Acute Effects of Blood Flow Restriction on Blood Lactate Concentration During an Exercise Bout

Original Research

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Abstract

Introduction: Does low-intensity, acute resistance exercise with blood flow restriction (BFR) elicit a similar blood lactate response as high-intensity exercise without BFR?

Methods: Participants ($N = 12$; 22 ± 3 years old) attended three visits. The first visit estimated participants' three-repetition maximum (3-RM) for right knee extension. At visits two and three, participants' blood lactate response was measured using a 1-RM percentage, counter-balancing BFR (37% 1-RM, 60% arterial occlusion pressure (AOP)) and non-BFR conditions (65% 1-RM). Baseline blood pressure and blood lactate were measured before the warm-up. Blood lactate response was measured at immediate post-exercise and two minutes post-exercise.

Results: A two-way repeated measures ANOVA found no main effect of treatment (BFR, non-BFR), $F(1, 9) = .470$, $p < .510$, but a difference over time, $F(2,18) = 23.294$, $p < .001$. Post-hoc analysis with a Bonferroni adjustment indicates that blood lactate concentration increased from baseline to immediate post-exercise ($p = .003$) and from baseline to two minutes post-exercise ($p = .001$).

Conclusions: Blood lactate concentrations were similar for knee extension with BFR at 60% AOP and 37% 1-RM, and non-BFR at 65% 1-RM groups. However, blood lactate concentration increased from baseline to post-exercise measures while working at 65% of 1-RM with BFR at 60% AOP.

Key Words: knee extensors, rehabilitation, exercise response, isokinetic dynamometer

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Introduction

Blood flow restriction (BFR) reduces arterial inflow and blocks venous outflow, a technique commonly used with resistance training (1). This method may promote skeletal muscle hypertrophy, help accelerate recovery, and could prevent atrophy in load-compromised individuals (e.g., post-operation knee surgery, osteoarthritis, osteoporosis)(1)). Specifically, BFR diminishes the amount of oxygen within a muscle group, which, in turn, stimulates muscle protein synthesis and increases muscle fiber recruitment, leading to a rapid increase in satellite cells (2). Moreover, BFR has been shown to induce hypoalgesia (i.e., a reduced sensation of pain), which may assist individuals with their pain tolerance, which could be exacerbated by higher intensity resistance exercise, and reduce pain as a limiting factor in recovery (3).

However, there is a need to identify a minimum effective arterial occlusion pressure (AOP) and exercise intensity, percentage of one-repetition maximum (1-RM) that could lead to adaptations and result in similar blood lactate responses observed with higher intensity resistance exercise, and reduce the likelihood of exercise discomfort, soreness outcomes that have been attributed to higher cuff pressures (4,5). Research from Das & Patan's (2022) systematic review of 48 protocols suggests that the maximal effect ranges between 60-80% AOP and 40-60% 1-RM. 60% AOP and 40% 1-RM represent the lower theoretical range for BFR. This review excluded intermittent BFR protocols, and only five studies included resistance-trained participants, emphasizing training interventions for strength gains with 4- to 16-week interventions. Thus, additional research is necessary to evaluate whether a 60% AOP at less than 40% 1-RM among resistance-trained participants with an acute response to intermittent BFR before progressing with a BFR exercise intervention. Therefore, if an intermittent BFR protocol elicits a similar blood lactate concentration response at 60% AOP and less than 40% 1-RM, it addresses gaps in prior research.

We set out to compare 60% AOP BFR at 37% 1-RM to a non-BFR control group at 65% 1-RM, evaluating the acute blood lactate response. While it is established that blood lactate assists in mediating metabolic adaptations and may further promote skeletal muscle tissue hypertrophy (6), a rise in blood lactate accumulation may also be a marker of hypertrophic effects and greater strength gains (7). Therefore, if BFR-combined low-intensity exercise leads to similar or increased blood lactate concentration compared to a control group (i.e., high-intensity non-BFR), this may indicate that BFR-combined exercise is an effective method of eliciting a similar hypertrophic response with reduced adverse effects (e.g., pain, joint stress). We hypothesize that knee extension exercise with BFR at a lower intensity will elicit similar blood lactate concentration compared to exercise conducted at high intensity without BFR immediately post-exercise and two minutes post-exercise compared to baseline.

