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The effect of blood flow restriction training with the QuadMill on peak isometric knee extensor strength

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The Effect of Blood Flow Restriction Training with the QuadMill™
on Peak Isometric Knee Extensor Strength

by

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ABSTRACT

Traditional training methodologies that improve muscular strength use loads as low as 75% of a person's one-repetition maximum and as high as 110% of a person's one repetition maximum. With these high loads comes a greater risk for injury. Blood flow restriction (BFR) training is a potential solution to this problem. BFR training originated in Japan, where it was called Kaatsu. With this method of training, a trainee ties a tourniquet around the proximal end of a limb to reduce blood flow to and from the limb's muscles. The purpose of this study was to determine whether three-weeks of BFR training on the QuadMill™ was more effective at increasing peak isometric knee extensor torque than three-weeks of non-blood flow restricted training on the QuadMill™. Twelve college-aged participants began the study and nine, five males and four females, completed the study. Each participant performed three one minute sets on the QuadMill™ three times per week for three-weeks. Blood flow to the one leg was restricted at the upper thigh during exercise sessions. The same leg was blood flow restricted at each exercise session. Peak isometric knee extensor strength was measured with a hand held dynamometer before and after the three-weeks of training. Peak isometric knee extensor torques were calculated as the product of the force measured by the hand held dynamometer and the moment arm of the limb (the perpendicular distance from the knee joint center to the line of action of the dynamometer force. The left or right limb of each subject was randomly chosen as the blood flow restricted limb throughout the study. A 2x2 (limb, time) ANOVA with repeated measures found significant differences in torque from pre-test to post-test in both limbs (p = .016), significant differences in torque between limbs (p = .022), and a significant limb by time interaction (p = .034). A paired sample t-test compared the changes in peak isometric knee extensor strength from pre-training to post-training for both the BFR limb and non-BFR limb. There was a significant difference between the changes in the BFR limb and the non-BFR limb from pre-training to post-training (p = .016). This study shows that both BFR training and QuadMill™ training are effective training modalities for the lower extremities.

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CHAPTER 1

INTRODUCTION

Blood flow restriction (BFR) while training with low loads has been shown to stimulate muscle hypertrophy and increase muscle strength (Takarada et al., 2000; Takarada, Sato, & Ishii, 2002). Traditional training methods used to produce muscle hypertrophy and increase muscular strength utilize loads of 75% or higher of a one repetition maximum (1RM). Within a therapeutic setting, such loads are unlikely attainable and thus it is difficult or impossible to achieve the same muscle hypertrophy and muscular strength benefits as when using higher loads. Current research shows BFR training can achieve the same metabolic stress as a non-BFR resistance training protocol with less total work, fewer repetitions, and less time under tension until volitional failure (Loenneke, Balapur, Thrower, Barnes, & Pujol, 2012). Low load BFR training has also been shown to reduce delayed onset muscle soreness (DOMS) compared to a non-BFR exercise (Wernbom, Järrebring, Andreasson, & Augustsson, 2009).

Statement of the Problem

Strength coaches and rehabilitation professionals are always seeking new and innovative methods for improving performance more efficiently. An exercise modality that can achieve the same results in muscle hypertrophy and muscular strength with less training volume and less intensity is ideal. Loenneke et al. (2012) found that a BFR training protocol reduces time to muscular fatigue, which can reduce the amount of time to train a specific muscle. The effectiveness of QuadMill™ training has not be well examined by researchers. More research on this device is needed to establish whether or not it can be used to train the lower extremity. Additionally, the efficacy of BFR during QuadMill™ training is currently unknown.

Purpose of the Study

The purpose of this study was to determine the effect of three-weeks of BFR training with the QuadMill™ on peak isometric knee extension strength in college aged individuals.

Hypotheses

The researcher hypothesized that there would be a significant difference between peak isometric knee extensor torques of the BFR limb and non-BFR limb, that there would be significant differences between peak isometric knee extensor torques from pre-test to post-test, and that there would be a significant time•limb interaction.

Delimitations

- The duration of this study was only three-weeks.
- Subjects were not experienced with training on the QuadMill™.
- Training only occurred on the QuadMill™ training apparatus.
- The BFR limb was randomly chosen at the beginning of the study.
- During testing of peak isometric knee extensor strength, all subjects had the left limb tested first and the right limb tested second.
- The subjects were college aged.

Limitations

- Cuff pressures may have varied during a training session. Popovici (2011) noticed a 10 mmHg reduction in cuff pressure from the beginning to the end of his training sets.
- Differences in muscle mass and fat mass in the thighs of the participants may have differed and these differences may have affected BFR.

- A hand held dynamometer was used to measure peak isometric knee extensor torques.

Assumptions

- It was assumed that each participant gave a maximum effort during each training session and was motivated for each session.
- It was assumed that each participant did not participate in any resistance training exercise of the lower extremities for the duration of the study.
- It was assumed that all participants had similar physical capabilities and fitness levels.

Definition of Terms

Blood Flow Restriction Training - a modality of exercise where blood flow to and from the exercised muscle is restricted via a tourniquet (Loenneke, Wilson, Wilson, Pujol, & Bemben, 2011).

QuadMill™ - a training device that is marketed as low impact eccentric training device for the lower extremities. The QuadMill™ includes a platform that oscillates up and down and forward and backward. A trainee stands on the platform and tries to maintain head and shoulders at a fixed height while the platform oscillates by flexing and extending the hips, knees, and ankles.

Significance of the Study

Many individuals have medical problems, injuries, or other concerns that are barriers to exercise. These individuals may be unable to exercise at higher training intensities and training volumes due to their conditions. This study may provide insight into a specific training modality that addresses both intensity and volume. Information from this study may provide more insight into how BFR training can be used in combination with a unique training modality to achieve greater gains in strength.

CHAPTER 2

REVIEW OF LITERATURE

The purpose of this study was to determine the effect of three-weeks of BFR training with the QuadMill^{TM} on peak isometric knee extensor strength of college aged individuals. This study is the first of its kind to examine BFR while training on the QuadMill™. This review of the literature consists of background information regarding the origins of BFR training, health implications of this training protocol, recent research on the QuadMill™, BFR training as a training modality for the elderly, and the methods for measuring isometric knee extensor strength.

Blood Flow Restriction Training

BFR training began as a rehabilitation tool, originally called Kaatsu. Studies in the early 2000's investigated the benefits of using BFR training with lower percentages of maximum voluntary intensity and the effects on muscle hypertrophy and strength. Takarada et al. (2000) found that BFR training with intensities less than 50% of 1RM produced muscle hypertrophy in an elderly population. Takarada et al. (2001) also showed that, even in trained athletes, an eight-week intervention of low intensity BFR training is effective for producing muscle hypertrophy and increasing muscle strength of the knee extensor muscles.

