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ORIGINAL ARTICLE

The Effects of Whole-Body Vibration Training with Blood Flow Restriction on Lower Extremity Muscle Activity and Hemodynamic Variables

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ABSTRACT

Background. While the increased interest in exercise programs combined with whole-body vibration training (WBVT) and those using blood flow restriction (BFR) has prompted various ongoing studies, most of these studies are fragmentary. **Objectives.** The study aims to investigate the effect of WBVT with BFR on lower limb muscle activity and hemodynamic variables to maintain muscle strength and prevent degenerative loss of skeletal muscle. **Methods**. Twenty-one undergraduate students were randomized into Group I (n=10), performing a squat exercise with WBVT, and Group II, (n=11), performing a squat exercise with WBVT with BFR at the 140-mmHg pressure level. The intervention was applied twice daily and 4 times weekly for 6 weeks. Both groups took the anthropometric, body mass, and lower limb muscle activity measurements before and after the intervention. **Results**. In the within-group comparison before and after the intervention, significant differences in rectus femoris muscle (RFM), biceps femoris muscle (BFM), and gastrocnemius muscle activities were found for Groups I ($p<0.05$) and II ($p<0.05$). The between-group comparison found significant differences in RFM and BFM activities ($p<0.05$). There were no significant differences in hemodynamic variables both within and between groups. **Conclusions**. The WBVT with BFR increased the RFM and BFM activities for lower limbs, while no variation in hemodynamic parameters was detected. The intervention is thus an effective strategy that can be applied in practice. Based on the findings, the scope of the intervention should be extended to include non-healthy individuals. Further studies of the multidimensional approach should also be conducted with additional variables to provide supporting evidence for the discussion of hemodynamic responses.

KEYWORDS: ***Blood Flow Restriction Therapy, Exercise Therapy, Hemodynamic, Lower Extremity, Vibration.***

INTRODUCTION

Adequate physical abilities are essential in healthy living, and, to maintain healthy levels of physical abilities, an emphasis is placed on the performance of regular resistance exercise (1). In general, approximately 8-12 weeks is necessary for muscle fiber development with an effect on muscle strength (2). For exercise intensity, a minimum of 70% repetition maximum (RM) is required (3), although individuals with low muscle strength may find it challenging to increase their muscle strength and achieve hypertrophy through high-intensity exercise. To resolve this drawback, whole body vibration training (WBVT), an exercise for muscle strengthening, has been recently suggested in exercise therapy. The WBVT is a method that applies safe levels of vibration frequency and

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amplitude to stimulate muscles and nerves (4). It is also a method to prevent muscle fatigue from enhancing muscle endurance (5). In WBVT, the skeletal muscles change length during the stimulation to promote the excitation of the spinal reflex (6), while the positive effect is exerted not only on the area of direct stimulation but also on the surrounding muscles (7). In addition, as the method effectively reduces muscle fatigue by increasing the blood flow volume and rate to increase peripheral blood circulation, methods combining WBVT with other forms of exercise have been suggested (8).

Recently, blood flow restriction (BFR) has been suggested to ensure the efficient use of limited exercise opportunities. The performance of resistance exercise using BFR has been promoted as a practical exercise to increase muscle strength, endurance, and hypertrophy in many individuals (9). The basic principle of BFR is the performance of exercise with a cuff to increase blood pressure in the arm or leg (10). The resulting partial obstruction to the blood flow is known to effectively induce structural changes in muscles at only 20% 1RM (11). In general, high-intensity exercises are known to have a notable impact on the recruited fast-twitch fibers (12), and low-intensity BFR training was shown to recruit the fast-twitch fibers despite the low intensity due to the acidification of the intracellular environment caused by restricted blood flow, which elicits the type III and IV chemical stimulations of the afferent neurons of muscles (13).

While the increased interest in exercise programs combined with WBVT and those using BFR has prompted various ongoing studies, most of these studies are fragmentary. Considering that the WBVT leads to a level of muscle activation equivalent to the level in low-load exercise (14) and that the BFR leads to increased recruitment of muscle fibers (15) and metabolic responses (16), it was hypothesized that combining WBVT and BFR would have a positive effect on the muscle activity and hemodynamic parameters.

This study thus aimed to investigate the effect of WBVT with BFR on the lower limb muscle activity and hemodynamic parameters in healthy individuals and to verify whether the effect on muscle activation and hemodynamic responses is additional to the effect of WBVT alone to provide the basic clinical data to contribute in future interventions.

