THE INFLUENCE OF SHORT-TERM OCCLUSION ON DYNAMICS OF ARTERIAL CIRCULATION IN CALF MUSCLES

Birutė Zacharienė, Jonas Poderys, Albinas Grūnovas, Algirdas Bolevičius
Lithuanian Academy of Physical Education, Kaunas, Lithuania

ABSTRACT

Research background and hypothesis. KAATSU training is a method based on workout in a local hypoxic environment. For the justification of its a detailed vascular response to circulatory disturbances is required.

Research aim. The aim of this study was to investigate the peculiarities of reactive hyperaemia depending on the duration of occlusion and preliminary filling with blood of the occluded limb.

Research methods. Arterial blood-flow intensity was measured by vein-occlusion plethysmography after 1, 2, and 3 minutes of occlusions. When the occlusion cuff was quickly inflated with air above 250 mmHg, the amount of blood in vessels was close to the conditions of physiological norm. While the leg was lifted above the heart level for 30 seconds, the amount of blood in the calf decreased. A slow blowing the air into the cuff created a situation when the amount of blood in vessels had increased before the blood-flow was arrested.

Research results. The peak blood-flow in the reactive hyperaemia phase depends on the duration of the occlusion and on the degree of filling with blood of segment under occlusion. The peak blood-flow readings were registered after occlusions conducted when the amount of blood in the limb had decreased before the occlusion and the lowest blood-flow readings was registered after occlusion done with the increased filling of vessels.

Discussion and conclusions. The initial filling of vessels with blood or the degree of tension of endothelial cells of vascular wall is the most significant influence on blood flow activation after short-term occlusions.

Keywords: blood flow arrest, reactive hyperaemia, occlusion plethysmography.

INTRODUCTION

Exercise physiology provides a lot of evidence that muscle working capacity during physical activity is determined by its blood supply (Depairon, Zicot, 1996; Fitzpatrick et al., 1996; Hughson et al., 1996; Smith, Norris, 2002). Changes in muscle blood flow directly influence the intensity of oxidative metabolic processes in the muscle, and at the same time, they indicate their working capacity (Depairon, Zicot, 1996; Hughson et al., 1996; Poderys, 2000). Thus, it is important to take into account factors influencing blood circulation trying to increase muscle working capacity. For this purpose, a number of methods aimed at increasing muscle working capacity have been suggested, among them using special regimes of muscle electrostimulation (Kibisha et al., 1992) for the improvement of muscle blood flow, various types of pressure chambers creating a negative pressure in them, which facilitates an increased blood flow into the limbs (Poderys, Trinkunas, 1999; Poderys, 2000). Besides, various combinations of methods for the improvement of muscle working capacity have been proposed showing how these combinations improve muscle capacity more substantially than any other stimulation method taken separately. For example, one of the variants of such combination of stimulation methods is a combination of so called "needle application" and negative pressure (Poderys, 2000).

The KAATSU training is a unique method of muscle training with restricting blood flow which might be applied for various purposes such as to increase of muscle mass, muscular strength or to prevent muscle atrophy (Sundberg et al., 1994; Sato et al., 2004; Credeur et al., 2009). Research on resistance training performed under ischemic conditions on physiological responses could provide important new insights into physiology of strength training. (Tanimoto et al., 2008; Kim et al., 2009). The aim of this study was to find out the peculiarities of reactive hyperaemia depending on the time of the occlusion as well as its character and preliminary filling with blood of the occluded limb blood vessels.

RESEARCH METHODS

Fourteen middle distance runners participated in the investigation. We had three stages of our research trying to achieve our objectives. *The first stage* was the investigation of changes in blood flow intensity after 1, 2, and 3 minutes of occlusion under the conditions of physiological norm, i. e. when the occlusion cuff was quickly inflated with air up to 250–260 mmHg of pressure in it. In this way, we considered that the amount of blood in the calf blood vessels during the occlusion was close to the conditions of physiological norm; *the second stage* took place after lifting the leg above the heart level and sustaining it in that position for 30 seconds. The amount of blood in the calf decreased by this manoeuvre and after a quick occlusion the leg was let down. The readings of arterial blood circulation after the end of the occlusion was registered in the sitting position; *the third stage* – involved slow blowing the air into the occlusion cuff (5 mmHG / s or slower) and filling of the calf blood vessels with blood before the blood flow is arrested. There is a larger amount of blood in the calf blood vessels than under the conditions of physiological norm.

