ORIGINAL SCIENTIFIC PAPER

Metabolic Response to Low-Intensity Resistance Training with Blood Flow Optimization in the Limbs

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Abstract

The purpose of the study was to evaluate the blood lactate reactive response to low-intensity resistance training with and without blood flow optimization in the limbs. The sample consisted of 9 female and 16 male participants, all second-year students enrolled in the "Special Physical Training in Security Forces" study program at the Faculty of Sports, University of Presov, who had one year of strength training experience but no prior Blood Flow Optimization (BFO) resistance training experience. The study design consisted of two training weeks, during which blood lactate samples were collected from the fingertips before and after each training session and analyzed using the Biosen C-Line device. Resistance training involved bodyweight resistance exercises, structured into a 40-minute session consisting of 20 minutes of upper-body exercises and 20 minutes of lower-body exercises. During the first week, students exercised with KAATSU AirBands to optimize blood flow in their limbs, using the KAATSU C3 controller with a constant pressure of 250 SKU. During the second week, students performed the same training protocol without the KAATSU AirBands. The results show that resistance training caused significant changes in blood lactate concentration ($p < .05$). Among female students, lactate levels increased by 3.43 mmol/L after training without AirBands and by 5.43 mmol/L with AirBands. Among male students, the increase was 5.04 mmol/L without AirBands and 5.06 mmol/L with AirBands. The use of KAATSU AirBands during resistance training had no statistically significant effect on blood lactate concentrations ($p > .05$) in both male and female students.

Keywords: *metabolism, blood flow restriction, physical training, KAATSU, combat sports*

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Introduction

Resistance training with restricted blood flow in the limbs (BFR) has been a current scientific topic in recent years, focusing, in particular, on the functional and physiological responses of the human organism. Although extensive research exists on both BFR training and lactate measurements, there is still limited information on the combined use of these methods. The present study aims to examine how low-intensity Blood

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Flow Optimization (BFO) resistance training and conventional resistance training affect blood lactate levels.

Lactate is a crucial intermediary in numerous metabolic processes, serving as a particularly mobile fuel for aerobic metabolism and playing a vital role in wound repair and regeneration (Gladden, 2004). According to Jenkins (2005), lactate is the final product of anaerobic glucose metabolism and is formed by the reduction of pyruvate through the action of lactate dehydrogenase, and skeletal muscle contains five isoforms of this enzyme. The blood lactate level is determined by the ratio between its formation and its metabolism. At rest, muscles slowly produce and release lactate in the range from 0.7 to 2 mmol/L, which is maintained in the blood in a basic amount. In addition to muscles, cells of the skin, brain, intestinal mucosa, as well as blood elements, especially erythrocytes, participate in the lactate production. The blood transports the resulting lactate to the liver, where it is utilized for gluconeogenesis in the Cori cycle, and a smaller portion of the lactate is also utilized by the kidneys (McMorris & Hale 2006). The heart and brain actively take up lactate. According to Ide and Secher (2000), during intense exercise, the brain seems to take up lactate, and its oxygen uptake also increases.

Fukuta et al. (2024) found that the elevated blood lactate level was maintained after muscle blood flow restriction training, whereas the lactate level significantly decreased after conventional training. Zhu et al. (2025) have concluded that blood flow restriction training can induce significant muscle activation and metabolic stress, and increase blood lactate concentration at low loads and arterial occlusion pressures between 70% and 80%. This may be achieved by employing specialized compression devices applied to proximal limbs to partially occlude blood flow. This training causes venous occlusion and arterial inflow restriction, which induces a partially hypoxic environment that stimulates the secretion of anabolic hormones and enhances muscle activation at lower exercise intensities as well. The results suggest that concentric blood flow restriction training leads to pronounced acute changes in muscle size, a response that may be an essential factor in promoting muscle hypertrophy (Yasuda et al., 2012). Therefore, one-repetition maximum (1RM) has to be taken into account in the process of strength development. According to Wang et al. (2025), upper limb blood flow restriction training can significantly enhance bench press strength. Blood flow restriction training with 40%–70% 1RM and ≥60% AOP is more likely to promote immediate upper limb strength. Blood flow restriction training combined with maximal effort and ≥60% arterial occlusion pressure can increase the blood lactate value and subjective fatigue degree of the subjects.