MATERIALS AND METHODS

Participants. This study was approved by the Institutional Review Board (SH-IRB 2021-70) and conducted on male students at S University located in Jeolla-nam-do, South Korea, from April-October, 2021. The inclusion criteria were individuals with no medical or surgical disease, with no musculoskeletal disease, with systolic blood pressure (SBP) below 140 mmHg and diastolic blood pressure (DBP) below 90 mmHg and with no hypertensive diabetes, and individuals who had no regularly performed an exercise for over six months. The participants were instructed to maintain at least 12 hours of fasting before measurements and were prohibited from excessive smoking or alcohol drinking. Twenty-one participants who understood the purpose of this study and voluntarily agreed to participate were included as subjects in this study.

Procedures. Ten participants were assigned to Group I to perform a squat exercise with WBVT, and 11 were assigned to Group II to perform a squat exercise with WBVT with BFR at the 140-mmHg pressure level. Each group performed the respective exercise 20 times per set for two sets, with 1 minute's rest between each set. The intervention was applied twice daily and four times weekly for 6 weeks. Before the intervention, muscle activities were measured using surface electromyography (EMG), and hemodynamic parameters were measured using a hemadynamometer. The same items were measured once again after the intervention for comparative analysis.

Anthropometric And Body Mass Measurements. Anthropometric and body mass measurements were taken using the BSM370, Inbody (South Korea). The participants were instructed to take off any heavy outerwear, shoes, wristwatches, and others to ensure the measured weight approximated their actual body weight, then to gaze ahead in a standing position with arms relaxed on the side and without exerting any force in a comfortable posture, while the measurements were taken.

Lower Limb Muscle Activity Measurement. Lower limb muscle activity was measured using the MP150 surface EMG (Biopac System Inc., Santa Barbara, CA, USA), and the converted digital signals were processed using the Acknowledge 3.91 software. Before the measurements, hair was removed from the participants' skin to minimize the resistance to EMG signals. Thin sandpaper was used to remove dead cells from the skin, which was kept clean using an alcohol swab. The sampling rate was set to 1,000 Hz with a 60 Hz notch filter and a 10-500 Hz band pass filter to minimize the noise.

EMG signals were collected from the rectus femoris muscle (RFM), biceps femoris muscle (BFM), tibialis anterior muscle (TAM), and gastrocnemius muscle (GM) to measure the lower limb muscle activity. The EMG cable was attached to the RFM, BFM, TAM, and GM muscle bellies in parallel to the muscle fiber and 2 cm intervals. The cable was fixed in position to prevent excessive movement. The participants were instructed to perform the maximal voluntary contraction (MVC) prior to taking measurements by sitting on a backrest chair with their hip and knee joints at 90° flexion and holding the edge of the chair for further stabilization. To measure the MVC of the RFM (knee extension), a non-elastic belt was used for fixation, and the thigh was tied, the target thigh was fixed in position by the hand of the therapist, and the participant was instructed to pull the belt and maintain the posture for 10 sec to perform the extension. To measure the MVC of the BFM (knee flexion), a non-elastic belt was used for fixation, and the thigh was tied, the target thigh was fixed in position by the hand of the therapist, and the participant was instructed to pull the belt and maintain the posture for 10 sec to perform the flexion. To measure the MVC of the TAM (dorsiflexion), the participant was instructed to place the feet in a neutral position while the therapist used one hand to fix the target calf and the other hand to apply resistance to the top of the foot and instructed the participant to push the hand on the foot to perform the MVC of dorsiflexion and maintain it for 10 sec. To measure the MVC of the GM (plantar flexion), the participant placed the feet in a neutral position while the therapist used one hand to fix the target calf and the other hand to apply resistance to the sole and instructed the participant to push the hand to perform the MVC of plantar flexion and maintain it for 10 sec.

For each muscle, triplicate measurements were taken with a minute's rest between each measurement. To elicit maximum effort from the participant, verbal encouragement was given during the MVC. The mean of triplicate measurements was applied rather than the highest value among the three for normalizing the EMG data (17).

Blood Flow Restriction. For an exercise combined with BFR, a low-intensity resistance exercise is often performed. However, the suitable cuff pressure remains unclear for a novice to perform a WBVT combined with BFR. Previous studies set the initial cuff pressure at 140 - 160 mmHg (18). For safety reasons and to ensure all participants complete the protocol, the cuff pressure in this study was set to 140 mmHg (19). The participant was guided to rest in a stable sitting position for 10 min. An elastic cuff restricts the blood flow in the lower limbs during BFR with a 50-mm width and a 24-inch length (Kaatsu-master, Sato Sports Plaza, Tokyo, Japan) that allows the digital control of air pressure. The cuff was applied to the most muscular part of each thigh with adjustments at a preset pressure level (20).

