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The Acute Effects of Blood Flow Restriction During Exercise

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ABSTRACT

Purpose: The purpose of this study was to determine the immediate physiological response that is elicited when performing low-intensity resistance exercise in conjunction with blood flow restriction (BFR) compared to the physiological response that occurs as a result of heavy load non-BFR resistance exercise. **Methods:** Subjects (n=5) completed seated, incline leg press over three experimental trials. Two were BFR trials {B-60 [restriction set to 60% arterial occlusion pressure (AOP) and B-10 [10% AOP]} with a resistance load equal to 20% of one-repetition maximum resistance (1RM) (sets x reps, 1 x 30 plus 3 x 15), and one non-BFR trial at 65% 1RM (HL) (3 x 10). Measurements recorded were heart rate (HR), rate of perceived exertion (RPE), pain perception, and blood lactate. **Results:** A 3 x 3 ANOVA revealed a significant interaction ($F_{4,16}$= 6.991, p = 0.002) between exercise condition and set for HR delta scores but no significant simple main effects. Blood lactate had no significant interaction ($F_{6,24}$ = 0.49, p = 0.81) or main effects for condition ($F_{3,1}$ = 2.05, p = 0.19) nor time ($F_{2,8}$ = 1.93, p = 0.18). No other significant differences were observed for RPE or pain. **Conclusion:** Low-intensity resistance exercise with BFR did not produce consistent differences in indicators of intensity of work or subjective perceptions of the work compared to high-load resistance exercise without BFR, indicating that the acute physiological responses were comparable between the exercise conditions.

Key Words: occlusion, anaerobic adaptations, weight training

INTRODUCTION

Blood flow restriction (BFR) has been used in conjunction with exercise since the 1970s and has become increasingly popular in the past few years (Thomas 2019). It has been shown to provide benefits for patients in recovery settings such as hospitals or physical therapy clinics, as well as providing performance benefits for elite athletes when used with resistance training (Thomas 2019). BFR involves the use of a tourniquet style cuff either inflated pneumatically or manually tightened around the proximal aspect of a limb (Weatherholt 2019). The pressure that is applied by the cuff results in the restriction of venous return out of the limb resulting in an increase in venous pooling in the working muscle (Madden 2019). This creates an anaerobic cellular environment, similar to that of heavy load resistance training (Madden 2019).

There have been reported benefits of muscle strength and hypertrophy with BFR use while training at intensities as low as 20% of the one-repetition maximum (1RM) (Madden 2019; Weatherholt 2019). As such, BFR devices are being used in clinical settings as well as in the strength and conditioning realm. Although it can be used by elite athletes to enhance performance, it has primarily been used when muscle hypertrophy is the target of the training, but high resistance is not possible (Nitzsche 2018). Previous literature has explored the effects of BFR on muscle hypertrophy and overall muscular strength gains as well as the ideal cuff width, arterial occlusion pressure (AOP), and set - repetition scheme (Madden 2019). Previous studies have determined that the use of 50% AOP is sufficient to produce muscle hypertrophy in low load (20 - 30% 1RM) settings with the use of a wide cuff for continuous occlusion throughout the duration of exercise (Madden 2019).

According to the review provided by Thomas (2016), there has been a significant amount of research regarding the long term (2-6+ weeks) effects of BFR used with resistance exercise on muscle hypertrophy, muscle strength development, and muscle endurance development. However, little research has been conducted on the immediate effects of BFR during resistance exercise with resistance-trained individuals. This study used heart rate (HR), rate of perceived exertion (RPE), pain perception (PP), and blood lactate (BL) to measure the effects of BFR with resistance exercise versus traditional resistance exercise. These measures were chosen based on their ability to change greatly in short periods of exercise signifying that there was a notable physiological response. An increase in all of these measures will signify that the intensity of the exercise has increased accordingly. It was hypothesized that when participants perform low-load resistance exercise with BFR at a high AOP, their bodies' physiological response would be similar to the physiological response that is produced during bouts of heavy load resistance exercise, resulting in similar measures for HR and RPE. It was predicted that for BL measures, the heavy load resistance exercise would have the highest increases, followed by the BFR trial with a high AOP, with the BFR trial with a low AOP having the lowest measures. It was expected that the BFR trials conducted with a low AOP would also have the lowest reported measures for HR and RPE. However, it was expected that the PP levels reported by subjects may be higher in the BFR trials as the application of a BFR cuff may be uncomfortable. The purpose of this study was to determine the immediate physiological response that is elicited when performing low-intensity resistance exercise in conjunction with BFR compared to the physiological response that occurs as a result of heavy load non-BFR resistance exercise.

