4-28-2022

Blood Flow Restriction and Various Intensity Exercise in the Upper Extremity

Noelle Ashlyn Kaminski
Grand Valley State University

Andrew Lowe
Grand Valley State University

Blood Flow Restriction and Various Intensity Exercise in the Upper Extremity

Andrew Lowe and Noelle Kaminski

A Projected Submitted to

GRAND VALLEY STATE UNIVERSITY

In

Partial Fulfillment of the Requirements

For the Degree of

Masters of Athletic Training

April 2022

GRAND VALLEY
STATE UNIVERSITY

The signatures of the individuals below indicate that they have read and approved the project of **Noelle Kaminski** and **Andrew Lowe** in partial fulfillment of the requirements for the degree of Master of Athletic Training.

<Tonya M. Parker>, Project Advisor — Date

<Matthew Feeback>, Project Advisor — Date

<Shari Bartz-Smith>, Graduate Program Director — Date

<Todd Sander>, Unit head — Date

Table of Contents:

Abstract..p. 4

Introduction..p. 5

Methods...p. 8

Design..p. 9

Results..p. 12

Discussion...p. 14

Conclusion/Acknowledgements...p. 16

References...p. 17

Abstract:

Purpose: To determine if using Blood Flow Restriction (BFR) combined with low-load exercise can elicit an increase in strength and tendon size of the distal biceps tendon when compared to high-load exercise protocol. Methods: Twenty-one participants (11 M, 10 F; 2 Left-handed: 19 Right-handed; Age range 18-25yoa) were randomized to either the treatment group (BFR + low-load exercise) or the control group (high load exercise). Participants were enrolled in a 7-week exercise protocol, with exercise sessions held twice weekly. The first week included measurements of each participant's 1 repetition maximum (1RM) and ultrasound measurements of the dominant distal bicep’s tendon. Participants in the experimental group performed seated biceps curls with the BFR cuff (Smart Tools) placed over the deltoid tuberosity, with the limb occlusion set to medium intensity. The Smart Tools device occluded the limb fully, then released down to 20% occlusion rate. BFR participants performed 4 sets of the exercise with 30 reps performed for the first set followed by 15 reps for sets 2 through 4 using a weight that was 40% of their predicted 1RM. Participants in the high-load group performed the same exercise for a duration of 4 sets with 10 reps for the first set followed by 8 for set 2 and 6 for sets 3 and 4, at 80% of their predicted 1RM. At the midpoint ultrasound measurements were taken. At the conclusion of the 7-week protocol final 1 repetition maximum and ultrasound imaging on the distal bicep’s tendon was performed. Results: There was a significant increase in muscle strength as measured by 1RM ($p=.003$). Within subject contrast revealed an increase in tendon size at each data point that was taken throughout the 7-week training period ($p<.001$). Conclusion: Both groups demonstrated increased tendon thickness over the 7-week protocol. However, exercise with the BFR cuff applied to the upper extremity did not elicit a greater increase in tendon thickness when compared to the control group. The data analysis does demonstrate that using low-load BFR can elicit similar effects as performing high-load training. Further data collection is ongoing, as more research is still needed on the topic.

Introduction:

Blood flow restriction works by reducing the flow of blood and oxygen into and out of the target muscle. The compression from the cuff prevents the outflow of venous blood while still allowing arterial blood flow. There are five effects that the use of BFR has on the body: a reduction of blood flow to the limb, changes the energy demand, an increase in the speed of muscle fatigue, earlier type 2 fiber recruitment and an increase in muscle hypertrophy and strength [4], [7]. Applying the cuff causes a reduction in blood flow to the target muscle which changes the energy demand earlier in the workout to anaerobic glycolysis [7], [10]. The transition to anaerobic glycolysis increases the speed of muscle fatigue because of an increase in intramuscular metabolite (hydrogen, lactate, and inorganic phosphate) accumulation [3]. This results in an earlier recruitment of type 2 fibers which leads to an increase in hypertrophy and strength. The blocking of the blood flow causes the muscle to become engorged as a result of fluid and metabolite accumulation. This accumulation activates the mechanistic target of rapamycin complex pathway (mTORC pathway) [4], [12]. The mTORC pathway is responsible for muscle protein synthesis. Muscle growth occurs when this pathway is elevated. During exercise, tension that is experienced by the muscle fibers is converted from a mechanical to a chemical signal. This transformation is known as Mechan transduction [1], [4]. The goal during exercise is to stimulate the mTORC pathway early on, which is the case when using BFR.

