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The Effect of Exercises with Blood Flow Restriction in the Limbs on the Development of Muscle Strength and Hypertrophy: A Pilot Study

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Abstract

Weight training with regulated blood flow in the limbs is characterized by low load intensity ranging from 30-50% of the one repetition maximum. The aim of the study was to assess the effect of weight training with regulated blood flow in the limbs on changes in muscle strength and hypertrophy. The research sample consisted of 5 participants aged 26.40±7.16 years who performed 10-week intervention program. The weekly microcycle consisted of three training sessions, which intensity was regulated by inflatable cuffs placed on proximal parts of upper and lower limbs. Body composition was assessed with InBody 720. Muscle strength of knee and elbow flexors and extensors was assessed with Cybex HUMAC NORM isokinetic dynamometer at four speeds ranging from 60-240°·s-1, supplemented by front squat and bench press with emphasis on speed during the concentric phase of the movement. The results showed an increase in knee flexor muscle strength that was not statistically significant. The present pilot-study points to the need for further verification of methods how to use regulated blood flow in training related to muscle strength and hypertrophy.

Keywords: *weight training, isokinetic dynamometry, body composition, KAATSU*

Introduction

The increase in muscle strength and hypertrophy should be related to the optimization of training variables applied in weight training exercises (Scheonfeld, Grgic, Van Ery & Plotkin, 2021). One of the main recommendations for the development of muscle strength and hypertrophy in weight training include setting the load intensity between 70-85% of the one repetition maximum (1RM) for 8-12 repetitions in 1-3 sets per exercise (Kraemer & Ratamess, 2004). On the other hand, it has been shown that using blood flow restriction (BFR) in the limbs, can develop muscle strength and hypertrophy even at load intensities lower than 50% of 1RM (Kim et al., 2017; Lixandrao at al., 2018; Grøenfeld, Nielsen, Mieritz, Lund & Aagard, 2020). In such a method of weight training, blood flow is regulated by a device that is similar to a medical pressure gauge. Using external cuffs that are fixed on the proximal parts of the upper and consequently the lower limbs, the pressure is determined, which can be considered as the degree of load intensity (Slysz, Stultz & Burr, 2016). The increase in muscle strength and hypertrophy by blood flow regulated exercise (BFR) is induced by multiple mechanisms (Loennekke, Wilson & Wilson, 2010). Loenneke, Fahs, Rossow, Abe and Bemben (2012) describe increased metabolic stress, greater involvement of fast-twitch muscle fibers, and increased cellular swelling as three determining mechanisms. As a result of blood flow restriction to the limbs, metabolic stress is induced on the basis of the accumulation of waste products of metabolism and tissue hypoxia. Metabolic stress induced by muscle work with blood flow restriction increases amino acid transport into muscle cells, resulting in muscle proteosynthesis (Wagner, 1996). It also has been shown that metabolic stress reactively increase growth hormone levels (Suga et al., 2010). The reactive increase in growth hormone levels is considered by Takarada et al. (2000) to be the primary mechanism for increasing in muscle strength and hypertrophy. Accumulated metabolic waste products in the muscle increase the involvement of fast-twitch muscle fibres (Yasuda et al., 2010). Although muscle

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hypertrophy has been demonstrated in all types of muscle fibers, according to Wagner (1996), fast-twitch muscle fibers have a greater potential to hypertrophy. The aim of this pilot study was to assess the effect of weight training with regulated blood flow in the limbs on changes in muscle strength and hypertrophy.

Methods

Participants

The experimental design is demanding in terms of individual approach, which was reflected in the research sample size. Five participants were included in the pilot study. It was necessary to supervise the correct application of inflatable cuffs on the proximal parts of the limbs and compliance with the set pressure in the cuffs, which determined the exercise intensity in the form of controlled blood flow restriction in the limbs. The research sample consisted of 3 females and 2 males with a mean age of 26.40±7.16 years. Before the intervention, participants had been regularly performing weight training and amateur combat training (boxing or karate) for more than one year with a frequency of 3 training session per week.

