applied (40% AOP). In the present study, the level of pressure applied did not appear to augment any of the adaptations observed following 8-weeks of training. This would suggest that BFR alone cannot make up for the lack of stimulus provided by loads of 15% 1RM (when training to failure). Further, the only apparent benefit of BFR was a reduction in the number of repetitions performed to volitional failure.

Hypertrophy as a Mechanism for Strength Adaptation

Muscle growth was observed in all conditions in the present study, despite a complete lack of strength adaptation in all low load training groups. Such findings defy convention, which would suggest that muscle growth is a mechanism for strength adaptation (Moritani & deVries, 1979). However, based on the lack of direct evidence that exercise induced increases in muscle size contribute to increases in muscle strength adaptation, our laboratory group has suggested that

these are separate and unrelated adaptations (Buckner et al., 2016). Previous literature has demonstrated that low-load alternatives to traditional resistance exercise often result in similar skeletal muscle growth as traditional high load training with divergent results found with strength (Martin-Hernandez et al., 2013; Mitchell et al., 2012; Ogasawara et al., 2013). When interpreting these studies it is perplexing that similar muscle growth does not result in similar strength adaptation. However, if these adaptations are considered as separate and unrelated, the large majority of the literature becomes easier to explain. This also brings in to question what the role of skeletal muscle hypertrophy is. Although compensatory skeletal muscle hypertrophy may serve some physiological purpose, it does not appear that is plays a role in strength adaptation. Morehouse may have been correct in 1963 when he suggested that "It has not been proved that hypertrophy is necessarily a desirable reaction", explaining that "some students are of the opinion that it may be simply a by-produce of training, perhaps a noxious one (Morehouse & Miller, 1963)." Thus, skeletal muscle hypertrophy may simply be a by-product of resistance exercise and serve no underlying purpose.

Given the lack of direct evidence that exercise induced skeletal muscle growth is important for strength adaptation, our research group has begun to design studies designed to examine the influence that skeletal muscle growth has on strength. We have observed that a group performing a one-repetition strength test twice a week (designed to increase only muscle strength) increased strength similarly to a group performing traditional resistance exercise (designed to increase muscle size and strength) twice a week. Of note, the increase in muscle size in the traditional resistance training group had no additive effect on strength adaptation (Mattocks et al., 2017). This same phenomenon has also been demonstrated in a small cohort of trained individuals

following 3-weeks of daily strength practice or traditional resistance exercise in combination with the strength practice (Dankel et al., 2016). The results of the present study further contribute to this body of literature demonstrating that increases in muscle size and increases in strength do not appear dependent on one another over an 8 week period. A criticism of all these studies is the duration over which adaptations are observed (i.e, 8 weeks or 3 weeks). Although this is a limitation, it is important to acknowledge that the original study that established muscle growth as a mechanism for strength adaptation was only 8 weeks in duration. Considering this, we believe these studies provide strong evidence against the long perpetuated mechanism of skeletal muscle growth for strength adaptation (Moritani & deVries, 1979).

Acute Swelling response

The acute swelling response showed that very low loads can produce a much greater swelling response compared to high load exercise. However, we were most interested in how the swelling response itself changes across time within each condition. Our results showed that a similar acute swelling response was observed across time (from mid to post) within each condition, providing some indication that there was not a large presence of swelling prior to taking measurements of muscle thickness. The changes in acute swelling observed between the pre to mid and pre to post time points were different only because participants performed one set of exercise during their initial visit instead of the complete protocol (4 sets of exercise). Although gradually increasing the protocol was not the original design, we decided this was the best approach given the amount of volume performed in the low load conditions. We have previously suggested that the acute swelling response itself can be exploited to confirm that skeletal muscle growth has occurred (Buckner et al., 2017). Results of this dissertation suggest that the acute swelling response can

likely be used to detect the presence of baseline swelling; however, our results (both acute and chronic) are contra to Buckner et al.'s (2017) hypothesis that the acute swelling response observed following traditional high load resistance training is a muscles maximal capacity for a swelling response. Meaning (for example) the swelling response observed with high loads can be exceeded with a lower load protocol (i.e., 15% 1RM to failure). These results suggest that the swelling response to a given protocol appears fairly repeatable across time and can possibly be used to detect the presence of baseline swelling.