There are two primary mechanisms behind blood flow restriction. The first primary mechanism is metabolic stress. The metabolic stress that the muscle experiences is caused by an overload of the mitochondria. As a result of an overload in the mitochondria, there is a decrease in oxidative phosphorylation and the Krebs cycle. Since oxidative phosphorylation and the Krebs cycle is decreased, the energy source transitions to anaerobic glycolysis. The transition to anaerobic glyclosis causes a build of lactate and hydrogen inside of the muscle. The rate of muscle fatigue is increased because of the buildup of lactate in hydrogen inside of the muscle. Without metabolic stress, hypertrophy and strength gains are near impossible with low loads [1, 3, 5]. Energy production requires a certain level of oxygen which is reduced as a result of the cuff, which leads to hypoxia of the muscle. Inside the body, type 1 fibers are more sensitive to oxygen reduction whereas type 2 fibers are oxygen-independent, so they produce energy quickly. These type 2 fibers also produce metabolites which increase fatigue. When working out at high level type 2 fibers are more likely to be recruited [4, 12]. When using BFR these metabolites become trapped in the muscle where they accumulate. This metabolic accumulation causes significant pain and discomfort which is a byproduct of muscle growth [1, 5]. The second primary mechanism of BFR is cell swelling. Cell swelling occurs as a result of blood pooling inside of the muscle. As a result of the compression from the cuff, cell swelling is accelerated [4, 12]. The compression from the muscular contraction prevents the fluid from leaving the muscle which leads to an increase in intramuscular blood plasma, which is key to muscle hypertrophy and muscle growth.

Blood Flow Restriction (BFR) is a technique used with a tourniquet-like object to restrict blood and oxygen flow to the target muscle [1, 8, 14]. The occlusion device is pumped with air, similar to a blood pressure cuff, and placed proximal to the target muscle. Most research and studies have investigated the use of BFR on post-op patients during rehabilitation. [2, 6, 12]. Blood Flow R was examined on the quadricep muscle group for postoperative anterior cruciate ligament reconstruction. The purpose of doing blood flow restriction rehabilitation is to increase strength, functional ability (a person's physical abilities to complete activities of daily living), and reduce the risk of reinjury [2, 6]. The conclusion of the systematic review was that the BFR technique with low intensity training resulted in positive remediation of quadricep muscle after atrophy [4].

Newer research has reported the use of BFR for hypertrophy of muscles in the extremities in healthy individuals. In the recent article, “Blood flow restriction training in clinical musculoskeletal rehabilitation: A systematic review and meta-analysis", there were 28 patients gathered in order to compare two types of training and differentiate which one resulted in higher muscle hypertrophy strength, physical function, pain, and effusion in anterior cruciate ligament reconstruction patients. This study concluded that BFR resulted in an increase in muscle hypertrophy and strength, and overall improvement of physical function [6]. Most research on BFR has been performed on the lower extremity, however its use on the upper extremity has shown promise [2 6 12].

The research using BFR for strength gains on non-injured patients is still relatively new, Salyers’ and colleagues' purpose was to determine if BFR with a low intensity workout regimen resulted in increases in muscular strength effect in college-aged individuals when compared to traditional resistance training. Their workout protocol for the BFR group was four sets (1 set x 30 repetitions and 3 sets x 15 repetitions). The control group consisted of four sets with progressive loads of 65%, 75%, 80% and 85% with 15, 10, 8, and 6 repetitions respectively. This study measured bench press and findings were partially inconclusive. The authors stated the BFR group did bench press more weight than the regular traditional training group [15]. There is potential for a positive outcome when using BFR to increase hypertrophy, however more research needs to be performed in order to have more conclusive results. The purpose of this study was to investigate the effects of blood flow restriction resistance training on the biceps brachii compared to resistance training in non-restricted arms.