Whole-Body Vibration Training. For the WBVT, the therapist guided the participant to practice the training on a vertical vibration platform for 2 min before the intervention to control the squat type and timing. The participant was guided to perform an isometric squat at a 120° knee angle, with the head and the eyes directed forward and an equal force on each foot. Three sets were performed with a 120-sec rest between the first and second sets and a 60-sec rest between the second and third sets (21). The vibration frequency was set to 30 Hz to induce an adequate level of muscle activation. During the exercise, the participant remained bare-footed to prevent any potential buffering effects of the shoes, while the vibration amplitude was set to 4 mm (22).

WBVT with BFR. For the WBVT with BFR, the same exercise protocol as the WBVT was performed by each participant. An elastic cuff restricted the blood flow in the lower limbs during BFR with a 50-mm width and a 24-inch length (Kaatsu Nano, Japan Co., Ltd.) that allows the digital control of air pressure. The cuff was applied to the most muscular part of each thigh with adjustments at a preset pressure level (20). The cuff pressure was set to 60% of each individual's arterial occlusion pressure (AOP). For the entire session, including the rest time, the AOP was recorded for each leg of each participant in a standing position. The mean absolute occlusal pressure during the exercise was 140±15 mmHg (23, 24).

Data analysis. The data in this study were analyzed using the SPSS 20.0 for Windows. The

Shapiro-Wilk test was performed to test the normality of subjects' general characteristics, and the homogeneity was tested using Levene's test. Paired t-test was performed to analyze the within-group RFM, BFM, TAM, and GM activities and the hemodynamic parameters. For between-group comparison, analysis of covariance was applied to the between-group post-test results after controlling the pre-test results by setting them as covariates. The level of significance (α) was set to $p < 0.05$.

RESULTS

Table 1 presents the general characteristics of the participants in this study. In the within-group comparison before and after the intervention, significant differences in RFM, BFM, and GM activities were found for Groups I ($p<0.05$; Table 2) and II ($p<0.05$; Table 3). In the between-group comparison, significant differences were found in RFM and BFM activities ($p<0.05$; Table 4). There were no significant differences in hemodynamic variables both within and between groups.

Table 1. General characteristics of the participants (Mean ± SE)

Items	Experimental group I (n=10)	Experimental group II (n=11)	p
Age (years)	24.72±2.46	23.83 ± 2.99	0.411
Height (cm)	175.78±4.81	176.17 ± 5.23	0.245
Weight (kg)	71.82±7.31	73.13 ± 8.89	0.184
BMI (kg/m2)	23.24±2.64	24.13 ± 3.12	0.424
SBP (mmHg)	113.17±11.84	115.67±10.14	0.629
DBP (mmHg)	81.39±5.12	82.82±8.23	0.781

Table 2. Comparison of changes within the experimental group I (Mean ± SE)

	Experimental group I (n = 10)		t	p
	pre-test	post-test		
Rectus Femoris	33.13±7.91	45.72±11.5	-8.398	0.032*
Biceps Femoris	25.6±6.01	38.89±6.85	-5.923	0.043*
Tibialis Anterior	13.45±3.78	15.47±1.45	-1.556	0.235
Gastrocnemius	5.66±2.65	13.16±3.99	-4.454	0.041*
SBP (mmHg)	113.17±11.84	115.43±10.15	-1.947	0.266
DBP (mmHg)	81.39±5.12	84.38±7.28	-1.412	0.414
MAP (mmHg)	92.14±6.81	94.12±6.15	-1.824	0.387
PP (mmHg)	37.14±5.94	35.36±8.42	2.143	0.262
HR (bpm)	67.25±12.81	74.31±13.83	-3.882	0.092
DP (bpm/mmHg)	7943.38±1513.65	8321.54±1927.98	-4.842	0.071

SBP, systolic blood pressure. **DBP,** diastolic blood pressure. **MAP,** mean arterial pressure. **PP,** pulse pressure. **HR,** heart rate. **DP,** double product.