The purpose of the study was to evaluate the organism's reactive response, especially capillary blood lactate levels measured before and after low-intensity resistance training combined with blood flow regulation in the limbs. We hypothesized that lactate levels following training with regulated limb blood flow would be significantly higher than those following low-intensity resistance training.

Materials and methods

Participants and design

The sample consisted of 9 female and 16 male second-year students enrolled in the "Special Physical Training in Security Forces" study program at the Faculty of Sports, University of Presov. Within the study program, students must demonstrate high levels of general and specific physical fitness as active participants in national combat sports contests. Table 1 shows the basic sample characteristics.

Procedures

The research design was divided into two weeks, during which lactate samples were taken before and 5 minutes after the training unit. The lactate samples were taken under medical supervision from capillary blood from the fingers, while observing hygiene requirements in a standard manner in a sitting position, with an individual adjustment of the depth of the lancet injection. The sample was taken without exerting effort to avoid mixing capillary blood with intercellular fluid. Lactate samples were taken into 20 μl Na-heparinised capillaries, which were subsequently placed in 1 ml containers with hemolysis solution and immediately subjected to analysis on the Biosen C-Line device, which works on the principle of the enzymatic-amperometric method using chip sensor technology. The device was calibrated before each evaluation of blood samples.

Training program

Before the study, students actively participated in a sample training unit and became familiar with the KAATSU training methodology. The resistance training program

Table 1. Sample characteristics

	n	Age	BH (cm)	IQR	BW (kg)	IQR	Muscle (kg)	IQR	Fat (kg)	IQR	Fat %
Females	9	20	161.6	7.0	55.2	5.6	22.4	1.3	14.9	7.4	26.9
Males	16	21	181.7	12.1	74.6	14.1	37.5	5.9	8.1	2.6	12.7

Note. n: number of subjects; BH: body height; BW: body weight; IQR: interquartile range.

Table 2. Resistance training program

	Upper limbs	Lower limbs	Sets and Reps	Rest
KAATSU Air Bands 250 SKU	Pushup	Squat	4 x 15	20 s.
	TRX Pullup	Fitball hamstring curls	4 x 15	20 s.
	Side Plank left and right	Calf raises	4 x 15	20 s.
		Plank	4 x 30 second	
No Bands	Pushups	Squats	4 x 15	20 s.
	TRX Pullups	Fitball hamstring curls	4 x 15	20 s.
	Side Plank left and right	Calf raises	4 x 15	20 s.
		Plank	4 x 30 second	

consisted of upper- and lower-body exercises. Students performed body-weight exercises that combined dynamic and isometric modes of muscle work. The principles of proportionality and sequence were followed to minimize health risks. Students were instructed to perform all exercises using the correct technique and without restrictions. Table 2 shows the individual exercises, including the exact number of sets and repetitions.

A single resistance training session lasted 40 minutes and consisted of 20 minutes of upper-body exercises and 20 minutes of lower-body exercises. During the first week, students exercised with bands to regulate blood flow to the extremities, and a week later, under identical conditions, without bands.

Students enrolled in the study had one year of strength training experience but no prior KAATSU resistance training experience. The main difference between the training programs was the use of KAATSU AirBands and blood flow restriction, during which students experienced a sensation of muscle failure during the final repetitions of a set. When exercising without KAATSU AirBands, exercise intensity was determined by the subjective parameter of repetitions in reserve. Students were able to perform four more repetitions than the prescribed number in the intervention.

KAATSU training equipment with AirBands

The KAATSU C3 device was used, which is the third generation of the KAATSU Cycle product. The device consists of a controller and four pneumatic elastic bands (two 4 cm-wide arm bands and two 5 cm-wide leg bands). Figure 1 shows the placement of the bands, including the KAATSU C3 controller.