Table 1. Description of the research sample

Participants	Gender	BH (cm)	BW (kg)	SMM (kg)	BFM (kg)	VFA (cm^2)
P01	♀	171	60.5	28.6	9.6	20.4
P02	♀	168	62.4	27.1	13.2	57.9
P03	♀	170	54.1	26.3	6.9	23.0
P04	♂	178	65.6	37.8	6.7	21.2
P05	♂	183	86.7	41.8	14.0	80.3

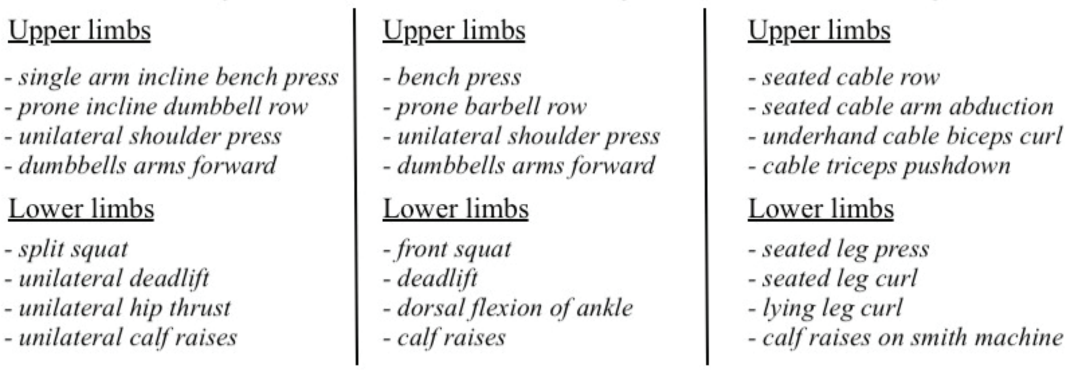
Note. BH: body height; BW: body weight; SMM: skeletal muscle mass; BFM: body fat mass; VFA: visceral fat area; ♀: females; ♂: males

Procedures and measurements

Before the pretest, participants were informed and consented to the purpose and procedures of testing, which was conducted in accordance with the ethical standards of the Declaration of Helsinki (Harris, Macsween & Atkinson, 2017). The research was approved by the ethics committee of the University of Presov and ethics committee of Hospital AGEL Košice - Šaca a. s. Body height was measured by the BSM170 stadiometer (Biospace, Seoul, North Korea) and body composition via bioelectrical impedance by InBody 720 (Biospace, Seoul, North Korea). Among the body composition parameters, we assessed body weight (BW), skeletal muscle mass (SMM), body fat mass (BFM) and visceral fat area (VFA). To ensure the objectivity of the results, the pretest and posttest were taken at the same time of the day. Subsequently, participants performed a 10-minute pretest warm-up on a cycle ergometer, with the addition of mobilization and isometric exercises. Local muscle strength was measured by a Cybex HUMAC NORM isokinetic dynamometer (Cybex NORM®, Humac, CA, United States) with emphasis on the extensors and flexors of the knee and elbow joints. Local muscle strength of knee joint extensors and flexors was measured in concentric muscle contraction in a range of motion of 90° at 60°·s^{-1}, 120°·s^{-1}, 180°·s^{-1}, and 240°·s^{-1}. Local strength of the elbow extensors and flexors was assessed in concentric muscle contraction in a range of motion of 120° at 60°·s^{-1}, 180°·s^{-1}, and 240°·s^{-1}. Testing consisted of three trials with maximal effort, preceded by two trials with submaximal effort to familiarize with the test procedure. Visual feedback and verbal motivation were provided during the execution of the muscle strength tests on the isokinetic dynamometer to ensure maximal stimulation of moral-volitional qualities. The level of strength abilities was also measured by front squat and bench press with emphasis on the speed of the concentric phase of the movement using the FiTROdyne Basic Peak Power LCD device (FiTRONiC, s.r.o., Slovakia). Testing consisted of two consecutive repetitions performed with maximal effort. Increasing the load continued until the speed dynamic regime decreased under the minimum dumbbell speed in the concentric phase of the movement at 0.7 m·s^{-1} (Zatsiorsky & Kraemer, 2006).

