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Original article

Blood pressure response to dynamic resistance exercise with different times under blood flow restriction on normotensive subjects: a randomized crossover trial

Resposta da pressão arterial ao exercício resistido com diferentes tempos sob restrição do fluxo sanguíneo em indivíduos normotensos: um estudo randomizado cruzado

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ABSTRACT

Introduction: Recommendations for time under blood flow restriction (BFR) during resistance training (RT) vary between 5 to 10 minutes, and beneficial effects on muscle mass and strength have already been reported. However, there exists the potential for longer times under restriction to produce greater acute activation of the exercise pressor reflex and subsequent sympathetic pathways leading to a greater hemodynamic response. **Objective:** To verify blood pressure responses to dynamic resistance exercise with different times (5 vs. 10 minutes) under blood flow restriction in normotensive subjects. **Methods:** In a randomized crossover trial design, twelve healthy and physically active male participants completed a training with BFR under the following protocols: control, BFR-5 minutes, BFR-10 minutes. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) measurements were taken by an experienced researcher immediately after each exercise set. **Results:** Both BFR-5 minutes and BFR-10 minutes induced acute elevations in SBP, DBP and heart rate (HR) as the sets progressed, without statistical differences between them. However, BFR-10 displayed a superior effect size for SBP and DBP compared to BFR-5 minutes. **Conclusion:** Based on the results of this study, the time under BFR during resistance exercise does not affect blood pressure response in normotensive subjects.

Keywords: resistance training; blood flow restriction therapy, blood pressure.

RESUMO

Introdução: A recomendação de tempo sob restrição de fluxo sanguíneo (RFS) durante o treinamento resistido (TR) pode variar entre 5 e 10 minutos, e já foram relatados efeitos benéficos para o desenvolvimento da hipertrofia e força muscular. No entanto, existe o potencial que o longo tempo sob restrição possa induzir maior ativação aguda do reflexo pressor durante o exercício e subsequentemente das vias simpáticas levando a uma maior resposta hemodinâmica. **Objetivo:** Verificar as respostas da pressão arterial ao exercício resistido com diferentes tempos sob restrição de fluxo sanguíneo em indivíduos normotensos. **Métodos:** Nesse estudo randomizado cruzado, doze participantes do sexo masculino saudáveis e fisicamente ativos completaram em ordem aleatória os seguintes protocolos: controle, RFS-5 minutos e RFS-10 minutos. As medidas da pressão arterial sistólica (PAS) e da pressão arterial diastólica (PAD) foram mensuradas por um pesquisador experiente imediatamente após cada série do exercício. **Resultados:** Tanto o RFS-5 minutos quanto o RFS-10 minutos induziram elevações agudas na PAS, PAD e frequência cardíaca (FC) à medida que as séries progrediam, sem diferenças estatísticas entre elas. No entanto, um tamanho efeito superior para a PAS e PAD foi apresentado para a condição RFS-10 comparado a condição RFS-5. **Conclusão:** Com base nos resultados do presente estudo, o tempo de restrição do fluxo sanguíneo durante o exercício resistido não altera a resposta pressórica em indivíduos normotensos.

Palavras-chave: treinamento de força; terapia de restrição de fluxo sanguíneo; pressão sanguínea.

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Introduction

Exercise training with blood flow restriction (BFR) is considered a progressive clinical rehabilitation modality to improve muscle mass and strength in patients that have musculoskeletal weakness in the process of returning to heavy-load exercise [1]. Studies report comparable increases in muscle mass compared to heavy-load resistance training (RT) [2,3], regardless of absolute occlusion pressure, cuff width, and occlusion pressure prescription method [3].

Despite the beneficial effect of BFR on lean mass and muscle strength [1], there exists significant heterogeneity in the application of potentially important BFR variables (e.g., absolute occlusion pressure, cuff width, and occlusion pressure prescription method). When not properly applied according to established guidelines, BFR may represent a safety concern and not be suitable for clinical populations that may require more precise control of BFR stimulus. Furthermore, a previous study stated that misuse of this method could lead to acute and abnormal elevations in sympathetic activity and risk of cardiovascular-related events (e.g., cardiac arrhythmia, myocardial infarction, stroke and sudden cardiac death) [4].

One of the concerns of BFR training is its safety profile for hypertensive and cardiovascular patients. In hypertensive populations, the increase in systolic and diastolic blood pressure during BFR training is higher than traditional exercise compared to normotensive peers [5]. Also, diastolic blood pressure during BFR training is higher when compared to traditional exercise [5]. Consequently, exercise demands on the cardiovascular system approach or exceed free-flow high-intensity exercise [6]. Thus, despite the assertions of BFR safety, possible side effects should be considered before the application in individuals with hypertension and cardiovascular disease [4]. Importantly, acute- and longitudinal BFR studies in patients with cardiovascular disease patients are poorly available [7].

