Original Research

Acute Cardiovascular Responses after a Single Bout of Blood Flow Restriction Training

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ABSTRACT

International Journal of Exercise Science 11(2): 20-31, 2018. Different types of exercise might produce reductions in blood pressure (BP). One physiological mechanism that could explain the lowering adaptation effect on BP after an exercise program is an improved in baroreflex control of muscle sympathetic nerve activity. Consequently, exploring the different methods of training and their post-exercise hypotension (PEH) becomes of interest for healthcare providers. Recently, it has been suggested that blood flow restriction training (BFR) can generate PEH. The aim of this study was to determine the acute response on cardiovascular variables after low intensity resistance training with BFR in normotensive subjects. Twenty-four male (24.38±3.88 years) performed four sets of plantar flexion at 30% 1RM (1x30 + 3x15 repetitions) with 30% of maximal occlusion pressure and 60 seconds resting period. The restrictive pressure was released during the intervals between sets. BP, heart rate (HR), blood oxygen saturation (SpO$_2$) and double product (DP) were measured in baseline, after each set of exercise and 15, 30, 45, 60 minutes and 24 hours after exercise. An immediate significant increase across the set was observed for HR values (11.5%) ($p<0.05$) during application the protocol. SBP and DBP values also increased during exercise although mildly (1.7% and 1%, respectively) without significant differences compared with pre-values. A post-exercise hypotension was obtained 15min post-training (SBP: -6.9%; DBP: -3%). There was no significant change in SpO2 and DP during and post-exercise with BFR. Cardiovascular responses were altered mildly during BFR-training and after the single bout. In conclusion, BFR in young normotensive humans generated post-exercise hypotension.

KEY WORDS: Low intensity resistance training, heart function, post-exercise hypotension, cardiovascular responses, blood flow restriction

INTRODUCTION

High blood pressure (values of blood pressure > 139±89 mmHg) is the largest public health problem worldwide because of its high prevalence and it is associated with increased cardiovascular risk and renal complications. Recently, it has been estimated that 54.5% of deaths caused by cardiovascular disease have been associated with hypertension. The same

study, which involves 154 countries and 8.69 million people, has registered an increase in the blood pressure (BP) prevalence of 17.307 to 20.526 cases per 100.000 persons from 1990 to 2015 (15).

The guidelines for the management of hypertension recommend lifestyle modifications, in particular, the combination of diet and exercise (e.g. aerobic and resistance training) (40). Exercise is considered as a non-pharmacological treatment, thus it is necessary to know the optimal dosage (posology) in order to obtain its maximal benefits (35). Moreover, many researchers have shown that a single bout of exercise is able to reduce blood pressure during the recovery period (38).

Different international organizations such as the Joint National Committee, the World Health Organization, the European Society of Hypertension, and the National High Blood Pressure Education Program have developed their exercise prescription among adults with hypertension (37). Thereby, resistance training has been shown to promote a decrease mean blood pressure (BP) 3-4 mmHg which is positive for hypertensive and normotensive population. However, because the ideal dose in terms of type of exercise, training frequency, interval of sets, etc. is unknown, the need of new exercise proposals is an emergent research field (8).

Low-intensity resistance training combined with blood flow restriction (LI-BFR) or KAATSU training has been shown to be an effective alternative to traditional resistance training (RT). This methodology uses an external tourniquet (cuff) in order to reduce the muscle blood flow and since 2000's has gained popularity in the research, both in the field of training and clinical exercise. Available scientific data has reported multiple benefits of LI-BFR in health outcomes and rehabilitation (e.g. reduce muscle atrophy) (20), increases in muscular strength and hypertrophy (16, 36, 44, 48) improvements in elderly (53), vascular function (19) and cardiovascular system (32). Thus, this training methodology results very useful for a large range of populations from athletes, recreationally training to clinical exercise.

There are at least three primary mechanisms through which BFR-LI resistance training is thought to operate: increased cellular swelling, enhanced metabolic stress, and increased muscle fiber recruitment (24). However scarce information has been published about cardiovascular effects. In this way, research has shown that a single session of exercise can cause an acute reduction of BP decreasing below resting values, a phenomenon known as post-exercise hypotension (PHE) (17, 38). Considering that adaptations may be a result from temporal summation of acute responses (10), systematic repetitions in PHE can induce a reduction of blood pressure.