Scientific Methods

Participants

Healthy males who achieved at least 75 minutes of resistance exercise per week, between the ages of 18 and 30 years, were recruited. Exclusion criteria included uncontrolled blood pressure (>139/89 mmHg), blood clotting issues, active cancer, impaired blood circulation, open incisions, fractures, varicose veins, or heart disease. This study was performed according to the Declaration of Helsinki and approved by the University of Alabama in Huntsville Institutional Review Board (IRB EE2024107). All participants gave signed, written informed consent before completing any experimental protocols.

Protocol

Participants visited the Human Performance Laboratory three times, each visit lasting approximately 30 minutes. A within-subjects study design examined blood lactate concentration (mmol/L) with BFR at low intensity and non-BFR at high intensity.

Anthropometric and Baseline Measures

Participants' height (Seca 213 Stadiometer, Chino, California, USA), weight (Tanita body composition scale, Tokyo, Japan), and blood pressure (Prosphyg^{TM} 760 cuff, Hauppauge, New York, USA), and a 3M Littmann Stethoscope (Maplewood, Minnesota, USA) were taken.

Warm-up

Next, participants performed a lower-body warm-up consisting of three minutes on an Air Wattbike (Wattbike LTD., Nottingham, UK). Participants were instructed to pedal at a light activity on the rating of perceived exertion (RPE) scale, approximately 50-60 revolutions per minute (RPM). Next, the dynamic warm-up consisted of one set of 10 bodyweight squats and one set of 10 alternating walking lunges on each leg. A one-minute rest period occurred before beginning the 3-repetition maximum (3-RM) protocol.

3-repetition Maximum (3-RM) Test

The 3-RM right leg knee extension values were obtained at visit one. After performing 15 warm-up repetitions on the HUMAC NORM (isokinetic dynamometer, Computer Sports Medicine, Inc., Salem, New Hampshire, USA), 3-RM testing began, with the load increasing by 5-20 kg based on the participants' RPE. After a one minute rest, the next set began. If the 3-RM attempt was not completed with ideal form (i.e., straight vertical spine, full knee range of motion, controlled speed), weight was reduced by 5-10 kg based on the participant's RPE. This process was repeated until participants obtained their 3-RM to estimate their 1-repetition maximum (1-RM) (8).

Visits Two and Three

Participants were randomized to receive either the BFR or non-BFR condition using an online random number generator, and conditions for visits two and three were counterbalanced.

