

THE EFFECTS OF BLOOD FLOW RESTRICTION TRAINING ON  $VO_{2MAX}$  AND 1.5  
MILE RUN PERFORMANCE

A Thesis

by

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## ABSTRACT

### THE EFFECTS OF BLOOD FLOW RESTRICTION TRAINING ON VO<sub>2MAX</sub> AND 1.5 MILE RUN PERFORMANCE

December 2016

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Blood flow restriction (BFR) training is a training strategy involving the use of cuffs or wraps placed around a limb during exercise to maintain arterial inflow to the muscle while preventing venous outflow. Blood flow restriction training with resistance has been shown to improve muscular power, sprinting speed, strength, hypertrophy and endurance. Non-resistance training methods using BFR, such as walking, may increase strength and hypertrophy however the effects on aerobic capacity are less uncertain and the research in this area is limited. The purpose of this study was to evaluate the effects of BFR walk training on VO<sub>2max</sub>, 1.5 mile run times, and muscular size. Ten well trained males underwent three weeks of lower extremity BFR walk training. Pre-and post-measurements of VO<sub>2max</sub>, 1.5 mile run times, and thigh muscle cross sectional area were recorded. Blood flow restriction walk training resulted in significant improvements in VO<sub>2max</sub> ( $p=.034$ ), significant decreases in 1.5 mile run time ( $p=.024$ ) and significant increases in thigh muscle cross sectional area ( $p=.016$ ). In conclusion, BFR walk training represents a singular training methodology for improving aerobic capacity, endurance

and muscular size at low training volumes and intensities. This may be beneficial for individuals undertaking concurrent strength and endurance training.

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## CHAPTER I

### INTRODUCTION

#### THE EFFECTS OF BLOOD FLOW RESTRICTION TRAINING ON $VO_{2MAX}$ AND 1.5 MILE RUN PERFORMANCE

According to the American College of Sports Medicine (ACSM) a regular program of exercise includes cardiorespiratory, resistance, flexibility and neuromotor exercise training to improve and maintain physical fitness and health (ACSM, 2011). The ACSM recommends engaging in moderate intensity cardiorespiratory training for 30 or more minutes per day for at least five days a week for a total of at least 150 minutes per week, vigorous intensity cardiorespiratory exercise for at least 20 minutes per day for three days a week for a total of at least 75 minutes per week, or a combination of moderate and vigorous intensity exercise to achieve a total energy expenditure of 500 to 1000 MET per minute per week. Two to three days per week, resistance exercises should be performed for each of the major muscle groups and neuromotor exercises that trains balance, agility and coordination. Finally, flexibility training for each of the major muscle tendon groups for 60 seconds per exercise on two days per week is recommended to maintain optimal joint range of motion (ACSM, 2011).

The ACSM also makes recommendations on optimal loading and frequency for resistance training. For untrained individuals it is recommended they resistance train with loads that correspond to an eight to twelve repetition maximum (RM) (ACSM, 2009). For individuals that have at least six months of resistance training experience it is recommended to use loads that allow for a one to twelve RM with an eventual emphasis

on heavy loading using a one to six RM range (ACSM, 2009). The recommendation for training frequency is two to three days per week for novices, three to four days per week for intermediate training and four to five days per week for advanced training.

The load required to produce dynamic muscular strength, hypertrophy, power and endurance has been extensively studied and the ACSM makes recommendations based on meta-analysis of the literature. Loads of 40% - 50% one repetition maximum (1RM) have been shown to produce dynamic strength and hypertrophy in novice individuals, however, it appears that to produce skeletal muscle hypertrophic change and neural adaptations in experienced individuals' progressive loads of 80% 1RM are required (ACSM, 2009). Therefore, to maximize strength gains novice and intermediate individuals need to train with loads that at 60% - 70% 1RM for 8 to 12 repetitions and advanced individuals need to train with loads at 80% - 100% 1RM (ACSM, 2009).

For muscle hypertrophy, it is recommended using loads that correspond to a 1 – 12 RM in a periodized progression with emphasis towards the 6 – 12 RM zone and rest periods of one to two minutes between sets and for most individuals this load will be equivalent their 70% 1RM for that exercise (ACSM, 2009; Wallden, 2015). Resistance training programs that emphasis hypertrophy should focus on high volume and multiple sets in contrast to power training, which entails using relatively light loads of 60% 1RM for lower body exercises and 30% - 60% 1RM for upper body exercises using high velocity contractions for three to five sets and three to five minute rest between sets (ACSM, 2009). Lastly, when training muscular endurance, loads of 40% - 60% 1RM are performed using high repetition sets of at least 15 repetitions and rest periods of less than 90 seconds in between sets (ACSM, 2009).

Strategically pairing a resistance load with a specific repetition range and a specific rest period recruits a specific energy system and a specific muscle fiber type. Wallden (2015) identifies parameters for training loads, repetitions, and rest for specific fiber types. Resistance training with loads of 80% that allows the individual to complete eight to twelve repetitions at a moderate pace is optimal for hypertrophy and this often results in activation of type IIA muscle fibers. Glycolytic anaerobic metabolism is the primary energy system being utilized during this type of training and rest periods of two minutes is typical between sets for recovery. Resistance training with loads of greater than 80% that allows the individual to complete one to six repetitions at fast pace is optimal for power, which often results in training adaptations to the nervous system. Fast twitch type IIB muscle fibers are activated and the ATP-CP system is the primary energy system being used. Muscular endurance training or strength-endurance training emphasizes recruitment of type I muscle fibers and primarily utilizes glycogen and aerobic metabolism. By using short rest periods of as little as 30 seconds and a repetition range of 12 – 20 or beyond, strength endurance training induces hormonal responses and improves sensitivity to adrenal stress and improves tolerance to lactic acid thus improving lactic threshold.

Endurance can be defined as the capacity to sustain a given velocity or power output for a maximal duration (Jones & Carter, 2000). Therefore, endurance performance is dependent on adequate delivery of oxygen to the tissue, aerobic synthesis of ATP and a steady supply of glycogen and lipids. Endurance training focuses on training adaptations in the cardiorespiratory system and neuromuscular system to improve delivery of oxygen from the atmosphere to the mitochondria and enhance cellular glycogen aerobic

metabolism (Jones & Carter, 2000). Conventional endurance training is any form of continuous exercise performed for a duration of at least five minutes to 240 minutes at an intensity of 65% to 100% of maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) (Jones & Carter, 2000). However, current recommendations from the ACSM stress that endurance exercise intensity should be prescribed based % $\text{VO}_2$  reserve (% $\text{VO}_2\text{R}$ ) or % heart rate reserve (%HRR), which is defined as the maximal oxygen uptake minus oxygen uptake at rest and the resting heart rate subtracted from the age based maximum heart rate, respectively (ACSM, 2011). Lounana, Campion, Noakes and Medellie (2007) evaluated 26 elite cyclists found that endurance exercise prescribed as a percentage of maximal oxygen uptake can over or under estimate the exercise intensity. They determined that % $\text{VO}_2\text{R}$  and %HRR more accurately determined an appropriate exercise intensity and there is a strong correlation of agreement between % $\text{VO}_2\text{R}$  and %HRR. Therefore, the ACSM has adopted using % $\text{VO}_2\text{R}$  or %HRR as the preferred method for prescribing endurance exercise intensity (ACSM, 2011).

