Effect of Concurrent Training with Blood Flow Restriction in the Elderly

Authors

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Key words
- strength training
- vascular occlusion
- interference effect
- aerobic training
- older

Abstract

The aim of this present study was to investigate on the effects of concurrent training with blood flow restriction (BFR-CT) and concurrent training (CT) on the aerobic fitness, muscle mass and muscle strength in a cohort of older individuals. 25 healthy older adults (64.7±4.1 years; 69.33±10.8 kg; 1.6±0.1 m) were randomly assigned to experimental groups: CT (n=8, endurance training (ET), 2 days/week for 30–40 min, 50–80% VO_{2peak} and RT, 2 days/week, leg press with 4 sets of 10 reps at 70–80% of 1-RM with 60 s rest), BFR-CT (n=10, ET, similar to CT, but resistance training with blood flow restriction: 2 days/week, leg press with 1 set of 30 and 3 sets of 15 reps at 20–30% 1-RM with 60 s rest) or control group (n=7). Quadriceps cross-sectional area (CSAq), 1-RM and VO_{2peak} were assessed pre- and post-examination (12 wk). The CT and BFR-CT showed similar increases in CSAq post-test (7.3%, $P<0.001$; 7.6%, $P<0.0001$, respectively), 1-RM (38.1%, $P<0.001$; 35.4%, $P=0.001$, respectively) and VO_{2peak} (9.5%, $P=0.04$; 10.3%, $P=0.02$, respectively). The BFR-CT promotes similar neuromuscular and cardiorespiratory adaptations as CT.

Introduction

Aging is accompanied by a progressive decrease in aerobic fitness, strength and muscle mass [2]. These decrements have been associated with increased incidence of type 2 diabetes [11], cardiovascular disease [30] and risk of accidental deaths from falls [7].

In this regard, the combination of both resistance (RT) and endurance (ET) training has been widely recommended due to its positive effects on the maintenance and/or increase in skeletal muscle mass and strength, and in aerobic fitness [2,4]. Current guidelines state that the ET and RT should be performed at intensities ≥60% of the maximal oxygen consumption (VO_{2max}) and ≥60% of the 1-RM load (high-intensity RT), respectively, in order to improve the function of the cardiovascular and neuromuscular systems [2,4]. However, some studies have shown that the association between high-intensity RT (HI-RT) and ET (i.e. concurrent training – CT) can impair the increase in muscle mass in elderly [17,29], which has been referred to as the interference phenomenon [6]. Accordingly, Sillanpää et al. [29] reported increased lower-limb muscle mass in elderly who performed 21 weeks of RT, but not in those who undertook a CT program. More recently, Karavirta et al. [17] found no increase in type II fiber CSA when RT sessions were alternated with ET. On the other hand, Izquierdo et al. [13] showed increased muscle mass in elderly undergoing CT. Importantly, CT volume was reduced due to a lower total volume of HI-RT (i.e. sets x repetitions x load) per week [13]. Therefore, strategies aimed at reducing the total volume of RT while maintaining its adaptive potential during a combined ET and RT program (CT program) are highly needed for the elderly.

Several studies have reported that low-intensity RT (20% 1-RM) combined with partial blood flow restriction (BFR-RT) is effective at inducing similar gains in muscle strength and mass as compared to conventional HI-RT (80% 1-RM) [20,21]. The low intensity adopted in this training methods is considered to be equivalent to those observed during the activities of daily life (10–30% of maximal work capacity) [1]. This low-intensity approach additional entails a lower risk of injury compared to conventional HI-RT, especially for the elderly [16,28]. Importantly, the lower intensity inherent to BFR-RT also decreases the total volume of RT, which has been suggested to be an important factor in preventing the CT-induced interference phenomenon. Thus, it seems plausible to speculate that the association

accepted after revision
August 14, 2014

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DOI http://dx.doi.org/10.1055/s-0034-1390496
Published online:
February 20, 2015
Int J Sports Med 2015; 36: 395–399 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

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of BFR-RT with ET may blunt the interference phenomenon observed after CT protocols, constituting an interesting and alternative approach to exercise aimed at increasing aerobic fitness, muscle mass and strength compared to regular CT.