A previous meta-analysis examining the effects of BFR training on blood pressure stated that the included studies were not designed to address whether BFR training affects blood pressure specifically and called for research on this topic [8]. Moreover, considering the different BFR application variables that may impact hemodynamic response, time under BFR is interestingly not debated [9]. Time under BFR might affect chemical and mechanical stimuli, activating the exercise pressor reflex and enhancing sympathetic output while reducing parasympathetic activity [4]. Other studies have sought to determine whether the continuous application of pressure could alter physiologic responses such as metabolic stress [10]. Thus, there is theoretical reason that manipulating time under BFR during RT might affect acute physiological responses.

Traditionally, the occlusive stimulus during BFR is applied continuously during exercise and the rest intervals (between 5 to 10 minutes total time under occlusion) [11]. There exists the potential for longer times under restriction to produce greater acute activation of the exercise pressor reflex and subsequent sympathetic pathways leading to a greater hemodynamic response. However, no studies have yet focused on whether time under restriction is an important variable in mediating the hemodynamic response to BFR exercise.

Therefore, the purpose of this study was to verify if the time of blood flow restriction alters blood pressure response during resistance exercise in healthy individuals. We hypothesized that BFR training with a longer time of restriction would display a higher hemodynamic response than shorter time restriction.

Methods

This randomized crossover study was approved by the Ethics and Research Committee of the Catholic University of Brasília, CAAE 39652920.4.0000.0029 and was conducted in accordance with the Declaration of Helsinki. Twelve healthy and physically active (according to PAR-Q short version) males [12], but inexperienced in resistance exercise, were recruited for the study. All participants were informed about the purpose, practical details, and possible risks associated with the experiment and before data collections began, each gave their consent by signing a consent form. Exclusion criteria were participants with any of the following conditions: musculoskeletal injuries in the lower limbs, continuous use of medication and nutritional supplements that could affect blood pressure response, resting blood pressure ≥ 140 x 90 mmHg, existing heart disease, peripheral vascular disease, diabetes, BMI ≥ 30, and one or more risk factors for thromboembolism [13].

Blood flow restriction protocols

This crossover trial was conducted within five visits, at the same time of day, separated at least 72 and no more than 96 hours. Signs of swelling and shortness of breath, changes in skin temperature, presence of tachycardia, pain or discoloration and swollen or distended varicose veins were visually monitored [14]. They were instructed not to perform any exercise 72-96 hours before exercise protocol.

The first visit consisted of signing the Informed Consent Form, completing questionnaires to assess the level of physical activity (IPAQ - short version), physical and health condition (PAR-Q), risk stratification for thromboembolism [13], and screening for medications and food supplements that could affect blood pressure. In addition, patients were evaluated by an experienced cardiologist. First, participants rested for 10 minutes in the supine position, relaxed, head and heels supported in a room with comfortable temperature (~25°C). Then, resting blood pressure was measured using an automatic monitor (*Microlife, Shenzhen, China*) where a cuff was placed on the participant's left arm, approximately 2 cm above the cubital fossa. Right after, a 12-lead electrocardiogram followed by an ankle-brachial blood pressure index (ABI) test was performed to verify the existence of peripheral vascular disease [15]. Body composition was evaluated by Dual-energy X-ray Absorptiometry (DXA). Calibration of equipment was provided and phantom was used to check calibration daily before body composition evaluation. The tests included a complete body scan in the supine position with the apparatus calibrated and operated by a technically trained professional. All metal objects were removed from the participant before the scan.

