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Effects of strength training with continuous or intermittent blood flow restriction on the hypertrophy, muscular strength and endurance of men

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ABSTRACT. The aim of the present study was to compare the effects of strength training (ST) with continuous or intermittent blood flow restriction (BFR) on the muscle hypertrophy (MH), dynamic muscle strength (DMS), isometric muscle strength (IMS) and localized muscular endurance (LME) of healthy men. Twenty-five men with experience in ST were randomly divided into 3 experimental groups: a) 4 low-load exercises at 20% of the one-repetition maximum (1RM) combined with continuous BFR (LL+CBFR), b) 4 low-load exercises at 20% of 1RM combined with intermittent BFR (LL+IBFR); and c) 4 low-load exercises at 20% of 1RM without BFR (LL). Twelve sessions of ST were performed (twice a week for 6 weeks). There were no differences between groups for all variables ($p > 0.05$). However, there were significant differences in time for the LME in the triceps pulley only in the LL+CBFR group ($p < 0.001$) and in the biceps pulley in the groups LL+CBFR, LL+IBFR and LL ($p < 0.001$, $p = 0.002$, $p = 0.032$), respectively, with large magnitudes only for the two forms of the BFR. It can be concluded that continuous or intermittent BFR seems to be a good alternative for the increase of the LME of the upper limbs in single-joint exercises.

Keywords: exercise; muscle strength; therapeutic occlusion; ischemia.

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Introduction

The American College of Sports Medicine recommends the practice of strength training (ST) with loads equal to or greater than 65% of a one-repetition maximum (1RM) for increased muscle strength and hypertrophy (American College of Sports Medicine [ACSM], 2009). However, seniors or people with special needs are less tolerant to high load percentages. In this context, some researchers have used an ST method called KAATSU training, which consists of the use of low-loads (20-30% of 1RM) in combination with blood flow restriction (BFR) promoted through standard cuffs (Sato, 2005). This method has been used to increase muscle hypertrophy (Laurentino et al., 2012; Vechin et al., 2015), muscle strength (Laurentino et al., 2012; Silva et al., 2015; Vechin et al., 2015; Sousa et al., 2017) and localized muscle endurance (LME) (Kacin & Strazar, 2011; Gil et al., 2017; Sousa et al., 2017). In addition, it has been used to increase functional capacity (Araujo et al., 2015) and isometric force (Chaves et al., 2016) and has been shown to be safe in relation to hemodynamics (Araújo et al., 2014; Neto et al., 2015; 2016a; 2016b; Vilaça-Alves et al., 2016; Neto et al., 2017a; 2017b).

In recent years, this method of ST has gained more notoriety in the scientific community; thus, several studies have been developed with the aim of understanding all of the procedures inherent to its application, with respect to safety, efficacy and adherence. As an example, one can observe the intensity of the load used (Suga et al., 2010), the cuff size (Rossow et al., 2012), the pressure used (Sumide, Sakuraba, Sawaki, Ohmura, & Tamura, 2009) and the form of application of BFR (continuous or intermittent) (Suga et al., 2012; Yasuda, Loenneke, Ogasawara, & Abe, 2013; Fitschen et al., 2014; Brandner, Kidgell, & Warmington, 2015; Neto et al., 2016a; 2017b; 2018). Among the studies that evaluated the application of BFR, only one study analyzed muscle strength and hypertrophy (Fitschen et al., 2014); however, this study used only one exercise with unilateral and single-joint execution. Although some studies have shown no significant differences between continuous and intermittent BFR in the muscle strength and hypertrophy of lower limbs (Fitschen et al., 2014), the muscle activation of the upper limbs (Yasuda et al., 2013) and the hemodynamics of the upper limbs (Neto et al., 2016a; 2017b), the best strategy for ST sessions combined with BFR (continuous or intermittent) with the aim of increasing muscle hypertrophy (MH), dynamic muscular strength (DMS), isometric muscle strength (IMS) and localized muscle endurance (LME) of the upper limbs has still not been defined.

Thus, upon reviewing the relevant literature, it was observed that continuous BFR promotes higher metabolic stress compared with intermittent BFR (Suga et al., 2012), further increasing the sensation of pain during the exercise sessions (Fitschen et al., 2014), which allows the increase in hemodynamics (Neto et al., 2016a; 2017a; 2017b). This effect may influence training adherence for people with special needs; however, studies analyzing ST sessions with BFR (continuous or intermittent) with apparently healthy people are needed, followed by studies with special populations.