Fahs et al. (2015) looked at middle aged- healthy individuals and sought to further examine the muscular adaptations with and without BFR training. This training protocol was 16 sessions in duration (3x per week frequency) and performed a knee extensor exercise at 30% 1RM until volitional failure with one limb blood flow restricted and the other limb was not blood flow restricted. The results of the study showed a significant difference in training volume (reps x sets) between the two limbs The BFR group had significantly less total training volume than the control group. The authors also reported that the anterior quadriceps thickness, strength, power, and endurance increased in both groups and reported no significant differences. Thus, the same level of performance was achieved using BFR training with a lower total work volume. Training frequency for BFR training is similar to traditional resistance training studies, which is 2-3 times per week (Loenneke & Pujol, 2009). Therefore due to the findings of Loenneke & Pojol, the frequency of this training study was set to three days per week and each limb could be trained with the same training frequency.

The current understanding of how BFR training can produce muscle hypertrophy and increase strength under lesser intensities is that it causes a state of metabolic stress. Due to the reduced flow of blood to and from the muscle, it is assumed the muscle cell becomes hypoxic (lack of oxygen) and a buildup of waste products (e.g., lactate) lead to muscular fatigue (Sudo, Ando, Poole, & Kano, 2015). Typically, mechanical stress, which is an increase in the load that the muscle is under, has been one of the primary causes of muscle hypertrophy (Goldberg, Etlinger, Goldspink, & Jablecki, 1975). Furthermore, increases in mechanical load will induce muscle hypertrophy (Spangenburg, 2009). Low intensity BFR training can cause an increase in muscle protein synthesis (Fujita et al., 2007). Higher load resistance training also shows an increase in muscle protein synthesis as shown by the authors, however, BFR can elicit a similar response with lighter external loads. Fujita et al. (2007) measured mixed muscle protein FSR, which is a direct measurement of amino acids being assembled into protein, in a control training group and a low intensity BFR training group. The control group trained without BFR. The BFR group trained with pressure cuffs inflated to a final pressure of 200 mmHg at the most proximal end of each limb according to the authors. The BFR group performed one set of 30 repetitions of bilateral leg extensions before a 30 second rest, then three more sets of 15 repetitions with a 30 second rest between sets at 20% 1RM. The control group followed the same protocol without the restriction of blood flow. The BFR group showed a significant increase in muscle protein synthesis from baseline to three hours post exercise, while the control group did not show any significant increases in muscle protein synthesis. Growth hormone levels significantly increased within 10 minutes post exercise and remained elevated for 40 minutes post exercise for the low intensity BFR group compared to the control group. These metabolic factors could be a possible mechanism for the muscle hypertrophy.

Fiber type recruitment has also been shown to be a primary mechanism for muscle hypertrophy and strength when performing BFR training. Yasuda et al., (2010) compared training volume with metabolite levels to induce muscle hypertrophy and concluded that the type of fiber recruited is the largest contributor to muscle hypertrophy. According to Henneman's size principle, smaller slow twitch muscle fibers are recruited before larger fast twitch fibers. In BFR training, the muscle is potentially in a more hypoxic environment, and this may cause an increase in fast twitch fiber type recruitment (Yasuda et al., 2010). During BFR training, there may be a lack of oxygen supplied to the muscles due to the restriction of blood flow (Kon, Ikeda, Homma, & Suzuki, 2012). Slow twitch muscle fibers (Type I) prefer to use aerobic pathways for supplying energy to produce force, while fast twitch fibers (Type II) are more effective at anaerobic methods. This might explain the shift in fiber type recruited during BFR training (from type I to type II).

BFR training has been shown to be a possible training intervention to improve vertical jump power. Gaviglio et al. (2015) trained four young men (ages 23, 24, 29, and 37 years, respectively). The subjects performed two maximal effort counter movement jumps (cmj) with two minutes of recovery between attempts. The subjects did this movement on a force plate and jump height and power were computed using a computer software. The training blocks consisted of 4 sets of 15 repetitions of back squatting at 30% 1RM and 4 sets of 10 repetitions per leg at bodyweight of Bulgarian split squats. Each group (BFR group and control group) performed this training protocol except the BFR group had their legs occluded at 50% arterial occlusion. Arterial occlusion was determined via a predictive equation (11) (occlusion = 5.893 × thigh circumference + 0.734 × lower body diastolic blood pressure + 0.912 × lower body systolic blood pressure – 220.046). Thigh circumference of the right thigh was measured at 33% of the distance from the inguinal crease to the top of the patella. The results of the study showed that the BFR group improved moderately to largely in vertical jump height compared to the control group.

Takada et al. (2011) examined the metabolic stress of BFR in two different types of track athletes, sprinters and endurance runners. Takada and colleagues determined metabolic stress by phosphocreatine levels and musculoskeletal pH decreases. The exercise of choice was a plantarflexion exercise at varying intensities (low intensity at 20% 1RM, high intensity at 65% 1RM, a low intensity with BFR, and a prolonged BFR group with 3 additional minutes under an occluded setting). Fast twitch muscle fiber recruitment was shown to occur in the HI, the LI-BFR, and the prolonged BFR conditions, but not in the LI condition. The researchers also concluded that the metabolic stress was greater in the endurance runners than in the sprinters and they believe that it could be associated with the differences in the VO2 peak in the two different types of athletes. This study could provide some insight into the benefits of endurance athletes using this type of resistance training to achieve a training effect.

The benefits of BFR training suggest muscular adaptations occur as a result of training, but there are also potential risks to BFR training. A case study by Tabata et al. (2016) reported a patient developed rhabdomyolysis, or "muscle cell death", after a bout of BFR training. Rhabdomyolysis causes the muscle cells to release a type of protein into the blood that the kidneys cannot filter. Signs and symptoms of rhabdomyolysis are dark urine, fatigue, and muscle soreness. This patient was an inactive person with a BMI of 28.1 kg/m^2 which classified him as obese and was suffering from a bacterial infection while he was training with BFR. When the man was checked into the clinic, the doctors addressed his symptoms with acetaminophen, oseltamivir, tranexamic acid, carbocysteine, and CAM. These factors were reported as the possible causes for the rhabdomyolysis but neither of these factors were reported as the cause for rhabdomyolysis.