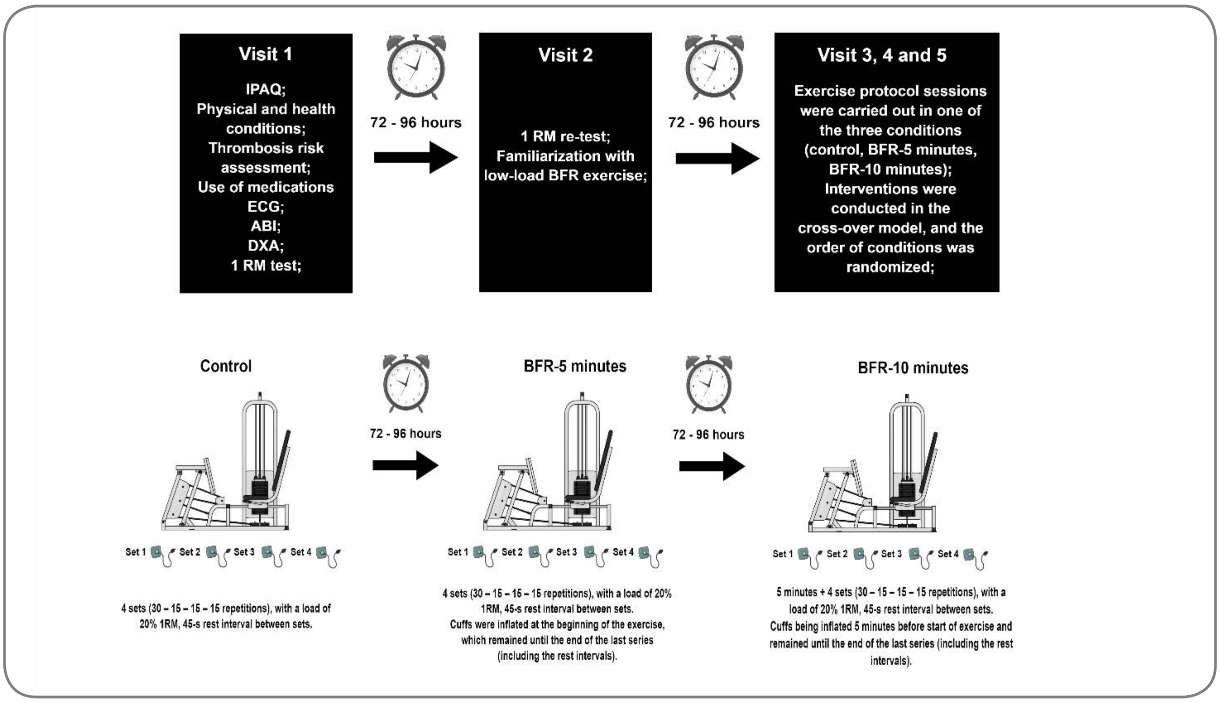
Finally, 1-RM was also evaluated in the first session. The test started with five minutes of general warm-up performed on a treadmill (*Imbrasport Millenium ATL, Imbramed, Porto Alegre, Brazil*) at ≤ 85% heart rate reserve. Afterward, participants performed three static stretching exercises for the hamstrings, hips, and quadriceps (1 set of 10-s). After that, the participants were positioned in the 45-degree leg press (*PowerTech, Riguetto, Campinas, Brazil*), maintaining the alignment of the ankle, knee, and hip joints to perform the specific warm-up and the test itself [16]. The 1-RM was found in a maximum of five attempts (separated by 3 minutes of recovery for each attempt). During the eccentric phase, the individuals were instructed to bend the knees to 90° flexion and in the concentric phase, to almost complete extension (approximately 20° of knee flexion). To have greater precision in the result, 1-RM was re-tested 96 hours after with a similar procedure, but the first load attempted was the load found in session one. For the value of 1 RM found, the weight of the leg press platform (which had 40 kg) was considered. During all tests, at least two researchers provided support to minimize the occurrence of exercise-related accidents.

As mentioned, the second session served as a retest of the 1-RM. In addition, this session served as familiarization to low-load BFR exercise as each participant performed one set of 30 repetitions at 20% 1RM using 50% arterial occlusion pressure determined in the 45-degree leg press.

In visits 3, 4, and 5, the exercise protocol sessions were carried out in one of the three conditions (control, BFR-5 minutes, BFR-10 minutes) described below. Interventions were conducted in the crossover model and subjects were assigned to conditions by randomly picking a protocol inside of an envelope. For the study scheme, see Figure 1.

Exercise protocol

The exercise was performed in the 45-degree leg press (PowerTech, Riguetto, Campinas, Brazil) that consisted of 4 sets (30 – 15 – 15 – 15 repetitions) with a load of 20% 1RM, ~45-s rest interval between sets, and a rhythm of 1-s for concentric and 1-s for eccentric (controlled by an audible metronome); thus, the exercise duration was approximately 5 minutes. Participants were comfortably positioned on the equipment and instructed to maintain the alignment between ankles, knees, and hips. In addition, a researcher controlled the range of motion (90° degrees of knee flexion in the eccentric phase and almost complete extension - approximately 20° degrees flexion - during the concentric phase). All participants performed the exercise under three conditions:



IPAQ = International Physical Activity Questionnaire; PAR-Q = Physical Activity Readiness Questionnaire; ECG = electrocardiogram; ABI = ankle brachial index; DXA = Dual-energy X-ray absorptiometry; 1 RM = 1 repetition maximum; BFR = blood flow restriction; BFR-5 = blood flow restriction 5 minutes protocol; BFR-10 = blood flow restriction 10 minutes protocol; AOP = arterial occlusion pressure. N = 12 participants

