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Perceptual effects and efficacy of intermittent or continuous blood flow restriction resistance training

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Summary

Blood flow restriction (BFR) exercise may be an alternative form of resistance training; however, a side of effect of BFR resistance exercise is acute muscle pain. Typically, BFR exercise studies restrict blood flow with a cuff continuously during the exercise bout, including rest periods. However, others have used intermittent BFR where the cuff is inflated only during sets. We performed two studies to compare intermittent and continuous BFR exercise. In study one, eleven subjects randomly proceeded through three treatments of unilateral leg extensions to failure: (i) continuous BFR, (ii) intermittent BFR and (iii) control (exercise without BFR). Pain measurements were taken immediately after each set. In study two, subjects ($n = 32$) underwent a 5-week resistance training programme after random assignment to one of the three conditions. Lean mass and strength were assessed at baseline and after training. Continuous BFR resulted in significantly greater pain than intermittent BFR or control. Both BFR conditions resulted in significantly fewer repetitions to failure than control. This suggests that an acute bout of intermittent BFR exercise may produce as much muscle fatigue as an acute bout of continuous BFR exercise, but with less pain. With training, maximal knee extension ($P = 0{\cdot}033$) and maximum knee flexion ($P = 0{\cdot}007$) strength increased among all groups. There were no significant differences between groups in strength or lean mass. These results suggest that short-term low-load resistance training increases muscle strength to a similar extent as low-load resistance training without BFR.

Introduction

The American College of Sports Medicine recommends training with loads at or above 70 percent of an individual's 1 rep maximum to stimulate skeletal muscle hypertrophy (American College of Sports Medicine position stand, 2009). However, many individuals, including injured athletes, the elderly, or patients with chronic disease may not be able to exercise at this high load. Therefore, effective exercise modalities that can be performed at lower loads are needed. Recently, blood flow restriction (BFR) exercise, which involves inflation of a cuff around the proximal end of an exercising limb, has been shown to be an effective training protocol at relatively low loads (generally 20–40% of 1 rep maximum). Despite the relatively low load, BFR training has been shown to result in increased muscle strength (Takarada *et al.*, 2000a, 2002, 2004; Madarame *et al.*, 2008; Clark *et al.*, 2011) and size (Takarada *et al.*, 2002, 2004; Madarame *et al.*, 2008) similar to that of high load exercise.

Typically, BFR exercise studies have used continuous BFR, in which the cuff remained inflated during the entire exercise period, including rest periods. Many studies have shown that resistance training with continuous BFR increases muscle strength (Takarada *et al.*, 2000a, 2002, 2004) and size (Takarada *et al.*, 2002, 2004) to a greater extent than the same exercise without BFR (control); however, not all studies have found an increase in strength with BFR exercise as compared to the same exercise without BFR (Burgomaster *et al.*, 2003). An alternative to continuous BFR training is to deflate the cuff during rest periods, otherwise known as intermittent BFR training. Similarly, intermittent BFR has been shown to increase muscle strength (Evans *et al.*, 2010) and size (Kacin & Strazar, 2011) over a no BFR control. Although both continuous and intermittent BFR training appear to increase skeletal muscle size and strength at low loads, to date, the efficacy of intermittent and continuous BFR training have not been directly compared.

A side effect of BFR resistance exercise is acute muscle pain and discomfort during the exercise (Weatherholt *et al.*, 2013). A previous study comparing pain during continuous BFR exercise with normal low-load exercise found that subjects experienced significantly more pain during continuous BFR exercise than exercise without BFR (Loenneke *et al.*, 2011a). This discomfort may deter some individuals who may benefit from BFR training from using this form of training, especially clinical populations who may suffer from hypersensitivity to pain. If intermittent blood flow restriction results in similar increases in muscle size and strength as continuous blood flow restriction with less discomfort, it may be more tolerable and readily used in both general and clinical populations. The purpose of the first study was to compare the effects of a single bout of continuous or intermittent BFR resistance exercise on perceptions of pain during low-load single leg extension exercise to failure. Following the observation that intermittent BFR exercise resulted in similar fatigue to continuous BFR exercise, we designed a study to compare the effects of 5 weeks of continuous or intermittent BFR resistance training on skeletal muscle size and strength.

