



Effects of low-load resistance training with blood flow restriction on the perceived exertion, muscular resistance and endurance in healthy young adults

Carlos Henrique de Lemos Muller^{1,2} · Thiago Rozales Ramis¹ · Jerri Luiz Ribeiro¹

Received: 6 September 2018 / Accepted: 7 February 2019 / Published online: 5 March 2019
© Springer-Verlag Italia S.r.l., part of Springer Nature 2019

Abstract

The objective was to verify the effect of low-load resistance training with blood flow restriction (LL + BFR) on the rating of perceived exertion (RPE). In addition, strength and muscular endurance were evaluated. 26 male subjects were divided into two groups: (a) low-load resistance training with blood flow restriction at 30% 1RM (one repetition maximum), and (b) high-load (HL) resistance training without blood flow restriction at 80% 1RM. The training lasted 8 weeks (three times a week) and consisted of elbow flexion and knee extensor exercises. RPE was assessed using the OMNI scale in sessions before and after training. The maximum dynamic force was evaluated using the 1RM test, and muscular endurance was assessed by the test of the number of repetitions at 60% 1RM. The RPE was higher in the pre-training session for elbow flexion exercise in the HL group as compared to the LL + BFR group (HL: 7.84 ± 1.25 LL: 6.34 ± 1.27 ; $p < 0.05$), besides being higher in the HL group in elbow flexion (HL: 8.61 ± 0.83 LL: 6.00 ± 1.53 ; $p < 0.05$) and knee extensor (HL: 8.38 ± 0.83 LL: 6.00 ± 1.89 ; $p < 0.05$) exercises in the post-training session when comparing the groups. Also in LL + BFR there was significant difference between moments in knee extensor (baseline: 8.30 ± 1.08 post: 6.00 ± 1.89 ; $p < 0.05$). There were strength gains in both groups, whereas they were greater for the HL group in the knee extensor exercise ($p < 0.05$). There were, in both groups, significant increase in muscular endurance ($p < 0.05$). Lastly, there was a negative correlation in strength with RPE in LL + BFR. In conclusion, the RPE reduced in LL + BFR resistance training compared to HL after 8 weeks of training. In addition, both methods were effective for increasing muscular strength and endurance.

Keywords Chronic effects · Ischemia · Vascular occlusion · Strength · OMNI scale

Introduction

Low-load resistance training with blood flow restriction (LL + BFR) has been shown to be an alternative method for strength and hypertrophy gains when compared to conventional resistance training (70–80% 1RM) [1, 2]. LL + BFR uses low loads (20–50% of 1RM) and a tourniquet cuff attached to the limb for blood flow restriction [3]. This method could, therefore, be an alternative for people who

cannot perform high-load resistance training (HL) due to the mechanical stress that is generated on the joints. In addition to strength and hypertrophy gains, resistance training also improves muscle endurance [4, 5]. However, when considering LL + BFR we did not verify studies in the literature that have evaluated the effects there of in muscular resistance.

Although evidence in the literature has demonstrated increased strength and hypertrophy, blood flow restriction resulting from pressure placed on a cuff leads to discomfort during exercise. It is known that exercises which cause discomfort become unpleasant and reduce the likelihood of the subject remaining in a training program [6]. That is why the evaluation of the rating perceived exertion (RPE) in LL + BFR exercises has been carried out [7, 8]. Although there are studies that propose this evaluation, few compare HL and LL + BFR exercise [9, 10] so that most of the studies compare low-load exercise without occlusion (LL) and LL + BFR exercise [11, 12]. In addition, we have not found

✉ Carlos Henrique de Lemos Muller
mullercarlos0@gmail.com

¹ Centro Universitário Metodista-IPA, Cel. Joaquim Pedro Salgado Street, 80 Petrópolis, Porto Alegre, RS 90420060, Brazil

² Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

studies in the literature that verify the effects of a LL + BFR training program on RPE. Only one study assessed RPE during a LL + BFR training protocol, however, it compared with LL [13]. The results demonstrated that RPE was higher in the exercises, where occlusion was used for 8 weeks. The longest study comparing LL + BFR and HL exercises was done by Martín-Hernández et al. [14], who had six training sessions. Even so, it was a very short intervention time to indicate whether the RPE in LL + BFR is greater than or less than that of HL.

An important issue which has not yet been demonstrated in the literature is the magnitude of strength and hypertrophy gains in LL + BFR and HL protocols when their training volumes (TV) are equalized. Much has been debated about whether the strength and hypertrophy gains between these two methods would be similar. In this regard, the evidence in the literature does not lead to a conclusion, because there are studies verifying similar results between LL + BFR and HL [1] and others more improvements for HL group [15, 16]. This is possible mainly because the TV between the groups is quite different. Thus, it is important to evaluate the strength and hypertrophy gains between the LL + BFR and HL protocols with equalized TV.

