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Does a resistance exercise session with continuous or intermittent blood flow restriction promote muscle damage and increase oxidative stress?

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ABSTRACT

The aim of this study was to compare the effect of low-load resistance exercise (LLRE) with continuous and intermittent blood flow restriction (BFR) on the creatine kinase (CK), lactate dehydrogenase (LDH), protein carbonyl (PC), thiobarbituric acid-reactive substance (TBARS) and uric acid (UA) levels in military men. The study included 10 recreationally trained men aged 19 ± 0.82 years who underwent the following experimental protocols in random order on separate days (72–96 h): 4 LLRE sessions at a 20% 1RM (one-repetition maximum [1RM]) with continuous BFR (LLRE + CBFR); 4 LLRE sessions at 20% 1RM with intermittent BFR (LLRE + IBFR) and 4 high-intensity resistance exercise (HIRE) sessions at 80% 1RM. The CK and LDH (markers of muscle damage) levels were measured before exercise (BE), 24 h post-exercise and 48 h post-exercise, and the PC, TBARS and UA (markers of oxidative stress) levels were measured BE and immediately after each exercise session. There was a significant increase in CK in the HIRE 24 post-exercise samples compared with the LLRE + CBFR and LLRE + IBFR ($P = 0.035$, $P = 0.036$, respectively), as well as between HIRE 48 post-exercise and LLRE + CBFR ($P = 0.049$). Additionally, there was a significant increase in CK in the LLRE + CBFR samples BE and immediately after each exercise ($\Delta = 21.9\%$) and in the HIRE samples BE and immediately after each exercise, BE and 24 post-exercise, and BE and 48 post-exercise (Δ values of 35%, 177.6%, and 177.6%, respectively). However, there were no significant changes in LDH, PC, TBARS, and UA between the protocols ($P > 0.05$). Therefore, a physical exercise session with continuous or intermittent BFR did not promote muscle damage; moreover, neither protocol seemed to affect the oxidative stress markers.

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KEYWORDS
Vascular occlusion; kaatsu; resistance training; cellular data

Introduction

The Japanese developed a resistance exercise (RE) programme known as kaatsu training nearly 50 years ago that involves vascular occlusion. This programme has been used to increase overall strength (Laurentino et al., 2012; Silva et al., 2015; Sousa et al., 2017; Vechin et al., 2015) and muscle mass (Laurentino et al., 2012; Vechin et al., 2015). Participants use low loads [20–30% of the one-repetition maximum (1RM)], which greatly deviates from the method established by the American College of Sports Medicine that recommends an intensity equal to or higher than 65% 1RM (ACSM, 2009), in combination with blood flow restriction (BFR) using elastic bands or standard sphygmomanometers (Manini & Clark, 2009; Sato, 2005). The exercise has been proven to be safe in relation to hemodynamics (Neto et al., 2016, 2016, 2015, 2016; Vilaça-Alves et al., 2016). In addition, the kaatsu training method has also been used to increase localised muscle endurance (Gil et al., 2015; Kacin & Strazar, 2011; Sousa et al., 2017) and functional capacity (Araujo et al., 2015).

Since the emergence of this method, several studies have standardised procedures to improve the safety and effectiveness of some parameters, including load intensity (Suga et al., 2010), cuff size (Rossow et al., 2012), pressure (Sumide, Sakuraba, Sawaki, Ohmura, & Tamura, 2009) and the BFR application method (continuous or intermittent). Studies have evaluated the effect of continuous and intermittent BFR on muscle activation (Yasuda, Loenneke, Ogasawara, & Abe, 2013) and the effects of BFR on metabolic stress and the recruitment of fast fibres (Suga et al., 2012), hemodynamics (Brandner, Kidgell, & Warmington, 2015; Neto et al., 2016) and muscle strength as well as lean mass (Fitschen et al., 2014). However, these studies used a single exercise with a unilateral and single-joint execution, except for two studies (Neto et al., 2016, 2016) that used multi-joint and bilateral exercises. Although previous studies found no significant differences in muscle strength or muscle mass in the lower limbs between

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continuous and intermittent BFR (Fitschen et al., 2014) or differences in muscle activation of the upper limbs (Yasuda et al., 2013), the best strategy for working with BFR in a training session for the upper limbs is unknown.

To identify the safest and most effective methods to apply kaatsu training, it is important to understand the effects of continuous and intermittent BFR during physical exercise sessions for the upper limbs. Metabolic stress seems to occur more with continuous BFR and high intensity exercise when compared to intermittent BFR (Suga et al., 2012), which appears to increase the pain experienced during exercise sessions (Fitschen et al., 2014). Since this can influence adherence to training, it is necessary to conduct studies in controlled healthy populations (e.g., young military personnel) with safety protocols and appropriate methods for extrapolation to populations with specialised needs.

Furthermore, the incidence of muscle damage and oxidative stress must be determined. Other studies have evaluated the effect of LLRE with continuous BFR (LLRE + CBFR) through biochemical markers of muscle damage (Clark et al., 2011; Karabulut, Sherk, Bemben, & Bemben, 2013; Madarame, Kurano, Fukumura, Fukuda, & Nakajima, 2013; Takarada et al., 2000) and oxidative stress (Garten, Goldfarb, Crabb, & Waller, 2015; Goldfarb et al., 2008; Takarada et al., 2000). However, no studies have evaluated the effect of LLRE with intermittent BFR (LLRT + IBFR) on biochemical markers of muscle damage and oxidative stress. Additionally, no previous studies have compared the acute effects of LLRE + CBFR or LLRE + IBFR in the upper limbs on muscle damage markers (creatine kinase [CK] and lactate dehydrogenase [LDH]) and oxidative stress markers (protein carbonyl [PC], thiobarbituric acid-reactive substances [TBARSs] and uric acid [UA]).