Methods

Acute study

Subjects

Healthy subjects (*n* = 5 men, *n* = 6 women), age 27 ± 3 years, who had not been resistance training in the previous 6 months were enrolled in the study. Subjects had an average height of 170·5 ± 6·5 cm, weight of 69·5 ± 13·6 kg, BMI of 23·8 ± 4·0 kg m^{-2}, systolic blood pressure of 118 ± 12 mm Hg and diastolic blood pressure of 77 ± 9 mm Hg. Subjects were screened prior to enrolment into the study. Individuals with chronic obstructive pulmonary disease, chronic heart failure, peripheral arterial disease, chronic kidney disease, diabetes mellitus, deep vein thrombosis, clinically diagnosed cardiovascular disease or orthopaedic problems that prevent exercise were excluded from participation. Subjects were instructed not to take caffeine, perform any exercise within 12 h prior to each visit or perform exercise during the 24 h following exercise sessions. In addition, subjects were instructed not to take any non-steroidal anti-inflammatory drugs within 12 h prior to exercise or in the 72 h following. All subjects were informed of the study details and risks prior to signing of the informed consent document. This study was approved by the University of Illinois Institutional Review Board.

Study design

Subjects came to the laboratory seven times over 6 weeks. During the first week, subjects underwent baseline testing which included measurements of height, weight, blood pressure and maximal quadriceps strength in the non-dominant leg. Over the next 5 weeks, they returned to the laboratory an additional six times and proceeded through a series of three conditions of single leg extensions with their non-dominant leg in a random order: (i) Control (no pressure cuff), (ii) Intermittent blood flow restriction exercise and (iii) Continuous blood flow restriction exercise. Exercise sessions were separated by at least 14 days. Immediately following each exercise session and 24 h later, subjects performed a maximal leg strength test in their non-dominant leg.

Strength test

Quadriceps and hamstring isokinetic muscle strength were evaluated in the non-dominant leg at baseline, immediately after and 24 h after each exercise session using an isokinetic testing mode on a Humac Norm isokinetic dynamometer (Cybex, Medway, MA). Straps were placed over the thighs, pelvis and torso regions to minimize movement during the test. The isokinetic concentric muscle torque during extension and flexion was evaluated at a speed of 60° s^{-1}, and the data were gravity-corrected. Participants performed two sets of 6 repetitions, with a 3-min rest between sets, and the concentric contraction that produced the highest torque was used for analysis. For all tests, participants were verbally encouraged to provide maximal effort.

Exercise protocol

At each exercise session, subjects were asked to perform as many repetitions as they could with their non-dominant leg for four sets with a 90-s rest between sets. Subjects used an isotonic resistance corresponding to 30% of their maximal strength for each exercise session. All repetitions were performed with a 2-s concentric and 2-s eccentric contraction, which were paced by a metronome. Exercise was ceased when subjects were unable to complete a repetition with a full range of motion. During blood flow restriction exercise, subjects had a 50-mm-wide cuff placed around their upper leg with an initial pressure of 30 mm Hg. After fitting of initial pressure, the cuff was directly inflated to 160 mm Hg around their upper leg immediately prior to exercise. The cuff contains a pneumatic bag along its inner surface that is connected to an electronic air pressure control system that monitors the restriction pressure (Kaatsu-Master Mini, Sato Sports Plaza, Tokyo, Japan).

During continuous BFR exercise, subjects had a blood pressure cuff inflated to 160 mm Hg around their upper leg before the start of exercise and the cuff remained inflated for the duration of the exercise, including rest periods. For intermittent BFR exercise, the cuff was inflated to 160 mm Hg before the start of exercise, deflated during rest periods and re-inflated prior to the next set. During the control exercise, subjects followed an identical exercise protocol without any blood flow restriction.

Pain measurement

Immediately after each set, subjects were asked to rate their worst pain experienced during the set on a scale of 1–10 as described by Cook *et al.* (1997) where the numbers corresponded with the following verbal cues: 0 – no pain at all, ½

– very faint pain, 1 – weak pain, 2 – mild pain, 3 – moderate pain, 4 – somewhat strong pain, 5 – strong pain, 7 – very strong pain and 10 – extreme pain. Subjects were given standardized sets of instructions on each scale prior to each exercise session. These instructions emphasized that their ratings of pain should indicate feelings of discomfort in the working muscles. Subjects confirmed that they understood these instructions prior to the initiation of exercise.

