

Artigo Original

The Cardiopulmonary Exercise Testing with Vascular Occlusion Achieved, At Lower Speeds, Oxygen Uptake Similar to A Traditional Maximum Test: A pilot Study**O Teste De Esforço Cardiopulmonar com Oclusão Vascular Atingiu, Em Menores Velocidades, Captação De Oxigênio Semelhante ao Teste Máximo Tradicional: Um Estudo Piloto**<http://dx.doi.org/10.18316/sdh.v11i3.10142>

Leonardo Peterson dos Santos^{1*} ORCID 0000-0001-8623-5596, Thiago Rozales Ramis¹ ORCID 0000-0002-5252-1209, Samuel Vargas Munhoz¹ ORCID 0000-0003-4252-9685, Rafaela Cavalheiro do Espírito Santo¹ ORCID 0000-0002-5518-3479, Juliana Martins Gattringer² ORCID 0009-0009-1503-344X, Jerri Luiz Ribeiro¹ ORCID 0000-0001-5194-5950

RESUMO

Introdução: Populações especiais podem ter dificuldade em realizar testes incrementais máximos devido à intensidade desses testes. Portanto, entender as alterações que ocorrem no teste incremental com restrição de fluxo sanguíneo (T_{máx}-RFS) e sem restrição (T_{máx}-TRAD) é fundamental. **Objetivo:** Comparar as respostas das velocidades, limiares ventilatórios (LV), consumo máximo de oxigênio (VO₂máx), lactato sanguíneo ([La]), frequência cardíaca (FC), tempo de exaustão e escala de Borg do T_{máx}-RFS vs. T_{máx}-TRAD. **Métodos:** Nesse estudo *crossover*, foram incluídos homens não atletas que foram submetidos a duas condições de testes (T_{máx}-RFS e T_{máx}-TRAD). Os dados foram analisados por meio de Equações de Estimativa Generalizada e teste de *Bonferroni*. Valores $p < 0,05$ foram considerados significativos. **Resultados:** Cinco homens foram incluídos (Idade: $22,6 \pm 1,1$ anos). O 1ºLV, 2ºLV e VO₂máx foram semelhantes nas duas condições. Contudo, o T_{máx}-RFS atingiu o 1ºLV (T_{máx}-TRAD, $9,0 \pm 0,7$ km/h; T_{máx}-RFS, $8,2 \pm 0,5$ km/h), 2ºLV (T_{máx}-TRAD, $13,8 \pm 1,6$ km/h; T_{máx}-RFS, $11,6 \pm 1,8$ km/h) e VO₂max (T_{máx}-TRAD, $15,6 \pm 2,9$ km/h; T_{máx}-RFS, $13,0 \pm 2,1$ km/h) em velocidades significativamente menores quando comparadas ao T_{máx}-TRAD ($p < 0,0001$). AFC no 2ºLV (T_{máx}-TRAD, $189,2 \pm 20,7$ bpm; T_{máx}-RFS, $173,2 \pm 10,6$ bpm; $p = 0,014$) e a FC máxima (T_{máx}-TRAD, $203,6 \pm 14,9$ bpm; T_{máx}-RFS, $178,8 \pm 9,7$ bpm; $p < 0,0001$) foram maiores no T_{máx}-TRAD. O T_{máx}-RFS apresentou maiores níveis de [La] quando comparado ao T_{máx}-TRAD para 1ºLV ($p = 0,019$) e 2ºLV ($p = 0,005$). **Conclusão:** Houve redução da velocidade do 1ºLV, 2ºLV e VO₂max, bem como, menor esforço cardíaco no 2ºLV e FC ao final do T_{máx}-RFS.

Palavras-chave: Aeróbico; Exercício; *Kaatsu*; Consumo de oxigênio; Oclusão vascular.

1 Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Rio Grande do Sul, Brazil.

2 Centro Universitário Metodista IPA, Porto Alegre, Rio Grande do Sul, Brazil

*Corresponding author: R. Ramiro Barcelos, 2400 - Santa Cecília, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre - RS, 90035-003; Phone: +55 51 3359 8837, Fax: +55 51 3359 8340. E-mail: leonardosantos@hcpa.edu.br