Considering the above, the hypothesis of the present study was that there would be no significant differences in MH, DMS, IMS and LME between the groups with continuous and intermittent BFR. Therefore, the aim of the present study was to compare the effects of ST with continuous or intermittent BFR on the MH, DMS, IMS and LME of healthy men.

Material and methods

Participants

Twenty-five men aged 18-36 years with experience in ST (practice time ⩾ 2 months and ⩽ 12 months) participated in the study (Table 1). The sample size was performed using *G*Power* 3.1 software (Faul, Erdfelder, Lang, & Buchner, 2007). Based on an a *priori* analysis, an N of 24 individuals was calculated, after adopting a power of 0.80, α = 0.05, a correlation coefficient of 0.5, a nonsphericity correction of 1 and an effect size of 0.35. It was verified that the 24 subjects were sufficient to provide 82.1% of the statistical power. As the study ultimately included 25 subjects, the *post hoc* analysis verified that the sample size was sufficient to provide 84.0% of the statistical power. For the calculation of the sample, the procedures suggested by Beck (2013) were adopted.

Subjects with an age range between 18 and 40 years old who responded negatively to all items of the *Physical Activity Readiness Questionnaire*/PAR-Q (Shephard, 1988), who had a body mass index less than 30 m^2 kg^{-1}, who had not presented any type of musculoskeletal lesion history in the upper limbs in the last 6 months and who were non-smokers were included in the study. Those who missed two consecutive sessions were excluded from the study. After explaining the risks and benefits of the research, the subjects signed an informed consent form elaborated according to the Helsinki Declaration. The study was approved by the local Ethics Committee (protocol nº 0476/13).

During the first and last visits to the laboratory, the following procedures were performed: initially, anthropometry (muscular hypertrophy) was assessed; then it was assessed 5 min. after the BFR point; after 15 to 20 min., isometric muscle strength (IMS) was assessed; then, after 3-5 min., evaluations of the maximum dynamic muscular strength (1RM) of each exercise (bench press, front pull down, triceps pulley, and pulley biceps curl, respectively) began; the evaluation of localized muscular endurance (LME) of the 4 exercises was then performed after 40-60 min. Twelve training sessions (twice a week) were performed between the two collections that took place during the first and last visits to the laboratory. The first session occurred 72 hours after the first visit (pre-test), and the last session occurred 72 hours before the last evaluation (post-test) (Figure 1). The 3 study groups performed the following routines: a) low-load ST at 20% of 1RM combined with continuous blood flow restriction (LL+CBFR), b) low-load ST at 20% of 1RM combined with intermittent blood flow restriction (LL+IBFR) and c) low-load ST at 20% of 1RM without BFR (LL). During the study, participants were instructed to refrain from exercising their upper limbs or ingesting nutritional supplements.

Procedures

Anthropometric evaluation and muscular hypertrophy

Initially, a scale (model 7755 Soehnle Professional®, Germany) was used to measure body mass, and a portable stadiometer (WCS, Cardiomed®, Brazil) was used for height measurement; these statistics were measured with accuracies of 0.1 kg and 0.5 cm, respectively. These measures were later used to obtain the body mass index (BMI) in m^2 kg^{-1}. Muscle hypertrophy (cross-sectional area of the arm) was assessed by means of the anthropometric measures of circumferences of both relaxed arms, as recommended by Frisancho (1974, 1981) by the circumference of both arms contracted and by the circumference of the thorax at expiration. All of these measures were standardized according to ACSM recommendations (2011) and were always measured by the same experienced evaluator. All evaluations were performed by an evaluator with more than 10 years of experience.