Therefore, the objective of this study was to verify the effect of a low-load resistance training program with blood flow restriction and with training volumes that are equalized in the rating of perceived exertion of healthy young adult subjects. In addition, it is to evaluate the responses to the parameters of strength and muscular endurance by virtue of training.

Methods

Participants

The subjects were males with 18- to 30-year-old (23.00 ± 2.67 years) and were randomly allocated in two experimental groups: (a) exercise at 80% 1RM without blood flow restriction and (b) exercise at 30% 1RM with blood flow restriction. In each experimental group one volunteer gave up the training due to personal problems. Thus, the LL + BFR and HL group ending with 13 volunteers.

Both groups performed the elbow flexion and knee extensor exercises (in this order), three times a week for 8 weeks of training with the volume equalized. The groups were assessed after and before training for all variables studied. The volunteers were evaluated as being healthy using a medical record questionnaire (PAR-Q). They were physically active as evaluated by means of a physical activity questionnaire (IPAQ) in a short version [17] and this tool is valid and reliable [17]. The participants were considered physically active if performed at least 150 min of physical activity per

week. They were non-smokers and they had not practiced resistance training for at least 3 months. We excluded subjects who used ergogenic (like anabolic steroids, protein and vitamin supplementation) and diuretic resources, which had been diagnosed with any type of metabolic disease, subjects with cardiovascular or circulatory diseases or other disorders that made exercise impossible. For the sample calculation the Winpepi version 4.0 program was used. The calculation of the sample size was based on the study done by Goldfarb et al. [18]. The confidence level was 95%, the coefficient of variation was 7.98, and the standard margin of error was 5%. Then, each experimental group had 14 volunteers. The procedures were performed in accordance with the Helsinki Declaration (1964) for experiments with humans. The study was approved by the Research Ethics Declaration of Committee of the Methodist University Center, IPA, under the number of stated opinion 364.202. All volunteers read and signed the Informed Consent (Table 1).

Testing procedures

During the first visit to the laboratory the subjects answered the IPAQ and the PAR-Q, and they were submitted to the anthropometric evaluation and familiarization with the exercises. In the following visits the one repetition maximum (1RM) test and the muscular endurance test at 60% 1RM were performed. Before starting the 8 weeks of training the volunteers participated in an exercise session, so it was done after the training period. In the exercise session before training a food records was made for compare macronutrients and micronutrients values (vitamins A, C and E). The volunteers were oriented to repeat the food records in the exercise session post-training. Moreover, in the sessions the RPE was evaluated with the OMNI scale [19]. Before the pre-training session, the subjects became familiar with OMNI scale. The RPE was evaluated at the end of the four sets for elbow flexion and knee extensor exercises in the pre- and post-training sessions. After the training period the subjects were submitted to the same evaluations (Fig. 1).

Table 1 Subject characteristics ($n=26$)

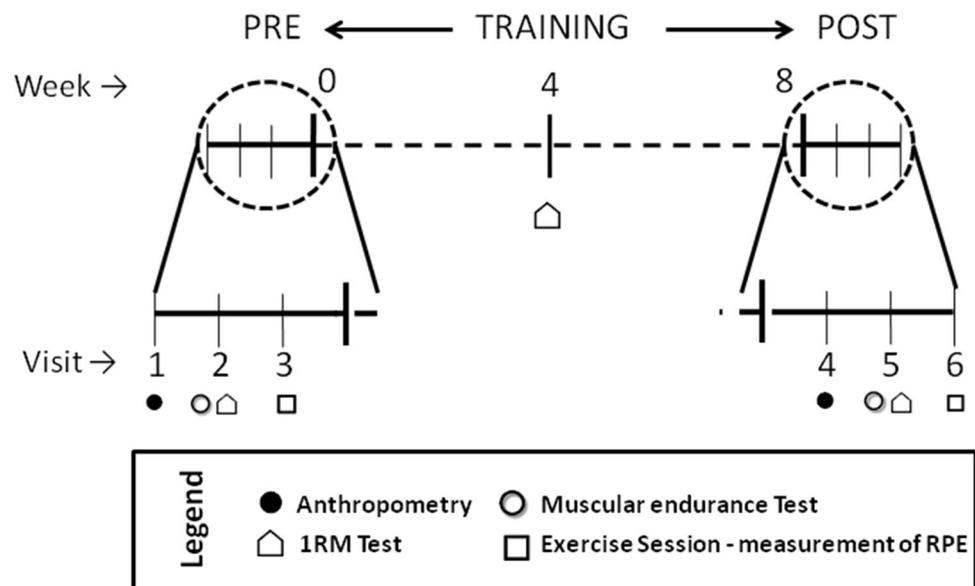
	LL + BFR	HL
Age (years)	23.53 ± 2.77	24.46 ± 2.56
Height (m)	1.73 ± 0.07	1.75 ± 0.05
Body mass (kg)	76.98 ± 13.61	79.37 ± 11.31
Adipose tissue (%)	28.63 ± 5.81	30.02 ± 4.96
Muscle mass (%)	44.12 ± 4.36	43.38 ± 3.97