Intervention

The intervention consisted of weight training sessions performed 3 times per week for 10 weeks. The training sessions consisted of dynamic strengthening exercises with a load intensity of 40% 1RM using regulated blood flow in the limbs. Blood flow was regulated using inflatable cuffs KAATSU AIRBANDS (KAATSU Global Inc., CA, United States) placed on the proximal parts of the upper or lower limbs and device KAATCU C3 (KAATSU Global Inc., CA, United States). The baseline pressure applied to the limbs was set at 200 SKUs (Standard Kaatsu Units), increasing linearly by 20 SKUs every week. The strength-



Monday	Wednesday	Friday
Upper limbs	Upper limbs	Upper limbs
- single arm incline bench press *- prone incline dumbbell row* *- unilateral shoulder press* *- dumbbells arms forward*	*- bench press* *- prone barbell row* *- unilateral shoulder press* *- dumbbells arms forward*	*- seated cable row* *- seated cable arm abduction* *- underhand cable biceps curl* *- cable triceps pushdown*
Lower limbs	Lower limbs	Lower limbs
- split squat *- unilateral deadlift* *- unilateral hip thrust* *- unilateral calf raises*	*- front squat* *- deadlift* *- dorsal flexion of ankle* *- calf raises*	*- seated leg press* *- seated leg curl* *- lying leg curl* *- calf raises on smith machine*

FIGURE 1. Intervention program

ening exercises applied in the weekly microcycle are presented in Figure 1.

The strength exercises were performed in 3 sets of 15 repetitions with 1 minute rest between the sets. The applied exercises were performed in a horizontal sequence, which is characterized by performing all sets of one exercise before moving to other exercise.

Statistical analysis

Based on the small size of the research sample, the median was used as a measure of central tendency and the quartile deviation as a measure of variability. Statistical analysis was performed using SPSS Statistics 20.0 software (IBM, Armonk, USA).

Results

Inter-individual comparison of input and output measurements of skeletal muscle mass showed the observed differences. In one case, there was a 0.7 kg increase in the proportion of muscle mass in the female participant. In the other participants, there was a decrease in skeletal muscle by an average of 0.95 kg, and in the male participants by 2.15 kg. The trend was reflected by an increased proportion of fat mass on average of 1.1 kg in females and 1.45 kg in males. The proportion of visceral fat increased from 33.8 cm2 to 42.9 cm2 in women and decreased from 50.7 cm2 to 48.7 cm2 in men. A visual interpretation showing the pretest and posttest muscle strength measurements of the men's knee joint extensors and flexors is presented in Figure 2.

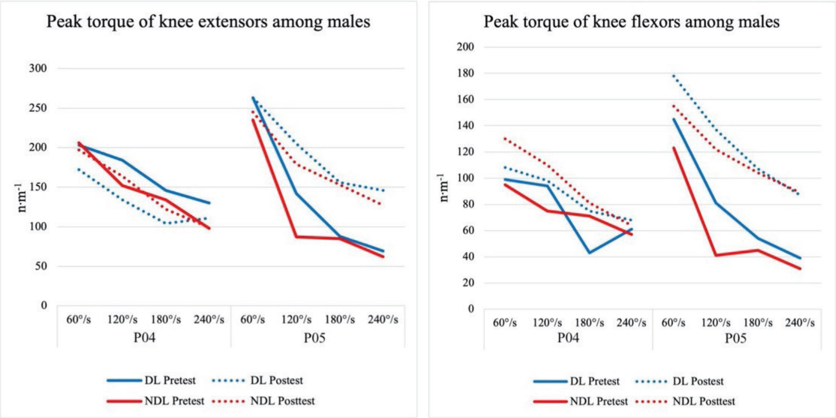


FIGURE 2. Peak torque of knee extensors and flexors in male sample. DL: dominant limb; NDL: non-dominant limb

Inter-individual comparison showed a decrease in muscle strength of the knee joint extensors of dominant and nondominant limb at angular velocity 60°·s^{-1} by 8 n·m^{-1} in both participants. In participant P04 a decrease of 23 n·m^{-1} in muscle strength in both limbs at angular velocity 180°·s^{-1} was similarly noted. In the second case, muscle strength increase of 72 n·m^{-1} were recorded at 120°·s^{-1}, 180°·s^{-1} and 240°·s^{-1} angular velocities. The analysis of knee joint flexor muscle strength showed improvement on dominant and non-dominant limb in both subjects at all angular velocities measured. The highest increase in knee joint flexor

Table 2. Descriptive statistics of pretest and posttest measurements of peak torque of knee extensors and flexors in female sample

