CHRONIC EFFECT ON FLOW - MEDIATED DILATION FROM LOW - INTENSITY RESISTANCE TRAINING WITH BLOOD FLOW RESTRICTION: A NARRATIVE REVIEW

Ratanyoo Longrak, and Wirat Sonchan
Faculty of Sport Science, Burapha University

Abstract

Resistance training has gained widespread popularity in recent times for enhancing the athletic potential of individuals. Given the increased knowledge about physical fitness, an ever-growing number of athletes and coaches are turning to resistance training for its numerous benefits, which include enhanced explosive strength, maximum power output, and muscle growth. However, heavy resistance training is, sometimes, not suitable for some athletes, such as for those who are weak. Thus, alternative training methods are being sought to overcome the limitations of traditional resistance training. One approach gaining popularity is low-intensity resistance training with blood flow restriction (BFR). This narrative review seeks to achieve 3 objectives: 1) to raise awareness about the importance of flow-mediated dilation (FMD); 2), to investigate the effect of low resistance training (30%1RM) with BFR and traditional heavy resistance training on blood vessel expansion ability; and 3), to provide valuable information to practitioners for decision-making regarding the use of these resistance training techniques. The data under review was collected from prior controlled trial studies obtained through a literature search conducted on PubMed. The findings indicated the capacity of blood vessels to expand changed after period of resistance training. A substantial impact of resistance training on FMD was reported that even a slight 1% decrease in FMD could significantly raise the risk of cardiovascular events by up to 8%. The results of 4 out of 5 randomized controlled trials suggested that low-intensity resistance training with BFR led to a significant increase in FMD after a training period, whereas heavy resistance training showed contrasting result. However, it appeared that the training volume played a crucial role, as excessive volume, even with low resistance, could have a negative effect on FMD. Individuals practicing low-intensity resistance training with BFR should carefully monitor their training volume to avoid adverse outcomes. Based on previous studies demonstrating positive effects on FMD, an intensity of 30-40% 1RM or 20% MVC was recommended.

Keywords: Resistance Training; Blood flow restriction; Flow - mediated dilation

Corresponding Author: Ratanyoo Longrak, Faculty of Sport Science, Burapha University
Email: Addmuscleclinicz@gmail.com

Introduction

Resistance training (RT), also known as strength training, is a form of exercise involving using resistance to develop muscular strength and endurance. This type of training has been shown to have numerous benefits in sports, including improved performance and injury prevention (Westcott, 2012). In recent years, a new technique of RT called **blood flow restriction (BFR)** has emerged, which involves partially restricting blood flow to the working muscles during exercise (Lorenz et al., 2021). One of the potential drawbacks of **traditional high-intensity RT (>60%1RM)** is that it can be quite intense and demanding, requiring long rest periods between sets and high volumes of training (De Salles, Simao, Miranda, Novaes, Lemos & Willardson, 2009). This can be challenging for athletes who need to balance their training with other demands such as, work, or other sports. **Low-intensity RT (<50%1RM)** with BFR training has been proposed as a potential solution to these challenges. BFR technique involves using a special cuff or elastic band to partially restrict blood flow to the working muscles during exercise (Lorenz et al., 2021). This restriction causes a buildup of metabolites in the muscles, which can stimulate muscle growth and adaptation even at lower levels of resistance (Pearson & Hussain, 2015). This means that athletes can achieve similar benefits to traditional RT with lower weights, shorter rest periods, and lower overall training volumes (Cerqueira et al., 2021). Technically, RT with BFR can be used as a time-efficient alternative (Lorenz et al., 2021). While this novel training method shows promise as a novel training method, there are also some potential concerns associated with this approach. One concern is that RT with BFR can cause a reduction in blood flow to the working muscles, which could lead to detrimental effect on vascular system (Miller, Tirko, Shipe, Sumeriski & Moran, 2021).

