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The Effects of Different Cuff Widths on Arterial Occlusion in the Upper Body

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THE EFFECTS OF DIFFERENT CUFF WIDTHS ON ARTERIAL OCCLUSION IN THE UPPER BODY

A thesis
presented in partial fulfillment of requirements
for the degree of Master of Science
in the Department of Health, Exercise Science
and Recreation Management
The University of Mississippi

by

Matthew B. Jessee

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ABSTRACT

The purpose of this study was to examine the effects three cuff widths (5 cm, 10 cm, 12 cm) have on arterial occlusion pressure (AOP) in the arm. A secondary purpose was to determine if arm circumference, blood pressure, arm length, and sex should be accounted for when applying these cuff widths. Two hundred and forty-nine participants visited the laboratory one time to measure arm length, arm circumference, brachial systolic (bSBP) and diastolic blood pressure (bDBP) followed by assessment of standing AOP as determined by a Doppler probe. One way repeated measure ANOVAs were used to examine differences between cuff widths and sex. Hierarchical linear regression was used to determine the variables explaining the most unique variance for each cuff width. Significant differences were observed between all cuff widths ($p < 0.001$) with AOP being highest for the 5 cm cuff [145 (19) mmHg] then 10 cm cuff [123 (13) mmHg], and 12 cm cuff [120 (12) mmHg]. Although a model consisting of arm circumference, bSBP, arm length, bDBP, and sex explained the most variance in AOP for all three cuffs (5 cm, $R^2 = 0.651$; 10 cm, $R^2 = 0.570$; 12 cm, $R^2 = 0.557$), arm circumference explained the most unique variance for each cuff width (5 cm, Part = .554; 10 cm, Part = .419; 12 cm, Part = .406). There were significant sex differences in AOP for the 5 cm [males 149 (19); females 142 (19) mmHg, $p = 0.003$, $d = 0.36$], 10 cm [males 127 (13); females 121 (13) mmHg, $p = 0.002$, $d = 0.46$], and 12 cm [males 122 (12); females 118 (12) mmHg, $p = 0.009$, $d = 0.33$] cuffs. Wider cuffs, in comparison to narrow cuffs require less pressure for AOP in the arm while standing. Future studies should report the cuff width used and carefully consider the impact it has on the amount of restriction occurring. Since AOP is affected by individual differences, the same

pressure should not be applied to all participants. In order to make BFR relative in the upper body, arm circumference and bSBP should be accounted for.

DEDICATION

This thesis is dedicated to my friends and family. Words can not describe how much you all mean to me, so I will just say thank you. Thank you for being there in the best of times and the worst of times.

LIST OF ABBREVIATIONS AND SYMBOLS

AOP	Arterial occlusion pressure
BFR	Blood flow restriction
bDBP	Brachial diastolic blood pressure
bSBP	Brachial systolic blood pressure
1RM	One-repetition maximum
MVC	Maximum voluntary contraction
MRTD	Maximum rate of torque development

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I have the very best friends a person could ever ask for. I don't see, or speak with most of you as much as I would like, but we always pick up where we left off. I appreciate your continued support and friendship.

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CHAPTER I: INTRODUCTION

In order to maintain a healthy lifestyle one should regularly participate in resistance training, as it is vital to muscular fitness. Advantages of resistance training include potential benefits regarding bone health (Moghadasi, & Siavashpour, 2012), as well as positive effects on body composition (Swanepoel et al., 2013), blood sugar levels (Castaneda et al., 2002), and insulin sensitivity (Klimcakova et al., 2006). It has been shown that muscle strength in particular has a protective effect against all-cause mortality even when controlling for cardiorespiratory fitness (Ruiz et al., 2008). In addition, muscular strength promotes greater independence in the elderly as it increases the ability to perform activities of daily living (Rantanen et al., 2002). Even though the potential benefits are well established, most people do not engage in the recommended amount of muscle strengthening activity, especially the elderly (Vezina, Der Ananian, Greenberg, & Kurka, 2014). In order to improve muscular strength it is recommended that individuals use a load of at least 60% of their 1-repetition maximum (1-RM) (ACSM, 2011). However, for certain populations such as the elderly or injured, higher loads may be contraindicated as it places more mechanical stress on the joints. In a summary of research regarding the topic, blood flow restriction (BFR) provides a safe, effective alternative to high load resistance training (Loenneke, Wilson, Marin, Zourdos, & Bemben, 2011). When BFR is combined with low load resistance training there are improvements in muscle size and strength in the elderly (Takarada et al., 2000), healthy (Yasuda, Fujita, Ogasawara, Sato, & Abe 2010), and athletic populations using loads as low as 20% 1-RM (Yamanaka, Farley, & Caputo, 2012)

Given the novelty of BFR, questions arise about its safety. Common questions regarding the safety of BFR are whether there is increased muscle damage when combined with exercise, or a susceptibility to blood clotting due to the restriction of blood flow. However, available evidence suggests that neither one is occurring to an appreciable level with BFR. For example, when considering muscle damage after a training protocol, acute changes in torque following BFR exercise were due to fatigue and not necessarily damage to the muscle (Loenneke et al., 2013b). Further, an investigation of blood markers indicative of muscle damage (creatine kinase) and inflammation (interleukin 6) following 6-weeks of training showed no differences between blood flow restriction training and traditional high load training at post-testing (Karabulut, Sherk, Bemben D., & Bemben M., 2013). Similarly, markers of blood coagulation do not increase after chronic or acute bouts of moderate BFR combined with exercise using low loads (Clark et al., 2011; Madarame et al., 2010).

Blood flow restriction is the process of using a restrictive cuff placed on the proximal portion of a limb with the goal of restricting arterial blood flow into the muscle and occluding venous blood flow out of the muscle (Yasuda et al., 2010). An important consideration when performing BFR is the inflation pressure applied to the limb. It is possible there is an optimal range of arterial restriction as it applies to BFR which if too low or too high may not produce the desired result (Loenneke, Thiebaud, Abe, & Bemben, 2014). For example, applying various pressures during BFR has been shown to produce different results in muscle activation (Loenneke et al., 2014) and metabolic responses (Yasuda et al., 2010). It is suggested that all research done with BFR should make an attempt to apply pressures relative to individuals rather than the same arbitrary pressure applied to all participants (Loenneke et al., 2013a). However, most studies still use an arbitrary pressure for all participants regardless of individual differences.

This is bad practice as arterial occlusion pressure when using a standard cuff size is determined by limb circumference in the lower body (Shaw, & Murray, 1982; Van Roekel, & Thurston, 1984; Loenneke et al., 2012). The variance between arterial occlusion pressures is largely explained by limb circumference and is not further explained by including body composition (i.e. muscle or fat thickness) (Loenneke at al., 2014). Therefore, applying the same arbitrary pressure to participants with different limb sizes could result in experiencing varied levels of arterial BFR, which in turn could compromise the overall safety, or effectiveness of the stimulus. In order to examine and understand the effects of varying levels of BFR, the cuff width should first be standardized.

Currently, most studies apply cuff widths (some unreported) and pressures arbitrarily (i.e. using the same pressure for every participant regardless of individual differences). The cuff used will ultimately dictate how the pressure is being applied to the tissue. Wider cuffs apply pressure over a greater distance, in turn exposing more of the underlying tissue to a restrictive pressure. This increases the resistance of blood to flow, which results in wider cuffs requiring a lower pressure to reach complete arterial occlusion (Crenshaw, Hargens, Gershuni, & Rydevik, 1988; Moore, Garfin, & Hargens, 1987; Graham, Breault, McEwen, Eng, & McGraw, 1993; Loenneke et al., 2012). If a wider cuff is used with a pressure determined from a study using a narrow cuff it could result in a condition of complete arterial occlusion, which is not the goal of BFR training. In addition, comparison of cuff widths used for BFR has shown that different widths may also have an effect on the cardiovascular response and perceived exertion to exercise (Rossow et al., 2012). In order to gain more insight into BFR, the methodological issue regarding the use of arbitrary cuff width in the upper body should be investigated and understood as it may play a critical role in arterial occlusion pressure. This in turn will lead to the possible development of more optimal pressure application as well as ensuring safety of those participating in BFR by itself or in combination with exercise.

Purpose

The purpose of the study was to investigate the effects of different cuff widths on arterial occlusion in the upper body. In addition, the factors contributing to those differences were investigated.

Research Question

How do cuff widths of 5cm, 10cm, and 12cm affect the final pressure necessary for arterial occlusion in the upper body?

