Acute Muscle Responses to Blood Flow Restriction Exercises in Post Bariatric Surgery Patients

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A thesis submitted to the faculty of
Brigham Young University
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Master of Science

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ABSTRACT

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Purpose: The purpose of this study was two-fold: (1) determine if muscle activation was greater in a BFR exercise condition compared to non-BFR exercise condition using MRI T2 mapping, and (2) determine if the muscle activation for both BFR and non-BFR exercise conditions differs between postbariatric surgery individuals and individuals in 2 control groups.

Methods: Three groups participated: (1) a normal-BMI group, (2) a postbariatric surgery group, and (3) a matched group for the surgery individuals. Ultrasound imaging was used to find the optimal BFR pressure for each participant. All participants participated in both BFR and non-BFR exercises. Using a 3-Telsa MRI, a T2 map was imaged prior to and immediately following exercise. Analyses included within-group-across-condition comparisons and within-condition-across-group comparisons. The outcome variable of interest was the change in muscle activation determined via T2 mapping.

Results: There was no statistical difference in the increase in muscle activation between BFR and non-BFR exercise conditions (p-value range 0.1091 to 0.9166). When comparing groups across conditions, we found that the surgery group elicited a significantly greater increase in activation compared to the normal-BMI group in every condition (p-value range 0.0014 to 0.0217) and in several muscles when compared to the matched group (p-value range 0.0060 to 0.0311). Other muscles compared to the matched group were not significantly different (p-value range 0.0683 to 0.129). No difference was found between the control groups (p-value range 0.2041 to 0.9557) in muscle activation for either condition.

Conclusion: These results did not suggest a difference between BFR exercise and non-BFR exercise for the calf-raise protocol. Postbariatric surgery patients elicited an equal muscle activation response in some conditions and a greater muscle activation response in others when compared to both control groups. Further research is needed to determine whether a greater intensity or duration of exercise is needed to elicit an acute response to BFR and what factors are contributing to the increased muscle activation seen in the postbariatric surgery group.

Keywords: muscle activation, T2 mapping, KAATSU
Table of Contents

TITLE PAGE ................................................................................................................................... i
ABSTRACT.................................................................................................................................... ii
Table of Contents ........................................................................................................................... iii
List of Tables .................................................................................................................................. v
List of Figures ................................................................................................................................ vi
INTRODUCTION .......................................................................................................................... 1
METHODS ....................................................................................................................................... 3
  Design ....................................................................................................................................... 3
  Participants ................................................................................................................................. 4
  Procedures ................................................................................................................................. 5
    Ultrasound Session Protocol ............................................................................................... 5
    Non-BFR Exercise Protocol ............................................................................................... 6
    BFR Exercise Protocol ........................................................................................................ 6
    MRI Protocol ...................................................................................................................... 6
  Muscle Activation Processing and Image Analysis ............................................................... 7
  Statistical Analysis .................................................................................................................... 8
RESULTS ....................................................................................................................................... 8
  Aim 1: Comparing Between BFR and Non-BFR Conditions ................................................... 9
  Aim 2: Comparison Between Groups for Each Condition ....................................................... 9
DISCUSSION ............................................................................................................................... 10
  Limitations .............................................................................................................................. 13
CONCLUSIONS........................................................................................................................... 14
List of Tables

Table 1. Participant Characteristics .............................................................................................. 18

Table 2. Change in Muscle Activation for All Participants.............................................................. 19
List of Figures

Figure 1: Procedural Flow Chart ........................................................................................................... 20

Figure 2. Effect of BFR Versus Non-BFR Exercise on Muscle Activation ........................................ 21

Figure 3. Changes in Muscle Activation with Non-BFR or BFR Exercise ........................................... 22
INTRODUCTION

Obesity is currently one of the largest epidemics to plague the United States and is defined as having a body mass index (BMI) equal to or greater than 30kg/m². In the year 2000, 30.5% of Americans were classified as obese and that prevalence rose to 42.4% in 2018 (1). Severe obesity, which is defined as having a BMI equal to or greater than 40kg/m² or those with a BMI of 35 to 39.9kg/m² and at least 2 obesity-related health conditions, is also rising and increased from 4.7% in 2000 to 9.2% prevalence in 2018 (1). The increased prevalence of obesity is associated with an increase in diabetes, cardiovascular disease, depression, metabolic syndrome and a variety of other health concerns (2–4). Due to its high prevalence and related comorbidities, the treatment of obesity has become an important topic of concern and research.