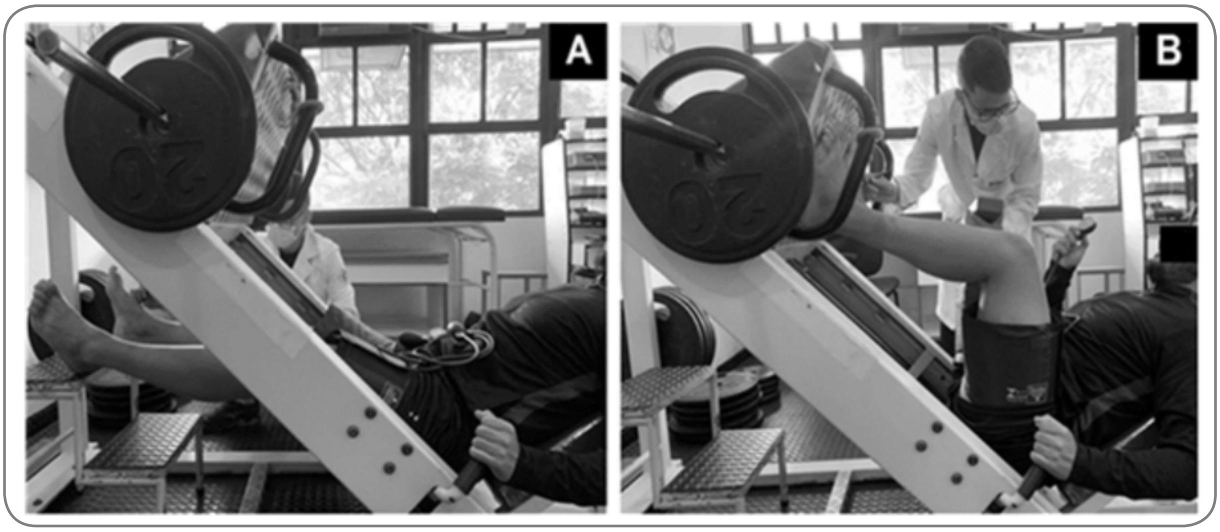
Figure 1 - Study scheme. General visits details

In protocol 1 (control), exercise was performed without BFR. In protocol 2 (BFR-5 minutes), cuffs were inflated at the beginning of the exercise and remained inflated until the end of the last series (including the rest intervals). Thus, duration under BFR was equal to the exercise duration (5 minutes). In protocol 3 (BFR-10 minutes), the same actions as in protocol 2 (BFR-5 minutes) were performed, but to maintain the same exercise volume as control and BFR-5 minutes, the cuffs were inflated for 5-minutes prior to beginning the leg press exercise making the duration under BFR 10 minutes (5 minutes previous + 5 minutes of exercise). The interval between protocols was a minimum of 72 and a maximum of 96 hours and participants reported to the lab at similar times of day to minimize diurnal variations.

In protocols BFR-5 minutes and BFR-10 minutes, BFR was induced by a pair of inflatable cuffs (Premium, Zhejiang, China) with 20 cm width x 42cm length (cuff bladder = 17 cm width x 37 cm length) placed on the proximal part of the thighs (as close as possible to the inguinal crease) with 50% of the total arterial occlusion pressure (AOP).

Arterial Occlusion Pressure (AOP)

Because of hemodynamic variations, AOP was checked before performing each exercise protocol (BFR-5 minutes and BFR-10 minutes). With the volunteer seated on the 45-degree leg press, two measurements were taken on each leg (one in recovery position and other in exercise execution position – feet on the platform) (Figure 2). A pair of inflatable cuffs (Premium, Zhejiang, China) was placed on the proximal part of the thighs (as close as possible to the inguinal crease). A small amount of water-based conductive gel (Mercur, Santa Cruz do Sul, RS, Brazil) was placed in the portable vascular doppler probe (DV 610B, Medmega, Franca, SP, Brazil) and this was positioned perpendicular on the dorsalis pedis artery with minimal pressure. AOP was determined when arterial pulse was interrupted according to previous studies [17,18]. Values of pressure used on cuffs are described in Table II.



A = resting position; B = exercise position. N = 12 participants
Figure 2 - Legs positions during arterial occlusion pressure measurements

Blood pressure measurement

Measurements were taken by an experienced researcher immediately after each exercise set. Furthermore, a cuff size corresponding to the participant's arm size was used [19]. A blood pressure cuff (Welchallyn, Chicago, IL, USA) was placed on the participant's left arm, approximately 2 cm above the cubital fossa. A researcher supported the participant's arm on a support so that the participant remained totally relaxed and the cuff was inflated 10 mmHg above Korotkoff sound stopped. Thus, cuff was deflated slowly and auscultatory measurement of systolic (SBP) and diastolic (DBP) blood pressure was performed (SBP and DBP) was annotated when the Korotkoff sound started and stopped, respectively) [20]. To not interfere in the time duration under BFR, measurements at post set 4 were taken after cuffs were deflated. Additionally, participants were also advised to maintain an empty bladder and not to talk during protocols (control, BFR-5 minutes, BFR-10 minutes) as these variables may impact blood pressure reading [19-21].