Hypothesis

It was hypothesized that as the cuff became wider it would result in a lower pressure needed for arterial occlusion.

Sub question

As cuff width changes, do limb circumference, brachial systolic blood pressure, brachial diastolic blood pressure, limb length and sex differences explain the variance in arterial occlusion differently?

Sub hypothesis

It was hypothesized that limb circumference would explain the most variance for each cuff width used in the upper body.

Significance of Study

This study investigated how arterial occlusion pressure changed across cuff widths. If differences between cuff widths were found it would give researchers the information necessary to choose the best cuff widths for studies. Further, the study determined what factors contributed most to the differences between each cuff width leading to a more proper pressure application as it determined which individual participant factors should be accounted for when applying BFR. In turn this potentially creates a more optimal, safer stimulus for BFR studies.

Assumptions

1. Participants answered all questions truthfully.
2. Participants were not using medication for hypertension.
3. Participants did not have caffeine within 8 hours of testing.
4. Participants were in a true resting state for arterial occlusion measurements.
5. Participants fasted for 2 hours prior to testing.

Delimitations

1. The results of this study are only applicable to men and women between the ages of 18-35.
2. The effects of differing cuff widths are limited to three cuff sizes (5cm, 10cm, 12cm).

Limitations

1. The effects of cuff width on BFR were not investigated during exercise.
2. The measure of arterial occlusion is not necessarily a measurement of blood flow volume. Arterial occlusion is only a measure of flow or no flow; the amount of flow was not determined.

Operational Definitions

1. Arterial Occlusion Pressure (AOP)- the minimal inflation pressure needed in a pneumatic air cuff applied to the upper arm to eliminate arterial blood flow measured at the radial artery.

2. Blood flow restriction (BFR) exercise- exercise while applying pressure via restrictive cuffs placed on a limb proximal to the working muscle. The pressure is applied to restrict blood flow to the exercising muscle.

3. One-Repetition maximum (1-RM)- a measure of strength; the maximum amount of weight that can be lifted for a given exercise with one muscular contraction.

4. Brachial systolic blood pressure (bSBP)- the pressure exerted against the vascular wall of the brachial artery during contraction of the heart.

5. Brachial diastolic blood pressure (bDBP)- the pressure exerted against the vascular wall of the brachial artery while the heart is relaxed.

CHAPTER II: LITERATURE REVIEW

History of Blood Flow Restriction Training

Applying blood flow restriction (BFR) while performing various modes of exercise has been studied since the 1930's. Barcroft & Millen used BFR in conjunction with calf raises in order to better understand blood flow during muscle contractions (1939). However, applying BFR while exercising with low load resistance for the purpose of increasing muscle size and strength has been credited to Yoshiaki Sato after noticing the numb feeling during prolonged kneeling was similar to the feeling he experienced in response to resistance training (Sato, 2005). Shinohara et al. (1998) was the first study published which examined BFR in combination with exercise and the effect it has on strength. They observed increases in maximal voluntary contraction (MVC) and maximum rate of torque development (MRTD) after two and four weeks of BFR training (Shinohara, Kouzaki, Yoshihisa, & Fukunuga, 1998).

Efficacy of Blood Flow Restriction Alone

Applying BFR without exercise produces enough of a stimulus to attenuate atrophy and losses in strength. During immobilization following ACL surgery, BFR applied to the upper thigh showed significantly less atrophy in the knee extensors when compared to control. The protocol consisted of 5 minutes BFR followed by 3 minutes rest applied 5 times twice daily for 11 days. The pressure was applied using a 9cm cuff inflated to a final pressure between 200-260 mmHg (Takarada, Takazawa, & Ishii, 2000). BFR with a 7.7 cm cuff inflated to 200 mmHg applied to healthy males immobilized at the ankle for 2 weeks prevented muscular weakness due to disuse and resulted in an attenuated loss of leg circumference when compared to a control, and isometric training group (Kubota, Sakuraba, Sawaki, Sumide, & Tamura, 2008). Applying a much lower BFR pressure of 50 mmHg (7.7 cm cuff) to the leg of males immobilized at the ankle produced similar results in attenuating atrophy (Kubota, Sakuraba, Koh, Ogura, & Tamura, 2010). Therefore, available evidence suggests even at very low pressures BFR in the absence of exercise elicits favorable responses in skeletal muscle.

Efficacy Of Blood Flow Restriction With Aerobic Exercise

Although BFR alone has been shown to slow the loss of muscle mass and strength, combining it with low intensity aerobic exercise results in increased muscle mass and strength. Walking in combination with BFR applied to the upper thigh using a 5cm cuff inflated to 200 mmHg increased muscle size and strength after 3 weeks in healthy young men (Abe, Kearns, & Sato, 2005) and after 6 weeks in active, older adults (Abe et al., 2010). In addition to improvements in muscle size and strength, BFR may also improve cardiovascular fitness. To illustrate, treadmill training at a final intensity of 40% VO_{2max} in combination with BFR (11 cm cuff, inflated to 200 mmHg) has resulted in improved VO_{2max} of trained basketball players following 2 weeks of training (Park et al., 2010). Older, sedentary women walking at 45% heart rate reserve while under BFR (5cm cuff; 160-180 mmHg) increased muscle size, strength, and VO_{2peak} (control group also increased VO2peak) after 10 weeks of training (Ozaki et al., 2011). Cycling at intensities of 40% VO_{2max} for 15 minutes 3 days/week for 8 weeks is also an effective modality to improve aerobic capacity, increase muscle size, and strength in young men when applying BFR (210 mmHg) (Abe et al., 2010). Improved vascular health has also been shown in elderly women after walking with BFR (140-200 mmHg) for 6 weeks (Iida et al., 2010). Thus, combining BFR with aerobic exercise results in small, but meaningful improvements in muscle size and strength.

Efficacy of Blood Flow Restriction With Low-load Resistance Exercise

BFR with low-load resistance exercise compared to other modalities provides the most robust stimulus for increases in muscle mass and strength (Loenneke, Wilson, Marin, Zourdos, & Bemben, 2012). Performing elbow flexion exercise while applying BFR to the upper arm using a 3.3 cm cuff inflated to 100 mmHg in combination with low-load resistance (50-30% 1RM) increased skeletal muscle size and strength similar to that of high-load (80%-50% 1RM) resistance training in older females after 16 weeks (Takarada et al., 2000). However, the appeal of BFR training is the ability to elicit similar adaptations through low workloads. A lower total workload is more beneficial when considering elderly and injured populations which may be contraindicated to training at high intensities or volumes. Even though low-load resistance training to failure results in increased muscle size and strength, BFR training (8 cm cuff; 100 mmHg) produces similar results with an overall workload 3 times lower, during a 6-week training program (Farup et al., 2015). As little as 6 days of elbow flexor training with 30% 1RM in combination with BFR (3cm cuff; 100 mmHg) increased muscle volume in men and eumenhorrheic women (Sakamaki, Yasuda, & Abe, 2012). Low-load BFR (100-160 mmHg) training can also be used to supplement a traditional high-load training program as it has been shown to produce favorable results in muscle size, and strength of young men after 6 weeks of training (Yasuda et al., 2011). As a supplement to a traditional high-load training program, BFR using elastic knee wraps, increased dynamic 1RM squat strength in collegiate football players after 7 weeks (Luebbers, Fry, Kriley, & Butler, 2014). This type of training also seems to have a positive effect on synergistic muscles that are not directly undergoing restriction of blood flow.

For example, BFR (160 mmHg) training with 30% 1RM in young men performing a free-weight bench press (Yasuda, Fujita, Ogasawara, Sato, & Abe, 2010) increased chest muscle size despite the restriction of blood flow only being applied to the upper arm. Similar results have been found in older women undergoing BFR (3.3cm cuff; 80 mmHg) while performing chest press using low-intensity elastic bands (Thiebaud et al., 2013). Low-load (30%1RM) bench press training in combination with BFR (3 cm cuff; 160 mmHg) for 6 weeks increased muscle size and strength, and had no adverse effects on carotid arterial compliance in comparison to a high-intensity load (75% 1RM) in young men (Ozaki et al., 2013).