A review paper by Jones and Carter (2007) discusses key parameters to improving endurance and aerobic capacity. Key parameters recommended by Jones and Carter (2007) are maximal oxygen uptake, exercise economy and lactate/ventilatory threshold are reviewed in the following paragraphs. An additional parameter discussed by Jones and Carter is oxygen uptake kinetics however this concept is closely linked to the lactate/ventilatory threshold and key concepts of oxygen uptake kinetics are discussed in that section.

Maximal oxygen uptake reflects an individual's maximal rate of aerobic expenditure and has been traditionally associated with success in endurance performance

(Lounana et al., 2007). Increasing  $VO_{2max}$  from endurance training is dependent on a number of factors such as individual fitness, training duration or volume, intensity and training session frequency. Jones and Carter (2007) assert that the optimal exercise volume and intensity for improving  $VO_{2max}$  is unknown but they cite evidence from the literature to suggest that high intensity training of at least three to five sessions per week with a minimum duration of 20 to 30 minutes for six to nine weeks is needed to increase  $VO_{2max}$  (Jones & Carter, 2007).

Jones and Carter reported that increases in  $VO_{2max}$  are likely to stabilize in a conventional training program and improvements in performance will come from factors such exercise economy, lactate threshold and oxygen uptake kinetics (Jones & Carter, 2007). Exercise economy is defined as the oxygen uptake required at a given absolute exercise intensity (Jones & Carter, 2007). Therefore, increased exercise economy is an advantage in endurance performance because it results in the lower utilization of an individual's  $VO_{2max}$  during endurance exercise. Exercise economy is related to physiologic and metabolic factors, biomechanics, technical performance and anthropometrics. Improvements in exercise economy may result from improved muscle oxidative capacity and muscle motor unit recruitment patterns (Jones & Carter, 2007). Studies reviewed by Jones and Carter, suggest increasing maximal leg strength with resistance training and resistance training with fast paced movement speeds coupled with low loads can improve exercise economy and endurance performance (Jones & Carter, 2007).

The exercise intensity at which blood lactate increases above resting levels (lactate threshold; LT) and the associated changes in gas exchange (ventilatory threshold;

VT) are powerful predictors of endurance performance (Santos-Concejero et al., 2014). Exercise above LT is associated with increases in metabolic, respiratory and perceptual stress and there is rapid onset of fatigue via the effects of metabolic acidosis and/or an accelerated depletion of muscle glycogen (Santos-Concejero et al., 2014). An improved LT/VT ratio with training is an excellent marker of enhanced endurance capacity, however, LT/VT is typically found at 50% to 80%  $VO_{2max}$  even in highly trained individuals (Jones & Carter, 2007). Training at lactate threshold results in several adaptations that benefits exercise performance such as increased sodium-potassium pump concentration, lactate transport and myoglobin concentration (Jones & Carter, 2007). Training at appropriate intensities to stimulate improvements in the LT/VT may be the result of several mechanisms that ultimately either slow the rate of lactate production or speed up the removal of lactate from the blood. Muscle biopsy studies have shown that elite endurance athletes have a predominance of type 1 muscle fibers and an increased capillarity of skeletal muscle (Jones & Carter, 2007). Type I muscle fibers have a slower rate of muscle glycogen utilization thus slowing the rate of lactate production and the increased capillarity of skeletal muscle has the effect of increasing maximal muscle blood flow and an increased surface area for the exchange of gases, substrates and metabolites (Jones & Carter, 2007). Training at lactate threshold results in a drift of  $VO_2$  values to that are greater than expected is called the  $VO_2$  slow component (Jones & Carter, 2007). Exercise training intensities that attenuate the slow component or extend the range at which the slow component does not develop results in improved endurance exercise performance (Jones & Carter, 2007).

One interesting conclusion made by Jones and Carter (2007) is that alterations in blood lactate levels, pulmonary ventilation, heart rate and plasma hormonal and metabolite levels that accompany endurance training may only partly explain enhanced endurance performance. They go on to suggest it appears that intramuscular changes and possibly alterations in motor unit recruitment patterns may be more important (Jones & Carter, 2007).

Conventional resistance and endurance training can be time consuming due to heavy loads and large volumes of training. The heavy loads and high volume used in conventional training may also result in injuries. A novel training strategy to circumvent the injury risk and time constraints of conventional training is blood flow restriction training. Blood flow restriction training is a method of inducing training adaptations in skeletal muscle by applying pneumatic cuffs or bands over the proximal portions of the either the upper or lower limbs. Previous research has demonstrated that blood flow restriction training (BFR) has positive effects on skeletal muscle hypertrophy, strength and power (Loenneke et al., 2012a). Under normal conditions with traditional weight training, training loads and intensity needs to be 60% - 70% of the one-repetition maximum (1RM) to induce muscle hypertrophy (ACSM, 2009).

Multiple training strategies for BFR training have been reported in the literature. However, BFR training programs using low load resistance training seems to be the most commonly employed strategy. Blood flow restriction training programs using low intensity loads of 20% - 30% 1RM and shorter volume training sessions appear to induce muscular hypertrophy similar to conventional resistance training with high load and long duration training (Loenneke et al., 2012a). A study by Suga et al. (2010) compared the

effects of BFR, exercise intensity and BFR pressure. The BFR protocol used three different exercise intensities and two different BFR pressures. The exercise intensities used were 20%, 30% and 40% 1RM of a calf exercise. The two pressures used were a moderate pressure, 130% of systolic blood pressure, and a high pressure, 200 mmHg. The pressures and intensities were compared against a control group performing the same calf exercise at 65% 1RM. The BFR protocol combining 30% 1RM with moderate pressure had similar results to the control group using 65% 1RM. Walking exercises have also become a commonly employed exercise modality with blood flow restriction and has been described as an effective alternative to high intensity resistance training. (Fahs et al., 2012).

According to Horiuchi and Okita (2012), it has been well established that aerobic training improves vascular function and thereby constitutes a preventive measure against cardiovascular disease. However, aerobic training is insufficient to develop muscular strength or inhibit muscle strength loss. Horiuchi and Okita (2012) review several studies that provided compelling data that exercise in conjunction with BFR maintains aerobic capacity and leads to muscle hypertrophy and strength increases. Blood flow restriction training may be a novel means of overcoming the contradiction between aerobic training and high intensity resistance training. This suggests that BFR training may be beneficial for athletes or individuals, such as military personnel, that require concurrent strength and endurance training. This may also have implications for injury rehabilitation because individuals recovering from injury often are not able to train at high intensities such as 70% 1RM.



Pneumatic compression is obtained by the use of patented devices such as Kaatsu Global, Inc or various other pneumatic compression cuff devices. Practical blood flow restriction training is an alternative method most commonly employed when using resistance training with low loads of around 20 – 30% of 1RM and with wraps that are wrapped at a perceived tightness of 7 out of 10. The cuffs or wraps are tightened to a pressure that maintains arterial blood inflow yet occludes venous blood outflow while at rest (Scott et al., 2016). During physical activity, muscular contractile strength overcomes the occlusive pressure thus allowing venous blood outflow. A wide range of exercise modalities has been coupled with BFR training. These include walking, swimming, cycling, resistance training and even sport specific skill drills. In contrast to conventional training which utilizes high intensity, heavy loads and often long durations, BFR training utilizes low intensity training loads of approximately 20% to 30% 1RM and training session durations are approximately 15 minutes for the upper body and 20 minutes for the lower body (Loenneke, Wilson, Marin, Zourdos, & Bembien, 2012c).