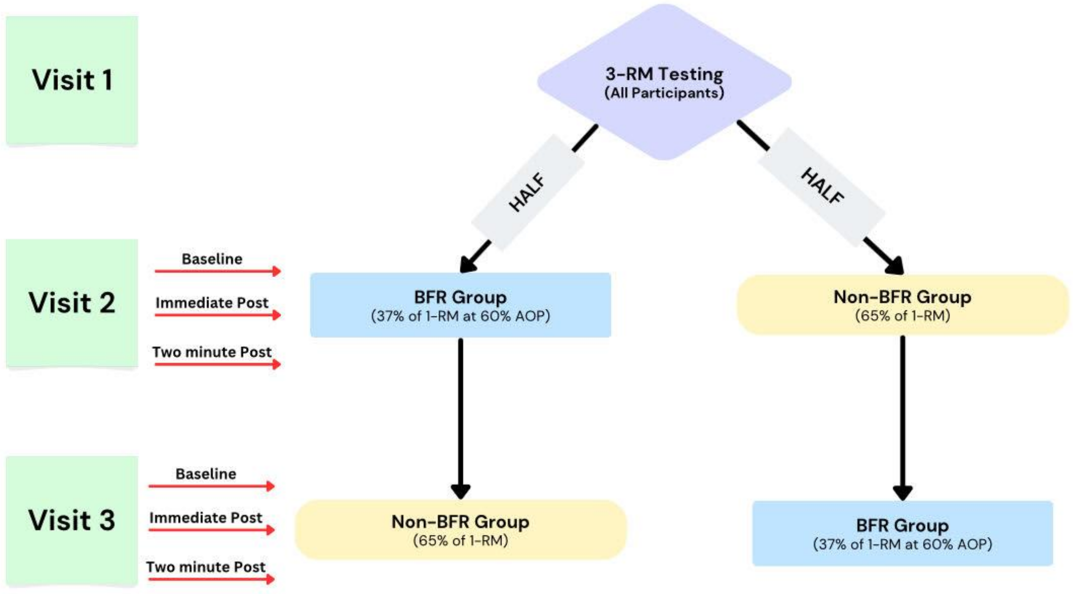

Figure 1. Protocol illustration. Red arrows represent blood lactate concentration timepoints*.* 3-RM: 3-repetition maximum; 1-RM: 1-repetition maximum; AOP: arterial occlusion pressure.

Blood Lactate Procedures

The lancet (prick), test strip, and Lactate Plus Meter (Nova Biomedical, Waltham, Massachusetts, USA) were prepared, along with alcohol pads and cotton gauze. Next, the puncture site (middle, ring, pinky digits) was prepared with single-use alcohol pads. The first blood formation was wiped away, the finger was squeezed, and the second blood formation was tested. The blood lactate concentration was reported as mmol/L.

Working Sets

The working sets consisted of three sets of ten repetitions at 65% of the participants' 1-RM for the non-BFR protocol with a one-minute rest between each set (9). Immediately after the last set, participants' blood lactate concentration was measured. After the second blood lactate sample, participants disengaged from the isokinetic dynamometer, walked to a nearby chair, and rested before their third and final blood lactate measure, two minutes post-exercise.

BFR Protocol

Our protocol adheres to the recommended reporting guidelines for BFR research (3).

Arterial Occlusion Pressure (AOP)

A Gulick Tape Measure (cm) was used to measure participants' upper thigh circumferences. The BFR cuff size was chosen based on the measured thigh circumference and was placed around the upper thigh, approximately six inches from the waistline. Participants lay supine on top of a medical table with the BFR SmartCuffs® with no autoregulation of pressure (Smart Tools Plus, Strongsville, OH, USA). An Edan SD3 Ultrasonic Pocket Doppler (EdanUSA, San Diego, CA, USA) was used to measure limb occlusion pressure of the posterior tibial artery. The BFR cuff was inflated until the arterial occlusion pressure was recorded, and then it was deflated. For the BFR condition, 60% AOP was utilized during the working sets.

Tourniquet Cuff Properties

The Smart Cuffs® are FDA-listed Class 1 Pneumatic Tourniquets by Smart Tools Plus. The cuffs are made of herringbone-woven nylon fabric, which lines the edge of the cuffs, and anti-microbial neoprene encasing the bladder system.

BFR Protocol

Participants were seated in the isokinetic dynamometer and performed a 15-repetition warm-up with their right leg using ~28.65% of their 1-RM obtained at visit one. Participants had one minute of rest and were fitted with a BFR Smart Cuff® before the three working sets. Three sets of ten repetitions at 37% of the participants' 1-RM with a one minute rest in between each set (10).

Timing of BFR

Smart Cuffs® were inflated to 60% AOP over ten-second periods for five seconds before the start of the working set, and were deflated at the end of each working set. Our protocol was if a participant could not complete all ten repetitions in each set with ideal form (i.e., straight vertical spine, full knee range of motion, controlled speed), they would perform as many as possible. For our protocol, all participants completed all ten repetitions in each set. During the one minute of rest, BFR cuff inflation began at 45 seconds, fully inflated within five seconds to the start of the next working set. After the ten repetitions, the cuff was deflated. Immediately after the last set was finished, blood lactate concentration was measured, followed by the immediate deflation of the BFR Smart Cuffs® and disengagement from the isokinetic dynamometer. The time between the immediate post-exercise blood lactate and the two minute post-exercise measures was recorded.