ABSTRACT

Introduction: Special populations may have difficulty performing maximum incremental tests due to the intensity of these tests. Therefore, understanding the changes that occur in incremental test with blood flow restriction (Tmax-BFR) and without blood flow restriction (Tmax-TRAD) is fundamental. **Objective:** To compare the responses of speeds, ventilatory thresholds (VT), maximum oxygen uptake (VO_2 max), blood lactate ([La]), heart rate (HR), exhaustion time, and Borg scale of Tmax-BFR vs. Tmax-TRAD. **Methods:** In this crossover study, non-athlete men who were submitted to two tests conditions (Tmax-BFR and Tmax-TRAD) were included. Data were analyzed using Generalized Estimating Equations and Bonferroni test. Values $p < 0.05$ were considered significant. **Results:** Five men were included (Age: 22.6 ± 1.1 years). The 1stVT, 2ndVT and VO_2 max were similar in both conditions. However, Tmax-BFR has reached 1stVT (Tmax-TRAD, 9.0 ± 0.7 km/h; Tmax-BFR, 8.2 ± 0.5 km/h), 2ndVT (Tmax-TRAD, 13.8 ± 1.6 km/h; Tmax-BFR, 11.6 ± 1.8 km/h) and VO_2 max (Tmax-TRAD, 15.6 ± 2.9 km/h; Tmax-BFR, 13.0 ± 2.1 km/h) at significantly lower speeds when compared to Tmax-TRAD ($p < 0.0001$). HR at 2ndVT (Tmax-TRAD, 189.2 ± 20.7 bpm; Tmax-BFR, 173.2 ± 10.6 bpm; $p = 0.014$) and Maximum HR (Tmax-TRAD, 203.6 ± 14.9 bpm; TBFR, 178.8 ± 9.7 bpm; $p < 0.0001$) were higher in Tmax-TRAD. The Tmax-BFR showed higher levels of [La] when compared to Tmax-TRAD for 1stVT ($p = 0.019$) and 2ndVT ($p = 0.005$). **Conclusion:** There was a reduction in speed of 1stVT, 2ndVT and VO_2 max, as well as lower cardiac effort in the 2ndVT and HR at the end of the test in the Tmax-BFR condition.

Keywords: Aerobic; Exercise; Kaatsu; Oxygen consumption; Vascular occlusion.

INTRODUCTION

Aerobic exercise improves the cardiorespiratory system and physical performance of walk and run practitioners. This increase in aerobic conditioning may also influence the improvement of sports performance¹, post-exercise recovery² and health³. Aiming at the benefits of aerobic exercise and seeking to reach all types of population, new exercises protocols have been developed allowing the use of less overload and with responses similar to those observed with high-intensity exercises^{4,5}. Low-intensity exercises performed with blood flow restriction (BFR) have been extensively studied and used in the scientific community. The use of BFR has been shown to be an efficient strategy for gains in muscle strength, muscle hypertrophy⁶, increased cardiorespiratory resistance⁷ and as a possible and important strategy capable of increasing physiological stress in aerobic exercise, even if using low speed⁷⁻¹⁰. Such benefits may positively impact populations in rehabilitation processes, groups of elderly, obese and individuals who cannot tolerate high exercises loads^{11,12}.

The cuff pressure used during BFR method may cause different responses in the cardiovascular system¹³. The exercise with partial BFR, for example, causes a partial restriction of arterial flow and a total restriction in the venous flow of the occluded muscles during exercise^{14,15}. Evidence shows that aerobic exercise with partial BFR is sufficient to cause an exacerbated increase in physiological stress¹⁶, increase in muscle mass, muscle strength, improve aerobic, anaerobic conditioning and maximum oxygen uptake (VO_2 max)^{7,15,17-19}. Thus, this decreased blood input and a stressed muscle environment may provide a stimulus for physical adaptation²⁰. Evidence demonstrates that the aerobic exercise protocol with BFR obtains acute and chronic responses similar to high-intensity exercises⁸.

Another important factor to be highlighted is the exercise prescription. We know that in an incremental test it is of great importance to identify the ventilatory thresholds (VT) of everyone¹⁰. However, little is debated about the importance of determining the thresholds and speeds of execution an incremental test in an environment of vascular occlusion^{7,9,11,19}. That said, as much as it is known that changes in intensities occur during the execution of an incremental test with BFR⁹, most studies report their responses compared to low-intensity exercises without BFR²¹⁻²⁴. Thus, little is known about the comparison of this protocol involving vascular occlusion with high-intensity aerobic exercises²⁵ or its behavior in a maximal incremental test^{9,10}. However, it is speculated that individuals submitted to

a maximum incremental test with blood flow restriction (Tmax-BFR) will obtain greater stress in the internal environment when compared to the same test without blood flow restriction (Tmax-TRAD)¹⁰. Still, positive results in these parameters may suggest changes in exercise prescriptions, since there are recommendations for the practice combined with partial BFR with intensities below 50% VO_2 max and its benefits through exercises are reported¹⁵.