Local Muscular Endurance

In the present study, we observed a similar increase in local muscular endurance across all groups, with the adaptations in low load conditions not influenced by the addition of restrictive pressure. Despite the low load training groups performing a much greater number of repetitions during each training visits, the testing load chosen (42.5% 1RM) did not cater to "specificity" of either group. Schoenfeld et al. (2015) found that low load training (25–35 repetitions to muscle failure) resulted in improvements in bench press muscular endurance; whereas high load training (8–12 repetitions to muscular failure) saw no improvements. Schoenfeld et al. (2015) hypothesized that divergent adaptions at the muscle fiber level may underlie these differences; however, the endurance catered to specificity of the low load group, which may better explain these findings (i.e., low load group trained at 30-50% 1RM and endurance test was performed with 50% 1RM). In addition, Schoenfeld (2015) used the baseline 1RM for the pre-endurance test and the post 1RM for the post endurance test. In the present study, we used the same load for pre and post endurance testing. Thus, these findings would suggest that endurance adaptations in the 7000 condition may result from the training load being a lower relative percentage during

post-testing; whereas adaptations in the low load conditions are likely a result from mitochondrial or other local adaptations (Burd et al., 2012). Much like other non-specific performance measures, we would suggest that the farther the task deviates from the training program, the more difficult it is to estimate what adaptations will be observed.

CHAPTER VI: CONCLUSIONS

The purpose of this study was to compare the acute skeletal muscle response (i.e., acute muscle swelling, acute torque decrements and muscle activity) following a variety of resistance training protocols (i.e., different combinations of arterial occlusion pressure and load) in the upper body. In addition, this study sought to examine long-term adaptations of skeletal muscle size, strength and endurance following 8 weeks of these various resistance-training protocols. Results of the present study shed important light regarding the efficacy of BFR when very low exercise loads are used. Primarily, it appears that very load loads (15%1RM) produce similar decreases in torque, and similar acute increases in muscle thickness when performed to volitional failure regardless of applied restrictive pressure. In addition, high pressures decreased the number of repetitions performed to volitional fatigue. Results of the present study also showed that acute changes in muscle thickness and torque are much greater than those observed in the high load training group, or previous investigations examining low loads. Interestingly, our chronic date demonstrated that loads of 15% (regardless of pressure applied) produce skeletal muscle growth. However, this response is not as robust as that observed following high load resistance training. In addition, training loads of 15% (with or without the application of BFR) do not produce increases in measures of strength.

Research Question (Acute)

Will the acute skeletal muscle response differ between traditional high load resistance exercise and very low load resistance exercise with and without the application of different blood flow restriction pressures?

Hypothesis

1. **It was hypothesized that, acute changes in torque and muscle thickness would be similar across all resistance exercise protocols (15% 1RM; 15% 1RM + 40% AOP; 15% 1RM + 80% AOP; 70% 1RM).**

   This hypothesis was not supported, as all low load conditions displayed significantly greater reductions in isometric torque compared to the high load condition.

2. **It was hypothesized that electromyography amplitude, as measured through EMG would be higher in the high load resistance condition (70% 1RM) compared to all other conditions.**

   This hypothesis was supported as the high load condition displayed greater EMG amplitude compared to all low load conditions.

3. Research Question (Chronic)

Will the chronic skeletal muscle adaptations differ between traditional high load resistance exercise and very low load resistance exercise with and without the application of different blood flow restriction pressures?

Hypothesis (Chronic)

4. **It was hypothesized that similar skeletal muscle growth would be observed across all resistance exercise conditions across the 8 week period.**

This hypothesis was partially supported, as similar muscle growth was observed across all conditions at the 70% site of the biceps. However, the high load condition displayed greater skeletal muscle growth than all low load conditions at the 50 and 60% sites.

5. **It was hypothesized that isometric and isotonic strength adaptations would be greatest in the traditional high load training condition (70% 1RM), with strength adaptations being similar between all low load conditions (regardless of AOP).**

   This hypothesis was partially supported in that the high load condition was the only condition to observe changes in 1RM strength. This hypothesis was not supported in that no changes in isometric or isokinetic strength were observed in any condition.

6. **It was hypothesized that muscular endurance would change similarly across exercise protocols.**

   This hypothesis was supported as all training conditions displayed similar changes in local muscle endurance following the 8 weeks of training.

Significance

Results of the present study may have implications for clinical populations, which may include: individuals recovering from injury (Ohta et al., 2003), individuals coming off bed rest (Cook et al., 2010) or those limited by other musculoskeletal disorders, in whom the ability to perform traditional resistance exercise may be limited (Ohta et al., 2003). Although loads of 15% 1RM are incredibly light, they do appear to stimulate a growth response. It is important to note that this response was not as robust as that observed following traditional high load training. Thus, higher loads may be preferential if the primary goal is to maximize muscle growth and strength adaptation. Perhaps more importantly, the present study provided some indication that BFR cannot augment muscle size and strength adaptations induced by a given training load. Rather, BFR decreases the volume of work necessary to reach momentary failure. This study sought to determine the efficacy of the addition of blood flow restriction to very low load resistance exercise, and there appears to be very little benefit to using BFR in combination with very low loads. In addition to this, our results shed further light on the relationship between changes in muscle size and changes in strength following training. Specifically, we observed changes in muscle size across very low load conditions, with no change in any strength measure. This adds to a growing body of literature demonstrating the independence of muscle size and strength adaptations, while also demonstrating that muscle growth can occur independent of the external load an individual must overcome (Ozaki et al., 2016).