Methods

Participants

Participants were recruited from Grand Valley State University consisting of both graduate and undergraduate students. Recruitment flyers were posted around campus and emails with the recruitment information were sent to students in the Movement Science department. The exclusion criteria for this study included: under the age of 18, current shoulder injury or shoulder surgery within the past 6 months, active/prior history of thromboembolism, currently pregnant, impaired circulation, lymphedema, sickle cell anemia, severe or unstable hypertension, uncontrolled diabetes, currently on blood thinners or medications known to increase clotting risk, current active infection, varicose veins, having any vascular access device, having had breast or lymph node surgery, having had or currently have atherosclerosis, and women within 2 weeks of receiving the Johnson & Johnson COVID-19 vaccine. Participants were also excluded in this study if they had any contraindications for the use of blood flow restriction such as increased intracranial pressure, open fracture or wound, previous revascularization of limb, a severe crush injury, uncontrolled diabetes, or having had a vascular or skin graft.

Randomization

Participants were randomly allocated to either the experimental group (BFR + exercise) or the control group (exercise only). Randomization was done by the co-investigators flipping a coin. If the coin landed on heads the participant was allocated to the experimental group and if it was tails the participant was allocated to the control group. The institutional review board of Grand Valley State University (Allendale, MI; [22-018-H]) approved this study. Informed consent was obtained from each participant prior to enrollment in the study.

Design

Baseline 1 repetition maximum (1RM) testing and imaging of the distal biceps brachii tendon was performed prior to initiating the exercise program. Participants first had their dominant distal biceps brachii tendon imaged by a co-investigator. Participants were positioned on a high-low table in the supine position with their shoulder in 90 degrees of abduction and their elbow in 90 degrees of flexion. Only the long-axis view of the distal biceps' brachii tendon was obtained. The tendon was identified in a long axis using the pronator window. The transducer was first placed horizontally on the distal 1/3 of the humerus, as the transducer was moved distally it was rotated 90 degrees perpendicular with the ulna, which brings the musculotendinous junction of the muscle and tendon into view. The thickness of the tendon was measured in the long axis view at 3 points (3, 5, and 7 mm) from the junction of the muscle. The average of these 3 points was used to represent the thickness of the tendon. A Siemens Acuson X300 Ultrasound Special machine fitted with a VF8-3 transducer was used at a depth of 6.0 cm for all images.

The final component of baseline testing was to determine each participant 1RM while performing elbow flexion. The "biceps curl" was selected for this study because of its ability to activate the biceps brachii muscle. Each participant began using a 5lb dumbbell and were instructed to complete 10 repetitions of the exercise through the whole range of elbow motion (flexion and extension) and to maintain a pace of 2 seconds for the concentric phase (flexion) and 2 seconds for the eccentric phase (extension). In order to keep track of the pace a metronome was used. Upon completion of a successful 10 repetitions the participant was allowed a 30 second break. The weight was increased by 5 lb and the process was repeated. The testing was terminated when the participant was unable to complete the 10 repetitions, unable to keep pace with the metronome or unable to go through the whole range of motion. The weight used during the last successful 10 reps was then entered into the equation: Predicted 1RM= weight lifted (lb.) / [1.0278 – (reps to fatigue * 0.0278)] [1]. The Brzycki equation was selected to determine 1RM for its high validity in the literature [1].

For the experimental group training weight was set to 40% of the predicted 1RM and for the control group the training weight was set to 80% of the predicted 1RM. For the experimental group 40% 1RM was selected as a result of its common use in previous BFR literature [4], [5], [8]. For the control group 80% 1RM was selected in order for the participants to experience hypertrophy and strength gains. Participants participated in twice weekly exercise sessions for a period of 7 weeks, in which all exercise sessions were supervised by a co-investigator. The BFR cuff used for this study was purchased through SMART TOOLS (Strongsville, OH). The pump used was able to calculate the limb occlusion pressure (LOP) for each participant along with the Upper Operational Pressure (UOP). The UOP is the maximum BFR cuff pressure determined for each user by the SmartCuffs BFR cuff (which is slightly less than the LOP). Participants in the experimental group performed seated biceps curls with the BFR cuff placed over the deltoid tuberosity, with the limb occlusion set to medium intensity, which was about 40% of the UOP. Each participant completed 4 sets of the exercise with 30 repetitions in the first set followed by 15 repetitions for sets 2 through 4. Similar to baseline testing, a metronome was used to regulate the speed of the flexion/concentric phase (2 seconds) and extension/eccentric phase (2 seconds). After each set participants were allowed a 30 second rest period while the cuff was still inflated.