Determination of the blood flow restriction point

The total blood flow restriction was obtained by vascular Doppler (MedPeg® DV -2001, Ribeirão Preto, State São Paulo, Brazil), in which the probe was placed on the radial artery (right and left arm) to determine blood pressure (mm Hg) during training. The participants were placed in the supine position, and a standard blood pressure cuff (Riester komprimeter pneumatic tourniquet to restrict blood flow circulation in the limbs) for the upper limb (width 60 mm, length 470 mm) was placed in the region of the axillary fold and was inflated to the point at which the auscultatory pulse of the radial artery was interrupted. The cuff pressure used during exercise was determined at 80% of the pressure required for the total restriction of blood flow in the resting state (Laurentino et al., 2012). The cuff was maintained (CBFR) and deflated (IBFR) between sets.

Isometric muscle strength

After determination of the BFR point, the isometric strength was measured by means of manual dynamometry (right and left) and scapular dynamometry tests. For the manual dynamometry test, the CROW® Dynamometer with a capacity of 50 kgf was used. The participant was situated in a standing position with elbows extended along the body, with forearms in slight pronation and fists in the neutral position. The volunteer was then instructed to apply a maximum and brief force in each of their hands, 3 times. The best result of 3 attempts in each hand was computed. For the scapular dynamometry test, the CROW® Dynamometer with a capacity of 50 kgf was used. The participant was situated in a standing position with shoulder abduction of less than 90º, elbow flexed, forearm in the neutral position, wrist slightly extended, thumb and fingers touching; when instructed by the evaluator, a retraction of the shoulder blade was performed. The best result of 3 attempts was computed.

Maximum dynamic muscle strength (1RM)

The evaluation of the maximum dynamic force/training load was evaluated through the 1RM test. The 3 groups performed 4 exercises in a bilateral manner: bench press, front pull-down, triceps pulley and pulley biceps curl. A 5 min. pattern was used for recovery time between exercises. Initially, each individual performed a warm-up with a series of 5 to 10 repetitions at 40 and 60% of the maximum perceived strength. After a 1 min. interval, the s series was performed, with between 3 and 5 repetitions at 60-80% of the maximum perceived strength. After 1 min. of rest, the force evaluation was started and was measured in up to 5 attempts, with the load adjusted before each new attempt. The recovery duration between attempts was standardized to 3-5 min. The test was interrupted when the individual could not execute the movement correctly, and the maximum load was considered the one mobilized in the last successful attempt.

Table 1. Characteristics of the subjects.

	LL+CBFR = 09	LL+IBFR = 08	LL = 08	p
Age (years)*	26.1 ± 5.0	23.8 ± 5.6	22.2 ± 3.5	0.277
BM (kg)*	67.5 ± 9.7	79.2 ± 9.3	78.0 ± 10.9	0.045
Height (m) *	1.71 ± 0.05	1.75 ± 0.07	1.75 ± 0.06	0.443
BMI (kg m^{-2})*	22.8 ± 2.2	25.8 ± 3.0	25.2 ± 2.4	0.054
PRLABF (mm Hg)†	108.8 ± 9.2	117.5 ± 10.3	-	0.090

*Differences by one-way ANOVA; †differences by independent t test; BM = body mass; BMI = body mass index; PRLABF = mean pressure used in restricting left arm blood flow; LL+CBFR = low load combined with continuous blood flow restriction; LL+IBFR = low load combined with intermittent blood flow restriction; LL = low load.

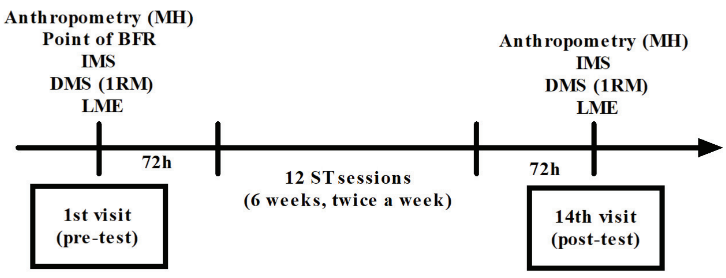

Figure 1. Experimental design. MH = muscle hypertrophy; BFR = blood flow restriction; IMS = isometric muscular strength; DMS = dynamic muscular strength; LME = localized muscular endurance; ST = strength training.