Arterial blood flow intensity (ml / min / 100 cm^3) in the calf was measured by vein-occlusion plethysmography while subject was sitting comfortably. The electroplethysmograph EMPR-01 and Witney type sensors were used.

RESEARCH RESULTS

The research results presented in Tables 1, 2 and Figure indicate that the increase of arterial blood flow in the reactive hyperaemia phase depends on the character and duration of the occlusion and on the degree of filling the calf vessels with blood before the arrest of the blood flow.

The highest readings, i. e. the peak blood flow, were registered after the occlusion conducted when the amount of blood in the limb was decreased before the occlusion and the lowest blood circulation readings were registered after the occlusion, when there was an increased flow of blood into blood vessels. The duration of the occlusion had direct influence on the maximal blood flow figures which were registered immediately after the occlusion. In all cases the highest degree of blood flow intensity was observed after the 3 minutes of occlusions.

Table 1. **The values of peak blood flow (ml / min / 100 cm^3) in the reactive hyperaemia phase depending on the duration of occlusion and on the degree of filling with blood of the segment**

Stages of the experiment		Duration of occlusion		
		1 min	2 min	3 min
I	Physiological norm	13.94 ± 0.40	17.04 ± 1.21	19.74 ± 0.59
II	Preliminary decreased amount of blood	20.79 ± 1.51	23.18 ± 0.69	25.84 ± 0.48
III	Increased amount of blood before occlusion	11.71 ± 0.57	17.05 ± 0.29	18.04 ± 0.38

Table 2. **The dynamics of the of arterial blood flow (ml / min / 100 cm^3) in the reactive hyperaemia phase after 1-minute occlusions**

Stages of the experiment		Time of measurement				
		Before occlusion	After 1–5 s	After 15 s	After 30 s	After 45 s
I	Physiological norm	1,63 ± 0.16	13.94 ± 0.40	3.43 ± 0.13	1.88 ± 0.14	1.62 ± 0.11
II	Preliminary decreased amount of blood	1.66 ± 0.10	20.79 ± 1.51	5.71 ± 0.37	2.61 ± 0.17	1.90 ± 0.12
III	Increased amount of blood before occlusion	1.64 ± 0.10	11.71 ± 0.57	2.78 ± 0.16	1.65 ± 0.10	1.63 ± 0.11

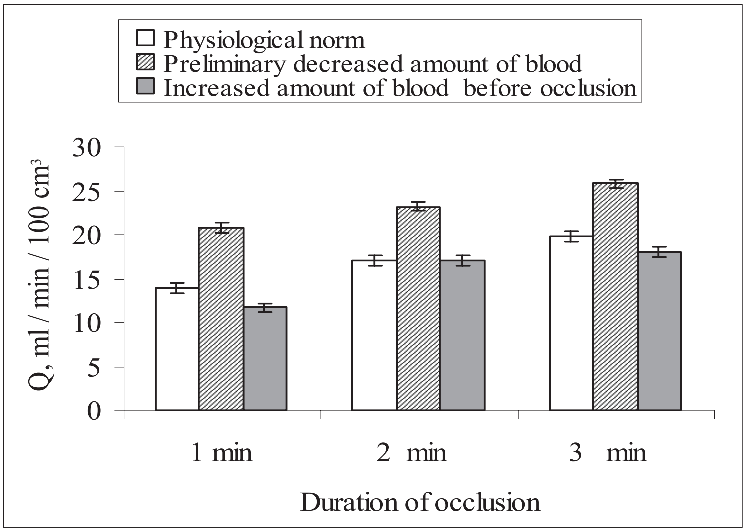

Figure. **The values of peak blood flow (ml / min / 100 cm^3) in the reactive hyperaemia phase depending on the duration of occlusion and on the degree of filling with blood of the segment**