Mean \pm SD

LL + BFR low load with blood flow restriction, HL high load

$p > 0.05$

Fig. 1 Experimental design. The tests and measurements were realized before and after 8 weeks of training. The 1RM test was performed in the fourth week of training, too. The exercise sessions were realized to measurement the rating of perceived exertion (RPE) with OMNI scale



Anthropometry was performed to characterize the sample using a plicometer (Mitutoyo with precision of 0.1 mm—Cescorf-Porto Alegre, Brazil), and a scale with a coupled stadiometer (MarcaWelmy, with capacity for 200 kg with precision of 0.1 kg and 0.005 m). To measure bone diameters, a caliper, an anthropometer (Cescorf-Porto Alegre, Brazil) and perimeters using a metric tape measure (Cescorf-Porto Alegre, Brazil) were used. To calculate body composition, the five-component methodology was used [20]. Markings and assessment techniques followed the standards of The International Society for the Advancement of Kinanthropometry (ISAK).

The one repetition maximum test was done for elbow flexion and knee extensor exercises. As a warm-up the subjects performed a series of ten repetitions with an estimated value of 50% 1RM. After a 5-min break, consecutive attempts were performed with progressive loads to reach 1RM using a maximum of five attempts. To determine the 1RM of each volunteer after each attempt, the Lombardi table [21] was used to correct the loads to be used in the subsequent series. In addition, the volunteers performed the movement with a 2-s rhythm for both concentric and eccentric phases. To that end, a metronome was used to control the rhythm of movement. The maximum load was found when the subject could perform only one repetition (concentric–eccentric phase of the movement) perfectly.

In the Muscular Endurance Test the volunteers performed as many repetitions as they could with 60% of the 1RM value. The repetitions were performed in a 2-s rhythm for each phase with the help of a metronome. The maximum number of repetitions was achieved when the volunteer was unable to perform flexion/extension and/or a controlled rhythm. At the time of the post-training test the 60% load

was determined according to the value previously found in the post-training 1RM test [22].

For determine the blood flow restriction, the subjects went to the Laboratory of Exercise Physiology of the IPA Methodist University Center, and when they arrived they were put in a supine position for 20 min so as to measure their blood pressure while resting. The blood flow restriction method was based on the study of Goldfarb et al. [18], in that for upper limbs the cuff was inflated to 20 mmHg below the systolic blood pressure, and on the lower limbs it was inflated to 20 mmHg above the systolic blood pressure. In both the upper and lower limbs the cuff was placed on the proximal region of the limb. The pressure cuff used for partial occlusion of limbs during exercise was 17 cm wide and 70 cm long for lower limbs, whereas for upper limbs it was 15 cm wide and 50 cm long.

To ensure that the methodology for blood flow restriction was reliable, an oximeter was used (Nellcor NPB 195, Mallinckrodt Inc., St. Louis, USA) after each series to ensure that there was no complete interruption of blood flow [18]. If the oximeter did not detect the pulse in the finger, the cuff pressure was reduced by 5–10 mmHg until the pulse was detected.

Subjects assigned to the HL group without blood flow restriction (80% 1RM) performed four sets of eight repetitions for both exercises. The LL + BFR (30% 1RM) also performed four sets. The exercises performed were elbow flexion and knee extensors, in this order. The resistance training was performed during 8 weeks with three sessions per week and the interval between sessions of at least 48 h. For the intensity to be the only variable between the groups, the equalization of the TV for the two exercises was performed according previous study of our group [23]. Briefly,

the number of repetitions of the LL + BFR group was stipulated according to the TV of the HL group. To do so, we first calculated the TV of the HL group by multiplying the overall mean of the 1RM by four (the number of sets) and by eight (the number of repetitions). Then, the average of 30% 1RM for the LL + BFR group for both exercises was calculated. Finally, to find the number of repetitions for the exercises in the LL + BFR group, the volume of the HL group was divided by the multiplication of the load average of 30% 1RM per 4 (the number of sets). From this point, the LL + BFR group performed 22 repetitions. In both groups the interval between the sets was 2 min and between the exercises there was a 3-min break. In the LL + BFR group the cuff remained inflated during the intervals between the series. The intensity and the number of repetitions described were used in the pre and post-training sessions and during the 8 weeks of training. The only change that occurred was an increase in load in the middle of the training (the fourth week) from a new 1RM test.

Statistical analysis

To evaluate the distribution of variables and verification of normality, the Shapiro Wilk test was used, assuming a normal homogeneous distribution. The Two-way ANOVA was used for comparison between groups and moments. Correlation analysis was performed using the Pearson Correlation Test. Values were considered to be statistically significant with $p < 0.05$. The data were analyzed in the GraphPad PRISM Software 6.0 statistical program.