Bariatric surgery has become the most effective long-term treatment for severe obesity and its coexisting metabolic conditions (5,6). Recipients experience caloric restriction, malabsorption, or a combination of the 2 that results in rapid weight loss during the 2 years following surgery. During that time, the lost weight is a combination of fat mass (FM) and fat-free mass (FFM). Research has shown the majority of the loss is FM, but up to one-third of the weight lost can be FFM, particularly skeletal muscle (7). In addition, after the first 2 years, patients generally cease to lose weight or begin to regain it (8), with the regained weight being almost entirely FM (9). A recent study suggested resistance exercise programs after surgery can lead to increased muscle strength and function (10). Improved muscle function and retention of muscle helps increase an individual’s resting metabolic rate (RMR), which decreases the likelihood of gaining fat (11). Thus, patients who exercise regularly after surgery may be less likely to regain weight due to metabolic effects associated with increases in muscle mass, muscle function, and RMR (12). However, adherence to regular exercise is low (13). In order to have
better adherence to a postsurgery exercise regime and decrease the likelihood of fat regain after surgery, a more attainable exercise regime may be needed.

In recent years blood flow restriction (BFR) exercises have been gaining popularity. Research shows that training with blood flow occlusion leads to hypertrophy in muscle with substantially less resistance than normally required (14,15). Generally, individuals must exercise at 70% to 80% of their 1 repetition maximum (1RM) or exercise to failure (16) to increase muscle size. BFR allows one to exercise at 20% to 30% of their 1RM and achieve similar increases in muscle size (17,18). Essentially, BFR exercise can deliver a training stimulus equivalent to traditional methods but at a lower perceived exertion: the exercise feels easier because it accomplishes the same result with less work. This increased efficacy has not only been seen in those seeking muscle growth, but also in those seeking to attenuate muscle atrophy. BFR has been used to help athletes recovering from injury (19) and slow the loss of muscle mass in aging individuals (20). Because of BFR’s efficacy in these specific populations, it may meet the unique needs of the postbariatric surgery patients.

Based on the existing research related to BFR’s ability to impede muscle loss and lead to muscle hypertrophy, bariatric surgery patients could benefit greatly from this intervention. Thus far, resistance training programs have shown to be effective in helping postsurgery patients retain muscle mass (21). However, this approach often has low adherence rates (22). BFR exercises may provide higher adherence rates due to the lower resistance of the exercise and the decreased time this exercise regime requires. As a therapeutic strategy, BFR training could mitigate muscle mass loss following surgery, and in the long term, help maintain a preferred body composition. Maintaining a healthy body composition for these individuals may lead to a reduction in the comorbidities associated with obesity.
Using a technique called MRI T2 mapping, we assessed whether BFR exercise elicited a greater muscle activation response than non-BFR exercise. The first aim (Aim 1) was to determine whether muscle activation in the superficial posterior compartment of the lower leg was greater in a BFR exercise condition compared to non-BFR exercise condition using MRI T2 mapping. We hypothesized that the muscle activation response would be greater in BFR exercise compared to non-BFR exercise in all subjects: active normal, postbariatric, and nonbariatric subjects.

The second aim (Aim 2) was to determine whether exercise-induced muscle activation in the superficial posterior compartment of the lower leg differs in postbariatric surgery individuals compared to nonsurgical controls under BFR and non-BFR exercise conditions. We hypothesized that exercise-induced muscle activation would not differ between the 3 groups in either the BFR or non-BFR conditions.

**METHODS**

**Design**

We conducted a randomized crossover study with 3 groups, 2 sessions with different conditions, and 1 dependent variable. The 3 groups were (1) a normal-BMI group (Control), (2) a postbariatric surgery group (Surgery), and (3) a matched group for the surgery individuals (Matched). All 3 groups were jointly considered for Aim 1 but were considered separately and compared to each other for Aim 2. A Latin square randomization was performed to determine session order. The analyses included within-group-across-condition comparisons as well as within-condition-across-group comparisons. The dependent variable of interest was the change in muscle activation determined via T2 mapping, measured in specific muscles within the superficial compartment of the posterior lower leg.
Participants

Thirty individuals (10 in each group), 18 years or older, enrolled in the study. Due to the nature of restricting blood flow, we excluded subjects with diagnosed hypertension or current use of antihypertensive medications, a history of blood clotting disorders, congestive heart failure, recent stroke (< 6 mo), peripheral vascular disease, recent coronary artery disease (myocardial infarction < 6 mo), or uncontrolled diabetes. In addition, participants were excluded if they had a severe lower extremity injury or surgery in the last year, had osteoarthritis, or were physically unable to complete the exercise protocol. All individuals were required to fit the inclusion criteria of the MRI facility (see Appendix 1) for safely entering the magnet.

Individuals in the Control group were required to have a BMI of 25 or less. Individuals enrolled in the Surgery group met the following inclusion criteria: (1) received bariatric surgery (either Roux-en-Y gastric bypass or sleeve gastronomy) in the past 2 to 5 years, increasing the likelihood that they were beyond the rapid weight loss stage and either maintaining or regaining weight, and (2) were under 300 lb, as that was the weight limit of the MRI table. Finally, individuals in the Matched group consisted of a 1:1 match (current age, within 5 years; sex; and BMI, within 5 kg/m²) to each participant in the postbariatric surgery group.