Localized Muscular Endurance (LME)

The LME was calculated by the maximum number of repetitions performed in the 4 exercises during a series with a fixed load of 40% of 1RM. The joint amplitude of the shoulder ranged from 90º to approximately 120º for bench press; the shoulder joint amplitude ranged from 180º to approximately 45º for the front pull-down; the joint amplitude of the elbow ranged from 90º to 0º for the triceps pulley; and the joint amplitude of the elbow ranged from 0º to approximately 145º for the pulley biceps curl. The velocity was controlled by a metronome, with a total execution time of 3 s (1.5 s for concentric action and 1.5 s for eccentric action) until the moment concentric failure occurred. When the participant could not maintain the cycle of repetitions within the series at the established cadence and amplitude, the concentric point of failure was determined, and the largest number of repetitions performed successfully was computed.

Training sessions

Twelve sessions were performed with bilateral execution: bench press (with conventional bar and calibrated weights), front pull-down, triceps pulley and pulley biceps curl (in conventional machines). The participants were randomly divided into 3 experimental groups with different interventions: a) 4 exercises at 20% of 1RM combined with continuous BFR (LL+CBFR); b) 4 exercises at 20% of 1RM combined with intermittent BFR (LL+IBFR) and c) 4 exercises at 20% of 1RM without BFR (LL). For the 3 groups, participants completed 4 sets of 15 repetitions, using 20% of 1RM with 30 s intervals between all sets and 1 min. between exercises. The groups with BFR used a standard blood pressure cuff (Riester komprimeter pneumatic tourniquet to restrict blood flow circulation in limbs) in the arms (width 60 mm, length 470 mm) placed in the most proximal region. For the LL+IBFR group, the cuff was deflated between the series, and for the LL+CBFR group, the cuff was kept inflated between the series; the cuff was always deflated at the end of each exercise. The execution speed for the 3 groups was set at 3 s (1.5 for the concentric muscular action and 1.5 for the eccentric muscular action) controlled by means of a metronome.

Total training volume

To calculate the total working volume (TV), the load was multiplied by the number of series and complete repetitions of all sessions of the 4 exercises (sessions x load x series x repetitions).

Statistical analysis

Statistical analysis was performed initially by the Shapiro-Wilk normality test and the Levene homogeneity test. The variables showed normal distribution and homogeneity ($p > 0.05$). One-way ANOVA followed by the Bonferroni post hoc test was used to compare the totals for amount of exercise, age, body weight, height and BMI between groups, and the independent t test was used to compare the BFR pressures used in the LL+CBFR and LL+IBFR groups. Two-way ANOVA followed by the Bonferroni post hoc test was used to analyze possible differences in the MH, DMS, IMS and LME variables. One-way ANOVA was used for the circumference of the thorax variable in which the groups departed from different conditions; the delta variation (Post-Pre) was calculated. The effect size (ES) was used to verify the magnitudes [trivial < 0.50, small = 0.50-1,25, moderate = 1.25-1.9 and large > 2.0] of the significant changes between the assessments of the study groups (Rhea, 2004). The level of significance was set at $p < 0.05$. All statistical analyses were performed using the statistical software SPSS version 20.0 (SPSS Inc., Chicago, IL).

Results

Muscular hypertrophy

In the comparative analysis of right arm MH, there were no significant interactions between group x time ($F = 0.037$, $\eta^2 = 0.002$, $p = 0.964$), in the group ($F= 2.668$, $\eta^2 = 0.108$, $p = 0.081$) and time ($F = 0.007$, $\eta^2 < 0.001$, $p = 0.933$). In the comparative analysis of MH of the left arm, there were no significant interactions between group x time ($F = 0.069$, $\eta^2 = 0.003$, $p = 0.934$), in the group ($F = 2.254$, $\eta^2 = 0.093$, $p = 0.117$) and time ($F = 0.026$; $\eta^2 = 0.001$; $p = 0.872$). The comparative analysis of the circumference of the contracted right arm showed that there were no significant interactions between group x time ($F = 0.066$; $\eta^2 = 0.003$; $p = 0.936$), in the group ($F = 2.011$; $\eta^2 = 0.084$; $p = 0.146$) and time ($F = 0.388$; $\eta^2 = 0.009$; $p = 0.536$). The comparative analysis of the circumference of the left contracted arm showed that there were no significant interactions between group x time (F = 0.023; η^2 = 0.001; p = 0.977), in the group (F = 2.029; η^2 = 0.084; p = 0.144) and time (F = 0.517; η^2 = 0.012; p = 0.476). The comparative analysis of chest circumference showed that there were no significant interactions between group x time (F = 0.025; η^2 = 0.001; p = 0.975) and time (F = 0.096; η^2 = 0.002; p = 0.759); however, there were significant interactions in the group (F = 5.539, η^2 = 0.201, p = 0.007). In the inter-group analysis by one-way ANOVA, it was observed that there were no significant differences between groups (p = 0.532) (Table 2).

