

# Effects of strength training with blood flow restriction on torque, muscle activation and local muscular endurance in healthy subjects

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**ABSTRACT:** The present study aimed to analyse the effects of six weeks of strength training (ST), with and without blood flow restriction (BFR), on torque, muscle activation, and local muscular endurance (LME) of the knee extensors. Thirty-seven healthy young individuals were divided into four groups: high intensity (HI), low intensity with BFR (LI+BFR), high intensity and low intensity + BFR (COMB), and low intensity (LI). Torque, muscle activation and LME were evaluated before the test and at the 2<sup>nd</sup>, 4<sup>th</sup> and 6<sup>th</sup> weeks after exercise. All groups had increased torque, muscle activation and LME ( $p < 0.05$ ) after the intervention, but the effect size and magnitude were greater in the HI, LI+BFR and COMB groups. In conclusion, the groups with BFR (LI+BFR and COMB) produced magnitudes of muscle activation, torque and LME similar to those of the HI group.

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## INTRODUCTION

In recent years, low-intensity (LI) training with blood flow restriction (BFR) has attracted much attention, both as a possible alternative to high-intensity (HI) exercise ( $\geq 70\%$  of one-repetition maximum [1RM]) in the context of rehabilitation and as a training method to increase strength and muscle hypertrophy in healthy subjects [27, 38]. Additionally, this method has been used to increase torque [14, 19, 34, 36], muscle activation [15, 17, 38-42], local muscular endurance (LME) [6, 7, 11, 13, 20, 36], and maximum strength [16, 35, 37]. Fujita et al. [9] reported that the reason for these increases is that LI strength training (ST) combined with BFR increases endurance, phosphorylation and muscle protein synthesis and promotes increased strength while providing the same gains as conventional ST with high loads.

In this regard, several studies have reported the acute [15, 17, 23-26, 38] and chronic [3, 4, 6, 7, 11, 13, 16, 20, 30, 35, 36, 42] effects of ST with BFR. Thus, some studies have evaluated the chronic effects of ST with BFR on isometric torque [14, 19, 34, 36] and LME [6, 7, 13, 20, 36] after application of LI ST with BFR. It was observed that only one study has evaluated the chronic effect of a unilateral knee extension isotonic training programme on isometric torque [14], and one study has investigated the effects of combined LI and HI ST with and without BFR in alternating sessions on muscle strength and size [43], but the exercise utilized was for upper limbs (bench press). Therefore, there is a lack of studies aiming to investi-

gate the effects of combined LI and HI ST with and without BFR on torque, LME and muscle activation in alternating sessions of the lower limbs. Additionally, understanding the chronic effect of BFR in the lower limbs in alternate sessions on the torque, LME and muscle activation could help the scientists and health professionals that work with this training method, and it would be an excellent strategy of intervention for the knee extensor muscles for different population groups. For example, the combination of HI and low load with the BFR sessions may be a good intervention option for highly trained people who cannot easily increase the strength and muscle hypertrophy, and this combination could generate different stimuli (tension and metabolic, respectively) since both are performed with HI.

Therefore, the aim of this study was to analyse the effects of six weeks of ST, with and without BFR, on torque, muscle activation, and LME of the knee extensors in healthy young individuals. We hypothesized that LI ST with BFR would promote increases in torque, muscle activation and LME similar to HI training without BFR.

## MATERIALS AND METHODS

**Subjects.** The study included individuals a) who were untrained in ST for at least six months; b) who were apparently healthy, aged between 18 and 30 years, and of both genders; c) with no history of osteo-articular problems in the lower limbs; d) who responded negatively to the Physical Activity Readiness Questionnaire (PAR-Q) [33];

e) who had no history of cardiovascular disease; and f) who had an ankle-brachial index (ABI) in the range 0.90–1.40 [28]. Individuals who did not regularly attend two consecutive training sessions per week were excluded.