Madarame et al. (2010) compared blood markers in ten healthy males with a mean age of 25.1 years. They compared the differences in biomarkers for thrombotic activity in the blood after four sets of leg presses at 30% 1RM with BFR and without BFR. Madarame et al. (2010) concluded that there were no significant changes in thrombotic activity associated with BFR training. This suggests that the pooling of blood expected during BFR does not likely lead to clot formation in the venous system, a dangerous condition that could lead to injury and possibly death if the clot were to reach the heart, lungs, or brain. Therefore, the risks presented above are considered negligible in an apparently healthy population. BFR training has been done on an elderly population in several studies which are listed below in the literature review, however people with cardiovascular diseases should not use BFR training as a modality of exercise due to the lack of knowledge on that particular population.

Healthy populations and the elderly without any cardiovascular complications should use BFR training and should follow the guidelines for BFR training accordingly.

BFR Training and Older Adults

Since BFR training doesn't require as large of mechanical loads as traditional strength training methods, the result is less mechanical stress on the musculoskeletal system. This alone makes BFR training an ideal training modality for training the elderly. Several studies have examined the effects of BFR training on strength in elderly populations (Libardi et al., 2015; Silva et al., 2015; Takarada et al., 2000).

Silva et al. (2015) compared a low intensity BFR training protocol to a high intensity strength protocol on 1RM in fifteen elderly women with osteoporosis. The mean age of the women was 62.2 years. Both protocols were 12 weeks long with two training sessions per week. The training exercise was knee extension. The high intensity protocol was four sets to failure with a weight of 80% 1 RM and a 2-min recovery between sets. The low intensity BFR protocol was four sets to failure with a weight of 30% 1RM and a 45 s recovery between sets. Both exercise modalities significantly increased the participants' 1RM. Since both protocols achieved the significant gains in strength it would be advantageous to perform the protocol with the least amount of mechanical stress (total external load).

Since bone density is important, especially in the older adults, Karabulut et al. (2011) compared changes in bone markers in older men who completed a high intensity resistance training program, a low intensity BFR resistance training program, or a no exercise. The average age of the men was 56.8 years. The high intensity group performed four sets to concentric failure with 80% of their 1 RM and there was a two minute rest between each set. The BFR group did four sets of 30% 1RM until concentric failure with 30 seconds of rest between sets. Each group trained twice a week with 48 hours between training sessions for twelve total weeks. Bone alkaline phosphatase and C-terminal cross linking telopeptide of type I collagen biomarkers were measured to determine the ratio of calcium deposition and reabsorption. The high intensity group showed an increase in the formation to reabsorption ratio of 23% and the low intensity BFR group showed an increase of 21%. Both programs were significantly better than the control group, which did not show any differences in strength at the six week and 12 week time points, and one method was not statistically different than the other, which means that low intensity BFR training was as effective for maintaining bone health as the more intense training program (Karabulut et al., 2011). The BFR group also performed one less repetition per set than the high intensity group. Since both groups performed the same number of sets per training session, the low intensity BFR group had a lower training volume than the high intensity group.

Takarada et al. (2000) investigated if a long term (16 week) BFR training protocol at low load would increase elbow flexor strength in 24 postmenopausal women whose average age was 58.2 years. The low intensity and the low intensity BFR groups used intensities less than 50% 1RM and the high intensity group used loads of 80% 1RM. The low intensity group was asked to match the repetitions to failure of the BFR group to keep training volume as close as possible. Training volume was calculated as load x repetitions. The low intensity BFR training group showed significant increases in isokinetic strength of the elbow flexors and cross sectional area of the biceps brachialis compared to the low intensity group, and displayed similar strength and muscle cross-sectional areas as the high intensity group. These results supported the researchers’ hypothesis that BFR would increase strength and muscle hypertrophy. The interesting finding of this study was the comparison in training volume between the three groups. The low intensity BFR and low intensity group showed similar training volumes 5,744 ± 503, 5,789 ± 613 kg*repetitions, respectively. The high intensity group training volume, however was 10,111 ± 757 kg*repetitions. The low intensity BFR group elicited similar results in strength and muscle hypertrophy compared to the high intensity group and with almost half of the training volume.

Libardi at al. (2015) were interested in concurrent training, which is the combination of aerobic training and resistance training, and if adding BFR training to the protocol would stimulate differences in 1RM strength, CSA, and $\dot{V}O_{2peak}$. Muscular strength was assessed by performing a 1RM on a leg press machine. The researchers used a graded treadmill test to assess $\dot{V}O_{2peak}$ and used a breath by breath analysis of data from a metabolic cart to get real time data on the participant during the test. The results of the study showed that both the concurrent training group and the concurrent training-BFR group had similar increases in CSA of the quadriceps muscles. The authors also concluded that BFR training in combination with concurrent training can increase aerobic fitness ($\dot{V}O_{2peak}$) by 10.3% and muscular strength by 35.5% (Libardi et al., 2015).

QuadMill™

The QuadMill™ is an exercise device meant to simulate the motion of mogul skiing. A flat platform oscillates vertically and horizontally (forward/backward) in a clockwise fashion. Participants stand on this platform and attempt to minimize movement of the body's head, neck, trunk, and arms as the platform moves. Thus, as the platform moves upwards, participants must flex the knees and hips, and as the platform moves downwards the participants extend the knees and hips. Given the expected contributions of the knee and hip extensors in preventing limb collapse during this activity, it can be expected that a significant portion of this exercise is eccentric. That is, activity of the knee and hip extensors during flexion represents an eccentric action. Given the participant maintains contact with the platform at all times, there is no impact-related eccentric actions such as those experienced during running, jumping, or hopping.

Crosby (2014) examined the effects of the QuadMill™ on vertical jump power, vertical jump height, and anaerobic power. The participants were college-aged individuals who completed a seven week, two sessions per week, training protocol using the QuadMill™. Crosby used a linear progression training model, increasing exercise intensity throughout the seven weeks by increasing cycles/min on the QuadMill™, or by adding weight to the subject using a weighted vest. His findings showed significant differences in the improvement of vertical jump power in the group that had trained on the QuadMill™ (1142 W to 1218 W) versus a normal resistance training control group (1067 W to 1091 W) and a non-activity control group (1056 W to 1061 W) from pre-test to post-test. Crosby also reported that the QuadMill™ training protocol took less total time than the resistance training protocol, which suggests that the QuadMill™ could be a time effective way to train the lower extremities in a power activity.

The QuadMill™ has had little research done on it since its introduction in 2002. This could be because the machine itself is no longer made, however the company that made the QuadMill™ now markets and sells a machine called the React Trainer. This machine duplicates the motion of the QuadMill™. Due to this lack of research, this study can provide more insight as to how this machine can be used as an effective training modality.