Heart rate monitoring during exercise

Heart rate (HR) was measured using Polar's FT1 HR monitor system (Polar, Kempele, FI) via a chest-worn sensor strap and a wristwatch HR receiver unit. To improve skin contact, a small amount of water-based conductive gel (Mercur, Santa Cruz do Sul, RS, Brazil) was placed in the sensor.

Statistical analysis

A two-way repeated measures ANOVA was conducted to examine the effects of different restriction times on blood pressure responses. Data are presented in mean ± standard deviation, unless otherwise stated. Analysis of the studentized residuals showed that there was normality as assessed by the Shapiro-Wilk test of normality and no outliers as assessed by no studentized residuals greater than ± 3 standard deviations. When a significant interaction was observed, a simple main effects analysis was applied and a Bonferroni Post-hoc was applied. For the two-way repeated measures ANOVA statistical test, the intragroup effect size was calculated for the variables SBP, DBP and HR. The omega squared ($\Omega 2$) recommended for small samples was used and values ≤ 0.01, $0.01 - 0.06$, $0.06 - 0.14$ and > 0.14 were considered: trivial, small, medium, and large, respectively [22]. Also, a delta (Δ) analysis was performed, which was calculated as follows: Δ^a = set 1 minus pre-training; Δ^b = set 2 minus pre-training; Δ^c = set 3 minus pre-training; Δ^d = post-training minus pre-training and post-training. Cohen's d was used to effect size between moments pre-exercise and set 1, pre-exercise and set 2, pre-exercise and set 3 and pre-exercise and post-training for variables SBP, DBP and HR. Hence, One-way ANOVA was conducted for comparisons between Δ group differences.

Coefficient of variation (CV) was used to calculate within participant variation (CV% = [SD/mean] x 100). The CV for leg press was 17.44%. Considering a minimum difference of 10 mmHg for DBP between groups [23,24], the power observed for interaction between restriction time and time on DBP was 0.85, effect size of 1.16, with an alpha error probability of 0.01. Power was calculated using G*Power 3.1.6 [25]. An alpha level of $\alpha \leq .05$ was considered significant, and all calculations were performed using SPSS (version 20.0).

Resultados

No adverse events occurred, and all participants were able to complete each exercise intervention. Intraclass correlation coefficient between 1-RM test and re-test was ICC = 0.92.

The characteristics of the sample are displayed in Table I. Table II reports mean pressure applied to the participant's thighs (in mmHg).

There was no interaction between time under restriction and moments on SBP, F(8, 88) = 1.88, p = 0.07. However, a main effect of time was observed F(4, 44) = 27.83, p = 0.001. As shown at table III, compared to pre-training, SBP was higher at sets one, two and three only for BFR conditions (mean difference of 19.50; 17.66 mmHg, 26.00; 28.50 mmHg, 26.16; 29.83 mmHg for BFR-5 minutes; BFR-10 minutes respectively), as well as, only for post-training at BFR-10 minutes (mean difference of 15.00 mmHg).

Table I - Characteristics of participants. Values described as mean ± standard deviation

Age (years)	22 ± 3.36
Body mass (kg)	70 ± 9.28
Height (cm)	175 ± 5.35
BMI (kg/m²)	22 ± 2.69
Body fat (%)	12 ± 7.33
1 RM (kg)	310 ± 51.28
Rest SBP (mmHg)	121 ± 11.71
Rest DBP (mmHg)	70 ± 6.37

BMI = body mass index; 1 RM = 1 repetition maximum; SBP = systolic blood pressure; DBP = diastolic blood pressure. N = 12 participants

Table II - Pressure used on cuffs during BFR protocols. Values described as mean ± standard deviation

	Rest position (mmHg)		Exercise position (mmHg)	
	Right thigh	**Left thigh**	**Right thigh**	**Left thigh**
BFR-5 minutes	73 ± 5.89	72 ± 7.56	72 ± 6.80	71 ± 6.78
BFR-10 minutes	73 ± 8.29	75 ± 7.61	72 ± 8.58	74 ± 9.24

BFR = blood flow restriction; BFR-5 = 5-minute protocol; BFR-10 = 10-minute protocol. n= 12 participants

Also, there was an interaction between time under restriction and moments on DBP, F(8,88) = 8,86, p = 0.001. For BFR-5 minutes, a statistically higher DBP at set three was observed compared to pre-training (mean difference of 8.75 mmHg). Besides, a statistically lower DBP at post-training was observed for BFR-10 minutes when compared to pre-training (mean difference of -11.41 mmHg). In addition, a statistically higher DBP was observed for sets one, two and three for BFR conditions compared to control (mean difference of 10.00; 10.00 mmHg, 11.66; 15.00 mmHg, 15.83; 15.83 mmHg for BFR-5 minutes; BFR-10 minutes respectively). See Table III.