Possible Mechanisms of Blood Flow Restriction

The exact mechanism responsible for the muscular adaptations to BFR is not exactly clear. The literature suggests it may be due to multiple mechanisms such as cell swelling, mechanical stress, and metabolic stress working alone or in concert with one another that produces favorable results in skeletal muscle (Pearson, & Hussain, 2014). Cell swelling may be responsible for the muscular response to BFR in the absence of exercise. Applying BFR to an immobilized limb at 70% arterial occlusion pressure with a 5cm cuff showed no significant increases in EMG activity, whole blood lactate, or heart rate indicating no changes in muscle activation or metabolic accumulation (Loenneke et al., 2012). However, there was a decrease in plasma volume in conjunction with an acute increase in muscle thickness suggesting a shift of fluid into muscle cells, which in turn may stimulate anabolic/ anti-catabolic pathways. Although previous studies have shown attenuated atrophy and loss of strength in immobilized legs undergoing BFR (Takarada, 2000; Kubota, 2008; Kubota, 2010) combining BFR with aerobic exercise elicits increased muscle size and strength. When combining low-intensity aerobic training with BFR there is an increased venous pooling of blood compared to applying BFR alone. The increased venous pooling may further augment the movement of fluid into the muscle cells explaining why BFR in combination with aerobic exercise increases muscle size and strength (Loenneke, et al., 2012). In addition to cellular swelling, adding mechanical stress to BFR using aerobic exercise may be the mechanism responsible for increases in size and strength. However, the increased muscle adaptation with aerobic modalities may not be as great as those found in response to BFR resistance exercise. The discrepancy in the amount of muscle size and strength gain between the modalities may be due to the addition of metabolic accumulation with resistance exercise. To illustrate this comparison, low intensity walking while applying BFR resulted in no real differences in whole blood lactate (Loenneke, Thrower, Balapur, Barnes, & Pujol, 2011). In contrast, evidence suggests an increase in metabolite accumulation (e.g. pH, CO_2, and blood lactate) after performing elbow flexion using 20% 1RM while undergoing BFR (3cm; 100/160 mmHg), which is enough to augment muscle activation over a repetition matched control group (Yasuda et al., 2010). Thus, BFR resistance exercise works through a mechanism of cellular swelling (Yasuda, Loenneke, Thiebaud, & Abe, 2012), and in addition it increases motor unit recruitment compared to BFR aerobic exercise. Further, the increased recruitment of larger motor units while undergoing BFR resistance exercise with low loads is similar to that of high load training (Suga et al., 2012). The mechanisms associated with BFR whether working alone or with one another are responsible for stimulating pathways associated with muscle hypertrophy (Gundermann et al., 2012; Laurentino et al., 2012; Manini et al., 2011).

Safety Considerations

When compared to other types of resistance training, BFR in combination with low load resistance exercise does not appear to pose any additional risk to participants with regards to muscle damage and blood clotting. At rest, following BFR exercise (5cm cuff; 160 mmHg-240 mmHg) with 20% 1RM there were no significant increases from baseline in creatine kinase (CK), which is a marker of muscle damage, and Interleukin-6 (IL-6) an inflammation marker, indicating a stimulus that does not induce chronic damage to the cellular membrane (Karabulut, 2013). Further, knee extensions to failure using 30% 1RM with BFR (13.5cm cuff; females-90 mmHG, males- 100 mmHg) increased translocation of heat shock proteins indicative of stress, but showed no observable signs of myofibrillar damage (Cumming, Paulsen, Wernbom, Ugelstad, & Raastad, 2014). Following BFR exercise, torque which may be the best indirect indicator of muscle damage (Warren, Lowe, & Armstrong, 1999) returned back to baseline within 24 hours. Therefore short-term decrements in torque associated with BFR may be attributable to muscle fatigue and not necessarily damage. To further illustrate this point, applying BFR with no form of exercise had no effect on torque, indicating any change in muscle function during BFR exercise may be due to the exercise and not BFR per se (Loenneke, 2013). Since BFR training involves a pooling of blood and metabolites such as lactate in working muscle thrombus may also be a concern. An investigation of prothrombin fragment I + II, thrombin-antithrombin III complex, D-dimer, and fibrin degradation product showed there is no increased risk of thrombin or clot formation following leg press exercise at 30% 1RM in combination with BFR as there were no increases in blood markers following the protocol (Madarame et al., 2010). Additionally, fibrinolytic activity a process involved in breaking down blood clots was actually increased after a bout of BFR exercise while markers of inflammation and coagulation were not affected (Clark, 2011). In the same study 4 weeks of BFR training did not result in any negative effects on nerve or vascular function, in fact, vascular function may actually be improved by BFR exercise. Elderly women not only experienced increases in muscle size and strength, but also showed improvement in venous compliance following 6 weeks of slow walk training combined with BFR (200 mmHg) (Iida et al., 2011). Similarly, arterial compliance was improved after 10 weeks of walk training in sedentary men and women using BFR with a 5cm cuff inflated to 200 mmHg (Ozaki, Miyachi, Nakajima, & Abe, 2011). In summary, BFR does not appear to pose any greater risk to participants compared to traditional resistance training.

Pressure Application

As BFR has been established as a stimulus for increases in muscle size and strength the application should be carefully considered as further studies are implemented. Applying arbitrary pressures in which participant and cuff differences are not accounted for may in fact have an effect on the protocol, participant safety and/or comfort, and the overall adaptation to the stimulus. For instance, complete arterial occlusion using a 3cm cuff resulted in participants being unable to complete a training protocol using repetitions of 30-15-15-15 when compared to moderate blood flow restriction (Yasuda et al., 2009). If an investigator inadvertently applies a pressure that occludes blood flow this could potentially affect the protocol and physiologic responses. For example, comparing various applied pressures (0 mmHg, 98 mmHg, 121 mmHg, and 147 mmHg) during BFR exercise resulted in differences in EMG activity during the exercise bout (Yasuda, Brechue, Fujita, Sato, & Abe 2008) illustrating the way in which pressure may alter the stimulus. An altered stimulus may in fact affect the acute and perhaps chronic adaptations to BFR training. For example, venous blood gases and metabolite responses to occlusion training are different with pressures of 100 mmHg and 160 mmHg using a 3cm cuff (Yasuda et al., 2010). When comparing a 50 mmHg BFR protocol to 200 mmHg, Kubota (2011) suggested that a too low a pressure might not be as effective in the attenuation of muscular atrophy. However, too high a pressure may potentially increase participant discomfort and risk of negative side effects (Rossow, 2012). Furthermore, the application of high pressures may be unnecessary, as it does not seem to provide a more desirable stimulus. Applying BFR (5cm cuff) beyond 50% of estimated arterial occlusion pressure did not appear to increase acute muscular responses during knee extension training (Loenneke et al., 2014). In summary, there seems to be an optimal range of pressure application during training with BFR, which maximizes beneficial muscle responses and minimizes participant risk or discomfort.

Cuff Type and Size

An important aspect of BFR methodology is the application of pressure through the use of elastic bands (Luebbers et al., 2014), elastic inflatable cuffs (Abe et al., 2010), or nylon inflatable cuffs (Loenneke et al, 2014). The majority of BFR literature use pneumatic inflatable cuffs. The cuff material seems to have little effect on arterial occlusion pressure provided the cuffs are the same width (Loenneke et al., 2013), however, an inverse relationship between cuff width and arterial occlusion pressure in the upper and lower body exists (Graham, 1993). This may be due to the manner in which pressure is transmitted to the underlying tissue. Crenshaw et al., 1988 found that wider cuffs in the arms and legs of cadavers transmit a greater percentage of the same applied pressure to deeper tissue; in turn this results in a lower pressure needed for arterial occlusion. In the upper body, after examining 3 cuff sizes (4.5cm, 8.0cm, and 15.5cm) applied to 7 males and 3 females it was found that as cuff width became wider, pressure needed for arterial occlusion became lower (Moore, 1987). A study done in the lower body using common cuffs found in literature (13.5cm and 5cm) with a large sample of 116 participants showed that a wide cuff required lower pressures to occlude blood flow in the supine position. Further, it established that limb circumference is the largest predictor of arterial occlusion pressure if the same size cuff is being applied (Loenneke, 2012). In addition to having an effect on arterial occlusion pressure, cuff width also elicits different cardiovascular responses as well as differences in participant comfort/discomfort. Wider cuffs (13.5cm) resulted in cardiovascular responses such as increased heart rate, increased brachial and central blood pressures, as well as higher ratings of perceived exertion and pain when compared to narrow cuffs (5 cm) inflated to the same pressure (130% of brachial systolic blood pressure) (Rossow, 2012). Further, one potential issue concerning the use of wide cuffs may be the diminished effect on increased muscle size. After a 4-week ischemic training protocol Kacin, and Strazar (2011) found that increases in cross-sectional area were smaller in the area of the muscle under cuff application. However, the difference in muscle size increases could also be due to the high pressure used for the study (230 mmHg), or heterogeneity of muscle as size increases are not typically uniform along the length of the muscle (Yasuda, Loenneke, Thiebaud, & Abe 2012). Regardless, using a narrow cuff could potentially minimize any effects on muscle adaptation if there is an adverse effect due to cuff application.