Therefore, in our study, we seek to understand the changes that occur in the Tmax-BFR compared to Tmax-TRAD. Our objective was to compare the acute responses of VT, VO_2 max, blood lactate ([La]), heart rate (HR), rating of perceived exertion (RPE), speeds and exhaustion time in a maximum incremental test with and without BFR in young adult men, not athletes. Thus, one of our hypotheses is that Tmax-BFR will achieve early responses of VT through lower speeds compared to the Tmax-TRAD. We also believe that the total test run time is shorter for Tmax-BFR. Another hypothesis is that the HR will behave at an increased rate for Tmax-BFR compared to Tmax-TRAD at the same speed. However, at intensity relative to the VT with occlusion, we believe that there may be a change in this HR between the tests. On the other hand, we believe that [La] and the RPE assessed by the Borg scale reach higher values in the Tmax-BFR compared to the Tmax-TRAD, due to the external pressure caused by the cuff. Such events may suggest that vascular occlusion may impact physiological changes, even at lower speeds, minimizing mechanical overload and producing benefits similar to Tmax-TRAD. In addition, changes in HR in Tmax-BFR related to VT may suggest changes in exercise prescription parameters, since there are prescription protocols based on HR.

MATERIALS AND METHODS

Experimental Approach to the Problem

This was a pilot study with crossover designed, with each participant serving as their own control. The subjects (n=5) were underwent a Tmax-BFR (maximum incremental test with blood flow restriction) and, at another time, they were subjected to the Tmax-TRAD (maximum incremental test without blood flow restriction). The order of the protocols was randomly drawn. Therefore, we performed a simple randomization. The procedure used was a coin-tossing. In both conditions, the subjects performed the same protocol for the maximum incremental test, differing in the blood flow restriction only. Conditions were assessed at before, during and after cardiopulmonary exercise testing. The dependent variables were VT, VO_2 max, [La], HR, RPE, speeds and exhaustion time. The independent variables were the maximum incremental test protocols.

Subjects

Seven young male adults, not athletes, were recruited from the community through flyers and advertisements on the internet. Then, the volunteers were screened and established inclusion and exclusion criteria for continuity in the study. We included men, aged between 21-30 years, physically active, assessed through a questionnaire on their level of physical activity (IPAQ-short version), university students, non-smokers, without orthopedic injuries and who did not have possible limitations or restrictions health, assessed by medical record questionnaire (PAR-Q). Individuals who used ergogenic or dietary resources, such as stimulant herbs, steroids or anabolic, who presented some disease that could make physical exercise impracticable (cardiovascular and circulatory diseases) and that showed possible health limitations and restrictions assessed by PAR-Q were excluded.

Experimental procedures and potential risks were explained before the subjects of the research read and signed the Informed Consent Form (ICF). This study was approved by the ethics committee of IPA Methodist University Center with protocol number 2.059.539.

Procedures

Two maximum incremental tests were performed on different days with at least 48 hours apart between visits. However, the participants attended the Exercise Physiology Laboratory at IPA Methodist University Center for 3 days. On the first day, participants' weight and height were assessed using a mechanical anthropometric scale (manual scale, Welmy brand). Then, an anthropometric evaluation was performed based on anatomical markings and on skin fold measurement technique, following the standards of the International Society for the Advancement of kinanthropometry (ISAK). The evaluation was carried out by an experienced evaluator. The difference between the first and second measurements was controlled. When the difference between the two measurements was greater than 5% for the folds or 1% for the other measurements, a third measurement was performed. The final value used for the analysis was the mean between the measurements. The body composition was calculated using a component method²⁶.

The blood pressure (BP) of each participant was measured and used to calculate the cuff fixation to blood flow restriction in the T_{max}-BFR. The BP was recorded in the sitting position after 20 minutes of rest for everyone. Then, with the cuff fixed in the proximal region of the lower limb (upper thigh), we started the determination protocol that consisted of inflating the pressure cuff at a pressure of 20 mmHg above the resting systolic blood pressure (SBP) predetermined^{17,27,28}. In this sense, a partial vascular occlusion occurs, which prevents only the venous flow, while a total occlusion prevents the venous flow and arterial flow. We opted for this protocol as it is a less aggressive intervention. The cuff used was 112 cm long per 16 cm thick (Nylon Cuff - Solidor brand; Porto Alegre, Brazil) and was used by all participants and kept inflated during all tests. A familiarization with the pressure cuff and face mask for capture oxygen uptake, on treadmill, was also performed in the first meeting.

The second meeting consisted of randomization and the realization of the protocol drawn for the day. Finally, after 48 hours, the subject returned to the laboratory to perform the opposite protocol. The test was performed at the same time of day in both conditions to control any possible daytime variation. Participants were instructed not to exercise for 48 hours prior to the tests and did not consume food or drinks in the 3 hours before the protocols, in addition to maintaining their usual food intake^{29,30} including increased shear stress and blood pressure. It is unclear if acute dynamic exercise alters local vascular function. The purpose of this study was to examine the role of exercise hemodynamics on the effects of acute exercise on vascular function, as evaluated by brachial artery flow-mediated dilation (FMD). All tests were performed on the same laboratory mat (model ATL10200 Inbramed, Porto Alegre, Brazil). The ventilation parameters were verified during both conditions by the breath-by-breath method using a circuit spirometry system (VO2000-Aerosport Medical). Finally, a hole for blood collection was made in the participant's ear, using disposable lancets, along with the use of alcohol and cotton to clean the place collected in the tests.