METHODS

Participants

Eight moderately active and resistance-trained subjects enrolled in the study, however due to the outbreak of COVID19 and University and laboratory closures only five (one male, four female) subjects completed the study. Subject demographics are reported in Table 1. The inclusion criteria were as follows: (i) all had been participating in at least 30 - 60 minutes of exercise for 2 - 3 days per week for the past 3 months; (ii) all had been participating in at least 2 days of resistance training for 30 - 60 minutes per week for the past 3 months; (iii) all had met physical activity requirements based on the Global Physical Activity Questionnaire (GPAQ); (iv) all had been cleared to perform moderate-intensity exercise through the completion of a Physical Activity Readiness Questionnaire (PAR-Q+); (v) all had no previous experience with BFR utilization during exercise; (vi) all did not have any history of blood clots or clotting disorders or any known medical conditions that would limit their ability to perform exercise with blood flow occlusion to the limbs. All participants were aware that their participation was voluntary and were informed of the possible risk and discomfort of the study and signed an informed consent document. Ethical approval was granted by the University of Lynchburg Institutional Review Board (Approval number LHS1920053). Participants were recruited on campus at the University of Lynchburg via campuswide email and through personal outreach efforts with invitations to participate.

Table 1: Subject demographics (n = 5)

Variables	*n*	*%*	*Cumulative %*
Sex			
Male	1	20	20
Female	4	80	100
	M	*SD*	*Range*
Age (yrs)	21.00	1.22	19 - 22
Height (m)	1.67	0.08	1.58 - 1.77
Body mass (kg)	68.02	9.30	52.70 - 75.20
Predicted 1-RM (kg)	122.08	62.55	79 - 231

Design

Each participant reported to the University of Lynchburg Walker Human Performance laboratory for the first visit, and then to the University of Lynchburg Turner Fitness Center for the following three visits. The first visit consisted of participants' anthropometric measures being recorded (age, sex, height, mass), a familiarization session, and a one-repetition maximum (1RM) session for the leg press. The following three visits consisted of three experimental trials conducted in a randomized order on separate days, with at least 48 hours between trials. The three experimental trials were two BFR trials: 20% of 1RM with BFR at 60% of AOP (B-60); 20% of 1RM with BFR at 10% of AOP (B-10); and a heavy load trial at 65% 1RM without BFR (HL).

Familiarization

During the initial visit, participants had their height (to the nearest 0.5 cm) measured on a wall mounted stadiometer (Seca 222; Chino, CA) and body mass (to the nearest 0.1 kg) measured on a digital scale (Tanita BWB-800AS; Arlington Heights, IL). Each subject was familiarized with the Borg 6 - 20 RPE scale (Borg 1982) and the pain perception scale that ranges from 0 - 10. Subjects were given the opportunity to ask questions regarding how to report their perceived exertion and pain on these scales. Subjects were instructed on how the heart rate monitor chest strap would be used and were given the opportunity to try on the heart rate monitor chest strap, which was worn during the duration of all exercise testing sessions. Subjects were instructed on the process of blood sample collection for the blood lactate measures and were familiarized with the blood lactate equipment that would be used during all exercise testing sessions. Subjects were familiarized with the BFR device: Smart Tools Smart Cuffs (Strongsville, Ohio) and how it would be used during the study.