Pressure For Arterial Occlusion

When applying BFR, inflation pressure should be made relative to the individual (Loenneke et al., 2013a). This ensures that all participants are receiving a similar stimulus. Currently, the same pressures are being applied to participants in upper body BFR studies regardless of differing cuff widths and individual differences (Table 1 and Table 2). All tissue underneath the cuff does not necessarily experience the same pressure applied by the cuff, in fact the deeper tissue experiences less pressure than tissue closer to the surface (Shaw & Murray, 1982). This is illustrated by a study that shows as the limb circumference becomes larger the pressure needed for occlusion becomes greater as well (Van Roekel, 1984). Individual differences, especially as they pertain to limb circumference should be considered when applying

BFR. In the upper and lower body 171 participants were tested using a 5cm cuff to determine which factors explained the most variance in arterial occlusion pressure. It was observed in the upper body while in the supine position, limb circumference and brachial systolic blood pressure should be accounted for when determining pressures for BFR training (Loenneke, 2014). However, no literature exists in the upper body using a large sample size to explain the differences between various common cuff widths and the effect they have on arterial occlusion pressure in the standing position.

CHAPTER III: METHODOLOGY

Participants

Two hundred and forty nine participants (102 males, 147 females) between the ages of 18-35 years old were recruited for the study through the use of flyers posted on campus, word of mouth, and class announcements on the campus of The University of Mississippi. Participants were required to fill out an exclusion criteria form. This form was aimed at identifying any exclusion criteria such as age outside of 18-35 years old, currently taking medication for hypertension, eating within 2 hours, or having ingested caffeine within 8 hours of testing. If the participant did not meet any exclusion criteria they were then asked to read, understand, and sign an informed consent form as well as complete a health history questionnaire.

Inclusion Criteria

1. Between the ages 18-35 years.
2. Not taking medication for hypertension.
3. Fasted for at least 2 hours before testing.
4. No ingestion of caffeine within 8 hours of testing

Exclusion Criteria

1. Outside the ages of 18-35 years.
2. Taking medication for hypertension.
3. Eating within 2 hours of testing

4. Ingested caffeine within 8 hours of testing.

Experimental Design

Upon arriving at the laboratory participants had their height and body mass measured. Next, limb circumference and length of the right upper arm was measured. Afterwards, participants were asked to rest comfortably in the seated position for 10 minutes. Once the participant rested for 10 minutes, systolic and diastolic blood pressure was measured using an automatic blood pressure machine. Participants remained seated and rested comfortably for 5 minutes. Following 5 minutes of rest, participants were asked to stand and a cuff was applied for the determination of arterial occlusion pressure #1. Once arterial occlusion pressure #1 was determined the cuff was deflated and removed. Participants were again asked to sit and relax comfortably for 5 minutes. At the conclusion of the rest period participants were asked to stand. At that time the second cuff was applied and arterial occlusion pressure #2 was determined, after which the cuff was immediately deflated and removed. Another seated rest period of 5 minutes was observed after which arterial occlusion pressure #3 was determined. Once arterial occlusion pressure #3 was measured the cuff was deflated and removed, completing the testing session. The cuffs widths (5cm, 10cm, 12cm) were applied in a randomized order.

Height and Body Mass

Standing height was measured to the nearest 0.1cm using a stadiometer. Participants were asked to remove shoes and any headwear or high hairstyles that may affect an accurate measurement. They were asked to stand up straight with heels together and against the stadiometer platform. Body mass was measured using a digital scale to the nearest 0.1kg. Participants were asked to remove shoes, excess clothing, and anything from their pockets to ensure a more accurate body mass measurement.

Blood Pressure

Systolic and diastolic blood pressure was measured using an automated blood pressure machine (Omron #HEM-907XL) in the seated position by applying the appropriate sized cuff to the right arm. At least two measurements were taken and the values were averaged. If the measurements differed by more than 5 mmHg a subsequent measure was taken.

Limb Anthropometry

Limb circumference and length were assessed on the right arm using a body tape measure. Limb circumference was measured at a distance halfway between the acromion and olecranon processes. Limb length was measured as the distance from the acromion process to the lateral epicondyle.

Arterial Occlusion Pressure

In the standing position one of three cuffs (SC5-5cm, SC10-10cm, SC12-12cm; Hokanson, Bellevue, WA, USA) was applied to the proximal portion of the right arm. Arterial pressure was determined by detecting a pulse using a handheld bidirectional Doppler probe placed at the radial artery. The cuffs were connected to an E20 Rapid Cuff Inflator (Hokanson, Bellevue, WA, USA) and inflated until the point at which no pulse was detected. The inflation pressure was recorded to the nearest 1 mmHg as arterial occlusion pressure (AOP). Upon determining AOP the cuff was immediately deflated. The process was repeated two more times using the remaining cuff sizes. Five minutes of rest separated each trial of arterial occlusion pressure. Cuffs sizes were applied in a randomized order.

Statistical Analyses

A one way repeated measures ANOVA was used to determine differences in AOP between cuff widths. If significant, a post hoc Fisher's LSD was used to determine where the differences were amongst cuffs. Hierarchical linear regression was used to determine which variables best predicted AOP for each cuff. Predictors were entered into the model in blocks starting with Block 1, which consisted of arm circumference and bSBP as they have both been shown to predict arterial occlusion pressure in the upper body. Block 2 added in bDBP and arm length due to bDBP having been a small predictor of AOP and limb length due to the assumption that a longer limb would result in a longer blood vessel in turn creating an increased resistance to blood flow. The final block, Block 3 added in sex, as it has not been shown to be a significant predictor of AOP. Changes in Pearson correlation, part correlation coefficient, R^2, standard error of the estimate (SEE), and the change in F-value was determined for each block. Variance inflation factor and Pearson correlations were used to determine the degree of multicollinearity of the ith independent variable with other independent variables for all hierarchical regression models. Multicollinearity between variables was defined as a VIF ≥ 10 and/or Pearson correlations of 0.85 or greater. To determine if sex differences existed in AOP across cuff widths, a repeated measures ANOVA with a between subject factor of sex was used. If there was an interaction, a Fishers LSD test was used to identify differences between cuff widths within each sex and independent sample t-tests were used to identify differences for sex within each cuff width. Cohen's d was used to determine the magnitude of difference. Data was analyzed using SPSS statistical software package version 19.0 (SPSS Inc., Chicago, IL). Significance was set at $p \leq 0.05$.

Table 1. Acute Upper Body BFR Exercise Studies

Author, Year	Cuff Width (cm)	Final Pressure (mmHg)	Exercise	Position
Barnett, 2015	5	40% AOP	Elbow Flexion	Standing
Brandner, 2014	10.5	80% SBP/ 130% SBP	Elbow Flexion	Unreported
Counts, 2015	5	40-90% AOP	Elbow Flexion	Standing
Dorneles, 2015	14.5	SBP – 20	Elbow Flexion	Unreported
Garten, 2015	Unreported	SBP – 20	Elbow Flexion	Unreported
Goldfarb, 2008	10	SBP – 20	Elbow Flexion	Unreported
Hollander, 2010	Unreported	SBP – 20	Elbow Flexion	Unreported
Madarame, 2010	3	130	Elbow Flexion/ Extension	Unreported
Maior, 2015	14	SBP – 20	Elbow Flexion	Standing
Neto, 2014	6	80% AOP	Elbow Flexion/ Extension	Unreported
Neto, 2014	6	80% SBP	Elbow Flexion/ Extension	Unreported
Reeves, 2006	Unreported	SBP – 20	Elbow Flexion	Standing
Sato, 2005	3	150% SBP	Elbow Flexion/ Extension	Unreported
Thiebaud, 2013	3	120	Elbow Flexion	Standing
Thiebaud, 2014	3.3	120	Elbow Flexion	Unreported
Vieira, 2013	Unreported	120	Elbow Flexion	Seated
Vieira, 2014	Unreported	110	Elbow Flexion	Unreported
Yasuda, 2006	3	100% SBP	Bench Press	Supine
Yasuda, 2008	3	0%, 80%, 100%, 120% SBP	Elbow Flexion	Seated
Yasuda, 2009	3	160/ 300	Elbow Flexion	Seated
Yasuda, 2010	3	100/ 160	Elbow Flexion	Seated
Yasuda, 2013	3	160	Elbow Flexion	Seated
Yasuda, 2014	3	160	Elbow Flexion	Unreported