Therefore, the aim of the present study was to investigate the effects of an exercise training program associating ET and BFR-RT (i. e. BFR-CT) in comparison with the traditional CT approach (ET + HI-RT) on aerobic fitness, muscle mass and muscle strength among a cohort of older individuals. Our hypothesis was that only the BFR-CT would induce muscle hypertrophy. We additionally hypothesized that both the BFR-CT and CT would produce similar increases in aerobic fitness and muscle strength.

Methods

Participants

25 older individuals (over 60 years of age) volunteered for this study. Inclusion criteria were: a) being considered sedentary or irregularly active according to the international questionnaire of physical activity level [8]; b) being free of cardiovascular and neuromuscular disorders and; c) not being classified as obese ($BMI > 30\,kg \cdot m^2$). The participants were ranked into quartiles according to their muscle strength and CSAq. Participants from each quartile were then randomly assigned to one of the following groups: concurrent training (CT, n = 8, age = 65 ± 3.7 years, weight = 68.2 ± 8.1 kg, height = 1.66 ± 0.1 m, BMI = 24.8 ± 2.6 $kg \cdot m^2$), concurrent training with moderate blood flow restriction (BFR-CT, n = 10, age = 64 ± 4 years, weight = 70.3 ± 8.0 kg, height = 1.63 ± 0.1 m, BMI = 26.3 ± 3.0 $kg \cdot m^2$) and control group (CG, n = 7, n = 8, age = 65 ± 4 years, weight = 69.2 ± 15.1 kg, height = 1.61 ± 0.1 m, BMI = 26.6 ± 4.4 $kg \cdot m^2$). A one-way ANOVA ensured the lack of between-group differences ($P > 0.05$) in the pre-training VO_{2peak}, muscle strength and CSAq values. The study was conducted in accordance with the Declaration of Helsinki, and ethical approval was granted by the ethics committee of the local university. Our study met the ethical standards of the International Journal of Sports Medicine [12].

Study design

This study was designed to test the efficacy of an alternative training model in which older individuals performed BFR-RT instead of regular HI-RT in combination with ET. Before the experimental protocol, quadriceps cross sectional area (CSAq) was obtained through magnetic resonance imaging (MRI). Afterwards, the participants engaged into 2 familiarization sessions to get acquainted with the training protocol and testing procedures. 72 h after the last familiarization session, the participants performed a leg press one-repetition maximum test (1-RM) and a $VO_{2max.}$ test. Participants were then assigned to one of the following groups: a) regular concurrent training group (CT: combination of HI-RT and ET); b) blood-flow restriction CT group (BFR-CT: combination of BFR-RT and ET) and; c) control group (CG). Training was performed 4 days a week (Monday and Thursday – RT and Tuesday and Friday – ET) for 12 weeks. The CSAq, leg press 1RM, and VO_{2peak} were reassessed after the experimental period. The 1-RM and VO_{2peak} were also assessed at mid-point (i. e. after 6 weeks of intervention) to adjust the training load.

Peak oxygen uptake (VO_{2peak})

The participants performed a maximum graded exercise test on a treadmill (Quinton TM55, Bothell, Washington, EUA). Gas exchange data were collected continuously using an automated breath-by-breath metabolic system (CPX, Medical Graphics, St. Paul, Minnesota, USA) [23]. The protocol consisted of a 2-min warm-up at $4\,km \cdot h^{-1}$, followed by increases in increments of $0.3\,km \cdot h^{-1}$ every 30 s until exhaustion. A 1 % grade was used to reproduce athletic track conditions [14]. The highest 30 s mean oxygen consumption value was defined as the peak oxygen consumption (VO_{2peak}), as a VO_2 plateau was not observed in any of the individuals. 3 experienced researchers detected the ventilatory threshold (VT) and respiratory compensation point (RCP) by standard visual analysis [26].