We tried to find the shortest possible duration of occlusion and conditions under which the highest possible arterial blood flow could be obtained. When the subject was sitting after conducting the occlusion, and there was a preliminary decreased amount of blood in the limb, relatively high level of peak blood flow was registered even after the performance of 1-minute of occlusion. This justified itself in all the subjects without exception. These peak blood flow figures were statistically higher ($p < 0.05$) than the figures obtained after 1-minute occlusions: 1 – in normal conditions, and 2 – when the amount of blood had increased before the occlusion. The intensity of blood flow was decreasing in the exponent-like manner and it fully returned to the preliminary level after 45 or 60 seconds after the end of 1-minute occlusion. The dynamics of the arterial blood flow after 1-minute arrest, are presented in Table 2. For example, after the occlusion conducted when the blood vessel filling with blood decreased, the amount of flowing blood was higher than the preliminary amount in the measurement made after 45 seconds, but in the measurement taken after 60 seconds, the amount of blood returned to its preliminary level.

DISCUSSION

Regulatory mechanisms of the systemic blood circulation are oriented to sustaining a gradient of pressure, necessary to insure needed blood circulation intensity in organs / working muscles. This happens in the combination of heart work indexes and the changes of total peripheral resistance (Schmidt, Thews, 1989; Ahlborg et al., 1996; Lash, 1996; Tschakovsky et al., 1996). The regulation of local blood circulation is done mostly by changing hydrodynamic resistance of blood vessels, i. e. by changing their diameter (Saltin, 1988; Tschakovsky et al., 1996). As hydrodynamic resistance is oppositely proportional to the blood vessel diameter in the fourth degree, the changes in their diameter are of much greater importance to the intensity of blood circulation in the organs than the changes in the arterial pressure (Schmidt, Thews, 1989).

The research results obtained indicate that increase of the arterial blood circulation in the reactive hyperaemia phase depends on the character and the duration of occlusion and on the degree of filling with blood of the primary segment under occlusion. Peak blood circulation readings were registered after the occlusion conducted when the amount of blood in the limb had decreased before the occlusion and the lowest blood circulation readings were registered after the occlusion when filling with blood of blood vessels had increased. This shows the importance of myogenic regulatory mechanisms (Sundberg, 1994). The duration of the occlusion did not have direct influence on the maximal blood flow amounts registered right after the end of the occlusion.

One of the goals of this study was to find the shortest possible duration of occlusion and conditions under which the highest possible arterial blood circulation activity could be obtained. In our research we found that when the subject was sitting after conducting the occlusion with a decreased amount of blood in the limb, relatively high indexes of peak blood circulation were registered even after one-minute occlusion. It was true for all the subjects without exception. This means, that having a goal to maximally activate limb muscle blood circulation using occlusion of minimal duration, the optimal decision would be to conduct a one-minute occlusion to a sitting person, after decreasing blood vessel filling at first.

Functional vasodilatation cannot be attributed to the changes in the local concentration of any single metabolic factor (Lash, 1996; Jones, Pole, 2007). Mechanical factors, such as vascular compression and increases in perfusion pressure, also affect vascular resistance and skeletal muscle blood flow. Yet the specific manner in which these mechanical factors interact is not well understood (Jones, Pole, 2007).

Recent determination that arterial vessels upstream from the active tissue and microcirculation, also dilate during reactive hyperaemia and during voluntary muscle contractions has led to the consideration that the vessels are primarily responsible for the regulation of bulk flow to the tissue (Lin, Duling, 1994; Tschakovsky et al., 1996). Consideration of the interrelations of the factors affecting vasomotor tone may lead to a better understanding of the regulation of muscle blood flow and the mechanisms which may explain the exiting growth and strength adaptations that occur with blood-occlusion training. The explanation lies within the finding that low-oxygen environments increase lactic acids production while the occlusion traps it inside the muscle tissue (Wernbom et al., 2008). Moreover, research suggests that the accumulation of lactic acid in the fast fibres is sensed by local chemical receptors and carried back to the hypothalamus, which ups the rate of growing hormone secretion (Tatsumi et al., 2006). In literature there some others hypothesis concerning the possible triggers of adaptation but all these possible explanations related with the intracellular signalling from blood vessels (Wernbom et al., 2008).

