



Original Article

Cardiovascular response to bouts of exercise with blood flow restriction

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Abstract. [Purpose] Occlusion training with low-intensity resistance exercises and blood flow restriction increases muscle cross-sectional area and strength. This form of training is used in rehabilitation; therefore, the aim of this study was to examine the effect of one occlusion training session on the cardiovascular response to bouts of exercise. [Subjects and Methods] Two groups took part: a control group without blood flow restriction and an experimental group with blood flow restriction. A single training session was used with the exercise intensity set at 40% of the one repetition maximum. Maximum voluntary contraction, arterial blood pressure, and electrocardiogram measurements were performed. [Results] Heart rate was slightly higher in the control group. The performed training had no effect on diastolic blood pressure in either group, however, a tendency for a small systolic blood pressure increase was observed during the session in the experimental group. JT interval changes did not reveal significant differences between groups. There were no significant changes in ST-segment depression during the exercise or at rest. A lower tendency for JT/RR increases was observed during the repeated exercise tasks with partial blood flow restriction. [Conclusion] Low intensity exercises carried out with a partial blood flow restriction do not result in significant overload of cardiac function.

Key words: Low intensity occlusion training, Foot articulation, Cardiovascular system

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INTRODUCTION

Exercise is one of the most powerful non-pharmacological method of affecting cells and organs in the body¹. Regular aerobic and resistance exercise training has a positive long-term impact on the cardiovascular system, which is a biologically complex adaptive system that is characterized by a variety of complex reactions to different training loads²⁻⁴.

While performing exercise, it is important that the body is supplied with oxygen and energy substances. This transporting function is performed by the cardiovascular system⁵. The power to transport these substances to cells is provided by the heart pushing the blood containing them. It has been known for long that blood flow intensification or even more accurate blood flow redistribution during exercise can increase blood supply to working muscles and consequently increase working capacity⁶. Nowadays, athletes and coaches are looking for the most efficient training method so as to achieve maximum results and to maintain these results for the longest possible period of time in order to minimize the probability of injury. Recently, an unconventional training method has been developed that uses blood flow restriction in the musculoskeletal system, otherwise known as the “Kaatsu” methodology. An example of this is a walking workout using blood flow restriction, which has been proven to be a useful method of improving muscle function, including muscle hypertrophy, strength, and endurance.

Everyone aims to train less and show better results. One of the potential ways to achieve this could be training with blood

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flow restriction^{7, 8}). Training with less weight reduces stress on joints and therefore minimizes the possibility of getting injured. Recently, blood flow restriction combined with low-intensity resistance exercise has been suggested as a useful exercise protocol to gain muscular strength and mass without an increase in blood pressure⁹. Exercises with blood restriction are also beneficial for enhancing muscle mass and strength. Some authors have suggested using as little as 20% of the maximum repetition weight during the training with blood restriction.

As it is almost impossible to evaluate large arterial function directly, various noninvasive methodologies have been used to evaluate arterial function in humans. Recording of an electrocardiogram (ECG) is one of the most practical noninvasive methods. In application of the ECG in sports physiology, ST-segment depression is the key index that refers to the degree of the occurrence of myocardial ischemia. This is of special significance in adolescent or young athletes, as it can be used to recognize unphysiological states during workouts.

Together hereditary and congenital abnormalities of the heart are the most common causes of nontraumatic death in sport in young athletes. In middle-aged recreational athletes, more than 90% of sudden cardiac deaths occur in males, and more than 90% are caused by atherosclerotic coronary artery disease¹⁰. Such findings encourage a greater interest in noninvasive ECG methods of research and in questioning the meaning of ST-segment depression at different workout and rest stages.

JT and/or QT intervals are important when it comes to prolonged ventricular repolarization. Basically, corrected QT or JT interval ($\uparrow Q_{Tc}$, $\uparrow J_{Tc}$) indices increases sudden death and other risks¹¹. However, some ECG parameters observed in a minority of athletes present diagnostic conundrums. The JT interval (*measured from the J-point up to the end of the T-wave*) describes the duration of ventricular repolarization, and shortening of the JT interval during physical load correlates with the increase in metabolic rate in the myocardium¹².