Table 2. Chronic Upper Body BFR Exercise Studies

Author, Year	Cuff Width (cm)	Final Pressure (mmHg)	Exercise	Position
Burgomaster, 2003	12	100	Elbow Flexion	Seated
Counts, 2015	5	40-90% AOP	Elbow Flexion	Standing
Credeur, 2010	Unreported	80	Handgrip	Unreported
Farup, 2015	8	100	Elbow Flexion	Seated
Hunt, 2012	13	80	Handgrip	Unreported
Leubbers, 2014	7.6	Unknown	Bench Press	Unreported
Lowery, 2014	Unreported		Elbow Flexion	Unreported
Moore, 2004	7	100	Elbow Flexion	Seated
Ozaki, 2013	3	160	Bench Press	Supine
Sakamaki, 2012	3	100	Elbow Flexion	Unreported
Takarada, 2000	3.3	~110 (avg)	Elbow Flexion	Seated
Thiebaud, 2013	3.3	120	Chest Press, Row, Shoulder Press	Seated
Weatherholt, 2013	3	180	Elbow Flexion/ Extension	Seated
Yamanaka, 2012	5	Unknown	Bench Press	Unreported
Yasuda, 2010	Unreported	160	Bench Press	Supine
Yasuda, 2011	Unreported	160	Bench Press	Supine
Yasuda, 2011	Unreported	160	Bench Press	Supine
Yasuda, 2012	3	160	Elbow Flexion	Unreported
Yasuda, 2014	3	170-260	Elbow Flexion/ Extension	Seated
Yasuda, 2014	3	270	Elbow Flexion/ Extension	Unreported

CHAPTER IV: RESULTS

Participant Characteristics

Two hundred forty-nine participants met inclusion criteria and consented to participate in the study. Of the 249 participants, 102 were male and 147 were female (41% and 59% respectively). Participant characteristics for the entire data set can be found in Table 3. Further, participant characteristics were separated by sex to examine any differences between males and females; these differences can be found in Table 4. Significant differences were present in age ($p = 0.001$), height ($p < 0.001$), body mass ($p < 0.001$), arm circumference ($p < 0.001$), arm length ($p < 0.001$), brachial systolic blood pressure (bSBP) ($p < 0.001$), and arterial occlusion pressure (AOP) for cuff widths of 5 cm ($p = 0.003$), 10 cm ($p = 0.002$) and 12 cm ($p = 0.009$). However, no differences existed in brachial diastolic blood pressure (bDBP) between sexes ($p = 0.309$). The largest differences (as determined by Cohen's d) between sexes were for height ($d = 2.27$), body mass ($d = 1.30$), arm circumference ($d = 1.31$), and arm length ($d = 1.71$). It is of note the effect size for sex differences in AOP for each cuff width were; $d = 0.36$ (5 cm), $d = 0.46$ (10 cm), and $d = 0.33$ (12 cm).

Table 3. Total participant characteristics (n = 249).

Variable	Mean (SD)	Minimum	Maximum
Age (yr)	21 (2)	18	34
Height (cm)	170.5 (9.8)	146	200
Body mass (kg)	74.4 (16.2)	45	141
Arm Circ (cm)	32.7 (4.8)	22	47
Arm Length (cm)	33.2 (2.7)	23	41
bSBP (mmHg)	110 (10)	89	148
bDBP (mmHg)	65 (8)	48	105
AOP 5cm (mmHg)	145 (19)	108	239
AOP 10cm (mmHg)	123 (13)	95	175
AOP 12cm (mmHg)	120 (12)	92	166

BMI: Body Mass Index; Arm Circ: Arm Circumference; bSBP: Brachial Systolic Blood Pressure; bDBP: Brachial Diastolic Blood Pressure; and AOP: Arterial Occlusion Pressure.

Table 4. Participant characteristics Male (n = 102) and Female (n = 147)

	Male			Female			
Variable	**Mean (SD)**	**Minimum**	**Maximum**	**Mean (SD)**	**Minimum**	**Maximum**	**Cohen's d**
Age (yr)	22 (3)	18	34	21 (2)*	18	34	0.40
Height (cm)	179.4 (7.0)	164	200	164.3 (6.4)*	146	184	2.27
Body mass (kg)	84.9 (14.9)	62	141	67.1 (12.7)*	45	121	1.30
Arm Circ (cm)	35.8 (3.9)	28	47	30.5 (4.1)*	22	47	1.31
Arm Length (cm)	35.3 (2.1)	30	41	31.8 (2)*	23	36	1.71
bSBP (mmHg)	114 (9)	91	148	107 (9)*	89	136	0.7
bDBP (mmHg)	65 (8)	48	85	66 (9)	48	105	-0.11
AOP 5cm (mmHg)	149 (19)	113	239	142 (19)*	108	229	0.36
AOP 10cm (mmHg)	127 (13)	102	175	121 (13)*	95	166	0.46
AOP 12cm (mmHg)	122 (12)	95	166	118 (12)*	92	155	0.33

BMI: Body Mass Index; Arm Circ: Arm Circumference; bSBP: Brachial Systolic Blood Pressure; bDBP: Brachial Diastolic Blood Pressure; and AOP: Arterial Occlusion Pressure. Significant differences between males and females indicated by * ($p < 0.05$).

Arterial Occlusion Pressure

A one-way repeated measures ANOVA revealed significant differences in AOP between cuff widths (Figure 1, $p < 0.001$). Pairwise comparisons showed AOP was highest for the 5cm wide cuff compared to the 10 cm ($p < 0.001$) and 12 cm wide cuff ($p < 0.001$). Also, AOP for the 10 cm wide cuff was higher in comparison to the 12 cm wide cuff ($p < 0.001$). Independent t-tests revealed significant differences in AOP between sexes for the 5 cm ($p = 0.003$), 10 cm ($p = 0.002$), and 12 cm ($p = 0.009$) wide cuffs (Figure 2). Further, within each sex, AOP was highest for the 5cm cuff and lowest for the 12cm wide cuff (5 cm > 10 cm > 12 cm, Figure 2).

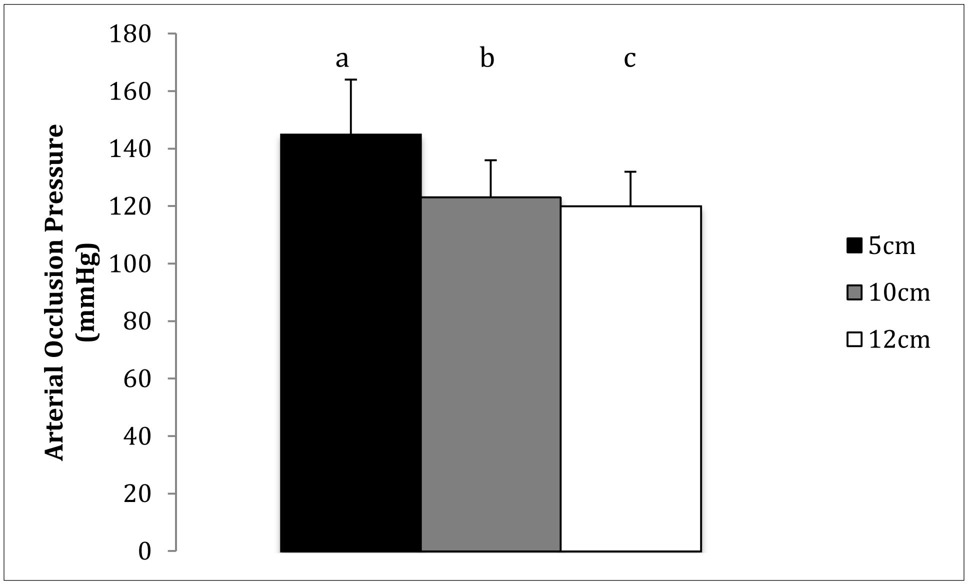

Figure 1. Cuff Width Arterial Occlusion Pressure
Cuffs with different letters represent significant differences in arterial occlusion pressure ($p < 0.05$). Variability represented as standard deviations.