Power Analysis

We employed a power analysis using G*Power (version 3.1.9.7 Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) to determine the minimum sample size required to achieve statistically meaningful results with a predetermined level of power (11). Approximately 10 subjects were needed for a standard power threshold of 0.8 and an effect size of 0.65. To account for attrition, 12 subjects were recruited for the protocol.

Statistical Analysis

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS version 30, Armonk, New York, USA). A two-way repeated measures analysis of variance compared blood lactate concentration (baseline, immediate post-exercise, two minute post-exercise blood lactate concentration (mmol/L)) via a within-subjects design (BFR and non-BFR conditions). Statistical significance was accepted at $p \leq 0.05$ a priori. The graph was created using Microsoft Excel. Data are reported as mean ± standard deviation, mean difference, and 95% confidence intervals (95% CI).

Results

Twelve participants were enrolled, with an average age of 21 (± 3) years old. Throughout the study, two participants dropped out: one due to an adverse event from a finger prick and one due to a scheduling conflict. All remaining participants completed the prescribed repetitions and sets, with adherence monitored systematically. Table 1 describes the baseline characteristics of the ten participants who completed the protocol.

Table 1. Baseline characteristics.

	(N = 10)
Age (years old)	21 ± 3
Weight (kg)	85.1 ± 12.2
Height (cm)	180.2 ± 6.1
Resting blood pressure (SBP / DBP mmHg)	126.0 ± 3.3 / 80.4 ± 3.1
Arterial occlusion pressure (AOP) (mmHg)	217 ± 23.7

Data are Mean ± SD. Resting blood pressure was taken from the brachial artery. Abbreviations: kg: kilograms; cm: centimeters; SBP: systolic blood pressure; DBP: diastolic blood pressure.

There were no outliers in the dataset, indicated by studentized residual values of ±3. A Shapiro-Wilk test of normality was used to assess whether the two within-subject factors met normality. A Mauchly's test of sphericity indicated that the assumption of sphericity was met for the two-way interaction (X^2 = .386, p = .824). There was no two-way interaction between condition and time, $F(2, 18)$ = .415, p = .667, partial n^2 = .044. There was no difference between conditions, $F(1,9)$ = .470, p = .510, partial n^2 = .05. There was a difference over time, $F(2,18)$ = 23.294, p < .001, partial n^2 = .721. Post-hoc analysis with Bonferroni adjustment for multiple comparisons was selected due to no assumption of independence among multiple comparisons (i.e., time). The results indicated that the baseline blood lactate concentration was statistically significant from immediate post-exercise (mean difference of -1.855, 95% CI -3.016 to -0.694, p = .003), baseline was also statistically significant from two minute post-exercise (mean difference of -2.515, 95% CI -3.870 to -1.160, *p* = .001), but immediate post-exercise was not statistically significant from two minute post-exercise (mean difference of -0.660, 95% CI -1.424 to .104, *p* = .096). Data are presented in Figure 1.