Our hypothesis states that the training gain achieved by training with the circulatory restriction applied during low-intensity exercising lies within the physiological limits of the cardiovascular system. The aim of this study was to the effect of a single occlusion training session on the cardiovascular response to bouts of exercise.

SUBJECTS AND METHODS

All subjects provided written informed consent before participation in the study. The subjects in the study were amateur athletes in track and field with 4–6 years of training experience, and they participated in two groups: a control group without blood flow restriction and experimental group with blood flow restriction ($n=24$, mean age 22.5 ± 1.5 years; body mass index 24.7 ± 0.5 kg/m²). The weight and body mass index (BMI) (TBF-300 body composition scale; Tanita, UK Ltd., West Drayton, UK) of the subjects were estimated while they were seminude (shorts and T-shirts). None of the subjects exercised for at least 12 hours and before the test or ate for at least 2 hours before the test. The physical load test was carried out during the competitive period of the sports season.

The study was designed to determine the effects of a single occlusion training session on the cardiovascular system. The participants underwent circulatory restriction with a 40-mm-wide cuff applied the groin¹³. The participants were seated on a calf muscles trainer, and the cuff air pressure was set at 120 mmHg (the approximate resting systolic blood pressure for each participant¹⁴). In this study, the calf muscles (*m. gastrocnemius* and *m. soleus*) and the sole flexion muscle (*m. flexor digitorum brevis*) were impacted by the occlusion. As part of a coherent muscular system, these muscles experience their maximum loads during locomotion.

Foot flexor muscle strength was measured using a dynamometer. The participants sat holding the dynamometry device with both hands. The knee of the working leg was fixed at an angle of 90°, and the ankle was fixed at an angle of 70°. The dynamometer was adjusted according to the foot size of the participant. Maximum voluntary contraction (MVC), measured in newton's (N), was performed three times, and the highest value was recorded. MVC was measured only before training in order to choose the individuals training workload.

Arterial blood pressure (ABP), an important cardiovascular functional parameter, was measured using the cuff method and by listening to the “Korotkoff tones.” ABP was measured before and after each set.

A computerized analysis system “Kaunas-load” was employed for continuous 12-lead ECG registration and analysis. Changes in RR interval or heart rate (HR), JT interval, ST-segment depression (*sum of negative values for 12 leads*), and in ratio of the JT/RR intervals were analysed.

As shown in other studies, low-intensity resistance exercise training with occlusion (20–50% MVC) increases both muscle cross-sectional area and strength¹⁵. Therefore, we used a single session of training with an exercise intensity of 40% MVC. Foot flexor muscle conditioning training was conducted as follows: three exercises comprising of the three sets of eight repetitions per set for each leg. A 2.5-min rest period was provided between exercises, and a 30-sec rest period was provided between sets. The participants were asked to lift the weight in time with a metronome (30 movement cycles per minute)¹⁶. Occlusion was applied before the exercise and was removed after each set of three exercises (3 sets, 3 exercises per set, and 8 repetitions per exercise).

The arithmetic mean (\bar{x}), standard deviation (s), and the arithmetic mean of the error (s_x) were calculated. A two-way independent samples Student's t-test was used to determine how reliable the mean difference was for performance indicator results. A significant difference between compared values was indicated when the error did not exceed 5% ($p<0.05$).

