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Acute impact of blood flow restriction on strength-endurance performance during the bench press exercise

AUTHORS: Mariola Gepfert[1], Jakub Jarosz[1], Grzegorz Wojdala[1], Michal Krzysztofik[1], Yuri Campos[2,3], Aleksandra Filip-Stachnik[1], Maciej Kostrzewa[1], Dawid Gawel[1], Agnieszka Szkudlarek[4], Piotr Godlewski[5], Petr Stastny[6], Michal Wilk[1]

[1] Institute of Sport Sciences, Jerzy Kukuczka Academy of Physical Education in Katowice, Poland
[2] Postgraduate Program in Physical Education, University of Juiz de Fora (UFJF), Juiz de Fora, Brazil
[3] Study Group and Research in Neuromuscular Responses, Federal University of Lavras (UFLA), Lavras, Brazil
[4] Department of Physical Pharmacy, Faculty of Pharmaceutical Sciences in Sosnowiec, Medical University of Silesia in Katowice, Poland
[5] Faculty of Physical Education, Gdansk University of Physical Education and Sport, Gdansk, Poland
[6] Department of Sport Games, Faculty of Physical Education and Sport, Charles University, Prague, Czech

ABSTRACT: The main goal of the present study was to evaluate the acute effects of blood flow restriction (BFR) at 70% of full arterial occlusion pressure on strength-endurance performance during the bench press exercise. The study included 14 strength-trained male subjects (age = 25.6 ± 4.1 years; body mass = 81.7 ± 10.8 kg; bench press 1 repetition maximum (1RM) = 130.0 ± 22.1 kg), experienced in resistance training (3.9 ± 2.4 years). During the experimental sessions in a randomized crossover design, the subjects performed three sets of the bench press at 80% 1RM performed to failure with two different conditions: without BFR (CON); and with BFR (BFR). Friedman's test showed significant differences between BFR and CON conditions for the number of repetitions performed ($p < 0.001$); for peak bar velocity ($p < 0.001$) and for mean bar velocity ($p < 0.001$). The pairwise comparisons showed a significant decrease for peak bar velocity and mean bar velocity in individual Set 1 for BFR when compared to CON conditions ($p = 0.01$ for both). The two-way repeated measures ANOVA showed a significant main effect for the time under tension ($p = 0.02$). A post-hoc comparisons for the main effect showed a significant increase in time under tension for BFR when compared to CON ($p = 0.02$). The results of the presented study indicate that BFR used during strength-endurance exercise generally does not decrease the level of endurance performance, while it causes a drop in bar velocity.

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Corresponding author:
Michal Wilk
Department of Sports Training
The Jerzy Kukuczka Academy of Physical Education
ul. Mikolowska 72a
40-065 Katowice, Poland
E-mail: m.wilk@awf.katowice.pl

ORCID:
Jakub Jarosz
0000-0002-6506-8263
Grzegorz Wojdala
0000-0002-2971-7414
Michal Krzysztofik
000-0003-2797-8431
Aleksandra Filip-Stachnik
0000-0003-2008-6158
Maciej Kostrzewa
0000-0003-2209-0839
Dawid Gawel
0000-0001-5884-9478
Agnieszka Szkudlarek
0000-0002-6891-9625
Piotr Godlewski
0000-0002-5054-6306
Petr Stastny
000-0003-2841-374X
Michal Wilk
0000-0001-5799-6337

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INTRODUCTION

Blood flow restriction (BFR), also referred to as ischemia or occlusion, is a training method commonly used during different physical activities [1], where an external pressure is applied to the most proximal region of the upper and/or lower limbs through of a cuff [2]. This training method causes a mechanical compression of the vasculature underneath the cuff in order to partially reduce the arterial blood flow and severely the venous one, impeding venous return during the exercise [3–6]. The cuff pressure level used during training under BFR is previously established based on the value corresponding to 100% of arterial occlusion pressure (% AOP) at the point where blood flow is completely cut off [7], then the pressure exerted by the cuff can be individually adjusted to perform training. Despite different possibilities of using BFR in the training process, such as preconditioning BFR, continuous BFR, or intermittent BFR [1, 7–13] the most commonly used technique includes continuous BFR used during several sets of resistance exercises without releasing the cuff during rest intervals.