According to the ACSM training with loads of less than 60% to 70% of 1RM are insufficient to substantially increase strength or muscle hypertrophy, however, resistance training with BFR and loads of 20% to 30% of 1RM have been shown to increase strength (ACSM, 2009; Loenneke et al., 2012c). Furthermore, BFR training has been shown to produce results similar in efficacy to conventional training and leads to improvement in muscular power, explosive power and sprinting speed (Loenneke et al., 2012c). The literature also suggests that using non-resistance training such as walking, cycling or swimming can produce muscular hypertrophy and strength similar to resistance BFR training (Loenneke, Fahs, Rossow, Abe, & Bembien, 2012b). A meta-

analysis conducted by Loenneke et al. (2012c) reviewed a small number of BFR studies which demonstrated good efficacy for improving endurance however the authors note that BFR training and endurance is an understudied component of BFR exercise training.

The mechanisms by which BFR training leads to training adaptations as compared to conventional training are not fully understood. However, BFR resistance training displays much higher levels of muscle activity when compared to conventional training which suggests increased muscle fiber recruitment is a driver of increased hypertrophy (Loenneke et al., 2012d). Blood flow resistance training also shows greater post-exercise protein synthesis, growth hormone elevations and increased molecular signaling responses as compared to matched loads with conventional training (Loenneke , Wilson & Wilson, 2010b, 2012f).

Blood flow restriction training originates from Japan and was developed by Dr. Yoshiaki Sato, M.D. It has been reported that Dr. Sato, who is also an avid body builder, stumbled upon the concepts for BFR in 1966 after a long meditation session in which he was kneeling with his hips resting on his ankles. Dr. Sato concluded that this must have occurred due to occlusion of the blood flow to his legs and he noted the sensation in his legs felt similar to sensations from resistance training. Over the next seven years, Dr. Sato experimented, often on himself, with various devices such as bicycle tubes, ropes and bands to recreate the moderation in blood flow. By 1973, Dr. Sato had created the first set of principles for blood flow restriction training and he named this Kaatsu training. Kaatsu in Japanese literally means additional pressure. By 1994, he developed and patented a pneumatically pressurized cuff system which has since been made available commercially.

Within the literature a few different types of equipment have been identified for BFR training. Kaatsu has already been previously discussed but it bears mentioning here that Kaatsu and Kaatsu training is a patented device and training method. Kaatsu devices and Kaatsu training are also referred to generically as blood flow moderation training. Delphi Medical manufactures surgical tourniquet devices and manufactures a modified pneumatic tourniquet system that is suitable for use in BFR training. A third type of equipment known as practical blood flow restriction training uses elastic wraps that are wrapped around the proximal limb to a perceived tightness of 7 out of 10. All three of the above mentioned methods and devices have been used in multiple studies.

#### Pressure Levels and Safety

Various cuff pressures have been used for BFR training. Some studies used an initial low pressure and progressed to higher pressures throughout the study. In other studies, the precise pressure was not disclosed and in the case of studies that utilized practical BFR only a perceived wrap tightness of 7 out of 10 is known. Reviews of the literature by Loenneke et al. (2013b, 2014c) suggest that precise pressure is an important issue and their reviews suggest that too much pressure can create risks and insufficient pressure will fail to produce a desirable training result. Loenneke et al. (2014a) reported cuff pressures that resulted in 40% to 50% arterial occlusion had the greatest effect on muscle activation and this effect on muscle activation plateaued at pressures above 50% arterial occlusion. Studies using practical blood flow training with a perceived wrap tightness of 7 out of 10 resulted in complete venous but not arterial occlusion and the investigators were able to elicit a hypertrophic response (Lowery et al., 2014; Wilson et al., 2013).

The use of blood flow restriction training appears to be very safe due to the lack of complete occlusion. It has been reported in the literature that inappropriate use of BFR training can result in dizziness or bruising (Scott, Slattery, Sculley, & Dascombe, 2014). Inappropriate use identified in the literature consisted of improperly placing the cuffs, cuff pressures too high, placing cuffs on both the upper and lower limbs simultaneously and inadequate hydration before and during training (Scott et al 2014). Two separate reviews failed to identify any clinical evidence of observed or reported adverse effects nor were any adverse changes observed in blood chemistry analysis such as an increased serum creatine kinase (Karabulut, Sherk, Bemben, & Bemben, 2013; Mattar. et al., 2014). However, Loenneke et al. (2011a, 2014b) and Pope et al. (2013) concluded that BFR training is contraindicated in special populations such as a history of deep vein thrombosis, pregnancy, varicose veins, hypertension and cardiac disease.

Blood flow restriction training appears to result in increased muscular fiber recruitment, increased muscle protein synthesis, increased growth hormone release and enhanced molecular signaling responses (Scott, Loenneke, Slattery, & Dascombe, 2016). There is evidence that BFR resistance training produces adaptations in muscular power, sprint running speed, and endurance, and that non-resistance training methods (like walking) with blood flow restriction also produce skeletal muscle hypertrophy (Loenneke et al., 2012e). There is also evidence that BFR may have an effect on  $VO_{2max}$  (Abe et al., 2010a, 2010b; Park et al., 2010) There is at least one study involving high intensity BFR training that shows a positive effect on increased time to exhaustion (Corvino et al., 2014). Thus, BFR training may be beneficial for improving aerobic performance and endurance in healthy, well trained and non-injured athletes.

Much of the research in blood flow restriction training has been focused in the areas of rehabilitation, muscular strength, hypertrophy and power. There is limited research in the area of sports performance, aerobic capacity and endurance. Furthermore, only a limited number of studies have utilized well-trained individuals to evaluate the efficacy of blood flow restriction training. The intention of this study is to evaluate the effects of blood flow restriction training on aerobic capacity by assessing  $VO_{2max}$ , and endurance performance on a 1.5 mile run time, in a population of well-trained individuals. If the effects are positive, this study presents a viable method to improve sports performance at low intensities and low volumes as well as a singular form of training that improves aerobic performance, endurance and muscular strength, hypertrophy and power.

#### SIGNIFICANCE OF THE STUDY

The knowledge gained from this study may lead to the development of a singular physical training methodology that can improve aerobic capacity, muscular strength and endurance with low intensity and low volume training. This training methodology may be highly beneficial for the military, first responders and overall sports performance training. The results of this study will also contribute to the body of knowledge in the fields of kinesiology, exercise physiology and sports performance in the use of novel method of training for which there is limited research.

#### HYPOTHESIS

It is hypothesized that blood flow restriction walk training will significantly improve  $VO_{2max}$  and 1.5 mile run times.

## OPERATIONAL DEFINITIONS

Well trained individuals are defined as those individuals that participate in strength and conditioning activities for at least five days a week within the last six months or longer.

Kaatsu is a patented training method that was developed by Dr. Yoshiaki Sato. The method involves compression of the vasculature proximal to the working muscles using an apparatus known as the Kaatsu Master Device.

Blood flow restriction training (BFRT) utilizes pneumatic compression of the vasculature proximal to the working muscles by means other than use of the Kaatsu Master Device.