Maximum dynamic strength test (1-RM)

The procedures for the 45° leg press 1-RM test followed previously described criteria [5]. In short, participants performed a general warm-up on a cycle ergometer at $20\,km \cdot h^{-1}$ for 5 min, followed by specific warm-up sets of 45° leg press exercise. In the first set, individuals performed 8 repetitions with a load corresponding to 50 % of their estimated 1-RM, obtained during the familiarization sessions. In the second set, they performed 3 repetitions at 70 % of their estimated 1RM. A 2-min interval was allowed between warm-up sets. After warming-up, the participants performed the leg-press 1-RM test protocol. First, they were seated in the machine and placed both feet in a self-selected position. The area of the leg press platform was divided into 10-cm squares to keep record of the feet location, which was reproduced thereafter. The machine was then unlocked, and the platform was lowered until a relative knee angle of 90° (i. e. measured with a manual goniometer) was obtained. The displacement of the leg press platform was reproduced in each trial by fixing a plastic device on the sliding track of the machine. The repetition started at complete knee extension, and participants lowered the platform until it touched the plastic device and then returned to full extension. Participants had up to 5 attempts to achieve an estimation of the leg press 1-RM. A 3-min interval was enforced between attempts.

Quadriceps cross-sectional area (CSAq)

CSAq was obtained through magnetic resonance imaging (MRI) (Signa LX 9.1, GE Healthcare, Milwaukee, WI, USA). Participants laid on the device in supine position with knees extended. Velcro stripes were used to restrain leg movements during image acquisition. An initial image was captured to determine the perpendicular distance from the greater trochanter to the inferior border of the lateral epicondyle of the femur, which was defined as the segment length. CSAq image was acquired at 50 % of the segment length in 0.8 cm slices for 3 s. The pulse sequence was performed with a view field between 400 and 420 mm, time repetition of 350 ms, eco time from 9 to 11 ms, 2 signal acquisitions, and matrix of reconstruction of 256 × 256. The images were transferred to a workstation (Advantage Workstation 4.3, GE Healthcare, Milwaukee, WI, USA) for CSAq determination. The segment slice was divided into skeletal muscle, subcutaneous fat tissue, bone, and residual tissue. Finally, CSAq was assessed by computerized planimetry on 2 different days, 72 h apart (Typical error $0.36\,cm^2$, 1.69 %).

Concurrent training (CT)

The CT protocol consisted of ET and HI-RT. The ET was performed on a 400-m track. Individuals either walked or ran for 40 min at intensities varying from 60 to 85 % VO_{2peak} (between VT and RCP) throughout the training period. After 6 weeks of training, vol-

Table 1 Training volume (sets × repetitions × load) of concurrent training (CT) and concurrent training with blood flow restriction (BFR-CT) groups in 1–6 and weeks 7–12.

Weeks/Training	weeks 1–6		weeks 7–12	
	CT	BFR-CT	CT	BFR-CT
ET (m)	3522.4 ± 301.5	3359.6 ± 219.3	5056.3 ± 775.9 *	5044.5 ± 611.1 *
RT (kg)	18830.1 ± 5956.1 #	10014.1 ± 4354.9	27611.4 ± 7458.3 #*	17704.2 ± 9440.9 *

* Significantly different from weeks 1 to 6 ($P<0.05$); # Significantly different from BFR-CT group ($P<0.05$); ET volume = total distance in meters (m); RT total volume = set × repetition × load (kg)

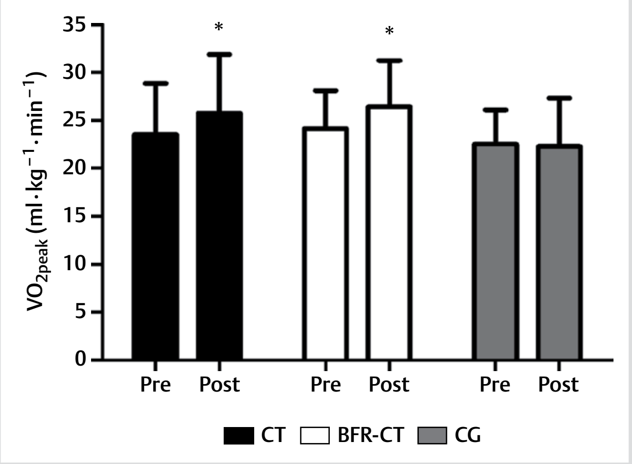

Fig. 1 Peak oxygen uptake (VO_{2peak}) before (Pre) and after (Post) the experimental protocols. * Significantly different from pre- to post-test ($P<0.05$).

ume increased to 50 min. The RT in CT group consisted of 4 × 10 repetitions 70 % 1-RM in the leg press exercise for the first 6 weeks of training (1-min rest between sets). During the remainder of the training period, intensity was increased to 80 % 1-RM.