Training study

Subjects

Thirty-two healthy subjects were recruited from the University of Illinois Urbana-Champaign campus and screened, as described above. Patient demographics are shown in Table 1. There were no significant differences in gender, age, anthropometric measures or any measure of muscle size or strength between groups at baseline.

Study overview

Subjects were randomly assigned to one of three conditions: (i) exercise with continuous BFR (CON), (ii) exercise with intermittent BFR (INT) or (iii) exercise without BFR (control). All groups completed the exercise intervention described below. Testing for strength and lean mass was performed at baseline and after 5 weeks of training. Muscle pain was taken after each set during the first and final workouts in which the subject completed 4 sets of each exercise to determine whether adaptation to pain occurs with BFR training.

Baseline testing

Muscle strength: Bilateral quadriceps femoris and hamstring muscle strength were evaluated using isokinetic dynamometry, as described above.

Lean mass: Whole body fat, lean and mineral-free lean mass were measured by dual emission X-ray absorptiometry, and regional lean and mineral-free lean mass were measured with computer software (DXA, Hologic QDR 4500A, Bedford, MA). Whole body and regional mineral-free lean mass was calculated by subtracting the bone mineral content from the lean mass quantity of the whole body or region of interest. Precision for DXA measurements of interest is ~1·0–2·0% in our laboratory.

1 Repetition Maximum (1RM): One repetition maximum was determined on the leg press, leg extension and hamstring curl equipment used for training (HUR USA Inc., Northbrook, IL). The testing protocol for each lift was as follows. Subjects completed 8–10 repetitions at an equivalent weight to 40–60% of individual's estimated 1RM. Subjects were given a 2–3-min rest and asked to complete a set of 3–5 repetitions at 60–80% of estimated 1RM. After another 2–3-min rest, subjects completed a 1RM attempt. If this weight was lifted successfully, 5–10 lbs was added and subjects attempted another repetition after a 2-min rest. This process was repeated until the subject was no longer able to successfully lift the weight through a complete range of motion. The last weight lifted successfully was used as the 1RM.

Training protocol

All subjects participated in a 5-week thrice weekly BFR resistance training protocol which consisted of leg press, leg extensions and seated hamstring curls at 30% of 1RM. In addition, subjects completed bodyweight standing calf raises with the same number of sets and repetitions. All exercises were performed at each workout session, and all repetitions were performed with an approximate 1-s eccentric and 1-s concentric contraction. To minimize soreness, subjects completed one set (30 repetitions), two sets (30 and 15 repetitions) and four sets (30, 15 and 15 repetitions) during the first 3 training sessions, respectively. During weeks 2 and 3,

Table 1 Subject characteristics.

	Control[a]	Intermittent BFR exercise[a]	Continuous BFR exercise[a]	*P* value[b]
Number	10	10	10	
Gender (m/f)	1/9	2/8	2/8	0·848
Age (year)	33 ± 9	29 ± 9	33 ± 9	0·681
Height (cm)	169·4 ± 6·5	168·7 ± 7·4	166·1 ± 8·7	0·599
Weight (kg)	78·4 ± 13·6	73·1 ± 20·8	74·3 ± 24·4	0·820
BMI (kg m^{-2})	27·5 ± 5·6	26·4 ± 9·0	26·3 ± 6·2	0·917
WB lean (kg)	52·83 ± 8·15	53·88 ± 12·21	49·48 ± 12·27	0·665
WB fat (kg)	26·97 ± 11·07	21·62 ± 15·07	24·83 ± 11·59	0·656
WB percent fat	33·02 ± 8·93	26·68 ± 11·31	32·48 ± 8·99	0·306
Leg MFLM (kg)	17·47 ± 3·19	17·99 ± 4·50	16·12 ± 4·12	0·624
Maximum extension (Nm)	159·1 ± 40·9	165·6 ± 50·0	155·3 ± 57·4	0·905
Maximum flexion (Nm)	81·1 ± 21·1	80·7 ± 25·7	71·2 ± 26·7	0·610

BFR, blood flow restriction; WB, whole body; MFLM, mineral-free lean mass.