Measurement of Isometric Knee Extensor Strength

The present study was delimited to use of a hand held dynamometer to measure peak isometric knee extensor torque. Bohannon (1990) compared the static knee extensor torques mesasured with a hand held dynamometer to those measured with an isokinetic dynamometer. The peak isometric knee torques of twenty women, average age 29.2 years, were measured with the subjects seated and stabilized with three straps. The torques were measured with the knee joint angle at 90 degrees. Two measures were made with the hand held dynamometer and two measures were made with a Cybex II isokinetic dynamometer with its velocity setting was set to zero. Both measurement techniques were highly reliable. The intra-class correlation coefficient was .945 for the hand held dynamometer and .932 for the isokinetic dynamometer. The mean peak isometric knee extensor torque was 129.4 ± 32.0 Nm for the hand held dynamometer and 126.3 ± 29.8 Nm for the isokinetic dynamometer. The inter-instrument reliability was fair with the intra-class correlation coefficient of .797. Bohannon (1990) concluded that hand held dynamometers are as reliable as isokinetic dynamometers.

The setup in Bohannon’s (1990) was very similar to that in the present study. The subject was stabilized with straps and the isometric knee extension torque was measured with the knee joint angle at 90 degrees. Unlike the present study, Bohannon’s (1990) subjects were all women, and the torques they produced were smaller than those produced by the men and women in the present study. Unlike most studies which have compared hand held dynamometer measures of isometric torques to isokinetic dynamometer measures of dynamic torques, Bohannon’s study compared hand held dynamometer measures of isometric torques torques to the isokinetic dynamometer measures of isometric torques. Bohannon’s results support the present study's use of a hand held dynamometer to measure peak isometric knee extensor strength.

Conclusion

BFR training has been found to be an effective modality for increasing muscle hypertrophy and muscular strength in a healthy population and has been shown to be a safe modality of resistance exercise when performed correctly. There has been limited research using the QuadMill™ to improve muscular strength and this study would be the first to combine BFR training and the use of the QuadMill™ as a training modality.

CHAPTER 3

METHODS

The purpose of this study was to determine the effect of three-weeks of BFR training with the QuadMill^{TM} on peak isometric knee extension strength of college aged individuals. The research protocol was approved by the SUNY Cortland Institutional Review Board and each participant signed an informed consent form prior to participating in the research (see appendices A and B). Nine participants completed two training sessions a week for three-weeks. The training sessions occurred on a QuadMill^{TM} while the blood flow to one leg was restricted at the upper thigh. Peak isometric knee extensor torque of each leg of each participant was measured before and after the three-weeks of training.

Participants

Twelve participants volunteered to participate in the study but three participants failed to complete the protocol. The remaining nine participants, five males and four females, were between 18 and 23 years old and were recruited from undergraduate classes. Inclusion criteria for the study followed the ACSM guideline for physical activity, which is 150 minutes a week of moderate physical activity (ACSM, 2008). Exclusion criteria for this study included any structural injury to the lower extremity such as sprains or fractures within the last six months, any neurological disorders, and participation in any intercollegiate varsity sports within the past year.

Isometric Knee Extension Strength Testing

Peak isometric knee extension strength of each leg was measured on the first day of training prior to the training session and again two days after the last training day. Each participant was tested using a hand held dynamometer (Lafayette Manual Muscle Tester

Model 01163 Lafayette, IN) that measures force in pounds. The force measurement was then converted to Newtons prior to calculating torque. Each participant sat in a chair and was then strapped to the chair with three straps. One strap across the trunk, just under the xiphoid process, held the participant's trunk against the back of the chair. One strap across the pelvis held the pelvis against the chair. A third strap across the thigh held the thigh of the tested leg against the chair seat and prevented the participant from lifting the thigh during the test. A hand held dynamometer (Lafayette Manual Muscle Tester, Model 01163, Lafayette, IN) was held with both hands by the researcher against the anterior surface of the participant's shin at the height of the medial malleolus while the knee was flexed to 90 degrees. The 90 degree knee angle was checked with a goniometer. The participant was then instructed to extend the leg at the knee and push against the hand held dynamometer with maximal effort for ten seconds. The researcher pushed back against the hand held dynamometer to prevent any change in the 90 degree knee joint angle. This force was measured perpendicularly to the tibia of the leg being tested. The hand held dynamometer displayed the peak force exerted during the 10 second trial. This peak force was recorded by the researcher. Before the first test, each participant performed a familiarity trial to become accustomed to the apparatus.

For the pre-test and post-test sessions, each participant performed three trials of the knee extension test with each leg. For each participant and testing session, the three test trials of the left leg were completed first and then the three test trials of the right leg were completed. Each participant had two minutes of rest between testing trials. Prior to testing, each participant was instructed to warmup as they normally would for any type of physical activity. Most participants did not do any warm up activity prior to the testing. Some participants, however, did do light in-place jogging and jumping jacks prior to testing.

During the post-test session, the shortest distance from the line of action of the dynamometer force to the transverse axis of the knee joint was measured for each leg. This distance, the moment arm of the force, was multiplied by the average peak force of the three trials for the leg to calculate the peak isometric knee extension torque of that leg. The lead researcher placed the dynamometer in the same position for both the pre- test and post- test. Before the participant performed their final knee extension trial, the distance from the center of the knee joint to the center of the pad on the hand dynamometer was measured. The following equation was used to calculate the peak knee extension torque:

Peak torque in Nm = (average peak force in N) x (moment arm in m)

Cuff Selection and Placement

Inflatable cuffs were used to restrict blood flow. The cuffs used in this study were the SC5™ 6x83cm (D.E. Hokanson, Inc in Bellevue, WA). This specific type of cuff was also used by Popovici (2011) in his training study of BFR during a maximal effort cycling protocol. The top edge of the cuff was placed at the proximal end of the thigh just below the acetabulofemoral joint (Popovici, 2011). Since the cuff used was considered a narrow cuff, the cuff pressure used for the training protocol was 230 mmHg, the pressure recommended for narrow cuffs (Loenneke, Fahs, & Rossow, 2012). Cuff pressure was measured via a sphygmomanometer that was attached to the cuff by a 1/16 T-fitting. The cuff occasionally deflated 10-20 mmHg after a training set on the QuadMill™. After each training set, the researcher checked the cuff pressure and reinflated the cuff to 230 mmHg, if needed.

The investigator randomized which leg was blood flow restricted by the order in which the participants arrived for testing on the first day of testing. The first participant to arrive for testing was assigned the left leg to be restricted and the second participant to enter the lab for testing was assigned the right leg to be restricted. Each odd numbered participant thus had his or her left leg restricted for all training sessions and each even numbered participant had his or her right leg restricted for all training sessions.