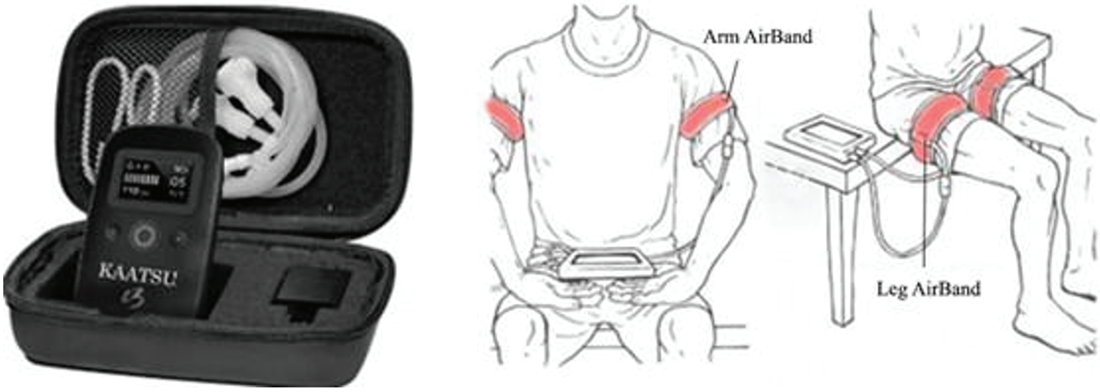

Figure 1. KAATSU C3 set

Each pressure level is expressed in Standard KAATSU Units (SKU), which can be adjusted in increments of 10 SKUs, ranging from 50 to 400. The Standard KAATSU Units, compared with blood pressure measured in millimetres of mercury (mmHg), measure compression against an air bladder inside the AirBand. During exercise, a constant AirBand pressure of 250 mmHg was applied, corresponding to approximately 45% of the blood flow in the brachial artery and 40% of the blood flow in the femoral artery, as verified by the Doppler ultrasonography using a Philips EPIQ system with a Philips L12-3 linear probe (Kokinda et al., 2024). The KAATSU AirBand tightness was adjusted individually for each student to achieve approximately 40–45% of arterial occlusion pressure (AOP).

Statistics

The Shapiro-Wilk test confirmed that the data were not normally distributed, so non-parametric methods were used. The Wilcoxon signed-rank test. was used to determine the differences in lactate concentrations between the pretest and posttest for both males and females. For each student, a difference score (Δ = pretest − posttest) was calculated and subsequently evaluated using the Wilcoxon signed-rank test. The effect size was determined using the coefficient r, which was calculated as the ratio of the Z-score to the square root of the sample size. Interpretation of the effect size was based on the criteria by Cohen (1988), with $r \geq 0.1$ indicating a small effect, $0.3 \leq r < 0.5$ a medium effect, and $r \geq 0.5$ a large effect.

Bioethical Committee

The presented procedures complied with the ethical standards of the AGEL Hospital Košice – Šaca a.s. and the University of Prešov (ECUP052024PO) for human experimentation in accordance with the Declaration of Helsinki. Each participant provided written informed consent voluntarily before participating in the study (Harriss, Jones, & MacSween, 2022).

Results

The absolute lactate concentrations before and after exercise for males and females, respectively, are graphically presented in Figures 2 and 3. The intraindividual assessment of lactate concentration among females shows that the most significant difference in lactate concentration between training with and without bands was recorded in subjects 3 and 4. Subject 3 did not experience any differences in lactate concentration after resistance training without bands. However, the application of bands caused a 5.72 mmol/L increase in lactate concentration after training. These subjects may have experienced increased local hypoxia and used anaerobic metabolism after the application of bands.

Figure 3 shows that seven male subjects experienced higher lactate concentrations after resistance training with bands. The remaining nine subjects had higher lactate concentrations after resistance training without bands. The intraindividual assessment showed that subject 13 experienced a 3.73 mmol/L increase in lactate concentration after resistance training with bands.