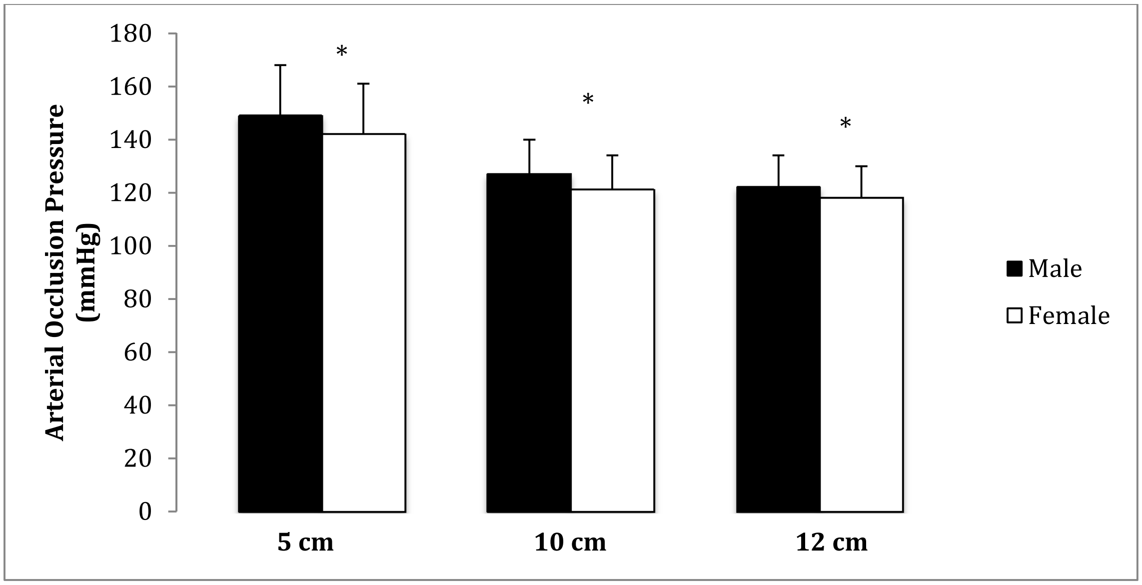

Figure 2. Sex Differences in Arterial Occlusion Pressure
Significant difference in arterial occlusion between males and females indicated by * ($p<0.05$). Variability represented as standard deviations.

Hierarchical Regression Models

The hierarchical linear regression model for the 5 cm wide cuff can be found in Table 5. Block 3 consisting of arm circumference, bSBP, upper arm length, bDBP, and sex explained the most variance for this cuff width. Examining standardized betas and part correlation coefficients revealed that arm circumference explained the most unique variance in each individual block. The model for the 10 cm wide cuff can be found in Table 6. Block 3 consisting of arm circumference, bSBP, upper arm length, bDBP, and sex explained the most variance for this cuff width. Examining standardized betas and part correlation coefficients revealed that arm circumference explained the most unique variance in block 2 and 3, whereas bSBP explained the most unique variance in block 1. The hierarchical model for the 12 cm wide cuff can be found in Table 7. Block 3, which consisted of arm circumference, bSBP, upper arm length, bDBP, and sex explained the most variance for this cuff width. Examining standardized betas and part correlation coefficients revealed that bSBP explained the most unique variance in each individual block. As cuff width changed, the part correlation coefficient for each variable also changed. Figure 3 illustrates the difference in part correlation coefficients of each variable within block 3 (which explained the most variance) for each cuff width. When partialing out the effects for all other variables, arm circumference explained the most unique variance in AOP for the 5 cm wide cuff (Part = .554), as well as the 10 cm (Part = .419), and 12 cm (Part = .406) cuffs. Brachial systolic blood pressure was the next largest predictor for the 5 cm (Part = .355), 10 cm (Part = .366), and 12 cm (Part = .387) wide cuffs. Arm length was not a significant predictor of AOP for any cuff widths. Brachial diastolic blood pressure did not explain much variance for any of the three cuff widths (5 cm Part = .068, 10 cm Part = .094, and 12 cm Part = .081. Sex, similar to bDBP did not explain much variance for any cuff widths (5 cm Part = .199, 10 cm Part = .144, and 12 cm Part = .156).

Table 5. Model for 5 cm wide cuff

Block 1	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.528	< .001	.527		
bSBP	.481	< .001	.480		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.741	.550	13.3	178.3	< .001
Block 2	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.605	< .001	.519		
bSBP	.390	< .001	.297		
Upper Arm Length	-.184	< .001	-.153		
bDBP	.216	< .001	.169		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.782	.611	12.4	155.2	< .001
Block 3	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.715	< .001	.554		
bSBP	.521	< .001	.355		
Upper Arm Length	-.058	.259	-.043		
bDBP	.096	.073	.068		
Sex	.315	< .001	.199		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.807	.651	11.8	140.0	< .001

bSBP: Brachial Systolic Blood Pressure; bDBP: Brachial Diastolic Blood Pressure.

Table 6. Model for 10 cm wide cuff

Block 1	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.408	< .001	.407		
bSBP	.547	< .001	.545		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.707	.49	9.8	96.4	< .001
Block 2	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.462	< .001	.396		
bSBP	.443	< .001	.338		
Upper Arm Length	-.137	.009	-.113		
bDBP	.220	< .001	.172		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.741	.549	9.3	87.5	< .001
Block 3	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.541	< .001	.419		
bSBP	.537	< .001	.366		
Upper Arm Length	-.046	.422	-.034		
bDBP	.133	.026	.094		
Sex	.227	.001	.144		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.755	.570	9.1	83.8	.001

bSBP: Brachial Systolic Blood Pressure; bDBP: Brachial Diastolic Blood Pressure.

Table 7. Model for 12 cm wide cuff

Block 1	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.373	< .001	.372		
bSBP	.558	< .001	.556		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.694	.481	9.3	86.5	< .001
Block 2	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.438	< .001	.376		
bSBP	.466	< .001	.355		
Upper Arm Length	-.160	.003	-.133		
bDBP	.208	< .001	.163		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.730	.533	8.8	78.5	< .001
Block 3	**Stand. β**	**p Value**	**Part**		
Arm Circumference	.524	< .001	.406		
bSBP	.568	< .001	.387		
Upper Arm Length	-.062	.288	-.045		
bDBP	.114	.060	.081		
Sex	.246	< .001	.156		
	R	**R^2**	**SEE**	**Mean Square Error**	**Sig. F Change**
	.747	.557	8.6	74.7	< .001

bSBP: Brachial Systolic Blood Pressure; bDBP: Brachial Diastolic Blood Pressure.

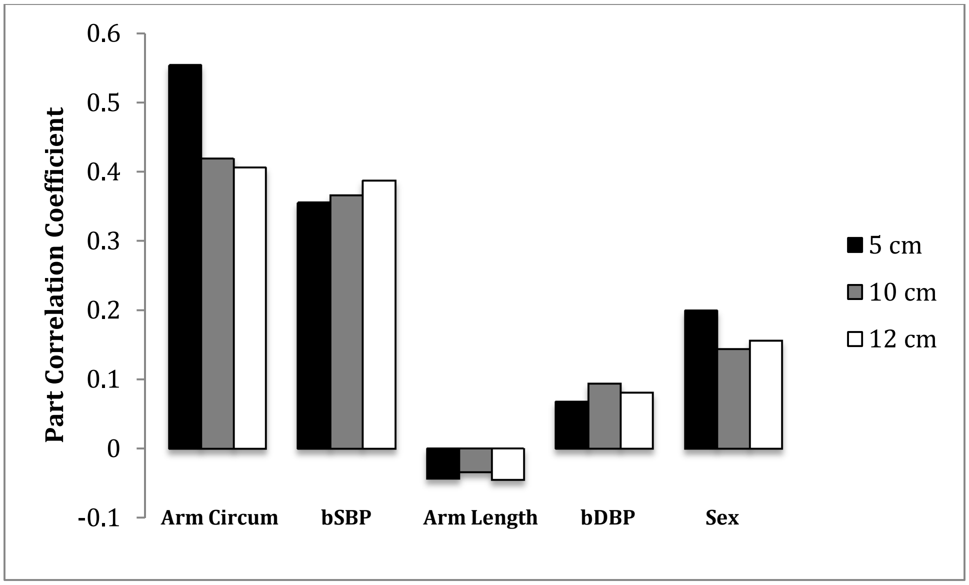

Figure 3. Part Correlation Coefficients for Cuff Widths
Arm Circum = 50% arm circumference; bSBP = brachial systolic blood pressure; bDBP = brachial diastolic blood pressure.