[a] Data expressed as mean ± SD.

[b] P value for group differences by analysis of variance.

subjects completed four sets (30, 15, 15 and 15 repetitions), and in weeks 4 and 5, subjects completed four sets (30, 20, 20 and 20 repetitions). In the INT and CON groups, subjects had a 50-mm cuff placed around their upper leg with an initial pressure of 30 mm Hg and inflated pressure of 160 mm Hg (Kaatsu-Master Mini). The cuffs were directly inflated to 160 mm Hg following initial fit at 30 mm Hg. Participants in the INT group had the cuff deflated between each set and each exercise, while participants in the CON group had the cuff inflated at the start of the first exercise and deflated following the completion of all four exercises. The rest period between all sets and each exercise was 1 min, and each workout took approximately 20–25 min to complete. All training sessions were separated by a minimum of 48 h.

Pain assessment

Pain was assessed during the first and final workouts in which the subject performed four sets of each lift, as described above.

Final testing

Muscle strength and lean mass were measured, as described above, 72–96 h following the final training session at the same time of day as baseline testing.

Statistical analysis

All statistics were performed using SPSS, version 18.0 (Armonk, NY, USA). Data were reported as mean ± standard deviation for all variables. In study one, repeated measures analysis of variance was used to determine differences in our primary outcomes. When significance was detected, a Tukey's post hoc test was performed to detect differences between groups. In study two, differences in subject characteristics at baseline were determined by analysis of variance (ANOVA) for continuous variables or a Mann–Whitney test for categorical variables. Repeated measures analysis of variance (ANOVA) was used to detect differences in our primary outcomes over time. When significance was detected, a Tukey's post hoc test was performed to detect differences between groups. Effect sizes for changes in strength were calculated using Cohen's d, as described by Rhea (2004). For all analysis, significance was determined with a 5%chance of type 1 error.

Results

Acute study

All subjects completed the 3 treatments in a random order. Pain significantly differed between treatments during sets 3 (P = 0·036) and 4 (P = 0·010, Fig. 1), with continuous BFR exercise being significantly more painful than both the control and intermittent conditions during each of these sets (P<0·05 for each condition). Pain did not significantly differ between intermittent BFR exercise and the control condition during any set. There were no significant differences in pain between treatments during sets one or two although there was a non-significant trend for pain during continuous BFR exercise to be greater than intermittent BFR or control during set two (P = 0·10).

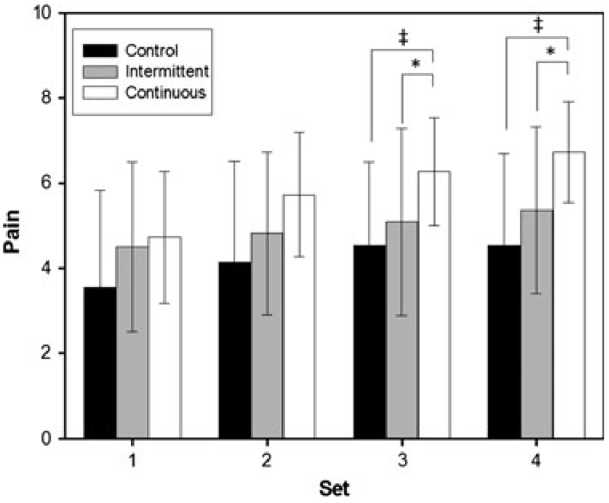

Figure 1 Pain experienced during sets of leg extensions with different conditions. Significant differences in pain were found between control versus continuous (‡P<0·05) and intermittent versus continuous (*P<0·05) conditions. Data presented as mean ± SD.

Significantly more repetitions were performed during the control condition than intermittent BFR exercise during sets two (P = 0·035), three (P = 0·002), and four (P<0·001) and continuous BFR exercise during sets three (P = 0·022) and four (P = 0·001, Fig. 2). Total repetitions performed during all four sets of the control condition (61 ± 12) were significantly greater than total repetitions performed during intermittent BFR exercise (51 ± 12, P<0·001) and continuous BFR exercise (50 ± 9, P<0·001). There were no significant differences between repetitions performed during the intermittent BFR exercise and continuous BFR exercise treatments. Isokinetic maximum voluntary contraction (MVC) was significantly decreased immediately after exercise (P = 0·002) and 24 h after exercise (P = 0·006) in all groups.