Blood was collected from individuals before, during and after ergospirometry to measure [Ia] concentration using Accutrend Plus Roche lactometer. The time interval used for [Ia] collection was based on the speed increment during the test (every 3 minutes). In both tests, we used a Polar RS100 frequency meter to collect the HR. With each increment in speed, the individual received a Borg scale to inform their perception of effort during the test. The scale used had as maximum level the number-10, which represents the maximum intensity. The Borg CR-10 scale is a general intensity scale for most subjective magnitudes and maybe used to measure effort and pain with the possibility to determine both relative and absolute intensity levels³¹. The VO₂max was determined as the highest value obtained at 30-second intervals during the test³².

Regarding to cardiopulmonary exercise testing, the test started with a 3-minute warm-up at 6 km/h, and immediately after warm-up, it was placed at a speed of 8 km/h so that every 3-minutes the speed was increased by 1 km/h until the participant was exhausted³³.

For the determination of VT, we used as criteria to the reach of first ventilatory threshold (1stVT), the lower workload in the respiratory equivalent of O₂ (VE/VO₂) without a concomitant increase of the

respiratory equivalent of CO₂ (VE/VCO₂)³⁴. For the reach of second ventilatory threshold (2ndVT) we used a lower workload in which VE/VO₂ increased simultaneously, but disproportionately to VE/VCO₂³⁴. In addition, the 1stVT and 2ndVT were also associated with the first and second non-linear increases in the ventilation curve plotted against VO₂ (34). The times and speeds to reach 1stVT (Speed-1stVT), the 2ndVT (Speed-2ndVT) and when reaching the speed of VO₂max (Speed-VO₂max).

At the end of both tests, the VT, VO₂max, [Ia] concentration, HR, Borg scale, speed during the test and maximum test speed were checked and evaluated for comparison of the protocols.

Statistical analysis

Normal distribution of all data was checked for all variables using Shapiro-Wilk test, assuming a homogeneous normal distribution. Regarding to interventions, the outcomes were analyzed using Generalized Estimating Equations (GEE). Comparisons between conditions were made using the Bonferroni test. In addition, Student's t test for Independent Samples was performed for each increment of speed on treadmill test, aiming to compare the heart rate between the conditions. Significantly different values were considered when $p < 0.05$. All data were analyzed using the Statistical Package for Social Sciences (SPSS) 17.0. The GraphPad Prism 8 software was used to generate the graphs.

RESULTS

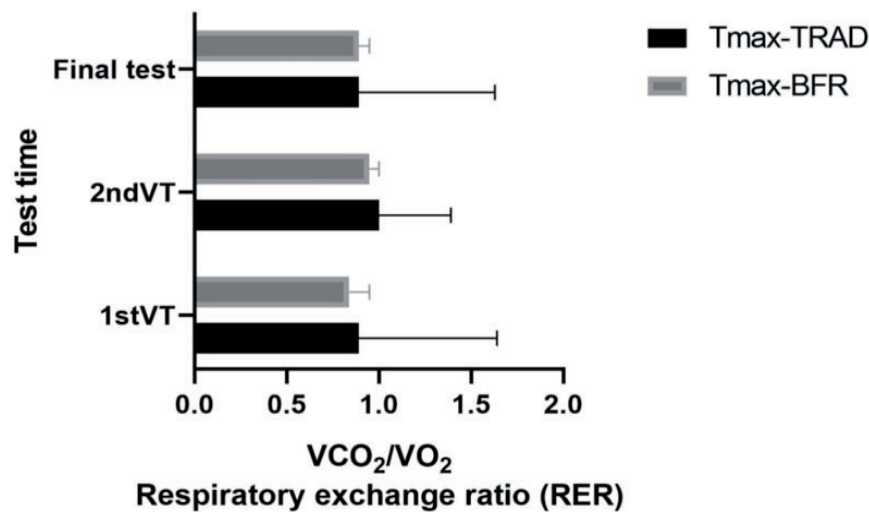
Five subjects completed both protocols. Participant characteristics are presented in table 1.

Table 1. Characterization of the sample (n=5).

Variables	Mean ± SD
Age (y)	22.6 ± 1.1
Height (cm)	170.4 ± 9.1
Body mass (kg)	67.0 ± 16.5
Body mass index (kg/m ²)	22.8 ± 3.1
Rest heart rate Tmax-TRAD	66.4 ± 10.4
Rest heart rate Tmax-BFR	68.6 ± 9.1

All participants were pushed to their performance limit. In this sense, to verify the maximum effort achieved, we measure the respiratory exchange ratio (RER). The RER for both conditions is shown in Figure 1.

