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Does blood flow restriction influence the maximal number of repetitions performed during the bench press? A pilot study

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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abstract

Background: The main goal of the presented study was to assess the effect of blood flow restriction (BFR) on the maximum number of repetitions in the bench press exercise (BP) with different movement tempos.

Material and methods: Four female athletes volunteered for the study. The experiment was performed following a randomized crossover design, with four different testing protocols: 2/0/X/0 fast tempo with BFR (FAST_{BFR}); 2/0/X/0 fast tempo without BFR ($\text{FAST}_{\text{NO-BFR}}$); 6/0/X/0 slow tempo with BFR (SLOW_{BFR}) or 6/0/X/0 slow tempo without BFR ($\text{SLOW}_{\text{NO-BFR}}$). During the experimental session, participants performed 5 sets of the BP at 80%1RM. The following variables were recorded: the maximal number of repetitions in every set ($\text{REP}_{\text{Set1-5}}$) and the total number of repetitions performed in 5 sets (TREP). Two-way ANOVA was used to show differences between variables.

Results: There were significant differences between $\text{FAST}_{\text{NO-BFR}}$ and $\text{SLOW}_{\text{NO-BFR}}$, between FAST_{BFR} and SLOW_{BFR} variables in $\text{REP}_{\text{Set1-5}}$ ($p < 0.05$) and TREP ($p < 0.01$). Similarly, there were significant differences between $\text{FAST}_{\text{NO-BFR}}$ and FAST_{BFR} variables in $\text{REP}_{\text{Set1,2,5}}$ ($p < 0.05$) and TREP. Significant differences between $\text{SLOW}_{\text{NO-BFR}}$ and SLOW_{BFR} variables were also found in $\text{REP}_{\text{Set1,5}}$ ($p < 0.05$), as well as in TREP ($p < 0.01$).

Conclusions: The use of BFR in resistance training improves the maximal number of REP during the BP.

Key words: occlusion, slow tempo, training volume.

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INTRODUCTION

The level of generated muscle strength is associated with an enhanced ability to perform a wide range of both general and specific sport tasks and also with a decreased injury rate [1]. Furthermore, it is considered a primary factor to success in a large variety of sports. Muscle strength can be enhanced due to regular resistance training with a proper manipulation of such variables as the external load (%1RM), the number of repetitions (REPs), the number of sets, and duration of rest intervals between the sets [2]. The bench press (BP) is one of the most common exercises used to improve maximal strength and power output of the upper limbs.

Planning resistance training programs is based on the use of adequate intensity and volume of exercise. The volume of effort is most commonly evaluated by the number of REPs performed in each set and their total number in the training session (TREP), while the intensity of effort is determined by the value of the external load (%1RM). Although the number of REPs is the most frequent method of evaluating the exercise volume, some authors indicate the unreliability of this method, especially in training with a controlled movement tempo [3–6]. A movement tempo is usually described using digits, with each digit expressing the duration of a particular phase of the movement. Since there is no standardized method of determination of the movement tempo, in this paper a unified description of the tempo according to the four-digit combination (e.g. 2/0/X/0), where each digit denotes the eccentric, isometric, concentric and isometric phases, respectively, was applied.

The total duration of particular phases of movement determines the duration of one repetition, which is defined as time under tension (TUT). Therefore, extending the duration of one REP by a slow movement tempo leads to an increased TUT value despite the constant value of exercise volume (evaluated based on the number of REPs performed). The research has confirmed that a faster movement tempo is more beneficial to the development of power output [2, 7], and also affects the maximum value of the external load (1RM) [8]. By contrast, a slower movement tempo reduces neuromuscular activity, which decreases the level of power output during the concentric phase [7] and leads to a decline in the maximum number of REPs performed during the set [4]. At the same time, a slower movement tempo increases the maximum TUT value compared to a faster tempo [7, 9], which may be beneficial for inducing muscle hypertrophy [9, 10].

In addition to the common strategies applied in resistance training, research on their modifications is conducted more and more often, both in terms of training methodology and additional training equipment. One of such options is to use occlusion during resistance exercise, also termed blood flow restriction (BFR). The BFR technique involves the use of a tourniquet [11], an inflatable cuff [12] or elastic wraps [13]. The compression is placed at the upper part of the limb to reduce the arterial blood flow and to shut the venous blood flow during exercise [14]. Shutting the venous blood flow and limiting the arterial blood flow are possible due to the differences between arteries and veins. The main mechanisms responsible for beneficial adaptive responses associated with training under BFR condition include increased mechanical tension and elevated metabolic stress [15].