Training study

Thirty-two healthy subjects were enrolled in the study. Two subjects dropped out due to scheduling conflicts. In all, 30 subjects completed the 5-week training protocol (n = 10 per group). All subjects completed 15 exercise sessions during the 5-week intervention period, and any missed exercise sessions were made up prior to the completion of training. All participants performed all prescribed sets and repetitions on each training day.

After 5 weeks of training, maximal isokinetic knee extension strength increased by 5·2 ± 10·41% (P = 0·033) and maximal isokinetic knee flexion strength increased by 6·4 ± 11·5% (P = 0·007, Table 2). The effect sizes for these changes ranged from 0·1 to 0·25. However, the change in maximal extension (P = 0·908) or flexion (P = 0·633) strength did not differ between groups over time. There were also no significant differences in any measure of lean mass, fat mass or mineral-free lean mass with training or in any group (P>0·05, Table 3).

Maximum pain reported during an exercise session significantly decreased from 4·36 ± 2·34 to 3·40 ± 2·12 with training (P = 0·005); however, there were no significant differences between groups over time.

Discussion

The primary finding from the first study was that 4 sets of single leg extensions to failure with continuous BFR or intermittent BFR resulted in significantly fewer repetitions to failure than the same exercise without BFR. In addition, an acute bout of continuous BFR to failure was significantly more painful than an acute bout of intermittent BFR exercise or the no BFR control condition during sets three and four. Taken together, this suggests that, acutely, intermittent BFR exercise may produce similar fatigue as continuous BFR exercise, but with less pain. Based on these results, we performed a second study investigating the effects of continuous BFR and intermittent BFR on skeletal muscle size and strength. We found that a 5-week thrice weekly low-load leg training protocol consisting of leg press, leg extensions, hamstring curls and calf raises resulted in significant increases in maximum extension and flexion strength. However, the magnitude of these effect sizes in untrained subjects is trivial (Rhea, 2004), and neither continuous nor intermittent BFR resulted in significant differences in any measure of lean mass or strength compared with exercise without BFR. These findings do not support the use of either continuous or intermittent BFR training to increase lean mass or strength in healthy untrained subjects during a 5-week thrice weekly lower body training protocol.

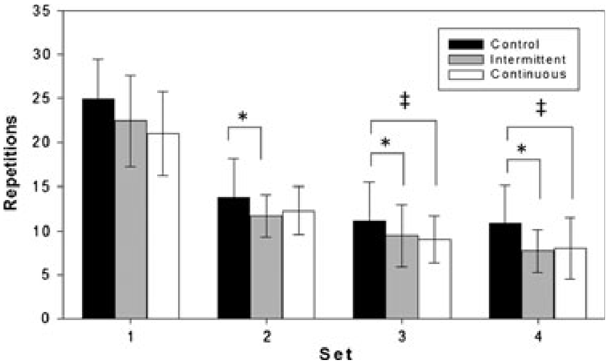

Figure 2 Repetitions performed during sets of single leg extensions with different conditions. Significant differences in repetitions performed were found between control versus continuous (‡P<0·05) and control versus intermittent (*P<0·05) conditions. Data presented as mean ± SD.

The results from our first study are similar to a previous study which found that continuous BFR resistance exercise to failure using knee wraps resulted in significantly more pain than the same exercise without BFR (Loenneke *et al.*, 2011a). Recently, increased discomfort during exercise was reported with BFR training despite a less aggressive exercise protocol than commonly used in BFR training studies (three sets of 15 repetitions) and a cuff inflation protocol that slowly ramped over the 8-week duration of the study (Weatherholt *et al.*, 2013). However, not all studies have found an increase in pain with BFR exercise. Wernbom *et al.* (2009) did not find any differences in pain between continuous BFR exercise and a no BFR control condition after three sets of leg extensions to failure, although it should be noted that the cuff pressured used in that study (100 mm Hg) was significantly less than the pressure used in the present study (160 mm Hg).