Results

There was no significant difference in height, body mass, and the percentages of fat mass and lean mass ($p > 0.05$) when comparing groups and moments. Table 1 shows the baseline values for sample characterization purposes.

The values for the 1RM pre- and post-training are shown in Table 2. For both groups there was a significant difference for the 1RM values when compared the moments

($p < 0.0001$). In the comparison between the groups there was no significant difference for the 1RM values in the pre-training evaluation ($p > 0.05$). However, after 8 weeks of training there was a significant difference for the 1RM values in the knee extensor ($p < 0.05$), being higher for the HL group (Table 2).

Upon comparing the number of repetitions with 60% 1RM in both groups between sessions, there is a significant difference for both the elbow flexion exercise and the knee extensor exercise ($p < 0.0001$). In the comparison between groups there was no significant difference ($p > 0.05$). The data are shown in Table 3.

To compare the RPE between pre and post-training sessions in the LL + BFR group, there was no significant difference in the elbow flexion exercise ($p > 0.05$). The values for the pre- and post-training sessions were: 6.34 ± 1.27 and 6.00 ± 1.53 , respectively. Regarding the knee extensor exercise, there was a significant difference ($p < 0.01$). The values for the pre- and post-training sessions were: 8.30 ± 1.08 and 6.00 ± 1.89 , respectively. In the HL group there was no significant difference for RPE in the elbow flexion ($p > 0.05$). The values in this exercise in the pre- and post-training sessions were: 7.84 ± 1.25 and 8.61 ± 0.83 , respectively. In the same way, there was no significant difference for knee extensor exercises

Table 3 Endurance test with 60% 1RM (no. of repetitions)

Exercise	LL+BFR		HL	
	Baseline	Post	Baseline	Post
Elbow flexion	11.46 ± 3.77	$18.92 \pm 5.94^\dagger$	12.08 ± 3.17	$18.08 \pm 4.19^\ddagger$
Knee extensor	10.85 ± 2.23	$21.62 \pm 3.82^\dagger$	10.62 ± 1.66	$18.77 \pm 3.79^\ddagger$

Mean ± SD

LL + BFR low load with blood flow restriction, HL high load, 1RM one repetition maximum

[†]Significant difference between baseline and post in LL+BFR, $p < 0.0001$

[‡]Significant difference between baseline and post in HL, $p < 0.0001$

Table 2 One repetition maximum (kg)

Exercise	LL+BFR		HL	
	Baseline	Post	Baseline	Post
Elbow flexion	16.15 ± 3.71	$19.08 \pm 3.75^\dagger$	15.46 ± 3.15	$19.62 \pm 3.57^\ddagger$
Knee extensor	73.46 ± 18.63	$96.15 \pm 15.85^{*\ddagger}$	80.62 ± 15.33	$117.46 \pm 18.22^{*\ddagger}$

Mean ± SD

LL + BFR low load with blood flow restriction, HL high load

[†]Significant difference between baseline and post in LL + BFR, $p < 0.0001$

[‡]Significant difference between baseline and post in HL, $p < 0.0001$

[§]Significant difference between groups in post, $p < 0.05$

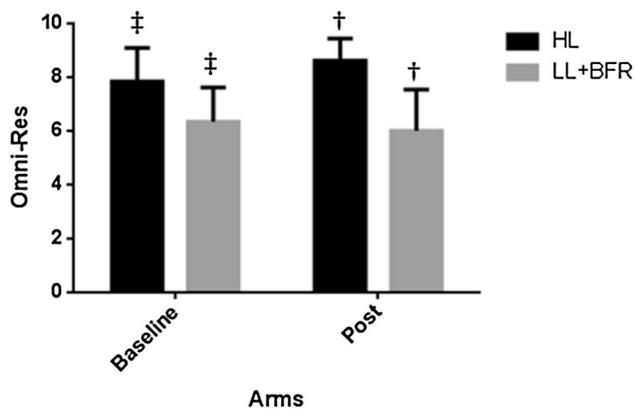


Fig. 2 Rate of perceived exertion (RPE) values of elbow flexion exercise in the study protocols. †Significant difference between groups in post, $p < 0.001$; ‡significant difference between groups in baseline, $p < 0.0001$. LL+BFR low load with blood flow restriction protocol