The aim of the present study was to compare the effect of low-load resistance exercise (LLRE) with continuous and intermittent BFR in the upper limbs, as defined in kaatsu training, on muscle damage and oxidative stress in military men to more common exercise. We hypothesised that high-intensity resistance exercise (HIRE) would significantly increase muscle damage compared to continuous and intermittent BFR. In addition, we expected that a high-intensity session and continuous BFR would significantly increase oxidative stress markers compared with intermittent BFR.

Methods

Participants

The study group was composed of 10 recreationally trained [1–5 years strength training (Rhea, 2004)] normotensive military men (age 19 ± 0.8 years, weight 78.8 ± 10.8 kg, height 174.6 ± 5.4 cm and body mass index [BMI] 25.7 ± 2.7 $m^2 \cdot kg^{-1}$, SBP = 123.83 ± 9.7 mm Hg; DBP = 79.8 ± 8.3 mm Hg). Participants who responded positively to any of the items on the Physical Activity Readiness Questionnaire (Shephard, 1988), missed one of the training sessions, presented musculoskeletal injuries in the upper limbs, smoked or hypertensive were excluded. Written informed consent was obtained from all participants after an explanation was given about the aims, risks and benefits involved in the study. The study was approved by the local Ethics Committee of Federal University of Paraiba (protocol number 0476/13) and performed in accordance with the ethical standards of the Declaration of Helsinki.

The sample size was calculated using G*Power software version 3.1. Based on an a priori analysis, the sample size of 10 was considered to have a power of 0.80, an α of 0.05, a correlation coefficient of 0.5, a nonsphericity correction of 1 and an effect size (ES) of 0.45, which correlated to a statistical power of 82.4% as calculated by adopting the procedures suggested by Beck (2013). This a priori analysis of the statistical power was conducted to decrease the probability of type II errors and to determine the minimum number of participants required for this investigation.

Study design

During the first visit to the laboratory, anthropometric parameters and muscle strength (bench press, lateral pull-down, triceps curl with pulley and biceps curl with pulley, respectively) were evaluated. After the first visit, the participants visited the laboratory on three separate occasions between 72 and 96 h apart to complete the following three protocols in random order using the crossover model (Figure 1): (a) an LLRE + CBFR session at 20% 1RM; (b) an LLRE + IBFR session at 20% 1RM and (c) a HIRE session at 80% 1RM. All three protocols were performed at the same time of the day, and the measurements were made before exercise (BE), immediately after exercise (IAE), 24 h after exercise (24 AE) and 48 h after exercise (48 AE). Participants in the study were instructed to avoid caffeine, chocolate, nutritional supplements and alcohol as well as to abstain from exercise for 4 weeks before, during and 4 weeks after the study period. In addition, participants were instructed to sleep for a minimum of 6 h the night before the training sessions. Finally, the participants were instructed to maintain the same eating habits during the study period and to not perform the Valsalva manoeuvre during the training sessions.

Procedures

Anthropometric evaluation and calculation of BFR

Initially, a stadiometer and scale (model 31, Filizola, São Paulo, Brazil) were used to measure the height and body mass to the nearest 0.5 cm and 0.1 kg, respectively. These measurements were calculated later to provide the BMI ($m^2 \cdot kg^{-1}$). Blood

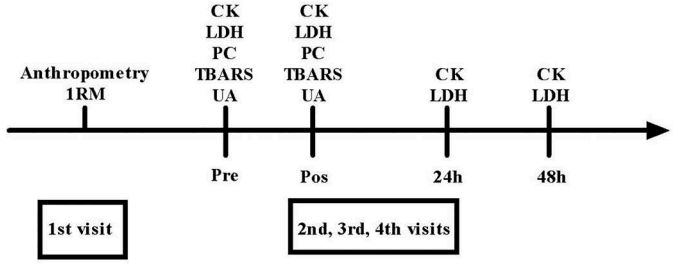

Figure 1. Graphical representation of the experimental design.
CK: creatine kinase; LDH: lactate dehydrogenase; PC: protein carbonyl; TBARS: thiobarbituric acid-reactive substance; UA: uric acid.

pressure was measured with the participants seated and a standard sphygmomanometer (komprimeter pneumatic tourniquet for haemostasis in extremities, Riester, Jungingen, Germany) for the arm (60 mm width and 470 mm length) that was placed in the region of the axillary fold to measure blood pressure at the beginning of each continuous and intermittent BFR protocol. Total BFR was obtained by multiplying the systolic blood pressure by 1.3 (Brandner et al., 2015; Neto et al., 2016, 2016; Suga et al., 2010). The cuff was inflated or deflated between each exercise set.

1RM test

Four exercises were performed bilaterally (bench press, front pulldown, triceps curl and direct biceps curl). Initially, each participant performed a warm-up with a series of 5–10 repetitions at 40–60% of the maximum perceived strength with a 1-min interval between each set. After the 1-min interval, a second series was performed with three to five repetitions at 60–80% of the maximum perceive strength. After a 1-min rest, five tests of strength were attempted, and the load was adjusted before each new attempt. The recovery time between attempts was standardised at 3–5 min with an interval of 20 min for recovery between different exercises. The test was interrupted when the individual failed to properly execute the movement and the maximum load considered was the load moved in the last successful attempt.

