

Moderate-Intensity Treadmill Walking With Blood Flow Restriction Improves Pulmonary Volumes in Older Adults

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Methods

This study was a prospective quasi-experimental pilot study with repeated measurements at two time points (pre- and post-intervention) separated by a 12-month period. A pre-post design was used to compare changes in the dependent variables both within and between groups. Given the exploratory nature of the study, the sample size was not determined through an a priori power calculation but was based on feasibility and participant availability. The findings were intended to estimate the effect size of blood flow restriction (BFR) on pulmonary volumes and to provide preliminary data for the design of future randomized controlled trials with greater statistical power.

A non-probabilistic convenience sample of 14 physically trained older women (mean age: 68.14 ± 3.59 years) was recruited from Oces Clinic (Metropolitan Region, Santiago, Chile). Participants were randomly allocated into two groups: (i) the Intervention Group ($n = 7$), which performed aerobic exercise based on a modified Bruce treadmill protocol combined with BFR at 30–40% of arterial occlusion pressure; and (ii) the Control Group ($n = 7$), which completed the same protocol without BFR. Both groups participated in the same moderate-intensity aerobic training program for 12 months, with progression and spirometric assessments every three months. Participants progressed to Stage 4 of the modified Bruce protocol by the end of the intervention.

Inclusion criteria were: (i) women aged 60–80 years without a diagnosis of chronic non-communicable diseases; (ii) physically active individuals; (iii) participation in structured exercise programs for at least 3 consecutive months; and (iv) a weekly physical activity volume of ≥ 180 minutes, assessed using the Global Physical Activity Questionnaire (GPAQ). Exclusion criteria included: (i) use of ergogenic aids; (ii) current smoking; (iii) diagnosis of cardiometabolic diseases; (iv) neurological disorders or lower-limb musculoskeletal impairments; and (v) peripheral vascular disease.

All participants were informed about the objectives and procedures of the study and provided written informed consent. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and was approved by a local ethics committee.

Procedures

The intervention lasted 12 months and consisted of three phases: (1) baseline assessments, (2) intervention, and (3) post-intervention reassessment using the same instruments applied at baseline. Assessments included anthropometric measurements such as body mass index (BMI) and mid-thigh circumference, as well as pulmonary function evaluation by spirometry. Baseline hemodynamic parameters, including heart rate (HR), blood pressure

(BP), and arterial occlusion pressure (AOP), were also recorded. Physical activity levels were assessed using the Global Physical Activity Questionnaire (GPAQ) (Cleland et al., 2014). Anthropometric characteristics of both groups are presented in Table 1.

Table 1. Anthropometric Characteristics of Participants

Variable	Intervention Group (Mean $\pm$ SD)	Control Group (Mean $\pm$ SD)
Age (years)	68.57 $\pm$ 4.35	67.71 $\pm$ 2.71
Body Mass (kg)	73.43 $\pm$ 9.43	72.14 $\pm$ 6.03
Height (m)	1.61 $\pm$ 0.03	1.63 $\pm$ 0.02
BMI (kg/m ²)	22.70 $\pm$ 2.95	26.88 $\pm$ 2.62
Thigh Circumference (cm)	54.14 $\pm$ 3.24	55.71 $\pm$ 3.01

Spirometric evaluations were performed every three months throughout the intervention period. Heart rate and blood pressure were monitored during each training session to ensure hemodynamic stability. Hydration status was assessed before and after each session according to the recommendations of the American College of Sports Medicine (Sawka et al., 2007).

Figure 1. Experimental Design

Instruments and Assessment Protocols

Baseline and post-intervention evaluations were conducted using standardized procedures. Resting heart rate was measured after five minutes of seated rest using a Polar® V800 heart rate monitor. Blood pressure was assessed using a Tycos® Mobile Series 767 aneroid sphygmomanometer. Pulmonary function was evaluated through spirometry using a CareFusion® desktop spirometer, following current technical recommendations for spirometry testing in adults.

2.2 Training Program

The training program was performed by both groups for 12 months, with a frequency of three sessions per week. Both groups completed the same training volume, with progressive increases in intensity based on treadmill speed and incline. Training progression was organized into four 3-month phases: T1 (Adaptation), T2 (Moderate Aerobic Walking 1), T3 (Moderate Aerobic Walking 2), and T4 (Moderate Aerobic Walking 3).