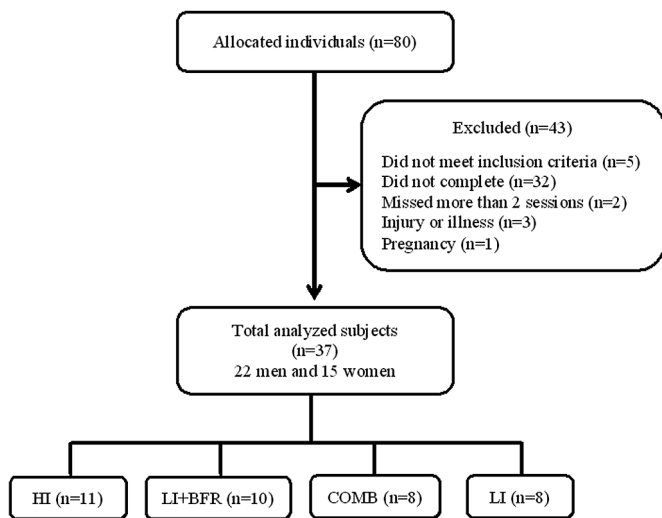


FIG. 1. Sample flowchart.

Note: HI=high-intensity group; LI+BFR=low-intensity with blood flow restriction group; COMB=combined group; LI=low-intensity group.

Of the total 80 allocated individuals, 43 were excluded and 37 were randomized to the four groups that completed the study (Figure 1): a) High intensity at 80% of 1RM (HI, n=11); b) Low intensity combined with BFR at 30% of 1RM (LI+BFR; n=10); c) HI combined with LI+BFR (COMB; n=8); and d) Low intensity at 30% of 1RM (LI; n=8), as shown in Table 1.

The sample design was constructed with the aid of G\*Power 3.1 software [8] and according to the procedures suggested by Beck [5]. Based on *post-hoc* analysis, for a sample of 37 individuals, with an effect size of 0.50, an  $\alpha = 0.05$  and a correlation coefficient of 0.5, a statistical power of 87.4% was obtained.

Subjects were informed about risks and benefits of the study and gave informed consent. The study was approved by the Ethics Committee on Research Involving Human Beings under protocol number 0389/2011, and all the procedures were performed in agreement with the Declaration of Helsinki.

Study design

Anthropometry, determination of BFR point, 1RM, LME, and familiarization of training were assessed at the first visit to the laboratory. On the second visit, evaluations of torque, EMG, 1RM retest, and LME (pre-test) were conducted. The interval between steps 1 and 2 was 96 hours and between steps 2 and 3 one week. In step three, there was a 48-hour interval between training sessions. After pre-test analysis, the experimental groups were trained for six weeks. Every 2 weeks of training torque and electromyographic (EMG) assessments were conducted. Post-testing was completed 48 h following the last training session (Figure 2).

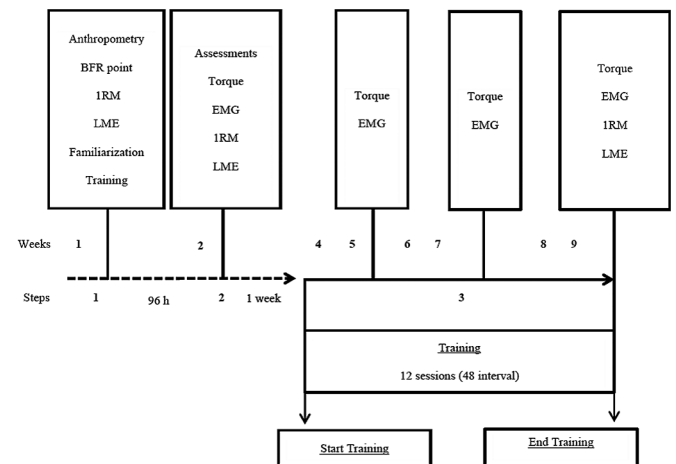


FIG. 2. Procedures in timeline.

Note: BFR=blood flow restriction 1RM=one repetition maximum; LME=local muscular endurance; EMG=electromyography.