Sample collection and processing

Blood samples (5 mL) were collected from the antecubital vein in vacutainer tubes 20 min BE, 60–90 s IAE, 24 PE and 48 PE and immediately placed on ice for transport. The blood samples were centrifuged at 1500 × *g* for 15 min at 4°C, and the plasma was removed and stored at −80°C for subsequent analysis.

Assessment of muscle damage and oxidative stress

The CK, LHD and UA levels were measured using a Bioclin® commercial kit following the manufacturer's specifications. TBARs and PC were measured as described in Rosa-Lima, Lannes, Viana-Gomes, Pierucci and Salerno (2015). The absorbance was read in a 96-well microplate on the Spectra Max Paradigm apparatus (Molecular Devices, USA). The intra-assay coefficient variation was 2.6% for CK, 1% for LHD, 0.51% for AU, 5.5% for TBARS and 4.7% for PC. The analysis of PC data was only available for five participants due to sample lost.

Experimental sessions

Four RE sessions were performed bilaterally as follows: bench press (with a conventional bar and calibrated weights), front pulldown, triceps curl and direct biceps curl (on conventional machines; Physicus®, Brazil). All participants executed three protocols in random order as follows: four LLRE + CBFR at 20% 1RM, four LLRE + IBFR at 20% 1RM and four HIRE at 80% 1RM (HIRE). For the LLRE + CBFR and LLRE + IBFR protocols, the participants completed a series of 30 repetitions followed by three sets of 15 repetitions at 20% 1RM with a 30-s interval between each series and a 1-min interval between each exercise while wearing a standard blood pressure sphygmomanometer (komprimeter pneumatic tourniquet for haemostasis in extremities, Riester, Jungingen, Germany) on the arms (60 mm width and 470 mm length) placed at the most proximal region (Neto et al., 2016, 2016). For the LLRE + IBFR protocol, the cuff was deflated fully between each set and between each exercise. For the LLRE + CBFR protocol, the cuff was kept inflated between each set but was fully deflated at the end of each exercise. For the HIRE protocol, the participants completed three sets of eight repetitions at 80% 1RM with 2-min intervals between each series and a 1-min interval between each exercise. The execution speed was controlled by a metronome set at 3 s, which was equally divided between concentric and eccentric muscle action. The total volume (VT) of the exercise was calculated by multiplying the total load by the number of sets and repetitions completed in the four exercises (load *x* sets *x* repetitions).

Statistical analysis

All statistical analyses were performed using SPSS version 20.0 (SPSS Inc., Chicago, IL, USA). The statistical analysis was initially conducted using the Shapiro–Wilk normality test and the Levene homogeneity test. The variables showed a normal distribution and homogeneity ($P > 0.05$). One-way ANOVA followed by the Bonferroni *post-hoc* test was used to compare the total exercise volume and the change of the CK and TBARSs between the protocols. The paired *t*-test was used to compare the two BFR protocols employed in the LLRE + CBFR and LLRE + IBFR protocols. Two-way ANOVA with repeated measures (protocols [LLRE + CBFR vs. LLRE + IBFR vs. HIRE] × time [BE vs. IAE vs. 24 h vs. 48 h]) followed by the Bonferroni *post-hoc* test was used to evaluate possible differences in the CK and LDH levels. Two-way ANOVA followed (protocols [LLRE + CBFR vs. LLRE + IBFR vs. HIRE] × time [BE vs. IAE]) by the Bonferroni *post-hoc* test was used to evaluate potential differences in the PC and UA levels. The ES was used to verify the magnitudes [trivial < 0.35, small = 0.35–0.80, moderate = 0.80–1.50 and large > 1.5] of changes between assessments of the protocols (Rhea, 2004). The percent change (Δ%) [(post − pre)/pre × 100] was used to express significant differences. The level of significance was set at $P \leq 0.05$.

Results

There was a significant difference in the sum of the VT of the four exercises between the protocols [LLRE + CBFR and LLRE + IBFR (4131.0 ± 608.2) vs. HIRE (5598.7 ± 836.7), $P < 0.001$], but no significant differences were observed between the LLRE + CBFR and the LLRE + IBFR protocols ($P = 1.000$). The paired *t*-test results indicated no significant differences between the two BFR methods used in the LLRE + CBFR and LLRE + IBFR protocols (160.95 ± 12.92 and 163.80 ± 10.52 mm Hg, $P = 0.444$, respectively).

The comparative analysis of CK indicated a significant interaction between the protocols and the BFR duration ($F_{(2, 6)} = 3.448$; $\eta^2 = 0.203$; $P = 0.020$). There was a significant difference between the LLRE + CBFR and HIRE ($P = 0.035$) and between the LLRE + IBFR and HIRE ($P = 0.036$) at 24 PE, and between the LLRE + CBFR and HIRE ($P = 0.049$) at 48 PE. Moreover, there was a significant difference between BE and IAE ($P = 0.010$, $\Delta = 21.9\%$;