There was no interaction between time under restriction and moments on HR, F(8, 88) = 0.89, p = 0.58. However, a main effect of time was observed F(4, 44) = 75.24, p = 0.001. For BFR condition, a statistically higher HR at sets one, two, three and post-training compared to pre-training was observed (mean difference of 20.66; 22.00 bpm, 23.08; 27.25 bpm, 25.08; 29.00 bpm and 26.58; 30.08 bpm for BFR-5 minutes; BFR-10 minutes respectively). Finally, for control session, a statistically higher HR at sets one, two, three and post-training compared to pre-training was observed (mean difference of 27.16 bpm, 27.83 bpm; 30.50 bpm and 32.75 bpm respectively). See Table III.

Table III - Blood pressure and heart rate response between protocols

	SBP pre-training (mmHg)	SBP set 1 (mmHg)	Δ^a (mmHg)	ES	SBP set 2 (mmHG)	Δ^b (mmHg	ES	SBP set 3 (mmHG)	Δ^c (mmHg)	ES	SBP post-training (mmHg)	Δ^d (mmHg)	ES
Control	123 ± 8.50	139 ± 20.10	16	1.0	144 ± 20.55*	21	1.3	141 ± 21.13	17	1.1	141 ± 22.39	17	1.0
BFR-5 minutes	122 ± 10.43	142 ± 19.92*	20	1.2	148 ± 17.59*	26	1.8	148 ± 18.99*	26	1.7	136 ± 21.18	14	0.8
BFR-10 minutes	126 ± 13.38	143 ± 15.57*	18	1.2	154 ± 14.43*	29	2.1	156 ± 15.59*	30	2.1	140 ± 10.87*	15	1.2

	BDP pre-training (mmHg)	BDP set 1 (mmHg)	Δ^a (mmHg)	ES	BDP set 2 (mmHg)	Δ^b (mmHg)	ES	BDP set 3 (mmHg)	Δ^c (mmHg)	ES	BDP post-training (mmHg)	Δ^d (mmHg)	ES
Control	74 ± 6.93	67 ± 7.78	-7	-1.1	68 ± 8.35	-6	-0.8	68 ± 7.54	-7	-1,0	65 ± 7.98	-9	-1.2
BFR-5 minutes	75 ± 3.73	77 ± 11.55‡	2‡	0.23	80 ± 9.53‡	5‡	0.8	83 ± 8.88‡	9‡	1.3	66 ± 10.84	-9#†¥	-1.1
BFR-10 minutes	75 ± 8.20	77 ± 6.51‡	2‡	0.1	83 ± 8.88‡	9‡	0.9	83 ± 8.88‡	9‡	0.9	63± 8.88*	-12#†¥	-1.4

	HR pre-training (bpm)	HR set 1 (bpm)	Δ^a (bpm)	ES	HR set 2 (bpm)	Δ^b (bpm)	ES	HR set 3 (bpm)	Δ^c (bpm)	ES	HR post-training (bpm)	Δ^d (bpm)	ES
Control	71 ± 8.57	98 ± 13.31*	27	2.4	99 ± 11.86*	28	2.7	102 ± 15.38*	31	2.5	104 ± 14.16*	33	2.8
BFR-5 minutes	71 ± 10.60	92 ± 12.28*	21	1.8	94 ± 11.98*	23	2.0	96 ± 14.83*	25	1.9	98 ± 13.25*	27	2.3
BFR-10 minutes	70 ± 10.02	92 ± 8.86*	22	3.0	97 ± 11.84*	27	2.5	99 ± 14.70*	29	2.3	100 ± 13.30*	29	2.5

SBP = systolic blood pressure; DBP = diastolic blood pressure; HR = heart rate; BFR = blood flow restriction; Δ = delta; Δ^a = set 1 minus pre-training; Δ^b = set 2 minus pre-training; Δ^c = set 3 minus pre-training; Δ^d = post-training minus pre-training and post-training.; ES = Cohen's d effect size (0.2 small; 0.2; 0.5 medium; 0.8 large; ≥ 1.0 very large); * = significant differences from pre-training time point ($p < 0.05$); ‡ = significant differences from control session at the same time point ($p < 0.05$); # = significant differences from Δ^a ($p < 0.05$); † = significant differences from Δ^b ($p < 0.05$); ¥ = significant differences from Δ^c ($p < 0.05$); ‡ = significant differences from control at the same time point ($p < 0.05$); n = 12 participants

For delta analysis, no differences between groups and moments for SBP was observed. However, DBP values were statistically higher for BFR conditions at moments post set 1, post set 2 and post set 3 compared to control. Thus, adding BFR demonstrated a superior increase in DBP, regardless of the duration used.