Future Research

Although loads of 15% 1RM do not appear to produce a robust muscle growth response, changes in muscle size were still observed. Further, it doesn't appear that BFR augments this response. It seems reasonable to suggest that intensities as low as 15% 1RM have the most application in clinical populations who are unable to lift heavier loads. However, the goal with such populations is likely a prevention of atrophy as opposed to an actual growth response. Future research should explore the application of very low loads for atrophy prevention during bed rest or rehabilitation. In addition, future research should continue to explore the role of skeletal muscle hypertrophy for strength adaptation. The present findings provide further evidence that

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VITA

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Education:

University of Mississippi – Oxford, Mississippi
Doctorate of Philosophy in Exercise Physiology January 2015 – Present
University of Nebraska- Lincoln, Nebraska August 2013 – May 2014
Doctorate of Philosophy in Nutrition and Health Sciences
Florida Atlantic University, Boca Raton, Florida January 2012 – August 2013
Master of Science in Exercise Science & Health Promotion August 2013
Temple University, Philadelphia, Pennsylvania August 2007-May 2011
Bachelor of Science in Kinesiology
Pompano Beach High School, Pompano Beach, Florida May 2007

Work Experience:

Graduate Research Assistant
University of Mississippi, University, Mississippi January 2015- Present
- Health, Exercise Science and Recreation Management
-Research in Skeletal Muscle Physiology Lab
-Teach lecture course: Behavioral Aspects of Weight Management

Adjunct Instructor
Florida Atlantic University, Boca Raton, Florida August 2014- December 2014
- Department of Exercise Science and Health Promotion
-Activity Courses

UN-L Doctoral Research Assistant August 2013 – May 2014
-Department of Nutrition and Health Science
-Teach Ex. Phys and Ex. Testing Labs
- Research

FAU Exercise Science Graduate Assistant January 2012- August 2013
-Teach *Health and Fitness for Life* courses
Schedule and oversee fitness and body composition tests to outside comm

-Assist in research
-Conduct Body composition analysis for FAU sports teams

Fitness Assistant
Bocaire Country Club, Boca Raton, Florida September 2011- Present
-Group fitness and personal training

Intern Strength Coach
Florida Atlantic University, Boca Raton, Florida January 2011- May 2011
-Assistant strength coach for Men's Basketball
-Strength coach for Men's Golf

Tumbling/Gymnastics Coach
Star Gym Gymnastics, Boca Raton, Florida January 2004-May 2007
-Teach gymnastics levels 4-6

Honors/ Awards:

Florida Atlantic University, College of Education
"Outstanding Exercise Science and Health Promotion Graduate Student" 2012/2013

Temple University
-Dean's list 2007-2011

Received NSCA "Challenge Scholarship 2015
-$1500

Elected "Student Representative" 2016
Southeastern ACSM, 2016 Regional Meeting

Professional Preparation:

Attended:

National Strength and Conditioning Annual Meeting, 2012
Providence, Rhode Island
National Strength and Conditioning Annual Meeting, 2013
Las Vegas, Nevada
South Eastern American College of Sports Medicine Annual Meeting, 2013
Greenville, South Carolina
American College of Sports Medicine Annual Meeting, 2014
Orlando, Florida
American College of Sports Medicine Annual Meeting, 2015
San Diego, California
South Eastern American College of Sports Medicine Annual Meeting, 2016
Greenville, South Carolina
American College of Sports Medicine Annual Meeting, 2016
Boston, Massachusetts
American College of Sports Medicine Annual Meeting, 2017
Denver, Colorado

Presentations/Abstracts:

1. Mouser JG, Laurentino GC, Scott J. Dankel, **Buckner SL**, Jessee MB, Counts BR, Mattocks KT, and JP Loenneke. "Blood Flow in Humans During Low-Load Exercise with and without Blood Flow Restriction." ACSM National Conference, June 2017, Denver, Colorado.

2. Loenneke JP, Dankel SJ, Jessee MB, **Buckner SL**, Mouser JG, and KT Mattocks. "Are Higher Blood Flow Restriction Pressures More Beneficial When Lower Loads Are Used?" ACSM National Conference, June 2017, Denver, Colorado.

3. Jessee MB, Mattocks KT, Counts BR, **Buckner SL**, Mouser JG, Dankel SJ, Laurentino GC, and **JP Loenneke**. The Acute Muscular Responses to Blood Flow Restricted Exercise Using Low and High Relative Pressures." ACSM National Conference, June 2017, Denver, Colorado.