Using previously collected pilot data, we ran a power analysis (alpha = 0.05, beta = 0.8) when comparing BFR and normal exercise in young, active individuals. Our analysis estimated that we would need 7 subjects in each group to detect a difference between exercise conditions if a similar effect size was seen in each comparison. A sample size of 7 is similar to other studies evaluating the effect of muscle activation using MRI (Gooding et al. had 8 subjects (26) and Adams et al. had 7 subjects (25)) and blood flow exercise studies (Manini et al. had 10 subjects
(27)). Consequently, we recruited 10 subjects for this study; having 10 subjects in each group ensured that we were adequately powered while allowing for a potential drop out.

**Procedures**

In the initial laboratory visit, participants reviewed the MRI screening form and the IRB-approved (X18242) informed consent form prior to providing consent (see Appendix 1 and 2, respectively). They were then fit with BFR bands and ultrasound was used to find the optimal inflation pressure of the band for subsequent visits. The next 2 visits were the randomized testing sessions during which participants completed 1 of the 2 exercise sessions (BFR and non-BFR exercise conditions) and MRI was used to determine muscle activation. Participants completed both testing conditions on separate days, a minimum of 7 days apart (see Figure 1).

**Ultrasound Session Protocol.** Participants reported to the MAJOR Lab in 292 of the Smith Fieldhouse of Brigham Young University. Upon arrival they were given a university IRB approved consent form. Their height and weight were recorded prior to being fitted with the BFR bands. Previous studies have shown that a pressure that provides 50% to 85% occlusion prior to exercise is sufficient for the intended results (28–31). We chose to use the KAATSU Master 2.0 (KAATSU Global, Inc., Huntington Beach, CA, USA) in order to provide a rapid, controlled occlusion during the BFR exercise condition in this study. To verify the correct amount of pressure needed for appropriate occlusion, participants were first given 10 minutes to rest, so that blood flow was at a steady baseline. A researcher with 10 years of musculoskeletal ultrasound imaging experience gathered images obtained in this study. Participants sat in a relaxed position on a treatment table with an upright, inclined back and thigh supported. The femoral artery was scanned using pulse-wave ultrasound. A 9L probe and GE Logiq S8 unit (GE-Healthcare Worldwide, Chicago, IL, USA) with integrated ECG was used to obtain these measurements.
Arterial diameter and average blood flow inside the artery were recorded over 12 cardiac cycles while the bands were loosely placed on the legs but not inflated. During this process, a 3-lead ECG was used to ensure that measurements were taken during diastole. Another measurement of the diameter and average flow of the artery was recorded with bands inflated. Percent occlusion was then calculated. The occlusion pressure was incrementally increased until the appropriate pressure was determined to ensure 50% to 85% occlusion. The band pressure was released between each incremental pressure increase.

**Non-BFR Exercise Protocol.** The exercise protocol was as follows: 3 sets of 25 calf raises with 30 to 60 seconds of rest between sets. Participants performed this exercise on a raised (19 cm) STEP Reebok platform, so that full dorsiflexion and plantarflexion could be obtained for each repetition. Subjects were required to complete a maximal effort and range of motion repetition prior to their first set. At peak plantarflexion, with their arm fully extended above the head, a marker was placed where their hand reached. This became their target, and they were required to reach that point with each repetition. Repetitions were counted for each set and each repetition was monitored to ensure full range of motion.

**BFR Exercise Protocol.** The BFR exercise protocol was the same as the non-BFR exercise protocol, except that KAATSU bands were used. After the prescan and prior to exercise, KAATSU bands were placed high on each thigh and rapidly inflated to the pressure determined during the ultrasound session. At the completion of the exercise, the bands were removed before the postexercise MRI scan.

**MRI Protocol.** We chose to image the muscles of the superficial posterior compartment (both heads of the gastrocnemius and the deeper soleus). T2 mapping allows the researcher to measure the activation level of not only superficial muscles, but also the muscles deeper in the
lower leg that contribute to plantar flexion. In addition, T2 mapping makes it possible to evaluate the area of the muscle being activated and the intensity at which that muscle has been activated. Furthermore, MRI T2 mapping has not yet been used to quantify the muscle activation of BFR exercises. Thus, we chose this method of measuring muscle activation for this study.

The right lower leg was scanned using a 3 Tesla magnet (TIM-Trio 3.0T MRI, Siemens, Erlangen, Germany) before exercise and immediately following exercise cessation (within 5 minutes). The calf was measured from the knee-joint space to the bottom of the lateral malleolus and then marked at the largest cross-sectional area prior to entering the magnet. The measurement of the leg length and mark location were recorded and used for a reference point in subsequent scans. The initial localizer scan was then centered on the marked location. After completing a localizer scan, the individual running the scan was able to center the following T2 scan on the widest part of the muscle (the initial localizer scan allowing him/her to see past the subcutaneous fat). This ensured that the majority of the superficial posterior muscles were scanned. A 2D Multi-Echo Spin Echo sequence with a matrix of 256 x 256 (RO x PE) with 8 echoes was used to acquire the images that would then be used to construct the T2 maps. An 8-channel foot/ankle coil was used to obtain a total of 88 slices per scan: 8 images at 11 different slice locations. The resolution was .6 by .6 mm with a slice thickness of 10 mm and an interslice gap of 2 mm. Repetition Time (TR) = 1800 ms and Echo Time (TE) = 10.5, 21, 31.5, 42, 52.5, 63, 73.5, and 84 ms.