Figure 1. Response of the respiratory exchange ratio through the maximum incremental test with blood flow restriction and maximum incremental test without blood flow restriction. 1stVT, First ventilatory threshold; 2ndVT, Second ventilatory threshold; Final test, Respiratory exchange ratio at the time of the test interruption; Tmax-BFR, Maximum incremental test with blood flow restriction; Tmax-TRAD, Maximum incremental test without blood flow restriction. Data expressed as mean and standard deviation (SD).

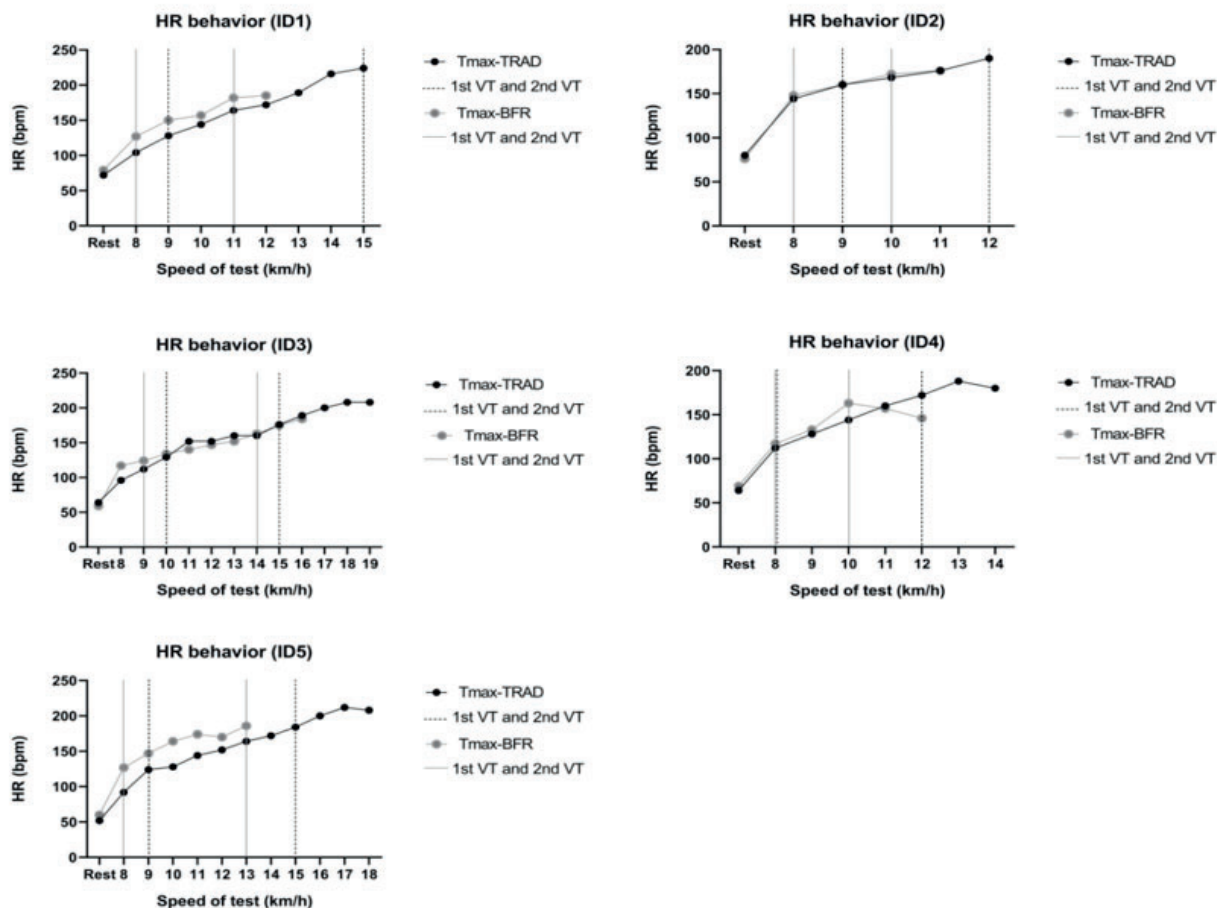


According to the GEE, the [la] concentration was statistically higher in the Tmax-BFR for 1stVT (Tmax-BFR, 3.3 ± 0.5 mmol/L; Tmax-TRAD, 2.8 ± 0.5 mmol/L; $p=0.019$) and in the 2ndVT (Tmax-BFR, 7.5 ± 1.7 mmol/L; Tmax-TRAD, 4.7 ± 1.1 mmol/L; $p=0.005$) when compared to Tmax-TRAD. No significant differences were found in the maximum [la] concentration (Tmax-BFR, 8.0 ± 1.5 mmol/L; Tmax-TRAD, 7.9 ± 1.5 mmol/L; $p=0.893$).