4. Mattocks KT, Jessee MB, Counts BR, **Buckner SL**, Mouser JG, Dankel SJ, Laurentino GC, and **JP Loenneke**. "Effects of Different Levels of Blood Flow Restriction on Arterial Occlusion Pressure and Perceptual Responses." ACSM National Conference, June 2017, Denver, Colorado.

5. Dankel SJ, Jessee MB, **Buckner SL**, Mouser JG, Mattocks KT, and JP Loenneke. "Cardiovascular and Perceptual Responses to Various Blood Flow Restriction Pressures and Exercise Loads." ACSM National Conference, June 2017, Denver, Colorado.

6. **Buckner SL**, Dankel SJ, Mattocks KT, Jessee MB, Mouser JG, Counts BR, Laurentino GC, and **JP Loenneke**. "Differentiating Swelling and Hypertrophy Following Repeated Bouts of Resistance Exercise." ACSM National Conference, June 2017, Denver, Colorado.

7. **Buckner SL.** Differentiating Swelling and Hypertrophy Through Indirect Assessment of Muscle Damage in Untrained Men Following Repeated Bouts of Resistance Exercise. SEACSM Invited Presentation, February 2017, Greenville, South Carolina.

8. Counts BR, **Buckner SL**, Dankel SJ, Jessee MB, Mattocks KT, Mouser JG, Laurentino GC, and Loenneke JP. The Acute Response to No Load Exercise: Is it Sufficient? ACSM National Conference, May 2016, Boston, Massachusetts.

9. Barnett BE, **Buckner SL**, Dankel SJ, Counts BR, Jessee MB, Mouser JG, Halliday TM and Loenneke JP. Circadian Rhythms in Blood Glucose and Blood Pressure: Are they Reproducible? ACSM National Conference, May 2016, Boston, Massachusetts. .

10. Mouser JG, **Buckner SL**, Counts BR, Dankel SJ, Jessee MB, Mattocks KT, Laurentino GC, and Loenneke JP. Venous versus Arterial Blood Flow Restriction: The Impact of Cuff Width. ACSM National Conference, May 2016, Boston, Massachusetts.

11. Ingram JW, **Buckner SL**, Dankel SJ, Counts BR, Mouser JG, Abe T, Laurentino GC, and Loenneke JP. The influence of time on determining blood flow restriction pressure. ACSM National Conference, May 2016, Boston, Massachusetts.

12. Mattocks KT, **Buckner SL**, Dankel SJ, Counts BR, Jessee MB, Mouser JG, Laurentinio GC, Abe T, and Loenneke JP. The Influence of Cuff Material on the Blood Flow Restriction Stimulus in the Upper Body. ACSM National Conference, May 2016, Boston, Massachusetts.

13. Laurentino GC, Mouser JG, **Buckner SL**, Counts BR, Dankel SJ, Jessee MB, Mattocks KT, Loenneke JP, Tricoli V. The influence of cuff width on regional muscle growth: Implications for Blood Flow Restriction Training. ACSM National Conference, May 2016, Boston, Massachusetts.

14. Jessee MB, **Buckner S.L**, Dankel SJ, Counts BR, Abe T, and Loenneke JP. The Influence of Cuff Width and Sex on Arterial Occlusion: Implications for Blood Flow Restriction Research. ACSM National Conference, May 2016, Boston, Massachusetts.

15. Loenneke JP, **Buckner S.L**, Dankel SJ, Jessee MB, Counts BR, Mouser JG, Mattocks KT, Laurentino GC, and Abe T. The Influence of Cuff Material on the Acute Muscular Response to Blood Flow Restricted Exercise in the Upper Body. ACSM National Conference, May 2016, Boston, Massachusetts.

16. **Buckner S.L**, Dankel SJ, Counts BR, Barnett BE, Jessee MB, Mouser JG, Halliday TM, and Loenneke JP. The Influence of Circadian Rhythms on Upper Body Isometric Strength, Muscle Thickness and Body Temperature. ACSM National Conference, May 2016, Boston, Massachusetts.

17. Dankel SJ, Counts BR, Barnett BE, **Buckner S.L**, Abe T, Zourdos MC, and Loenneke JP. Muscle adaptation to 21 Straight Days of Elbow Flexor Exercise in Trained Individuals. ACSM National Conference, May 2016, Boston, Massachusetts.

18. **Buckner, S.L**., et al. "Comparing passive angle–torque curves recorded simultaneously with a load cell versus an isokinetic dynamometer during dorsiflexion stretch tolerance assessments." *Medical engineering & physics* 37.5 (2015): 494-498. Presented at the American College of Sports Medicine National Annual Convention, Orlando, FL).

19. Switalla, J.R., Housh, T.J., Cochrane, K.C., Jenkins, N.D.M, **Buckner, S.L**., Goldsmith, J.A., Schmidt, R.J., Johnson, G.O., Cramer, J.T, Bergstrom, H.C. Metabolic, cardiovascular, and perceptual responses during treadmill running severe intensity treadmill running: Limiting factors of exercise performance? (Presented at the National Strength and Conditioning Association Annual Convention, 2015, Orlando, FL).