Flow - mediated dilation

Flow mediated dilation (FMD) is a fascinating physiological phenomenon that characterizes the ability of blood vessels to widen in response to augmented blood flow, triggered by increased metabolic demand (Silva, Meneses, Parmenter, Ritti-Dias & Farah, 2021). This property is a fundamental manifestation of endothelial function, which defines the capacity of the endothelial layer lining the inner surface of blood vessels to regulate blood flow, and it plays a crucial role in maintaining cardiovascular homeostasis. FMD has emerged as a pivotal parameter in biomedical research, particularly in the assessment of the efficacy of various therapeutic interventions for cardiovascular disease (Thijssen et al., 2011). A common method used to evaluate FMD is non - invasive ultrasound imaging of the dilation of an artery in response to increased blood flow, providing valuable information about the status of vascular health. In the context of RT, FMD is a valuable tool for evaluating the impact of various training regimens on vascular function and for assessing the efficacy of interventions designed to enhance cardiovascular health (Briceno - Torres, Carpio-Rivera, Solera - Herrera, Forsse, Grandjean, & Moncada-Jimenez, 2023).

According to a meta-analysis conducted by Inaba, Chen, and Bergmann (2010), merely 1% reduction in FMD was found to be associated with an 8% increase in the risk of future cardiovascular events, as revealed from 14 studies with a total of 5,547 participants. The increase in diameter of the measured artery has been attributed to the rise in shear stress of blood flow and release of nitric oxide, particularly through exercise (Tremblay, & Pyke, 2018; Green, Dawson, Groenewoud, Jones, & Thijssen, 2014). Additionally, RT with BFR has been shown to elevate shear stress and nitric oxide due to training - induced reactive hyperemia (Horiuchi & Okita, 2012). Reactive hyperemia is characterized by the magnitude of blood flow that rushes into the target muscle after a short period of BFR (Rosenberry & Nelson, 2020). For example, In a study conducted by Mouser, Gallo, VanDongen and Welsch (2017), the acute effects of blood flow after low-intensity RT with and without BFR were investigated in 137 participants, consisting of 64 men and 73 women. The training protocol involved 1 set of 30 repetitions followed by 3 sets of 15 repetitions with biceps curls exercise at 30% of one - repetition maximum (1RM). Blood flow was measured at baseline, during sets 1 to 4, and 1- and 5-minutes post - exercise. The results indicated that the degree of blood flow in the BFR group significantly decreased when the cuff was inflated in both men and women, and during RT sets 1 - 4, both groups showed significant increases in blood flow to the working muscle in both sexes ($p < 0.001$). However, the magnitude of increase in the BFR group was significantly less than that in the group without BFR in all sets. At 1 minute after releasing the cuff, the blood flow significantly increased in the BFR group compared to sets 1-4, and was not significantly different from the group without BFR. Nevertheless, the huge increase in the magnitude of blood flow change to muscle after the last set of training with BFR indicated the state of reactive hyperemia, which may in turn contribute to the increased ability of the artery to dilate (Horiuchi et al., 2012). In another study conducted by Gundermann, Walker, Reidy, Borack, Dickinson, & Drummond (2012), it was shown that low - intensity RT with BFR performing leg extension at 20% 1RM for 4 sets resulted in a significant increase ($p < 0.05$) in femoral artery blood flow after finishing training, and the increased flow remained significantly high ($p < 0.05$) until 15 minutes post-exercise. Furthermore, it is proposed that the accumulation of metabolites and nitric oxide production induced by BFR training also act as vasodilator stimuli, which can cause flow-mediated changes (Loenneke, Wilson, Marin, Zourdos, & Bemben, 2010).

Materials and methods

The present manuscript reviewed the current body of evidence that examined the effect of low-intensity resistance training with blood flow restriction on arterial compliance and arterial stiffness index. The search for articles was carried out using the database: PubMed. The descriptors used as search term were: “Resistance training” OR “Weight training” AND “Blood flow restriction” OR “BFR” AND “Flow-mediated dilation” OR “FMD”. Six articles that had involved measuring flow-mediated dilation as a result of resistance training were selected.