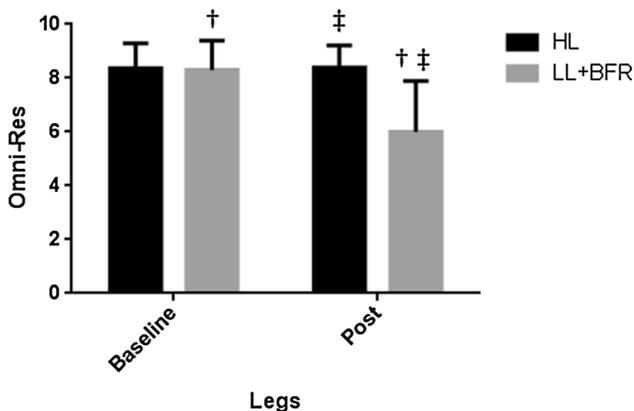


Fig. 3 Rate of perceived exertion (RPE) values of knee extensor exercise in the study protocols. †Significant difference between baseline and post in LL+BFR, $p < 0.01$; ‡significant difference between groups, $p < 0.01$. HL high-load protocol, LL+BFR low load with blood flow restriction protocol

between sessions: 8.36 ± 0.93 and 8.38 ± 0.83 , respectively. When comparing the groups, in the pre-training session, the RPE in the elbow flexion showed a significant difference, being higher for HL ($p < 0.0001$). In the post-training session there was a significant difference in the elbow flexion ($p < 0.0001$) and knee extensor exercises ($p < 0.01$), being higher for the HL group. The data are shown in Figs. 2 and 3. Lastly, a negative correlation was verified between the RPE and the 1RM (load in kg) in the LL+BFR ($r = -0.6972$, $p < 0.0001$) in the knee extensor exercise. The data are shown in Fig. 4a. To demonstrate the individual values of RPE in both groups in baseline and post in the knee extensor exercises, the Fig. 4b, c are shown.

Discussion

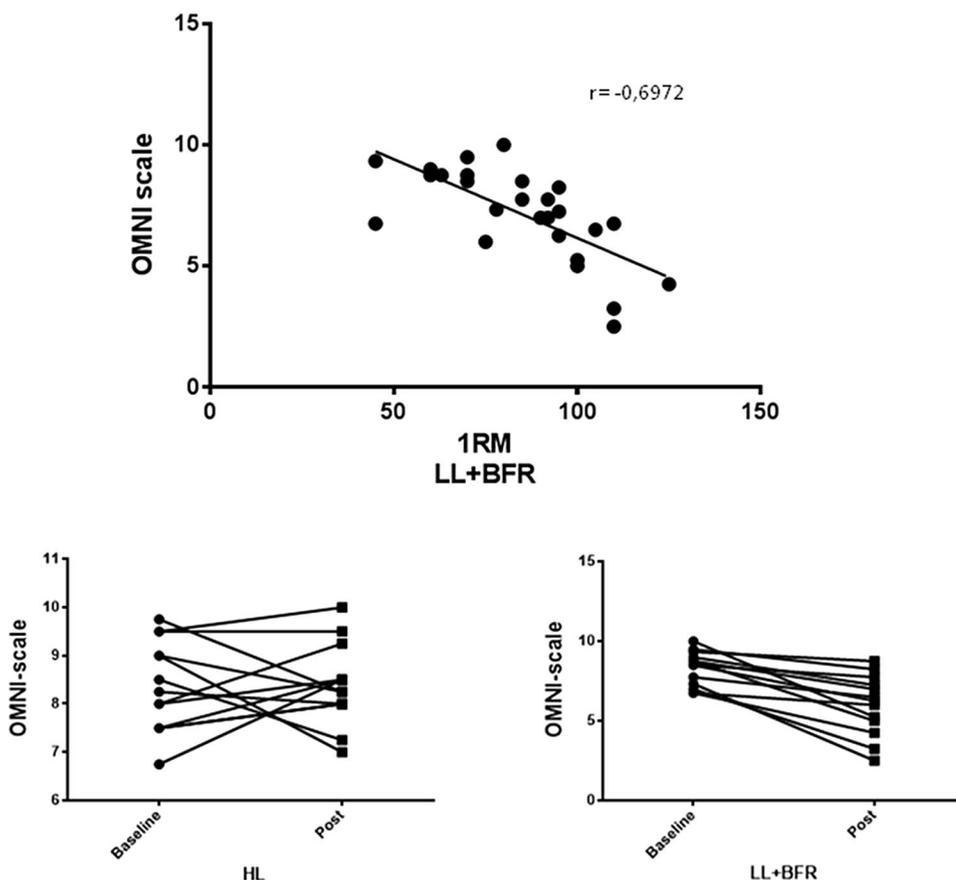
This study verified the effects of two strength training protocols (HL and LL+BFR) with equalized training volumes in RPE, resistance and muscular endurance. The main finding was that 8 weeks of LL+BFR makes it possible for there to be less RPE of exercise than HL in young adult subjects. The training period was also effective for increasing muscle resistance and endurance in the LL+BFR and HL groups. In addition, a negative correlation was verified between the RPE and the parameters of muscular resistance in LL+BFR in the knee extensor exercise.