20. Jenkins, N.D.M., Housh, T.J., Bergstrom, H.C**., Buckner, S.L**., Cochrane, K.C., Hill,

E.C., Smith, C.M., and Cramer, J.T. Muscle size, muscle strength, electromyography, mechanomyography, and voluntary activation during four weeks of high- vs. low-load resistance training. (Presented at the National Strength and Conditioning Association Annual Convention, 2015, Orlando, FL).

21. Bergstrom, H.C., Housh, T.J., Cochrane, K.C., Jenkins, N.D.M., **Buckner, S.L**., Goldsmith, J.A., Schmidt, R.J., Johnson, G.O., and Cramer, J.T. Factors Underlying the Perception of Effort during Constant Heart Rate Running. 47(5S):785-788, 2015. (Presented at the American College of Sports Medicine National Annual Convention, San Diego, CA).

22. Bergstrom, H.C., Housh, T.J., Cochrane, K.C., Jenkins, N.D.M., **Buckner, S.L**., Goldsmith, J.A., Schmidt, R.J., Johnson, G.O., and Cramer, J.T. Sustainability, physiological, and perceptual responses at the critical heart rate during treadmill running. (Presented at the National Strength and Conditioning Association National Annual Convention, 2014, Las Vegas, NV).

23. Cochrane, K.C., Housh, T.J., Bergstrom, H.C., Jenkins, N.D.M., **Buckner, S.L**., Cramer, J.T., Johnson, G.O., and Schmidt, R.J.. Comparison of perceptual and physiological fatigue thresholds during cycle ergometry. (Presented at the National Strength and Conditioning Association National Annual Convention, 2014, Las Vegas, NV).

24. Jenkins, N.D.M., **Buckner, S.L**., Goldsmith, J.A., Bergstrom, H.C., Cochrane, K.C., Housh, T.J., and Cramer, J.T. The effects of six weeks of moderate aerobic exercise combined with conjugated linoleic acid supplementation on peak oxygen uptake, gas exchange threshold, and respiratory compensation point. (Presented at the National Strength and Conditioning Association National Annual Convention, 2014, Las Vegas, NV).

25. Jenkins, N.D.M., **Buckner, S.L.**, Goldsmith, J.A., Bergstrom, H.C., Cochrane, K.C., Schmidt, R.J., Johnson, G.O., Housh, T.J., and Cramer, J.T. Reliability and comparisons of handgrip strength, leg extension muscle function, and balance. (Presented at the National Strength and Conditioning Association National Annual Convention, 2014, Las Vegas, NV).

26. Bergstrom, H.C., Housh, T.J., Cochrane, K.C., Jenkins, N.D.M., **Buckner, S.L**., Baker, B., Schmidt, R.J., Johnson, G.O., and Cramer, J.T. Neuromuscular responses during continuous exercise at, above, and below critical power. 46(5S):668-677, 2014. (Presented at the American College of Sport Medicine Annual Convention, Orlando, FL).

27. Jenkins, N.D.M., **Buckner, S.L**., Bergstrom, H.C., Cochrane, K.C., Palmer, T.B., Schmidt, R.J., Johnson, G.O., Housh, T.J., and Cramer, J.T. Age related differences in rates of torque development and rates of rise in electromyographic amplitude. 46(5S):456-461, 2014. (Presented at the American College of Sport Medicine Annual Convention, Orlando, FL).

28. **Buckner, SL**., Graves, BS. "A Comparison of body fat percentages among Exercise Science and Health Promotion students vs. Non-Exercise Science and Health Promotion students ages 20-29 at Florida Atlantic University" (Presented at the Florida Atlantic University College of Education Research Symposium, November 2012)

Other:

Schedule and oversee all outside testing in the Florida Atlantic University Department of Exercise Science and Health Promotion "Human Performance Lab" January 2012 – August 2013

Body Composition Testing for Teams and Individuals
Hydrostatic weighing, Ultrasound, Bod Pod
Blood Lactate Testing For Athletes and Individuals
Vo_{2Max}/Submaximal testing
Equitest for Older Individuals
Assessment of Ocular, Vestibular and Somatosensory balance as well as gait analysis

Teach and Assist in "Practicum" at Florida Atlantic University

An Applied class that allows older individuals to come to Florida Atlantic University and receive exercise prescriptions from undergraduate students.

Areas of Interest/
Current Work
Publications In Peer Reviewed Journals:

1. Jessee MB, Mattocks KT, **Buckner SL**, Dankel SJ, Mouser JG, Abe T, and JP Loenneke. "Mechanisms of Blood Flow Restriction: The New Testament." Techniques in Orthopedics. (In Press).