Multicollinearity

None of the variables met the criteria for multicollinearity as determined by no values of VIF ≥ 10 (Table 8, highest observed value = 2.4), and no correlation coefficients ≥ 0.85 (Table 9, highest observed value = 0.607).

Table 8. Variance Inflation Factors

Variables	VIF
Arm Circumference	1.6
bSBP	2.1
Arm Length	1.8
bDBP	1.9
Sex	2.4

bSBP: Brachial Systolic Blood Pressure; bDBP: Brachial Diastolic Blood Pressure.

Table 9. Values for Multicollinearity Amongst Variables

	Arm Circ	bSBP	Arm Length	bDBP	Sex
Arm Circ	-	.076	.499*	.100	-.542*
bSBP	.076	-	.250*	.607*	-.308*
Arm Length	.499*	.250*	-	.076	-.647*
bDBP	.100	.607*	.076	-	.065
Sex	-.542*	-.308*	-.647*	.065	-

Arm Circ; Arm Circumference; bSBP: Brachial Systolic Blood Pressure; and bDBP: Brachial Diastolic Blood Pressure. * denotes significance (p<0.05).

Regression Formulas

The formula for each cuff width is as follows (Sex: Male = 0, Female = 1).

AOP 5 cm (mmHg) = 2.926 (Arm circumference) + 1.002 (bSBP) – 0.428 (Arm Length) + 0.213 (bDBP) + 12.668 (Sex) – 68.493

AOP 10 cm (mmHg) = 1.545 (Arm circumference) + 0.722 (bSBP) – 0.235 (Arm Length) + 0.205 (bDBP) + 6.378 (Sex) – 15.918

AOP 12 cm (mmHg) = 1.393 (Arm circumference) + 0.710 (bSBP) – 0.294 (Arm Length) + 0.164 (bDBP) + 0.6419 (Sex) – 8.752

CHAPTER V: DISCUSSION

This study revealed significant differences in arterial occlusion pressure (AOP) when comparing 5 cm, 10 cm, and 12 cm cuff widths applied to the upper arm. In addition, significant differences in AOP were present between males and females for each cuff. It was found that a model consisting of arm circumference, brachial systolic blood pressure (bSBP), arm length, brachial diastolic blood pressure (bDBP), and sex explained the most variance in AOP for all three cuffs. However, when controlling for all other variables arm circumference was responsible for explaining the most unique variance in AOP for each cuff width, followed by bSBP. In comparison, bDBP and sex seemed to explain little unique variance. Furthermore, upper arm length was not a significant predictor of AOP for any cuff. As the cuff became wider the amount of unique variance explained by arm circumference became less, however it was still responsible for explaining the most unique variance for all three cuff widths.

Main Findings

1. There were significant differences in AOP between 5 cm, 10 cm, and 12 cm wide cuffs
    a. The pressure required for arterial occlusion was greatest when applying the 5cm wide cuff and lowest when applying the 12 cm wide cuff.
2. Arterial occlusion pressure was significantly higher for males than females for each cuff width.

3. A model consisting of arm circumference, bSBP, arm length, bDBP, and sex explained the most variance in AOP for each cuff width.

4. Arm circumference explained the most unique variance for each cuff when controlling for all other variables.

Arterial Occlusion Pressure

The results of the present study determined that there were significant differences in AOP across the three different cuff widths applied in the upper body. A narrow cuff required a higher inflation pressure to occlude blood flow in comparison to a wider cuff. This was evident in our data when comparing 5 cm cuff (mean AOP = 145 mmHg), 10 cm cuff (mean AOP = 123 mmHg), and 12 cm cuff (mean AOP = 120 mmHg) widths. In congruence with our findings, Loenneke et al. (2012) found that wide nylon cuffs (13.5 cm) occluded blood flow at a lower pressure compared to a narrow elastic cuff (5 cm) in participants lying in the supine position. Similar relationships between cuff width and AOP have been found in the upper (Crenshaw et al. 1988; Graham et al. 1990; Moore et al. 1987) and lower body (Alastair et al. 2004; Crenshaw et al. 1988; Graham et al. 1990). The differences in AOP due to cuff width seem to be explained by the way pressure applied from the cuff is distributed to tissue underneath. Hargens et al. (1987) studied the distribution pattern of tissue fluid pressure underneath an 8 cm wide cuff and observed a peak in pressure at mid-cuff accompanied by a decrease in tissue fluid pressure as distance to the cuff edges became smaller. Further investigation by Crenshaw et al. (1988) compared these patterns using an 18 cm wide cuff on the thighs and a 12 cm wide cuff on the arms of disarticulated cadavers. At the same inflation pressure the authors observed a wider plateau of high tissue fluid pressure mid-cuff using the wider option, meaning a larger amount of tissue was exposed to a higher pressure versus the narrow cuff distribution. Furthermore, there was less disparity between the tissue fluid pressure in deep tissue and the applied pressure from the wide cuff compared to a narrow cuff inflated to the same pressure.

Factors Predicting AOP

An investigation of the factors thought to influence AOP revealed a model that consisted of arm circumference, bSBP, upper arm length, bDBP, and sex explained the most variance for all three cuff widths. Of these variables, arm circumference explained the most unique variance in AOP for each cuff when partialing out the effects of all other variables. This coincides with previous data in the lower body by Loenneke et al. (2012) showing limb circumference to be the largest predictor of AOP when applying a wide or narrow cuff. Moore et al. (1987) also found the same to be true in the upper body when comparing multiple cuff widths, though the sample size was quite small (n = 10). Loenneke et al. (2015) further supported this using a 5 cm wide cuff applied to 171 participants in the supine position. Interestingly, a model including composition of the limb (i.e. muscle and fat) did not explain any additional unique variance in AOP when compared to a model including limb circumference of the upper (Loenneke et al. 2015) and lower body (Loenneke et al. 2012; Loenneke et al. 2015). According to Hargens et al. (1987) the amount of pressure within the limb is a function of tissue depth. The distribution of pressure from cuff inflation creates a pattern such that subcutaneous tissue experiences a greater percentage of applied pressure compared to the deep tissue. Moreover, the disparity between subcutaneous and deep tissue fluid pressure becomes even greater as limb size increases. The data from Shaw and Murray (1982) supports this concept as the authors found that mean tissue fluid pressure in the thigh of cadavers was lower in larger legs. Therefore, as circumference of the limb increases, a greater cuff inflation pressure would need to be applied in order to create a large enough tissue fluid pressure for arterial occlusion.

In the present study bSBP was the next largest predictor of AOP for each cuff width, although the significance of bSBP in predicting AOP has been variable in the upper and lower body. For example, in the lower body, Alastair et al. (2004) determined bSBP alone was not correlated well enough with AOP to be used as a predictor. Similarly, Loenneke et al. (2012) questioned the method of using bSBP for prediction of AOP in the lower body, as it did not explain any additional variance when added to a model consisting of leg circumference, ankle blood pressure, and bDBP. The authors determined using ankle blood pressure seems to be a more appropriate measure to determine AOP in the lower body, as it is more specific to the limb being measured. In the upper body, Moore et al. (1987) concluded bSBP was not a significant predictor of AOP when applying cuff widths of 4.5 cm, 8 cm, and 15.5 cm to seven males and three females. In contrast, the current study, as well as Loenneke et al. (2015) found bSBP to be a significant predictor of AOP in the upper body. However, limb circumference was still responsible for explaining the most unique variance when accounting for all other variables. Interestingly, Van Roekel and Thurston (1985) determined bSBP to be more important than limb circumference when determining AOP for the upper and lower body. It is of note the participants were under anesthesia so it would be difficult to compare differences between studies. Also, if the cuff (45.2 cm wide) used to determine AOP in the upper body was similar in width to the cuff for blood pressure measures it seems reasonable to believe the numbers would be quite similar.