Currently, only a few studies have compared the acute effects of BFR on strength-endurance performance [13–17]. In this regard, Wernbom et al. [14] and Loenneke et al. [16] showed that resistance exercise under BFR decreased maximal number of performed repetitions (REP) during the leg extension at 30% of 1 repetition maximum (1RM) compared to control conditions. This result was partly compatible with the study by Wernbom et al. [15] who also showed a significantly lower number of repetitions performed under BFR compared to the control conditions at loads of 20, 30, and 40% 1RM. However, such differences were not observed at higher loads (50% 1RM). The comparison of acute impact of BFR on strength-endurance performance for the upper limbs was made by the Rawska et al. [17] and Wilk et al. [13]. Rawska et al. [17] showed an increase in the number of performed repetitions (5 sets) during the bench press exercise at a load of 80% 1RM under BFR (80% AOP) compared to control conditions what is contrary to results of other studies [14–16]. Similarly, Wilk et al. [13] also showed that BFR significantly increased the number of performed REP and time under tension (TUT) during the bench press exercise at 60% 1RM. Moreover, the extremely high cuff pressure equal to 150% AOP induced a greater increase in strength-endurance performance compared to the pressure of 100% AOP [13]. Therefore, the acute impact of BFR on strength-endurance performance may be related to the level of cuff pressure, as well as to the value of load used during the resistance exercise. In addition, the acute impact of BFR may be related to the muscular area in which the occlusion is applied (upper limb or lower limb). The lower limbs, due to their larger circumference, to produce a similar effect require higher absolute pressure than the upper limbs [18–20]. Furthermore, according to a study by Gepfert et al. [21], the positive effect of BFR on acute performance may depend not only on cuff width and circumference of limbs but also on the length of the occluded limb.

Since the bench press exercise is one of the most popular upper-body resistance exercises, with numerous variations (e.g., flat, incline, decline, wide-grip, and closed-grip) commonly used in practice, as well as in experimental research [22–25], the main goal of this study was to evaluate the effects of continuous BFR on strength-endurance performance during the bench press exercise at a load 80% 1RM. The exercise variables of BFR were set based on recommendations by Patterson et al. [3] who suggested that the restriction time during the resistance exercise should last from 5 to 10 min per exercise consisting of 2 to 4 sets. It was hypothesized that BFR would decrease strength-endurance performance during the bench press exercise performed at 80% 1RM. Thus, the results of the present study can help coaches in choosing the best training method when the main goal is to improve strength-endurance performance.

MATERIALS AND METHODS

The experiments were performed in the Strength and Power Laboratory at the Academy of Physical Education in Katowice, Poland. In a randomized crossover design, each participant performed two different testing protocols in a random and counterbalanced order, one week apart: without BFR (CON); and continuous BFR (BFR). Before the main tests, two familiarization sessions were performed. One week before the first main session, maximal bench press strength (1RM) was performed. During each experimental session, the subjects performed the bench press exercise at 80% 1RM, with 3 sets of the maximal number of repetitions in each with 3 min rest intervals between each set. Each repetition was performed with a maximal speed of movement in the eccentric and concentric phases of movement [26, 27]. During the BFR condition occlusion was kept throughout the trial. The following variables were measured: number of performed repetitions (REP), time under tension (TUT), peak bar velocity (PV), and mean bar velocity (MV).

Subjects

Fourteen healthy men with experience in resistance training (3.9 ± 2.4 years) volunteered for the study after completing an informed consent form (age = 25.6 ± 4.1 years; body mass = 81.7 ± 10.8 kg; bench press 1RM = 130.0 ± 22.1 kg). The main inclusion criteria were: a bench press personal best of at least 120% body mass and that the subject was free from musculoskeletal injuries for at least 6 months before the study. The subjects were instructed to maintain their normal dietary habits over the course of the study for the duration of the experiment. They were informed about the benefits and potential risks of the study before providing their written informed consent for participation and were allowed to withdraw from the study at any time. The study protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland (02/2019), and all procedures were in accordance with the ethical standards of the Declaration of Helsinki, 1983.

Procedures

Familiarization Session and the 1RM Strength Test

Two weeks before the main experiment, the subjects performed two familiarization sessions. During the familiarization session, each subject performed 3 sets of the bench press exercise under BFR, at a load of 50% of their estimated 1RM, with the maximal number of performed repetitions. One week before the main experiment the 1RM bench press test was performed as described elsewhere [7]. During the 1RM test, the rest interval between successful trials was 5 min. Hand placement on the barbell was set at 150% of the individual bi-acromial distance, and this was used for all main trials [28].