Practical blood flow restriction training (PBFRT) is an alternative means of applying this pressure through the use of elastic wraps or bands. The bands are wrapped around the proximal portion of the limbs to a perceived tightness of 7 out of 10. The term PBFRT is used to differentiate it from the more carefully controlled methods (Kaatsu or BFRT) in which pneumatic cuffs are used to produce a calibrated pressure.

## ASSUMPTIONS

Fundamental assumptions of the study are the  $O_2$  analyzer accurately measures  $VO_{2max}$  and that the Kaatsu device and/or other BFRT equipment is accurately calibrated for reproducible pressures. It is also assumed that the participants of the study are not taking any supplements or otherwise training in a manner outside of the study that may impact  $VO_{2max}$ .

## DELIMITATIONS

This study is limited to healthy, well trained males aged 18 to 50 and as such the results of this study may or may not be applicable to females of any age or males outside the age ranges of this study.

#### LIMITATIONS

A major limitation to this study is that only an experimental group was used. Other limitations of this study are that well-trained participants are often also highly competitive and thus there may be a potential for some degree of a “Hawthorne effect”, the study was limited to males and an elite level military population.

## CHAPTER II

### BLOOD FLOW RESTRICTION TRAINING

#### Mechanisms

The primary drivers of hypertrophic change in skeletal muscle are mechanical loading and metabolic stress (Pearson & Hussain, 2015). Several investigators have proposed multiple explanations by which BFR training produces adaptations in skeletal muscle however the consensus of the literature is that metabolic stress is largely responsible (Loenneke et al., 2010b). Blood flow restriction training appears to create a high level of metabolic stress through elevated blood lactate levels, increased release of growth hormone and increased levels of insulin like growth factor – 1 (IGF-1) (Loenneke et al., 2010b). Blood flow restriction training also appears to increase the activity of heat shock proteins and increase cellular swelling which may potentiate BFR's effects on metabolic stress (Loenneke et al., 2010b, 2012b). It has also been proposed that the metabolic stress created by BFR results in increasing levels of muscular fatigue which in turn leads to greater than expected type 2 muscle fiber recruitment (Loenneke et al., 2010b, 2011b). Additionally, greater than expected increased rates in molecular signaling pathways such as mTOR, myostatin and muscle protein synthesis have been observed during and post-exercise with BFR training when compared to conventional training methods (Loenneke et al., 2010).

Three studies from the literature were identified that compare the effects of muscle protein synthesis from BFR training to conventional training. All three studies concluded that BFR training resulted in an acute increase in muscle protein synthesis and this same effect was not observed when the same training protocol was performed



without blood flow restriction (Fry, 2010; Fujita, 2007; Gundermann, 2012).

Furthermore, a study by Gundermann (2014) found that muscle protein synthesis was increased by 42% at three hours post BFR training and was increased by 69% at 24 hours post exercise BFR training.

Greater than expected type 2 muscle fiber recruitment has been observed with BFR training and has been suggested as the primary mechanism to explain BFR trainings effectiveness in developing muscular strength and size. Sundberg (1994) demonstrated that 45 minutes of unilateral resistance training resulted in greater electromyographic (EMG) activity in the BFR training group compared to the control group. During a leg press at 30% 1RM greater EMG activity was observed in the BFR group as compared to a non BFR control group (Wilson, 2013). In two separate studies conducted by Yasuda (2013, 2014a) greater EMG activity was observed with BFR arm exercises when compared to control groups. There were two studies that failed to show a statistically significant effect on EMG activity with BFR training (Wernborn, 2009; Yasuda, 2014b).

Three studies identified in the literature compared changes in muscle force production with BFR to conventional resistance training. Two of the studies found no statistically significant difference in muscle force production between BFR and conventional resistance training (Neto, 2014a; Wernborn, 2012). Cook (2014) reported continuous knee extension exercises with BFR at 20% 1RM resulted in greater fatigue when compared to the control group. However, Wernborn (2012) used loads of 30% 1RM during BFR conditions and Neto (2014a) used loads of 80% 1RM during BFR conditions. This data suggests that acute muscular fatigue may not be an important mechanism, however, the two studies that failed to demonstrate a significant result used

relatively higher loads which may not have allowed for enough repetitions to induce effective levels of metabolic or neural stress. Nearly all BFR resistance training protocols recommend performing all sets to momentary muscle failure so additional trials may be necessary to determine if acute muscular fatigue and relative loads are dependent and significant mechanisms.

Metabolic stress and blood lactate levels are believed to play an important role in training adaptations associated with BFR training. Several studies from the literature were identified which evaluated the effects of blood lactate and metabolic stress in comparison of BFR training and conventional training. Not all studies demonstrated a significant difference in blood lactate levels between BFR training groups and conventional training groups (Loenneke et al., 2010a, 2012e, 2012f). One study using an all-female study group actually demonstrated higher blood lactate levels in the conventional group over the BFR training group (Kim, 2014). However, multiple studies using males and mixed gender training groups have shown significantly increased levels of blood lactate accumulation in BFR resistance training groups when compared to conventional resistance training (Inagaki, 2011; Manini, 2012; Yasuda, 2014a). Two studies used non-resistance BFR training methods to evaluate metabolic stress. Eight healthy males exercised for 30 minutes at 40%  $VO_{2max}$  under BFR conditions which demonstrated a significant increase in blood lactate levels as compared to the conventional training group (Kumagai, 2012). A second study that evaluated nonresistance training methods used electrical muscle stimulation which did demonstrate a significant increase in blood lactate levels but only after the cuffs were deflated (Inagaki, 2011). In addition to blood lactate levels, other intra muscular metabolites such

as phosphocreatine, intramuscular pH and glycogen levels have shown significant differences in BFR training compared to conventional training (Suga, 2009; Suga, 2010; Suga, 2012; Takada, 2012). Sundberg (1994) using unilateral BFR resistance training demonstrated significant degrees of glycogen depletion, lower intramuscular ATP, lower creatine phosphate levels and increased nitric oxide formation under BFR conditions versus conventional training.

Yasuda et al. (2014b) and Loenneke et al. (2012d) demonstrated rapid increases in muscle thickness using resistance BFR training at loads of 20% 1RM. Although these two studies did not compare the results to a non-BFR training group or conventional training these studies do demonstrate that there are measurable training effects from BFR training.

Low load resistance training has been shown to result in increased ratings of perceived exertion despite the fact that BFR training involved a total overall lower volume of training compared to high intensity resistance training (Vieira et al., 2014). This increased perceived exertion may be due to the effects of BFR on heart rate, blood pressure and stroke volume. Changes in heart rate may play the least significant role in increased perceived exertion as two studies that compared differences in heart rate only between BFR training and conventional training found no significant difference between the groups (Loenneke et al., 2012d; Neto, 2014b). However, when increases or decreases in blood pressure and stroke volume were taken into account statistically significant increased levels of perceived exertion were observed with BFR training as compared to conventional training (Araujo, 2014; Kumagai, 2012; Major, 2015; Poton, 2014; Vieira, 2013). Blood flow restriction training appears to result in decreases in systolic blood

pressure and stroke volume. These hemodynamic changes accompanied with exercising to failure during BFR training likely accounts for the increased perceived exertion (Vieira et al 2014).