Maximum dynamic muscle strength (1RM)

In the comparative analysis of DMS of the bench press exercise, there were no significant interactions between group x time (F = 0.067, η^2 = 0.003, p = 0.935), in the group (F = 0.208, η^2 = 0.009, p = 0.813) and time (F = 0.089; η^2 = 0.002; p = 0.767). In the comparative analysis of DMS of front pull-down exercise, there were no significant interactions between group x time (F = 0.107, η^2 = 0.005, p = 0.899), in the group (F = 0.370, η^2 = 0.017, p = 0.693) and time (F = 0.431; η^2 = 0.010; p = 0.515). In the comparative analysis of DMS of the triceps pulley exercise, it there was no significant interactions between group x time (F = 0.102; η^2 = 0.005; p = 0.903), in the group (F = 0.132; η^2 = 0.006; p = 0.876) and time (F = 0.241; η^2 = 0.005; p = 0.626). In the comparative analysis of DMS of exercise, pulley biceps curl, there were no significant interactions between group x time (F = 0.055, η^2 = 0.002, p = 0.947), in the group (F = 0.191, η^2 = 0.009, p = 0.827) and time (F = 0.739, η^2 = 0.017, p = 0.395) (Table 3).

Isometric muscle strength

In the comparative analysis of the IMS of the right arm, there were no significant interactions between group x time (F = 0.029, η^2 = 0.001, p = 0.971), in the group (F = 1.253, η^2 = 0.054, p = 0.296) and time (F = 1.642; η^2 = 0.036; p = 0.207). The comparative analysis of the left arm IMS showed that there were no significant interactions between group x time (F = 0.108; η^2 = 0.005; p = 0.897), in the group (F = 0.545; η^2 = 0.024, p = 0.584) and time (F = 1.018; η^2 = 0.023; p = 0.318). In the comparative analysis of the scapular IMS, there were no significant interactions between group x time (F = 0.068, η^2 = 0.003, p = 0.935), in the group (F = 2.613, η^2 = 0.106, p = 0.085) and time (F = 0.294, η^2 = 0.007, p = 0.591) (Table 4).

Localized muscle endurance

In the comparative analysis of LME of the bench press exercise, there were no significant interactions between group x time (F = 0.087, η^2 = 0.004, p = 0.917), in the group (F = 0.989, η^2 = 0.043, p = 0.380) and time (F = 2.805; η^2 = 0.060; p = 0.101). In the comparative analysis of LME of the front pull-down exercise, there were no significant interactions between group x time (F = 0.158, η^2 = 0.007, p = 0.855) and in the group (F = 2.454, η^2 = 0.100, p = 0.098); however, there was a significant difference in time (F = 5.000, η^2 = 0.102, p = 0.030). In the intragroup analysis, there were no significant differences in the groups, but the effect sizes were LL+CBFR = 0.62, LL+IBFR = 1.05 and LL = 0.62. In the comparative analysis of the LME of the triceps pulley, there were no significant interactions between group x time (F = 3.060, η^2 = 0.122, p = 0.057) and in the group (F = 1.615, η^2 = 0.068, p = 0.210); however, there was a significant difference in time (F = 13.544, η^2 = 0.235, p = 0.001). In the intragroup analysis, there were significant differences only in the LL+CBFR group (p < 0.001, ES = 2.31, Magnitude: large), the other groups presented the following ES (LL+IBFR = 0.57 and LL = 0.39). In the comparative analysis of the LME of the pulley biceps curl exercise, there were no significant interactions between group x time (F = 0.886, η^2 = 0.039, p = 0.419) and in the group (F = 1.451, η^2 = 0.062, p = 0.245); however, there was a significant difference in time (F = 32.018, η^2 = 0.421, p < 0.001). In the intragroup analysis, there were significant differences only in the 3 groups (LL+CBFR [p < 0.001, ES = 2.63, Magnitude: large], LL+IBFR [p = 0.002; ES = 2.10; Magnitude: large] LL [p = 0.032, ES = 1.26, Magnitude: moderate]) (Table 5).

