

Blood micro-circulation state as a marker of the human body reserve capabilities to perform physical activity

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Abstract:

Reserve body capabilities and human health state assessment at the early stages of genesis is an urgent problem not only in clinical practice, but also in the field of physical education and sports. *Purpose:* application of the technique of laser Doppler flowmetry in physical education classes for the study of blood micro-circulation in students with health abnormalities. *Materials and methods.* The experiment involved 117 students (boys n=53, girls n=64, aged 18.4 ±0.3 years), who had a special medical group for physical education according to the results of periodic medical examination. To assess the functional state of the micro-circulation system, a laser blood micro-circulation device «LAZMA-PF» was used. Testing was carried out in the middle of the school day, during the inter-session period, in a state of physiological rest. Registration of laser Doppler flowmetry (LDF) was performed from the skin of the index finger of the left hand, in a sitting position. The assessment of blood oxygen saturation (saturation, SPO2) was performed using a pulse oximeter. *Results.* When studying micro-circulation in students of different sexes, there is a relative weakening of arterial vascular tone and an increase in blood volume in arterioles in males, as well as a deeper modulation of blood flow in this category of students. At the same time, the coefficient of variation value shows an improvement in the state of micro-circulation in girls. This is realized in the mechanisms of ensuring vascular tone, where in girls there is an increase in the neurogenic and endothelial components of regulation, and in boys there is an increase in passive links in ensuring micro-circulation. In girls, there is an increase in blood oxygen saturation, as well as a higher rate of heart rate and systolic blood pressure. The studied parameters indicate an increase in tension in the cardiovascular system regulation in male students. *Conclusions.* The data obtained during the study of students' body micro-circulation can be used for dynamic monitoring of students' with disabilities health status, and, if necessary, to correct motor activity and the mode of educational and daily activities. Undoubtedly, conducting these research works is also useful when conducting stress tests, as well as when studying the dynamics of changes in the functional status of micro-circulation in different periods of the academic year.

Key Words: physical education (PE), physical activity, micro-circulation, Laser Doppler flowmetry (LDF)

Introduction

The functional state of blood micro-circulation study is relevant in assessing the adaptive properties of the human body to the factors causing shifts in systemic homeostasis (Kozlov, 2017). In the system of micro-vessels, the main functional unit is the process of micro-circulation, in which the supply of nutrients and oxygen to cells and the excretion of metabolic products occurs. Morphologically, the micro-circulation system of blood supply is represented by arterioles, circulatory and lymphatic capillaries, venules and interstitial space (Barkhatov, 2014). In addition, there are arteriovenous anastomoses that are involved in ensuring peripheral hemodynamics: they create ways for the blood flow to bypass the capillary bed. This physiological feature has an important adaptive value when performing physical activity. (Bergstrand, 2009).

The active participation of students in the educational and training processes of physical education actualizes the need to assess the functional state of the body (Bocharin et al., 2020). In this case, the assessment of functional indicators acts as an indicator of a person's state of health and the level of his/her physical qualities development. The micro-circulation system state can act as one of the first functional systems providing urgent

adaptation of the body to external factors and systemic homeostasis (Martusevich et al., 2022; Bocharin et al., 2022). Taking into account the functional feature of blood micro-circulation, which is one of the first to respond to physical exertion, it is possible to use the results of its determination to assess the state of the body's reserve capabilities and the level of human health. Especially such a timely diagnosis of the body functional characteristics is necessary for students with diseases of somatic genesis. In various countries, the number of students with certain diseases tends to increase. According to Gerber et al. (2017) and Collins et al. (2017) every second student has deviations from the norm in the state of health. A large number of students (up to 20%) are completely exempt from academic physical activity (Glazkova et al., 2020).

Students with health disabilities are given increased attention by PE teachers when performing physical activities in the classroom (Momot et al., 2020; Mozolev, 2020). It is due not only to the student's existing disease, but also to their low rates of motor development (Badau et al., 2021).