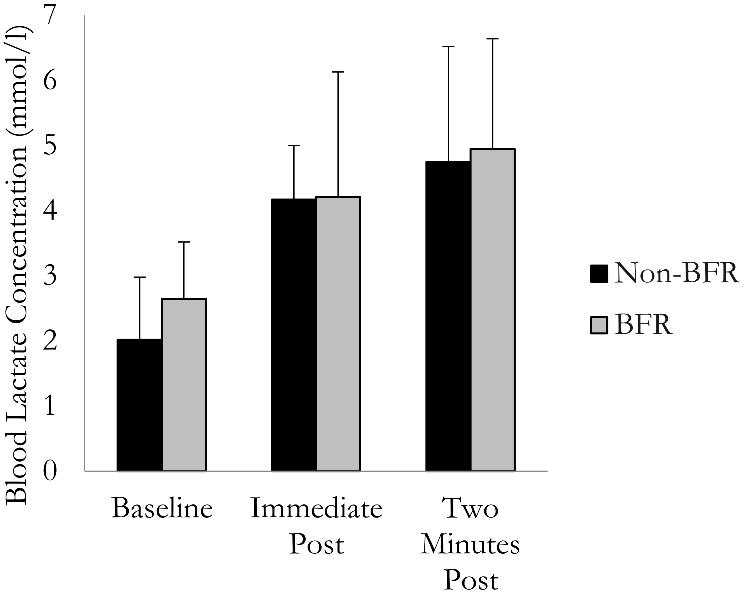

Figure 2. BFR and Non-BFR Group Blood Lactate Concentration. Blood lactate concentration was measured across groups and time. Data are reported as Mean ± SD error bars. There was a difference over time, *F*(2,18) = 23.294, $p <$ .001, partial η^2 = .721. Post-hoc analysis with Bonferroni adjustment for multiple comparisons indicated that the baseline blood lactate concentration was statistically significant from immediate post-exercise (*p* = .003), and the baseline was statistically significant from two minutes post-exercise (*p* = .001). Abbreviations: Non-BFR: no blood flow restriction group; BFR: blood flow restriction group.

Discussion

The findings of this study provide key insights into the acute effects of intermittent BFR in a resistance-trained population, while comparing the lower threshold of the suggested BFR maximal effect to within-subjects control (4). The primary objective of this study was to determine whether low-intensity BFR exercise (60% AOP, 37% 1-RM) would elicit a similar blood lactate response to non-BFR high-intensity exercise (i.e., 65% 1-RM). There were no significant differences between groups (i.e., BFR, non-BFR, *p* = .510), suggesting that acute resistance training with BFR may lead to a similar blood lactate concentration response as acute resistance training without BFR. The study found statistical differences in blood lactate concentration across time. Specifically, blood lactate concentration differed at baseline compared to the immediate post (p = .003), and baseline was also different from two minutes post (*p* = .001). The study's findings provide preliminary evidence that rejects the null hypothesis, as blood lactate concentration increased over time while remaining consistent between the two groups (BFR, non-BFR). Indeed, blood lactate concentration increased significantly over time in both conditions, with no differences observed between BFR and non-BFR conditions. Therefore, BFR-combined low-intensity exercise resulted in similar blood lactate concentration responses compared to a control group (i.e., high-intensity with non-BFR).

Our study emphasized the acute blood lactate response among young, strength-trained males via a crossover within-subjects design for intermittent BFR. While 60% AOP falls within the lower range of previously reported hypertrophic response (50-80% AOP (4)), 60% AOP was selected to determine if it was sufficient to elicit a similar blood lactate response compared to high-intensity exercise. Large effect sizes have been reported among known studies that have evaluated non-intermittent BFR among resistance-trained individuals (4). For example, Gavenda et al. (2020) enrolled trained males, utilized 60% AOP, and had a Cohen's *d* of 1.01. Additionally, Bemben et al. (2019) used 50% AOP with trained females, who reported a combined Cohen's *d* of 1.35. Regarding exercise intensity, Rauro et al. (2019) utilized 40% of 1-RM, and among recruited untrained, older women (>60 years old), the effect size was Cohen's *d* = 2.77. Lixandrao et al (2015) also utilized 40% 1-RM, recruited untrained, young men, and reported a Cohen's *d* of 0.53. For more direct comparisons of our study, the partial eta-squared fixed effects was converted to Cohen's *d* was 1.45 with

90% CI (0.91, 2.00), demonstrating that 60% AOP at 37% 1-RM resulted in a similar blood lactate concentration response in young, trained males in comparison to acute, high-intensity exercise (65% of 1-RM).