Different types of exercise have been proved achieving PHE including resistance training (21, 38) and LI-BFR in normotensive subjects (values of systolic BP: 80-120 mmHg, and diastolic BP: 60-80 mmHg) as well as hypertensive patients (values of BP > 139±89 mmHg) (2, 6, 7). Resistance training induced PHE has been maintained to 24 hours after a single session (23, 37,

39, 43). Therefore, RT with and without blood flow restriction is prescribed for the control of BP values.

However, there are some gaps that have not been elucidated about the effects of BFR-LI on post-exercise BP response; therefore, it is necessary to identify an optimal load of BFR-LI that can result the greatest possible effect of PHE. Recently, it has been called for concern in order to provide the importance of the pressor reflex from blood flow restriction exercise as physiological phenomena that leads the necessity of be cautioned in the prescription of BFR in clinical cardiac condition and healthy subjects (49). Exercise physiology explains that the skeletal muscle exercise pressor reflex (EPR) determines the cardiovascular response to physical activity, including during BFR training. This response is characterized by hyperactivity of sympathetic nervous system and could explain an increased in cardiac outcome including blood pressure (30, 48). There are two factors that modulate EPR such as metaboreflex and muscle mechanoreflex, both that are increased during blood flow restriction exercise by the cuff pressure on the skeletal muscle. Maybe EPR could be the mechanism of the increase blood pressure reported in the BFR exercise (45). There is unknown if the excessive response in BP during the exercise could be influence in PHE. By the other hand, subjects trained in resistance training without BFR have shown a reduction on EPR to dynamic exercise (14). Finally, there is little information as to the intensity of the effort necessary to induce PHE (52). Speculation exists on whether BFR-LI play a role on EPR but there is little evidence about it. In this sense, the possible effects of BFR-LI on PHE have not been elucidated yet.

Therefore, the aim of the present study was to investigate the acute effects of BFR-LI on cardiovascular responses. Although the potential application of BFR exercise in the clinical population has been found in the literature, we recruited healthy non-hypertensive subjects because is a more accessible population and there are not usually associated with cardiovascular diseases. In addition, the knowledge of post-exercise hypotensive response in normotensive subjects can help to promote greater efficacy and safety during BFR-LI training.

METHODS

Participants
Twenty-four voluntary, healthy and well-trained participants were recruited from University of Alicante (24.38±3.88 years, 178.08±11.01 cm, 72.71±13.02 kg, 22.79±2.70 BMI). They completed a medical health history form. Informed consent was obtained from each participant prior study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008. The study was approved by the Institutional Review Board at the Alicante University of Spain. Exclusion criteria were the presence of any diagnosed cardiovascular disease, peripheral vascular disease, hypertension, diabetes, smoking, blood anticoagulant medications, and/or any medical condition that precludes a program of weight lifting. Participants were not using performance enhancing medications or stimulants like caffeine minimum 72 hours before the experimental trial.

The participants were instructed not to participate in an exercise program during the last 2 days prior the intervention, neither during or 24 hours after the experimental session. Participant's characteristics, including one repetition maximum (1RM) and BFR pressure, are presented in Table 1.
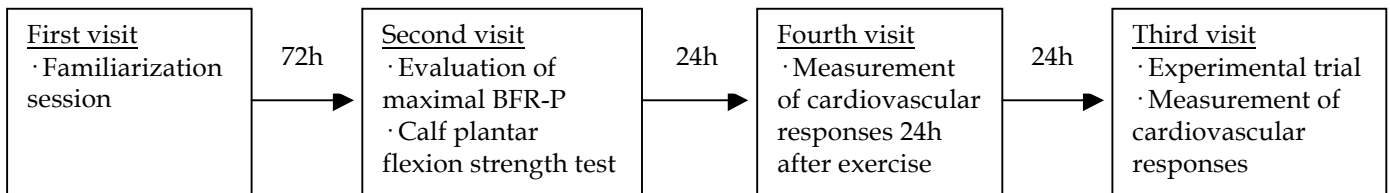
Table 1. Participant's characteristics

	Subjects (n=24)
Age (years)	24.38±3.88
Height (cm)	178.08±11.01
Weight (kg)	72.71±13.02
BMI (kg/m²)	22.79±2.70
1RM (kg)	133.21±22.1
BFR-P (mmHg)	47.65±19.82

Values are expressed as mean ± Standard Deviation (SD). *BMI, body mass index; RM, repetition maximum; BFR-P, blood flow restriction pressure.*

Protocol
Participants attended the laboratory on four visits. In the first visit the participants underwent a familiarization session and the other three visits were used to apply the experimental trials and to carry out the corresponding measurements. The familiarization session was conducted at least 72 hours before starting the experimental trials. The other four visits to the laboratory were on consecutive days.