QuadMill™ Training Protocol

The QuadMill™ is used by the participant standing on the platform with feet in a comfortable, self-selected standing position. The orientation of the platform remains fixed as it moves vertically and horizontally in a circle with a diameter of approximately 43.5 cm. In one cycle, the platform moves forward and upward, then backward and upward, then backward and downward, and then forward and downward.

The training volume on the QuadMill™ can be varied by the amount of time on the machine and the number of cycles during that training period. During each cycle of the machine a participant executes one squat motion on the machine. The cycle velocity of the machine and the time on the machine are related to the amount of total work that each participant performs. Pilot data were collected to determine the relationship between the cycle velocities of the QuadMill™ to the intensity setting of the QuadMill™. Cycle velocity was measured at each intensity setting from 5 to 100 in increments of 5. These data were collected without a person on the platform of the QuadMill™, or with no load. Cycle velocity was also measured at the training intensities of 10, 25, and 30 with a 75 kg person on the platform of the QuadMill™. Figure 1 shows that the relationship between cycle velocity and intensity setting for the no load and 75kg load conditions. These relationships were relatively linear and the three velocities for 75 kg load condition closely matched those of the no load conditions for the same three intensities. The three intensities for the 75 kg subject were the same intensities used in this training study.

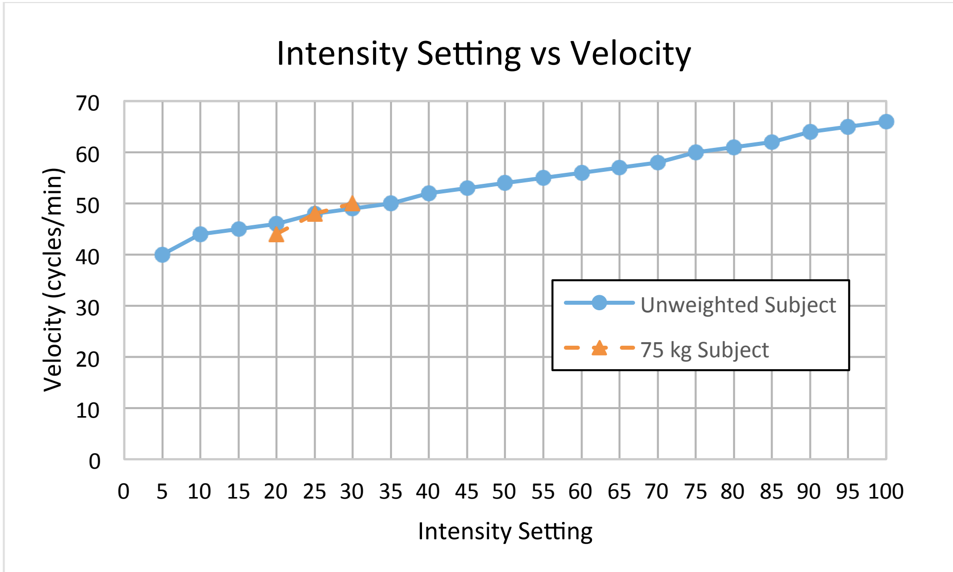

Figure 1. QuadMill™ settings and velocities for no load and 75 kg subject

The participants followed a three-week training protocol on the QuadMill™. Prior to the start of the three-week training protocol, the researcher explained the operation of the QuadMill™ to the participants and allowed them to become familiar with its use. Each participant was given the opportunity to participate in a familiarity trial to become adjusted to the machine. The familiarity trial took place during the first interest meeting before the study actually began. The subjects began testing three days after the familiarity meeting. During the first training session, each subject started the training protocol with the intensity set at 20 on the QuadMill™ and a set duration of one minute. During the second training week, the intensity was increased to 25 and during the third training week, the intensity was increased to 30. For all three-weeks of training, the number of sets per session was three and the duration of each set was one minute. Each participant was instructed to warm up as they normally would for physical activity before each training session. Each participant either came into the training session from the gym for cardiovascular conditioning. The participants were not allowed to strength train the lower extremities during the duration of the study. The participants also were seen doing some light in place jogging in the lab before each training session on the QuadMill™ as a means to warm up. The three-week training protocol is shown in table 1.

Table 1

QuadMill™ Training Protocol

	Monday	Wednesday	Friday
Week 1	Pre-testing & 3 x 1 minute @ 20 Intensity	3 x 1 minute @ 20 Intensity	3 x 1 minute @ 20 Intensity
Week 2	3 x 1 minute @ 25 Intensity	3 x 1 minute @ 25 Intensity	3 x 1 minute @ 25 Intensity
Week 3	3 x 1 minute @ 30 Intensity	3 x 1 minute @ 30 Intensity	Post-testing

Once the pre-test session and the QuadMill™ familiarity trial were completed, the participants began the three-week, three days per week training protocol. There were eight possible training days for this study. The participants were allowed to miss up to 2 sessions during the three-week training protocol, but none did. Each session was separated by 48 hours. On the ninth training session, the participants were tested for peak isometric knee extensor strength rather than going through a normal training day. For each participant at least 48 hours elapsed after the last training session before post-testing occurred.

Statistical Analysis

All statistical procedures were performed in SPSS Version 24 (Armonk, NY). A 2x2 (time, limb) ANOVA with repeated measures was used to determine the effects of QuadMill™ training and BFR on peak isometric knee extension torque in a college aged population. Alpha was set at .05. Effect size was calculated as partial eta squared (η^2).

CHAPTER 4

RESULTS

The purpose of this study was to determine the effect of three-weeks of BFR training with the QuadMill™ on peak isometric knee extension strength of college aged individuals. The participants participated in a three day per week training protocol on the QuadMill™ for three-weeks. Blood flow was restricted in one leg during each training session. Tests of peak isometric knee extensor strength were completed before and after the three-weeks of training.

Results

The 2x2 (time, limb) ANOVA with repeated measures yielded a significant increase in torque from pre to post training on the QuadMill™ ($F_{1,8}$ = 8.838, *p* = .018, η^2 = .525, power = .740), a significant difference in torque between the BFR limb and non-BFR limb ($F_{1,8}$ = 8.026, *p* = .022, η^2 = .501, power = .700), and a significant time•limb interaction ($F_{1,8}$ = 6.494, *p* =.034, η^2 = .448, power = .609). A paired sample t-test compared the changes in peak isometric knee extensor strength from pre-training to post-training for both the BFR limb and non-BFR limb. There was a significant difference between the change in torque for the BFR limb and the non-BFR limb from pre to post-training (, *t* = 3.054, df(7), *p* = .016). Group means for pre to post isometric torque by limb are reported in Table 2 and shown graphically in Figure 2. Individual data are presented in Appendix D.