BFR AOP Determination Test

While in a prone position on a plinth, the BFR cuffs were applied unilaterally around each subject's right proximal thigh, as close to the acetabulofemoral joint as possible. Ultrasound gel was applied to the lateral ankle and Doppler blood flow monitor was placed posterior to the lateral malleoli. The Doppler was used to detect the presence of blood flow in the peroneal artery. The BFR cuff was inflated slowly until auditory blood flow was no longer detected. The cuff was deflated to hear auditory blood flow through the doppler and then reinflated until auditory blood flow was no longer audible. The process allowed us to determine a distinct

arterial occlusion pressure (AOP), based on the pressure reading when blood flow could no longer be heard through the doppler. BFR testing was administered at 60% AOP and 10% AOP unilaterally in the BFR trials; no BFR was used during the heavy load control trial.

Standardized Warm-up

Prior to the 1RM test and each of the experimental trials, all subjects completed a standardized warm-up: 5-min at minimum 60 rpm on a stationary bicycle ergometer, 10 walking knee to chest pulls on each side, 10 ankles pull quad stretch on each side, 10-m toy soldiers, 15 anterior/posterior leg swings, 15 medial/lateral leg swing, 12 air squats, and 12 hip hinges. Subjects were given guided instructions and a pictorial guide for each of the exercises in the standardized warm-up.

One Repetition Maximum (1RM) Predictive Testing for Leg Press

Each subject completed 3RM testing to predict their 1RM for the leg press. Subjects were asked to predict their 1RM for the leg press; this predicted 1RM was used to determine the starting resistance that was used for the leg press warm-up by using the following equation: Predicted 1RM (kg) * 0.50 = Warm-up Resistance (kg) (Haff 2016). The warm-up set consisted of 10 repetitions at 50% of the predicted 1RM (Haff 2016). For the following sets, the resistance was gradually increased each set by 10-20% for 5 sets (Haff 2016). The subjects were asked to perform a 3 repetition maximum (3RM); the 3RM was recorded when the subjects could not perform more than 3 repetitions of the leg press at a certain resistance (Haff 2016). The following equation was then used to predict the true 1RM for the subjects: 1RM (kg) = (3 x

0.0338 + 0.9849) * 3RM Repetition Weight (kg) (Haff 2016). The subjects' predicted 1RM are presented in Table 1.

Experimental Trials

All three experimental trials were conducted on separate days in a random order. Prior to the beginning of each experimental trial, participants completed the standardized warm-up. For BFR trials (B-60, B-10) an initial set of 30 repetitions, followed by three sets of 15 repetitions were performed with 60 seconds of rest between each set. For the HL trials, 3 sets of 10 repetitions were performed with 60 seconds of rest between each set. During the BFR trials, a metronome was used to maintain a consistent lifting pace between participants. The metronome was set to 50 beats per minute and the subjects were instructed to perform flexion at the knee on one beat and extension of the knee on the second beat such that one full repetition took two beats to complete (Loenneke 2016). The metronome was not used during the HL trials as to allow the subjects to maintain their self selected pace as though they were completing a workout on their own.

Measurements

Blood Lactate. Blood lactate was measured at rest prior to the onset of exercise for all trials. Blood lactate was then measured immediately following the completion of all repetitions, and then 5 minutes and 10 minutes post-exercise with the BFR cuff removed for the BFR trials. Blood samples were collected via a finger prick. An alcohol wipe was used to wipe one of each participant's fingers prior to blood withdrawal. A lancet was used to prick the subjects' fingers and the initial blood was wiped away with a clean tissue and disposed of. A blood lactate test

strip connected to a Lactate Plus meter (Nova Biomedical, Waltham, MA: validity = 0.97, reliability = 0.99) was touched to the subjects' fingers to collect the blood sample (Hart 2013).

Heart Rate. Heart rate was constantly measured and monitored throughout the experimental sessions. Resting heart rate was measured in a seated position before the warm-up protocol was completed. Following the completion of the warm-up protocol heart rate was measured prior to the onset of exercise for all trials. During exercise, heart rate was recorded immediately prior to and following each set of repetitions. Heart rate was measured with a Polar T31 coded transmitter strap and Polar FT1 heart rate monitor (Bethpage, NY: validity=0.976, reliability=0.96) (Montes 2019).