Chronic adaptation from high- vs low-intensity RT with BFR

Over the past decade, several studies have investigated the effects of RT with BFR on FMD. Credeur, Holwerda, Restaino, King, Crutcher, & Laughlin (2010) conducted a study in which they examined the effects of four weeks of hand grip training with BFR on brachial artery FMD. The study included 12 healthy adults with an average age of 22 years. The training consisted of using a hand grip dynamometer for 20 minutes per day, three days per week, at 60 % maximum voluntary contraction, with the BFR cuff applied to the upper arm. While the results showed a significant increase in hand grip strength and forearm circumference (by 16.71 % and 2.42 %, respectively; $p = 0.05$), there was a significant decrease in FMD by 30.36 % ($p = 0.0001$) after training (pre - training = 0.27mm, post - training = 0.19mm). Interestingly, although the shear stimulus area under curve was significantly higher after four weeks of training (from 5472.9 to 6776.2; $p < 0.05$), FMD decreased, suggesting that the effects of BFR on FMD are complex and require further investigation.

In 2013, a study explored the impact of unilateral dynamic plantar flexion exercise with BFR on popliteal artery FMD in 11 healthy men with an average age of 22 years. The study involved performing 3 sets of the exercise at 30%1RM until volitional failure, with the BFR cuff applied to the distal thigh, for a period of 6 weeks, 3 times a week. The results indicated that the popliteal artery FMD significantly increased after 2 and 4 weeks of training ($p = 0.002$ and $p = 0.014$, respectively) and returned to near baseline at the end of week 6. The FMD percentage at baseline was 5.0%, which increased to 7.6% at week 2, 6.6% at week 4, and 5.7% at week 6. Additionally, the researchers observed a significant increase in maximal popliteal diameter after 6 weeks of training (from 6.06 mm to 6.26 mm, $p = 0.048$). The results also showed a significant increase in peak reactive hyperemia during the intervention period ($p = 0.03$). This study provided evidence that shear stress was the primary stimulus for increasing FMD and that the peak reactive hyperemia blood flow significantly increased during the training period, from 256 and 254 ml / min at rest to 1,716 and 1,736 ml / min in weeks 2 and 4, respectively, which corresponded to the significant increase in FMD during these weeks (Hunt, Galea, Tufft, Bunce, & Ferguson, 2013).

In a study conducted by Severin (2016) the effect of isometric hand grip training was investigated [66]. Participants were divided into two groups: BFR younger adults (n = 8, age 22.2 years) and BFR older adults (n = 10, age 63.2 years), and all had a healthy status before the study. Both groups trained at 20% maximum voluntary contraction, and after 4 weeks of training, FMD increased to a greater extent in both groups (12.45 % to 12.67 % and 8.59 % to 9.42 %, respectively). Changes in brachial artery diameter were also observed. The younger group had resting and hyperemia diameter of 0.32 mm and 0.34 mm, respectively, while the older group had resting and hyperemia diameter of 0.36 mm and 0.37 mm, respectively, before training. After 4 weeks of training, the younger group had resting and hyperemia diameter of 0.34 mm and 0.36 mm, respectively, while the older group had resting and hyperemia diameter of 0.39 mm and 0.43 mm, respectively. In addition, it should be noted that previous research conducted by Credeur et al. (2010) found a decrease in brachial artery FMD after hand grip training, which is in contrast to the findings of Severin and group (Severin, 2016). The difference in results could be attributed to the difference in intervention intensities, as Credeur's study used a higher intensity of 60 % maximum voluntary contraction, while Severin and group's study used a lower intensity of 20 % maximum voluntary contraction.