Research findings appear to demonstrate that there is an increased metabolic cost to skeletal muscle with the use of BFR training (Cayot, 2015; Mendonca, 2015; Neto, 2014b). Mendonca (2015) demonstrated the post-exercise oxygen consumption was greater in the BFR training group compared to the non-BFR control group during five sets of three minute intervals with one minute rest of treadmill walking. Other studies that evaluated BFR resistance training and found significant decreases in microvascular oxygenation post-exercise compared to conventional training groups (Cayot, 2015; Neto, 2014b). This increased metabolic cost of BFR training suggests that BFR training may be effective for developing endurance in addition to skeletal muscle hypertrophy.

Conventional resistance training at the appropriate load and duration has been shown to result in increased growth hormone release (Wallden 2015). Six studies from the literature were identified which evaluated growth hormone response to BFR training (Abe et al., 2006b; Fujita et al., 2007; Inagaki et al., 2011; Kim et al., 2014; Manini et al., 2012; Patterson et al., 2013). Five of the studies demonstrated an increased and greater growth hormone response to BFR training as compared to the non-BFR training group. Kim et al. (2014), using an all-female study, did demonstrate an increase in growth hormone with BFR training and with the control group however the response between groups was not statistically significant. Three studies using BFR resistance training demonstrated a greater acute increase in growth hormone and increased post-exercise release of growth hormone (Fujita et al., 2007; Manini et al., 2012; Patterson et al.,

2013). Abe et al. (2006b) using non-resistance BFR walk training on the treadmill demonstrated a greater post-exercise release of growth hormone compared to the control group. Electrical muscle stimulation under BFR conditions without exercise also demonstrated a greater release of growth hormone compared to a non-BFR electrical muscle stimulation control group (Inagaki et al., 2011). These studies suggest that growth hormone release plays a significant role in the training adaptations observed with BFR training.

Gundermann et al. (2014) evaluated molecular signaling responses and found that post-exercise BFR resistance there was increased phosphorylation of the mTORC1 pathway. This study did not compare the results against a control however it does demonstrate that low load BFR resistance training does produce a molecular signaling response. Fujita et al. (2007) demonstrated increased phosphorylation of S6K1 and decreased eEF2 in the BFR training group and no response was observed in the control group. Increased mTOR signaling was observed in response to BFR resistance by Fry et al. (2010) and Gundermann et al. (2012). Vascular endothelial growth factor (VEGF) mRNA transcription increases were observed in a BFR resistance training group but not the control group (Larkin et al., 2012; Patterson et al., 2013). Greater hypertrophic signaling at one hour and 24 hours post-exercise BFR resistance training was observed as compared to the control group (Wernborn et al., 2013). Blood flow restriction training has also been shown to produce changes in heat shock protein and natural killer cells in comparison to non-BFR control groups. Therefore, it appears that low load and low intensity BFR training produces a significant effect on a wide range of molecular

signaling pathways and thus may be a significant mechanism to explain the training adaptations observed with BFR training.

### Blood Flow Restriction Training

There has been one study published that demonstrates blood flow restriction training has a positive effect on sprint running speed (Cook, Kilduff, & Beaven, 2014). This study investigated the effects of blood flow restriction resistance training on sprint running performance in 20 male semi-professional rugby players. The subjects performed 5 sets of 5 repetitions in bench press, pull ups and squats 3 times per week for three weeks. The intervention was lower body focused meaning the subjects only used the compressions cuffs on the lower limbs even while doing upper body exercises. Greater improvements were observed in bench press, squat and maximum sprint running time in the blood flow restriction group as compared to the non-occlusion control group. Greater increases in salivary testosterone were also observed in the blood flow restriction group as compared to the control group. The authors also noted that greater improvement in bench press strength resulting from lower body blood flow restriction suggests there is a systemic training effect of BFR training.

One study was found in the literature that assessed the effects of blood flow restriction training on endurance. A study by Cook, Brown, Deruisseau, Kanaley and Ploutz-Snyder (2010) evaluated the effectiveness of lower limb blood flow restriction training using dynamic knee extension resistance training to attenuate muscle loss and weakness after 30 days of unilateral lower limb suspension. Sixteen subjects underwent 30 days of unilateral lower limb suspension. Measurements of muscle strength, cross sectional area and endurance of the knee extensors were collected before and after the 30

days of limb suspension. Eight subjects (5 male, 3 female) participated in dynamic knee extension resistance training using a load of 20% 1RM and BFR conditions for three sessions per week during the 30 days of limb suspension while eight subjects did no exercise during the limb suspension. Muscular endurance in the knee extensors improved 31% in the exercise group while it decreased 24% in the control group (Cook et al., 2010). Cook et al. (2010) concluded the lower limb BFR training of the knee extensors is effective in maintaining muscle strength and size during 30 days of limb suspension and it resulted in improved knee extensor muscular endurance.

A study was conducted to evaluate the effect of BFRT or normobaric hypoxic exposure combined with low load resistance training on muscular strength and endurance (Manimmanakom, Hamlin, Ross, Taylor, & Manimmanakom, 2013). The study used well trained net ball players divided into three groups. One group took part in 5 weeks of knee flexor and extensor training using a load of 20% 1RM and BFR conditions. A second group trained the knee flexor and extensor muscles using a 20% 1RM load under normobaric hypoxic conditions and a third group trained under normobaric normoxic conditions with no other stimulus. All groups trained at the same intensity and frequency. All subjects completed a series of lower limb strength and endurance tests prior to and at the completion of the study intervention. Both the BFR training and the normobaric hypoxic training groups yielded substantial improvements in muscle strength and endurance as compared to the control group (Manimmanakom et al., 2013).

Fahs et al. (2014a) completed a study to determine the muscular adaptations to low load resistance training performed to fatigue with and without BFR training. Twelve males and six females completed 18 sessions over six weeks of knee extension training to

fatigue. One limb trained under BFR conditions and the other limb trained under non-BFR conditions using a matched load. Before and after the training, muscle thickness, strength, power and endurance was measured in each limb. Exercise training volume to reach fatigue was significantly higher in the non-BFR trained limb (Fahs et al., 2014a). Strength, power and endurance measurements were similar in both limbs at the completion of the study, however, muscle thickness was significantly higher in the BFR trained limb (Fahs et al., 2014a). Although the results between the BFR trained limb and the non-BFR trained limb, BFR enhanced the hypertrophic effect of low load training and significantly reduced the volume of training needed to elicit enhanced muscle function (Fahs et al., 2014a).

A study conducted by Libardi et al. (2015) assessed the effects of BFR training on aerobic fitness, muscle mass and muscle strength in 25 healthy older adults. The subjects were randomly assigned to either a control or experimental groups. The control group performed endurance training at 50%-80%  $VO_2$  peak for 30 to 40 minutes two days per week and resistance training using loads at 70%-80% 1RM for two days a week. The experimental group completed a similar exercise program under BFR conditions and using low loads of 20% - 30% 1RM and  $VO_2$  peak. Quadriceps cross sectional area, 1RM and  $VO_2$  peak were measured pre and post in both groups. The control group and the BFR group yielded similar increases in quadriceps cross sectional area, 1RM and  $VO_2$  peak (Libardi et al., 2015). The investigators concluded the BFR training promotes cardiorespiratory and neuromuscular adaptations equivalent to conventional training however at much lower loads and intensities (Libardi et al., 2015).