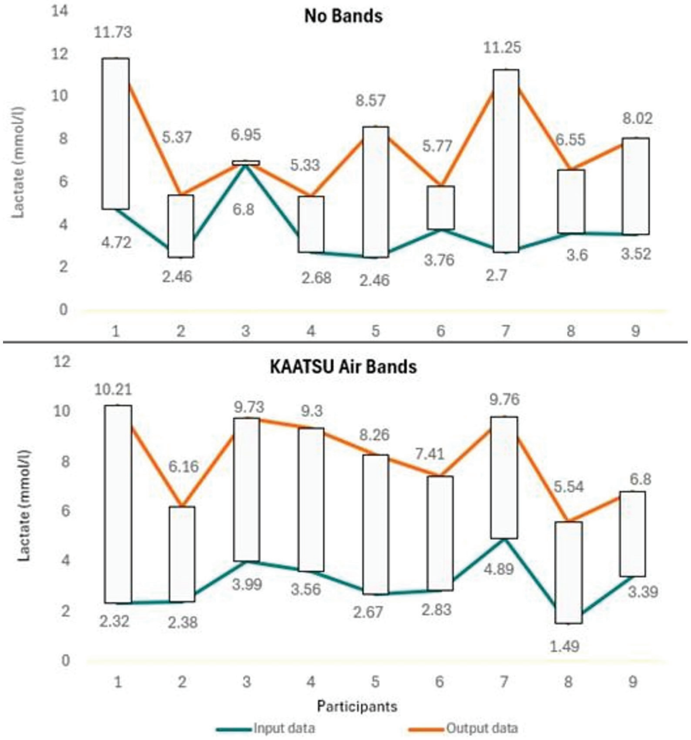

Figure 2. Blood lactate response: females

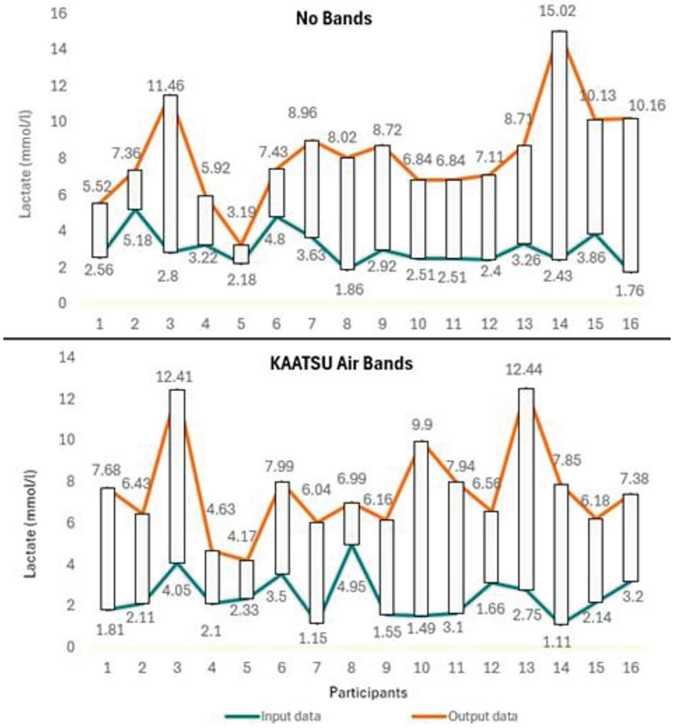

Figure 3. Blood lactate response: males

Comprehensive data evaluation has revealed that females experienced higher lactate concentrations after resistance training with bands. The median difference in lactate concentration was 1.31 mmol/L. The results of the Wilcoxon signed-rank test demonstrated a statistically significant ($p < .01$) increase in lactate concentration after exercise in both training programs, with a large effect size ($r = .89$). In the male group, a median difference in lactate concentration of 0.54 mmol/L was observed, with higher values recorded after training without bands. Similarly, in males, statistically significant ($p < .001$) increases in lactate levels after exercise were observed, with a large effect size ($r = .88$). The training program induced a reactive metabolic response in the organism. However, the difference in lactate concentration between resistance training with and without bands was not statistically significant (Table 3). However, no statistically significant difference was found between the program using bands and the program without bands ($p > .05$).