In the literature several studies have demonstrated increased strength using LL+BFR [24–26]. Our study demonstrated strength gains in a protocol of 8 weeks, corroborating with Laurentino and colleagues [1] that demonstrated similar strength and hypertrophy gains between LL+BFR and HL groups in subjects who performed knee extensor exercises. On the other hand, Yasuda et al. [26], upon investigating the combined effect of LL+BFR and HL training for 6 weeks demonstrated the greatest improvements in strength for the HL group in comparing a combination of HL+LLBFR and LL+BFR. In the combined group strength gains were similar to those of the HL group. Because of the lower strength gains compared to the other two groups, LL+BFR would not allow for strength gains induced by neural adaptation in the first weeks of the training [26]. Thus, it is possible that adaptations for strength improvements in LL+BFR could be different.

This study equalized the training volume (TV) between groups. Our results have demonstrated that in both groups there was an increase in strength and greater gains for the HL group in the knee extensor exercises. Few studies in the literature have controlled the TV between the groups [26, 27]. The study by Martín-Hernández et al. [27] controlled the TV to compare two LL+BFR training protocols of different volumes regarding strength gains. Thus, only the study by Yasuda et al. [26], who had similar TV between the groups, can be compared with our results. In this study strength and hypertrophy gains were greater for the HL group after 6 weeks of training.

Another important result was the significant increase in the number of repetitions performed in the 60% 1RM test in both groups. The muscle fiber recruitment theory indicates that with increased muscle contraction intensity there is a proportional increase in recruitment of type II fibers [28]. According to Loenneke et al. [29] in LL+BFR and HL there is recruitment of type II fibers. This would happen because of the restriction of blood flow that would result in less availability of oxygen to the muscle, which

Fig. 4 The effect of resistance training in PRE. **a** Correlation between rating of perceived exertion (measured with OMNI scale) and strength parameters (measured by 1RM) in the LL + BFR ($p < 0.0001$). **b** Individual values of rating of perceived exertion in the HL group. **c** Individual values of rating of perceived exertion in the LL + BFR group in baseline and post. *HL* high-load protocol, *LL + BFR* low load with blood flow restriction protocol



would generate a deficit of strength. This deficit would be offset by the recruitment of type II fibers. Therefore, a similar increase in muscle endurance levels in both groups would occur due to the lack of specificity of the two types of training to improve this capacity.

In the present study the RPE was lower in LL + BFR as compared to HL. In addition, taking into consideration only the pre-training session the RPE was also greater for the HL group in the exercise of elbow flexion. This agrees with a study of Neto et al. [30] that verified lower RPE in upper body exercises with LL + BFR in comparison with HL. Importantly, in this study the exercise volume were controlled similarly to the present study. In contrast to our findings, most studies evaluating a LL + BFR session have observed in subjects a greater RPE when compared to a session without blood flow restriction. However, many of these studies have only compared the RPE between LL + BFR and LL exercises [11, 31], which would justify a greater RPE for the LL + BFR session. In the studies that have evaluated HL exercises with LL + BFR, the results seem to be conflicting. There are studies that present a greater perception of effort for the HL sessions [26, 32], others do not observe a difference between the sessions [33] and some observed greater RPE for the LL + BFR sessions [7, 8, 10]. Since studies have different degrees of intensity, numbers

of sets and repetitions, in addition to different pressures for restricting blood flow, it is difficult to reach a consensus as to whether the RPE in LL + BFR is greater than that in HL. To our knowledge this is one of the first studies to evaluate the effect of LL + BFR on RPE. Our results show that LL + BFR, when compared to HL (with equalized training volumes between protocols), maintains and/or reduces RPE at the end of the training. Upon assessing six LL + BFR and HL exercise sessions, Martín-Hernández et al. [14] showed a lower degree of RPE in both groups in the last exercise sessions (5th and 6th sessions) with no difference between groups. In our study the RPE in the subjects of the HL group was not reduced, which could be explained by the adjustment of loads in the fourth week of training. Furthermore, it is possible that the adjustment of loads in the LL + BFR group did not affect the RPE, since they were already adapted to the blood flow restriction that remained the same throughout training.

The lower RPE in the LL + BFR group in the post-training session compared to the HL group may indicate that this type of training would be effective in clinical practice for people undergoing rehabilitation. Some studies have demonstrated that LL + BFR may be suitable for strength and hypertrophy improvements in these cases [34, 35]. Upon evaluating women with osteoarthritis in the knee, Segal

et al. [35] found that 4 weeks of LL + BFR was effective for improving strength in the quadriceps without causing a worsening sensation of pain. Likewise, Ferraz et al. [34] also found gains in strength and hypertrophy after 12 weeks of LL + BFR in women with osteoarthritis which were not different from the HL group. Furthermore, the perception of pain was reduced after training in the LL + BFR group, which did not occur in the HL group. Thus, use LL + BFR could be effective for improving the patients' clinical condition.