Table 3. Comparison of changes within the experimental group II (Mean ± SE)

	Experimental group II (n = 11)		t	p
	pre-test	post-test		
Rectus Femoris	33.62±9.51	49.03±11.84	-11.698	0.008*
Biceps Femoris	21.43±5.91	39.99±7.73	-10.974	0.013*
Tibialis Anterior	17.43±3.84	20.44±4.09	-2.275	0.384
Gastrocnemius	6.62±1.69	14.04±2.63	-6.871	0.028*
SBP (mmHg)	115.67±10.14	113.83±9.85	1.347	0.388
DBP (mmHg)	82.82±8.23	85.44±7.09	-2.140	0.257
MAP (mmHg)	92.38±6.73	95.13±8.28	-3.011	0.159
PP (mmHg)	32.68±6.77	29.86±7.29	2.755	0.232
HR (bpm)	71.45±10.28	75.45±17.28	-4.882	0.087
DP (bpm/mmHg)	8003.25±2135.12	8241.84±2335.24	-5.842	0.064

SBP, systolic blood pressure. **DBP,** diastolic blood pressure. **MAP,** mean arterial pressure. **PP,** pulse pressure. **HR,** heart rate. **DP,** double product.

Table 4. Comparison of changes between groups (Mean ± SE)

	Experimental group I (n = 10)		Experimental group II (n = 11)		F	p
	pre-test	post-test	pre-test	post-test		
Rectus Femoris	33.13±7.91	45.72±11.5	33.62±9.51	49.03±11.84	3.925	.038*
Biceps Femoris	25.6±6.01	38.89±6.85	21.43±5.91	39.99±7.73	3.125	.047*
Tibialis Anterior	13.45±3.78	15.47±1.45	17.43±3.84	20.44±4.09	2.218	0.154
Gastrocnemius	5.66±2.65	13.16±3.99	6.62±1.69	14.04±2.63	2.154	0.184
SBP (mmHg)	113.17±11.84	115.43±10.15	115.67±10.14	113.83±9.85	2.047	0.284
DBP (mmHg)	81.39±5.12	84.38±7.28	82.82±8.23	85.44±7.09	1.324	0.414
MAP (mmHg)	92.14±6.81	94.12±6.15	92.38±6.73	95.13±8.28	1.241	0.324
PP (mmHg)	37.14±5.94	35.36±8.42	32.68±6.77	29.86±7.29	1.489	0.241
HR (bpm)	67.25±12.81	74.31±13.83	71.45±10.28	75.45±17.28	1.332	0.407
DP (bpm/mmHg)	7943.38±1513.65	8321.54±1927.98	8003.25±2135.12	8241.84±2335.24	2.128	0.221

SBP, systolic blood pressure. **DBP,** diastolic blood pressure. **MAP,** mean arterial pressure. **PP,** pulse pressure. **HR,** heart rate. **DP,** double product.

DISCUSSION

In this study, an intervention of WBVT with BFR was performed, and the effect on lower limb muscle activity and hemodynamic parameters was determined. The discussion based on the results is as follows.

The training using BFR has been shown to improve musculoskeletal development, including muscle mass and strength (25), while varying the systemic effects of different application methods (26). Among the related previous studies, Kang et al. (27) recruited 17 undergraduate students and investigated the effect of a 6-week intervention of weight-based exercise with BFR on muscle function and thigh circumference, and reported significant differences in the maximum torque/weight (%) of the hamstring of each thigh and the circumference of each thigh to suggest that the weight-based exercise with BFR could be an effective method to improve the lower limb muscle strength and hypertrophy in clinical settings. In Ramis et al. (28), 28 younger adults followed an 8-week intervention of high-intensity resistance training and low-intensity resistance training with BFR, and the muscle strength and activity were compared. The results showed that muscle thickness and activity increased to equal levels in both groups suggesting that low-intensity resistance training with BFR could be a clinically useful method to increase muscle strength and activity. In a study by Scarpelli et al. (29), male older adults with sarcopenia and knee arthritis performed BFR training. The cross-sectional area and thickness of the vastus lateralis muscle were assessed using ultrasound, and the results showed an increase in muscle mass to suggest that BFR training is an effective method for individuals who may not be able to perform an exercise. Centner et al. (30) recruited 50 healthy female subjects to examine the effects of BFR and WBVT on muscle function, and after a 10-week intervention, the cross-sectional area of the muscles showed a greater increase in the WBVT+BFR group than in the WBVT group. The results indicated advantages for muscle strengthening for individuals prohibited from performing high-load training.