The basic component of programming resistance exercise under BFR is to determine the optimal compression value. Many studies have used BFR pressure determined based on brachial systolic blood pressure (bSBP) [16,17]; however, due to a wide variety of cuffs, it is recommended to apply pressure using relative to the individual's value of arterial occlusion pressure (%AOP) [18]. Measurement of AOP can be made by inflating the cuff to such an extent where the blood flow is cut off and a percentage of that pressure is used under BFR condition [18]. Scientific studies using BFR in resistance training have indicated that as opposed to conventional strength training, long-term adaptations following the use of BFR are more related to the effect of muscle hypertrophy [19]. In conventional strength training, adaptations occur following simultaneous hypertrophic and neurological changes [20]. A particular interest in BFR training concerns the application of this form of physical exercise using a low external load (less than 50%1RM). Studies have shown that the increase in muscle hypertrophy following training using BFR and external loads of 30%1RM is the same as in conventional strength training with high external loads (above 70%1RM) [19].

To date, only a few studies have analysed the effects of BFR applied during training with high external loads (above 70%1RM). A study by Luebbers et al. [21] confirmed that resistance training (7 weeks) with BFR and high external loads resulted in a higher increase in maximal strength compared to the group following resistance training with BFR yet with low external loads. Furthermore, the group using low external loads and BFR achieved adaptations that were similar to those in the group using resistance training without BFR, but with high external loads. Research indicates that regardless of whether BFR is used or not, the effectiveness of resistance training is significantly affected by the value of the external load [19]. Similar conclusions have been provided by Neto et al. [22], who analysed the effect of BFR on muscle fatigue during exercise with high external loads. The results of Neto et al. [22] showed higher neuromuscular fatigue (decrease in muscle activity) after a set of barbell squats until muscle failure using a high load (80%1RM) with simultaneous BFR compared to the group not using BFR.

Due to the lack of available data analysing the effects of training with BFR and a high external load, the main goal of the present study was to assess the effect of BFR on the maximum number of repetitions in 5 sets of the bench press exercise.

MATERIAL AND METHODS

The experiment was performed following a randomized crossover design, where each participant performed a familiarization session with a 1-RM test and four different testing protocols 3-4 days apart. During each experimental session, participants completed the exercise protocol performing the bench press (BP) with different movement tempos and with or without BFR. Each experimental session consisted of five sets of the BP using 80%1RM with 3 min rest intervals in between. The maximal number of repetitions was performed in each set. The following variables were recorded: the maximal number of repetitions in every set (REP_{Set1-5}) and the total number of repetitions performed in 5 sets (TREP). Participants were required to refrain from resistance training 48 hours prior to each experimental session, and they were familiarized with the protocol as well as with the benefits and potential risks of the study. All participants provided written informed consent to participation.

PARTICIPANTS

Four (4) healthy female athletes, experienced in resistance training (3.9 ±0.63 yrs), volunteered for the study after completing an ethical consent form (age =

27.3 ±2.2 years; body mass = 53.3 ±7.7 kg; BP 1RM = 55.2 ±9.5 kg; mean ±SD). All study participants were over 18 years of age and they were expected to be able to perform a bench press with the load of at least 100% of their body mass. Participants were allowed to withdraw from the experiment at any moment and were free of any pathologies or injuries. The study protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland, according to the ethical standards of the Declaration of Helsinki, 1983.

PROCEDURES

Familiarization Session and One-Repetition Maximum Strength Test

A familiarization session preceded 1RM testing. The 1RM test is a reliable measurement to evaluate muscle strength regardless of the muscle group location or gender. When participants arrived at the laboratory, they first cycled on an ergometer for 5 minutes and then performed a general upper body warm-up of 10 body weight pull ups and 15 body weight push-ups. Next, participants performed 15, 10, and 5 BP repetitions using 45, 55, and 65% of their estimated 1RM, respectively. Hand placement on the barbell was set at 150% individual bi-acromial distance (BAD). The positioning of the hands was recorded to ensure consistent hand placement during all experimental sessions. Participants then executed single BP repetitions with a 5 minute rest interval between successful trials. The load for each subsequent attempt was increased by 2.5 kg, and the process was repeated until failure.