Knopes (2019) suggests conducting an assessment of the body adaptive reserves of students with the disease and assigned to a «special» health group in PE classes. It will make it possible to effectively build a program of the educational process of physical education corresponding to the state of their physical capabilities and health. For this purpose, various methods are used to assess the body functional parameters (Koryagin, 2018). In the practice of physical education, instrumental methods of monitoring students' body reserve capabilities have become widely used, which allow giving objective dynamics of functional indicators. For example, the heart rate variability method is used (Guzi et al., 2020; Christian et al., 2021; Bouchard et al., 2022).

To assess the reserve capabilities of the human body based on the results of the blood micro-circulation system analysis, the method of laser Doppler flowmetry (LDF) is used. The method is based on the assessment of blood perfusion by measuring the Doppler shift of frequencies and determining the rays reflected from red blood cells, which makes it possible to determine the speed of their movement in the sensing surface (Humeau, 2007; Hoff et al., 2009). This method is non-invasive, does not require special training and can be performed in the conditions of regular training sessions. Despite the information available in the scientific literature on the use of the laser Doppler flowmetry method in clinical practice and in the field of physical culture (Fedirko, Garkava, 2016; Connor, Carvalho, 2019), the issues of using this technique to assess the reserve capabilities of students with diseases and performing physical activities continue to be poorly studied. We believe that using the results of Doppler flowmetry will improve the efficiency of the educational process of students' physical education. It is due to the possibility of timely diagnosis of changes in the functional parameters of micro-circulation, which will allow making adjustments to the educational process of physical education at an early stage of training.

Purpose. Using the technique of laser Doppler flowmetry to study the micro-circulation of blood in students with health abnormalities in physical education classes.

Material & methods

117 students (53 boys and 64 girls aged 18.4 ± 0.3 years) of the first, second and third years of study at the Medical University of Russia took part in the research. According to the results of a periodic medical examination, all project participants have a special medical group for physical training. All students signed an informed voluntary consent before participating in the experiment and could at any time refuse to continue participating in the research. The conducted research project does not contradict the principles of the Helsinki Declaration on Biomedical Research of 2008.

To assess the functional state of the blood micro-circulation system, a portable software and hardware laser complex «LAZMA-PF», developed by the scientific and production association «LAZMA» was used. During the blood micro-circulation study, laser radiation emanates from the device, which spreads from it to the surface under study, is reflected from red blood cells and comes back to the device for photometry in the receiver and signal analysis by a software and hardware complex. As a result, the result of laser Doppler flowmetry (LDF) is displayed on the screen of a personal computer in a special program in the form of a signal with an amplitude proportional to the speed of blood flow and the number of red blood cells. The created LDF-gram, based on the analysis of the perfusion oscillation graph, represents the result of assessing the blood micro-circulation state.

The assessment of blood oxygen saturation (saturation, SPO₂) was performed using a pulse oximeter (included in the «Esteck Complex» hardware and software package). Students were tested during the inter-session period, in the middle of the school day in a state of physiological rest. Registration of laser Doppler flowmetry was performed in a sitting position from the skin surface of the index finger of the left hand. The recording duration was at least 5 minutes. The functional state of LDF was assessed by the arithmetic mean value of the blood micro-circulation index (M), the mean square deviation of the amplitude of fluctuations in blood movement from the arithmetic mean (σ), by the ratio of the value between blood perfusion and the value of its variability (coefficient of variation, Kv), by the indicator of oxidative metabolism (IOM). The latter indicator was evaluated by the relationship between the nutritional component of blood perfusion and the fluorescence amplitude of the coenzyme Nicotinamide adenine dinucleotide + hydrogen (NADH).

In the process of data processing, the software made it possible to perform a statistical analysis based on the registration of wavelet oscillations, where small wave amplitudes of the blood flow components were revealed (A). Such fluctuations are associated with myogenic (Am), neurogenic (An) and endothelial (Ae) mechanisms of regulation of blood flow. The effect is exerted by passive wavelet oscillations (Gurova, &

Ryzhakin, 2015), which are associated with respiratory movements (Ad) and heart rate (Ac). The sum of active and passive oscillations in the total power of the spectrum was estimated in perfusion units. The studied parameters were correlated with the normative values presented by the equipment developers.