In this study, likewise, both groups; WBVT+BFR and WBVT, displayed significant improvements in RFM, BFM, and GM activities ($p<0.05$), and the between-group comparison showed significant differences in RFM and BFM activities ($p<0.05$) to lend support to the previous studies. Based on the result, the squat exercise on the vibration platform was shown to have led to the overall strengthening of lower limb muscles, while the effect of the WBVT with BFR was notably higher. The higher level of muscle strengthening via the WBVT with BFR compared to the WBVT alone may be due to the delayed blood flow to the arteries and veins via BFR (31), which may induce the cardiovascular drift to increase the metabolites (32). Although the precise mechanism of muscular, functional improvement is unknown, it is possible that type II muscle fibers are improved (33) or an endocrine response is induced by increased growth hormones (34). Meanwhile, Lin et al. (35) applied a local vibration with BFR to eight healthy male adults, and the result of examining the changes in muscle activity showed that the GM and BFM had not significantly changed, while only the RFM had significantly increased. It was in contrast to the present investigation, which could be because the subjects in Lin et al.'s study (35) did not perform a squat exercise but maintained a sitting position during measurements so that the GM and TAM remained almost without any contraction or shortening. At the same time, the level of BFR may fall upon the same cuff pressure if the thigh circumference exceeds the calf circumference, which is thought to be a result of the lack of effect of BFR on calf muscle activation during the local vibration.

The BFR training seems to demand a careful approach as it may elicit negative results from exercise because the increased pressure due to the cuff pressure could reduce the blood flow and increase cardiovascular responses (36). Kumagai et al. (37) and Loenneke et al. (38) performed studies in which BFR was combined with aerobic exercise, and the results showed significant differences in SBP, DBP, and MAP. Staunton et al. (39) examined the acute hemodynamic responses to a BFR-combined aerobic exercise. They reported that the experimental group with BFR displayed greater significant differences compared to the control group without BFR, which did not vary between younger and older adult participants. Such hemodynamic changes are closely associated with aerobic exercise as determined by the VO_{2max} (40), and it can be concluded that the combination with BFR leads to changes in hemodynamic responses more efficiently without cardiovascular risk.

In this study, no significant variation was found between the WBVT+BFR and WBVT groups for all hemodynamic parameters, which concurs with previous studies. Most participants were shown to maintain normal blood pressure and heart rate so that, despite the lack of significant variation across all variables of hemodynamic parameters, the method of WBVT with BFR is potentially safe and effective in maintaining normal levels of hemodynamic factors overall.

Meanwhile, the MAP, a known predictor of cardiovascular disease, plays a crucial part in determining the rate of blood flow through systemic circulation, as it is the mean blood pressure upon blood transport to all tissues (41). An increase in MAP was also reported to confer positive effects (42). Scott et al. (43) measured the blood pressure in 15 female older adults who performed a low-load exercise, a low-load exercise combined with BFR, and a high-load exercise. The results showed that the low-load exercise with BFR, compared to the high-load and low-load exercises, led to a higher level of MAP, while the low-load exercise with BFR and the high-load exercise were similar to implicate a potential application of BFR training to healthy older adults. Kambič et al. (44) likewise reported a significant fall in SBP but not in the DBP or the heart rate at rest in the BFR group after the intervention when the acute effect of resistance training with BFR (30-40% 1-RM) was investigated across 24 patients with coronary artery disease. In the present investigation, the MAP did not vary significantly between the WBVT+BFR and WBVT groups after the 6-week intervention, but a gradual increase was observed, which is presumed to be due to a positive effect on the hemodynamic responses.

Compared with previous studies, the results in this study indicate that the combination of WBVT with BFR has an additional effect on lower limb muscle activation. It may be applied in further studies to develop various exercise programs using BFR.

The limitations of this study were as follows: first, all participants were male undergraduate students, so it is difficult to generalize the results to all age and gender groups. Second, all participants were individuals of the general population rather than patients, which implies potential confounders arising from the difficulty of controlling the factors of daily activities.

CONCLUSION

This study was conducted on undergraduate students to determine the effect of WBVT with BFR on lower limb muscle activity and hemodynamic parameters. The results showed significantly increased RFM and BFM activities in the WBVT+BFR group compared to the WBVT group. No variation in hemodynamic parameters was detected. Based on the findings, the scope of the WBVT with BFR should be extended to include non-healthy individuals. Further studies of the multidimensional approach should also be conducted with additional variables to provide supporting evidence for the discussion of hemodynamic responses.