An interesting finding in this study was the negative correlation found among RPE and 1RM values in LL + BFR in the knee extensor exercise. In this group a less RPE was related with a higher maximum dynamic strength. In this regard, we suggest that the lower work load (30% 1RM), in LL + BFR, and the maintenance the same restriction of blood flow enabled a rapid adaptation to effort. This followed after fourth week of training even with a new 1RM test. These data are shown in Fig. 4b, c where the RPE values between baseline and post-training diminished in every volunteer in LL + BFR, but not in every volunteer in HL group. Then, this rapid adaptation to effort in the LL + BFR appears to allow strength gains with less discomfort than HL group.

Conclusion

The LL + BFR seems to result in lower RPE compared to the HL, because of training. Considering that both methods allowed for an increase in strength and muscular endurance after 8 weeks, this result could demonstrate that with the passage of sessions the LL + BFR would become less uncomfortable, which would be important for the subjects to remain in a training program, thus making it an effective tool in musculoskeletal rehabilitation programs. Future studies can verify, in this method, the RPE with other exercises and more weeks of training, especially in people with orthopedic problems.

Acknowledgements We would like to thank the IPA Methodist University Center - (Porto Alegre, Brazil), the Higher Education Personnel Training Coordination (Capes) and the Foundation for the Rio Grande do Sul State Research (Fapergs).

Funding This study was funded by the Higher Education Personnel Training Coordination (CAPES) and the Foundation for the Rio Grande do Sul State Research (FAPERGS). We would like to thank the Centro Universitário Metodista-IPA (Porto Alegre, Brazil).

Compliance with ethical standards

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

Informed consent Informed consent was obtained from all individual participants included in the study.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

1. Laurentino GC, Ugrinowitsch C, Roschel H, Aoki MS, Soares AG, Neves M Jr, Aihara AY, Fernandes Ada R, Tricoli V (2012) Strength training with blood flow restriction diminishes myostatin gene expression. *Med Sci Sports Exerc* 44(3):406–412
2. Takarada Y, Takazawa H, Sato Y, Takebayashi S, Tanaka Y, Ishii N (2000) Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. *J Appl Physiol* 88(6):2097–2106
3. Fahs CA, Loenneke JP, Rossow LM, Thiebaud RS, Bemben MG (2012) Methodological considerations for blood flow restricted resistance exercise. *J Trainol* 1(1):14–22
4. Campos GE, Luecke TJ, Wendeln HK, Toma K, Hagerman FC, Murray TF, Ragg KE, Ratamess NA, Kraemer WJ, Staron RS (2002) Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur J Appl Physiol* 88(1–2):50–60
5. Van Roie E, Bautmans I, Coudyzer W, Boen F, Delecluse C (2015) Low- and high-resistance exercise: long-term adherence and motivation among older adults. *Gerontology* 61(6):551–560
6. Ekkekakis P, Parfitt G, Petruzzello SJ (2011) The pleasure and displeasure people feel when they exercise at different intensities: decennial update and progress towards a tripartite rationale for exercise intensity prescription. *Sports Med* 41(8):641–671
7. Pinto RR, Polito MD (2016) Haemodynamic responses during resistance exercise with blood flow restriction in hypertensive subjects. *Clin Physiol Funct Imaging* 36(5):407–413
8. Poton R, Polito MD (2016) Hemodynamic response to resistance exercise with and without blood flow restriction in healthy subjects. *Clin Physiol Funct Imaging* 36(3):231–236
9. Neto GR, Sousa MS, Costa e Silva GV, Gil AL, Salles BF, Novaes JS (2014) Acute resistance exercise with blood flow restriction effects on heart rate, double product, oxygen saturation and perceived exertion. *Clin Physiol Funct Imaging* 36(1):53–59
10. Vieira A, Gadelha AB, Ferreira-Junior JB, Vieira CA, Soares Ede M, Cadore EL, Wagner DR, Bottaro M (2015) Session rating of perceived exertion following resistance exercise with blood flow-restriction. *Clin Physiol Funct Imaging* 35(5):323–327
11. Loenneke JP, Kearney ML, Thrower AD, Collins S, Pujol TJ (2010) The acute response of practical occlusion in the knee extensors. *J Strength Cond Res* 24(10):2831–2834
12. Yasuda T, Fukumura K, Iida H, Nakajima T (2015) Effect of low-load resistance exercise with and without blood flow restriction to volitional fatigue on muscle swelling. *Eur J Appl Physiol* 115(5):919–926
13. Weatherholt A, Beekley M, Greer S, Urtel M, Mikesky A (2013) Modified Kaatsu training: Adaptations and subject perceptions. *Med Sci Sports Exerc* 45(5):952–961
14. Martín-Hernández J, Ruiz-Aguado J, Herrero JA, Loenneke JP, Aagaard P, Cristi-Montero C, Menéndez H, Marín PJ (2016) Adaptation of perceptual responses to low load blood flow restriction training. *J Strength Cond Re* 31(3):765–772
15. Lixandrão ME, Ugrinowitsch C, Laurentino G, Libardi CA, Aihara AY, Cardoso FN et al (2015) Effects of exercise intensity