A review by Das & Paton (4) identified 11 protocols that used less than 40% of 1-RM intensity for leg extension/quadriceps extension exercises. Of those protocols, two recruited trained young males, not including intermittent protocols. de Lemus Muller et al. (2019) used a brachial artery systolic blood pressure plus 20 mmHg for their relative AOP percentage, training three times a week for eight weeks. In comparison, Manimmanakorn et al. (2013) used 160 mmHg on day 1 of exercise training, then increased it by 10 mmHg until training day 8, reaching a pressure of 230 mmHg (16,17). Applying similar approaches to our sample in Table 2, the resting brachial artery systolic blood pressure is 68 ± 7%. For our sample, a pressure of 170 mmHg would correspond to 79 ± 9% based on the participants' 100% AOP. Notably, our protocol observed similar blood lactate concentration responses from 60% AOP, 37% of 1-RM (BFR), and 65% of 1-RM (non-BFR) with lower relative AOP percentages compared to two other methodological approaches.

Table 2. Arterial Occlusion Pressure (AOP) protocol comparison.

Subjects	AOP mmHg	60% AOP mmHg	Brachial Artery (BA) SBP	BA SBP + 20 mmHg	BA SBP + 20 mmHg % AOP	170 mmHg % AOP
1	230	138	124	144	63%	74%
2	192	115	126	146	76%	89%
3	250	150	126	146	58%	68%
4	190	114	128	148	78%	89%
5	250	150	128	148	59%	68%
6	226	136	130	150	66%	75%
7	220	132	126	146	55%	77%
8	210	126	126	146	70%	81%
9	220	132	128	148	67%	77%
10	182	109	118	138	76%	93%
Mean	**217**	**130**	**126**	**146**	**68%**	**79%**
SD	**24**	**14**	**3**	**3**	**7%**	**9%**

AOP: arterial occlusion pressure; SBP: systolic blood pressure.

Despite key findings from this research study, it is important to acknowledge its limitations. Perhaps two minutes after acute exercise was not a long enough time period to evaluate the blood lactate concentration response during recovery. Indeed, future methodology should consider additional time points (e.g., 5 min, 10 min, and 15 min post-exercise), providing evidence to evaluate the blood lactate concentration recovery response after acute resistance exercise. Additionally, our findings apply to this specific population—strength-trained males —and this blood flow restriction protocol at 37% or 65% 1-RM intensity, 60% AOP, and leg extension exercise. As such, future research should consider how to streamline and expand recommendations for strength training. For example, exercise mode, exercise intensity, and cuff pressure may alter the training load for diverse populations (e.g., those with varying fitness, gender, and/or age) to enhance the generalizability of these BFR recommendations. Moreover, our smaller sample size should warrant a cautious interpretation, and these preliminary results are most applicable to the population evaluated. Since only males were recruited, our study design is limited in regard to sex differences. Finally, our acute protocol evaluates the response following a single bout of exercise, not an exercise intervention. Longitudinal designs are necessary to assess skeletal muscle adaptation to this specific protocol.

Practical Applications

This preliminary evidence may inform future minimal thresholds for BFR training (i.e., percentage of AOP, % of 1-RM). While we were able to elicit a similar blood lactate response among strength-trained males for an acute bout, additional research is necessary to inform clearance and recovery kinetics following acute bouts, response to chronic training, and expansion across different populations to inform future recommendations.

Conclusions

Our results support using low-intensity acute resistance exercise (e.g., 60% AOP and 37% of 1-RM) to achieve a similar blood lactate response compared to high-intensity resistance exercise (65% of 1-RM), which may be useful for future chronic training, given past evidence of reduced adverse effects (e.g., pain, joint stress). Further BFR-related research will help refine future BFR protocol recommendations to promote skeletal muscle hypertrophy, accelerate recovery, and prevent atrophy in individuals who are load-compromised.

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