Experimental session

Four testing sessions were used for the experimental trials. Hand placement on the barbell was set at 150% BAD. The general and specific warm-up for the experimental sessions was identical to the one used during the familiarization session. After the warm up, participants started the main testing and performed 5 sets of the BP with the maximal number of repetitions in every set at 80%1RM with 3-minute rest intervals in a randomized crossover design:

- 2/0/X/0 fast tempo with BFR (FAST_{BFR}),
- 2/0/X/0 fast tempo without BFR ($\text{FAST}_{\text{NO-BFR}}$),
- 6/0/X/0 slow tempo with BFR (SLOW_{BFR}),
- 6/0/X/0 slow tempo without BFR ($\text{SLOW}_{\text{NO-BFR}}$),

The movement tempo was controlled with a metronome guided movement cadence in the eccentric phase (Korg MA-30, Korg, Melville, New York, USA). The concentric phase was performed at the maximal movement tempo (X). Each experimental set was performed to concentric failure. All repetitions were performed without bouncing the barbell off the chest, without intentionally pausing at the transition between the eccentric and concentric phases, and without raising the lower back off the bench. The intervals between following experimental sessions were 3–4 days. All familiarization and experimental sessions were recorded by means of a Sony camera (FDR-AX53). During the experimental trials participants were encouraged to perform at the maximal effort according to the recommendations by Brown and Weir [23]. All participants completed the described testing protocol.

Blood flow restriction

During the experiment with BFR, participants wore elastic cuffs (Smart Tools Plus LLC, Strongsville, USA) around the most proximal region of both arms [24]. The cuff pressure was set to the value of ~80% of full arterial occlusion pressure of the upper limb at rest. The level of vascular restriction was controlled by a handheld Doppler Edan SD3 with an OLED screen and a 2 MHz probe made by Edan Instruments (Shenzhen, China) [18]. The restriction of the muscular blood flow was maintained for the entire exercise session (including rest periods) and was released immediately upon completion of the testing protocols.

STATISTICAL ANALYSIS

The Shapiro-Wilk, Levene and Mauchly’s tests were used in order to verify the normality, homogeneity and sphericity of the sample data variance. Two-way ANOVA was used to show differences between collected variables. In the event of a significant main effect, post hoc comparisons were conducted using Tukey’s test. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using Statistica 9.1 and Microsoft Office, and were presented as means with standard deviations.

RESULTS

There were significant differences between $\text{FAST}_{\text{NO-BFR}}$ and $\text{SLOW}_{\text{NO-BFR}}$ as well as between FAST_{BFR} and SLOW_{BFR} variables in $\text{REP}_{\text{Set1-5}}$ ($p < 0.05$) and TREP ($p < 0.01$), as presented in Tables 1 and 2.

Similarly, there were significant differences between $\text{FAST}_{\text{NO-BFR}}$ and FAST_{BFR} variables in $\text{REP}_{\text{Set1,2,5}}$ ($p < 0.05$) and TREP (Table 3). Significant differences between $\text{SLOW}_{\text{NO-BFR}}$ and SLOW_{BFR} variables were also found in $\text{REP}_{\text{Set1,5}}$ ($p < 0.05$) as well as in TREP ($p < 0.01$) (Table 4).

Table 1. Differences in $\text{REP}_{\text{Set1-5}}$ and TREP in the NO-BFR group between tempos 2/0/X/0 and 6/0/X/0

Bench Press	2/0/X/0	6/0/X/0	P
Set1	6.6 ±0.5	5.6 ±0.5	0.01*
Set2	6.3 ±0.5	4.3 ±0.5	0.01*
Set3	6.3 ±0.5	3.3 ±0.5	0.01*
Set4	5.0 ±0	3.0 ±0.5	0.01*
Set5	4.6 ±0.5	3.0 ±0.5	0.01*
Total REP	29.0 ±1.7	19.3 ±1.5	0.01*

All data are presented as mean ±standard deviation; *statistically significant differences $p < 0.05$

Table 2. Differences in $\text{REP}_{\text{Set1-5}}$ and TREP in the BFR group between tempos 2/0/X/0 and 6/0/X/0