Sundberg, Eiken, Nygren and Kaijser (1993) compared the effects ischemic and non-ischemic non-resistance training in the lower limbs. Peak oxygen uptake and total time to fatigue for one legged exercises were measured before and after four weeks of training (4 sessions per week). Each leg was trained for 45 minutes, one leg received a 20% blood flow reduction (ischemic leg) and the other leg without blood flow reduction (non-ischemic leg). In the ischemic leg, total time to fatigue and peak oxygen uptake increased 27% and 24% respectively (Sundberg et al., 1993). In the non-ischemic leg, total time to fatigue and peak oxygen uptake increased 10% and 14% respectively (Sundberg et al., 1993). The investigators concluded ischemic training produced a significant and exaggerated increase in peak oxygen uptake and endurance as compared to identical non-ischemic training (Sundberg et al. 1993).

Sundberg, CJ (1994) conducted a second study evaluating endurance markers in response to ischemic non-resistance lower limb training. The training was held for four weeks, four days a week and 45 minute long sessions. One limb received 16% blood flow reduction and the contralateral limb served as the control receiving no blood flow reduction. Peak oxygen uptake and total time to fatigue increased significantly in the ischemic leg (Sundberg, 1994). Furthermore, during ischemic exercise, as compared to non-ischemic exercise, there was a higher degree of glycogen depletion, a greater depletion of type II, but not of type I fibers, a greater electromyographic activity, higher catecholamine concentrations, lower intramuscular ATP and creatine phosphate content, and an increased nitric oxide formation as estimated by increased plasma nitrate content (Sundberg, 1994).

A literature review yielded four studies which evaluated the effects on non-resistance BFR training on aerobic capacity. Abe et al. (2010a) divided a group of men and women age 60 to 78 into two groups: a low intensity BFR walk training group and a non-exercising control group. In this study data on isometric and isokinetic strength, muscle-bone cross sectional area and peak oxygen uptake ( $VO_{2\text{ peak}}$ ) was collected and analyzed over a six-week period. Abe et al. (2010a) did observe significant increases in isometric and isokinetic strength and increases in muscle-bone cross sectional area. The researchers hypothesized that there would be an increase in  $VO_{2\text{ peak}}$  following BFR walk training due to the relatively low target heart rate zone needed to improve aerobic capacity in an elderly adult population (Abe et al., 2010a). However, no significant increase in  $VO_{2\text{ peak}}$  were observed (Abe et al., 2010a). This finding concurs with prior studies using conventional high intensity training that also failed to produce significant improvements in aerobic capacity in elderly adults (Abe et al., 2010a). According to the researchers the increases in muscle mass obtained in this study group should have yielded more significant increases in aerobic capacity thus they concluded that the training failed to produce the necessary changes in muscle oxidative capacity in an elderly adult population (Abe et al., 2010a).

Abe et al. (2010b) conducted a second study using low intensity BFR cycle training in males age 20 to 26 years old. In this study Abe et al. (2010b) collected data on thigh muscle cross sectional area, isometric leg strength,  $VO_{2\text{ max}}$  and exercise time until exhaustion. Thigh muscle cross sectional area and isometric leg strength both increased significantly compared to the control group (Abe et al., 2010b). Significant improvements in  $VO_{2\text{ max}}$  and exercise time to exhaustion were observed in the BFR group but not the

control group (Abe et al., 2010b). An interesting note in regards to his study by Abe et al. (2010b) is that the BFR cycle training group completed 15 minutes of training at an intensity of 40%  $\text{VO}_{2\text{max}}$  three times a week for eight weeks whereas the control group trained for 45 minutes three times a week for eight weeks. Therefore, this suggests that low volume BFR training produces significant improvements when compared to higher volume conventional training.

Corvino et al. (2014) evaluated the effects of four weeks of low intensity BFR cycle training on time to exhaustion. Time to exhaustion was determined by measuring the time to voluntary exhaustion on a cycle ergometer at a constant work load of 110% peak power output ( $P_{\text{peak}}$ ) (Corvino et al., 2014). Thirteen physically active males and females between the ages of 20 and 26 performed three sessions per week for four weeks of 30%  $P_{\text{peak}}$  intensity BFR cycle training. At the conclusion of the protocol, there was a significant increase in the time to exhaustion while cycling at 110%  $P_{\text{peak}}$  in the BFR group but not the control group (Corvino et al., 2014). The control group followed the exact same exercise protocol in terms of duration and intensity yet no training adaptations were observed in the control group (Corvino et al., 2014). It was due to this observation that lead the investigators to conclude that the metabolic and physiologic strains induced by BFR conditions and not exercise intensity that resulted in the increased aerobic capacity of the BFR training group (Corvino et al., 2014).

Park et al. (2010) conducted a two week BFR walk training using college male basketball players to investigate the effects of BFR walk training on cardiorespiratory endurance, anaerobic power and muscle strength in an elite athletic population. The protocol involved walking on the treadmill for five sets of three-minute walking with

one-minute rest in between sets. Training was held for two sessions a day and six days a week for a total of 24 sessions. Treadmill speed was initially set at 4km/h at a 5% grade and gradually increased to 6km/h at a 5% grade which resulted in a training intensity of approximately 40%  $VO_{2max}$  (Park et al., 2010). The investigators found a tendency for muscular strength and anaerobic power to increase in the BFR group versus the control group but the results were not statistically significant (Park et al., 2010). However, the investigators did find a statistically significant improvement  $VO_{2max}$  and maximal minute ventilation (Park et al., 2010). Although this study failed to demonstrate significant improvements in muscular strength and anaerobic power, which the investigators contribute to the regular levels of resistance training performed by the basketball players, this study did demonstrate significant improvements in aerobic capacity in an elite athletic population (Park et al., 2010).

CHAPTER III  
METHODOLOGY  
PARTICIPANT

This study was approved by the TAMU-SA Institutional Review Board and all subjects signed an informed written consent prior to participating. Subjects were selected via word of mouth and as willing volunteers from the US Air Force 350<sup>th</sup> Special Operations and Tactics Training Squadron. Ten male volunteers aged 24 to 47 were chosen for this study (Table 1). Selection criteria for this study included those airmen who were healthy, had no musculoskeletal injuries, and were not on any medications that could impact blood flow. All subjects underwent a basic medical screening which included height, weight, blood pressure (BP), resting heart rate (HR), ventilatory respirations, and completion of the PAR-Q (appendix A). None of the subjects indicated any contraindication to exercise.

(Table 1).

*Subject Descriptive Statistics*

	Total (N=10)
Age (yrs)	34.3±7.07
Height (cm)	178.3±1.06
Weight (kg)	85.0±1.98

PROCEDURES

Total thigh muscle cross-sectional area was measured and estimated with a flexible fiberglass tape to measure thigh circumference ( $C_t$ ) 20cm above the knee, fat-plus-skin thickness ( $S_Q$ ) was measured over the quadriceps, 20cm above the knee using calipers and the distance across the medial and lateral femoral condyles ( $d_e$ ) was measured with calipers. Thigh muscle cross sectional (CSA) area was then calculated using the following equation:  $CSA = 0.649 \times ((C_t/\pi - S_Q)^2 - (0.3 \times d_e)^2)$  (Knapik, Staab, & Harman, 1996).