Muscle Activation Processing and Image Analysis

All images obtained from the MRI scans were processed using Matlab (The MathWorks, Inc., Natick, MA, USA) to generate the T2 map from the images. We used the Horos Viewer for MacOS (Horos Project, Geneva, Switzerland) imaging program to segment the soleus and the
medial and lateral gastrocnemius heads in the lower leg. The cross-sectional area and the T2 values were recorded for the center 5 slices. The average activation measured within the cross-sectional area specific to each segmented muscle in these slices was analyzed. The researchers who processed the images were blinded as to the time period (pre or post), the condition (BFR or non-BFR), and group assignment (Control, Matched, or Surgery). Following processing, exercise-induced muscle activation was calculated by subtracting the preexercise activation level from the postexercise activation level.

**Statistical Analysis**

Aim 1. Covariates for this aim were preexercise levels of activation, height, weight, age, sex, and muscle size. We ran a mixed model ANCOVA to analyze all 27 participants as a whole, then each group separately, to investigate the effect of BFR.

Aim 2. The independent variables for our Aim 2 analysis were group and exercise condition. We removed the covariates from the previous analysis that were accounted for in the design of the study (height, weight, age, and sex). Muscle size and the pretest level were still included. The dependent variable was the change in T2 value, or the representation of muscle activation, when comparing the preexercise and postexercise maps. By using a mixed model ANOVA, we were able to compare the change in muscle activation from preexercise to postexercise within conditions across groups.

Significance level was set to an alpha less than 0.05. No reduction was made for multiple comparisons. SAS 9.0 (SAS Institute, Cary, SC, USA) was used to complete this analysis.

**RESULTS**

Demographic information on subjects is included in Table 1. We enrolled 10 participants in each group. However, 3 participants, 1 from the Matched group and 2 from the Surgery group,
failed to show up for testing and were dropped from this study. All of the remaining subjects were able to complete the entire exercise regime for both conditions.

**Aim 1: Comparing Between BFR and Non-BFR Conditions**

Figure 2 represents our findings for Aim 2. Each bar represents the mean change in muscle activation from preexercise to postexercise conditions. All bars are positive, indicating that every condition and group increased in T2 time following exercise. Our results showed there were no statistical differences in muscle activation between exercise conditions in all participants for any of the muscles we measured or for the sum of the muscle area (Total) (p-values range 0.1091–0.9166; see Figure 2A). For specific values on each of the muscles measured, see Table 2.

Totals for each of the randomized groups are presented in Figure 2B, demonstrating no differences in muscle activation for BFR and non-BFR exercise conditions in any of the 3 groups (p-values range 0.2044–0.6451).

**Aim 2: Comparison Between Groups for Each Condition**

For each condition (BFR and non-BFR), postbariatric surgery individuals elicited a greater muscle activation than either of the control groups. Compared to the normal-BMI individuals, this was the case for every muscle measured (p-value range 0.0014–0.0217).

When comparing the postbariatric surgery group to the matched group, a significant activation difference was seen in soleus for BFR (mean difference of 2.52 ± 1.10 ms; p = 0.0311) and non-BFR (mean difference of 2.6 ± 1.11 ms and p = 0.0285). In the BFR condition, there was a significant difference seen in the medial gastrocnemius (mean difference of 4.56 ± 1.51 ms; p = 0.0060) and in the total compartment (mean difference of 9.13 ± 3.60 ms; p = 0.0185), but no difference seen in the lateral gastrocnemius (p = 0.0855). In the non-BFR condition, there
was a trend towards significance in the medial gastrocnemius (p = 0.0683) and no significant
difference seen in the lateral gastrocnemius (p = 0.1290) or in the total compartment (p = 0.0911;
see Figure 3).

There were no significant differences in muscle activation between the 2 control groups
for any of the measured muscles (p-value range 0.2041–0.9557).

**DISCUSSION**

The results of this study demonstrated that the MRI T2 map detected an increase in
muscle activation as a result of exercise for all participants. Contrary to our Aim 1 hypothesis,
there was not a significantly greater increase in muscle activation in the BFR exercise condition
compared to non-BFR exercise in the participants as a whole or for any particular group. In
support of our Aim 2 hypothesis, postbariatric surgery patients did elicit a similar increase in
muscle activation in some muscles and an even greater response in other muscles, when
compared to the normal-BMI and Matched control groups.