Determination of blood flow restriction pressure (BFR)

External compression for BFR during the intervention was performed according to Laurentino et al. [16]. To do so, we used a specially adapted sphygmomanometer (18 cm wide x 80 cm long). This device was placed on the most proximal portion of the thigh and inflated until interruption of the auscultatory pulse of the tibial artery, established with the aid of a portable vascular Doppler (MedPeg DV -2001, Ribeirão Preto, SP, Brazil). The cuff pressure used during exercise for the LI+BFR and COMB groups was 80% of the total BFR pressure in the resting state, which was kept constant throughout the exercise. The average pressures on the lower limbs used

TABLE 1. Anthropometric sample characteristics.

Variables	HI (men=5; women=6)	LI+BFR (men=7; women=3)	COMB (men=5; women=3)	LI (men=5; women=3)	ICC	p
Age (years)	20.73 ± 3.79	23.70 ± 4.90	24.75 ± 4.86	22.38 ± 2.61	0.949	<0.001
BM (kg)	64.30 ± 12.76	76.09 ± 21.88	66.82 ± 11.55	62.58 ± 9.31	0.801	0.002
Height (m)	1.69 ± 0.12	1.72 ± 0.09	1.69 ± 0.09	1.65 ± 0.08	0.978	<0.001
BMI (kg · m <sup>-2</sup> )	22.4 ± 3.79	25.18 ± 4.98	23.17 ± 2.14	22.93 ± 3.88	0.967	<0.001

Note: HI=high-intensity group; LI+BFR=low-intensity with blood flow restriction group; COMB=combined group; LI=low-intensity group; BM=body mass; BMI=body mass index.

throughout the experiments were  $141.56 \pm 12.19$  and  $129.83 \pm 11.87$  mm Hg for the LI+BFR and COMB groups, respectively.

### *Torque and surface electromyogram (EMG)*

For data recording, subjects were seated and had their knee flexed at an angle of  $60^\circ$  and the ankle fixed to the resistance arm bracket of the power system with trunk and pelvis maintained at approximately  $90^\circ$ , set by bands in the trunk, pelvis and thigh to avoid compensatory movements. Subjects were then asked to perform three maximal voluntary isometric contractions (MVICs) each lasting five seconds at intervals of 60 seconds [31].

Knee extension isometric torque (vastus medialis [VM], rectus femoris [RF] and vastus lateralis [VL]) was recorded using an EMG-Force integrated system, composed of a Bonett chair with strain gages fixed on the chair's resistance arms [21]. The amplified signal was digitized using a 16-channel A/D converter board with 12-bit resolution at a sampling frequency of 1000 Hz.

The software used for capturing and processing strength signals and EMG was the BioMed (digital polygraph) application. Surface EMG signals (root mean square [RMS] and median frequency [ $F_{med}$ ]) were captured simultaneously with strength using a system with the following settings: biological amplifier (CMRR > 95 dB), high input impedance (10 M $\Omega$ ), low noise (<5  $\mu$ V RMS), bandwidth 10-490 Hz and 1500x gain.

Active bipolar electrodes (Skintact, Austria), with a distance of 20 mm between poles, were placed in the centre of the VM, RF and VL muscles [12] to record electrical activity of the quadriceps, which was calculated by averaging the values obtained from the sum of the three evaluated muscles and normalized according to the peak MVIC divided by the pre-test value. To ensure that the electrodes were placed at the same points in all assessments, volunteers were marked with a long-lasting dye (henna), and when it had nearly disappeared a new layer was applied, which ensured that the electrodes were placed in the same place. Furthermore, during the entire test week, marking was performed.

The entire EMG signal capture process was performed in accordance with Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations [12].

### *Maximum dynamic strength test (1RM)*

The 1RM was determined three weeks before the start of the ST. Procedures followed *American College of Sport Medicine* recommendations [2], in which subjects were instructed not to perform any physical activity or strenuous effort for at least 24 hours prior to testing.

For the warm-up, each subject performed a set of 5 to 10 repetitions with a load of 40% of perceived maximum weight; after one minute of rest, the individual performed the second set of three to five repetitions with 60% to 80% of perceived maximum weight.

The 1RM test procedures were then initiated, in which each volunteer performed up to five attempts of a unilateral knee extension (dominant limb) on the extensor chair (Body fitness, Brazil) with intervals of three to five minutes between attempts. The 1RM test was performed at pre-test and at the 2<sup>nd</sup>, 4<sup>th</sup> and 6<sup>th</sup> weeks, while the training load was adjusted at each evaluation on each occasion based on the previous evaluation.