All subjects then underwent  $VO_{2max}$  testing at the TAMU-SA laboratory using a standard Bruce protocol, which started at a 10% grade at 2.7 kilometers per hour (kph) (1.7 mph) for stage one, then increase in both speed and grade every three minutes. Prior to testing, a TrueOne2400 metabolic cart (Parvo-Medics, Sandy Lake, UT) was calibrated as mandated by the manufacturer. Subjects were fitted with a FS2 Polar HR monitor (Polar Electro Inc, Lake Success, NY), nose plugs, and a head gear that supported a one-way valve mouthpiece, which was connected to the metabolic cart with a flexible hose. Heart rate,  $VO_2$ , and rating of perceived exertion (RPE) using Borg's 6-20 scale (appendix B) was collected at the end of each stage. When the subject could no longer continue, they straddled the treadmill and the speed was immediately brought down to 4.8 kph (3.0 mph) at zero grade for a three-minute cool-down.

At least 24 hours after the  $VO_{2max}$  test, subjects then ran a 1.5 mile run for time at an outdoor 400m track. Subjects were fitted with a FS2 Polar HR monitor and then given 10 minutes to perform a self-selected warm-up. When more than one subject was being tested at the same time, starts were staggered in order to avoid pacing with other subjects.

Time was kept with a standard stop watch and recorded for each lap, as well as HR. At the end of six laps, RPE was recorded as well as average and maximal HR.

The intervention was three weeks in length during which all subjects participated in a total of 15 sessions, five sessions per week. The experimental group used a KAATSU Global Nano pneumatic blood flow restriction device (Tokyo, Japan) with inflatable cuffs around the proximal portion of the thigh. The cuffs were inflated to pressures that restricted venous return but not arterial supply. At the start of each training session, each subject's optimal pressure, which is the maximum pressure at which "muscle homeostasis is disturbed" but blood flow is not completely occluded, was determined. Optimal pressure was defined as the pressure that resulted in a beefy red coloration in the limbs, the strongest sense of pulsation beneath the cuff and a capillary refill time of three seconds.

The exercise protocol required the test subjects to walk on the treadmill at a speed equivalent to 45%  $\text{VO}_2$  reserve (%  $\text{VO}_2\text{R}$ ). With the cuffs applied and inflated to a baseline pressure of 25-30 Standard Kaatsu Units (SKU), subjects sat for 8 cycles of 20 seconds cuff inflation and 5 seconds cuff deflation as a warm up. After each cuff deflation period, cuff pressure was increased by 20 SKU's and by the final cycle cuff pressure was inflated to the optimal pressure. The warm up lasted approximately 3 minutes and 40 seconds. At the conclusion of the warm up period, cuff pressure was inflated to optimal pressure and the subjects proceeded to walk at a speed equivalent to their 45%  $\text{VO}_2\text{R}$  for a 20 minute training session. Each 20 minute session was broken down into five stages: 4 minutes at a 1% grade, 4 minutes at a 2% grade, 4 minutes at a 3% grade, 4 minutes at a 4% grade and 4 minutes at a 5% grade. A treadmill gradient

ranging from at least 1% to 5% was chosen to accurately reflect the energetic cost of outdoor running and to create variability in muscle recruitment at the hip, knee and ankle (Franz & Kram, 2012; Jones & Doust 1996). At each stage the subjects were instructed to adjust their speed to maintain an intensity equivalent to their 45%  $VO_{2R}$ .

At the conclusion of the three week protocol, all subjects had their  $VO_{2max}$ , thigh muscle cross sectional area and 1.5 mile run times reevaluated in the same manner as described above and the variables were analyzed for any significant differences.

#### STATISTICAL ANALYSIS

Repeated measures ANOVA were used to assess the differences between groups for  $VO_{2max}$ , 1.5 mile run and thigh muscle cross-sectional area. Alpha was set at .05 for all tests. All statistics were run using SPSS v23 (Chicago, IL).



## CHAPTER IV

## RESULTS

A repeated measures ANOVA revealed that significant differences ( $F_{(7)} = 6.92, p = .034$ ) existed between pre-BFR  $VO_{2\max}$  ( $44.2 \text{ ml/kg/min} \pm 7.3 \text{ ml/kg/min}$ ) and post-BFR  $VO_{2\max}$  ( $45.7 \text{ ml/kg/min} \pm 6.4 \text{ ml/kg/min}$ ). Similarly, a repeated measures ANOVA indicated that significant differences ( $F_{(7)} = 8.17, p = .024$ ) existed between pre-BFR 1.5 mile run times ( $643 \text{ sec.} \pm 75 \text{ sec.}$ ) and post-BFR 1.5 mile run times ( $636 \text{ sec.} \pm 73 \text{ sec.}$ ). Finally, a repeated measures ANOVA also revealed that significant differences ( $F_{(7)} = 9.95, p = .016$ ) existed between pre-BFR thigh muscle cross sectional area ( $67.4 \text{ cm}^2 \pm 38.3 \text{ cm}^2$ ) and post-BFR thigh muscle cross sectional area ( $95.0 \text{ cm}^2 \pm 32.0 \text{ cm}^2$ ).

## CHAPTER V

## DISCUSSION

The purpose of this study was to determine if blood flow restriction walk training would have a positive effect on  $VO_{2max}$  and an inverse effect on 1.5 mile run times. Blood flow restriction walk training significantly improved  $VO_{2max}$  and 1.5 mile run times. Blood flow restriction walk training also significantly increased thigh muscle cross sectional area. The main hypothesis is accepted.

The results of this study demonstrated a 3.5% improvement in  $VO_{2max}$  in well-trained males aged 24 to 47. The current literature using non-resistance modalities (i.e. walk training or cycle training) and BFR is limited; however, there are three prior studies that have also evaluated the effects of non-resistance BFR training on aerobic capacity. Abe et al. (2010a) completed a trial of six weeks of walk BFR training in a population of 19 older adults ranging in age 60 to 78 and found no significant change in  $VO_{2peak}$  the conclusion of the study although there was a significant improvement in the performance of fitness tests. Abe et al. (2010b) also evaluated the effects of BFR cycle training on  $VO_{2max}$  in a group of 19 young males (mean age  $23.0 \pm 1.7$  years). The trial lasted for eight weeks and subjects performed 15 minutes of cycling at an intensity of 40%  $VO_{2max}$  for 3 days a week and ultimately demonstrated a 6.4% improvement in  $VO_{2max}$ , which was significant. Park et al. (2010) found a significant improvement of 11.6% in  $VO_{2max}$  in a sample of male college basketball players after two weeks of BFR walk training. In this study, seven male subjects walked on the treadmill using BFR for two sessions per day for six days a week. Although the results of the current study are significant in accordance with the above mentioned studies, the percentage of improvement is less than

the two prior studies by Abe et al. (2010b) and Park et al. (2010). However, both prior studies used a total of 24 BFR training sessions versus the 15 total training sessions in this study and taking this difference into consideration the total rate of improvement in  $VO_{2max}$  may have possibly corresponded with the prior studies if carried out with similar durations and frequencies.

The results of the current study revealed a statically significant decrease in 1.5 mile run times which, on average, there was seven second decrease. Currently, there is no other study that could be found that has evaluated the effects of non-resistance BFR training on endurance running performance. Only one other study has evaluated the effects of non-resistance BFR training on endurance performance. Corvino et al. (2014) found a 53% increase in time to exhaustion using BFR cycle training for three sessions per week for four weeks using nine males and two females (age  $22 \pm 5$  years). Although a direct comparison between the current study and Corvino et al. (2014) is difficult because two different measures of endurance performance was used, both studies were similar in length and number of BFR training sessions. Both studies revealed a significant improvement in endurance using non-resistance BFR training.