The relationship between the intensity and volume of RT and endothelial function, as measured by FMD, was investigated (Morishima, Fry, Acute, Nakamoto, & Takano 2018). Their findings showed that even at low-intensity, high - volume RT could impair FMD, while low - volume RT was able to maintain FMD even at high-intensity. A crossover study was conducted to compare three different RT protocols in 13 young and healthy participants, with an average age of 21 years, who visited the laboratory on three occasions, spaced seven days apart. The leg extension exercise was selected for the study. In the moderate - intensity exercise with moderate repetitions protocol, participants performed 5 sets of 10 repetitions at 70%1RM, with an average weight of 80.5 kg. In the low - intensity exercise with high repetitions protocol, participants performed 40 repetitions for 5 sets at 30%1RM, with an average weight of 34.1 kg. In the high - intensity exercise with low repetitions protocol, participants performed 3 repetitions for 5 sets at 85%1RM, with an average weight of 96.5 kg. FMD in the brachial artery was measured at 10-, 30-, and 60 - minutes post - exercise. The results demonstrated that FMD significantly decreased in the high - volume protocols, regardless of the intensity level. The baseline FMD for the moderate - intensity trial was 7.9%, and it decreased to 4.2%, 4.4%, and 3.5% at 10-, 30-, and 60 - minutes post - exercise, respectively. The baseline FMD for the low - intensity trial was 8.2%, and it decreased to 4.4 %, 4.4%, and 5.1% at 10-, 30-, and 60 - minutes post - exercise, respectively. However, in the low - volume but high - intensity trial, FMD was maintained unchanged, with a baseline of 7.6% and values of 7.6%, 8.4%, and 8.4% at 10 -, 30 -, and 60 - minutes post - exercise, respectively (Morishima et al., 2018). These findings suggest that reducing the number of repetitions can be a useful training strategy to counteract the detrimental effects of high - intensity RT on FMD by decreasing the duration of hypertension.

In a subsequent study, Kambic and colleagues explored the potential of RT with BFR to improve vascular FMD. The study involved 24 patients with coronary artery disease, of whom 12 were randomly assigned to an 8-week program of RT with BFR at an intensity of 30 – 40 % 1 repetition maximum using leg extension exercise. The results showed that, following the training program, muscle strength significantly increased, as measured by 1RM, from 45.75 kg to 54.71 kg ($p < 0.001$), and systolic blood pressure significantly decreased by 6.77 mmHg ($p = 0.030$). While there was a trend towards improvement in brachial artery FMD in patients training with RT with BFR, from pre - to post - training measurements (6.48 % to 8.04 %), this was not statistically significant (Kambic, Jakobsgaard, Stevens, & Jespersen, 2019).

More recently, a study investigated the effect of BFR training on vascular function through the measurement of FMD at the brachial artery (Early, Stewart, Johannsen, Lavie, & Thomas, 2020). The study recruited 31 healthy adults, with an average age of 23 years, who were randomly assigned to one of three groups: traditional RT (RES) at 60 % 1RM, RT with BFR at 30% 1RM, and a control group. The training protocols involved arm extension, arm curl, leg extension, leg curl, and heel raise exercises, which were performed 2 - 3 times per week. The BFR group applied the cuff at both upper arms and upper thighs, and performed a total of 3 sets of 30 repetitions per set, while the RES group performed 3 sets of 10 repetitions per session. The results showed that FMD did not change in the control group, but increased in both the RES and BFR groups (9.9 % and 8.1 %, respectively) after 8 weeks of training.

Table 1. Effect of blood flow restriction RT on flow-mediated dilation

Study	Duration	Subject	Intensity	Training intervention	Exercise	Primary outcome
Credeur et al. 2010	4 weeks	12 healthy young men and women	60%MVC	Moderate intensity BFR training	Handgrip training	FMD significantly decreased by 30.36% (from 0.27mm to 0.19mm) (p = 0.0001).
Hunt et al. 2013	6 weeks	11 healthy young men	30%1RM	Low intensity BFR RT	Dynamic plantar flexion	Maximal popliteal diameter significantly increased after 6 weeks of training (from 6.06 mm to 6.26mm, p = 0.048)
Severin et al. 2016	4 weeks	8 healthy young and 10 healthy older adults	20%MVC	Low intensity BFR training	Handgrip training	FMD increased in both younger and older adults (from 12.45% to 12.67% and from 8.59% to 9.42%, respectively)
Morishima et al. 2018	Acute	13 healthy young men	30%1RM 70%1RM 85%1RM	Low intensity RT Moderate intensity RT High intensity RT	Leg extension	Brachial artery FMD significantly decreased after exercising in high volume moderate and low intensities protocols Brachial artery FMD was maintained unchanged in low volume high intensity protocol
Kambic et al. 2019	8 weeks	24 patients with coronary artery disease	30-40% 1RM	Low intensity BFR RT	Leg extension	Brachial artery FMD in patient slightly increased from pre to post measurement (from 6.48% to 8.04%)
Early et al. 2020	8 weeks	31 healthy young women	30%1RM 60%1RM	Low intensity BFR RT Moderate intensity RT	Arm extension Arm curl Leg extension Leg curl Heel raise	Brachial artery FMD increased in both training groups (8.1% and 9.9%, respectively).