### *Local muscular endurance (LME) and training volume*

LME was calculated as the maximum number of repetitions of the unilateral knee extension achieved in a single set with a fixed load of 40% of 1RM. The articular range of motion (ROM) was from  $90^\circ$  to  $0^\circ$ , at a speed controlled by a metronome (Tagima, Brazil), with total movement execution time of four seconds (two seconds for concentric action and two seconds for eccentric action) until the point that concentric failure occurred. When the individual could not maintain the repetition cycle within the sets to the established cadence and amplitude, the concentric point of failure was determined, and the highest number of successfully performed repetitions was computed.

### *Strength training (ST) programme*

ST was performed over two sessions per week, with 48-hour intervals between them, for six weeks (totalling 12 sessions). The exercise used was a unilateral knee extension (dominant limb), which was trained using a conventional knee extension machine (Body fitness, Brazil). Individuals were trained using only the dominant leg in order to prevent a cross-transfer effect [19]. All groups performed four sets until concentric failure.

The HI group performed traditional multiple sets training, with a load of 80% of 1RM without BFR and with a two-minute interval. The LI+BFR group executed an exercise protocol with BFR using the same BFR determining cuff, at an intensity of 30% of 1RM and intervals of 30 seconds between sets. The COMB group trained with a mixed approach, combining an HI ST session (four sets at 80% of 1RM with an interval of two minutes) with an LI+BFR session (four sets at 30% of 1RM with a 30-second interval) executed alternately. The LI group performed traditional multiple sets training, at 30% of 1RM and a rest interval of 30 seconds.

### *Statistical analyses*

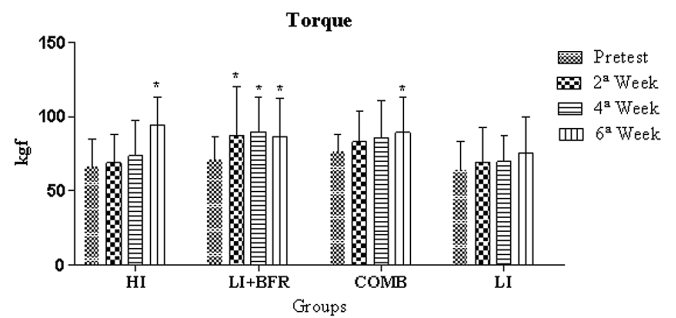
All analyses were performed using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL). Data normality was verified using the Shapiro-Wilk test and the homogeneity of the variances using the Levene test. All the variables showed normal distribution ( $p > 0.05$ ). The reliability of the sample characteristics (age, body mass, height, and BMI) was verified by the interclass correlation coefficient (ICC) (Table 1). A two-way ANOVA of repeated measures [groups (HI vs. LI+BFR vs. COMB vs. LI) x time (pre-test vs. 2<sup>nd</sup> week vs. 4<sup>th</sup> week vs. 6<sup>th</sup> week)] was used to evaluate the effects of training on all dependent variables, followed by the Tukey post hoc test to locate the main differences.

As the RMS variable did not fulfil the assumption of homogeneity, we used the delta variation to avoid erroneous comparisons (2<sup>nd</sup>/pre-test; 4<sup>th</sup>/pre-test; 6<sup>th</sup>/pre-test; 4<sup>th</sup>/2<sup>nd</sup>; 6<sup>th</sup>/2<sup>nd</sup>; 6<sup>th</sup>/4<sup>th</sup>), so one-way ANOVA was used to compare the groups. Effect sizes (ES) were calculated as [(Post-training Mean – Pre-training)/Pre-Training SD], and classified according to the magnitude [trivial < 0.50, small = 0.50 to 1.25, moderate = 1.25-1.90, and large > 2.0] [29], and percentage changes ( $\Delta\%$ ) were used to express possible differences between the first (pre-test) and fourth (6th week – post-test) evaluations. A significance level of 5% was adopted for all comparisons.