To our knowledge, the acute effects of intermittent BFR exercise perceptions of pain have only been investigated in one previous study. Wernbom *et al.* (2006) found that four sets of leg extensions to failure, in which the cuff was released

Table 2 Maximum isokinetic torque measurements before and after 5 weeks of training.

	Control[a]			**Intermittent BFR**[a]			**Continuous BFR**[a]		
	Baseline	**Final**	**Effect size (*D*)**	**Baseline**	**Final**	**Effect size (*D*)**	**Baseline**	**Final**	**Effect size (D)**
Maximum Torque Extension (Nm)	159·1 ± 40·9	167·4 ± 45·6	0·20	165·7 ± 53·0	171·0 ± 48·7	0·10	155·4 ± 57·4	161·6 ± 58·6	0·11
Maximum Torque Flexion (Nm)	71·2 ± 26·7	74·0 ± 22·3	0·10	80·4 ± 25·7	86·9 ± 19·14	0·25	71·2 ± 26·7	74·0± 22·3	0·10

[a] Data expressed as mean ± SD.

Table 3 Body composition measurements before and after 5 weeks of training.

	Control[a]		Intermittent BFR[a]		Continuous BFR[a]			
	Baseline	**Final**	**Baseline**	**Final**	**Baseline**	**Final**	***P* value[b]**	***P* value[c]**
Weight (kg)	78·4 ± 13·9	78·3 ± 14·2	74·3 ± 23·4	73·8 ± 22·1	73·1 ± 19·9	73·3 ± 12·0	0·624	0·681
WB fat (kg)	26·93 ± 11·28	26·90 ± 11·35	21·61 ± 15·24	21·64 ± 15·43	24·83 ± 11·80	25·14 ± 11·99	0·584	0·733
WB lean (kg)	52·83 ± 8·35	52·79 ± 8·57	53·88 ± 12·46	53·43 ± 11·85	49·48 ± 12·49	49·31 ± 11·70	0·405	0·811
WB MFLM (kg)	50·21 ± 8·03	50·18 ± 8·26	51·40 ± 11·95	50·96 ± 11·35	47·34 ± 12·17	47·16 ± 11·35	0·413	0·803
Leg lean (kg)	18·47 ± 3·38	18·38 ± 3·64	18·93 ± 5·41	18·84 ± 5·00	16·94 ± 4·74	17·09 ± 4·74	0·900	0·492
Leg MFLM (kg)	17·45 ± 3·26	17·37 ± 3·54	17·99 ± 5·22	17·90 ± 4·81	16·12 ± 4·59	16·27 ± 4·55	0·892	0·483

BFR, blood flow restriction; WB, whole body; MFLM, mineral-free lean mass.

[a] Data expressed as mean ± SD.

[b] P value for a main effect of time by repeated measures analysis of variance.

[c] P value for a treatment x time interaction by repeated measures analysis of variance.

during rest periods between exercise, resulted in significantly more pain than the control condition, which performed exercise without BFR. These results contradict the present study which found no significant differences in pain between intermittent BFR exercise and the control at any time point measured. The reason for the differences between studies may have been due to the type of cuff used. The cuff used by Wernbom *et al.* had a width of 135 mm, which is much larger than the Kaatsu-Master Mini cuff used in this study, 50 mm. In addition, the cuff pressure used in the previous study (200 mm Hg) was higher than the present study (160 mm Hg). The differences in cuff width and pressure may have led to differences in blood flow dynamics. Indeed, Loenneke *et al.* (2011b) have shown that as cuff width increases, the pressure needed to restrict blood flow decreases. Thus, the increased cuff width combined with the increased cuff pressure used in Wernbom *et al.* may likely resulted in greater blood flow restriction than was used in the current study and may have resulted in increased perceptions of pain.