Experimental Sessions

In a randomized and counterbalanced order, the subjects performed the bench press exercise under 2 different testing conditions: without BFR (CON) and with continuous BFR (BFR). During each testing protocol, the subject performed three sets of the bench press against an individualized load of 80% 1RM, with a 3 min rest interval between sets. During each set, the subjects performed the maximal number of repetitions possible, with maximal movement tempo in the eccentric and concentric phase of the movement. A linear position transducer system (Tendo Power Analyzer, Tendo Sport Machines, Trencin, Slovakia) was used for the evaluation of bar velocity [29]. The measurement was made independently in each repetition and automatically converted into the values of bar velocity (peak, mean). During the experimental sessions, the following variables were registered:

1. REP – number of repetitions (n).
2. TUT – time under tension (s).
3. PV – peak velocity (m/s).
4. MV – mean velocity (m/s).

Peak bar velocity was obtained from the best repetition performed in a particular set. Mean bar velocity was obtained as the mean of

TABLE 1. Comparisons between the experimental conditions for all measured variables

Condition	Set	Number of performed repetitions [n] (95%CI)	Time Under Tension [s] (95%CI)	Peak Velocity [m/s] (95%CI)	Mean Velocity [m/s] (95%CI)
Blood Flow Restriction	Set 1	8.29 ± 1.90 (7.19 to 9.38)	19.79 ± 5.41 (16.66 to 22.91)	0.55 ± 0.16* (0.46 to 0.64)	0.31 ± 0.08* (0.27 to 0.36)
	Set 2	7.07 ± 1.86 (6.00 to 8.14)	17.64 ± 2.41 (16.25 to 19.03)	0.51 ± 0.16 (0.42 to 0.61)	0.29 ± 0.07 (0.25 to 0.33)
	Set 3	5.36 ± 1.65 (4.41 to 6.31)	14.07 ± 4.46 (11.49 to 16.65)	0.47 ± 0.13 (0.39 to 0.55)	0.28 ± 0.06 (0.24 to 0.31)
Control	Set 1	8.14 ± 2.38 (6.77 to 9.52)	16.29 ± 5.62 (13.04 to 19.53)	0.60 ± 0.06* (0.51 to 0.70)	0.35 ± 0.07* (0.31 to 0.39)
	Set 2	6.79 ± 1.81 (5.74 to 7.83)	15.07 ± 2.76 (13.48 to 16.66)	0.54 ± 0.15 (0.42 to 0.62)	0.30 ± 0.06 (0.27 to 0.33)
	Set 3	5.71 ± 1.73 (4.72 to 6.71)	13.43 ± 2.95 (11.72 to 15.13)	0.50 ± 0.13 (0.42 to 0.57)	0.27 ± 0.06 (0.23 to 0.30)
Effect Size	Set 1	0.07	0.63	0.41	0.53
	Set 2	0.15	0.99	0.19	0.15
	Set 3	0.21	0.17	0.23	0.17

Note: All data are presented as mean SD. CI = confidence interval; BFR = blood flow restriction; *Statistically significant differences $p < 0.05$.

all repetitions performed in particular sets. All subjects completed the described testing protocol that was carefully replicated in subsequent experimental sessions.

Blood Flow Restriction

During the BFR sessions, the subjects wore pressure cuffs at the most proximal region of both arms. For this experiment, we used KAATSU cuffs (Master, Sato Sports Plaza, Tokyo, Japan), which are characterized as "narrow" 4-cm cuffs [7]. To determine the individual pressure value, after a 5 min rest interval, the value of full arterial occlusion pressure was determined. The measurement was conducted twice on each limb and the obtained differences were within 20 mmHg, with the average value used to set the cuff pressure for the exercise protocol [30]. The cuff pressure for the bench press exercise was set to 70% of full arterial occlusion pressure (240 ± 22 mmHg). The level of vascular restriction was monitored using a handheld Edan SD3 Doppler with an OLED screen and a 2 MHz probe made by Edan Instruments (Shenzhen, China). For the BFR condition, the occlusion was applied 3 min before the start of the first set of the bench press exercise and was maintained for all experimental sets, and also during the rest intervals.