To our knowledge, no previous research has been conducted to specifically investigate the relationship between AOP and arm length. However, we chose to include upper arm length in the model due to the possible role it has in hemodynamics. Blood pressure is dependent upon many variables such as viscosity, as well as the diameter and length of the blood vessel. When all other variables remain unchanged, increasing or decreasing the length of a vessel will change the fluid pressure within that blood vessel (Widmaier, Raff, & Strang, 2011). When controlling for all other variables, upper arm length did not explain any additional variance in AOP for any cuff width. We hypothesized this particular finding may be due to the vessel length restricted by the cuff remaining constant within and between subjects (due to cuff width application); therefore no change in pressure would result. In comparison, the limb circumference does not change within subjects, but does change between subjects. To illustrate this point, a 5 cm wide cuff applied to a long limb would restrict the same length (5 cm) of blood vessel when applied to a short limb. Although the vessel length may change between participants with arm length the portion of that vessel being restricted by the cuff remains the same.

Brachial diastolic blood pressure was responsible for explaining some variance in AOP for all three cuffs, although the amount was small in comparison to arm circumference and bSBP. This agreed with data from Loenneke et al. (2012 and 2015) in the lower body and the upper body. The difference in variance explained by bDBP and bSBP may be due to the similarity of AOP measurements and bSBP in the upper body, given that AOP is the lowest restrictive pressure at which blood flow is ceased and bSBP is the highest restrictive pressure at which blood flows after being occluded. Similar to bDBP, sex differences explained little variance in AOP in comparison to arm circumference and bSBP. To our knowledge no previous studies have been designed to look at the specific relationship between sex and AOP.

Cuff Width Changes

Across cuff widths the amount of unique variance explained by arm length, bDBP, and sex was relatively small when controlling for all other variables. As previously mentioned, arm circumference explained the most variance for each cuff, however, as the cuff became wider the amount of unique variance explained by circumference became less. Crenshaw et al. (1988) also suggested limb circumference becomes less of a factor for wider cuffs, yet the present data revealed it was still responsible for explaining the most unique variance in AOP, even for the widest cuff (12 cm). However, Loenneke et al. (2012) determined limb circumference had a greater influence on AOP for a wide cuff compared to a narrow cuff in the lower body. This discrepancy could potentially be due to some methodological differences. The wide cuff used by Loenneke et al. (2012) was nylon whereas the narrow cuff used was elastic and exerts an initial pressure when placed on the limb. Also, the present study was conducted in the upper body with participants in the standing position compared to the supine position.

In comparison to arm circumference, bSBP explained less unique variance for the 5 cm wide cuff. Even though bSBP explained a greater portion of variance as cuff width became larger it was still not as much as that uniquely explained by arm circumference. Although previous research varies as it pertains to bSBP being a significant predictor of AOP, Loenneke et al. suggests it is logical in the upper body given how similar the two measurements are. It is reasonable to believe that bSBP would explain more variance in AOP if the cuff size used to restrict blood flow was similar to the one used for blood pressure measurements. Graham et al. (1990), examined AOP as a function of the ratio between cuff width and limb circumference, stating AOP would become sub-systolic at a ratio greater than 0.3. Although the present data does not support this exact idea it does seem to support the trend of an increasingly larger cuff width to limb ratio resulting in a lower pressure needed for AOP.

Sex Differences

Differences in AOP were present between sexes, resulting in a higher pressure needed to occlude blood flow in males for all three cuff widths. Although previous studies included males and females as participants when investigating cuff width differences, none to our knowledge have been specifically designed to investigate the effect sex differences have on AOP. However, Loenneke et al. (2015) retrospectively separated differences by sex and determined circumference was still responsible for explaining the most variance in AOP. Even though differences existed in AOP between sexes they seem to be driven by anthropometric differences, more specifically differences in limb circumference. As determined by effect sizes the largest differences between males and females were height, body mass, arm circumference, and arm length. Of these variables, arm circumference has been repeatedly demonstrated to be a large predictor of AOP, and therefore it can be reasonably assumed to be driving the differences between sexes.

CHAPTER VI: CONCLUSIONS

The purpose of this study was to compare the effects common cuff widths used in blood flow restriction (BFR) would have on arterial occlusion pressure (AOP) of the upper body. In addition, the study was designed to examine which factors (arm circumference, brachial systolic blood pressure (bSBP), arm length, brachial diastolic blood pressure (bDBP), and sex) were responsible for predicting AOP and how those factors would change between cuff widths used.

Hypothesis

It was hypothesized that as the cuff became wider it would result in a lower pressure needed for arterial occlusion (AOP).

The hypothesis was supported by the data. The 5 cm cuff required the greatest amount of pressure in order to occlude blood flow, followed by the 10 cm cuff. The 12 cm cuff required the least amount of pressure to reach arterial occlusion.

Sub question

As cuff width changes, will limb circumference, brachial systolic blood pressure, brachial diastolic blood pressure, limb length and sex differences explain the variance in arterial occlusion differently?

Sub-hypothesis

It was hypothesized that limb circumference would explain the most variance for each cuff width used in the upper body.

The hypothesis was supported by the data. Although the amount of unique variance explained by arm circumference became less as the cuff became wider, it was still responsible for explaining the largest amount of unique variance in AOP for each individual cuff.

Significance

Blood flow restriction in combination with low load resistance training is a safe, effective modality to improve muscle mass and strength. This type of training may be a useful alternative to those contraindicated to high load resistance training. Training with BFR, or research investigating BFR should be done so only after careful consideration of the cuff width being applied. Results of the present study indicate AOP in the upper body is different when applying various cuff widths in the standing position. This highlights the need for researchers to identify the cuff width used in order for methodology to be truly replicable. In addition, rather than using an arbitrary inflation pressure (i.e. same pressure for each individual) for BFR in the upper body it should be based upon individual differences, specifically differences in arm circumference and bSBP, thus ensuring all participants are receiving the same relative stimulus. Given that low load resistance exercise in combination with BFR has been shown to increase muscle size and strength to a similar degree across low and high pressures (Counts et al. 2015), being able to avoid these higher pressures may potentially reduce the risk of adverse effects. Lastly, the equations derived from this study will provide a quick, inexpensive way for researchers and clinicians to determine AOP in the upper body using three common cuff widths.

Future Research

Data from the current study should be followed up in future studies by determining what differences exist between common cuff widths applied during BFR exercise. Also, as AOP is not a measure of blood flow volume it should be investigated how blood flow is impacted by variables such as cuff width, arm circumference, bSBP, arm length, bDBP, and sex differences.

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VITA

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EDUCATION

2013-Present Master of Science, Exercise Science, Present
University of Mississippi, Mississippi 38677
Thesis Title: The effects of different cuff widths on arterial occlusion in the upper body.

2008-2012 Bachelor of Science, Exercise Science, May 2012
Appalachian State University, North Carolina 28608

PROFESSIONAL EXPERIENCE

2013-Present Graduate Teaching Assistant, Department of Health, Exercise Science, and Recreation Management, University of Mississippi, Oxford MS

RESEARCH EXPERIENCE

2013-Present Kevser Ermin Applied Physiology Laboratory
University of Mississippi

TEACHING EXPERIENCE

2015-Present HP 191 Personal and Community Health (Summer 2015)
University of Mississippi

ES 396 Allied Health Terminology (Spring 2015)
University of Mississippi

2014-Present ES 402 Exercise Leadership (Fall 2014)
University of Mississippi

ES 457 Exercise Testing and Prescription Laboratory (Summer 2014, Spring 2015)
University of Mississippi

ES 349 Physiology of Exercise Laboratory (Summer 2014, Fall 2014)
University of Mississippi
HP 203 First Aid and CPR (Spring 2014, Summer 2014, Fall 2014)
University of Mississippi

EL 218 Advanced Fencing (Spring 2014)
University of Mississippi

El 153 Sports Conditioning (Spring 2014, Spring 2015)
University of Mississippi

EL 118 Beginning Fencing (Spring 2014)
University of Mississippi

2013-Present EL 151 Weight Lifting (Fall 2013)
University of Mississippi

EL 124 Racquetball (Fall 2013)
University of Mississippi

PROFESSIONAL AFFILIATIONS

2012-2015	National Strength and Conditioning Association (NSCA)
2013- Present	American Red Cross (ARC)
2015-Present	American College of Sports Medicine (ACSM)

LABORATORY COMPETENCIES

1. Exercise Prescription
2. Muscular Strength Testing
3. Extensive Weight Training Experience
4. Arterial Occlusion
5. VO2max Testing
6. First Aid/CPR/AED Instructor Certified (American Red Cross)
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SERVICES

2014-Present	Academic Advisor for HESRM undergraduate students

MENTORSHIP

2014-Presnt	Jeremy Loenneke, PhD University of Mississippi
2008-2012	N. Travis Triplett, PhD Appalachian State University