2. **Buckner, S. L**., Jessee, M. B., Dankel, S. J., Mattocks, K. T., Abe, T., & Loenneke, J. P. (2018). Resistance exercise and sports performance: The minority report. *Medical hypotheses*, *113*, 1-5.

3. Dankel SJ, Jessee MB, **Buckner SL**, Mouser JG, Mattocks KT, and JP Loenneke. "Are higher blood flow restriction pressures more beneficial when lower loads are used?" Physiology International. (In Press).

4. Mattocks, K. T., **Buckner, S. L**., Jessee, M. B., Dankel, S. J., Mouser, J. G., & Loenneke, J. P. (2017). Practicing the Test Produces Strength Equivalent To Higher Volume Training. Medicine and science in sports and exercise. (In Press)

5. **Buckner, S. L**., Loenneke, J. P., & Loprinzi, P. D. (2017). Protein timing during the day and its relevance for muscle strength and lean mass. Clinical Physiology and Functional Imaging. (In Press)

6. **Buckner, S. L**., Mouser, J. G., Dankel, S. J., Jessee, M. B., Mattocks, K. T., & Loenneke, J. P. (2017). The General Adaptation Syndrome: Potential misapplications to resistance exercise. Journal of Science and Medicine in Sport. (In Press)

7. Dankel SJ, Mouser JG, Jessee MB, Mattocks KT, **Buckner SL**, and JP Loenneke. "Post-exercise blood flow restriction attenuates hyperemia similarly in males and females." European Journal of Applied Physiology (In Press).

8. Dankel, S. J., **Buckner, S. L**., Counts, B. R., Jessee, M. B., Mouser, J. G., Mattocks, K. T., ... & Loenneke, J. P. (2017). The acute muscular response to two distinct blood flow restriction protocols. Physiology International, 104(1), 64-76.

9. Mattocks, K. T., Jessee, M. B., Counts, B. R., **Buckner, S. L**., Mouser, J. G., Dankel, S. J., ... & Loenneke, J. P. (2017). The effects of upper body exercise across different levels of blood flow restriction on arterial occlusion pressure and perceptual responses. Physiology & behavior, 171, 181-186.

10. **Buckner, S. L**., Dankel, S. J., Mattocks, K. T., Jessee, M. B., Mouser, J. G., Counts, B. R., ... & Loenneke, J. P. (2017). Differentiating swelling and hypertrophy through indirect assessment of muscle damage in untrained men following repeated bouts of resistance exercise. European journal of applied physiology, 117(1), 213-224.

11. Counts, B. R., **Buckner, S. L**., Mouser, J. G., Dankel, S. J., Jessee, M. B., Mattocks, K. T., & Loenneke, J. P. (2017). Muscle growth: To infinity and beyond? Muscle & Nerve. (In Press)

12. Jessee, M. B., Mattocks, K. T., **Buckner, S. L**., Mouser, J. G., Counts, B. R., Dankel, S. J., ... & Loenneke, J. P. (2017). The acute muscular response to blood flow-restricted exercise with very low relative pressure. Clinical Physiology and Functional Imaging. (In Press)

13. **Buckner, S. L**., Dankel, S. J., Counts, B. R., Jessee, M. B., Mouser, J. G., Mattocks, K. T., ... & Loenneke, J. P. (2017). Influence of cuff material on blood flow restriction stimulus in the upper body. The Journal of Physiological Sciences, 67(1), 207-215.

14. Dankel, S. J., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., **Buckner, S. L**., & Loenneke, J. P. (2017). Training to fatigue: the answer for standardization when assessing muscle hypertrophy?. Sports medicine (Auckland, NZ), 47(6), 1021-1027.

15. **Buckner, S. L**., Dankel, S. J., Mattocks, K. T., Jessee, M. B., Grant, M. J., & Loenneke, J. P. (2017). Muscle size and strength: another study not designed to answer the question. European journal of applied physiology, 117(6), 1273.

16. **Buckner, S. L.,** Mouser, J. G., Jessee, M. B., Dankel, S. J., Mattocks, K. T., & Loenneke, J. P. (2017). What does individual strength say about resistance training status?. Muscle & nerve, 55(4), 455-457.

17. Mouser, J. G., Dankel, S. J., Jessee, M. B., Mattocks, K. T., **Buckner, S. L**., Counts, B. R., & Loenneke, J. P. (2017). A tale of three cuffs: the hemodynamics of blood flow restriction. European journal of applied physiology. (In Press)

18. Edwards, M. K., **Buckner, S. L**., Loenneke, J. P., & Loprinzi, P. D. (2017). Association between sedentary behavior and normal-range lactate dehydrogenase activity. Postgraduate Medicine, 129(4), 484-487.