Statistical Analysis

All statistical analyses were performed using Statistica 9.1. Results are presented as means with standard deviations. The Shapiro-Wilk tests were used in order to verify the normality, homogeneity, and sphericity of the sample data variances, respectively. Differences between the BFR and CON conditions were examined using repeated measures two-way ANOVA (2 conditions × 3 sets). The statistical significance was set at $p < 0.05$. Effect sizes for main effects and interactions were determined by partial eta squared (η^2). Partial eta squared values were classified as small (0.01 to 0.059), moderate (0.06 to 0.137) and large (> 0.137). Post hoc comparisons using the Tukey's test were conducted to locate the differences between mean values when a main effect or an interaction was found. For pairwise comparisons, effect sizes were determined by Cohen's d which was characterized as large ($d > 0.8$), moderate (d between 0.8 and 0.5), small (d between 0.49 and 0.20) and trivial ($d < 0.2$) [31]. Percent changes with 95% confidence intervals (95CI) were also calculated. Statistical significance was set at $p < 0.05$.

RESULTS

The Shapiro-Wilk tests indicated that the normality of the data has been violated for REP, PV, and MV. Therefore, for REP, PV, and MV to indicated statistical differences was used Friedman's test. The Friedman's test showed significant differences between BFR and CON conditions for REP (Chi-square ANOVA = 37.8; $p < 0.001$; Kendall's W = 0.54); for PV (Chi-square ANOVA = 35.3; $p < 0.001$; Kendall's W = 0.50) and for MV (Chi-square ANOVA = 36.2;

$p < 0.001$; Kendall's W = 0.52). The pairwise comparisons for REP did not demonstrate the significant differences in Set 1; Set 2 and Set 3 between BFR and CON conditions. The pairwise comparisons for PV showed significant differences in Set 1 between BFR and CON conditions ($p = 0.01$; 0.55 vs 0.60 m/s; respectively). The pairwise comparisons for MV showed significant differences in Set 1 between BFR and CON conditions ($p = 0.03$; 0.31 vs 0.35 m/s; respectively; table 1).

The two-way repeated measures ANOVA did not indicate a significant interaction effect for TUT ($p < 0.07$; $\eta^2 = 0.18$). However, there was a significant main effect for TUT ($p = 0.02$; $\eta^2 = 0.35$). A post-hoc comparison for the main effect showed a significant increase in TUT for BFR when compared to CON ($p = 0.02$; 17.2 vs. 14.9 s; respectively; table 1).

DISCUSSION

The main finding of the study was that BFR used during strength-endurance exercise does not decrease the level of endurance performance based on the number of performed repetitions and time under tension, which is contrary to the initial hypothesis. The presented study showed that the number of performed repetitions did not differ significantly between conditions, however, an increase in time under tension for BFR was observed when compared to control conditions. The results also showed a significant decrease in peak and mean bar velocity for BFR compared to control conditions but only in the first set of the bench press exercise.

The current research analyzed two important aspects related to the effects BFR used during the resistance exercise on the level of strength-endurance performance. The first is related to the impact of BFR on the volume of effort, while the second is related to bar velocity changes. With regard to the impact of BFR on work volume, our results are inconsistent with previous studies. In this line, Wernbom et al. [14, 15] and Loenneke et al. [16] showed that exercise under BFR caused a decrease in the number of performed repetitions. In contrast, Wilk et al. [30] observed an increase in the number of performed repetitions for BFR condition when compared to the control condition. However, the presented results did not show significant differences in the number of performed repetitions among BFR and control conditions. The main factors that can contribute to differences in results between the previous and our study may be related to the occlusion pressure, the muscular area which was occluded, the type of resistance exercise performed, and the external load used.