Participants in the control group performed the same exercise for 4 sets with 10 repetitions for the first set followed by 8 repetitions for set 2 and 6 repetitions for sets 3 and 4. Participants in this group also had a 30 second rest between sets. For the duration of the study participants in both groups were asked to refrain from upper extremity strength training. At the mid-point of the 7-week training protocol ultrasound imaging was performed. At the conclusion of the training protocol post-tests of 1RM and ultrasound imaging were performed using the same procedures as baseline testing.

Statistical analysis

Data from 1RM testing (pre- and post-test) and ultrasound measurements (pre-, mid-, and post-test) was entered into SPSS software (Grand Valley State University, Grand Rapids, USA). One repetition maximum was examined with an ANOVA (2 groups x 2 levels). Ultrasound data were analyzed using a repeated measures ANOVA (2 groups x 3 levels).

Results

The analysis was a 2x2 (BFR, Control) and 2 levels (pre, post), the interaction effect of that was not significant (p=0.9). Therefore, the individual factors of groups were examined separately. There was a significant increase in muscle strength as measured by 1RM (p=0.003) from pre-test to post-test. The analysis was a 2x2 (BFR, Control) and 3 levels (pre, mid-point, and post), the interaction effect of that was also not significant (p=0.86). Therefore, the individual factors of groups were examined separately. Within subject contrast revealed an increase in tendon size at each data point that was taken throughout the 7-week training period (p<0.001).

For the baseline ultrasound measurement, the lower bound of the 95% confidence interval was 6.781, the upper bound was 7.446. The lower and upper bound calculations for the midterm and post-test for the 95% CI, are found in Figure 3. The mean and standard deviation for the pretest ultrasound, mid-test, and posttest for each group is shown in Figure 1. The mean and standard deviation in pounds for pretest 1 repetition maximum and posttest are shown in figure 2. There was a significant increase in muscle strength as measured by 1RM (p=0.003). Within subject contrast revealed an increase in tendon size at each data point that was taken throughout the 7-week training period (p<0.001).

Mean (SD) in lbs		
	Pretest 1RM	Post-test 1 RM
Control	22.75 (8.89)	27.25 (7.71)
BFR	23.67 (8.97)	27.44 (9.88)

Figure 1

The differences in the mean (lbs) of the 1 RM between the control group and the BFR group. Two measurements were taken, pretest and post-test. Shown in the table, there was an increase in both groups for weight when doing 1 RM bicep curl.

Mean (SD) in mm			
	Pretest bicep tendon size (mm)	Mid-test bicep tendon size	Post-test bicep tendon size
Control	6.97 (0.74)	7.54 (0.79)	8.14 (0.71)
BFR	7.25 (0.70)	7.86 (0.64)	8.40 (0.60)

Figure 2

The differences in the mean (mm) of the bicep tendon size between the control group and the BFR group. Three measurements were taken, pretest, mid-test, and post-test. Shown in the table, there was an increase in both groups for bicep tendon size (mm).

Bicep tendon size measurements				
US	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	7.113	0.159	6.781	7.446
2	7.702	0.161	7.365	8.038
3	8.269	0.147	7.961	8.577

Figure 3

We are 95% confident that the true pre-testing measurement of bicep tendon is between 6.781 - 7.446 mm and the true post-test measurement is between 7.961 - 8.577 mm. This shows an increase in bicep tendon size between the original measurement and the post-test measurement.