Table 2. Comparative analysis of muscular hypertrophy (MH) between groups at pre- and post-test moments.

Variables	LL+CBFR		LL+IBFR		LL	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
RAMH (cm^2)	75.6 ± 12.4	75.2 ± 10.3	85.7 ± 17.7	87.6 ± 19.0	82.4 ± 11.4	82.0 ± 13.3
LAMH (cm^2)	75.8 ± 12.5	75.0 ± 10.4	84.2 ± 16.8	86.8 ± 19.1	81.9 ± 11.5	82.1 ± 12.7
CCRA (cm)	32.3 ± 2.1	32.8 ± 1.6	34.0 ± 3.7	34.8 ± 3.3	33.6 ± 2.6	33.8 ± 2.6
CCLA (cm)	32.1 ± 2.0	32.7 ± 1.8	33.9 ± 3.6	34.7 ± 3.7	33.4 ± 2.5	33.8 ± 2.6
CT (cm)	91.6 ± 7.1	92.0 ± 6.7	97.7 ± 4.3	98.7 ± 5.4	96.7 ± 5.7	96.7 ± 5.0

RAMH = right arm muscular hypertrophy; LAMH = left arm muscular hypertrophy; CCRA = circumference of the contracted right arm; CCLA = circumference of the contracted left arm; CT = circumference of the thorax; LL+CBFR = low load combined with continuous blood flow restriction; LL+IBFR = low load combined with intermittent blood flow restriction; LL = low load.

Training pressure and total training volume

The independent t-test revealed no significant differences between groups for LL+CBFR vs. LL+IBFR ($p = 0.090$) in the BFR pressures used in the left arm (Table 1). There were no significant differences in the sum of the total volume (12 sessions) of the 4 exercises between groups (LL+CBFR [30,585.6 ± 5629.1] vs. LL+IBFR [29,339.1 ± 5491.5] vs. LL [29,447.1 ± 4724.2], $p = 0.865$).

Discussion

The present study compared the effects of ST with continuous or intermittent BFR on MH, DMS, IMS and LME in healthy men. To our knowledge, this study was the first that verified the chronic effects of ST sessions combined with BFR with upper limb exercises performed in bilateral, single- and multi-joint movements on neuromuscular adaptations. Thus, the main findings were: a) there were no significant differences between groups with continuous and intermittent BFR in all MH, DMS, IMS and LME variables; b) the LME in the triceps pulley increased only in the LL+CBFR group; c) the LME in the pulley biceps curl exercise increased in the groups LL+CBFR, LL+IBFR and LL, but the large magnitude occurred only for the groups with continuous and intermittent BFR; and d) muscles that undergo direct influence of the BFR (biceps and triceps) were the ones that obtained the most benefits with the two BFR techniques (single-joint exercises).

Regarding the neuromuscular adaptations of MH and DMS, only one study analyzed the 5-week effects of ST with continuous and intermittent BFR on MH and DMS (Fitschen et al., 2014). The findings of this study corroborate our results, as these authors did not find significant differences in MH and DMS between the forms of BFR. When analyzing the studies, it is observed that the neuromuscular adaptations are similar between the forms of BFR; however, they seem to occur regardless of the segment used (upper *vs.* lower), the execution form (unilateral *vs.* bilateral and single- *vs.* multi-joint) and training volume. These results may have occurred because there are no significant differences in the acute form of lactate (Neto et al., 2017b), muscle activation (Yasuda et al., 2013) and muscle damage and oxidative stress (Neto et al., 2018) between continuous and intermittent BFR, factors that directly interfere in the process of neuromuscular adaptation. In this context, metabolic changes and recruitment of motor units among the main factors influencing the increases in MH (Loenneke, Wilson, Marín, Zourdos, & Bemben, 2012; Pope, Willardson, & Schoenfeld, 2013; Pearson & Hussain, 2015) and DMS (Loenneke et al., 2012; Pope et al., 2013).