A great deal of research has been conducted to understand why BFR exercises elicit the
response they do. In addition to activating metabolic pathways that lead to protein synthesis and
muscle hypertrophy (23,32,33), there are specific immediate responses that would be expected to
increase T2 time. BFR has been shown to lead to increased muscle activation and fiber
recruitment seen via EMG (24). However, we suspected that EMG would pose significant issues
for this population due to the high levels of subcutaneous fat and the depth of muscles of interest.
Researchers that compared T2 maps to EMG muscle stimulation (25) found highly positive
correlations between these 2 measures of muscle activation. In addition, the pooling of blood
created by BFR exercises leads to an increase of muscle metabolites (14), which is one of the
leading factors that increases T2 times (34,35). Based on the results of previous studies
indicating that BFR exercise produces increased muscle metabolite levels and greater muscle activation compared to non-BFR exercise, we fully expected to observe a greater T2 time with our BFR exercise condition. However, our data did not show a greater level of muscle activation with BFR compared to a standard, nonrestrictive exercise protocol. We suspect that this may be due to the intensity and/or duration of our exercise regime.

Some BFR studies had an exercise regime of only 1 exercise with a predetermined number of repetitions (23,24,36); however the studies by Yasuda et al. and Wilson et al. were both looking at long-term training effects rather than acute responses to exercise. Other BFR studies exercised to fatigue (18,37,38). The general protocol recommended by KAATSU is 3 exercises within a 20-minute time period (39). Initially, a longer protocol was proposed for this study, but in an effort to focus on our target muscles, that regime was reduced to 1 exercise: 3 sets of 25 calf raises. A study by Kinugasa et al. used solely calf raises as an exercise protocol when measuring T2 muscle activation and saw an increase in the T2 signal from preexercise to postexercise conditions (40). Based on these previous studies, we felt this exercise protocol would be sufficient to elicit a response. However, it is possible that we may not have pushed the muscles enough to stimulate the kind of response seen in other BFR studies.

In our study, we found that the Surgery group elicited a greater response to the exercise and saw a greater increase in activation in every muscle compared to the Control group. Since the exercises were done with only body weight, our initial thought was that it could be due to the increased workload created by a greater body weight. However, research conducted by Jenner et al. suggests that increased T2 time correlates with increased exercise intensity (power and rate) rather than work (41). In addition, when comparing the Surgery group to the Matched group with similar BMIs, the Surgery group elicited a greater response in some of the muscles. Since these 2
groups were matched by weight and thus did a similar workload, we do not believe that workload alone is responsible for this difference in muscle activation. It is possible that the Surgery group had a lower fitness level relative to both control groups, which may have elicited a greater metabolic response to the exercise protocol, resulting in higher levels of lactate and inorganic phosphate (34,35,42). When untrained or less fit individuals engage in physical activity, they often experience higher levels of lactate and inorganic phosphate (43,44). Both of these metabolites directly effect T2 relaxation time measured by MRI (45). In addition to the production of these metabolites, the higher T2 times in the Surgery group may be due to each participant’s ability to clear lactate. Lactate clearance is key for an individual’s ability to recover from exercise (46). Lactate levels following exercise are directly related to the relative intensity of the exercise participated in (47) and are lower in fit individuals doing the same workload as untrained individuals. Though we were able to scan our participants within 5 minutes of exercise, lactate clearing begins immediately following exercise; research has shown that clearance rates are affected by an individual’s training level and fitness, independent of exercise parameters (48). Thus, the production of lactate and inorganic phosphate along with lactate clearance are all factors related to fitness level that could explain why our postbariatric surgery participants saw a greater T2 time increase in response to an exercise workload similar to their Matched controls.

We did not test for fitness in any of the 3 groups we recruited. However, our Control group did engage in a generally more active lifestyle, which may have increased their fitness levels. In addition, the lower body weight of our Control group constituted a reduced absolute workload in a body-weight dependent exercise with a fixed number of sets and repetitions. Differences in both relative fitness and absolute workload may contribute to the stark differences in muscle activation observed between the Surgery and Control groups in both BFR and non-
BFR conditions. We suggest that future studies examine fitness levels as well as metabolic responses to exercise to better understand the physiology behind T2 mapping and of postbariatric surgery patients during exercise.

One more point to consider is how far out after surgery our participants were. We chose individuals in this year range because we believe their stable weight would give more reliable results and provide clinically relevant information for the millions of postsurgical patients who are currently in the weight maintenance or weight regain phase. However, despite the generalizability benefits, our design precluded the opportunity to gain insight into how people would respond to this form of exercise during rapid weight loss. Due to their severe negative energy balance in the first few months following surgery, patients would be expected to respond differently in many metabolic parameters and may stand to benefit even more from a greater hypertrophy stimulus at a lower exercise intensity. Future studies may consider investigating patients early after surgery to learn how BFR exercises may affect muscle loss during their rapid weight loss period.