19. Dankel, S. J., Counts, B. R., Barnett, B. E., **Buckner, S. L**., Abe, T., & Loenneke, J. P. (2016). Muscle adaptations following 21 consecutive days of strength test familiarization compared with traditional training. Muscle & Nerve. (In Press)

20. Dankel, S. J., **Buckner, S. L**., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., ... & Loenneke, J. P. (2017). Can blood flow restriction augment muscle activation during high-load training?. Clinical Physiology and Functional Imaging. (In Press)

21. Mattocks, K. T., Jessee, M. B., Counts, B. R., **Buckner, S. L**., Mouser, J. G., Dankel, S. J., ... & Loenneke, J. P. (2017). The effects of upper body exercise across different levels of blood flow restriction on arterial occlusion pressure and perceptual responses. Physiology & behavior, 171, 181-186.

22. Ingram, J. W., Dankel, S. J., **Buckner, S. L**., Counts, B. R., Mouser, J. G., Abe, T., ... & Loenneke, J. P. (2017). The influence of time on determining blood flow restriction pressure. Journal of Science and Medicine in Sport. (In Press)

23. Dankel, S. J., Mouser, J. G., Mattocks, K. T., Counts, B. R., Jessee, M. B., **Buckner, S. L**., ... & Loenneke, J. P. (2016). The widespread misuse of effect sizes. Journal of Science and Medicine in Sport. 20(5) 446-450.

24. Dankel, S. J., Mattocks, K. T., Jessee, M. B., **Buckner, S. L**., Mouser, J. G., Counts, B. R., ... & Loenneke, J. P. (2016). Frequency: The Overlooked Resistance Training Variable for Inducing Muscle Hypertrophy?. *Sports Medicine*, *5*(47), 799-805.

25. **Buckner, S. L**., Dankel, S. J., Mattocks, K. T., Jessee, M. B., Mouser, J. G., Counts, B. R., & Loenneke, J. P. (2016). The problem of muscle hypertrophy: revisited. Muscle & nerve, 54(6), 1012-1014.

26. Counts, B. R., Rossow, L. M., Mattocks, K. T., Mouser, J. G., Jessee, M. B., **Buckner, S. L**., ... & Loenneke, J. P. (2016). Let's talk about sex: where are the young females in blood flow restriction research?. Clinical Physiology and Functional Imaging. (In Press)

27. Dankel, S. J., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., **Buckner, S. L**., & Loenneke, J. P. (2017). Training to fatigue: the answer for standardization when assessing muscle hypertrophy?. Sports medicine (Auckland, NZ), 47(6), 1021-1027.

28. Dankel, S. J., **Buckner, S. L**., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., ... & Loenneke, J. P. (2016). Post-exercise blood flow restriction attenuates muscle hypertrophy. European journal of applied physiology, 116(10), 1955-1963.

29. **Buckner, S. L**., Dankel, S. J., Counts, B. R., Barnett, B. E., Jessee, M. B., Mouser, J. G., ... & Loenneke, J. P. (2016). Does the time of your health screening alter your "health"?. International Journal of Cardiology, 220, 524-526.

30. Counts, B. R., **Buckner, S. L**., Dankel, S. J., Jessee, M. B., Mattocks, K. T., Mouser, J. G., ... & Loenneke, J. P. (2016). The acute and chronic effects of "NO LOAD" resistance training. Physiology & Behavior, 164, 345-352.

31. **Buckner, S. L**., Jessee, M. B., Mattocks, K. T., Mouser, J. G., Counts, B. R., Dankel, S. J., & Loenneke, J. P. (2017). Determining Strength: A Case for Multiple Methods of Measurement. Sports medicine (Auckland, NZ), 47(2), 193-195.

32. **Buckner, S. L**., Loprinzi, P. D., & Loenneke, J. P. (2016). Why don't more people eat breakfast? A biological perspective. The American journal of clinical nutrition, 103(6), 1555-1556.

33. Mattocks, K.T., Dankel, S.J., **Buckner, S.L.,** Jessee, M.B., Counts, B.R., Mouser, J.G., ... & Loenneke, Jp. (2016). Periodization: What is it good for?. Journal of Trainology, 5(1), 6-12.

34. **Buckner, S. L**., Dankel, S. J., Counts, B. R., Barnett, B. E., Jessee, M. B., Mouser, J. G., ... & Loenneke, J. P. (2016). Do rhythms exist in elbow flexor torque, oral temperature and muscle thickness during normal waking hours?. Physiology & behavior, 160, 12-17.

35. **Buckner, S. L**., Loenneke, J. P., & Loprinzi, P. D. (2016). Single and combined associations of accelerometer-assessed physical activity and muscle-strengthening activities on plasma homocysteine in a national sample. Clinical Physiology and Functional Imaging. (In Press).

36. **Buckner, S. L**., Loenneke, J. P., & Loprinzi, P. D. (2016). Cross-sectional association between normal-range lactate dehydrogenase, physical activity and cardiovascular disease risk score. Sports Medicine, 46(4), 467.