Effect size

Considering the effect size values between groups for main effect of time, a superior magnitude of treatment effect for BFR-10 minutes as compared with control and BFR-5 minutes were observed for SBP, and DBP. For HR, no differences between BFR-10 minutes and Control were observed, but a higher effect size for BFR-10 minutes compared to control was observed. See Table IV.

Table IV - Values of effect size for main effect of time

Parameters	Control	BFR-5 minutes	BFR-10 minutes
	Ω	Ω	Ω
PAS, mmHg	0.11 (moderate)	0.21 (large)	0.36 (large)
PAD, mmHg	0.11 (moderate)	0.27 (large)	0.43 (large)
FC, bpm	0.46 (large)	0.37 (large)	0.46 (large)

Ω = effect size; SBP = systolic blood pressure; DBP = diastolic blood pressure; HR = heart rate; BFR = blood flow restriction. N = 12 participants. Source: authors

Discussion

To our knowledge, this is the first study to examine the hemodynamic response in normotensive participants after different times under blood flow restriction. Therefore, the significant new findings are 1) Both BFR-5 minutes and BFR-10 minutes induced acute elevations in SBP, DBP, and HR as the sets progressed, without differences between them. 2) Furthermore, DBP demonstrated a superior increase with BFR exercises compared to control group, regardless of the time used. This indicates that the duration of BFR up to 10 minutes does not alter pressure responses in normotensive subjects.

Although studies to make similar comparisons in normotensive individuals are scarce, a previous acute study demonstrated that BFR training (20% 1RM) in hypertensive women subjects provoked increases SBP and DBP similar to high-load RT (65% 1RM) in the leg press exercise, with additional increases in blood pressure observed during the rest intervals compared to pre-exercise resting values [26]. The protocol consisted of three sets of 15 repetitions with 30 seconds rest with a continuously applied cuff pressure throughout the three sets [26,27]. Thus, it is possible to infer that time under BFR totaled between 4 to 6 minutes. During exercise in the BFR condition, SBP and DBP elevated to 237 mmHg and 139 mmHg, generating a larger hemodynamic response than traditional strength training while also displaying greater values of blood pressure during the rest intervals (e.g., during 2nd rest interval - SBP = 182 mm Hg vs. 143 mmHg in high load RT, $p < 0.05$).

Similar results in hypertensive patients were observed in another intervention [28]. Greater acute increases in SBP (212 mmHg) and DBP (123 mmHg) similar to high-load RT were recorded along with greater relative increases in blood pressure values during the pauses between sets. The cuff pressure was sustained during the experimental sessions of BFR and released immediately after the end of the third set

[26,27]. While not reported, we estimate based on repetition cadence that time under BFR was between 4 to 6 minutes. Taken together, these results might shape guidance that hypertensive participants may benefit from deflation of the BFR stimulus (e.g., intermittent BFR) at some point during BFR exercise, as that could attenuate increases in SBP and DBP [29] observed during the pauses.

A previous study showed potential applicability of a cyclical BFR protocol and its effect on blood pressure and norepinephrine levels compared to conventional RT [29]. The exercise session duration for both conditions was 40 minutes (divided into 4 x 10 min blocks). For BFR training, each 10-min block consisted of a 5-min exercise period with the cuff inflated and 5-min reperfusion with the cuff deflated. For conventional RT (65% of 1RM), the session was performed in the same manner but without inflatable thigh cuffs [29]. Results demonstrated that plasma norepinephrine, stroke volume, cardiac output, mean arterial pressure, and total peripheral resistance were augmented with conventional RT compared to BFR training [29]. This attenuated increase in sympathetic activity and hemodynamic responses during cyclical BFR (5-min exercise period with the cuff inflated and 5-min reperfusion with the cuff deflated) could be potentially adapted for clinical populations [29].

However, contrary to research on hypertensive populations, our data did not show differences between different times under BFR in hemodynamic response. Importantly, the hemodynamic response to BFR is less exaggerated in normotensive populations [5]. For this reason, these data should not be extrapolated to populations where excessive blood pressure elevations during exercise may be a concern. Thus, studies investigating the time under BFR in specific populations (e.g., hypertensive patients) should be carried out to better determine the parameters for prescribing this type of exercise.

A recent guideline recommended that BFR RT restriction time should be between 5 to 10 minutes per exercise with at least 1-3 minutes of reperfusion between exercises [11]. Conversely, for AT the restriction time recommended is 5 to 20 minutes [11]. However, the increase in time under restriction during AT may unnecessarily increase hemodynamic responses, particularly in clinical patients whose pressor reflex may be altered. Although metabolic accumulations are typically much less in AT allowing for longer times under restriction.

Future investigations into BFR AT exercise could look to incorporate a similar model as the current study to determine differential hemodynamic responses in BFR AT protocols of different time intervals.