Although no study has compared the effects of continuous and intermittent BFR on LME, some studies have evaluated the effects of ST with continuous BFR alone (Takarada, Sato, & Ishii, 2002; Kacin & Strazar, 2011; Sousa et al., 2017) or intermittent BFR alone (Gil et al., 2017). The results of these studies corroborate our findings, suggesting that the improvement of LME after ST with BFR occurs regardless of the form of the restriction (continuous or intermittent), the manner of execution (unilateral *vs.* bilateral and single- *vs.* multi-joint), load percentage (20-50% of 1RM), training duration (4 to 8 weeks) and training volume, which may occur in both men and women who are apparently healthy and who are athletes. This increase in LME seems to be associated with the condition of intramuscular hypoxia promoted by BFR because this mechanism can stimulate increases in capillarization due to increased vascular endothelial growth factor (VEGF) expression and can improve the performance of LME (Larkin et al., 2012).

Regarding the neuromuscular adaptations of IMS measured by manual and scapular dynamometers after ST with intermittent BFR, only one study had this objective (Chaves et al., 2016). These authors performed an ST program with women following their menstrual cycle phases for 4 weeks with bilateral elbow flexion and analyzed manual and scapular IMS before and after the end of the 8 sessions. The findings of this study partially corroborate our findings, as the authors found no significant increase at the end of the 8 sessions, and they only found significant increases in the intermediate evaluation (ovulatory phase of the menstrual cycle) in the dynamometry test of the right hand and scapular dynamometry, which may have occurred due to hormonal changes that occur during the menstrual cycles of women. This non-IMS increase may be associated with the characteristics of the exercises and tests used to verify the IMS, which seems to be a limitation of our findings and the findings of Chaves et al. (2016) and suggests that the IMS should be evaluated in future studies after ST with specific exercises for the tests used.

Table 3. Comparative analysis of the maximum dynamic muscular strength (DMS) 1RM of the 4 exercises between the groups at the pre- and post-test moments.

Exercises	LL+CBFR		LL+IBFR		LL	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
BP	77.6 ± 17.2	78.0 ± 15.4	72.9 ± 14.4	76.4 ± 16.7	75.5 ± 11.9	75.4 ± 13.7
FP	69.0 ± 13.0	69.2 ± 12.5	65.9 ± 13.9	70.5 ± 14.8	63.8 ± 12.3	66.6 ± 14.9
TRP	31.3 ± 6.8	31.6 ± 6.0	30.7 ± 4.8	32.6 ± 5.6	32.3 ± 4.8	32.6 ± 6.1
PBC	34.4 ± 5.9	35.1 ± 6.2	34.1 ± 8.0	36.1 ± 6.9	32.7 ± 5.9	34.7 ± 6.2

BP = bench press; FP = front pull-down, TRP = triceps pulley; PBC = pulley biceps curl; LL+CBFR = low load combined with continuous blood flow restriction; LL+IBFR = low load combined with intermittent blood flow restriction; LL = low load.

Table 4. Comparative analysis of isometric muscular strength (IMS) between groups at pre- and post-test moments.

Variables	LL+CBFR		LL+IBFR		LL	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
MDRA (kgf)	46.1 ± 6.7	48.9 ± 6.6	50.0 ± 7.3	53.4 ± 8.3	48.5 ± 9.4	50.6 ± 7.2
MDLA (kgf)	45.2 ± 6.4	48.8 ± 7.3	48.7 ± 10.6	51.4 ± 10.7	48.3 ± 7.3	49.2 ± 7.5
SD (kgf)	25.5 ± 5.0	25.7 ± 6.3	30.3 ± 9.6	31.6 ± 8.5	29.3 ± 7.8	31.4 ± 7.4

MDRA = manual dynamometry of the right arm; MDLA = manual dynamometry of the left arm; SD = scapular dynamometry; LL+CBFR = low load combined with continuous blood flow restriction; LL+IBFR = low load combined with intermittent blood flow restriction; LL = low load.

Table 5. Comparative analysis of localized muscular endurance (LME) of the 4 exercises (repetitions) between the groups at the pre- and post-test moments.