Concurrent training with blood flow restriction (BFR-CT)

The ET protocol was the same between the 2 training groups. The RT in the BFR-CT group consisted of 1 × 30 repetitions and 3 × 15 repetitions 20 % 1-RM associated with partial blood-flow restriction (i.e. BFR-RT) in the leg press exercise. After the 6th week of training, the exercise intensity was increased to 30 % 1-RM. A 1-min rest interval was allowed between sets. Participants trained with an air cuff placed at the inguinal fold, and a moderate blood-flow restriction was sustained throughout the training session (50 % of the complete occlusion pressure), including the rest intervals. No adverse effects from the blood flow restriction protocol (e.g., excessive fatigue or pain) were reported by any of the participants.

Determination of the blood flow restriction

Individuals in the BFR-CT group were asked to rest comfortably in supine position. A vascular Doppler probe (DV-600; Marted, Ribeirão Preto, São Paulo, Brazil) was placed over the tibial artery to capture its auscultatory pulse. For the determination of blood pressure (mmHg) necessary for complete vascular restriction (pulse elimination pressure), a standard blood-pressure cuff (175 mm (width) 920 mm (length)) was attached to the participant's quadriceps (inguinal fold region) and then inflated up to the point at which the auscultatory pulse was interrupted [10]. The cuff pressure used during the training protocol was determined as 50 % of the necessary pressure for complete blood flow restriction in a resting condition. The average pressure used throughout the training protocol was 67 ± 8.0 mmHg.

Statistical analysis

Data are presented as mean ± standard deviation. Data normality and variance equality were assessed through the Shapiro-Wilk and Levene tests. A mixed model, assuming group and time as fixed factors and subjects as a random factor, was implemented for the analysis of total volume of RT (sets x repetitions x load) and volume of ET (distance in meters), VO_{2peak}, leg press 1-RM, and CSAq. In case of significant F-values a Tukey adjustment was used for multiple comparison purposes. The significance level was set at $P<0.05$.

Results

Training volume

Table 1 shows the difference in training volume between the 2 training groups. Total RT volume (sets x repetitions x load) in the BFR-CT was lower than in the CT group (41 % from week 1 to 6, $P=0.02$ and 34 % from week 7 to 12, $P=0.02$). No significant differences in ET volume were detected between the 2 groups ($P>0.05$). Both groups showed significantly increased ET (CT: 43.1 % and BFR-CT: 49.7 %; $P<0.0001$) and RT (CT: 40.5 % and BFR-CT: 69.6 %, $P<0.0001$) volumes throughout the training period (when comparing weeks 1–6 and 7–12).

Peak oxygen uptake (VO_{2peak})

The CT and BFR-CT groups showed significantly increased VO_{2peak} from pre- to post-test (9.5 %, $P=0.04$ and 10.3 %, $P=0.02$, respectively) (**Fig. 1**). No significant differences in VO_{2peak} values were detected between groups at the post-test ($P>0.05$). No significant difference was observed in VO_{2peak} from pre- to post-test in the CG (−1.1 %, $P>0.05$).

Maximum dynamic strength test (1-RM)

Both the CT and BFR-CT groups increased the leg press 1-RM values from pre- to post-test (38.1 %, $P<0.001$ and 35.4 %, respectively; $P=0.001$) (**Fig. 2**), but no differences were detected between the 2 groups at post-test ($P>0.05$). There were no significant changes in leg press 1-RM for the CG from pre- to post-test (−4.3 %, $P>0.05$).