Limitations

This study has multiple limitations. Although the purpose of the study was to use normal BMI individuals, fitness may affect occlusion pressure or results seen in the T2 maps and thus could be considered for an inclusion criterion in future studies. We included generally active individuals, but fitness was not part of the criteria. It may be useful to test fitness levels in future studies. Another limitation is that our choice of exercise regime may not have had the necessary duration or intensity to elicit the kind of muscle activation seen in other BFR studies.
CONCLUSIONS

This study sought to better understand the dynamics of BFR via T2 mapping and to explore BFR exercises as a more attainable exercise option for postbariatric surgery patients. This study did not find a difference in the increase of muscle activation between BFR and non-BFR exercise for the calf-raise protocol. Exercise elicited a greater muscle activation response in postbariatric patients’ response compared to both a normal-BMI control group and a nonsurgery-matched control group for both BFR and non-BFR exercise conditions. Further research will need to be conducted to determine whether a greater intensity or duration of exercise is needed to elicit an acute response to BFR and what factors are contributing to the increased muscle activation seen in the postbariatric surgery group. BFR may still prove to be a more attainable exercise for postbariatric surgery patients.

Acknowledgements of Funding

A grant from the Exercise Sciences Department at Brigham Young University allowed for the compensation of participants. A grant from the BYU MRI Facility funded the use of the MRI.
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Table 1. Participant Characteristics

<table>
<thead>
<tr>
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<th>Control Group (n = 10)</th>
<th>Match Group (n = 9)</th>
<th>Surgery Group (n = 8)</th>
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<tr>
<td>Sex (Female)</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>Age (yrs)</td>
<td>29.8 (± 10.63)</td>
<td>42.67 (± 9.38)</td>
<td>42.75 (± 8.75)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.87 (± 6.96)</td>
<td>164.97 (± 8.23)</td>
<td>168.75 (± 6.95)</td>
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<tr>
<td>Weight (kg)</td>
<td>73.48 (± 7.19)</td>
<td>80.02 (± 13.15)</td>
<td>83.4 (± 11.09)</td>
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<tr>
<td>BMI</td>
<td>24.3 (± 1.2)</td>
<td>31.1 (± 7.0)</td>
<td>29.2 (± 2.6)</td>
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<tr>
<td>Occlusion Pressure</td>
<td>356 (± 54.95)</td>
<td>391 (± 87.93)</td>
<td>407 (± 83.57)</td>
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Table 2. Change in Muscle Activation for All Participants (Averages and Standard Deviations)

<table>
<thead>
<tr>
<th></th>
<th>BFR Pre/Post Difference</th>
<th>p-Value</th>
<th>Non-BFR Pre/Post Difference</th>
<th>p-Value</th>
<th>Difference Between Conditions</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soleus</td>
<td>4.53 (± 0.45)</td>
<td>&lt; .0001</td>
<td>4.18 (± 0.45)</td>
<td>&lt; .0001</td>
<td>0.35 (± 0.34)</td>
<td>0.3118</td>
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<td>Medial Gastroc</td>
<td>8.64 (± 0.74)</td>
<td>&lt; .0001</td>
<td>7.91 (± 0.73)</td>
<td>&lt; .0001</td>
<td>0.73 (± 0.44)</td>
<td>0.1091</td>
</tr>
<tr>
<td>Lateral Gastroc</td>
<td>7.28 (± 0.85)</td>
<td>&lt; .0001</td>
<td>6.99 (± 0.85)</td>
<td>&lt; .0001</td>
<td>0.29 (± 0.55)</td>
<td>0.9174</td>
</tr>
<tr>
<td>Total</td>
<td>20.83 (± 1.69)</td>
<td>&lt; .0001</td>
<td>19.40 (± 1.67)</td>
<td>&lt; .0001</td>
<td>1.43 (± 1.08)</td>
<td>0.1966</td>
</tr>
</tbody>
</table>
Figure 1: Procedural Flow Chart
Figure 2. Effect of BFR Versus Non-BFR Exercise on Muscle Activation

BFR = blood flow restricted; Med Gastroc = medial gastrocnemius; Lat Gastroc = lateral gastrocnemius; ms = milliseconds; Control = normal weight controls; Surgery = bariatric surgery patients 2–5 years postoperative.

All comparisons of muscle activation by exercise condition (BFR versus Non-BFR), either in the total sample or within each study group were nonsignificant: all $p > 0.2$. 

21
Figure 3. Changes in Muscle Activation with Non-BFR or BFR Exercise

BFR = blood flow restricted; Med Gastroc = medial gastrocnemius; Lat Gastroc = lateral gastrocnemius; ms = milliseconds
* indicates significant difference from normal weight controls, † indicates significant difference from matched nonsurgical controls, $p < 0.05$. 
APPENDIX 1

BYU MRIRF Screening Form

All information is held in confidence and will not be part of any aspect of the study for which you are participating.