Conclusion and direction for future study

In conclusion, literature synthesizing had shown that resistance training both at high-intensity (> 60%1RM) and low - intensity (< 50%1RM) had the effects on FMD. After only short periods of training (about 4 weeks), the significant change could already by observed. Based on the available evidence, it appears that low-intensity RT with BFR might have the potential to improve FMD, particularly during dynamic contraction. Four out of the six studies showed an increase in FMD to certain extent. All four studies that used BFR dynamic exercises reported an increase in FMD of the brachial artery and popliteal artery. Nevertheless, the exercise intensity and volume also played a significant role in both isometric and dynamic contraction on FMD. High volume RT, even at low-intensity, could impair FMD, as well as low volume RT could maintain FMD even at high-intensity. Limiting excessive training volume was recommended for practitioners and using the intensity around 30%1RM or 20%MVC was sufficient for low-intensity protocol. Based on the showing data, it seemed that RT with BFR could be a safe alternative program for maintaining FMD during dynamic exercise in both younger and older adults. However, the number of current studies were still very limited. Further research is required, especially in women who have been under-represented in the research setting, to confirm the relationship between RT with BFR and FMD as well as the potential long - term effects of these interventions (more than 8 weeks).

References

Briceno - Torres, J. M., Carpio - Rivera, E., Solera - Herrera, A., Forsse, J., Grandjean, P. W., & Moncada-Jimenez, J. (2023). Low - intensity resistance training improves flow - mediated dilation in young hispanic adults. *Journal of strength and conditioning research, 37*(2), 298 – 304.

Cerqueira, M. S., Lira, M., Mendonça Barboza, J. A., Burr, J. F., Wanderley E Lima, T. B., Maciel, D. G., & De Brito Vieira, W. H. (2021). Repetition failure occurs earlier during low - load resistance exercise with high but not low blood flow restriction pressures: A systematic review and meta - analysis. Retrieved from https://pubmed.ncbi.nlm.nih.gov/34319945/

Credeur, D. P., Holwerda, S. W., Restaino, R. M., King, P. M., Crutcher, K. L., & Laughlin, M. H. (2010). Effects of handgrip training with venous restriction on brachial artery vasodilation. *Medicine and Science in Sports and Exercise, 42*(7), 1296 - 1302.

De Salles, B. F., Simao, R., Miranda, F., Novaes, J. daS., Lemos, A., & Willardson, J. M. (2009). Rest interval between sets in strength training. *Sports medicine, 39*(9), 765 – 777.

Early, K. S., Stewart, A. D., Johannsen, N. M., Lavie, C. J., & Thomas, J. R. (2020). Effect of blood flow restriction training on muscular performance, pain and vascular function. *International Journal of Sports Physical Therapy, 15*(6), 892 - 900.

Green, D. J., Dawson, E. A., Groenewoud, H. M. M., Jones, H., Thijssen, D. H. J. (2014). Is flow - mediated dilation nitric oxide mediated?: A meta-analysis. *Hypertension, 63*(2), 376 - 382.

Gundermann, D. M., Walker, D. K., Reidy, P. T., Borack, M. S., Dickinson, J. M., & Drummond, M. J. (2012). Reactive hyperemia is not responsible for stimulating muscle protein synthesis following blood flow restriction exercise. *Journal of Applied Physiology, 112*(9), 1520 - 1528.