Perceived Pain. For the B-60 and B-10 trials, perceived pain was first recorded immediately following the inflation of the BFR cuff to 60% AOP or 10% AOP, respectively. Perceived pain was then recorded at the completion of every 15 repetitions for both BFR trials. For the HL trial, perceived pain was recorded at the completion of every 10 repetitions. Perceived pain was measured using a standard visual analog scale; ranging from 0 (no pain) to 10 (worst possible, unbearable, excruciating pain).

Rate of Perceived Exertion. Rate of perceived exertion was measured at the completion of each of the four sets of repetitions for the B-60 and B-10 trials. For the HL trial, rate of perceived exertion was measured following the completion of every 5 repetitions. Rate of perceived exertion was measured using the Borg Rate of Perceived Exertion scale (Borg 1982); ranging from 6 (no exertion) to 20 (maximal exertion).

Statistical Analysis

Statistical analysis was completed using SPSS version 26 (IBM Corp. Armonk, NY) and JASP 12.1 (Amsterdam, Netherlands) to determine statistical significance. Subject demographics are presented as mean ± standard deviations. Due to HR being a continuous variable and being assessed both pre- and post- each set of exercises, delta scores were calculated for HR (post - pre) for each exercise set. A 3 x 3 repeated measure ANOVA was used to compare delta HRs between trials (B-60, B-10, and HL) and exercise sets (sets 1-3). Bonferroni post-hoc tests were used to analyze simple main effects. A paired sample t-test was used to compare delta HR from B-60 and B-10 in set 4; the HL trial did not include a fourth set. The alpha level was set *a priori* at <0.05. A 3 x 4 repeated measures ANOVA was used to compare trials (B-60, B-10, and HL) and time for lactate (baseline, post, post 5min, post 10min) with an alpha level set *a priori* at <0.05. Multiple one-way repeated-measures analysis of variances (ANOVA) were used to compare three trials (B-60, B-10, and HL) on dependent variables (RPE and perceived pain) at each time point. To control the overall error rate, a Bonferroni correction was used to adjust the *a priori* alpha level for RPE and perceived pain (critical value/number of tests).

Results

Heart Rate

Delta scores were calculated for heart rate for each set of exercises and compared across exercise conditions and sets. Means and standard deviations for resting heart rate and for delta heart rate for each set are included in Table 2. A 3x3 repeated measure ANOVA revealed a significant interaction ($F_{4,16}$= 6.991, p = 0.002) between exercise condition and set. Post-hoc analyses demonstrated no significant simple main effects. Delta HR for set 4 of B-10 and B-60 did not statistically differ, $t(4) = 0.602$, $p = 0.58$.

Table 2: Descriptive statistics for delta HR (bpm) across set and exercise condition

	B-10		B-60		HL	
	M	*SD*	*M*	*SD*	*M*	*SD*
Resting	91.80	19.98	94.60	10.43	90.60	7.16
Delta HR- Set 1	27.80	9.50	27.20	10.04	19.80	4.49
Delta HR- Set 2	34.80	12.68	19.20	9.73	26.20	8.59
Delta HR- Set 3	21.00	15.23	29.80	4.49	34.40	8.30
Delta HR- Set 4	26.20	9.50	27.80	8.59	--	--

Delta score = post - pre

Perceived Pain

One-way repeated measure ANOVAs revealed no significant differences in perceived pain between exercise conditions at varying time points. A Bonferroni correction was made to the alpha level to control for overall error (adjusted alpha = 0.008).