This study was approved by the Regional Biomedical Research Ethics Committee (Lithuanian University of Health Sci-

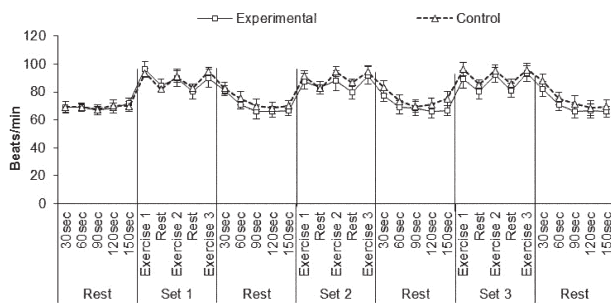


Fig. 1. Changes in heart rate during exercise and at rest

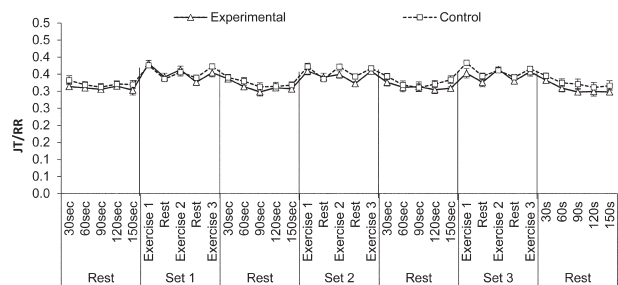


Fig. 2. Dynamics of JT/RR during exercise and at rest

Table 1. Average increase in systolic and diastolic ABP during exercise sets

	Systolic (mmHg)			Diastolic (mmHg)		
	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
Experimental	10.3 ± 3.5	10.6 ± 2.9	11.6 ± 3.2	4.6 ± 3.5	3.0 ± 3.8	3.7 ± 3.3
Control	7.6 ± 4.1	9.0 ± 3.4	12.6 ± 4.0	2.0 ± 3.1	1.9 ± 3.4	1.8 ± 2.7

ences, Kaunas, Lithuania) (No: BE-2-10, 26-03-2015).

RESULTS

The results of the research showed that before the exercise, the average HR was 69.1 ± 4.0 beats/min. HR average in the control group was 69.2 ± 3.7 beats/min. HR showed a significant increase during exercise, increasing to 96.3 ± 4.9 beats/min in the experimental group and to 94.1 ± 3.8 beats/min in the control group. During recovery from the first set, HR was 84.8 ± 5.4 beats/min in the subjects with the circulatory restriction, while the value for the other group was 82.0 ± 3.1 beats/min. As displayed in Fig. 1, the changes in the HR during the first set were the same in both groups; however, continuation of the exercise tasks revealed that the values after each set in the control were higher than those in the experimental group.

Before the study, there was no significant statistical difference between the groups when comparing both systolic and diastolic ABP ($p < 0.05$). In addition, we did not find any difference between groups in terms of changes in diastolic ABP during exercise, and we observed a low tendency for systolic ABP to increase in response to repeated sets of exercise (Table 1).

At the onset of exercising, JT interval changes did not reveal significant differences between groups. The applied occlusion had no influence on ST-segment depression during exercise or at rest. JT/RR values registered before exercise during the rest and while at first set of exercises were not significantly different; however, a tendency for a lower increase in JT/RR during the repeated exercise sets performed with partial circulatory restriction was observed (Fig. 2).

DISCUSSION

The cardiovascular system, is a vital body system and the model of human body response to exercising¹²⁾ outlines it as the most important part of the supplying systems. Results obtained during this study revealed that the increase in HR during the exercise was more notable in the control group compared with the experimental group. It was also determined that the application of the partial circulation restriction caused lower JT/RR ratio values in the ECG. In assessing these findings it is important to discuss the physiological meaning of these indicators. As it was shown by other authors¹⁷⁾, the JT/RR ratio allows depiction of the mobilization of the cardiovascular system during exercising. If we were to multiply the abovementioned ratio by 60, it would allow us to depict the situation over time, that is, how many seconds per minute the heart (myocardium) was contracted and consequently how long the cardiac musculature was at rest. The data from this study indicate that cardiac muscle strain was slightly lower when the low-intensity exercise was carried out with a partial circulatory restriction.