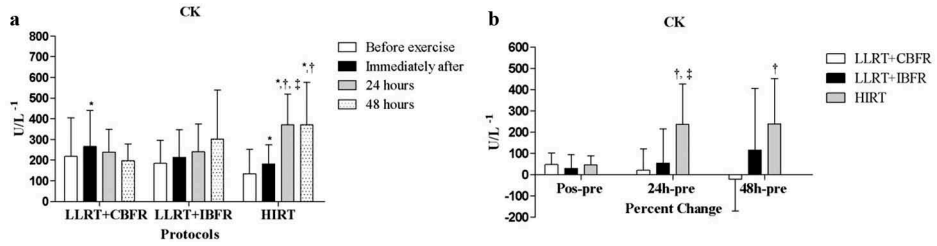

Figure 2. Creatine kinase levels between exercise protocols and time of collection. Panel a graphs the absolute measured levels creatine kinase (CK) between the protocols before exercise, immediately after exercise and 24 and 48 h after exercise (n = 10). Panel b shows the calculated changes in the CK levels between pre-exercise levels to immediately, 24 and 48 h post-exercise.
†Significant difference between LLRE + CBFR and HIRE; ‡significant difference between LLRE + IBFR and HIRE; *significant difference compared with the period before exercise.A: Two-way ANOVA with repeated measures; B: one-way ANOVA (Delta); LLRE + CBFR: low-load resistance exercise combined with continuous blood flow restriction; LLRE + IBFR: low-load resistance exercise coupled with intermittent blood flow restriction; HIRE: high-intensity resistance exercise.

ES = 0.25) for the LLRE + CBFR, but no significant difference was observed for the LLRE + IBFR ($P > 0.05$). Additionally, there was a significant increase BE and IAE, BE and 24 PE, and BE and 48 PE ($P = 0.011$, $\Delta = 35\%$, ES = 0.39; $P < 0.001$, $\Delta = 177.6\%$; ES = 1.97; $P = 0.002$, $\Delta = 177.6\%$, ES = 1.97, respectively) for the HIRE protocol (Figure 2(a)). The one-way ANOVA indicated significant differences in the delta values between the LLRE + CBFR and HIRE ($P = 0.012$) and between the LLRE + IBFR and HIRE protocols ($P = 0.040$) BE and 24 PE and between the LLRE + CBFR and HIRE protocols ($P = 0.048$) BE and 48 PE (Figure 2(b)).

The comparative analysis of LDH indicated no significant interaction between the protocols and the time points ($F_{(2, 6)} = 0.972$; $\eta^2 = 0.067$; $P = 0.418$), between the protocols ($F_{(2, 6)} = 0.270$; $\eta^2 = 0.020$; $P = 0.765$), and between time points ($F_{(2, 6)} = 1.947$; $\eta^2 = 0.067$; $P = 0.163$) (Figure 3).

The comparative PC analysis indicated no significant interaction between the protocols and the time points ($F_{(2, 6)} = 0.084$; $\eta^2 = 0.007$; $P = 0.920$) and between the protocols ($F_{(2, 6)} = 0.682$; $\eta^2 = 0.054$; $P = 0.515$). However, there was a significant correlation between PC and the time points ($F_{(2, 6)} = 8.117$; $\eta^2 = 0.253$; $P = 0.009$) (Figure 4). There was no significant increase in the PC levels over time for the LLRE + CBFR, LLRE + IBFR and HIRE protocols ($P = 0.177$; $P = 0.127$; $P = 0.062$, respectively).

The comparative analysis of TBARSs indicated no significant differences between the protocols ($P > 0.05$) (Figure 5).

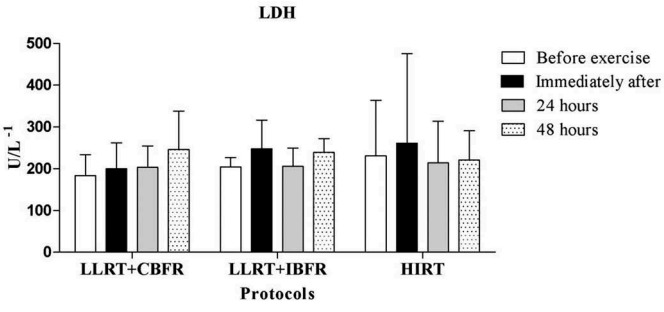

Figure 3. Measured lactate dehydrogenase (LDH) levels. Graphical representation of the LDH for comparison between the protocols before exercise, immediately after exercise along with 24 and 48 h after exercise (n = 10).
LLRE + CBFR: low-load resistance exercise combined with continuous blood flow restriction; LLRE + IBFR: low-load resistance exercise combined with intermittent blood flow restriction; HIRE: high-intensity resistance exercise.

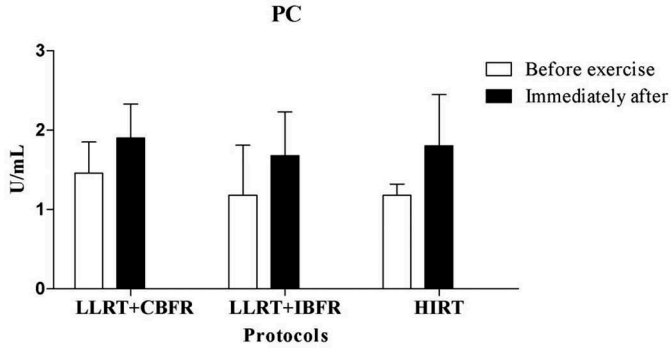

Figure 4. Protein carbonyl (PC) levels before and immediately after different exercise protocols. PC levels were measured in serum samples of participants (n = 5) obtained before or within 1 min of the end of three different exercise programmes.
LLRE + CBFR: low-load resistance exercise combined with continuous blood flow restriction; LLRE + IBFR: low-load resistance exercise combined with intermittent blood flow restriction; HIRE: high-intensity resistance exercise.

The comparative analysis of UA indicated no significant interaction between the protocols and the time points ($F_{(2, 6)} = 1.653$; $\eta^2 = 0.109$; $P = 0.210$), between the protocols ($F_{(2, 6)} = 0.268$; $\eta^2 = 0.019$; $P = 0.767$), and between the time points ($F_{(2, 6)} = 3.195$; $\eta^2 = 0.106$; $P = 0.085$) (Figure 6).