Variables			Pretest	Posttest
			Median±Quartile deviation (min/max)	
DL	60°·s^{-1} KE	n·m^{-1}	157.00±4.75 (146.00/165.00)	152.00±7.25 (127.00/156.00)
	60°·s^{-1} KF		95.00±8.00 (76.00/108.00)	89.00±5.50 (84.00/106.00)
	120°·s^{-1} KE		102.00±8.75 (95.00/130.00)	102.00±6.75 (96.00/123.00)
	120°·s^{-1} KF		75.00±7.75 (57.00/88.00)	76.00±7.25 (65.00/94.00)
	180°·s^{-1} KE		85.00±4.75 (98.00/79.00)	92.00±6.50 (69.00/95.00)
	180°·s^{-1} KF		54.00±4.75 (52.00/71.00)	58.00±5.75 (56.00/79.00)
	240°·s^{-1} KE		72.00±1.25 (68.00/73.00)	75.00±4.00 (60.00/76.00)
	240°·s^{-1} KF		49.00±4.50 (43.00/61.00)	50.00±6.50 (49.00/75.00)
NDL	60°·s^{-1} KE		138.00±12.00 (127.00/175.00)	144.00±3.25 (133.00/146.00)
	60°·s^{-1} KF		83.00±8.75 (69.00/104.00)	91.00±9.50 (73.00/111.00)
	120°·s^{-1} KE		98.00±7.75 (92.00/123.00)	99.00±6.75 (95.00/122.00)
	120°·s^{-1} KF		58.00±10.25 (54.00/95.00)	66.00±10.75 (57.00/100.00)
	180°·s^{-1} KE		75.00±5.75 (72.00/95.00)	80.00±5.25 (73.00/94.00)
	180°·s^{-1} KF		50.00±6.50 (46.00/72.00)	50.00±6.50 (50.00/76.00)
	240°·s^{-1} KE		58.00±8.00 (43.00/75.00)	65.00±3.75 (60.00/75.00)
	240°·s^{-1} KF		41.00±7.75 (37.00/68.00))	46.00±6.00 (45.00/69.00)

Note. DL: dominant limb; NDL: non-dominant limb; KE: knee extensors; KF: knee flexors muscle strength was observed in the non-dominant limb at angular velocity of 120°·s^{-1} by 26.4 n·m^{-1}. On the contrary, the lowest increase was observed at angular velocity of 60°·s^{-1} on the dominant limb by 8.4 n·m^{-1}.

Comparison of the medians showed an increase in muscle strength of the knee joint extensors of non-dominant limb at all angular velocities measured. In the inter-individual comparison, the increase was demonstrated in all participants only at the 240°·s^{-1} angular velocity. Comparing the knee joint flexors median values, an improvement was noted at all angular velocities studied except 60°·s^{-1} on the dominant limb and 180°·s^{-1} on the non-dominant limb, where no change occurred. Inter-individual comparison showed an increase in muscle strength in all participants at all angular velocities except at 60°·s^{-1} on the dominant limb, where two participants showed a decrease in muscle strength. A visual interpretation showing the pretest and posttest muscle strength measurements of the men's elbow joint extensors and flexors is presented in Figure 3.

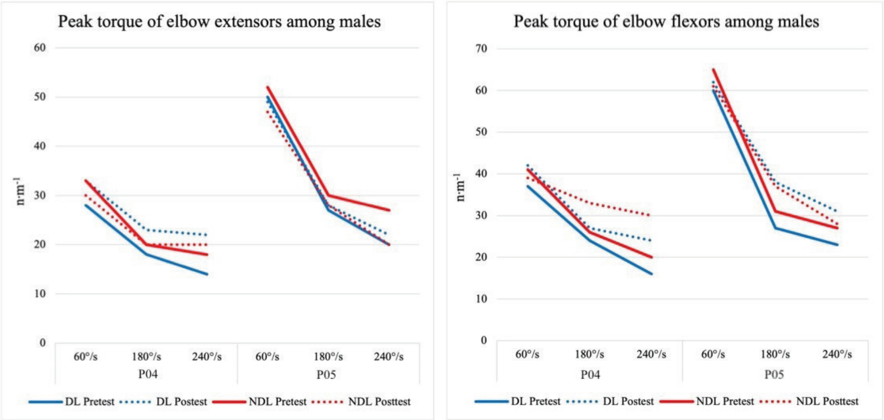


FIGURE 3. Peak torque of elbow extensors and flexors among males. DL: dominant limb; NDL: non-dominant limb