Quadriceps cross-sectional area (CSAq)

The CT and BFR-CT groups showed significant increases in CSAq from pre- to post-test (7.3 %, $P<0.0001$ and 7.6 %, $P<0.0001$, respectively) (**Fig. 3**). No between-group differences were observed in the post-test ($P>0.05$). No significant difference was observed in CSAq from pre- to post-test in the CG (−2.2 %, $P>0.05$).

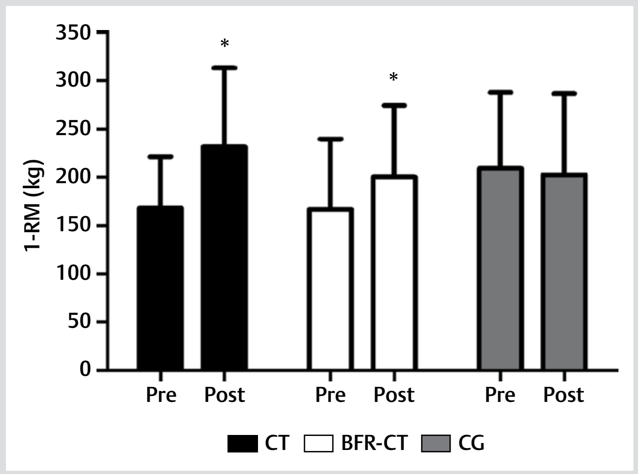

Fig. 2 Maximum dynamic strength test (1-RM) before (Pre) and after (Post) the experimental protocols. * Significantly different from pre- to post-test ($P<0.05$).

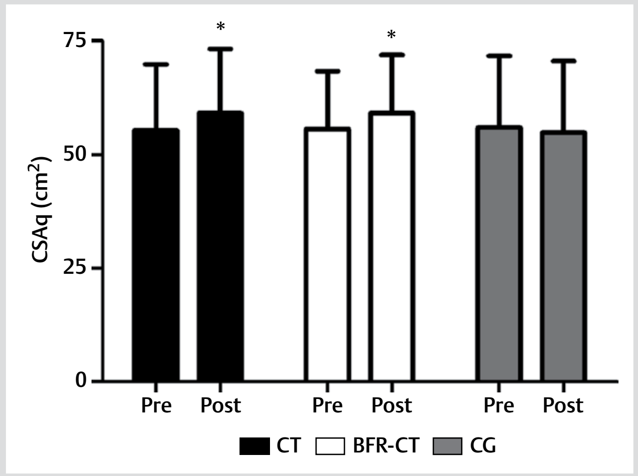

Fig. 3 Quadriceps cross-sectional area (CSAq) before (Pre) and after (Post) the experimental protocols. * Significantly different from pre- to post-test ($P<0.05$).

Discussion

The American College of Sports Medicine recommends performing endurance training (ET) and high-intensity resistance training (HI-RT) concomitantly to improve aerobic fitness, strength, and muscle mass in the elderly [2,4]. The present study aimed at investigating the effects of ET combined with low-intensity RT associated with partial blood-flow restriction (RT-BFR) as an alternative model to the traditional recommendation (i.e. ET+HI-RT) [2]. The main findings of the present study were that the VO_{2peak}, muscle strength and CSAq were similarly improved between the 2 training methods.

Regarding the improvements in aerobic fitness, our data are in accordance with previous findings that have shown increases in VO_{2peak} after traditional CT (i.e. ET combined with HI-RT) [17,29]. Similarly, Karavirta et al. [17] showed a 10% increase in VO_{2peak} after 21 weeks (40–90 min of ET at an intensity with an aerobic and anaerobic threshold) of CT. In the present study, both the CT and BFR-CT groups performed similar ET intensities (60–85% VO_{2peak}) and volumes (60 min, ~4245.7 m per session), resulting in comparable improvements in VO_{2peak} (9.5 and 10.3%, respectively). These findings support the incorporation of ET associated with either HI-RT or BFR-RT in exercise training routines aimed at improving aerobic fitness in the elderly. This is of particular interests as older individuals that show higher VO_{2peak} values are at a lesser risk of developing metabolic syndrome [15,35], diabetes [18] and cardiovascular diseases [19].