Bench Press	2/0/X/0	6/0/X/0	P
Set1	9.0 ±1	7.3 ±0.5	0.05*
Set2	9.6 ±1.5	5.0 ±0.5	0.01*
Set3	6.6 ±1.5	4.3 ±0.5	0.05*
Set4	6.6 ±0.5	3.6 ±0.5	0.01*
Set5	6.6 ±0.5	3.3 ±0.5	0.01*
Total REP	38.6 ±4.0	23.6 ±0.5	0.01*

All data are presented as mean ± standard deviation; *statistically significant differences $p < 0.05$

Table 3. Differences in $\mathrm{REP}_{\mathrm{Set1\text{-}5}}$ and TREP for the 2/0/X/0 tempo between the BFR and NO-BFR groups

Bench Press	NO-BFR	BFR	P
Set1	6.6 ±0.5	9.0 ±1	0.02*
Set2	6.3 ±0.5	9.6 ±1.5	0.02*
Set3	6.3 ±0.5	6.6 ±1.5	0.7
Set4	5.0 ±0	6.6 ±0.5	0.9
Set5	4.6 ±0.5	6.6 ±0.5	0.01*
Total REP	29.0 ±1.7	38.6 ±4.0	0.01*

All data are presented as mean ±standard deviation; *statistically significant differences $p < 0.05$

Table 4. Differences in $\mathrm{REP}_{\mathrm{Set1\text{-}5}}$ and TREP for the 6/0/X/0 tempo between the BFR and NO-BFR groups

Bench Press	NO-BFR	BFR	P
Set1	5.6 ±0.5	7.3 ±0.5	0.02*
Set2	4.3 ±0.5	5.0 ±0.5	0.3
Set3	3.3 ±0.5	4.3 ±0.5	0.1
Set4	3.0 ±0.5	3.6 ±0.5	0.1
Set5	3.0 ±0.5	3.3 ±0.5	0.37
Total REP	19.3 ±1.5	23.6 ±0.5	0.01*

All data are presented as mean ± standard deviation; *statistically significant differences $p < 0.05$

DISCUSSION

The study showed that both the movement tempo and the use of BFR significantly affected the exercise volume in terms of the number of REPs performed. The results demonstrated a significantly higher REP value for the FAST compared to the SLOW movement tempo. A significant difference between FAST and SLOW tempos was observed for both the NO-BFR and the BFR group. Importantly, when comparing the number of repetitions performed following the same movement tempo between the BFR and NO-BFR groups (Tables 3, 4), the use of BFR resulted in a significant increase in REP values.

The study showed that regardless of whether or not BFR was used, the SLOW movement tempo during the BP caused a significant decrease in the maximum number of REPs performed as well as a decrease in TREP values compared to the FAST movement tempo, which is consistent with previous results obtained Wilk et al. [3]. The results of the present study show that in the $\mathrm{FAST}_{\mathrm{NO\text{-}BFR}}$ tempo protocol, a significantly higher number of REPs was performed compared to the $\mathrm{SLOW}_{\mathrm{NO\text{-}BFR}}$ tempo protocol in each of the 5 sets. Furthermore, significant differences were found also in TREP, where for the $\mathrm{FAST}_{\mathrm{NO\text{-}BFR}}$ tempo protocol, this value was 29 ±1.7 REPs, whereas for the $\mathrm{SLOW}_{\mathrm{NO\text{-}BFR}}$ tempo protocol the number of performed REPs was significantly lower and amounted 19.3 ±1.5 REPs. Similar differences in the number of TREP were observed between $\mathrm{FAST}_{\mathrm{BFR}}$ and $\mathrm{SLOW}_{\mathrm{BFR}}$ (38.6 ±4 and 23.6 ±0.5 REP, respectively). A lower number of REPs performed in both $\mathrm{SLOW}_{\mathrm{NO\text{-}BFR}}$ and $\mathrm{SLOW}_{\mathrm{BFR}}$ compared to $\mathrm{FAST}_{\mathrm{NO\text{-}BFR}}$ and $\mathrm{FAST}_{\mathrm{BFR}}$ is mainly due to the duration of performance of one repetition. The duration of effort during the ECC phase at the SLOW tempo was three times longer than during the FAST tempo (6 and 2s, respectively). Several times longer duration of exercise for the SLOW tempo (with both BFR and NO-BFR) leads to higher energy expenditure during each REP, which in consequence contributes to the earlier onset of fatigue. Duration of effort or, as some authors define, TUT [3], can be an indicator of the exercise volume regardless of the number of repetitions. Three times longer duration of one repetition for the SLOW compared to the FAST tempo indicates that during slow movement, each repetition generates more fatigue, which directly leads to the decrease in the maximum number of REPs. Sakamoto and Sinclar [4] reported a significantly lower number of REPs completed during a slower compared to a faster movement tempo, but no previous studies have analyzed such changes during exercise with BFR.