Discussion

To date data collection is still ongoing since the current sample size of 21 is too small to draw specific conclusions. There is a trend found within the data collected, there was a significant difference with an increase in bicep tendon hypertrophy for both groups following the training protocol. Both groups also demonstrated an increase in 1RM from pre-test to post-test, but no difference between groups. The 1 repetition maximum testing was performed in order to determine any muscular strength gains experienced by the participants after finishing the training protocol [1]. The repetition scheme and the weight that was used during the training protocol was selected in order to induce an increase in muscular strength. The results from the post-test 1RM demonstrated that our training protocol was effective in increasing muscular strength for participants in both groups. The ultrasound measurements were performed in order to determine if the target tendon experienced any hypertrophy/growth in thickness over the duration of the training protocol [14]. The results from the pre- to mid- to post-test ultrasound measurements demonstrated that our training protocol produced an increase in tendon thickness for participants in both groups.

This study is one of the only ones that has investigated the effects of BFR on the biceps brachii directly. In the literature today very few research studies have been performed investigating the use of BFR and its effects on the upper extremity. The studies on the effects of low-load BFR that we have analyzed produced similar results to our studies. Similar to the results found in our study, Madarame et al. found that low-load training combined with BFR increases muscular size and strength [6]. Continuing the research, Brumitt et al. concluded that there was no difference between BFR and high-load exercise when looking at an increase in supraspinatus tendon thickness [7]. In the meta-analysis by Grøfeldt et al., concluded that there was no difference in maximal muscle strength gains between low-load BFR and high-load training when investigating the effects of BFR on the quadriceps muscle [14]. Slayers et al. discovered in his study that BFR was comparable to traditional hypertrophy for both the upper and lower extremity [16]. Finally, Hughes et al. concluded that BFR resulted in an increase in muscle hypertrophy and strength to a similar extent as high-load resistance training when used following an ACL reconstruction surgery[12].

The results from this study demonstrated that utilizing BFR at low-loads can produce similar effects as those of high-load training. For patients who are unable to lift heavy weights BFR could be an option in order to strengthen the musculature. BFR can be used inside the clinical setting for a variety of cases such as for pre-operative patients, post-operative patients, elderly patients to combat muscle atrophy, to strengthen the surrounding musculature following a muscular injury, and for patients who would like to increase their muscular strengthen using BFR as an alternative to high-load training [1], [2].

Conclusion

Both the control group and the experimental group demonstrated increased tendon thickness over the 7-week training protocol. Traditional exercise did not elicit a greater increase in tendon thickness when compared to the BFR cuff and a lower load applied to the upper extremity. The data analysis demonstrates that using low-load BFR can elicit similar effects as performing high-load training. Further data collection is ongoing, as more research is still needed on the topic.

Acknowledgments

Thanks to the guidance of Tonya Parker and Matthew Feeback, Andrew Lowe and Noelle Kaminski were able to accomplish the research of blood flow restriction on upper extremity. Thanks to Bailey Wilks, taking over the research after the graduation of Andrew Lowe and Noelle Kaminski.

References

1. Amarante do Nascimento, M., Cyrino, E., Nakamura, F., Romanzini, M., Pianca, H., & Queiroga, M. (2007). Validation of the Brzycki equation for the estimation of 1-RM in the bench press. *Revista Brasileira de Medicina Do Esporte*, *13*, 40e–42e.

2. Burd et al. (2009). Exercise training and protein metabolism: influences of contraction, protein intake, and sex-based differences. J Appl Physiol. 106:1692–701.

3. Sugaya M, Yasuda T, Suga T, Okita K, Abe T. Change in intramuscular inorganic phosphate during multiple sets of blood flow-restricted low-intensity exercise. *Clin Physiol Funct Imaging*. 2011;31(5):411-413. doi:10.1111/j.1475-097X.2011.01033.x

4. Hughes, L., Paton, B., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2017). Blood flow restriction training in clinical musculoskeletal rehabilitation: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(13), 1003–1011. https://doi.org/10.1136/bjsports-2016-097071

5. Cook S. (2010). Skeletal muscle adaptations following blood flow-restricted training during 30days of muscular unloading. J Appl Physiol (1985).109:341-349.https://doi.org/10.1152/japplphysiol.01288.2009