**RESULTS**

Total training volume (12 sessions) was determined by load x repetitions. The average volume for each group was as follows: HI=584.05 kg; LI+BFR=295.63 kg; LI=310.0 kg; and COMB=432.8 kg. There were significant increases between HI vs. LI+BFR ( $p<0.001$ ), HI vs. LI ( $p<0.001$ ), and HI vs. COMB ( $p=0.045$ ).

There were no statistically significant differences for the post-test in the isometric torque for the intergroup analysis ( $p>0.05$ ). In the intra-group analysis, significant increases were observed in the HI group between the pre-test and the 6<sup>th</sup> week ( $p<0.001$ ,  $\Delta=43\%$ ), the 2<sup>nd</sup> and the 6<sup>th</sup> weeks ( $p<0.001$ ,  $\Delta=36.4\%$ ) and the 4<sup>th</sup> and 6<sup>th</sup> weeks ( $p<0.001$ ,  $\Delta=28\%$ ). There were also significant increases between evaluations for the pre-test and the 2<sup>nd</sup> week, the pre-test and the 4<sup>th</sup> week, and the pre-test and the 6<sup>th</sup> week ( $p=0.003$ ,  $\Delta=24.2\%$ ;  $p<0.001$ ,  $\Delta=27.5\%$ ; and  $p=0.004$ ,  $\Delta=22.7\%$ , respectively) for the LI+BFR group. There was also a significant increase between the pre-test and the 6<sup>th</sup> week ( $p=0.027$ ,  $\Delta=17.4\%$ ) in the COMB group, as shown in Figure 3.



**FIG. 3.** Comparative analysis of isometric torque between experimental group evaluations.

\* Significant differences to the pre-test

Note: HI=high-intensity group; LI+BFR=low-intensity with blood flow restriction group; COMB=combined group; LI=low-intensity group.

In the intergroup analysis of RMS by one-way ANOVA, no differences were observed between groups when the difference between the percentages deltas was compared (2<sup>nd</sup>/pre-test; 4<sup>th</sup>/pre-test; 6<sup>th</sup>/pre-test; 4<sup>th</sup>/2<sup>nd</sup>; 6<sup>th</sup>/2<sup>nd</sup>; 6<sup>th</sup>/4<sup>th</sup>;  $p>0.05$ ). In the EMG signal RMS intra-group analysis, significant increases were observed in the COMB group between the pre-test and the 2<sup>nd</sup> week ( $p=0.032$ ;  $\Delta=51.3\%$ ); the pre-test and the 4<sup>th</sup> week ( $p<0.05$ ; HI:  $\Delta=52.9\%$ , LI+BFR:  $\Delta=98.6\%$ , COMB:  $\Delta=77.2\%$ , LI:  $\Delta=4.8\%$ ) and the pre-test and the 6<sup>th</sup> week ( $p<0.05$ ; HI:  $\Delta=55.3\%$ , LI+BFR:  $\Delta=80.9\%$ , COMB:  $\Delta=80.9\%$  LI:  $\Delta=36.7\%$ ). Significant increases were also detected in the HI group between the 2<sup>nd</sup> and 4<sup>th</sup> weeks ( $p=0.003$ ;  $\Delta=51.1\%$ ) and the 2<sup>nd</sup> and 6<sup>th</sup> weeks ( $p=0.002$ ;  $\Delta=53.5\%$ ), as shown in Table 2 and Table 3.

Statistically significant differences were observed in the  $F_{med}$  intergroup analysis between HI and LI+BFR at the 2<sup>nd</sup> week ( $p<0.001$ ). Significant reductions were observed in the HI group in the intra-group