APPLICABLE REMARKS

- The findings reported in this study suggest significantly increased RFM and BFM activities in the WBVT+ BFR group compared to the WBVT group. No variation in hemodynamic parameters was detected.
- Based on the findings, the scope of the WBVT with BFR should be extended to include non-healthy individuals.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Dae-Keun Jeong, Sam-Ho Park. *Acquisition of data:* Jun-Su Park. *Analysis and interpretation of data:* Dae-Keun Jeong, Sam-Ho Park. *Drafting the manuscript:* Dae-Keun Jeong, Jun-Su Park. *Critical revision of the manuscript for important:* Sam-Ho Park. *Intellectual content:* Dae-Keun Jeong. *Statistical analysis:* Dae-Keun Jeong, Sam-Ho Park. *Administrative, technical, and material support:* Dae-Keun Jeong, Jun-Su Park. *Study supervision:* Sam-Ho Park.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, Nieman DC, Swain DP. American College of Sports Medicine. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc. 2011; 43:1334-1359. [**doi**:10.1249/MSS.0b013e318213fefb] [**pmid**:21694556]

2. Powers SK, Howley ET. Exercise physiology: Theory and application to fitness and performance (4th Ed). MgGraw-Hill. 2001.
3. American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription. 8th ed. Seattle: Williams & Wilkins. 2009.
4. Yang X, Wang P, Liu C, et al. The effect of whole body vibration on balance, gait performance and mobility in people with stroke: a systematic review and meta-analysis. Clin Rehabil. 2015:29(7);627-38. [**doi**:10.1177/0269215514552829] [**pmid**:25311142]
5. Jo YR. The Effect of Frequency to Whole body Vibration Exercise on Ankle Joint Spasticity and Gait Performance in Patients with Chronic Stroke. Master's Degree. Honam University. 2018. [**doi**:10.18857/jkpt.2018.30.4.135]
6. Yule CE, Stoner L, Hodges LD, et al. Does short-term whole-body vibration training affect arterial stiffness in chronic stroke? A preliminary study. J Phys Ther Sci. 2016:28(3); 996-1002. [**doi**:10.1589/jpts.28.996] [**pmid**:27134400]
7. Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol. 2000:20(2);134-42. [**doi**:10.1046/j.1365-2281.2000.00238.x] [**pmid**:10735981]
8. Kerschan-Schindl K, Grampp S, Henk C, et al. Whole-body vibration exercise leads to alterations in muscle blood volume. Clin Physiol. 2001:21(3);377-82. [**doi**:10.1046/j.1365-2281.2001.00335.x] [**pmid**:11380538]
9. Jessee MB, Buckner SL, Dankel SJ, Counts BR, Abe T, & Loenne ke JP. The influence of cuff width, sex, and race on arterial occlusion: Implications for blood flow restriction research. Sports Med, 2016;46:913-92. [**doi**:10.1007/s40279-016-0473-5] [**pmid**:26820301]
10. Loenneke JP, Fahs CA, Wilson JM, Bemben MG. Blood flow restriction: the metabolite/volume threshold theory. Med Hypotheses 2011;77:748-752. [**doi**:10.1016/j.mehy.2011.07.029] [**pmid**:21840132]
11. Vanwye WR, Weatherholt AM, Mikesky AE. Blood flow restriction training: implementation into clinical practice. Int J Exerc Sci. 2017;10(5):649-654.
12. Kraemer WJ, & Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc. 2004;36, 674-688. [**doi**:10.1249/01.MSS.0000121945.36635.61] [**pmid**:15064596]
13. Manini TM, & Clark BC. Blood flow restricted exercise and skeletal muscle health. Exerc Sport Sci Rev. 2009;37(2):78-85. [**doi**:10.1097/JES.0b013e31819c2e5c] [**pmid**:19305199]
14. Pollock RD, Woledge RC, Mills KR, Martin FC, Newham DJ. Muscle activity and acceleration during whole body vibration: efect of frequency and amplitude. Clin Biomech 2010;25:840-846. [**doi**:10.1016/j.clinbiomech.2010.05.004] [**pmid**:20541297]
15. Yasuda T, Fukumura K, Fukuda T, Lida H, Sato Y, Yamasoba T et al. Effects of low-intensity, elastic band resistance exercise combined with blood fow restriction on muscle activation. Scand J Med Sci Sports. 2014;24:55-61. [**doi**:10.1111/j.1600-0838.2012.01489.x] [**pmid**:22734915]
16. Fujita S, Takashi Abe, Micah. Blood fow restriction during low-intensity resistance exercise increases S6K1 phosphorylation and muscle protein synthesis. J Appl Physiol. 2007;103:903-910. [**doi**:10.1152/japplphysiol.00195.2007] [**pmid**:17569770]
17. Centner C, Ritzmann R, Schur S, Gollhofer A, & König D. Blood flow restriction increases myoelectric activity and metabolic accumulation during whole-body vibration. Eur J Appl Physiol. 2019;119(6):1439-1449. [**doi**:10.1007/s00421-019-04134-5] [**pmid**:30949807]
18. Fahs CA, Loenneke JP, Rossow LM, Thiebaud RS, Bemben MG. Methodological onsiderations for blood flow restricted resistance exercise. J Trainol. 2012;1:14-22. [**doi**:10.17338/trainology.1.1_14]
19. Ozaki H, Sakamaki M, Yasuda T, Fujita S, Ogasawara R, Sugaya M, Nakajima T, Abe T. Increases in thigh muscle volume and strength by walk training with leg blood flow reduction in older participants. J Gerontol A Biol Sci Med Sci. 2011;66:257-263. [**doi**:10.1093/gerona/glq182] [**pmid**:20974731]
20. Abe T, Sakamaki M, Fujita S, Ozaki H, Sugaya M, Sato Y, et al. Effects of low-intensity walk training with restricted leg blood flow on muscle strength and aerobic capacity in older adults. J Geriatric Phys Ther. 2010;33(1):34-40.