6. Patterson, S. D., Hughes, L., Warmington, S., Burr, J., Scott, B. R., Owens, J., Abe, T., Nielsen, J. L., Libardi, C. A., Laurentino, G., Neto, G. R., Brandner, C., Martin-Hernandez, J., & Loenneke, J. (2019). Blood flow restriction exercise: Considerations of methodology, application, and safety. *Frontiers in Physiology*, *10*. https://doi.org/10.3389/fphys.2019.00533

7. Madarame, H., Neya, M., Ochi, E., Nakazato, K., Sato, Y., & Ishii, N. (2008). Cross-transfer effects of resistance training with blood flow restriction. *Medicine and Science in Sports and Exercise*, *40*(2), 258–263. https://doi.org/10.1249/mss.0b013e31815c6d7e

8. Brumitt, J., Hutchison, M., Kang, D., Klemmer, Z., Stroud, M., Cheng, E., Cayanan, N. and Shishido, S., 2020. Blood flow restriction training for the rotator cuff: A randomized controlled trial. *International Journal of Sports Physiology and Performance*, 15(8), pp.1175-1180.

9. Hughes, L., Rosenblatt, B., Haddad, F., Gissane, C., McCarthy, D., Clarke, T., Ferris, G., Dawes, J., Paton, B., & Patterson, S. D. (2019). The effectiveness of blood flow restriction vs. heavy load resistance training during post-surgery rehabilitation of anterior cruciate ligament reconstruction patients: A UK national health service randomised controlled trial. *International Journal of Sports Physical Therapy*, *14*(6), S9–S10.

10. Jessee et al. (2018). Mechanisms of blood flow restriction: The new testament. Techniques in orthopaedics. 33(2): 72-79. doi: 10.1097/BTO.0000000000000252

11. Charles, D., White, R., Reyes, C., & Palmer, D. (2020). A systematic review of the effects of blood flow reconstruction training on quadriceps muscle atrophy and circumference post ACL reconstruction. *International Journal of Sports Physical Therapy*, *15*(6), 882–891. https://doi.org/10.26603/ijspt20200882

12. Loenneke et al. (2012). The acute muscle swelling effects of blood flow restriction. Acta Physiological Hungarica, 99(4), 400–410. doi:10.1556/aphysiol.99.2012.4.4

13. Hughes, Luke, Benjamin Rosenblatt, Fares Haddad, Conor Gissane, Daniel McCarthy, Thomas Clarke, Graham Ferris, Joanna Dawes, Bruce Paton, and Stephen David Patterson. Comparing the effectiveness of blood flow restriction and traditional heavy load resistance training in the post-surgery rehabilitation of anterior cruciate ligament reconstruction patients: A UK National Health Service Randomised Controlled Trial." *Sports Medicine* 49, no. 11 (November 2019): 1787–1805. https://doi.org/10.1007/s40279-019-01137-2.

14. Patterson, S. D., & Brandner, C. R. (2018). The role of blood flow restriction training for applied practitioners: A questionnaire-based survey. *Journal of Sports Sciences*, *36*(2), 123–130.

15. Charles, D., White, R., Reyes, C., & Palmer, D. (2020). A systematic review of the effects of blood flow restriction training on quadriceps muscle atrophy and circumference post ACL reconstruction. *International Journal of Sports Physical Therapy*, *15*(6), 882–891. https://doi.org/10.26603/ijspt20200882
Lixandrao et al. (2017). Magnitude of muscle strength and mass adaptations between high- load resistance training versus low-load resistance training associated with blood-flow restriction: A systematic review and meta-analysis. Sports Med, 48(2): 361-378

16. Reynolds, J., Gordon, T. and Robergs, R., 2006. Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *The Journal of Strength and Conditioning Research*, 20(3), p.584.

17. Salyers, Zachary R., Jame Larkin, Michael Lane, and Aaron Sciascia. The effect of blood flow restriction training on body composition and muscular strength in college-aged individuals." *Medicine & Science in Sports & Exercise* 50 (May 2, 2018): 18–18. https://doi.org/10.1249/01.mss.0000535142.10594.4f.

18. Spitz et al. (2020). Blood flow restricted exercise and discomfort. JSCR. Volume Publish Ahead of Print. doi: 10.1519/JSC.0000000000003525