During the studies of Wernbom et al. [14, 15] and Loenneke et al. [16] in which a decrease in performance for the BFR condition was observed, occlusion was applied to the lower limbs, nonetheless, in this study, as well as in the study of Wilk et al. [30], the occlusion was applied to the upper limbs. The upper limbs, due to their smaller circumference, require a lower absolute pressure than the lower limbs to produce similar effects [18–20]. Although our study used a higher cuff pressure compared to those of Wernbom et al. [14, 15] (222 ± 22 mmHg; 100 mmHg; 200 mmHg; respectively), we did not observe a decrease in the number of performed repetitions for the BFR condition. The higher cuff pressure than that used in the present study was used in the exercise protocol proposed by Wilk et al. [30]. In this study, Wilk et al. [30] showed that cuff pressure at 100% AOP increased the number of performed repetitions compared to control conditions, but only in the third set of the bench press exercise. However, the additional increase of cuff pressure to a value at 150% AOP caused an additional increase in the number of performed repetitions for all sets under BFR when compared to control conditions [30]. Despite all of the above studies performed resistance exercises until muscle failure, it should be mentioned that each of them used not only a cuff pressure, as well as a different external load. The pressure of the cuff applied during resistance exercise may be dictated to some degree by the external load used [3]. In this sense, Wernbom et al. [14] and Loenneke et al. [16] verified a significant decrease in the number of repetitions performed under BFR when a load of 30% 1RM was used. Wernbom et al. [15] also showed a significant decrease in the number of performed repetitions under BFR at loads of 20, 30, and 40% 1RM but such a decrease was not observed at 50% 1RM, which is similar to our study. During the resistance exercise performed to muscle failure, the external load used determines the duration of exercise (lower load, higher number of repetitions, longer time under tension). The lower external load compared to a higher one, allows to perform an exercise for a longer time, which induces higher metabolic reactions and consequently, may result in a significant reduction in exercise capacity under BFR conditions [14]. This may explain why BFR used during low load resistance exercises reduces the maximum number of repetitions. However, Dankel et al. [32] showed a significant decrease in the number of repetitions performed during dumbbell elbow flexion under BFR despite the use of a higher load (70% 1RM), which is contrary to our results. In this way, it seems that the main reasons for differences in our result to those of previous studies can be related to different types of exercises used. In the present study, the muscle occlusion was used in the upper limb (arms), while the main muscles involved in the bench press exercise are the pectoralis major and anterior deltoid [33, 34]. Therefore, the BFR used in this area does not seems to affect the changes taking place in the pectoralis major and deltoid muscles, the two primary muscles involved in the bench press exercise [35]. On the contrary, the studies in which a decrease in the number of performed repetitions was observed under BFR used experimental exercise protocols in which the muscle occlusion was applied to the primary muscles involved in exercise [14, 16, 32]. Thus, it is possible suggest that the type of exercise used may be an important factor in determining the impact of BFR on the number of repetitions performed during a strength-endurance task.

Although that number of performed repetitions during the resistance exercise is a common variable used to determine the volume of effort, a higher number of repetitions does not necessarily mean a longer time under tension [28, 36]. According to McBride et al. [37]

and Wilk et al. [38], the volume of effort during the resistance exercise should be determined based not only on the number of performed repetitions but also on the value of time under tension [1, 37, 38]. Nevertheless, currently, only one previous study analyzed the impact of BFR on time under tension [30]. Wilk et al. [30] showed a significant increase in time under tension during a resistance exercise under BFR when compared to control conditions. A similar increase in time under tension for BFR condition was also observed in our study. Despite all three sets of the bench press exercise were performed to muscle failure, there was no decrease in time under tension associated with BFR [14, 16]. On the contrary, there was an improvement in the time under tension for the BFR condition compared to the control. However, with increased time under tension, we observed a simultaneous decrease in PV and MV but only in the first set of the bench press under BFR which is partially contrary to the results of Wilk et al. [30] and Wilk et al. [39]. The increase in time under tension observed in the BFR condition may be related to the mechanical work generated by the cuff. A cuff is a passive element, but during the eccentric phase of the movement, the strain of the cuff material can store and return elastic energy during the concentric phase of the movement [7, 24] allowing the exercise to be carried out for a longer period of time.

In the present study, there was no negative impact of BFR regarding endurance performance. It is surprising since there was a large duration of time under occlusion for the BFR condition. Previous studies showed that BFR leads to the immediate onset of physiological and metabolic stress [1, 40, 41], which consequently leads to increased fatigue and decreased exercise performance compared to control conditions [14, 16]. Despite the greater metabolic stress potentially induced by BFR [41], the results did not show negative effects on the number of performed repetitions and on the time under tension compared with control conditions. However, attention should be paid not only to the direct effect of BFR on exercise capacity but also to the potential post-exercise physiological consequences, such as possible muscle damage or even rhabdomyolysis [42, 43]. Exercise-induced muscle damage is typically caused by unaccustomed eccentric exercise with high load, while the combination of BFR with resistance exercise may cause a significant increase in metabolic stress, the level of muscle damage, especially when performing exercises in a multiple set training session [44, 45]. Unfortunately, in the present study, we did not assess, metabolic and hormonal changes, as well as the level of muscle damage indices post-exercise, which is the basic limitation of the presented study.

CONCLUSIONS

The results of the present study indicated that BFR used during upper limb resistance exercise performed to muscle failure does not decrease the level of strength-endurance performance, however, it was observed a decrease in bar velocity. Further the results of this study showed that a training session using the bench press exercise performed to muscle failure at 80% 1RM increases time under tension without a negative impact on the number of performed repetitions. Therefore, the use of BFR with a pressure of 70% AOP during the resistance exercise with a high load could induce additional physiological responses with the latter possibly being more influential.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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