No significant differences were found between the Tmax-BFR and Tmax-TRAD conditions on the 1stVT (Tmax-BFR, 22.80 ± 4.0 ml/kg/min; Tmax-TRAD, 25.6 ± 6.4 ml/kg/min; $p=0.097$), 2ndVT (Tmax-BFR, 39.6 ± 12.0 ml/kg/min; Tmax-TRAD, 42.2 ± 9.0 ml/kg/min; $p=0.062$) and VO_2 max (Tmax-BFR, 52.8 ± 12.0 ml/kg/min; Tmax-TRAD, 55.0 ± 9.9 ml/kg/min; $p=0.061$). However, we observed that the Tmax-BFR reached the ventilatory thresholds and VO_2 max (Speed-1stVT, 8.2 ± 0.5 km/h; Speed-2ndVT, 11.6 ± 1.8 km/h and Speed- VO_2 max, 13.0 ± 2.1 km/h) with lower speeds compared to the Tmax-TRAD (Speed-1stVT, 9.0 ± 0.7 km/h and Speed-2ndVT, 13.8 ± 1.6 km/h and Speed- VO_2 max, 15.6 ± 2.9 km/h), thus obtaining a statistical difference in all observed speeds ($p<0.0001$). In regarding to the time to exhaustion, the Tmax-TRAD had a mean time to exhaustion of 28.80 ± 8.64 minutes, while the Tmax-BFR had a mean time to exhaustion of 21.00 ± 5.61 minutes, with no statistical difference between the conditions ($p=0.129$).

In order to assess HR, it was decided to compare this variable based on the increment in speed on the tests and also on the reach of the VT of each condition. Thus, no matter how much the average HR is higher at each speed in the Tmax-BFR, we did not find any significant difference between the conditions for each speed increment ($p>0.05$). Figure 2 shows the HR behavior of each individual.

Figure 2. Behavior of heart rate per individual at each speed increase between maximum incremental test with blood flow restriction and maximum incremental test without blood flow restriction. 1stVT, First ventilatory threshold; 2ndVT, Second ventilatory threshold; bpm, Beats per minute; HR, Heart rate; ID, Identification / subject; Km/h, Kilometers per hour; Tmax-BFR, Maximum incremental test with blood flow restriction; Tmax-TRAD, Maximum incremental test without blood flow restriction.



However, at an intensity relative to VT between conditions, a significantly lower HR was found for Tmax-BFR in the 2ndVT (Tmax-BFR, 173.2 ± 10.6 bpm; Tmax-TRAD, 189.2 ± 20.7 bpm; $p=0.014$) and when the HR of maximum oxygen uptake ($HR-VO_2max$) was reached (Tmax-BFR, 178.8 ± 9.7 bpm; Tmax-TRAD, 203.6 ± 14.9 bpm; $p<0.0001$). There was no significant difference on 1stVT for HR (Tmax-BFR, 128.6 ± 11.6 bpm; Tmax-TRAD, 130.6 ± 17.8 bpm; $p=0.461$).

In addition, we found no statistical difference between the Tmax-BFR and Tmax-TRAD conditions on the Borg scale for the 1stVT (Tmax-BFR, 3.0 ± 1.6 ; Tmax-TRAD, 3.2 ± 0.8 ; $p=0.818$) and 2ndVT (Tmax-BFR, 7.6 ± 1.7 ; Tmax-TRAD, 7.2 ± 2.8 ; $p=0.791$). However, we observed a significantly smaller difference for the Borg scale at the end of the tests (Tmax-BFR, 9.4 ± 0.5 ; Tmax-TRAD, 10.0 ± 0.0 ; $p=0.006$).

The data from [Ia], VT, VO_2max , speed, HR and Borg scale are showed in Table 2.

Table 2. Description and evaluation of lactate, speeds, oxygen uptake, heart rate and Borg scale between the maximum incremental test with blood flow restriction (n=5) and without blood flow restriction (n=5) by generalized estimating equations.

Variables	Conditions	1 st VT [ρ]	2 nd VT [ρ]	VO ₂ max [ρ]
Lactate (mmol/L)	Tmax-TRAD	2.8 ± 0.5	4.7 ± 1.1	7.9 ± 1.5
	Tmax-BFR	3.3 ± 0.5*	7.5 ± 1.7*	8.0 ± 1.5
	[ρ]	[$\rho=0.019$]	[$\rho=0.005$]	[$\rho=0.893$]
VO₂ (ml/kg/min)	Tmax-TRAD	25.6 ± 6.4	42.2 ± 9.0	55.0 ± 9.9
	Tmax-BFR	22.8 ± 4.0	39.6 ± 12.0	52.8 ± 12.0
	[ρ]	[$\rho=0.097$]	[$\rho=0.062$]	[$\rho=0.061$]
Speed (km/h)	Tmax-TRAD	9.0 ± 0.7	13.8 ± 1.6	15.6 ± 2.9
	Tmax-BFR	8.2 ± 0.5*	11.6 ± 1.8*	13.0 ± 2.1*
	[ρ]	[$\rho<0.0001$]	[$\rho<0.0001$]	[$\rho<0.0001$]
HR (bpm)	Tmax-TRAD	130.6 ± 17.8	189.2 ± 20.7	203.6 ± 14.9
	Tmax-BFR	128.6 ± 11.6	173.2 ± 10.6*	178.8 ± 9.7*
	[ρ]	[$\rho=0.461$]	[$\rho=0.014$]	[$\rho<0.0001$]
Borg Scale	Tmax-TRAD	3.2 ± 0.8	7.2 ± 2.8	10.0 ± 0.0
	Tmax-BFR	3.0 ± 1.6	7.6 ± 1.7	9.4 ± 0.5*
	[ρ]	[$\rho=0.818$]	[$\rho=0.791$]	[$\rho=0.006$]