Table 2

Pre-training and Post-training Peak Isometric Knee Extension Torques (mean ± SD)

	BFR (n = 9)	Non-BFR (n = 9)
Pre-training Torque (Nm)	138 ± 34	167 ± 45
Post-training Torque (Nm)	160 ± 43	173 ± 46
Change from pre to post (%)	23.2 ± 19.5*	11.2 ± 15.0*

*Note: * p < .05*

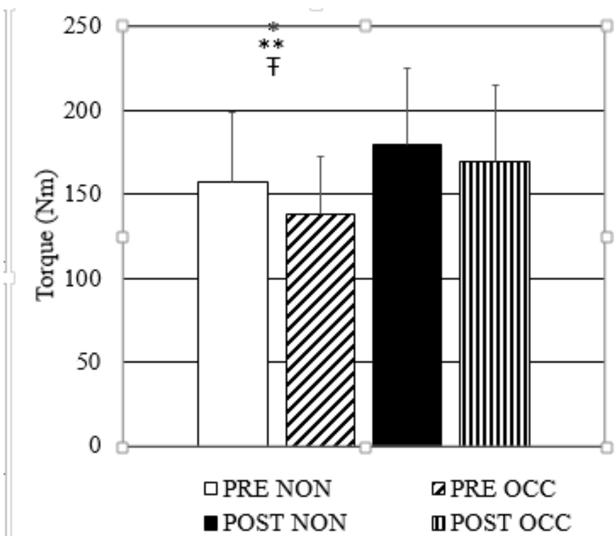

Figure 2. Pre-test and post-test peak isometric knee extensor torques for BFR and non-BFR limbs. Note: *Significant difference in torque from pre to post (*p* < .05); **Significant difference in torque between limbs (*p* < .05); Ŧ Significant time•limb interaction (*p* < .05).

Discussion

The results of the 2x2 ANOVA showed that there were significant differences in torque at the level of each limb, from pre to post training protocol, and a significant interaction between time and limb (Table 2, Figure 2). The statistical analysis showed that not only did the BFR training significantly improve peak isometric knee extensor torque, but that the QuadMill™ itself was an effective method for improving peak isometric knee extensor torque over the three-week training period. The peak isometric knee extensor torque of the BFR limb improved more than that of the non-BFR limb, as indicated by the significant limb•time interaction and the results of the paired- samples t-test. The peak isometric knee extenror torque improved by 23.15% ± 19.5% in the BFR limb and by 11.21% ± 14.986% in the non-BFR limb.

Each participant was assigned a limb for the BFR training based on a counterbalanced design based on their arrival time to the laboratory. Of the original 12 participants, the right limb was designated as the BFR limb for 6 participants and the left limb for 6 participants. The left limbs of the three participants who did not complete the study were the BFR limbs. Thus, only three participants who completed the study had their left limb restricted while six participants had their right leg restricted. The larger torques produced by the non-BFR limb may have been caused by the difference in numbers of participants with restricted left and right legs. No diagnostic tests or self-reports were used to identify a dominant and non-dominant leg. This may also be a reason for the high standard deviations across the torque measurements. However, the findings of this study concur with the findings of Pope et al. (2015), Takarada, Sato, and Ishii (2002), and Libardi et al. (2015).

One suggested reason for the significant difference in the peak torque for both time points as well as in each limb is the greater metabolic demand of BFR training compared to traditional non-BFR training. BFR partially restricts blood flow, which causes a build up of lactate and a lack of oxygen (Yasuda et al., 2010, Kon et al., 2012). This produces a shift in fiber type recruitment that is similar to traditional, high load resistance training which is a shift from slow twitch to fast twitch muscle fibers.

The intensity on the QuadMill™ was set to 20, 25, or 30, which correspond to cycle rates of approximately 46, 48, and 49 cycles per minute, and are on the lower half of the QuadMill™ intensity scale. However, given the lack of supporting evidence for the efficacy of the QuadMill™ as a training tool, it is necessary to establish its potential using lower settings first. In addition, higher settings may not have been possible for the population selected, as they had no previous experience on the QuadMill™. It was important that all participants be able to complete each training session. The approximate cycle rates of the QuadMill™ range from 40 cycles per minute at the lowest intensity setting of 5, to 66 cycles per minute at the highest intensity setting of 100. The relatively low training intensities of 20, 25, and 30 produced greater training effects on the BFR limb than the non-BFR limb (Table 2, Figure 2). Anecdotally, the participants did report to the researcher that the BFR limb felt a greater level of fatigue after each set than the non-BFR limb (data not reported here).

The greater training effect on the BFR limb could also be due to neuromuscular adaptations rather than a physiological adaptation due to the short duration of the study (Carroll, Riek, & Carson, 2001). That is, the novel task of the QuadMill™ may not have altered muscular quality (e.g., increase in muscle protein, greater anaerobic capacity), but produced better ability to access current muscle function through more effective, complete recruitment of available motor units. Further examination of this should be a part of the future research done in this area. Specifically, electromyographic activity and biopsies of muscle tissue would be necessary to evaluate specific cellular versus neuromuscular adaptations.

Not only has this study added to the literature of BFR, but it also has provided information about the use of the QuadMill™ as a training device. This machine is relatively novel in the scientific literature. It has not been used in many research studies and is not present in many fitness facilities. Thus, information about its effectiveness as a training device is scarce. In this study, during each training session, a participant was on the machine for a total of three minutes (three one minute sets separated by one minute of rest between each set). After only eight training sessions, a significant increase in the peak isometric knee extension strength of both the BFR and non-BFR limbs was observed, although the strength increase in the non-BFR limb was smaller. It should be noted though that the non-BFR limb started out stronger than the BFR limb, which may have influenced these results. It can be inferred from these outcomes that training on the QuadMill™ has an acute effect on the muscular strength of the lower extremities. The total amount of time that the participants were present for a training session was, on average, about six minutes. A typical lower extremity strength training protocol using weights requires the participant to be in the gym for longer than this amount of time. Therefore, the QuadMill™ may present an alternative form of training to increase strength that can be accomplished with less exercise time than a traditional weight training regimen. Total energy expenditure, muscular power, endurance, and other benefits of a traditional training program were not evaluated in the present study so the effectiveness of the QuadMill™ on those performance measures are currently unknown.

CHAPTER 5

SUMMARY, CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effect of three-weeks of BFR training with the QuadMill™ on peak isometric knee extension strength of college aged individuals. While determining the efficacy of the training modality itself, this study also added to the limited body of knowledge on the QuadMill™, which is a unique lower extremity training apparatus.