- and occlusion pressure after 12 weeks of resistance training with blood-flow restriction. *Eur J Appl Physiol* 115(12):2471–2480
16. Vechin FC, Libardi CA, Conceição MS, Damas FR, Lixandrão ME, Berton RP et al (2015) Comparisons between low-intensity resistance training with blood flow restriction and high-intensity resistance training on quadriceps muscle mass and strength in elderly. *J Strength Cond Re* 29(4):1071–1076
 17. Craig CL, Marshall AL, Sjoström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P (2003) International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 35(8):1381–1395
 18. Goldfarb AH, Garten RS, Chee PDM, Cho C, Reeves GV, Hollander DB, Aboudehen KS, Francois M, Thomas C, Kraemer RR (2008) Resistance exercise effects on blood glutathione status and plasma protein carbonyls: influence of partial vascular occlusion. *Eur J Appl Physiol* 104(5):813–819
 19. Robertson RJ, Goss FL, Rutkowski J, Lenz B, Dixon C, Timmer J, Frazee K, Dube J, Andreacci J (2003) Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Med Sci Sports Exerc* 35(2):333–341
 20. Marfell-Jones TO, Stewart A, Carter L (2006) International standards for anthropometric assessment. International Society for the Advancement of Kinanthropometry, Glasgow, Scotland, pp 21–111
 21. Lombardi VP (1989) Beginning weight training: the safe and effective way. C. Brown, Dubuque
 22. Anderson T, Kearney JT (1982) Effects of three resistance training programs on muscular strength and absolute and relative endurance. *Res Q Exerc Sport* 53(1):1–7
 23. Ramis TR, Muller CHL, Boeno FP, Teixeira BC, Rech A, Pompermayer MG et al (2018) Effects of traditional and vascular restricted strength training program with equalized volume on isometric and dynamic strength, muscle thickness, electromyographic activity, and endothelial function adaptations in young adults. *J Strength Cond Res*. <https://doi.org/10.1519/JSC.0000000000002717>
 24. Patterson SD, Ferguson RA (2010) Increase in calf post-occlusive blood flow and strength following short-term resistance exercise training with blood flow restriction in young women. *Eur J Appl Physiol* 108(5):1025–1033
 25. Patterson SD, Ferguson RA (2011) Enhancing strength and post occlusive calf blood flow in older people with training with blood-flow restriction. *J Aging Phys Act* 19(3):201–213
 26. Yasuda T, Ogasawara R, Sakamaki M, Ozaki H, Sato Y, Abe T (2011) Combined effects of low-intensity blood flow restriction training and high-intensity resistance training on muscle strength and size. *Eur J Appl Physiol* 111(10):2525–2533
 27. Martin-Hernandez J, Marin PJ, Menendez H, Ferrero C, Loenneke JP, Herrero AJ (2013) Muscular adaptations after two different volumes of blood flow-restricted training. *Scand J Med Sci Sports* 23(2):114–120
 28. Egan B, Zierath JR (2013) Exercise metabolism and the molecular regulation of skeletal muscle adaptation. *Cellmetab* 17(2):162–184
 29. Loenneke JP, Wilson GJ, Wilson JM (2010) A mechanistic approach to blood flow occlusion. *Int J Sports Med* 31(1):1–4
 30. Neto GR, Novaes JS, Salerno VP, Gonçalves MM, Piazeria BK, Rodrigues-Rodrigues T, Cirilo-Sousa MS (2017) Acute effects of resistance exercise with continuous and intermittent blood flow restriction on hemodynamic measurements and perceived exertion. *Perceptual Motor Skills* 124(1):277–292
 31. Yasuda T, Loenneke J, Ogasawara R, Abe T (2013) Influence of continuous or intermittent blood flow restriction on muscle activation during low-intensity multiple sets of resistance exercise. *Acta Physiol Hung* 100(4):419–426
 32. Kim E, Gregg LD, Kim D, Sherk VD, Bembem MG, Bembem DA (2014) Hormone responses to an acute bout of low intensity blood flow restricted resistance exercise in college-aged females. *J Sports Sci Med* 13(1):91–96
 33. Manini TM, Yarrow JF, Buford TW, Clark BC, Conover CF, Borst SE (2012) Growth hormone responses to acute resistance exercise with vascular restriction in young and old men. *Growth Horm IGF Res* 22(5):167–172
 34. Ferraz RB, Gualano B, Rodrigues R, Kurimori CO, Fuller R, Lima FR, Roschel H (2018) Benefits of resistance training with blood flow restriction in knee osteoarthritis. *Med sci sport exer* 50(5):897–905
 35. Segal NA, Williams GN, Davis MC, Wallace RB, Mikesky AE (2015) Efficacy of blood flow-restricted, low-load resistance training in women with risk factors for symptomatic knee osteoarthritis. *PM&R* 7(4):376–384

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.