Inter-individual comparison showed a decrease in muscle strength of elbow joint extensors in participant P04 at angular velocity 60°·s^{-1} by 3 n·m^{-1} on the non-dominant limb. At all other velocities measured, there was an improvement in the performance of the participant. In participant P05 there was a decrease in muscle strength at angular velocity 60°·s^{-1} on both limbs by 3 n·m^{-1}. At the same time, there was a decrease in muscle strength of the non-dominant limb at 120°·s^{-1} and 180°·s^{-1} angular velocities by 4.5 n·m^{-1}, whereas there was an increase in muscle strength of the dominant limb at these velocities by 1.5 n·m^{-1} on average. Participant P04 showed an improvement in elbow flexor muscle strength at all angular velocities measured by 5.8 n·m^{-1}. Similarly, participant P05 showed an improvement at all velocities observed by 5.6 n·m^{-1}, except for the non-dominant limb at angular velocity 60°·s^{-1}, where a decrease in muscle strength by 4 n·m^{-1} was noted.

Table 3. Descriptive statistics of pretest and posttest measurements of peak torque at elbow extensors and flexors in female sample

Variables			Pretest	Posttest
			Median±Quartile deviation (min/max)	
DL	60°·s-1 EE	n·m^{-1}	20.00±4.00 (19.00/35.00)	26.00±1.25 (22.00/27.00)
	60°·s^{-1} EF		31.00±2.50 (23.00/33.00)	31.00±1.50 (28.00/34.00)
	180°·s^{-1} EE		16.00±0.25 (15.00/16.00)	18.00±1.00 (16.00/20.00)
	180°·s^{-1} EF		19.00±1.50 (19.00/20.00)	20.00±1.25 (19.00/24.00)
	240°·s^{-1} EE		14.00±5.00 (15.00/19.00)	18.00±1.00 (15.00/19.00)
	240°·s^{-1} EF		16.00±1.00 (12.00/16.00)	15.00±3.50 (5.00/19.00)
NDL	60°·s^{-1} EE		23.00±1.00 (19.00/23.00)	28.00±2.50 (20.00/30.00)
	60°·s^{-1} EF		28.00±2.00 (23.00/31.00)	26.00±2.00 (20.00/28.00)
	180°·s^{-1} EE		16.00±0.50 (15.00/19.00)	16.00±1.00 (15.00/19.00)
	180°·s^{-1} EF		18.00±1.00 (15.00/19.00)	19.00±1.75 (19.00/24.00)
	240°·s^{-1} EE		15.00±0.75 (12.00/16.00)	15.00±0.75 (12.00/16.00)
	240°·s^{-1} EF		18.00±1.50 (14.00/20.00)	18.00±2.75 (9.00/20.00)

Note. DL: dominant limb; NDL: non-dominant limb; EE: elbow extensors; EF: elbow flexors

Comparing differences in female sample, an increase in the elbow joint extensors muscle strength of the dominant limb at all angular velocities was measured, while increases at 60°·s^{-1} were noted in the non-dominant limb. In the inter-individual comparison, an increase in muscle strength was shown in all participants only on the non-dominant limb at angular velocity of 60°·s^{-1}. On the other hand, when comparing the median values of elbow joint flexors, improvement was observed only at 180°·s^{-1} angular velocity on the dominant and non-dominant limb. Inter-individual comparison did not show such increase in muscle strength in only one participant on the dominant limb. In terms of bilateral movements during front squat and bench press, the following differences can be shown by comparing the pretest and posttest values. Two female participants showed an increase in velocity during the concentric phase of the movement by an average of 0.9 m/s, while one participant showed no change in performance. An improvement of 0.14 m/s was recorded in only one participant, with no changes in performance recorded in the other participant. On the contrary, the effect of strength training with regulated blood circulation in the limbs was demonstrated on velocity changes during the concentric phase of movement in the bench press lying position in only one participant by 0.04 m/s. A decreased velocity by 0.08 m/s was similarly noted in only one participant, with no changes in performance in the latter case. In men, no changes in velocity were recorded during the concentric phase of movement in the bench press.