This study was a three-week training study. Twelve subjects began the study, and a total of nine subjects completed the entire training protocol, including pre-testing and post-testing. Each subject's peak isometric knee extensor strength of each leg was measured using a hand held dynamometer that was placed on the anterior surface of the shin at the level of the medial malleolus. The measurement was taken with the participant's knee angle at 90 degrees and with the participant's thigh and trunk strapped to a chair to prevent movement. After the testing was complete, moment arms of each leg were measured so that peak torque could be calculated. The BFR limb was chosen according to the order the participant arrived for the pre-test and first training session.

The results of the study showed that the peak isometric knee extension strength of the BFR limb increased significantly more than that of the non-BFR limb. The result concurs with previous research on BFR. Even though significance was achieved, there was a large standard deviation within both groups. Hansen et al. (2015) showed similar values in knee extensor torque using a hand held dynamometer. The subjects within this study were also of a mixed gender (male and female) which also could have caused the large standard deviation within the data. The subjects could also not have been at a similar fitness level. According to the inclusion criteria, the subjects only had to perform 150 minutes of moderate physical activity according to the ACSM guidelines. That leaves a lot of variability between the subjects as the subjects could range from being just avid walkers to recreational athletes.

Conclusions

The results of this study support the hypothesis that the BFR limb would experience significantly greater increases in muscular strength compared to the non-BFR limb when matched with the same work load and intensity. This study has provided more information about the efficacy of BFR and it was the first of its kind to combine BFR with training on the QuadMill™.

Implications and Recommendations

More research using the QuadMill™ itself needs to be completed if this device is to be established as an effective training device for the lower limbs. Another recommendation for future research is to evaluate the use of elastic bands with pressure cuffs as a method to restrict blood flow in order to possibly establish a more cost effective approach to BFR. The study design could change by having each participant perform each type of training protocol (BFR training and traditional forms of strength training) for an extended period of time and have each protocol separated from one another. Or have a control group perform traditional strength training comopared to a BFR group to see if one has a greater response than the other in age matched, similarly fit, individuals. The study could also use an isokinetic dynomometer to test the subjects in a dynamic movement rather than isometric, and/or the subjects could perform traditional strength exercises using machines or weights (such as those in a gym setting) rather than using the QuadMill™. This study shows promise for the

QuadMill™ as a training modality, however in reality the machine is not in abundance at the local gym level and the need for this study to be replicated using standard gym equipment is a must so that the local fitness enthusiast or fitness professional can reap the benefits of BFR training. The study could be expanded to examine the long term effects of BFR training on muscular strength. Another avenue that could be pursued is to measure dominance in each limb and measure any imbalances in strength or muscle size and see if BFR training of the non-dominant limb would help decrease those asymmetries over time.

Since there has been research into the athletic population with BFR training, future research should also target clinical populations. Work by Takarada et al. (2000, 2001) has shown that BFR training can be applied to these populations, however the discomfort of the pressure cuff needs to be addressed before implementing BFR training with this population. Perhaps further research needs to explore the effects of different cuff pressures and their impact on measures such as muscular strength and hypertrophy. If there are similar gains in strength and hypertrophy at more comfortable pressures, then BFR could be applied to clinical populations, such as the elderly.

This study was done using healthy, college- aged individuals and the results of the study showed that BFR could be a potential training modality for this population. BFR training utilizes smaller training loads compared to other strength training protocols. Athletes that are stuggling to stay motivated or having troubles being able to recover from their current training modality could potentially use BFR exclusively or simply add it to their current training program since there has been research, including this study that suggests that BFR elicits gains in strength.

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APPENDIX A
IRB Approval Letter

MEMORANDUM

SUNY Cortland
Institutional Review Board

To:	Brandon Schrom Peter McGinnis
From:	Kimberly Jackson, Reviewer *on behalf of* Institutional Review Board
Date:	3/29/2017
RE:	Institutional Review Board Approval

In accordance with SUNY Cortland's procedures for human research participant protections, the protocol referenced below has been approved for a period of one year:

Title of the study:	Effects of QuadMill™ Training with Blood Flow Occlusion on Peak Isometric Knee Extensor Strength		
Level of review:	**Expedited**	**Protocol number:**	161742
Project start date:	Upon IRB approval	**Approval expiration date*:**	3/28/2018

* **Note:** *Please include the protocol expiration date to the bottom of your consent form and recruitment materials.* For more information about continuation policies and procedures, visit www.cortland.edu/irb/Applications/continuations.html

The federal Office for Research Protections (OHRP) emphasizes that investigators play a crucial role in protecting the rights and welfare of human subjects and are responsible for carrying out sound ethical research consistent with research plans approved by an IRB. Along with meeting the specific requirements of a particular research study, investigators are responsible for ongoing requirements in the conduct of approved research that include, in summary:

- obtaining and documenting informed consent from the participants and/or from a legally authorized representative prior to the individuals' participation in the research, unless these requirements have been waived by the IRB;
- obtaining prior approval from the IRB for any modifications of (or additions to) the previously approved research; this includes modifications to advertisements and other recruitment materials, changes to the informed consent or child assent, the study design and procedures, addition of research staff or student assistants, etc. (except those alterations necessary to eliminate apparent immediate hazards to subjects, which are then to be reported by email to irb@cortland.edu within three days);
- providing to the IRB prompt reports of any unanticipated problems involving risks to subjects or others;
- following the principles outlined in the Belmont Report, OHRP Policies and Procedures (Title 45, Part 46, Protection of Human Subjects), the SUNY Cortland College Handbook, and SUNY Cortland's IRB Policies and Procedures Manual;
- notifying the IRB of continued research under the approved protocol to keep the records active; and,
- maintaining records as required by the HHS regulations and NYS State law, for at least three years after completion of the study.

Miller Building, Room 402 • P.O. Box 2000 • Cortland, NY 13045-0900
Phone: (607) 753-2511 • Fax: (607) 753-5590

In the event that questions or concerns arise about research at SUNY Cortland, please contact the IRB by email irb@cortland.edu or by telephone at (607)753-2511. You may also contact a member of the IRB who possesses expertise in your discipline or methodology, visit http://www.cortland.edu/irb/members.html to obtain a current list of IRB members.

Sincerely,

Kimberly Jackson, Reviewer *on behalf of*
Institutional Review Board
SUNY Cortland

APPENDIX B
Informed Consent

SUNY Cortland
Kinesiology Department

Effect of the QuadMill™ with Occlusion Training on Peak Isometric Knee Extensor Strength
Lead Investigator: Brandon J Schrom, B.S.
Phone: (518) 376-7437; E-Mail: brandon.schrom@cortland.edu

Purpose:

Thank you very much for your interest to be a participant in this research study. This study is titled "The Effect of the QuadMill™ with Occlusion Training on Peak Isometric Knee Extensor Strength." The objective of this study is to determine if differences in knee extensor strength result after training on a novel training apparatus (the QuadMill™) with blood flow occluded in one leg and not the other.