In the intervention group, BFR was applied using a 108 $\times$ 10 cm pneumatic cuff (BodyPro®, Kinemax®) positioned at the proximal portion of the thigh, approximately three finger-widths below the gluteal fold. Occlusion pressure was set at 30–40% of arterial

occlusion pressure (AOP), determined using a Tycos® Series 767 aneroid sphygmomanometer and an 8-MHz vascular Doppler probe placed over the posterior tibial artery of the right leg.

The Control Group performed the same aerobic treadmill training protocol (adapted from the Modified Bruce Protocol) without BFR. Both groups completed moderate-intensity aerobic exercise three times per week following the prescribed progression. Adherence was considered satisfactory because all participants completed at least 80% of the scheduled sessions.

Blood Flow Restriction Treadmill Exercise Prescription Model

Variable	Intervention Group (n = 7)	Control Group (n = 7)
Days per Week	Monday–Wednesday–Friday	Monday–Wednesday–Friday
Training Method	Lower-limb BFR methodology (Patterson et al., 2019)	N/A
Physical Capacity	Aerobic	Aerobic
Occlusion Pressure	30–40% AOP	N/A
Restriction Type	Continuous	N/A
Warm-up	Dynamic multi-joint movements and stretching (McMillan et al., 2006)	Same
Warm-up Duration	12 minutes	12 minutes
Training Protocol	Modified Bruce Protocol up to Stage 4	Modified Bruce Protocol up to Stage 4

Note: Cardiopulmonary exercise protocol based on the Modified Bruce Test. Each stage lasted 3 minutes. Speed was expressed in kilometers per hour (km/h) and incline as a percentage (%). N/A = not applicable.

Statistical analyses

Statistical analyses were performed using IBM SPSS® software version 25.0. Data normality was assessed using the Shapiro–Wilk test. Descriptive data are presented as mean $\pm$ standard deviation (SD). For pre- and post-intervention comparisons of spirometric variables, paired Student's t-tests were used when data were normally distributed, whereas the Wilcoxon signed-rank test was applied when the assumption of normality was not met. Additionally, between-group comparisons for body mass index (BMI) and mid-thigh circumference were conducted using the independent samples Student's t-test (parametric) or the Mann–Whitney U test (non-parametric), as appropriate. Statistical significance was established at $p < 0.05$ for all analyses.

Given the exploratory nature of this pilot study, no a priori sample size calculation was performed. A post hoc statistical power analysis was conducted using the observed effect size for FEV₁ in the BFR intervention group (Cohen's $d = 1.91$; baseline vs. 9–12 months). With $\alpha = 0.05$ and $n = 7$ participants per group, the estimated statistical power exceeded 0.85, surpassing the conventional threshold of 0.80 (Cohen, 1988). These findings support the adequacy of the sample size to detect within-group changes of the observed magnitude, while acknowledging that between-group comparisons may have been underpowered. Larger randomized controlled trials are required to confirm these findings.

Results

Both the BFR and Control groups demonstrated a progressive increase in FEV₁ (L) throughout the intervention period. The intervention group exhibited a significant increase in FEV₁ compared with baseline during the first six months of intervention ($p < 0.01$), increasing from approximately 2.2 L at baseline to approximately 3.1 L at 9–12 months, with the greatest improvements observed between months 1–3 and 3–6. The Control group also showed a progressive increase, although of smaller magnitude and without reaching statistical significance at the corresponding time points, increasing from approximately 2.4 L at baseline to approximately 2.9 L at the end of the intervention period. The final comparison between groups was not statistically significant (ns), indicating that although higher values were observed in the intervention group, the difference did not reach statistical significance.

Regarding forced vital capacity (FVC, L), both groups showed a progressive increase throughout the follow-up period. The BFR group demonstrated slightly higher values, increasing from approximately 2.8 L at baseline to approximately 3.0 L at 9–12 months compared with the Control group; however, these differences did not reach statistical significance between groups.