Furthermore, the lower number of REPs performed in both $\text{SLOW}_{\text{NO-BFR}}$ and SLOWBFR tempo protocols compared to $\text{FAST}_{\text{NO-BFR}}$ and FAST_{BFR} may be related to the less effective use of the stretch-shortening cycle (SCC). A study by Wilk et al. [7] demonstrated that using a slower movement tempo caused less efficient use of the SCC, which decreased power output generated during the 6/0/X/0 compared to the 2/0/X/0 movement tempo. Therefore, a slower movement tempo in the ECC phase reduces the efficiency of the movement during the CON phase, which, in our study, may have caused a lower value of the maximum number of REPs performed in the SLOW compared to the FAST tempo. However, it is important to note that no previous studies have analyzed differences in the maximum number of REPs between protocols with a constant tempo of movement, yet with a simultaneous application of BFR. The present study showed that the FAST_{BFR} movement tempo resulted in a significantly higher number of REPs as well as TREP compared to SLOW_{BFR}. This indicates that BFR is not a factor significantly differentiating between changes in the maximum number of REPs performed at FAST and SLOW tempos.

What is important, the study showed that in the FAST_{BFR} tempo protocol, the maximum number of REPs performed increased compared to $\text{FAST}_{\text{NO-BFR}}$. In the FAST_{BFR} protocol, TREP was significantly greater compared to $\text{FAST}_{\text{NO-BFR}}$ (38.6 ±4.0; 29.0 ±1.7, respectively). Similar differences were observed in the SLOW tempo protocol (23.6 ±0.5; 19.3 ±1.5, for SLOW_{BFR} and $\text{SLOW}_{\text{NO-BFR}}$, respectively), but these differences were smaller compared to those observed for the FAST tempo protocol. Studies that have analyzed the effect of BFR on immediate and long-term adaptations indicated that increased metabolic stress was the main adaptive factor [15, 25]. The increase in the metabolic stress following the use of BFR results from the accumulation of by-products of physical exercise in the part of the limb starting from the restriction location [25]. However, the results of our study not only did not show a decrease in exercise capacity during the use of BFR, but surprisingly, they showed an increase in this capacity (the number of REPs). Participants performed more REPs at both FAST and SLOW tempos when using BFR compared to the exercise without BFR. Thus, the results of our study contradict the Pearson and Hussain’s [15] statement about a reduction in exercise capacity when using BFR. However, it should be noted that muscle occlusion used in the study was performed on the upper limb (upper arm), while the main muscles involved in the BP are the pectoralis major and anterior deltoid [26]. The triceps brachii muscle also shows high activity during the BP, but BFR in this area did not result in a decrease in exercise capacity during the BP. Another important factor that may have a significant effect on the higher value of REPs performed during exercise with BFR is the mechanical work generated by the tourniquet. Previous research has confirmed that wearing knee wraps enables athletes to lift greater loads or perform more repetitions with a given load [27, 28]. It is thought that this is because elastic energy is generated as knee wraps stretch during the lowering phase, returning this energy during the lifting phase [27]. A similar effect may occur when the cuff is used during BFR. A cuff is a passive element, but during the movement, especially in the eccentric contraction, the strain of the material from which the cuff is made increases. As a result mechanical energy is accumulated, and its release during concentric contraction induces increases in the number of performed REPs.

CONCLUSIONS

The use of BFR in resistance training can improve its effectiveness not only through physiological and metabolic responses, but also through the effect of mechanical work generated by the tourniquet itself. Regardless of whether BFR is used or not, the movement tempo in resistance exercise has a significant effect on exercise volume. Furthermore, through modification of the duration of the ECC phase of the movement, one can introduce additional stages of periodization in the development of hypertrophy, strength and power output, which opens up new opportunities for modification of resistance training variables.

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