Repetitions to failure were significantly lower with either continuous or intermittent BFR exercise than the control condition. Additionally, there was no significant difference between the number of repetitions performed with continuous or intermittent BFR exercise, which suggests that both types of BFR exercise fatigue the muscle similarly during exercise. This finding may be important because muscle protein synthesis has been shown to increase after training to failure, regardless of load, suggesting that intermittent BFR exercise may provide similar benefits to continuous BFR exercise (Burd *et al.*, 2010). However, muscle protein synthesis was not measured in our study. Numerous previous studies have also found decreases in repetitions to failure with either a single set of BFR exercise (Loenneke *et al.*, 2011c) or multiple sets of continuous BFR exercise (Wernbom *et al.*, 2009; Loenneke *et al.*, 2011a); however, to our knowledge, the present study is the first to show that intermittent BFR resistance exercise reduces time to muscle fatigue similarly to continuous BFR resistance exercise. Moreover, we showed that an acute bout of intermittent BFR resistance exercise reduced time to failure with significantly less pain than continuous BFR.

Many previous studies have found increases in muscle size and strength with either continuous (Takarada *et al.*, 2000a, 2002, 2004; Madarame *et al.*, 2008) or intermittent (Evans *et al.*, 2010; Kacin & Strazar, 2011) BFR training. The mechanism for these changes is currently unknown. However, BFR is thought to increase skeletal muscle size and strength through increased metabolic stress (Takada *et al.*, 2012), skeletal muscle cell swelling (Loenneke *et al.*, 2012), increased recruitment of fast twitch muscle fibres (Takarada *et al.*, 2000b) and/or increased skeletal muscle fatigue, which may decrease time to muscular failure (Loenneke *et al.*, 2011d) and result in an increase in protein synthesis (Fry *et al.*, 2010).

In the present training study, we observed an overall 5·2% and 6·4% increase in maximum extension and flexion strength, respectively. These results are similar to Clark *et al.* (2011) who observed an approximately 8% increase in strength in untrained subjects after 4 weeks of thrice weekly leg extension training with 30% of 1RM. However, the effect sizes (0·10–0·25) associated with these changes would be considered minimal in an untrained population (Rhea, 2004), and it should be noted that we cannot rule out a learning effect as a source of these improvements. In addition, we did not observe any differences in strength between BFR training or the same exercise without BFR. Although many studies (Takarada *et al.*, 2000a, 2002, 2004; Madarame *et al.*, 2008; Evans *et al.*, 2010) have observed significant increases in strength with BFR training compared with exercise without BFR, this has not been found in all studies. Two studies (Burgomaster *et al.*, 2003; Laurentino *et al.*, 2008) observed no significant differences in strength between exercise with or without BFR after 8 weeks of training; however, training in these studies was performed at 50% of 1RM or greater which likely resulted in vascular occlusion during contractions in both groups due to the increased intramuscular pressure during contraction (Sadamoto *et al.*, 1983). In a study using 20% of 1RM, Sumide *et al.* (Sumide *et al.*, 2009) did not observe a significant difference in isokinetic strength measured at an angular velocity of 60 degrees per second between exercise with or without BFR after 8 weeks of thrice weekly training in untrained subjects. These results are similar to the present study which found no significant differences in isokinetic strength at 60° s^{-1} between exercise with or without BFR in untrained subjects.

Numerous previous studies have observed increases in muscle size using either intermittent (Kacin & Strazar, 2011) or continuous (Takarada *et al.*, 2002, 2004; Madarame *et al.*, 2008) BFR training. However, in the present study, we did not observe any significant differences in lean mass either with training or between groups. This is likely due to the methodology used to measure muscle mass. The previous studies assessed muscle size via MRI; however, we assessed muscle mass via DXA which may have not been sensitive enough to detect small changes in lean mass that may have occurred over a 5-week training period. However, we cannot rule out the possibly that this training did not increase muscle size.