**TABLE 2.** Comparative analysis of root mean square (RMS) between experimental group evaluations.

Evaluations	Groups				p
	HI	LI+BFR	COMB	LI	
Pre-test	2.51 ± 1.23	1.52 ± 0.47	2.20 ± 0.84	3.90 ± 2.04	0.004
2 <sup>nd</sup> week	2.54 ± 1.56	2.42 ± 1.21	3.33 ± 2.06*	2.75 ± 1.00	0.147
4 <sup>th</sup> week	3.84 ± 2.07*	3.02 ± 1.21*	3.90 ± 2.16*	3.98 ± 2.10*	0.246
6 <sup>th</sup> week	3.90 ± 2.04*	2.75 ± 1.00*	3.98 ± 2.10*	4.58 ± 1.16*	0.134
Delta percentage (post / pre)					
2 <sup>nd</sup> / Pre-test	1.07 ± 0.56	1.68 ± 0.88	1.46 ± 0.51	1.27 ± 0.53	0.203
4 <sup>th</sup> / Pre-test	1.54 ± 0.30	2.08 ± 1.04	1.72 ± 0.57	1.50 ± 0.60	0.241
6 <sup>th</sup> / Pre-test	1.63 ± 0.48	1.85 ± 0.57	1.78 ± 0.67	1.48 ± 0.62	0.562
4 <sup>th</sup> / 2 <sup>nd</sup>	1.71 ± 0.65	1.40 ± 0.67	1.22 ± 0.43	1.28 ± 0.51	0.283
6 <sup>th</sup> / 2 <sup>nd</sup>	1.77 ± 0.70	1.37 ± 0.84	1.31 ± 0.65	1.26 ± 0.41	0.335
6 <sup>th</sup> / 4 <sup>th</sup>	1.04 ± 0.17	0.95 ± 0.20	1.12 ± 0.61	1.03 ± 0.33	0.771

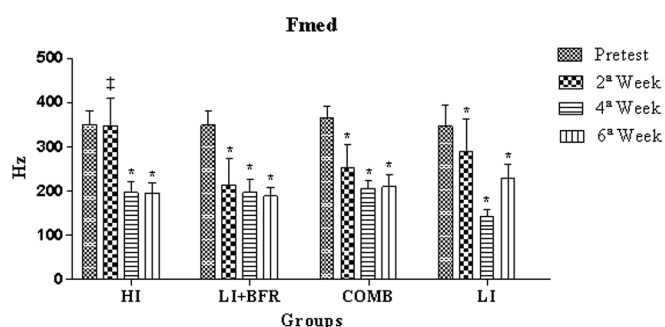
Note: HI=high-intensity group; LI+BFR=low-intensity with blood flow restriction group; COMB=combined group; LI=low-intensity group. \* Significant differences to the pre-test.

**TABLE 3.** Effect size values (magnitude) between the pre-test and the 6<sup>th</sup> week of muscle activation (RMS and F<sub>med</sub>), LME and muscle strength (1RM) between experimental groups.

Variables	HI (n=11)	LI+BFR (n=10)	COMB (n=08)	LI (n=08)
RMS (RMS%MVC) ES	1.13	2.61	2.11	1.05
Magnitude	Small	Large	Large	Small
F <sub>med</sub> (Hz) ES	5.09	4.91	6.02	2.38
Magnitude	Large	Large	Large	Large
LME (Repetitions) ES	27.5	26.1	19.3	22.7
Magnitude	Large	Large	Large	Large
Strength (Kg) ES	1.49	1.02	1.08	0.59
Magnitude	Moderate	Small	Small	Small

Note: HI=high-intensity group; LI+BFR=low-intensity with blood flow restriction group; COMB=combined group; LI=low-intensity group; RMS=root mean square; ES=effect size; F<sub>med</sub>=median frequency; LME= local muscular endurance.