Brigham Young University
Magnetic Resonance Imaging Research Facility
Tel: (801) 422-9420

Name (first, middle, last): ________________________________

Today’s Date: ___ / ___ / ___ (mm/dd/yyyy) Time: ___ : ___ (am) (pm)

Date of Birth: ___ / ___ / ___ Height (ft. in.): _______

Sex (circle one): Male Female Weight (lbs.): _______

Are you fluent in English? □ Yes □ No

Can you lie still for an hour? □ Yes □ No

Are you pregnant or could you be pregnant? □ Yes □ No □ N/A

Are you currently breastfeeding? □ Yes □ No □ N/A

Have you ever had an MRI examination or participated in an MRI study? □ Yes □ No

If so, did you have complications? □ Yes □ No

If yes, please explain: ________________________________________________________________

Have you ever been injured by a metal object or foreign body (e.g., bullet, BB, shrapnel)? □ Yes □ No

If yes, what was the object: __________________________________________________________

Is any of it still present in your body? ________________________________________________

Have you ever worked with metal (e.g., welder, grinder, fabricator)? □ Yes □ No

If yes, did you always wear proper eye protection: ______________________________________

Describe what you did and the environment in which you worked: ________________________

Have you ever had an eye injury involving a metallic object (e.g., metallic slivers, shavings)? □ Yes □ No

If yes, what was the object: _________________________________________________________

Is any of it still in your eye? ________________________________________________________
Check if you have **ANY** of the following:
Please be honest: It is for your safety. All of your responses are confidential.

**IMPORTANT INSTRUCTIONS**

1) The objects below can be hazardous or interfere with the MRI exam. Please go through the list carefully and check any that apply to you.

2) Before entering the scan room, remove any and all metallic objects and the following: hearing aids, dentures, false teeth, partial plates, keys, beepers, cell phones, pagers, eyeglasses, hair/bobby pins, barrettes/hair clips, jewelry, body piercing jewelry, watches, safety pins, paperclips, money clips, credits cards, bank cards, any magnetic strip cards, coins, pens, pocket knives, nail clippers, tools, clothing with metal fasteners and/or zippers, and clothing with metallic threads.

<table>
<thead>
<tr>
<th>Item</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Pacemaker</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Implanted Cardiac Defibrillator (ICD)</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Aneurysm Clip</td>
<td>___</td>
<td>___</td>
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<tr>
<td>ANY Electronic, Mechanical, and/or Magnetic Implant and/or Biostimulator or Neurostimulator Type:</td>
<td>___</td>
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<tr>
<td>Any Type of Ear Implant (e.g., cochlear, stapes, etc.)</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Spinal Cord Stimulator</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Internal Electrodes or Wires</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Aortic or Carotid Artery Clips</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Hearing Aid (Remove before MRI scan room entry)</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Insulin or Other Implanted Infusion Pump</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Swan-Ganz or Thermodilution Catheter</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Antimicrobial Athletic Clothing</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Heart Valve or Stent</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Shunt (intraventricular or spinal)</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Vascular Coil, Umbrella (filter for clots), or Stent</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Access Port and/or Catheter</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Prosthesis (limbs, joints, or eye)</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Joint Replacement (hip, knee, etc.)</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Metal (circle) Rods / Plates / Screws / Nails / Pins / Clips / Other:</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Surgical Staples, Clips, or Wire Sutures</td>
<td>___</td>
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<tr>
<td>IUD, Diaphragm, Male Implant Which brand?</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Sinuspex (metal fragments) / Gunshot Injury. Location:</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Metal Fragments in Eye (history as a grinder or welder)</td>
<td>___</td>
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<tr>
<td>Implanted Drug Infusion Device</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Eyelid Spring or Wire</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Medication Patch (nicotine, nitroglycerine, Other:</td>
<td>___</td>
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<tr>
<td>Wire Mesh Implant</td>
<td>___</td>
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<tr>
<td>Removable (circle) Dentures / Retainers / Other</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Permanent Retainers or Metal Braces</td>
<td>___</td>
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<tr>
<td>Dental Bridge</td>
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<tr>
<td>Bronzing / Tanning Lotions</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Body Piercing that Cannot Be Removed (Removables must be removed before entry into MRI scan room)</td>
<td>___</td>
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<tr>
<td>Hair Pins or Hair Piece / Wig / “Weave” (if there are ferromagnetic items involved, you will have to remove item before MRI scan room entry)</td>
<td>___</td>
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<tr>
<td>Breast Expander / Markers / Implants / Other</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Acticoat Silver Wound Dressing</td>
<td>___</td>
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<tr>
<td>Any Other Implants (e.g., pill camera, etc.) Type:</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Any Other Type of Internal Coil, Filter, or Stent</td>
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<tr>
<td>Halo Vest</td>
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<td>___</td>
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<tr>
<td>Spinal Fixation Device</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Spinal Fusion Procedure</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Any Type of Implant Held in Place by a Magnet, Type:</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Any IV Access Port (e.g., braccial, Hickman, port-a-cath, pcc line, etc.)</td>
<td>___</td>
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<tr>
<td>Radiation Seeds (e.g., cancer treatment)</td>
<td>___</td>
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<tr>
<td>Colored Contact Lenses</td>
<td>___</td>
<td>___</td>
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<tr>
<td>Claustrophobia</td>
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<td>___</td>
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<tr>
<td>Tattoo and/or Permanent Make-up (e.g., hps, eyeliners, etc.)</td>
<td>___</td>
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APPENDIX 2

Consent to be a Research Subject

Introduction
This research study is being conducted by Lance Davidson PhD, PT; Victoria Violette BS; at Brigham Young University to evaluate blood flow restriction exercises in different populations. You were invited to participate because you are 18 or older, do not have a recent lower leg or foot injury, and are in good cardiovascular health. Your total time commitment for this study is 120 minutes.