First visit · Familiarization session	72h	Second visit · Evaluation of maximal BFR-P · Calf plantar flexion strength test	24h	Fourth visit · Measurement of cardiovascular responses 24h after exercise	24h	Third visit · Experimental trial · Measurement of cardiovascular responses

Figure 1. Scheme with the protocol used in our intervention. *BFR-P, blood flow restriction pressure.*

Familiarization session: In this visit, the participants were familiarized with the exercise and the use of BFR-LI. The participants were instructed on the correct technique for performing plantar flexion exercise. This including providing instructions about foot placement on the platform, the range of motion and breathing rate. Moreover, participants underwent a short exposure to BFR at low inflation pressure (20mmHg) while performing the exercise.

Maximal blood flow restriction pressure: Evaluation of the level of occlusion that triggered total restriction of arterial fluid was carried out by placing a blood pressure cuff on the leg beneath the knee joint and inflating it until the echographic signal (Mindray Z6) at 10Hz of blood supply from the posterior tibia branches of the popliteal artery disappeared, which its corresponds with 100% occlusion.

The 30% of blood flow restriction was achieved using a high precision compression meter (Riester Komprimeter, Riester, Jungingen, Germany). The cuff dimensions were 57 cm length x 9 cm width. With the participant sitting on the leg press machine, the cuffs were applied with

an initial pressure of 20mmHg. Then, cuff pressure was incrementally increased by 20mmHg every 30 seconds until reaching the 30% of the total arterial occlusion of each subject.

In general, BFR studies inflate pressure cuffs to a value higher than brachial diastolic blood pressure (cuff pressure of 100-200 mmHg) in order to restrict vascular blood flow, however, there are no standardized cuff pressures or cuff width in the BFR-LI studies.

Calf plantar flexion strength test (1RM): The maximum repetition was determined using a total range of movement in dominant's leg. The exercise was performed on a leg press machine (TYH Fitness brand). Initially, participants performed unilateral plantar flexion with a load of 50%1RM (estimated) with 15 repetitions. After that, the load was adjusted to 70% and performed 10 repetitions. These sets served as a specific warm up (5). After that, the weight was adjusted individually and the participant was told to perform repetitions until volitional failure. If the subject manages to perform more than 5 repetitions, the load increased by 5%. If the subject does not complete 5 repetitions, 1RM was estimated by the Epley's formula (1RM = Load [kg] · (1 + [0.033 · number of repetitions]) (27). Five min of rest between attempts were allowed.

First experimental trial: After a warm up for 5 minutes on bicycle at 70W at a cadence of 60-70rpm, a set of specific dynamic stretching exercise were conducted. The specific warm up was composed of one set of 15 repetitions of plantar flexion exercise with your own body weight.

Training volume was set at 75 repetitions (30, 15, 15, 15 repetitions, with 60-seconds rest between sets) for the dominant leg performing the plantar flexion exercise in leg press machine in sitting position. Training intensity was 30% 1RM. The occlusion pressure was released during the intervals between sets. We used 30% of total arterial occlusion (47.6 mmHg) because greater level of pressure (e.g. >40% of arterial occlusion pressure) it seems that is not necessary in blood flow training oriented to increase muscle size and strength (9). Therefore, a study demonstrated that this pressure level induced changes in total muscle work during BFR-LI exercise (50). Each repetition took approximately 1 second for the concentric phase and 1 second for the eccentric phases that were checked with a digital metronome.

Measurement of cardiovascular parameters: Blood pressure (BP), heart rate (HR) and double product (DP) were measured 5-minute before starting the training sitting on a stretcher using an automatic BP monitor (Tensoval Duo Control Hartmann; OMRON). The cuff was placed on the left arm in position extended.

Then, BP and HR were measured during the resting intervals between sets of exercise, in a sitting position. In addition, the variables were also measured at 15, 30, 45 and 60 minutes and 24 hours after exercise.

The blood oxygen saturation was measured before and during the resting intervals of sets of exercise, as well as 60 minutes and 24 hours post-trial.

Statistical Analysis

Data are presented as mean and standard deviation. All variables were checked to ensure that they complied with the assumptions of normality (Kolomogorov-Smirnov normality test) and homocedasticity (Levene test). One-way ANOVA for repeated-measures was performed for each dependent variable. We assumed an alpha level of $p < 0.05$. Statistical analysis was carried out using SAS software 9.3 for Windows.