analysis between the pre-test and the 4<sup>th</sup> week, the pre-test and the 6<sup>th</sup> week, the 2<sup>nd</sup> and 4<sup>th</sup> weeks, and the 2<sup>nd</sup> and 6<sup>th</sup> weeks ( $p < 0.001$ ,  $\Delta = 43.7\%$ ;  $p < 0.001$ ,  $\Delta = 44.0\%$ ;  $p < 0.001$ ,  $\Delta = 43.2\%$ ; and  $p < 0.001$ ,  $\Delta = 43.4\%$ , respectively). There were also significant reductions between evaluations for the pre-test and the 2<sup>nd</sup> week, the pre-test and the 4<sup>th</sup> week, and the pre-test and the 6<sup>th</sup> week ( $p < 0.001$ ,  $\Delta = 38.6\%$ ;  $p < 0.001$ ,  $\Delta = 43.4\%$ ; and  $p < 0.001$ ,  $\Delta = 45.8\%$ , respectively) in the LI+BFR group. There were also significant reductions between evaluations for the pre-test and the 2<sup>nd</sup> week, the pre-test and the 4<sup>th</sup> week, and the pre-test and the 6<sup>th</sup> week in the COMB group ( $p < 0.001$ ,  $\Delta = 30.8\%$ ;  $p < 0.001$ ,  $\Delta = 43.4\%$ ; and  $p < 0.001$ ,  $\Delta = 42.6\%$ , respectively). In the LI group, there were significant reductions between evaluations for the pre-test and the 2<sup>nd</sup> week, the pre-test and the 4<sup>th</sup> week, the pre-test and the 6<sup>th</sup> week, the 2<sup>nd</sup> and 6<sup>th</sup> weeks, and the 4<sup>th</sup> and 6<sup>th</sup> weeks ( $p = 0.036$ ,  $\Delta = 16.3\%$ ;  $p < 0.001$ ,  $\Delta = 58.5\%$ ;  $p < 0.001$ ,  $\Delta = 33.7\%$ ;  $p < 0.001$ ,  $\Delta = 50.4\%$ ;  $p = 0.021$ ,  $\Delta = 20.8\%$ ; and  $p < 0.001$ ,  $\Delta = 59.7\%$ , respectively), as shown in Figure 4.



**FIG. 4.** Comparative analysis of F<sub>med</sub> between experimental group evaluations.

Note: \* Significant differences to the pre-test; † Significant difference between HI and LI+BFR in the 2<sup>nd</sup> week.

HI=high-intensity group; LI+BFR=low-intensity with blood flow restriction group; COMB=combined group; LI=low-intensity group.

Table 3 shows percentage changes ( $\Delta\%$ ), effect sizes (ES) and magnitudes for evaluations in all groups, pre-test and post-test (6 weeks).

## DISCUSSION

This study analysed the effects of six weeks of ST, with and without BFR, on torque, muscle activation, and LME of the knee extensors in healthy young individuals. To our knowledge, this was the first study to verify the influence of LI and HI ST with BFR in alternating sessions on torque, muscle activation, and LME in lower limbs. The main findings of this study were: a) significant increases in isometric torque in the HI, LI+BFR, and COMB groups after intervention and b) significant increases in RMS, F<sub>med</sub>, and LME for all groups.

Some studies have assessed the chronic effect of LI ST with BFR on muscle torque [14, 36, 42]. Yasuda et al. [42] investigated the effects of six weeks of concentric and eccentric LI ST with BFR on the muscle torque of ten young men performing elbow flexion exercises three days a week for six weeks. Each individual performed four sets (30x15x15x15) of unilateral elbow flexions (30% of 1RM), with one arm trained prioritizing the concentric phase and the other prioritizing the eccentric phase. The authors observed significant increases in torque (8.6%) for the concentric phase after training but not for the eccentric phase (3.8%). Comparing these results with those of the present study, it can be observed that for exercise performed unilaterally, irrespective of the body section (upper or lower), ST performed with BFR appears to improve torque.

Furthermore, some studies that determined that ST with BFR had an acute effect on muscle activation [39, 40] also observed that BFR increased muscle activation compared to training without BFR, with greater amplitude of the EMG signal in the concentric phase [42]. This increased muscle activation can lead to acute changes that are reflected in increases in muscle size and muscle cell swelling, which may be important factors in promoting muscle hypertrophy [42].

One study evaluated the chronic effect of ST with BFR on muscle activation [14]. The authors found that low-load ST with BFR did not affect motor unit activation of muscle and tendon properties, but there was an increase to high intensity, which diverges from our findings. It is speculated that it may have occurred because in the study by Kubo *et al.* [14] subjects trained with one leg using a low load with BFR and the other leg at high intensity without BFR; however, in our study, different groups were used, thus avoiding the cross-training effect [19].