Description of the Study:

This study is a five week training study that consists of testing sessions during the first week of the study, on the eighth day of the study, and during the fifth week of the study. Each test session will take about 15 minutes to complete. For the testing, the lead investigator will measure peak isometric knee extensor strength in each of your legs. The actual training will be on the QuadMill™. Each training session will take about 10 minutes to complete. Before testing and training begin, you will be asked to fill out the informed consent and the PAR-Q to assess risk factors for cardiovascular disease. Once that paperwork is filled out you one of your legs will be randomly chosen be occluded while you train on the QuadMill™.

The testing apparatus is a standard office chair with a force measurement device attached to it. You will sit in the chair and straps will be placed across your chest, waist, and thighs to prevent movement movement of your trunk and thighs in the chair. Once you are secured in the chair, your lower leg will be moved to set your knee angle at 90 degrees. A strap attached to the chair and a force measuring device will be placed around your shin and adjusted so that the angle of your knee cannot exceed 90 degree. You will then be instructed to attempt to extend your leg as hard as possible against this strap for ten seconds. You will then get one minute of rest in before the next trial. You will perform three trials per leg. During these trials, the force measuring device measures your peak isometric leg strength. Testing will happen one week before the training protocol begins, on the eighth training day, and three days after the training protocol ends.

The training apparatus is the QuadMill™ which is a unique machine that trains the lower extremities. You will be given the opportunity to familiarize yourself with the machine prior to the first day of training. At the beginning of each training session, the lead investigator or an assistant will help you attach the blood pressure cuff to the top of your thigh that has been randomly selected to be occluded. On the first day of training the intensity of the Quadmill™ will be set to 20 out of 100 and you will perform three- one minute sets on the QuadMill™ with one minute of rest in between each set. You have the right to stop at any time during the training protocol. The training protocol will be five weeks in duration with three training days per week. Each week, the intensity level on the QuadMill will increase by a level of 5 out of 100.

Risks/ Benefits:

You may feel light discomfort in the leg that is occluded compared to the leg that is not occluded during the exercise session. As for all new training protocols, you may experience muscle soreness in the lower extremities for up to 72 hours post exercise. Benefits to this training study are that you have the opportunity to experience a new type of training and may potentially increase muscle size and strength in your lower extremities. There have been a few rare, but reported cases of rhabdomyolysis with blood occlusion training. This disease is when the muscle tissue dies from being over used. This disease is very treatable as long as there is immediate medical care. Signs of rhabdomyolysis include severe muscle pain lasting longer than 48 hours, extreme muscle fatigue, and dark or brown urine. The precautions taken in this study to prevent rhabdomyolysis include the blood pressure cuff selection and low pressure as well as the total training volume and intensity of the exercise program. The reported cases of rhabdomyolysis associated with occlusion training were older individuals who were untrained and had a prior medical history and should not have been exercising at such an intensity. You are a young, healthy, trained individual, so your risk of experiencing rhabdomyolysis is low.

Confidentiality and Right to Leave Study

If you wish to participate in this study, all of your information will be on file in the SUNY Cortland Biomechanics Lab desktop computer. This computer is password protected and is on the secure SUNY Cortland network. Your data will be coded by an ID number that only the lead researcher will know. This information will not leave the desktop computer in the biomechanics lab.

You are free to withdraw your consent and stop participating in this study at any time without penalty. Even if you begin participating and then realize that you do not want to continue, you are free to stop.

If you have any questions throughout this study feel free to contact Brandon Schrom (lead researcher) at 518-376-7437 or Brandon.schrom@cortland.edu. You may also contact the faculty sponsor, Dr. Peter McGinnis, at peter.mcginnis@cortland.edu. If you have any further questions about your rights as a participant in research you may contact the Institutional Review Board by email irb @cortland.edu, by phone 607-753-2511, or by mail: Institutional Review Board, Miller Building, Room 402, PO Box 2000, Cortland, NY 13045. For emergency contacts, please feel free to contact the SUNY Cortland Health Services by phone, 607-753-4811, the SUNY Cortland EMS at 607-753-4112, or the Cortland Regional Medical Center at 607 756-3500.

I (print name) ___________________________________ **have read the description of the project for which this consent is requested, understand my rights, and I hereby consent to participate in this study.**

Participant Signature:
____ Date: ____________

Lead Investigator Signature:
____ Date: ____________

SUNY Cortland IRB
Protocol Approval Date: 3/29/2017
Protocol Expiration Date: 3/28/2018

APPENDIX C
PAR-Q

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

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

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

If you answered

YES to one or more questions

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

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

NO to all questions

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

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

DELAY BECOMING MUCH MORE ACTIVE:

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

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

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

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

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

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

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE OF PARENT ______________________________ 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 D
Pre- and Post-test Peak Isometric Torques and Changes in Torque for Each Participant

Participant #	BFR limb	BFR limb moment arm (m)	Pre-test BFR Torque (Nm)	Post-test BFR Torque (Nm)	Change in BFR Torque (%)	Non-BFR limb	Non-BFR limb moment arm (m)	Pre-test Non-BFR torque (Nm)	Post-test Non-BFR Torque (Nm)	Change in Non-BFR Torque (%)
1	Left	0.432	118.63	193.60	63.20	Right	0.419	134.03	194.80	45.34
2	Right	0.406	113.82	125.33	10.11	Left	0.432	135.28	149.81	10.74
3	Left	0.432	170.62	237.20	39.02	Right	0.419	212.76	235.69	10.78
4	Right	0.419	218.35	245.51	12.44	Left	0.432	236.56	245.01	3.57
5	Right	0.387	140.88	143.58	1.92	Left	0.432	143.92	145.24	0.92
6	Right	0.356	111.77	125.96	12.70	Left	0.432	137.01	147.83	7.90
7	Left	0.432	140.72	151.99	8.01	Right	0.356	134.66	130.75	-2.90
8	Right	0.432	123.75	158.33	27.94	Left	0.432	148.85	183.93	23.57
9	Right	0.406	143.59	191.49	33.36	Left	0.393	167.41	168.92	0.90
Mean	-	0.411	142.46	174.78	23.19	-	0.416	161.16	178.00	11.20
SD	-	0.026	33.98	44.90	19.55	-	0.026	37.96	40.66	14.99