RESULTS

Hemodynamic responses during and post-exercise with BFR-LI are depicted on table 2.

Table 2. Hemodynamic values during and post-exercise with BFR-LI.

	SBP (mmHg)		DBP (mmHg)		HR (bpm)	
	Mean ± SD	CI (95%)	Mean ± SD	CI (95%)	Mean ± SD	CI (95%)
Pre	123.6±15.7	117.0 – 130.2	74.5±11.0	70.1 – 78.8	66.2±12.9	60.4 –71.8
1º set	125.8±15.9	119.1 – 132.3	75.3±13.6	70.8 – 79.6	73.8±15.2*	68.0 – 79.4
2º set	120.7±15.1	114.0 – 127.2	72.2±12.0	67.8 – 76.5	71.3±14.6	65.5 – 76.9
3º set	123.4±17.4	116.7 – 130.0	70.9±8.9	66.4 – 75.2	71.3±13.8	65.6 – 77.0
4º set	123.3±18.8	116.6 – 129.9	71.3±12.3	66.8 – 75.6	73.7±16.2	67.9 – 79.3
Post-15min	115±15.9*	108.3 – 121.6	72.2±14.1	67.8 – 76.5	69.0±13.3	63.3 – 74.7
Post-30min	115.3±14.4	108.7 – 121.9	70.5±9.1	66.1 – 74.9	66.6±12.9	60.8 – 72.2
Post-45min	114.4±16.7	107.7 – 121.0	70.0±7.6	65.6 – 74.3	63.8±12.3	58.1 – 69.5
Post-60min	113.3±14.7	106.6 – 119.8	71.4±8.7	66.9 – 75.7	63.7±13.4	57.9 – 69.3
Post-24h	115.3±15.8	108.6 – 121.9	69.8±8.4	65.4 – 74.1	66.3±11.2	60.6 – 71.9

Values are expressed as the mean ± SD; CI: Confidence Interval. *$p<0.05$

HR increased significantly only after the first set of exercise (11.5%; p=0.0417). However, HR measurements returned to baseline values after exercise (p>0.05). There was only a significant decrease in SBP 15 min post-exercise (-6.9%; p=0.0199). There was no significant change in SpO2 and DP during and over time post-exercise (Tables 3 and 4).

Table 3. Blood oxygen saturation measurement pre-exercise, during and 60 minutes and 24 hours post-exercise.

	SpO2 (%)	
	Mean ± SD	IC (95%)
Pre	98.0±0.8	97.6 – 98.3
1º set	97.7±1.1	97.3 – 98.0
2º set	97.8±1.0	97.4 – 98.1
3º set	97.8±0.9	97.4 – 98.2
4º set	97.6±1.0	97.2 – 98.0
Post-60min	97.7±0.8	97.3 – 98.0
Post-24h	98.0±0.8	97.6 – 98.4

Values are expressed as the mean ± SD; CI: Confidence Interval. *$p<0.05$

There was a statistical difference in SBP, HR and DP among every condition of time (SBP: F value=9.77, p<0.0001; HR: F value=10.7, p<0.0001; DP: F value=17.8, p<0.0001). There were no significant differences in DBP and SpO$_2$ values.

Table 4. Analysis of DP pre-exercise, during and post-exercise.

	DP	
	Mean ± SD	IC (95%)
Pre	8202.5±2026.0	7332.4 – 9072.5
1º set	9323.2±2393.3	8453.1 – 10193.0
2º set	8633.1±2207.1	7763.0 – 9503.1
3º set	8834.1±2263.2	7964.0 – 9704.1
4º set	9216.8±2482.2	8346.7 – 10087.0
Post-15min	8002.2±2131.7	7132.1 – 8872.2
Post-30min	7681.1±1787.2	6811.0 – 8551.1
Post-45min	7293.5±1675.9	6423.4 – 8163.5
Post-60min	7248.3±1860.2	6378.2 – 8118.3
Post-24h	7673.5±1893.4	6803.4 – 8543.6

Values are expressed as the mean ± SD; CI: Confidence Interval. *$p<0.05$

DISCUSSION

Although an acute bout of sub-maximal exercise can cause cardiovascular changes, there are few and controversial published data on the effect of different types and exercise intensities on blood pressure, heart rate and double product. An increased understanding on BFR-LI induced cardiovascular responses could have various implications on clinical setting, rehabilitation programs and research design.