Table 3: Repeated measure ANOVAs for perceived pain across time and exercise condition

	B-10		B-60		HL				
	M	*SD*	*M*	*SD*	*M*	*SD*	F	*p*	η2
Cuff inflation	0.40	0.55	0.60	0.55	--	--	1.00	0.37	0.04
Post-1st set	1.20	0.84	2.20	1.30	--	--	10.00	0.03*	0.21
Post-2nd set	2.00	1.87	3.40	1.82	1.40	1.67	2.98	0.11	0.22
Post-3rd set	2.00	2.12	3.80	1.48	2.00	2.12	3.45	0.08	0.46
Post-4th set	2.00	2.00	4.20	1.10	--	--	1	0.03	0.73
Post-final set	2.20	2.28	4.80	0.84	2.60	2.61	8.06	0.01	0.668

Rate of Perceived Exertion

Multiple one-way ANOVAs revealed no statistically significant differences in ratings of perceived exertion between exercise conditions at varying time points (Table 4). A Bonferroni correction was made to the alpha level to control for overall error (adjusted alpha = 0.01).

Table 4: Repeated measure ANOVAs for RPE across time and exercise condition

	B-10		B-60		HL				
	M	*SD*	*M*	*SD*	*M*	*SD*	F	*p*	η2
Post-1st set	10.00	1.58	9.40	2.07	12.00	2.24	3.68	0.07	0.28
Post-2nd set	10.80	2.78	11.20	2.05	11.20	1.92	0.09	0.91	0.01
Post-3rd set	11.00	2.24	12.00	2.55	12.40	2.51	0.576	0.58	0.07
Post-4th set	11.60	1.67	12.20	1.64	--	--	0.38	0.57	0.04
Post-final set	11.80	1.92	13.40	1.52	13.60	2.61	2.06	0.19	0.16

Blood Lactate

Means and standard deviations for lactate levels for trials (B-60, B-10, and HL) and for times (baseline, post, post 5min, and post 10min) can be found in Table 5. Following a 3 x 4 repeated measure ANOVA, no statistically interaction ($F_{6,24} = 0.49$, $p = 0.81$) was reported between trials

and time. No significant main effects were found for trials ($F_{3,1} = 2.05$, $p = 0.19$) nor time ($F_{2,8} = 1.93$, $p = 0.18$).

Table 5: Repeated measure ANOVAs for blood lactate (mM) across time and exercise condition

	B-10		B-60		HL	
	M	*SD*	*M*	*SD*	*M*	*SD*
Resting	1.74	0.52	4.16	3.30	2.62	1.03
Post- final set	4.18	1.24	4.78	2.36	5.10	1.92
5 min post-final set	4.40	2.40	4.92	1.97	5.12	2.15
10 min post-final set	3.32	1.22	4.02	0.88	5.20	3.63

DISCUSSION

The aim of this study was to compare the acute physiologic response of BFR in conjunction with resistance exercise to traditional heavy load resistance exercise without BFR. The results showed no significant difference for HR between the three trials, indicating that the intensity level was matched between B-60, B-10 and HL. It was observed that there was not a significant difference for RPE between the three trials, suggesting that subjects' perceived exertion was similar despite the differences in load and AOP. For PP, there was no significant difference between the three trials, suggesting that there was not an increase in pain levels with higher BFR pressure levels. There was no significant difference between trials for BL measures, indicating similar physiologic intensities between trials.

It was expected that HR levels would be increased for the B-60 and HL trials compared to the B-10 trial, however there was no significant difference reported for these trials. Loenneke

(2012) showed no significant differences between BFR and no BFR trials for HR suggesting that BFR without exercise does not increase HR levels. The Loenneke (2012) study was focused specifically on the effects of BFR without exercise, we expected our results for HR levels to be different from this study in that the addition of exercise with the BFR would subsequently increase HR. Ilett (2019) saw increases in HR with resistance exercise across each set and declines in HR during the recovery between sets. It was shown that HR was greater for the HL trial and the BFR trials that used higher AOPs in the pneumatic cuffs, indicating an increase in intensity (Ilett 2019). The Ilett (2019) study had subjects completing seated unilateral isometric knee extensions, which is very different from our method of exercise: incline leg press. The difference in body positions during exercise in this study and the Ilett (2019) study could have affected hemodynamics during exercise accounting for the differences in HR measures.