The literature is limited with regards to protocols directly comparing BFR AT to BFR RT on hemodynamics. A previous study compared the effects of BFR-RT (4 sets x 15 – 15 – 15 – 15 at 30% of 1RM at 50% AOP, with 1 min interval between sets) with BFR AT exercise (composed of 20 minutes of continuous treadmill walking at 40% of VO2peak with 50% AOP) on hemodynamic responses in older adults [30]. In both sessions, continuous application of cuff pressure was maintained throughout the exercise, being released just after the last repetition of the last set during BFR protocol and at 20 min during aerobic exercise with BFR. Interestingly, independently of a longer time restriction with AT, a lower SBP, DBP, peripheral vascular resistance peak and a faster heart rate recovery was observed compared to BFR-RT [30]. Similar results of a lowering of SBP and DBP were observed in normotensive subjects when BFR-RT was compared to BFR AT in another study [31]. These results raise important considerations with BFR AT that may impact prescription of BFR RT in clinical practice. Despite the longer time under restriction, BFR AT appears to be a suitable strategy to mitigate the excessive increases in SBP and DBP associated with BFR RT.

While more research is needed to determine optimal application parameters (e.g., intensity, duration and BFR pressures), BFR AT likely displays these changes due to an attenuated accumulation of intramuscular metabolites, reducing the magnitude of the exercise pressor reflex and subsequent sympathetic activation despite the longer time under restriction [32]. Therefore, based on the results of our study, future research should investigate whether the addition of passive restriction prior to a bout of BFR AT could further alter hemodynamic responses. Furthermore, heart rate variability has considerable potential to assess the effects of time under restriction in autonomic nervous system in health and cardiovascular patients and warrants further research.

Finally, the increase in blood pressure during exercise occurs by a mechanism known as the pressor reflex, in which it stimulates the sympathetic nervous system and inhibits the parasympathetic nervous system [4]. In our results, SBP did not present a significant difference between protocols, however the DBP was significantly higher in the protocols with BFR regardless of time under BFR. We speculate that the increase in DBP in BFR-5 and BFR-10 is due to the venous system congestion caused by the application of cuffs during exercise [5].

Some limitations of the present study should be highlighted. Cross-over designs may face problems with carryover effects and possible systematic differences between hemodynamic responses during the later compared to the earlier sessions. Also, the indirect cuff method used to measure blood pressure response during BFR training might underestimate SBP and overestimate DBP values and the validity is very poor when compared to that of directly measured intra-arterial pressure [33]. However, considering the practical applicability, auscultatory technique is still the traditional approach for measuring SBP and DBP in clinical settings. Finally, blood pressure was measured after and not during exercise and post-training was measured after deflation of the cuff to maintain similar times under restriction, so the values shown may differ from those achieved during exercise. In alignment with our methodology, some papers measured blood pressure after cuff was deflated [26,34]. Further, there may be an underestimation of the hemodynamic changes post-exercise due to the deflation of the cuff. That's why only set three was used for delta analysis and not set 4 (post-training). Thus, the increased BP in earlier sets was attenuated by the deflation. This in fact underestimated the BP response during our protocol. Future studies should maintain the restriction while obtaining blood pressure values as that may give a more accurate assessment.

Practical applications

While both long and short time under BFR can potentially increase blood pressure during exercise, long time (10 minutes) under BFR displayed a superior effect size for SBP and DBP in normotensive individuals. Although speculative, manipulating BFR variables strategically could increase the safety of medically compromised populations (e.g., hypertensive individuals and patients under cardiac rehabilitation). This could increase the number of hypertensive individuals who pursue BFR training as a mode of exercise.

Conclusion

Based on the present study results, time under BFR during resistance exercise does not affect blood pressure response in normotensive subjects despite a larger effect size in longer durations. However, due to the overall lack of studies in this thematic, future research on this topic is warranted in upper body RT as well as in hypertensive populations.

Academic link

This article represents part of Leandro Lima de Sousa's master's thesis, supervised by the professor Dr. Carlos Ernesto Santos Ferreira from the Catholic University of Brasília, Taguatinga, Distrito Federal, Brazil.

Conflict of interest

NR is the founder of THE BFR PROS, a BFR education company that provides BFR training workshops to fitness and rehabilitation professionals across the world using a variety of BFR devices. NR has no financial relationships with any cuff manufacturers/distributors. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Authors' contributions

Research conception and design: Sousa LL, Ferreira CES, Nascimento DC; **Data collection:** Sousa LL, Silva RC, Silva TF, Barbosa JMS; **Data analysis and interpretation:** Nascimento DC, Rolnick N, Rosa BV; **Statistical analysis:** Nascimento DC, Rolnick N; **Writing of the manuscript:** Nascimento DC, Rolnick N, Sousa LL, Rosa BV, Ferreira CES; **Critical review of the manuscript for important intellectual content:** Nascimento DC, Rolnick N, Ferreira CES

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