37. Jenkins, N. D. M., Housh, T. J., **Buckner, S. L**., Bergstrom, H. C., Smith, C. M., Cochrane, K. C., ... & Cramer, J. T. (2016). Four weeks of high-versus low-load resistance training to failure on the rate of torque development, electromechanical delay, and contractile twitch properties. Journal of musculoskeletal & neuronal interactions, 16(2), 135.

38. Jessee, M. B., **Buckner, S. L**., Mouser, J. G., Mattocks, K. T., & Loenneke, J. P. (2016). Letter to the editor: Applying the blood flow restriction pressure: the elephant in the

room. American Journal of Physiology-Heart and Circulatory Physiology, 310(1), H132-H133.

39. Ozaki, H., Loenneke, J. P., **Buckner, S. L**., & Abe, T. (2016). Muscle growth across a variety of exercise modalities and intensities: contributions of mechanical and metabolic stimuli. Medical hypotheses, 88, 22-26.

40. Jessee, M. B., **Buckner, S. L**., Dankel, S. J., Counts, B. R., Abe, T., & Loenneke, J. P. (2016). The influence of cuff width, sex, and race on arterial occlusion: implications for blood flow restriction research. Sports Medicine, 46(6), 913.

41. **Buckner, S. L**., Abe, T., Counts, B. R., Dankel, S. J., Barnett, B. E., & Loenneke, J. P. (2015). Muscle and fat mapping of the trunk: a case study. Journal of ultrasound, 18(4), 399.

42. **Buckner, S. L**., Loenneke, J. P., & Loprinzi, P. D. (2015). Lower extremity strength, systemic inflammation and all-cause mortality: Application to the "fat but fit" paradigm using cross-sectional and longitudinal designs. *Physiology & behavior*, *149*, 199-202.

43. Jenkins, N. D., Housh, T. J., **Buckner, S. L**., Bergstrom, H. C., Cochrane, K. C., Hill, E. C., ... & Cramer, J. T. (2016). Neuromuscular adaptations after 2 and 4 weeks of 80% versus 30% 1 repetition maximum resistance training to failure. The Journal of Strength & Conditioning Research, 30(8), 2174-2185

44. Jenkins, N. D., Housh, T. J., **Buckner, S. L**., Bergstrom, H. C., Cochrane, K. C., Smith, C. M., ... & Cramer, J. T. (2015). Individual Responses for Muscle Activation, Repetitions, and Volume during Three Sets to Failure of High-(80% 1RM) versus Low-Load (30% 1RM) Forearm Flexion Resistance Exercise. *Sports*, *3*(4), 269-280.

45. Bergstrom, H. C., Housh, T. J., Cochrane, K. C., Jenkins, N. D., Zuniga, J. M., **Buckner, S. L**., ... & Cramer, J. T. (2015). Factors underlying the perception of effort during constant heart rate running above and below the critical heart rate. European journal of applied physiology, 115(10), 2231-2241.

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Grants

Intellectual Contributions

Loenneke JP. Principal Investigator (2017). "Have improper analyses cost us millions: reassessing inter-individual responses to exercise." National Institutes of Aging. $300,000 (In Review).

Loenneke JP. Principal Investigator (2017). The muscular and vascular effects of very low loads with and without different levels blood flow restriction. American College of Sports Medicine $10,000 (Not Funded).

Loenneke JP. Principal Investigator (2016). Does low load exercise in combination with blood flow restriction attenuate muscle damage and/or confer a protective effect to a subsequent bout of high load exercise in statin users? National Institutes of Aging. $144,000 (Not Funded).

Loenneke JP. Principal Investigator (2015) Application Title: An Investigation into the Circadian rhythms of muscle function and balance in young and older adults? National Institutes of Aging. $145,000 (Not Funded).

Mentorship

Jeremy Loenneke, PhD
The University of Mississippi (2014 – Present)

Barbara Sue Graves, PhD
Florida Atlantic University (2012-2016)

Service:

Southeastern American College of Sports Medicine 2016-Present
Executive Board: Student Representative
University Of Mississippi, Exercise Science Department
Chair Search Committee 2016-2017
American College of Sports Medicine
Student Affairs Committee 2017- Present

External Peer Reviewer
Journal of Strength and Conditioning Research
Trainology

Activities & Interest:

Volunteer tumbling coach for Northeast Rebels 2006- 2008
Oakland Park, Florida
Member of Temple University Gymnastics club team 2009-2011
Philadelphia, Pennsylvania
World Record Holder of "Most Consecutive 90 Degree Pushups"
Record Submitted to Guinness World Records November 2012

Skills: Computer: MS Words, Excel, PowerPoint, Mac and PC literate
Efficient with equipment utilized in applied physiology labs and
Different methods of body composition.