21. Gómez-Bruton A, González-Agüero A, Matute-Llorente A, Julián C, Lozano-Berges G, Gómez-Cabello A, et al. Do 6 months of whole-body vibration training improve lean mass and bone mass acquisition of adolescent swimmers? Arch Osteoporos. 2017;12:69. [**doi**:10.1007/s11657-017-0362-z] [**pmid**:28733931]
22. Ritzmann R, Gollhofer A, Kramer A. The infuence of vibration type, frequency, body position and additional load on the neuromuscular activity during whole body vibration. Eur J Appl Physiol. 2013;113:1-11. [**doi**:10.1007/s00421-012-2402-0] [**pmid**:22538279]
23. Giles L, Webster KE, McClelland J, Cook JL. Quadriceps strengthening with and without blood fow restriction in the treatment of patellofemoral pain: a double-blind randomised trial. Br J Sports Med 2017;51:1688. [**doi**:10.1136/bjsports-2016-096329] [**pmid**:28500081]
24. Loenneke JP, Thiebaud RS, Fahs CA, Rossow LM, Abe T, Bemben MG. Blood fow restriction does not result in prolonged decrements in torque. Eur J Appl Physiol. 2013;113:923-931. [**doi**:10.1007/s00421-012-2502-x] [**pmid**:23014796]
25. Ida H, Nakajima T, Kurano M, Yasuda T, Sakamaki M, Sato Y, et al. Effects of walking with blood flow restriction on limb venous compliance in elderly subjects. Clin Physio Funct Imaging. 2011;31(6):472-476. [**doi**:10.1111/j.1475-097X.2011.01044.x] [**pmid**:21981459]
26. Bowman EN, Elshaar R, Milligan H, Jue G, Mohr K, Brown P, et al. Proximal, distal, and contralateral effects of blood flow restriction training on the lower extremities; a randomized controlled trial. Sports Health. 2019;11(2):149-156. [**doi**:10.1177/1941738118821929] [**pmid**:30638439]
27. Kang DY, Kim HS, Lee KS, Kim YM. The effects of bodyweight-based exercise with blood flow restriction on isokinetic knee muscular function and thigh circumference in college students. J Phys Ther Sci. 2015;27(9):2709-2712. [**doi**:10.1589/jpts.27.2709] [**pmid**:26504274]
28. Ramis TR, de Lemos Muller CH, Boeno FP, Teixeira BC, Rech A, Pompermayer M, et al. Effects of traditional and vascular restricted strength training program with equalized volume on isometric and dynamic strength, muscle thickness, electromyographic activity, and endothelial function adaptations in young adults. J Streng Condit Res. 2020;34(3):689-698. [**doi**:10.1519/JSC.0000000000002717] [**pmid**:30063556]
29. Scarpelli MC, Bergamasco JGA, Arruda EA, et al. Resistance training with partial blood flow restriction in a 99-year-old individual: a case report. Front Sports Act Living. 2021;22(3):671764. [**doi**:10.3389/fspor.2021.671764] [**pmid**:34240050]
30. Centner C, Ritzmann R, Gollhofer A, König D. Effects of whole-body vibration training and blood flow restriction on muscle adaptations in women: a randomized controlled trial. The J Streng Condit Res. 2020;34(3):603-608. [**doi**:10.1519/JSC.0000000000003401] [**pmid**:31842133]
31. Iida H, Kurano M, Takano H, Kubota N, Morita T, Meguro K,Sato Y, Abe T, Yamazaki Y, Uno K, Takenaka K, Hirose K, Nakajima T. Hemodynamic and neurohumoral responses to the restriction of femoral blood flow by KAATSU in healthy subjects. Eur J Appl Physiol. 2007; 100: 275-285. [**doi**:10.1007/s00421-007-0430-y] [**pmid**:17342543]
32. Loenneke JP, Fahs CA, Wilson JM, Bemben MG. Blood flow restriction: the metabolite/volume threshold theory. Med Hypotheses. 2011;77:748-752. [**doi**:10.1016/j.mehy.2011.07.029] [**pmid**:21840132]
33. Yasuda T, Brechue WF, Fujita T, Shirakawa J, Sato Y, Abe T. Muscle activation during low-intensity muscle contractions with restricted blood flow. J Sports Sci. 2009;27(5):479-489. [**doi**:10.1080/02640410802626567] [**pmid**:19253083]
34. Pierce JR, Clark BC, Ploutz-Snyder LL, Kanaley JA. Growth hormone and muscle function responses to skeletal muscle ischemia. J App Phys. 2006;101(6):1588-1595. [**doi**:10.1152/japplphysiol.00585.2006] [**pmid**:16888046]
35. Lin TC, Cheng CC, Cai ZY. Effects of local vibration with blood flow restriction on muscle activation. Isokin Exer Sci. 2018;26(1):9-15. [**doi**:10.3233/IES-171174]
36. Jessee MB, Dankel SJ, Buckner SL, Mouser JG, Mattocks KT, Loenneke JP. The cardiovascular and perceptual response to very low load blood flow restricted exercise. Inter J Sports Med. 2017;38(8):597-603. [**doi**:10.1055/s-0043-109555] [**pmid**:28651256]