Horiuchi, M., & Okita, K. (2012). *Blood flow restricted exercise and vascular function.* Retrieved from https://pubmed.ncbi.nlm.nih.gov/23133756/

Hunt, J. E. A., Galea, D., Tufft, G., Bunce, D., & Ferguson, R. A. (2013). Time course of regional vascular adaptations to low load resistance training with blood flow restriction. *Journal of Applied Physiology*, *115*(3), 403 - 411.

Inaba, Y., Chen, J. A., & Bergmann, S. R. (2010). Prediction of future cardiovascular outcomes by flow - mediated vasodilatation of brachial artery: A meta - analysis. *International Journal of Cardiovascular Imaging, 26*(6), 631 - 640.

Kambic, T., Jakobsgaard, J. E., Stevens, A., & Jespersen, N. R. (2019). Blood flow restriction resistance exercise improves muscle strength and hemodynamics, but not vascular function in coronary artery disease patients: A pilot randomized controlled trial. Retrieved from https://pubmed.ncbi.nlm.nih.gov/31244668/

Loenneke, J. P., Wilson, J. M., Marin, P. J., Zourdos, M. C., & Bemben, M. G. (2010). A mechanistic approach to blood flow occlusion. *International Journal of Sports Medicine, 31*(1), 1 - 4.

Lorenz, D. S., Bailey, L., Wilk, K. E., Mangine, R. E., Head, P., Grindstaff, T. L., & Morrison, S. (2021). Blood Flow Restriction Training. *Journal of athletic training, 56*(9), 937 – 944.

Miller, B. C., Tirko, A. W., Shipe, J. M., Sumeriski, O. R., & Moran, K. (2021). The Systemic Effects of Blood Flow Restriction Training: A Systematic Review. *International journal of sports physical therapy, 16*(4), 978 – 990.

Morishima, T., Fry, A. C., Acute, L. N., Nakamoto, H., & Takano, H. (2018). High - intensity resistance exercise with low repetitions maintains endothelial function. *American Journal of Physiology - Heart and Circulatory Physiology, 315*(3), 681 - 686.

Mouser, J. G., Gallo, S., VanDongen, N. S., & Welsch, M. A. (2017). Blood flow in humans following low-load exercise with and without blood flow restriction. *Applied Physiology, Nutrition, and Metabolism, 42*(11), 1165 - 1171.

Pearson, S. J., & Hussain, S. R. (2015). A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. *Sports medicine, 45*(2), 187 – 200.

Rosenberry, R., & Nelson, M. D. (2020). Reactive hyperemia: A review of methods, mechanisms, and considerations. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 318*(3), R605 - R618.

Severin, M. J. (2016). *Flow mediated vasodilation changes in older and younger adult groups after 4 weeks of low intensity hand grip isometric training with vascular occlusion* (Doctoral dissertation), Iowa State University. Retrieved from https://lib.dr.iastate.edu/etd/15808

Silva, J. K. T. N. F., Meneses, A. L., Parmenter, B. J., Ritti - Dias, R. M., & Farah, B. Q. (2021). Effects of resistance training on endothelial function: A systematic review and meta - analysis. *Atherosclerosis, 333*, 91 – 99.

Thijssen, D. H., Black, M. A., Pyke, K. E., Padilla, J., Atkinson, G., Harris, R. A., Parker, B., Widlansky, M. E., Tschakovsky, M. E., & Green, D. J. (2011). Assessment of flow - mediated dilation in humans: a methodological and physiological guideline. *American journal of Physiology Heart and Circulatory Physiology, 300*(1), H2 – H12.

Tremblay, J. C., & Pyke, K. E. (2018). Flow - mediated dilation stimulated by sustained increases in shear stress: A useful tool for assessing endothelial function in humans? *American Journal of Physiology - Heart and Circulatory Physiology, 314*(3), H508 - H520.

Westcott W. L. (2012). Resistance training is medicine: Effects of strength training on health. *Current sports medicine reports, 11*(4), 209 – 216.

Received: 2023, February 21
Revised: 2023, December 5
Accepted: 2023, December 11