Discussion

This study compared the acute effects on muscle damage and oxidative stress of an RE session for the upper limbs combined with continuous or intermittent BFR in military men. To the best of our knowledge, this study was the first to perform an analysis on CK and LDH level to assess muscle damage and the biomarkers PC, TBARS and UA for oxidative stress. Our main findings were as follows: (a) the use of CBFR or IBFR did not cause muscle damage; (b) CBFR increases the CK levels immediately after training; (c) CBFR and IBFR did not appear to change the level of oxidative stress markers and (d) HIRE induced muscle damage but did not change the oxidative stress markers.

Although no previous studies have evaluated the effect of CBFR and IBFR on muscle damage, some studies have evaluated the effect of RE with continuous BFR (RE + CBFR) (Clark et al., 2011; Karabulut et al., 2013; Loenneke et al., 2013; Madarame et al., 2013; Takarada et al., 2000; R. Thiebaud

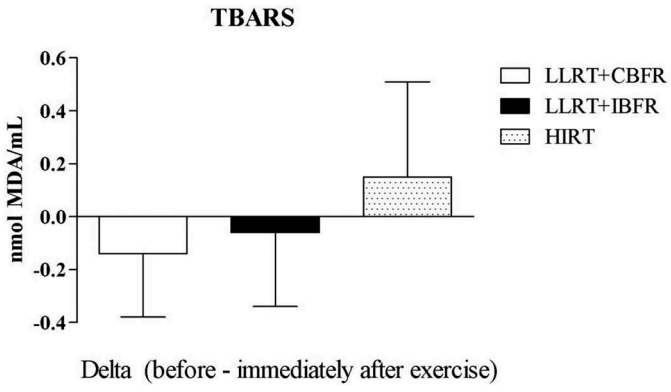

Figure 5. Changes in thiobarbituric acid-reactive substance (TBARS) levels between the protocols. The change in TBARS levels were calculated between the measured values from participant serum before and after exercises (n = 10). LLRE + CBFR: low-load resistance exercise combined with continuous blood flow restriction; LLRE + IBFR: low-load resistance exercise combined with intermittent blood flow restriction; HIRE: high-intensity resistance exercise.

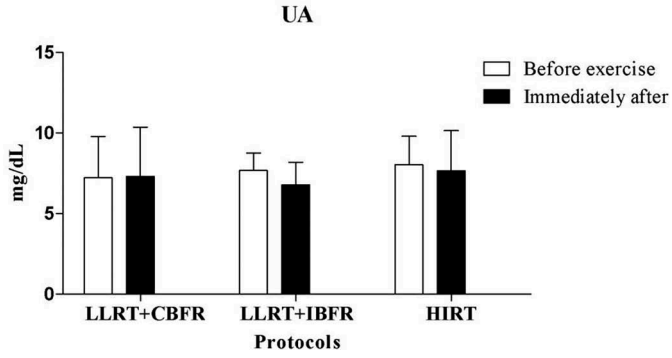

Figure 6. Uric acid (UA) levels before and immediately after exercise. The level of UA was measured in participant serum obtained before and after exercise (n = 10).
*Significant difference compared with the period before training; LLRE + CBFR: low-load resistance exercise combined with continuous blood flow restriction; LLRE + IBFR: low-load resistance exercise combined with intermittent blood flow restriction; HIRE: high-intensity resistance exercise.

et al., 2014; R. S. Thiebaud, Yasuda, Loenneke, & Abe, 2013; Umbel et al., 2009; Wernbom, Paulsen, Nilsen, Hisdal, & Raastad, 2012; Wilson, Lowery, Joy, Loenneke, & Naimo, 2013). However, only four studies evaluated the effects of BFR on biochemical markers (Clark et al., 2011; Karabulut et al., 2013; Madarame et al., 2013; Takarada et al., 2000), while other studies evaluated the effect of BFR on muscle damage using pain perception scores. Our analysis of the results from the present study combined with those from other studies that evaluated muscle damage using biochemical analysis or assessment scores indicated that muscle damage did not appear to occur after either CBFR or IBFR regardless of the exercise execution strategy (unilateral vs. bilateral or single-joint vs. multi-joint) or the amount of exercise (one exercise vs. one session). One explanation is that the LL exercises combined with BFR did not increase oxidative stress markers, which would corroborate the findings of Goldfarb et al. (2008) and Garten et al. (2015). These results lead us to hypothesise that muscle damage is not caused by BFR based on the absence of mechanical stress (Pearson & Hussain, 2015), and the absence of an oxidative stress, as shown herein and in the study by Goldfarb et al. (2008).

Muscle damage may be more associated with mechanical stress caused by high-load exercises, which significantly increase stress in the muscle fibres (Pearson & Hussain, 2015; Roig et al., 2009), and this damage may occur in larger magnitudes in eccentric actions (Roig et al., 2009). However, the use of exercises with predominantly eccentric actions in combination with BFR may prevent muscle damage (Sudo, Ando, Poole, & Kano, 2015). Furthermore, although BFR protocols are conducted with low loads, the intensity is considered high, leading to the accumulation of metabolites and hormones without generating mechanical stress, which may explain the absence of muscle damage (Pope, Willardson, & Schoenfeld, 2013). The findings of the present study did not indicate an increase in the production of free radicals (oxidative stress). Therefore, we speculate that there were no significant changes in cell membranes and that muscle injury, accompanied by inflammation, did not occur in the muscle fibres (Córdova & Navas, 2000). These conclusions are corroborated by the absence of changes in the CK and LDH levels in the BFR protocols. Thus, as more metabolic stress seems to occur with continuous BFR and high-intensity exercise when compared to intermittent (Suga et al., 2012), it is speculated that oxidative stress can also be increased further in these protocols. In addition, it is observed that intense and continuous exercise is accompanied by the production of free radicals that cause alterations of the cellular membranes. This leads to muscle fibre injury, accompanied by an inflammatory process, which leads to a reduction in muscle function, the release of muscle enzymes, evident histological changes and muscular pain (Kuipers, 1994; Nosaka & Clarkson, 1995).