37. Kumagai K, Kurobe K, Zhong H, Loenneke J, Thiebaud R, Ogita F, et al. Cardiovascular drift during low intensity exercise with leg blood flow restriction. A physio Hungarica. 2012;99(4):392-399. [**doi**:10.1556/APhysiol.99.2012.4.3] [**pmid**:23238541]
38. Loenneke JP, Fahs CA, Rossow LM, Abe T, Bemben MG. The anabolic benefits of venous blood flow restriction training may be induced by muscle cell swelling. Med Hypotheses. 2012;78(1):151-154. [**doi**:10.1016/j.mehy.2011.10.014] [**pmid**:22051111]
39. Staunton CA, May AK, Brandner CR, Warmington SA. Haemodynamics of aerobic and resistance blood flow restriction exercise in young and older adults. Euro J appl physio. 2015;115(11):2293-2302. [**doi**:10.1007/s00421-015-3213-x] [**pmid**:26142277]
40. Horiuchi, M & Okita, K. Blood flow restricted exercise and vascular function. Inter J Vascular Med, 2012. [**doi**:10.1155/2012/543218] [**pmid**:23133756]
41. Kenney WL, Willmore J, Costill D. Physiology of Sport and Exercise. Champaign Urbana: IL, Human Kinetics. 2013
42. Renzi CP, Tanaka H, Sugawara JUN. Effects of leg blood flow restriction during walking on cardiovascular function. Med Sci Sports Exer. 2010;42(4): 726. [**doi**:10.1249/MSS.0b013e3181bdb454] [**pmid**:19952840]
43. Scott BR, Peiffer JJ, Thomas HJ, Marston KJ, Hill KD. Hemodynamic responses to low-load blood flow restriction and unrestricted high-load resistance exercise in older women. Frontiers Physiol. 2018;9:1324. [**doi**:10.3389/fphys.2018.01324] [**pmid**:30327609]
44. Kambič T, Novaković M, Tomažin K, Strojnik V, Jug B. Blood flow restriction resistance exercise improves muscle strength and hemodynamics, but not vascular function in coronary artery disease patients: a pilot randomized controlled trial. Frontiers Physiol. 2019;10:656. [**doi**:10.3389/fphys.2019.00656] [**pmid**:312446680]