Table 3. Comparison of FEV₁ and FVC between the Blood Flow Restriction Intervention Group and the Control Group during the 12-month intervention period.

Months	BFR-IG (mean $\pm$ SD)	Control group (mean $\pm$ SD)	Within-group p BFR-IG vs. baseline		Within-group p Control vs. baseline		Between-group p	
			FEV ₁	FVC	FEV ₁	FVC	FEV ₁	FVC
Baseline	FEV ₁ : 2.26 $\pm$ 0.39 FVC: 2.22 $\pm$ 0.52	FEV ₁ : 2.49 $\pm$ 0.36 FVC: 2.72 $\pm$ 0.50	—	—	—	—	0.274	0.012 *
1–3	FEV ₁ : 2.48 $\pm$ 0.43 FVC: 2.73 $\pm$ 0.53	FEV ₁ : 2.47 $\pm$ 0.35 FVC: 2.73 $\pm$ 0.50	0.041 *	0.003 **	0.612	0.724	0.963	0.021 *
3–6	FEV ₁ : 2.98 $\pm$ 0.51 FVC: 2.92 $\pm$ 0.54	FEV ₁ : 2.71 $\pm$ 0.39 FVC: 2.75 $\pm$ 0.51	0.003 **	0.018 *	0.184	0.531	0.289	0.556
6–9	FEV ₁ : 3.13 $\pm$ 0.54 FVC: 2.98 $\pm$ 0.55	FEV ₁ : 2.85 $\pm$ 0.41 FVC: 2.75 $\pm$ 0.51	0.002 **	0.021 *	0.143	0.498	0.298	0.433
9–12	FEV ₁ : 3.16 $\pm$ 0.54 FVC: 3.01 $\pm$ 0.56	FEV ₁ : 2.94 $\pm$ 0.42 FVC: 2.81 $\pm$ 0.52	0.001 **	0.028 *	0.047 *	0.312	0.413	0.502

Note: Within-group comparisons were performed using the Wilcoxon signed-rank test (each time point vs. baseline). Between-group comparisons were conducted using the Mann–Whitney U test. * $p < 0.05$; ** $p < 0.01$. SD = standard deviation; FEV₁ = forced expiratory volume in one second; FVC = forced vital capacity; BFR-IG = blood flow restriction intervention group.

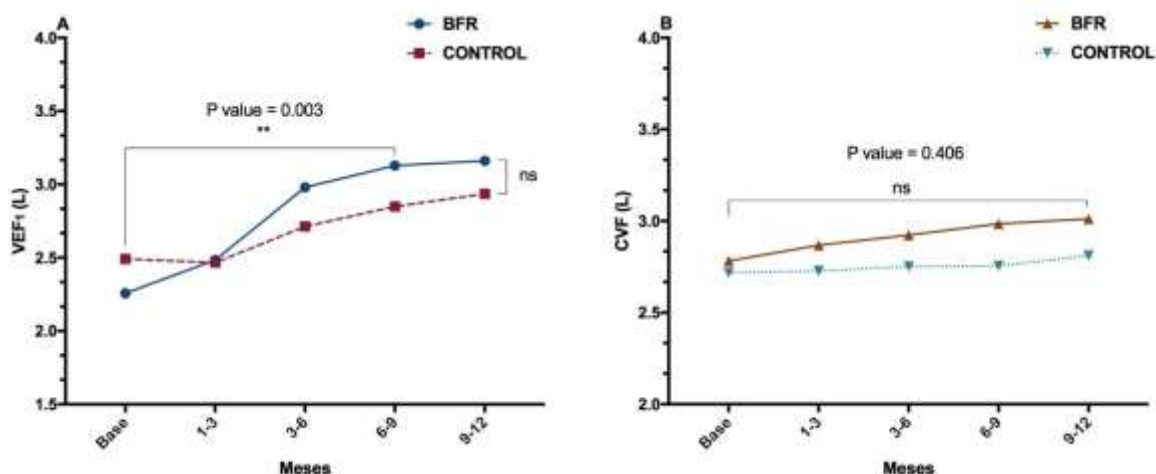


Figure 1. Comparison of FEV₁ and FVC between the Blood Flow Restriction Intervention Group and the Control Group during the 12-month intervention period.