The measured increases in muscle damage and oxidative stress were similar between CBFR and IBFR. Since no significant differences were found between the BFR methods, it was observed that it would not be necessary to increase the metabolic stress with continuous BFR (Suga et al., 2012). In addition, IBFR causes less muscle pain (Fitschen et al., 2014), promotes a lower increase in hemodynamics (Neto et al., 2016, 2016) and has a smaller hypotensive effect (Neto et al., 2016), which may allow a greater amount of training and provide a longer period of tolerable stress with BFR due to the lower sensation of pain. Our findings, together with previous studies, indicated that IBFR might be a better option for those who use this training method to increase muscle activation (Yasuda et al., 2013), gains in muscle strength and lean body mass (Fitschen et al., 2014) that would be an excellent exercise option for both athletes and non-athletes.

There are some limitations associated with the study design. First, blood pressure was measured in a sitting position, but only a single exercise was performed in this position (front pull) and other exercises required participants to change position. In contrast, the evaluation of possible blood pressure constraints from body positions different from that of the exercises seems to be common in the literature (Araujo et al., 2015; Gil et al., 2015; Laurentino et al., 2012; Neto et al., 2015, 2016; Sousa et al., 2017). Furthermore, although the PC levels were evaluated in only five participants, the use of a small sample size to evaluate this method of training did not seem to be

a significant limitation because the small sample size involved a single variable (Goldfarb et al., 2008; Takarada et al., 2000). Another limitation was absence of an evaluation of pain, range of motion and reduced muscle strength that could help further explain the results. Lastly, the ability to extrapolate our conclusions to other populations that differ from the characteristics of the study participants is unknown.

Conclusion

An LLRE session for the upper limbs combined with continuous and intermittent BFR did not seem to promote muscle damage, although CBFR increased the CK levels IAE. Additionally, neither protocol appeared to change oxidative stress markers. Moreover, a HIRE session seemed to cause muscle damage without altering oxidative stress markers. Further studies are required to evaluate different markers of muscle damage and oxidative stress for chronic and acute conditions, particularly studies involving different BFR pressures, different cuff thicknesses and different percentage loads in several populations.

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We have nothing to declare.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

ACSM. (2009). American college of sports medicine. Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, *41*(3), 687–708. doi:10.1249/MSS.0b013e3181915670

Araujo, J. P., Neto, G. R., Loenneke, J. P., Bemben, M. G., Laurentino, G., Batista, G., … Cirilo-Sousa, M. S. (2015). The effects of water aerobics in combination with blood flow restriction on strength and functional capacity in post-menopausal women. *Age*. doi:10.1007/s11357-015-9851-4

Beck, T. W. (2013). The importance of a priori sample size estimation in strength and conditioning research. *Journal of Strength and Conditioning Research*, *27*(8), 2323–2337. doi:10.1519/JSC.0b013e318278eea0

Brandner, C. R., Kidgell, D. J., & Warmington, S. A. (2015). Unilateral bicep curl hemodynamics: Low-pressure continuous vs high-pressure intermittent blood flow restriction. *Scandinavian Journal of Medicine and Science in Sports*, *25*(6), 770–777. doi:10.1111/sms.12297

Clark, B. C., Manini, T. M., Hoffman, R. L., Williams, P. S., Guiler, M. K., Knutson, M. J., … Kushnick, M. R. (2011). Relative safety of 4 weeks of blood flow-restricted resistance exercise in young, healthy adults. *Scandinavian Journal of Medicine and Science in Sports*, *21*(5), 653–662. doi:10.1111/j.1600-0838.2010.01100.x

Córdova, A., & Navas, F. J. (2000). Os radicais livres e o dano muscular produzido pelo exercício: Papel dos antioxidantes. *Revista Brasileira De Medicina Do Esporte*, *6*(5), 204–208. doi:10.1590/S1517-86922000000500006

Fitschen, P. J., Kistler, B. M., Jeong, J. H., Chung, H. R., Wu, P. T., Walsh, M. J., & Wilund, K. R. (2014). Perceptual effects and efficacy of intermittent or continuous blood flow restriction resistance training. *Clinical Physiology and Functional Imaging*, *34*(5), 356–363. doi:10.1111/cpf.12100

Garten, R. S., Goldfarb, A., Crabb, B., & Waller, J. (2015). The impact of partial vascular occlusion on oxidative stress markers during resistance exercise. *International Journal Sports Medicine*, *36*(7), 542–549. doi:10.1055/s-0034-1396827

Gil, A. L. S., Neto, G. R., Sousa, M. S. C., Dias, I., Vianna, J., Nunes, R. A. M., & Novaes, J. S. (2015). Effect of strength training with blood flow restriction on muscle power and submaximal strength in eumenorrheic women. *Clinical Physiology and Functional Imaging*, *35*. doi:10.1111/cpf.12291