Table 3. Lactate response to resistance training (mmol/L)

Females						
Wilcoxon signed-rank test	n	Median	IQR	Z	p	r
No Bands	9	Pre: 3.52	1.08	-2.67	.008	.89
		Post: 6.95	2.80			
KAATSU AB	9	Pre: 2.83	1.18	-2.67	.008	.89
		Post: 8.26	2.93			
Δ KAATSU vs. No Bands	9			-1.13	.260	.38
Males						
No Bands	16	Pre: 2.68	1.03	-3.52	.00044	.88
		Post: 7.72	2.70			
KAATSU AB	16	Pre: 2.12	1.54	-3.52	.00044	.88
		Post: 7.18	1.79			
Δ KAATSU vs. No Bands	16			-0.10	.918	.03

Note. n: number of subjects; IQR: interquartile range; AB: AirBands; Pre: pretest; Post: posttest; Z: Wilcoxon signed-rank test statistic; p: p-value; r: effect size; Δ: difference between post- and pre-exercise values

Discussion

The results of the study indicate that low-intensity blood flow optimized (BFO) resistance training does not induce a significantly higher metabolic response than bodyweight resistance training in both women and men. In young and physically fit athletes, the application of BFO alone without additional mechanical loading need not be a sufficient stimulus for increasing metabolic stress.

To maximize the metabolic response and potential for muscle adaptation, the optimization of training parameters with emphasis on the level of occlusive pressure, type, volume, and intensity of exercise appears to be decisive. Studies by Durand et al. (2003) and Kraemer et al. (2006) show that lactate production rates during concentric exercise are higher than during eccentric exercise. Resistance exercise with BFR stimulates muscle protein synthesis. However, the mechanisms underlying these effects are largely unknown (Gundermann et al., 2012). On the other hand, Loenneke et al. (2012) suggest that no measurable changes occur in whole blood lactate, indicating that significant changes in hydrogen ion concentration are unlikely to happen with BFR in the absence of exercise. The only two variables investigated that did change with BFR only were acute increases in real-time ultrasound-measured muscle thickness and a decrease in hematocrit determined plasma volume. These changes were maintained following the removal of the cuff, suggesting that the acute changes in muscle thickness were actual acute increases in muscle size and were not attributed to venous pooling. This acute change in size has also been observed following low-intensity BFR resistance training.

A study by Nancekievill et al. (2025) demonstrated that both males and females significantly increased their lean body mass and muscle strength. At 30% of 1-repetition maximum (1-RM) and blood flow restriction cuffs set to 60% of each individual's limb occlusion pressure, males improved strength to a greater extent than the females. According to Franz et al. (2020), blood flow restriction training is gaining popularity because it enables gains in muscle mass and strength despite using low mechanical loads combined with external venous occlusion. Using invasive measurements based on the principles of the arterial and venous catheters, the authors found that intravascular pressures increased more during low-intensity exercise. The analysis of arterial and venous blood gases revealed metabolic acidosis, accompanied by increased lactate production and elevated K+, Ca2+, and Na+. In their study, Fry et al. (2010) found that leg circumference was increased to a much larger extent in the BFR group. Obviously, leg circumference is not a direct measure of cell swelling. However, it should be noted that cell swelling is an anabolic proliferative signal in which proteins associated with osmosensing are activated.