The present study found that systolic and diastolic ABP were higher throughout the entire study. Higher changes in ABP were observed in the experimental group¹⁸⁾. This corresponds to the findings of other research showing that application of occlusion increases vascular wall elasticity¹⁹⁾. It is important to note that vascular wall elasticity is one of the main factors that affect diastolic arterial blood pressure. The fact that certain blood vessels were clamped during the research could have also influenced the increase of diastolic ABP. Performing the exercised with partial circulatory restriction is not just healthier for joints (as smaller weights are used); a previous study also showed that no manifestations of thrombosis were observed when using occlusion²⁰⁾.

Partial blood flow restriction had no significant effect on coronary vessel function. This was evident from the ECG

ST-segment depression rate of change. The heart reserve possibility of largely depends on whether the demand for oxygen is satisfied and on as how quickly and sufficiently oxygen is delivered to the heart during the exercise. When the myocardium is insufficiently supplied with blood there is a lack of oxygen in the myocytes. When coronary heart blood vessels are insufficiently supplied with blood, during the exercise, changes occur in the balance of metabolic processes and subsequently in electric potentials of myocytes. As a result of these processes, ST-segment depression is visible in ECG records. Thus assessment of the degree of ischemic episodes during exercise is also essential and indicates the functional state of the heart.

Partial blood flow restriction had an ambiguous effect on blood pressure changes during the exercise. Systolic ABP values continued to be higher during the exercise, while changes in diastolic ABP were not registered. Repeating the exercise increased fatigue, and the body was forced to mobilize more and more resources to perform a given exercise task. Therefore, in the analysis of the research results, we assessed manifestations of variations in functional indices of the cardiovascular system, i.e., changes of mobilization and recovery. We concluded that when a partial blood flow restriction was applied during repeated exercise, the heart mobilization and recovery features were better reflected in the JT/RR ratio than in HR.

In assessment of manifestations of HR fluctuations, it was found that the amplitude of HR change in response to exercise repetitions remained the same, while the increase in mechanical work duration of the myocardium, as indicated by the JT/RR ratio, was lower, which can be interpreted as indicating that the heart could perform its pumping function with more ease. This was confirmed by the changes in JT in the ECG data, which demonstrated changes in exactly the same direction. The physiological sense of JT can be defined as follows: The JT interval in a recorded ECG is measured from the connection point J to the end of the T wave (point J corresponds to the moment when the ECG curve after the S wave returns to isolines). The JT interval indicates ventricular repolarization processes and can be used as an indicator of the repolarization duration. Also JT interval variation is related to changes in the intensity of myocardial metabolism^{21, 22}.

Despite all the provided positive conclusions on the subject, we cannot affirm that exercise should be performed only by applying the occlusion training method. Firstly, it requires special equipment, the ability to use the special equipment, and knowledge of the application procedures. Secondly, there are authors who claim that training with occlusion does not provide reliable results²³. On the other hand, in a study made by Maior in 2015, an interesting conclusion was drawn that is application of occlusion training is more effective when movement is carried out through one joint^{24, 25}. Thus, no unanimous conclusion can be made at present, but perhaps scientists will carry out more research in the future to determine the body's response to applying blood flow restriction with different pressure levels.

In summary we conclude that applying partial blood flow restriction with occlusion training in the groin area resulted in a lower degree of HR increase in response to repeated exercise compared with training without occlusion. However, this partial blood flow restriction does not increase the myocardium load and has no significant effect on coronary vascular function. Partial blood flow restriction affects the change in blood pressure during exercise in an ambiguous way. Systolic ABP values continue to be higher during the change in blood pressure, while diastolic ABP changes are not expressed. In conclusion, this study confirmed the hypothesis that there is no additional strain on cardiac functioning during occlusion training carried out by exercising with partial blood flow restriction in the groin area.

The results obtained during the study suggest that such kind of occlusion training could be applied for health training and rehabilitation purposes. Occlusion training by using a low intensity of exercise triggers changes in muscular tissue similar to high-intensity exercise training. Meanwhile, the cardiovascular system during exercise does not experience higher overload, which could be a risk factor for cardiac patients and physically inactive persons. This type of exercising could be considered safe.

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