The results of this study revealed a 41% statically significant increase in thigh muscle cross sectional area. Thigh muscle cross sectional area was included as a variable due to the lack of a control group in this study. Multiple studies have been identified in the literature that have found hypertrophic changes in skeletal muscle using both resistance BFR training and non-resistance BFR training. Therefore, it has been demonstrated that non-resistance BFR training appears to be highly effective for increasing muscle size (Abe et al., 2006b; Abe et al., 2010; Kubota et al., 2008; Sakamaki

et al., 2011). Abe, Kearns, and Sato (2006b) evaluated nine males who used BFR walk training for three weeks. The subjects completed two sessions per day, six days a week for the duration of the three week trial. At the conclusion of the trial, MRI-measured thigh CSA increased on average of 4% to 7%. Significant increases in serum growth hormone, one repetition maximum and maximum isometric strength were observed with an average increase of 8% to 10% (Abe, Kearns, Sato, 2006b). Abe et al. (2010b) also used MRI-measured thigh muscle CSA in a study using young adults and low intensity BFR cycle training and demonstrated an average increase of 3.4% to 5.1% CSA (Abe et al. 2010b). Kubota, Sakuraba, Sawaki, Sumide, and Tamura (2008) immobilized the left ankle of 15 healthy males for two weeks and the subjects were instructed to use crutches with non-weight bearing during this period. Subjects were divided into three groups: a control group that performed non-activity, an isometric training group that performed series of isometric knee flexor, knee extensor and plantar flexor exercises twice daily for two weeks, and a BFR group that received twice daily for two weeks sessions of blood flow restriction without any activity. The investigators measured thigh and leg circumferences pre and post. The investigators found that there was a significant decrease in thigh and leg circumference in the control and isometric training group after two weeks of ankle immobilization and non-weight bearing. However, the thigh and leg circumferences were preserved in the BFR group and disuse atrophy had been prevented (Kubota et al., 2008). Sakamaki, Bembem, and Abe (2011) had nine males complete two daily sessions, six days a week for three weeks of BFR walk training. A control group of eight males performed the same walk training without BFR. Cross sectional area of the upper and lower leg was measured with MRI pre-walk training and post walk training.

After BFR walk training, MRI-measured CSA in the upper leg and lower leg CSA increased by 3.8% and 3.2% respectively compared to controls (Sakamaki, Bembem & Abe 2011). The results of the current study yielded a much larger percentage of increase in thigh muscle CSA than other studies in the literature. There are several factors that may explain this: 1. In the current study MRI measurements were not available and thigh muscle CSA was estimated using an anthropometric assessment. The anthropometric assessment used has been validated and compared against MRI-measurement and, in spite of the accuracy of the method, it can result in overestimates from 18% to 30% (Knapik et al., 1996). 2. The greatest changes in measurements in this study were observed in the skinfold measurements. Knapick et al. (1996) noted that the greatest source of overestimation of thigh muscle CSA using the anthropometric equation occurred in the skinfold measurements. Knapick et al. (1996) observed that caliper spring tension was the could produce an absolute error rate of 43%. When the investigators used a reduced tension caliper they noted the absolute error rate decreased to 27% (Knapick et al., 1996). 3. The participants in this study were prohibited from any additional specific training or supplements that may result in improvements in aerobic capacity however they were still allowed to continue with normal strength training during the study. 4. Lastly, post-intervention thigh muscle CSA measurements were taken on the last day of the training protocol. Two prior studies that evaluated muscle thickness observed acutely sharp increases in muscle thickness following BFR training (Loenneke et al., 2012d; Yasuda et al., 2014b). Even considering that the anthropometric assessment may have resulted in an overestimate the observed increase in thigh muscle CSA represents a significant result that is in agreement with other studies in the literature.

There are various proposed mechanisms as to why resistance training or non-resistance training performed with BFR may be expected to improve aerobic capacity and endurance. One study from the literature evaluated ten male and ten females who completed three sets of knee extension exercises at a load of 20% 1RM under BFR conditions and non-BFR conditions. Although females performed more repetitions than males, all subjects performed 30% fewer repetitions under the BFR conditions than the non-BFR conditions (Labarbera, Murphy, Laroche, & Cook, 2013). The authors felt the greater stimulus to fatigue under BFR conditions might be expected to produce a greater response for endurance.

Adaptions in muscular size, muscular hypertrophy and muscular power have been simultaneously observed in response to BFR resistance and non-resistance BFR training. Studies have identified several beneficial physiological adaptations that occur following blood flow restriction training that may benefit endurance training, performance, and aerobic capacity. For example, walking exercise with blood flow restriction has been shown to improve venous compliance in comparison to walking without blood flow restriction (Lida et al., 2011) and resistance training with blood flow restriction appears to improve microvascular filtration capacity to a greater extent than resistance training without blood flow restriction (Evans et al. 2010). This could be due to increased muscle capillarization following the training with blood flow restriction. Moreover, Fahs et al., (2014b) found that six weeks of unilateral knee extensor resistance training with blood flow restriction led to increased arterial stiffness, while no such changes were observed in a similar condition without blood flow restriction. Hunt et al. (2013) also found that six weeks of unilateral plantar flexion resistance training at 30% of 1RM led to a range of

vascular adaptations. Finally, Hunt et al. (2012) reported increases in brachial artery diameter in response to a program of resistance training with blood flow restriction that were greater than those seen following a similar protocol without blood flow restriction.

A major limitation of this study was the lack of a control group. The U.S. Air Force graciously provided access to facilities and personnel to complete this study however permission was granted for a limited timeframe and a limited number of airmen. Permission was given for ten participants and only eight subjects completed the study because two were sent on deployments during the course of the study. The decision was made to only use an experimental group in the anticipation that some subjects may be dropped for any number of reasons. Another limitation in this study was that the total number of BFR training sessions were fewer in number (15 vs. 24) than other comparable studies in the literature.

Future research in the use of non-resistance BFR training on the effects of endurance performance and aerobic capacity is warranted. Recommendations for future study include using various BFR training protocols, larger sample sizes, and including both male and female subjects. Future research should also include using gold standard measurements such as MRI and the collection of blood and tissue samples for various hormone levels, and other markers that may help to provide an understanding of the physiological mechanisms behind BFR training.

In conclusion, the results show that low intensity BFR walk training does have a significant effect on aerobic capacity, running endurance performance and skeletal muscle hypertrophy. There was a significant increase in  $VO_{2max}$  and thigh muscle cross sectional area between pre- and post-BFR walk training. There was also a significant

decrease in 1.5 mile run times between pre- and post-BFR walk training. Therefore, based on the evidence one can conclude that BFR walk training is an acceptable singular methodology that results in simultaneous improvements in aerobic capacity, endurance performance and skeletal muscle hypertrophy at low intensities and low volumes.



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## APPENDIX A

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

# PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

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

If  
you  
answered

## YES to one or more questions

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

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

## NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

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

### DELAY BECOMING MUCH MORE ACTIVE:

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

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

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

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

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

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

NAME \_\_\_\_\_

SIGNATURE \_\_\_\_\_

DATE \_\_\_\_\_

SIGNATURE OF PARENT \_\_\_\_\_

WITNESS \_\_\_\_\_

or GUARDIAN (for participants under the age of majority)

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



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## APPENDIX B

**Borg's 6-20 Rating of Perceived Exertion (RPE)**

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion



## VITA

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