Goldfarb, A. H., Garten, R. S., Chee, P. D. M., Cho, C., Reeves, G. V., Hollander, D. B., … Kraemer, R. R. (2008). Resistance exercise effects on blood glutathione status and plasma protein carbonyls: Influence of partial vascular occlusion. *European Journal of Applied Physiology*, *104*(5), 813–819. doi:10.1007/s00421-008-0836-1

Kacin, A., & Strazar, K. (2011). Frequent low-load ischemic resistance exercise to failure enhances muscle oxygen delivery and endurance capacity. *Scandinavian Journal of Medicine and Science in Sports*, *21*(6), 231–241. doi:10.1111/j.1600-0838.2010.01260.x

Karabulut, M., Sherk, V. D., Bemben, D. A., & Bemben, M. G. (2013). Inflammation marker, damage marker and anabolic hormone responses to resistance training with vascular restriction in older males. *Clinical Physiology and Functional Imaging*, *33*(5), 393–399. doi:10.1111/cpf.12044

Kuipers, H. (1994). Exercise-induced muscle damage. *International Journal of Sports Medicine*, *15*(3), 132–135. doi:10.1055/s-2007-1021034

Laurentino, G. C., Ugrinowitsch, C., Roschel, H., Aoki, M. S., Soares, A. G., Neves, M., Jr., … Tricoli, V. (2012). Strength training with blood flow restriction diminishes myostatin gene expression. *Medicine and Science in Sports and Exercise*, *44*(3), 406–412. doi:10.1249/MSS.0b013e318233b4bc

Loenneke, J. P., Thiebaud, R. S., Fahs, C. A., Rossow, L. M., Abe, T., & Bemben, M. G. (2013). Blood flow restriction does not result in prolonged decrements in torque. *European Journal of Applied Physiology*, *113*(4), 923–931. doi:10.1007/s00421-012-2502-x

Madarame, H., Kurano, M., Fukumura, K., Fukuda, T., & Nakajima, T. (2013). Haemostatic and inflammatory responses to blood flow-restricted exercise in patients with ischaemic heart disease: A pilot study. *Clinical Physiology and Functional Imaging*, *33*(1), 11–17. doi:10.1111/j.1475-097X.2012.01158.x

Manini, T. M., & Clark, B. C. (2009). Blood flow restricted exercise and skeletal muscle health. *Exercise and Sport Sciences Reviews*, *37*(2), 78–85. doi:10.1097/JES.0b013e31819c2e5c

Neto, G. R., Novaes, J. S., Dias, I., Brown, A., Vianna, J., & Cirilo-Sousa, M. S. (2016). Effects of resistance training with blood flow restriction on hemodynamics: A systematic review. *Clinical Physiology and Functional Imaging*. doi:10.1111/cpf.12368

Neto, G. R., Novaes, J. S., Gonçalves, M., Batista, G. R., Mendonça, R. M. S. C., Miranda, H. L., … Cirilo-Sousa, M. S. (2016). Hypotensive effects of resistance exercise with continuous and intermittent blood flow restriction. *Motriz: Revista De Educação Física*, *22*(3), 198–204. doi:10.1590/S1980-6574201600030011

Neto, G. R., Novaes, J. S., Salerno, V. P., Gonçalves, M. M., Piazera, B. K. L., Rodrigues-Rodrigues, T., & Cirilo-Sousa, M. S. (2016). Acute effects of resistance exercise with continuous and intermittent blood flow restriction on hemodynamic measurements and perceived exertion. *Perceptual and Motor Skills*, 0031512516677900.

Neto, G. R., Sousa, M. S. C., Costa, P. B., Salles, B. F., Novaes, G. S., & Novaes, J. S. (2015). Hypotensive effects of resistance exercises with blood flow restriction. *Journal of Strength and Conditioning Research*, *29*(4), 1064–1070. doi:10.1519/JSC.0000000000000734

Neto, G. R., Sousa, M. S. C., Silva, G. V. C., Gil, A. L. S., Salles, B. F., & Novaes, J. S. (2016). Acute resistance exercise with blood flow restriction effects on heart rate, double product, oxygen saturation and perceived exertion. *Clinical Physiology and Functional Imaging*, *36*(1), 53–59. doi:10.1111/cpf.12193

Nosaka, K., & Clarkson, P. M. (1995). Muscle damage following repeated bouts of high force eccentric exercise. *Medicine and Science in Sports and Exercise*, *27*(9), 1263–1269. doi:10.1249/00005768-199509000-00005

Pearson, S. J., & Hussain, S. R. (2015). A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. *Sports Medicine*, *45*(2), 187–200. doi:10.1007/s40279-014-0264-9

Pope, Z. K., Willardson, J. M., & Schoenfeld, B. J. (2013). Exercise and blood flow restriction. *Journal of Strength and Conditioning Research*, *27*(10), 2914–2926. doi:10.1519/JSC.0b013e3182874721

Rhea, M. R. (2004). Determining the magnitude of treatment effects in strength training research through the use the effect size. *Journal of Strength and Conditioning Research*, *18*(4), 918–920.