Discussion

This pilot-study investigated the effect of weight training with regulated blood flow in the limbs on changes in muscle strength and hypertrophy. In relation to muscle hypertrophy, a decrease in the level of skeletal muscle mass was not observed only in one female participant. Second, due to weight training with regulated blood flow in the limbs, the level of muscle strength of knee extensors decreases at angular velocity $60°\cdot s^{-1}$. Contrarily, the level of muscle strength of knee flexors increases at angular velocity $240°\cdot s^{-1}$. In addition the level of muscle strength of elbow extensors and flexors increases at angular velocity $180°\cdot s^{-1}$.

Comparing the results of our study with Miller, Tirko, Shipe, Sumeriski and Moran (2021) which confirm the positive effect of training with regulated blood flow in the limbs on muscle hypertrophy, our results point to decrease of skeletal muscle mass. Non-significant improvement in muscle circumference and thickness after exercising with BFR was also noticed in the of study of Thiebaud, Yasuda, Loenneke and Abe (2013). Pressure caused by application of inflatable cuffs on limbs during weight training induces specific conditions in which muscle failure occurs even at low load intensities. It shows that increased cellular swelling may be a reactive, as well as an adaptive change in muscle hypertrophy, due to the placed cuffs. It is a hypoxic environment that enhances the training effect in exercising muscle (Takada et al., 2012). Cook, Kilduff and Beaven (2014) suggest that higher recruitment of fast twitch fibers during the weight training with regulated blood flow enhances the muscle hypertrophy. Mechanical tension and metabolic stress seem to be the factors primarily responsible for hypertrophic adaptations following blood flow restriction training. Weight training with regulated blood flow in the limbs can enhance muscle hypertrophy in case of low level of muscle strength. However, the relative extent to which these specific mechanisms are induced by the factors in weight training with regulated blood flow in the limbs, as well as their range of involvement in BFR weight training-induced muscle hypertrophy, requires further exploration (Pearson & Hussain, 2015). In relation to body fat, we observed non-congruent results in comparison with findings of Lixandrão et al. (2018) who showed a decrease in fat mass.

In relation to muscle strength our results are in contrast with previous findings presented by Early et al. (2018), Hill et al. (2020) and Bradley, Bunn, Feito and Myers (2022), who reported an increase in the level of maximal strength due to weight training with regulated blood flow. The study of Hill et al. (2020) compared 4 weeks isokinetic low-load weight training with and without BFR. The results showed greater increases in concentric peak torque with application of BFR in training sessions. Comparative analysis of Yang et al. (2022) showed that training with regulated blood flow in the limbs increases the knee extensors and flexors isokinetic torque, muscle strength of lower limbs and maximal strength in squat. Regarding to applicated load intensity and findings of our study, Manini and Clark (2009) emphasize that load measured by 1RM and maximal voluntary contraction is an important factor influencing the training effect. According to them, the recommended load intensity for optimal training effect is from 20% to 30% of 1RM. Another study by Spitz et al. (2023) compared isotonic and isokinetic strength training. The findings revealed that resistance training led to significant increases in both specific and non-specific muscle strength, with a smaller effect size associated with non-specific muscle strength. The combination of BFR with weight training showed significant benefits in terms of muscle strength, even at low load intensity, and it is comparable or more efficient than strength training (Wilk et al., 2018). The results in the studies by Cook et al. (2014) and Bowman et al. (2019) showed congruent findings with our research in relation to speed strength. In addition, Hill et al. (2020) concede that the weight training with regulated blood flow in the limbs positively affects the level of explosive power compared to weight training without blood flow regulation. On the other hand, it is necessary to emphasize that weight training with regulated blood flow in the limbs with low load intensity does not affect the level of muscle strength as strength training with high load intensity (Yasuda et al., 2011).

Conclusion

Based on the results it seems that the weight training with regulated blood flow restriction does not affect muscle hypertrophy in athletes. Therefore, in following research is necessary to take into account nutritional habits of participants, which can significantly affect muscle hypertrophy. In maximal strength development, it shows that weight training with regulated blood flow in the limbs at load intensity at 40% of 1RM is insufficient. That points to the need for modification of external load and more vigorous monitoring of internal load during weight training with regulated blood flow in the limbs. Contrary to speed strength, the results point to an increase. This creates scopes for the use of BFR in weight training at a load intensity of 40% of 1RM without emphasis on speed movement during exercising especially in microcycles focused on speed strength development. The findings of the present pilot-study point to the need for further verification of methods how to use regulated blood flow in training related to muscle strength and hypertrophy.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial and financial relationships that could be construed as a potential conflict of interest.

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