CONCLUSIONS AND PERSPECTIVES

Increase of the arterial blood flow in reactive hyperaemia phase depends on the character and the duration of occlusion and on the degree of filling with blood of the primary segment under occlusion, i. e. on the relaxation or tension of the endothelium of blood-vessels.

The highest readings in the peak blood flow were registered after the occlusion conducted when the amount of blood in the limb had decreased before the occlusion and the lowest blood circulation readings were registered after the occlusion when filling with blood of blood vessels had increased.

It is important to reveal the peculiarities of vascular reactions related to the restriction of blood flow and blood flow arrest on what the resistance training under hypoxic conditions is based. Finding an optimal influence is an important practical and scientific problem.

REFERENCES

Ahlborg, G., Ottosson-Seeberger, A., Hemsen, A., Lundberg, J. M. (1996). Central and regional hemodynamic effects during infusion of Big endothelin-1 in healthy humans. *Journal of Applied Physiology,* 80, 1921–1927.

Credeur, D. P., Hollis, B. C., Welsch, M. A. (2009). Effects of handgrip training with venous restriction on brachial artery vasodilation. *Medicine & Science in Sports & Exercise*, 4, 67–75.

Depairon, M., Zicot, M. (1996). The quantitation of blood flow/metabolism coupling at rest and after exercise in peripheral arterial insufficiency, using PET and 15–0 labelled tracers. *Angiology*, 47, 991–999.

Fitzpatrick, R., Taylor, J. L., McCloskey, D. I. (1996). Effects of arterial perfusion pressure on force production in working human hand muscles. *The Journal of Physiology*, 495, 885–891.

Hughson, R. L., Shoemaker, J. K., Tschakovsky, M. E., Kowalchuk, J. M. (1996). Dependence of muscle VO_2 on blood flow dynamics at onset of forearm exercise. *Journal of Applied Physiology,* 81, 1619–1626.

Jones A. M., Poole, D. C. (2007). *Oxygen Uptake Kinetics in Sport, Exercise and Medicine.* London and New York: Routlege.

Kibisha, R. P., Savel'ev, A. K., Iurov, A. I. (1992). The effect of electrostimulation on the blood flow and muscle activity of the flexors in the cat foot. *Fiziolcheskij Zhurnal SSSR Imeni I. M. Sechenova,* 78, 37–45.

Kim, S. J., Sherk, V. D., Bemben, M. G., Bemben, D. A. (2009). Effects of short-term, low-intensity resistance training with vascular restriction on arterial compliance in untrained young men. *International Journal of KAATSU Training Research,* 5, 1–8.

Lash, J. M. (1996). Regulation of skeletal muscle blood flow during contractions. *Proceedings of the Society for Experimental Biology and Medicine,* 211, 218–235.

Lin, Y., Duling, B. R. (1994). Vulnerability of conducted vasomotor response to ischemia. *American Journal of Physiology,* 267, H 2363–2370.

Poderys, J. (2000). *Širdies ir kraujagyslių sistemos greitos ir lėtos adaptacijos savybės, atliekant fizinius pratimus: habilitacinis darbas*. Kaunas.

Poderys, J., Trinkunas, E. (1999). *Venous Occlusion Plethysmography for the Assessment of the Microcirculation Under Influence of Calf's Stretch Exercise: Biomedical Engineering Proceedings of International Conference* (pp. 125–129). Kaunas: Technologija.

Saltin, B. (1988). Capacity of blood flow delivery to exercising skeletal muscle in humans. *American Journal of Cardiology*, 62, 30–35.

Sato, Y. (2004). History and recent progress of KAATSU resistance training. *Clinical Journal of Sport Medicine*, 21, 209–213.

Schmidt, R. F., Thews, G. (1989). *Human Physiology.* Second Completely Revised Edition. Berlin.

Smith, D. J., Norris S. R. (2002). *Training Load and Monitoring an Athletes Tolerance for Endurance Training: Enhancing Recovery*. Human Kinetics. P. 81–102.

Sundberg, C. J. (1994). Exercise and training during graded leg ischemia in healthy man with special reference to effects on skeletal muscle. *Acta Physiologica Scandinavica (Supplement),* 615, 1–50.

Tanimoto, M., Madarame, H., Ishii, N. (2008). Muscle oxygenation and plasma growth hormone concentration during and after resistance exercise: Comparison between "KAATSU" and other types of regimen. *International Journal of KAATSU Training Research,* 1, 51–56.