Roig, M., O'Brien, K., Kirk, G., Murray, R., McKinnon, P., Shadgan, B., & Reid, D. W. (2009). The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: A systematic review with meta-analyses. *British Journal of Sports Medicine*, *43*(8), 556–568. doi:10.1136/bjsm.2008.051417

Rosa-Lima, F. L., Lannes, L., Viana-Gomes, D., Pierucci, A. P. T. R., & Salerno, V. P. (2015). Protein carbonyl levels correlate with performance in elite field hockey players. *Applied Physiology, Nutrition, and Metabolism*, *40*(7), 683–688. doi:10.1139/apnm-2014-0456

Rossow, L. M., Fahs, C. A., Loenneke, J. P., Thiebaud, R. S., Sherk, V. D., Abe, T., & Bemben, M. G. (2012). Cardiovascular and perceptual responses to blood-flow-restricted resistance exercise with differing restrictive cuffs. *Clinical Physiology and Functional Imaging*, *32*(5), 331–337. doi:10.1111/j.1475-097X.2012.01131.x

Sato, Y. (2005). The history and future of KAATSU training. *International Journal of KAATSU Training Research*, *1*(1), 1–5. doi:10.3806/ijktr.1.1

Shephard, R. J. (1988). PAR-Q, canadian home fitness test and exercise screening alternatives. *Sports Medicine*, *5*(3), 185–195. doi:10.2165/00007256-198805030-00005

Silva, J. C. G., Neto, G. R., Freitas, E., Neto, E., Batista, G., Torres, M., & Sousa, M. S. C. (2015). Chronic effect of strength training with blood flow restriction on muscular strength among women with osteoporosis. *Journal of Exercise Physiologyonline*, *18*(4), 33–41.

Sousa, J. B. C., Neto, G. R., Santos, H. H., Araújo, J. P., Silva, H. G., & Cirilo-Sousa, M. S. (2017). Effects of strength training with blood flow restriction on torque, muscle activation and local muscular endurance in healthy subjects. *Biology of Sport*, *34*(1), 83–90.

Sudo, M., Ando, S., Poole, D. C., & Kano, Y. (2015). Blood flow restriction prevents muscle damage but not protein synthesis signaling following eccentric contractions. *Physiological Reports*, *3*(7), e12449. doi:10.14814/phy2.12449

Suga, T., Okita, K., Morita, N., Yokota, T., Hirabayashi, K., Horiuchi, M., … Tsutsui, H. (2010). Dose effect on intramuscular metabolic stress during low-intensity resistance exercise with blood flow restriction. *Journal of Applied Physiology*, *108*(6), 1563–1567. doi:10.1152/japplphysiol.00504.2009

Suga, T., Okita, K., Takada, S., Omokawa, M., Kadoguchi, T., Yokota, T., … Horiuchi, M. (2012). Effect of multiple set on intramuscular metabolic stress during low-intensity resistance exercise with blood flow restriction. *European Journal of Applied Physiology*, *112*(11), 3915–3920. doi:10.1007/s00421-012-2377-x

Sumide, T., Sakuraba, K., Sawaki, K., Ohmura, H., & Tamura, Y. (2009). Effect of resistance exercise training combined with relatively low vascular occlusion. *Journal of Science and Medicine in Sport*, *12*(1), 107–112. doi:10.1016/j.jsams.2007.09.009

Takarada, Y., Nakamura, Y., Aruga, S., Onda, T., Miyazaki, S., & Ishii, N. (2000). Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *Journal of Applied Physiology*, *88*(1), 61.

Thiebaud, R., Loenneke, J. P., Fahs, C. A., Kim, D., Ye, X., Abe, T., … Bemben, M. G. (2014). Muscle damage after low-intensity eccentric contractions with blood flow restriction. *Acta Physiologica Hungarica*, *101*(2), 150–157. doi:10.1556/APhysiol.101.2014.2.3

Thiebaud, R. S., Yasuda, T., Loenneke, J. P., & Abe, T. (2013). Effects of low-intensity concentric and eccentric exercise combined with blood flow restriction on indices of exercise-induced muscle damage. *Interventional Medicine and Applied Science*, *5*(2), 53–59. doi:10.1556/IMAS.5.2013.2.1

Umbel, J. D., Hoffman, R. L., Dearth, D. J., Chleboun, G. S., Manini, T. M., & Clark, B. C. (2009). Delayed-onset muscle soreness induced by low-load blood flow-restricted exercise. *European Journal of Applied Physiology*, *107*(6), 687–695. doi:10.1007/s00421-009-1175-6

Vechin, F. C., Libardi, C. A., Conceição, M. S., Damas, F. R., Lixandrão, M. E., Berton, R. P. B., … Chacon-Mikahil, M. P. T. (2015). Comparisons between low-intensity resistance training with blood flow restriction and high-intensity resistance training on quadriceps muscle mass and strength in elderly. *Journal of Strength and Conditioning Research*, *29*(4), 1071–1076. doi:10.1519/JSC.0000000000000703

Vilaça-Alves, J., Neto, G. R., Morgado, N. M., Saavedra, F., Lemos, R., Moreira, T. R., … Reis, V. M. (2016). Acute effect of resistance exercises performed by the upper and lower limbs with blood flow restriction on hemodynamic responses. *Journal of Exercise Physiologyonline*, *19*(3), 100–109.

Wernbom, M., Paulsen, G., Nilsen, T. S., Hisdal, J., & Raastad, T. (2012). Contractile function and sarcolemmal permeability after acute low-load resistance exercise with blood flow restriction. *European Journal of Applied Physiology*, *112*(6), 2051–2063. doi:10.1007/s00421-011-2172-0

Wilson, J. M., Lowery, R. P., Joy, J. M., Loenneke, J. P., & Naimo, M. A. (2013). Practical blood flow restriction training increases acute determinants of hypertrophy without increasing indices of muscle damage. *Journal of Strength and Conditioning Research*, *27*(11), 3068–3075. doi:10.1519/JSC.0b013e31828a1ffa

Yasuda, T., Loenneke, J. P., 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 Physiologica Hungarica*, *100*(4), 419–426. doi:10.1556/APhysiol.100.2013.4.6

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