Muscle strength has also been show to decrease with aging [9]. In this respect, HI-RT (i.e. ≥60% 1-RM) has been widely recommended in order to offset some of the age-related loss in muscle function [2]. Previous studies reported similar increases in muscle strength after traditional CT when compared to isolated HI-RT in older adults [17,29]. For instance, Sillanpää et al. [29] showed similar increases in lower-limb muscle strength after 21 weeks of either CT or HI-RT (17 and 15%, respectively). In the present study, we also found a similar increase in muscle strength between the CT (38.1%) and BFR-CT (35.4%) groups. Importantly, the BFR-CT group pursued lower-intensity RT as well as lower total volume of RT compared to the CT group. This is probably due to fatigue in BFR-RT during BFR-CT, which can increase the recruitment of muscle fibers, in particular type II fibers [31–33]. Suga et al. [31] showed that the recruitment of fast-twitch fiber, evaluated by Pi-splitting, was induced by supplementing the low-intensity resistance exercise with blood flow restriction. In addition, the study also showed that recruitment of fast fibers in BFR-RT was similar to HI-RT [31]. The mechanism by which fatigue can increase the recruitment of motor units is not well understood. It is suggested that the partial restriction of blood flow during RT causes low oxygen supply to the active skeletal muscle [34], promoting increased metabolite accumulation and decreased intramuscular pH. This in turn results in altered motor unit firing rate and recruitment patterns [32], leading to neuromuscular adaptations and increased muscle strength.

The reduction in functionality during aging is also associated with a progressive decline in muscle mass [22]. Adults appear to lose only 5–10% of muscle mass from ages 20 to 50. However, losses are much greater from the ages 50 to 80, ranging from 30–40% [22]. To minimize such losses and also to promote muscle hypertrophy, HI-RT has been extensively recommended [2–4]. However, when HI-RT is associated with ET (i.e. CT), impairments in muscle hypertrophy are thought to occur [17,29]. This interference phenomenon seems to be related to greater total volumes of HI-RT. In this regard, Izquierdo et al. [13] found a significant increase in muscle mass after a low-volume HI-RT+ET training. In the present study, total RT volume was different across conditions. The BFR-CT showed a lower total volume of RT compared the CT group. However, contrary to our initial hypothesis, both training methods were equally effective in increasing muscle mass in the elderly (BFR-CT: 7.6% and CT: 7.3%). Notwithstanding the fact that the total volume of RT was ~37.5% higher in the CT than in the BFR-RT group, it was still lower than those observed in previous studies that found a blunted hypertrophy response when combining HI-RT and ET in older individuals [17,29]. It is therefore possible that a low total volume of either HI-RT or BFR-RT is required to avoid the interference phenomenon associated with ET. Although similar results were found between the 2 training methods, the lower lifting loads employed in the BFR-CT groups entails less mechanical stress on the knee joints, which may confer an interesting advantage for the elderly, especially those with joint problems.

The equipment used in our BFR-model is an adapted sphygmomanometer that is able to restrict the thigh blood flow. Thus, this simple and inexpensive device may be used in health clubs, fitness clubs, and so on. This suggestion is further supported by the fact that a couple large-scale studies have attested to the safety of BFR-RT method, even for the elderly [25,27,36]. Furthermore, muscle damage resulting from BFR-RT seems to be minimal, as evidenced by the small decrease in muscle function and increase in muscle soreness after its execution [24]. Minimizing these 2 factors can be particularly important for the elderly, as it enables the maintenance of daily life activities without increasing the risk of injury due to falls caused fatigue and muscle weakness.

In conclusion, we reported that aerobic fitness, strength, and muscle hypertrophy were similarly increased following the combination of ET with either HI-RT (traditional CT) or BFR-RT (BFR-CT). Our findings suggest that BRF-CT may be an effective alternative approach to the current recommendations regarding exercise prescription for the elderly.

Acknowledgements

This study was funded by National Counsel of Technological and Scientific Development – CNPq.

Conflict of interest: The authors declare that they have no conflict of interest.

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