Exercises	LL+CBFR		LL+IBFR		LL	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
BP	30.1 ± 9.4	33.0 ± 10.8	29.7 ± 7.6	32.6 ± 4.5	25.8 ± 3.6	30.6 ± 3.5
FP	34.0 ± 8.8	39.5 ± 8.9	41.3 ± 9.7	51.5 ± 10.7	39.3 ± 15.9	49.2 ± 22.1
TRP	22.8 ± 5.4	35.3 ± 6.9*	25.6 ± 7.7	30.0 ± 4.9	24.0 ± 6.6	26.6 ± 4.9
PBC	19.2 ± 3.6	28.7 ± 7.4*	20.3 ± 3	28.3 ± 4.7*	19.1 ± 4.1	24.3 ± 2.8*

*Significant difference when compared with the pre-test; BP = bench press; PF = front pull-down, TRP = triceps pulley; PBC = pulley biceps curl; LL+CBFR = low load combined with continuous blood flow restriction; LL+IBFR = low load combined with intermittent blood flow restriction; LL = low load.

Upon analyzing the findings of the present study and those of the existing literature, it is observed that intermittent BFR may become an excellent option for those who work with this training method. The neuromuscular adaptations of muscle activation (Yasuda et al., 2013), DMS and MH (Fitschen et al., 2014) and heart rate and double product (Neto et al., 2017b) are similar between continuous and intermittent BFR, even though there is no consensus about metabolic stress (Neto et al., 2017b; Suga et al., 2012). However, intermittent BFR has a lower perception of effort (Neto et al., 2017b) and a lower sensation of pain (Fitschen et al., 2014), which may allow greater adherence among individuals using the method.

In relation to the muscles that undergo direct influence of the BFR, the biceps and triceps obtained the most benefits with the two BFR techniques (single- and multi-joint exercises), which seems to be directly related to the mechanisms involved in this process. In this sense, Loenneke, Wilson, and Wilson (2010) mentioned that hyperemia and H+ ion concentrations increased more at the occluded site, which promoted the increase of perception of effort and appeared to improve neuromuscular performance. This information seems to be confirmed in the study by Neto et al. (2017b), who observed that local perception of effort appeared to increase more after continuous and intermittent BFR of the limbs involved with BFR (e.g., biceps and triceps) when compared with muscles that are not involved with BFR (e.g., pectoral and dorsal). However, the study by Yasuda, Fujita, Ogasawara, Sato, and Abe (2010) partially corroborates our findings, as increases in muscular strength (6%), triceps muscle mass (8%) and pectoralis major muscle mass (16%) were observed after 2 weeks of bench press training. These increases may have occurred due to the sensitivity of the materials used for MH evaluation; these authors used ultrasound, and we used anthropometry.

This study has some limitations. First, the instruments used to verify MH are not the gold standard, and the double indirect method (anthropometry) was used but seems to have a good practical applicability, a fact observed in the study by Abe, Kearns, and Sato (2006), who verified an increase in MH with this method after application of BFR. s, the BFR pressure was verified in the lying position, but the exercises were performed in different positions (lying down, sitting and standing); however, these differences seem to be common for studies for evaluating BFR in different positions than those of the exercises (Laurentino et al., 2012; Araujo et al., 2015; Neto et al., 2015; Silva et al., 2015; Neto et al., 2016b; Gil et al., 2017).

Finally, the short intervention time (6 weeks) and the small number of sessions (12 sessions) may have influenced the results, however; in the literature, the great majority of the studies present times of intervention ranging from 4 to 6 weeks (Fitschen et al., 2014; Chaves et al., 2016; Gil et al., 2017; Sousa et al., 2017) and 8 to 12 sessions (Chaves et al., 2016; Gil et al., 2017; Sousa et al., 2017).

Conclusion

In conclusion, the two forms of BFR (continuous or intermittent) seem to be a good alternative for the increase of LME of the upper limbs in single-joint exercises, although they seem to promote improvements in the mean values when compared pre- and post-test in the variables of MH, DMS and IMS. Thus, health professionals can use intermittent BFR for healthy populations and athletes as no different from continuous BFR, but intermittent BFR appears to be safer for different populations. These data are relevant for the development of future research because intermittent BFR would reduce the BFR time of the upper limb session, which would lead to greater safety in the method. Therefore, studies comparing the two forms of BFR on neuromuscular adaptations and hemodynamics with different exercises, intensities and different percentages of BFR using standard gold equipment should be performed.

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