Tatsumi, R., Liu, X., Pulido, A. et al. (2006). Satellite cell activation in stretched skeletal muscle and the role of nitric oxide and hepatocyte growth factor. *American Journal of Physiology-Cell Physiology,* 290, C 1487–1494.

Tschakovsky, M. E., Shoemaker, J. K., Hughson, R. L. (1996). Vasodilation and muscle pump contribution to immediate exercise hypereamia. *American Journal of Physiology,* 271, H 1697–1701.

Wernbom, M., Augustsson, J., Raastad, T. (2008). Ischemic strength training: A low-load alternative to heavy resistance exercise? *Scandinavian Journal of Medicine & Science in Sports,* 18, 401–416.

TRUMPALAIKĖS OKLIUZIJOS ĮTAKA BLAUZDOS RAUMENŲ ARTERINEI KRAUJOTAKAI

Birutė Zacharienė, Jonas Poderys, Albinas Grūnovas, Algirdas Bolevičius
Liietuvos kūno kultūros akademija, Kaunas, Lietuva

SANTRAUKA

Tyrimo pagrindimas ir hipotezė. Netradicinių treniravimo metodų ieškoma nuolatos. Vienas iš tokių yra KAATSU metodas, vadinamas okliuzine treniruote. Jo pagrindimui būtinas išsamus kraujagyslių reakcijos į kraujotakos sutrikdymus pažinimas.

Tikslas: ištirti blauzdos reaktyvinės hiperemijos ypatumų priklausomumą nuo okliuzinio kraujotakos sutrikdymo trukmės, okliuzijos atlikimo greičio ir kraujagyslių prisipildymo krauju kiekio okliudavimo momentu.

Metodika. Arterinės kraujotakos intensyvumas blauzdoje tiriamajam sėdint buvo matuojamas veninės okliuzinės pletizmografijos metodu. Arterinės kraujotakos kaita tirta esant fiziologinės normos būsenai, t. y. okliuduojama greitu, didesniu nei 250 mmHg, oro pripūtimu į varžtį. Kai tiriamasis 30 s palaikydavo pakeltą koją aukščiau nei širdies lygis ir po greito okliudavimo nuleisdavo žemyn, galūnėje prieš okliudavimą būdavo santykiškai pamažinamas kraujagyslių prisipildymas krauju. Taip pat blauzdos kraujotakos kaita tirta orą į varžtį pučiant lėtai – šitaip kraujotaka sustabdoma blauzdos kraujagyslėse ir santykiškai padidinamas kraujo kiekis.

Rezultatai. Ilgesnės trukmės okliudavimas sukeldavo didesnį kraujotakos suintensyvėjimą nei trumpesni kraujotakos sutrikdymai. Arterinės kraujotakos padidėjimas priklausė ir nuo pradinio kraujagyslių prisipildymo krauju laipsnio. Didžiausios kraujotakos reikšmės užregistruotos tada, kai buvo okliuduojama sumažinus kraujagyslių prisipildymą krauju, mažiausios – kai prieš okliudavimą santykiškai padidinamas kraujo kiekis blauzdos kraujagyslėse. Taigi okliuzijos pobūdis, taip pat ir okliuzijos trukmė yra veiksniai, lemiantys kraujotakos kaitos ypatumus reaktyvinės hiperemijos fazėje.

Aptarimas ir išvados. Reikšmingiausią įtaką kraujotakos suaktyvėjimui reaktyvinės hiperemijos fazėje turi pradinis kraujagyslių sienelės ištempimo laipsnis, tiesiogiai priklausantis nuo kraujagyslėse esančio kraujo kiekio, t. y. kraujagyslės sienelės endotelio ištempimo ar atsipalaidavimo laipsnio.

Raktažodžiai: kraujotakos sutrikdymas, reaktyvinė hiperemija, okliuzinė pletizmografija.

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Corresponding author **Birutė Zacharienė**
Lithuanian Academy of Physical Education
Aušros str. 42–31, LT-44221 Kaunas
Lithuania
Tel + 370 37 302650
E-mail biruseb@gmail.com