Values expressed as mean and standard deviation. 1stVT, First ventilatory threshold; 2ndVT, Second ventilatory threshold; bpm, Beats per minute; HR, Heart rate; km/h, Kilometers per hour; mmol/L, Millimoles per litre; ml/kg/min, Milliliters per kilogram per minute; Tmax-BFR, Maximum incremental test with blood flow restriction; Tmax-TRAD, Maximum incremental test without blood flow restriction; VO₂, Oxygen uptake; VO₂max., Maximum oxygen uptake reaches stage. *, Statistically significant difference, $p<0.05$.

DISCUSSION

The main findings of our study were that the Tmax-BFR, at lower speeds, had oxygen uptake and RPE similar to the Tmax-TRAD, however with higher [la] concentrations. In this sense, the Tmax-BFR was able to reach the VT and VO₂max in advance. Furthermore, even with no statistically significant difference, there was a reduction in the test time when performing the Tmax-BFR, which may be interesting in practice. Another important finding was that the behavior of the HR appears to be different between the conditions when analyzed by the intensity relative to the VT. Thus, Tmax-BFR showed lower cardiac effort to achieve similar intensities to the Tmax-TRAD at the 2ndTV and HR-VO₂max.

Aerobic exercise with BFR is an efficient technique, capable of producing results in cardiorespiratory fitness similar to exercises without BFR^{35,36}, however with the advantage of achieving such benefit at lower intensities³⁷. Therefore, we suggest that even when exercising with lower speeds, central adaptations are acquired by reaching VT in advance and with the advantage of reducing mechanical stress. Additionally, when combined with walking, exercise with BFR may simultaneously increase aerobic capacity, muscle strength and muscle size, which would be potentially beneficial for many people²⁷.

Exercise with BFR has become an important health promotion methodology, becoming an alternative training for populations that cannot tolerate high mechanical loads^{38,39}. PubMed and Science Direct databases, including the reference lists of relevant papers. Two independent reviewers extracted study characteristics and MSK and functional outcome measures. Study quality and reporting was assessed using the Tool for the assessment of Study quality and reporting in EXercise. ELIGIBILITY: Search results were limited to exercise training studies investigating BFR training in clinical MSK rehabilitation, published in a scientific peer-reviewed journal in English. RESULTS: Twenty studies

were eligible, including ACL reconstruction (n=3). Its effects are similar to those of high intensity exercises, ensuring increases in aerobic, anaerobic condition and VO_2 max in short periods of exercise, which may generate peripheral and central adaptations^{7,17,19}. However, it is extremely rare to find articles that demonstrate the behavior of T_{max}-BFR in comparison with traditional ergospirometric tests¹⁰. In our study, VT and VO_2 max were not different between T_{max}-BFR and T_{max}-TRAD conditions, but if we observe, the Speed-1stVT and Speed-2ndVT, as well as the Speed- VO_2 max of the test, were lower in the T_{max}-BFR. Therefore, in the T_{max}-BFR, lower speeds generated the same oxygen uptake, and consequently, the same caloric expenditure than T_{max}-TRAD performed at higher speeds. In addition, as shown in Figure 1, the predominant energy substrate remains the same, despite the lower speed. In this way, we were able to achieve, in a more economical way, aerobic, anaerobic and VO_2 max conditions similar to the T_{max}-TRAD. In this sense, clarifying the behavior of T_{max}-BFR at VT and whether speeds influence the condition with BFR in healthy people is of great importance. Thus, for a greater understanding of the method, it is important to investigate subjects who cannot tolerate high training loads, since reaching the VT in advance, by means of lower speeds, suggests possibilities of seeking central and peripheral adaptations with less mechanical stress, which may impact individuals with orthopedic injuries and low level of physical conditioning, thus facilitating a probable adherence to exercise¹¹.