Regarding SBP, DBP and DP, our findings reported no changes during exercise. However, there was a significant reduction in SBP 15 min after exercise, probably caused by the effect termed post-exercise hypotension (PEH). The reason that can explain this effect is the decreased of cardiac output that was not fully compensated by increased systemic peripheral vascular resistance (27).

The scientific evidence has found that BP rises during acute resistance exercise bout (28) and BFR-LI training. For instance, Brandner et al. (4) observed an increase in BP during BFR-LI exercise continuous at 80% of SBP and intermittent BFR-LI at 130% of SBP, although these values returned to baseline values within 5-minute after application of the protocol for all conditions measured. In addition, Vilaça-Alves et al. (54) and Downs et al. (12) also observed an increase in SBP beyond increase in the HR during exercise for all conditions measured. In fact, Poton and Polito (42) observed that the BFR-LI caused higher SBP and HR values when it is compared with a protocol without partial occlusion, especially at the end of the third series of the exercise. However, in the Poton´s study the blood flow restriction pressure was higher than our study, furthermore, restriction pressure was continuously applied.

In contrast to the studies aforementioned, for our surprising, we did not find increases on BP and DP during BFR-LI training. A reason that could explain these findings may be related to lower muscle mass involved in the exercise (e.g. plantar flexion) used in our protocol. In addition, we speculate that lower BP and DP responses during BFR-LI protocol may have been influenced by the low restrictive pressure used in the protocol (47.65 mmHg) beyond releasing restrictive pressure during intervals between sets.

Our findings show that SBP decreased 15 minutes post-exercise (6.9%). This post-exercise hipotensive effect (PHE) has been observed in other studies (2, 27, 33). For example, Araujo et al. (2) demonstrated a reduction in BP values until 60 minutes post-exercise in fourteen hypertensive subjects after BFR-LI. Neto et al. (33) reported the effect of intensity from BFR-LI on PHE, which it was observed only the PHE in the intensity at 20% 1RM compared to 30% 1RM. However, when BFR-LI was compared to high intensity training protocol, PHE was similar between intensities (31) or, in some cases, the PHE was observed only following HI (46).

Another variable measured in our study was HR. It is known that HR modified its conduct in order to respond to active muscle demand (3, 13, 26) so it is necessary that the different variables of resistance training (e.g. volume, intensity, rest, and frequency) have to be adjusted to have the best effect on BP and HR (3, 11, 26).

Our results show an increase in HR after first set of exercise. Similar increases were observed by Loenneke et al. (25) and Rossow et al. (46). Especially regarding HR, Hollander et al. (18) also showed that the BFR-LI induce higher values of HR than other protocols without BFR during performing an exercise bicep curl. This difference could be attributed to the pressor reflex (49). In addition, the increase in HR only after first set of exercise can be explained by the low muscle demand from exercise protocol and the low restrictive pressure used.

The double product (DP) is the product of SBP and heart rate and serves as valid predictor of myocardial oxygen consumption during exercise. Our results show a discreet increment in DP during exercise and mild reduction post-exercise without significant differences. One possible explanation that may support our results is the reduction of cardiac output as a result of BFR-training. A study with BFR has reported a reduction in DP due to decrease in the venous return (42).

The blood oxygen saturation (SpO2) was also measured during and after BFR-LI conditions. The index of myocardial oxygen consumption remained above 97% at all times so it was not affected throughout the trial or post-exercise. Conflicting results from our data have been shown by Neto et al. (34). In this study, the authors observed reductions in the SpO2 after exercise with the use of different exercise intensities (80-20% 1RM vs 30% 1RM) and level of the blood occlusion (80% maximal occlusion). The divergence from results between studies may be related to the exercise protocols.

In conclusion, low-intensity resistance training (30% 1RM) with blood flow restriction in plantar flexor exercise is associated with mild acute increment of hemodynamic responses, especially in HR, and hypotension 15 min post-exercise. Future researches should be addressed to determine hypotensive effects in hypertensive and normotensive subjects and the different parameters in pressor reflex response during BFR-LI.

One limitation of the current study is the absence of a control condition. However, several studies have demonstrated that cardiovascular responses to low-intensity BFR are more pronounced when compared to without BFR in different populations (4, 41). The small participation of women in our study could be other limiting factor, especially regarding data extrapolation (32).

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