HL resistance exercise is typically associated with higher RPE levels compared to low load resistance exercise (Lixandrao 2019). It was hypothesized that there would be an increase in RPE levels for B-60 and HL compared to B-10, although no statistically significant difference was found. Lixandrao (2019) found that when taken to failure, both high intensity resistance exercise (80% 1RM) and low intensity resistance exercise (30% 1RM) had statistically significant higher RPE compared to a BFR resistance exercise trial. The Lixandrao (2019) study also utilized incline leg press as the method of resistance exercise. It is expected that the differing results could be attributed to the intensity of exercise, as our study did not have the subjects complete the leg press to muscular fatigue as was done in the Lixandrao (2019) study.

Adding BFR to low load resistance exercise is expected to increase PP, regardless of muscular fatigue (Lixandrao 2019). Due to the high AOP, it was hypothesized that the B-60 trial would have the highest levels of PP followed by HL, with B-10 having the lowest PP levels. Lixandrao (2019) showed that when taken to failure, both high intensity resistance exercise and low intensity resistance exercise had statistically significant higher PP compared to BFR resistance exercise. These findings contradicted our hypothesis as well as the hypothesis from the Lixandrao (2019) study. Similar to the differences seen in the RPE measures, the difference in results between our study and the Lixandrao (2019) study could be attributed to the intensity of the exercise as the Lixandrao study subjects completed incline leg press to muscular fatigue.

Elevation in BL levels is expected as normal physiological responses to exertion and as exertion level increases, BL levels are expected to increase accordingly (Goodwin 2007). It was hypothesized that BL levels would increase the most in the HL trial, followed by the B-60 trial, with the B-10 trial having the lowest levels. Mota (2018) showed no statistically significant difference for BL at any time during any of the trials, which corresponds with the data collected from this study. Many other studies have found that BFR increases BL during exposure and after exposure compared to no BFR and that resistance exercise with higher loads had higher BL than resistance exercise with lower loads (Nietzsche 2018, Valerio 2017, Ilett 2019). The Nietzsche (2018) study may have had more significant results in the BL measures as they completed bilateral BFR on the incline leg press, while we had unilateral BFR on the incline leg press, this could account for the increase in BL as there would be increased muscle activity and strain. The Ilett (2019) study used seated unilateral knee extensions as the mode of exercise which could

have affected the hemodynamics differently, accounting for the spread in BL following the completion of exercise.

One limitation of this study was the small sample size (n=5). Although there were some trends that started to appear, the majority of the data was statistically insignificant. Statistical power may have improved had there been more subjects. Another limitation was volume matching between trials. Due to the set-repetition scheme that was selected: B-60 and B-10 at 30/15/15/15 and HL at 10/10/10, it was difficult to pair the collected data so that the volumes from the different conditions matched. Should this study be conducted again, volume matching should be considered a crucial factor in the experimental design. In addition, the experimental trials were not conducted in a private controlled lab setting due to equipment limitations. All experimental trials were conducted in a public fitness center which led to us encountering a few problems: 1) having access to only one leg press machine: if someone else was using it the subject would have to wait, 2) distraction: during some exercise trials the gym was nearly empty and during others there would be groups of at up to fifty gym members crowding the space, 3.) noise level: as more people entered the fitness center, the noise level would go up, sometimes making it difficult for the subjects to hear the metronome or communicate their RPE and PP levels. For more accurate results, this study should be conducted in a lab setting that allows for a more controlled environment.

BFR used in conjunction with low load resistance exercise can be used as an alternative to heavy load resistance exercise. Physiologic and perceived intensity and pain levels were matched for the B-60, B-10, and HL trials indicating that intensity was matched for all three

trials. The use of BFR with resistance exercise could be beneficial for use in physical therapy or strength and conditioning settings where heavy load resistance exercise is not an option due to physical limitations such as joint injury or muscle weakness.