It is also known that the BFR exercise have the capacity to increased HR⁴⁰more recently, the use of low-intensity resistance exercise with blood-flow restriction (BFR, increase the recruitment of fast-twitch muscle fibers⁴¹, intensified the production systemic of hormone⁴⁰more recently, the use of low-intensity resistance exercise with blood-flow restriction (BFR and stimulate physiological adaptation¹¹. The HR has a continuous and gradual increase during the increment in intensity in aerobic exercise⁴²gradual increase in heart rate (HR, however its behavior appears to be greater when adding BFR, even at lower speeds^{8,22,43}. This is due to the reduction in stroke volume, probably due to the decrease in venous return due to the use of the leg cuff⁴⁴. Thus, an action of activation of pressure reflexes stimulates the sympathetic flow, subsequently increasing HR and cardiac contractility⁴⁵. Our study showed that HR response is higher for T_{max}-BFR with each speed increase compared to T_{max}-TRAD, but with no significant difference between conditions. However, when comparing HR relative to VT and VO_2 max, we observed lower values for HR with significant difference in the 2ndVT and in the HR- VO_2 max by T_{max}-BFR compared to T_{max}-TRAD, thus impacting on lower cardiac demand in this condition. We speculate that variations in methods of applying blood flow restriction, such as different brands and sizes of cuffs, different pressures used during the protocol, as well as the size and composition of subjects' limbs, may result in discordant responses across studies⁴⁶. Even so, this finding is important, since there are exercise prescription protocols based on HR, being necessary, greater care regarding the use of the BFR prescribed by the HR.

Finally, it is known that the [la] concentration is generally increased in cases of tissue hypoxia⁴⁷. Therefore, the external compression used in the BFR method is associated with increased lactate production⁴⁸, being able to cause increased muscle activation during low intensity muscle contractions⁴¹. In addition, as it is considered a important method to determine the intensity of transition between the aerobic and anaerobic phase in continuous exercise⁴⁹ and also considering that [la] is higher at each VT in our study, it may be said that the use of the BFR method may provide stimuli for both phases, in addition to being an important indicator of the intensity of physical activity and muscle fatigue^{7,19}. On the other hand, we believe that, despite the influence of external compression in the BFR method, the intensity of the exercise also collaborates to generate an increase or not in the production of [la] compared to the conditions without BFR^{9,21}. In this sense, testing the intensity of exercise with BFR becomes extremely relevant, since [la] is a marker of injury, which may be related to VT and the muscle discomfort index. Additionally, we had no reports of discomfort as measured by the Borg scale between conditions³¹.

Thus, observing the results achieved in populations of young adult men, not athletes, the BFR method may emerge as a possible important tool for people who cannot tolerate high loads caused by high-intensity exercise. Besides, the anticipation of VT, as well as the acute effect of this method on the

parameters evaluated, mainly with regard to HR related to VT and VO_2 max, may suggest a possible change in the exercise prescription¹⁵. Therefore, the importance of this work is substantial, since this is the first study to find lesser effects on HR for the method with BFR when relating this parameter to VT and VO_2 max. However, this study has some limitations. The main one was the low number of participants, so that variations in the individual response may affect the whole. Another limitation was the fact that we did not have a comparison between groups (Tmax-BFR group vs Tmax-TRAD group). Therefore, the comparison was performed between the same subjects (participants serve as their own controls). In this sense, more studies comparing the protocols (two different groups) are needed to confirm these results. Furthermore, to expand on these findings, future studies need to be carried out to identify whether these results also extend to clinical populations.

The results of the present study suggest that Tmax-BFR, even reducing the speed and the total test time, presents a ventilatory pattern similar to the Tmax-TRAD. Another factor to be highlighted was that Tmax-BFR had HR lower than Tmax-TRAD relative to VT (2ndVT and HR- VO_2 max), presenting itself as a favorable strategy for young adult men, not athletes. Thus, the strategy with BFR may emerge as a possibility for the population that does not support higher intensity exercises, in addition to allowing possible changes in exercises prescription based on HR.

CONCLUSION

Because of the low workloads, exercise combined with BFR may be an alternative exercise method for individuals who have some orthopedic¹², cardiovascular, or metabolic limitation⁵⁰. In addition, the Tmax-BFR may also become an alternative method for individuals who are returning from injuries, in rehabilitation, or even in athletes who wish to reduce the loads imposed in planned periods of high loads, also assisting in the exercise prescription processes. Future studies with a larger number of participants and using two different groups are needed to reinforce our findings. From that, it will be possible to expand this methodology in the elderly, rheumatic patients, or patients with endothelial dysfunction.

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Authors' contribution

LPS: Conceptualization, data curation, formal analysis, investigation, methodology, writing - original draft, and writing - review & editing.

TRR: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, writing - original draft, and writing - review & editing.

SVM: Conceptualization, investigation, methodology, writing - original draft, and writing - review & editing.

RCES: Investigation, methodology, and writing - review & editing.

JMG: Conceptualization, investigation, methodology, and writing - review & editing.

JLR: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, writing - original draft, and writing - review & editing.

Conflict of interest

The authors declare no conflict of interest.

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