Procedures
If you agree to participate in this research study, the following will occur:

Ultrasound Imaging Session:
• You will report to 292 SFH, wearing loose shorts to allow access to your upper thigh.
• You will lie on a treatment table with your knee slightly bent and your thigh support on a pillow.
• ECG leads will be placed on your chest near your arms and on one hip.
• The ultrasound probe with gel will be placed on your leg on your upper thigh to be able to see the femoral artery.
• KAATSU blood flow restriction bands will then be placed on your legs and inflated before another image of the femoral artery is taken. The cuff’s pressure may have to be minorly adjusted to ensure the proper occlusion is obtained.
• Your time commitment for this session will be 30 minutes.

MRI Sessions (2):
• You will report to the BYU MRI Facility, wearing shorts to allow access to your lower leg.
• Upon arrival, you will fill out the BYU MRIRF Screening Form again. If approved by the MRI personnel, you will then be prepared for the scan.
• You will be prepared for the MRI scan by removing any metallic objects.
• Marks will be made on your lower leg using a soft-tip marker. These will indicate the location at which we will secure a small vitamin E tablet to your leg with medical tape.
• You will then be brought into the magnet room and will lie on the scan table. Your knee will be slightly bent and secured with pads to minimize movement during the scan.
• You will be given hearing protection through which the MRI operator can communicate with you during the scan.
• Following the scan, you will participate in the exercise protocol, either with or without the KAATSU bands.
• You will perform 3 sets of 25 calf raises on a raised platform with 30-60 seconds between each set.
• Upon completion of exercise you will again be placed in the MRI for another scan.
• Your time commitment for each of these sessions will be 45 minutes.

Risks/Discomforts
While extremely unlikely, you might be allergic to the ultrasound gel and might develop a mild skin irritation. If this happens, the gel will be washed from your skin and the session will stop. There may also be some additional risks or discomforts due to MRI. There are no known adverse effects from exposure to magnetic fields. However, if you are pregnant or believe you may be pregnant, you should not take part in this research. The MRI may be harmful to an unborn baby. The scanner makes a loud, banging noise while it is taking pictures. You will be given a set of ear plugs to help with the noise. Some people undergoing this procedure become acutely anxious or get claustrophobic. If this happens to you, you can tell us through the microphone, and we will stop the procedure immediately. You may experience some muscular aches and fatigue from lying motionless within a confined space during the imaging. If you have any metal clips, metal plates, or a pacemaker in your body, you should tell the investigator about it immediately. MRI may not be appropriate under some of the following conditions: a cardiac pacemaker; metal fragments in eyes,
skin, body; heart valve replacement; brain clips; venous umbrella; being a metal worker or welder; aneurysm surgery; intercranial bypass; renal or aortic clips; prosthetic devices such as middle ear, eye, joint, or penile implants; joint replacements; hearing aid; neurostimulator; insulin pump; IUD; shunts/stents; metal mesh/coil implants; metal plates, pins, screws, or wires or any other metal implant; permanent eyeliner or eyebrows. Since this is an investigational study, there may be some unknown risks that are currently unforeseeable. In order to screen for any potential risks, you will be provided the MRI safety screening form upon arrival to the BYU MRI research facility. If any conflicts are reported, you will be excluded from this study. We are also introducing a fairly new exercise protocol in this study (blood flow restriction exercises), from which you may experience delayed onset muscle soreness in the days following exercise.

**Benefits**
There will be no direct benefits to you. It is hoped, however, that through your participation researchers will better able to understand blood flow restriction exercise and its applications. This will help in future research and also the retention of muscle mass in post bariatric surgery patients.

**Confidentiality**
The research data will be kept on a password-protected computer housed in a locked room and only the researchers will have access to the data. In order to protect a participant’s identity, you will be assigned a unique code. At the conclusion of the study, all identifying information will be removed and the data will be kept in the password-protected computer. No identifiable data will be presented in the written publication of this study.

**Compensation**
Participants will be compensated $30.00 (cash) for participating in this study. Compensation will be prorated. You will receive $10.00 for completing the first MRI exercise session and $20.00 for completing the second MRI exercise session.

**Participation**
Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely.

**Questions about the Research**
If you have questions regarding this study, you may contact Victoria Violette at bfrmistudy@gmail.com for further information.

**Questions about Your Rights as Research Participants**
If you have questions regarding your rights as a research participant contact IRB Administrator at (801) 422-1461; A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu.

**Statement of Consent**
I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Name (Printed): __________________________ Signature __________________________ Date: _____________