One study investigated the effects of combined LI and HI ST with and without BFR in alternating sessions on muscle strength and size, but the exercise used was the bench press [43]. The findings of the study by Yasuda *et al.* [43] corroborate those in the present study (inferior limbs). The authors obtained similar results for the combined and high intensity groups for maximum strength and MVIC. It can be observed with these results that the combination of low load strength exercise with BFR and high loads can be an excellent alternative for improving performance of maximum muscle strength and MVIC in upper and lower limbs. This may have occurred due to the variation of the stimulus (tensional and metabolic), which appears to be an excellent option for strength conditioning professionals. It is worth mentioning that we did not find in our study significant increases for the LI group with BFR, which trained to fatigue, which differs from the findings of Mitchell *et al.* [22] and Fahs *et al.* [7]. This may have occurred because the training proposed by Mitchell *et al.* [22] and Fahs *et al.* [7] used different training for each leg, which may have promoted a cross training effect and thus promoted an increase in torque or muscle strength in the LI group without BFR similar to the group with BFR [19].

Intra-group analysis revealed significant increases in LME in the groups using BFR. In this regard, the results of the few studies that have evaluated LME after training with BFR [6, 7, 11, 13, 20, 36] corroborate the findings of this study. Kacin and Strazar [13] studied LME after subjecting 10 men to four ST sessions per week for four weeks, with and without BFR. Four unilateral knee extension sets were performed in each protocol (at 15% MVIC) until muscle fatigue. One limb was trained with BFR ( $\geq 230$  mm Hg), and the opposite limb was trained without BFR. The LME of each limb was recorded before and after training, regardless of the training protocol. The authors observed significant increases in both limbs, but with significantly higher increases for the limb that trained with BFR (63% and 27%) vs. without BFR (36% and 11%).

Takarada *et al.* [36] also evaluated LME after subjecting 17 male athletes to two weekly sessions of LI ST over eight weeks with and without BFR. Each group performed four sets of bilateral knee extensions (at 50% 1RM) until muscle fatigue. The LI+BFR group improved LME. Analysing the results of studies by Kacin and Strazar [13] and Takarada *et al.* [36] and comparing them with the present study,

it can be observed that regardless of form (unilateral or bilateral), load percentage (30-50% of 1RM or 15% of MVIC), and training volume and duration (4, 6 and 8 weeks), ST performed with BFR seems to improve LME in apparently healthy male and female athletes.

Furthermore, some studies have found an acute effect of ST with BFR on LME [38], and it has been observed that BFR can significantly reduce LME compared to ST without BFR. This reduction in LME can be explained by increased muscle fatigue and metabolite accumulation promoted by BFR, as these factors have an inverse relationship with increased LME [32]. Thus, this relationship, when detected in the acute phase, can justify the chronic benefits of ST with BFR on increasing LME.

It is thought that LI ST with BFR reduces myostatin expression in a manner similar to HI training [16], increasing metabolite accumulation and the expression of factors of the mammalian target of rapamycin signalling pathway (mTOR), muscle protein synthesis (S6K1), lactate, growth hormone, insulin-like growth factor (IGF-1), satellite cells and heat shock proteins [9, 18, 38]. In acute and chronic forms, it can increase torque and LME, in addition to reducing muscle fatigue after 12 weeks of intervention.

The current study has some limitations. Firstly, the number of sessions was low, as a greater number of sessions (16-36) is effective in increasing strength and muscle hypertrophy [1, 16]; however, twelve sessions are useful for increasing strength and muscle hypertrophy [10]. Secondly, the pressure was based on arterial occlusion that was measured in the supine position, but the exercises were performed in the standing position. This method was chosen based on previous literature [16]. Although this may have been a limitation, our stimulus appeared adequate given the beneficial response we observed in strength. Finally, there was no measurement of muscle size.

## CONCLUSIONS

In conclusion, LI ST with BFR over six weeks increased LME and isometric torque and reduced muscle fatigue, with results approaching the levels of those found in HI training. Therefore, it is important to conduct new experiments to study the physiological and biochemical aspects of LME and fatigue, especially involving different individuals, exercises and intensities, for a better understanding of the process underlying muscular adaptation to ST with BFR.

**Conflicts of interest:** The authors declare that they have no conflicts of interest.

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