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References

Barnes MJ, Fraser J, Coley K, Perry BG. Is postexercise blood flow restriction a viable alternative to other resistance exercise protocols? *Res Quar Exerc Sport*. 2018;89(4):504–10.

Borg G.A. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982; 14:377-381.

Goodwin ML, Harris JE, Hernández A, Gladden LB. Blood lactate measurements and analysis during exercise: A Guide for Clinicians. *J Diabetes Sci Technol*. 2007;1(4):558–69.

Haff GG, Triplett NT (Ed.). Essentials of strength training and conditioning. 4th ed. Champaign, IL: Human Kinetics. 2016

Hart S, Drevets K, Alford M, et al. A method-comparison study regarding the validity and reliability of the Lactate Plus analyzer. *BMJ Open*. 2013;3:e001899.

Hill EC, Housh TJ, Smith CM, Keller JL, Schmidt RJ, Johnson GO. Eccentric and concentric blood flow restriction resistance training on indices of delayed onset muscle soreness in untrained women. *Eur J Appl Physiol*. 2019;119(10):2363–73.

Ilett MJ, Rantalainen T, Keske MA, May AK, Warmington SA. The effects of restriction pressures on the acute responses to blood flow restriction exercise. *Front Physiol*. 2019;10.

Lixandrão ME, Roschel H, Ugrinowitsch C, Miquelini M, Alvarez IF, Libardi CA. Blood-flow restriction resistance exercise promotes lower pain and ratings of perceived exertion compared with either high- or low-intensity resistance exercise performed to muscular failure. *J Sport Rehabil*. 2019;28(7):706–10.

Loenneke J, Fahs C, Thiebaud R, Rossow L, Abe T, Ye X, et al. The acute muscle swelling effects of blood flow restriction. *Acta Physiol Hung*. 2012;99(4):400–10.

Loenneke JP, Kim D, Fahs CA, Thiebaud RS, Abe T, Larson RD, et al. The influence of exercise load with and without different levels of blood flow restriction on acute changes in muscle thickness and lactate. *Clin Physiol Funct Imaging*. 2016;37(6):734–40.

Madden SJ. Current evidence for the use of blood-flow restriction in resistance training. *J Aus Streng Cond*. 2019;27(4):63–7.

Mattocks KT, Mouser JG, Jessee MB, Buckner SL, Dankel SJ, Bell ZW, et al. Perceptual changes to progressive resistance training with and without blood flow restriction. *J Sports Sci*. 2019;37(16):1857–64.

Montes J, Navalta JW. Reliability of the polar T31 uncoded heart rate monitor in free motion and treadmill activities. *Int J Exerc Sci*. 2019;12(4):69-76.

Mota MR, da Fonseca JEC, Abdelmur SBM, Leite MM, Silva AO, Dantas RAE, et al. Physiological and hemodynamic effects of blood flow restriction training on quadriceps. *J Exerc Physiol Online*. 2018;21(3):79–85.

Nitzsche N, Schulze R, Weigand F, Hummer N, Schulz H. Comparison of an acute resistance training on the lactate concentration with and without blood flow restriction at different loads. *Dtsch Z Sportmed*. 2018;2018(11):337–43.

Smart Cuffs [Internet]. Blood Flow Restriction Cuffs - Smart Cuffs | Smart Tools Plus. 2019 [cited 2019Nov8]. Available from: https://www.smarttoolsplus.com/detail.cfm/id/76/name/smart-cuffs

Thomas K. The benefits of blood flow restriction training for rehabilitation. *Co-Kine J*. 2019(1):24–31.

Valério DF, Berton R, Conceição MS, Canevarolo RR, Chacon-Mikahil MPT, Cavaglieri CR, et al. Early metabolic response after resistance exercise with blood flow restriction in well-trained men: a metabolomics approach. *Appl Physiol Nutr Metab*. 2018;43(3):240–6.

Weatherholt AM, Vanwye WR, Lohmann J, Owens JG. The effect of cuff width for determining limb occlusion pressure: a comparison of blood flow restriction devices. *Int J Exerc Sci*. 2019;12(3):136–43.