A study by Pignanelli et al. (2021) summarized knowledge about skeletal muscle and cardiovascular adaptations. In athletes, higher performance levels and oxidative capacity are underlying factors of BFR training adaptations. Monitoring the applied pressure in the bands during every BFR training session is crucial in terms of minimizing the health risks and optimizing training effects. A study by Nitzsche et al. (2018) demonstrated that resistance training on the leg press with blood flow restriction without pressure control yielded significant differences in lactate concentration at low to moderate loads compared to training without BFR. However, the arterial occlusion pressure rate used in the study remains unclear. Bodybuilders often use cuffs to apply pressure to their limbs without targeted pressure regulation. In some cases, subjective feelings can aid in determining the optimal cuff compression and ultimately in achieving the desired effects. Freitas et al. (2000) compared the cuffs with and without pressure regulation. Their study revealed that both males and females exhibited similar metabolic responses, with males showing a higher blood lactate concentration than females. Xu et al. (2025) studied a sample of young male collegiate boxers and found that BFR training performed at 40% of arterial occlusion pressure enhanced upper-limb anaerobic power and fatigue resistance. The pressure rate in the cuffs is a frequently discussed topic, creating a platform for further research.

Strengths and Limitations of the study

The strengths of the study include the representation of both males and females, as well as the implementation of research in the educational environment for future experts in sports, which increases its practical relevance. At the same time, the training program presented provides a safe foundation for applying the BFO method, which appears to be a suitable complement to the sports training of students in security forces and combat sports.

Due to the specifics of bodyweight resistance training, it is not possible to accurately quantify exercise intensity using a percentage of 1RM. This may be considered a limitation of the present study, as it restricts the precise standardization and comparability of training load across participants. As confirmed by Zourdos et al. (2016), in resistance training, examining the number of "repetitions in reserve" is a more appropriate surrogate for assessing perceptual intensity than the traditional rating of perceived exertion. The students were able to perform approximately four more repetitions, corresponding to a low-to-moderate exercise intensity. On the other hand, when using KAATSU AirBands, students experienced a sensation of muscle failure during the final repetitions of the sets and were unable to perform any more repetitions.

An additional limitation of the study may be the timing at which lactate samples were collected. According to Machado et al. (2013), blood lactate reached its peak concentration at the fifth minute after the test across all protocols. However, it would be advisable to perform multiple samplings at different time intervals to capture the dynamics of lactate concentration increase and elimination.

Available literature suggests that pressures lower than approximately 50% of AOP may be insufficient to induce a substantial metabolic or neuromuscular response in trained individuals (Das & Paton, 2022; Zhu et al., 2025). Experimental data further indicate that lactate responses and muscle activation increase markedly only at 70–80% AOP, not at lower pressures (Zhu et al., 2025). This supports our observation that a pressure of approximately 40–45% AOP may not be sufficient to elicit a robust metabolic response in strength trained participants.

Conclusions

Blood flow manipulation, in conjunction with compression bands placed on the upper or lower limbs, may significantly affect the physiological processes associated with muscle fatigue and the organism's metabolic response. It appears that even during low-intensity resistance training, band pressure is the determining factor, as it can regulate arterial blood flow. We may conclude that students with high physical performance levels did not show significant differences in blood lactate concentrations between conventional resistance training and KAATSU training.

The training sessions presented have minimal mechanical and metabolic effects on the organism, creating the prerequisites for more optimal manipulations with the volume and intensity of specific training stimuli. The training controlled in this manner is a suitable complement to combat sports and practical tests during studies. Further strength development with a significantly higher metabolic response requires additional verification of the training methodology, focusing on increasing exercise intensity and the corresponding arterial occlusion pressure exerted by the bands on the human vascular system.

It may be concluded that a band with arterial pressure at a level of up to 50% occlusion is a safe option for low-intensity resistance training in healthy and trained athletes. It is essential to analyze additional indicators, especially heart rate, level of muscle tissue oxygenation, and performance indicators, according to the sports specialization.

Hypothesis testing showed that lactate concentrations following training with regulated limb blood flow were not significantly higher than those following low-intensity training without KAATSU AirBands.

Acknowledgements

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Conflicts of Interest

The authors declare no conflict of interest.

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