To our knowledge, our study is the first study to examine the adaptations to acute muscle pain during exercise that occurs as a result of BFR training. Previous studies have shown that an acute bout of BFR resistance exercise is more painful than the same exercise without BFR (Loenneke *et al.*, 2011a; Weatherholt *et al.*, 2013). However, in the present training study, we show that acute muscle pain during exercise decreases after 5 weeks of exercise, with or without BFR. These results differ from our acute study which showed that an acute bout of continuous BFR leg extension exercise to failure was significantly more painful than the same exercise with intermittent BFR or the no BFR control. However, there are several possible reasons for this discrepancy. First, pain was measured using a subjective scale which likely resulted in variability between subjects. In the acute study, we performed a crossover design to ensure that all subjects experienced all treatments; however, in the training study, subjects only rated pain during the treatment they were assigned, which likely resulted in the differences observed between studies. Additionally, in the training study, baseline pain measurements were not obtained until the second week of training after subjects increased to four sets on each exercise. This differed from the acute study where pain was measured during an initial four set bout of exercise. Therefore, it is possible that starting with a low volume and allowing adaptation may attenuate the increases in pain reported with continuous BFR exercise. Moreover, the training load in the acute study was based off of isokinetic load, while training load in the training study was based off of a 1RM test. This may have resulted in training loads >30% in the acute study and resulted in the discrepancies in repetitions observed in the training and acute studies. Furthermore, this may have impacted pain ratings. In addition, the differences in repetition tempo between the acute (2 s eccentric and concentric) and training (1 s eccentric and concentric) may have resulted in differences in repetitions performed and perceptions. Finally, in the acute study, subjects trained until failure; however, in the training study, subjects were instructed to perform a specific number of repetitions. Therefore, it is possible that increases in pain may only be observed during continuous BFR resistance exercise to failure. Future studies are needed to determine whether perceptions of pain with BFR exercise differ depending upon whether failure is reached.

There are several reasons why the results of the present training study may have differed from previous investigations. We used a standard pressure of 160 mm Hg for each subject; however, previous research has shown that limb circumference has a significant effect on blood flow dynamics during BFR exercise (Loenneke *et al.*, 2011b). Therefore, differences in limb circumference may have affected the results of this experiment. However, pressures as low as 50 mm Hg have been shown to increase muscle strength and endurance over low-load training (Sumide *et al.*, 2009); therefore, our cuff pressure was likely high enough to elicit a response, regardless of thigh circumference. We also used a heterogeneous population of males and females; however, there were no significant differences in gender between groups. Patient hydration status was not measured prior to DXA measurements; however, all measurements were performed at the same of time of day to account for diurnal variation. We did not collect 1RM data at post-testing; therefore, although isokinetic strength did not differ between groups, we cannot determine the effect of our intervention on 1RM.

We did not retest 1RM during the training protocol; however, we did not observe rapid increases in strength with training. Furthermore, BFR training has been shown to increase strength at loads as low as 20% 1RM (Abe *et al.*, 2005; Sumide *et al.*, 2009). Therefore, it is likely that subjects were training at a sufficient load throughout the study. Additionally, our training protocol consisted of 4 exercises ramping up to 30, 20, 20 and 20 repetitions on each of 4 sets, respectively. This may have resulted in a greater training stimulus than previous studies using fewer repetitions (Madarame *et al.*, 2008; Yasuda *et al.*, 2010; Clark *et al.*, 2011) and exercises (Takarada *et al.*, 2000a, 2002, 2004; Madarame *et al.*, 2008; Kacin & Strazar, 2011). Therefore, the subjects in our control group may have received a greater training stimulus than control groups in previous studies. We did not control for a learning effect in our strength measurements. Thus, we are unable to determine whether the trivial increase in strength with training is a result of a training effect or a learning effect from the repeated testing.

In conclusion, we found that during a single bout of exercise, continuous BFR exercise resulted in significantly more pain after sets three and four than intermittent BFR exercise or the control condition. Moreover, repetitions to failure did not differ between continuous and intermittent BFR exercise. These results indicate that an acute bout of intermittent BFR resistance exercise to failure causes as much muscle fatigue as continuous BFR resistance exercise to failure. Thus, intermittent BFR exercise to failure may be a more pleasant alternative to typically used continuous BFR exercise. Based on these, we performed a training study and showed that 5 weeks of low-load lower body resistance training resulted in significant increases in muscle strength. However, the magnitude of effect sizes was trivial, and there were no significant differences in muscle strength between groups. There were also no significant differences in lean mass with training or between groups. These results suggest that during a 5-week thrice weekly lower body resistance training protocol in untrained individuals, intermittent BFR and continuous BFR increase muscle strength and size to a similar extent as the same exercise without BFR. However, future studies are needed to compare both perceptual effects and efficacy of intermittent and continuous BFR training in trained individuals as well as in clinical populations.

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Conflicts of interest

The authors have no conflicts of interest.

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