The data were processed by methods of variational statistics using software packages Statistica 10.1 for Windows and Microsoft Excel 2016. Each sample is represented as an arithmetic mean (M) and standard error (m). To check the group data of samples for the normality of the distribution, the Kolmogorov-Smirnov criterion with the Lilliefors correction was used. To identify the statistical significance of the values of indicators between students of different sexes, a parametric Student t-test was used. The differences were considered significant at $p < 0.05$.

Results

Figure 1 shows an example of recording blood micro-circulation according to the LDF-gram registration data based on a graphical recording of perfusion oscillations.

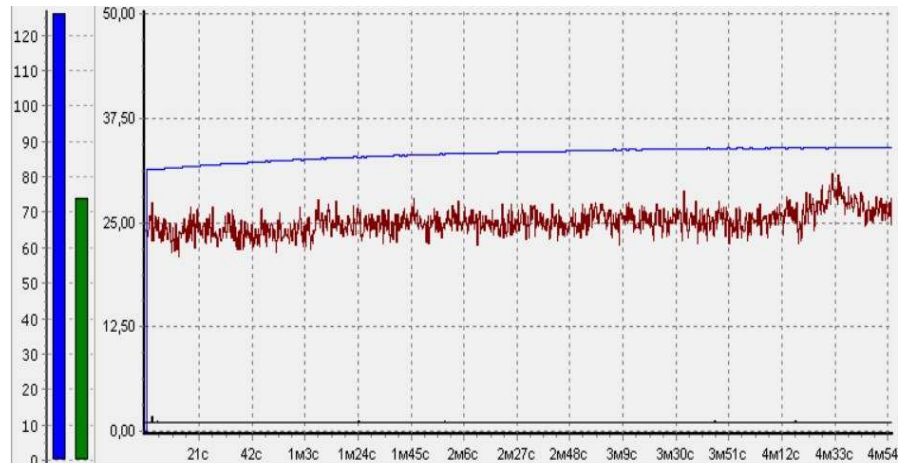


Fig. 1. Example of recording an LDF gram

The LDF method makes it possible to determine in a non-invasive way the functional state of the capillary bloodstream, as well as the regulation of micro-vessels by myogenic, neurogenic, endothelial, respiratory and cardiac mechanisms, using amplitude-frequency analysis.

The analysis of the students' micro-circulatory bed indicates the active state of the mechanisms for ensuring capillary blood flow of subjects performing physical exercises. It is evidenced by the micro-circulation parameter, which was 8.2% higher in boys compared to girls ($p < 0.05$). Its increase may indicate a relative weakening of arterial vascular tone and an increase in blood volume in arterioles in males. In young men, the mean square deviation value of the amplitude of blood flow fluctuations was also at a higher value ($p < 0.05$), which indicates a deep modulation of blood flow in them. It may be due to the intensification of the vascular tone active control mechanisms in young men and the relative predominance of tonic sympathetic influences in girls. At the same time, the girls showed an increase in the coefficient of variation by 5.8% ($p < 0.05$), which indicates an increase in the activation of the endothelial component of the micro-vascular tone regulation in them, and, consequently, an improvement in the micro-circulation state. Thus, the level of tissue perfusion with blood in boys is slightly higher relative to girls. However, the relationship between tissue perfusion and its variability indicates an improvement in the general state of micro-circulation in girls, presumably due to a more active inclusion of the endothelial mechanism of vascular tone regulation. In general, all indicators of blood micro-circulation are within the normative values (chart 1)

Table 1. Functional state of the students' micro-circulatory bed, $M \pm m$

Gender attribute/ Indicator	Boys	Girls	$P_{\text{boys-girls}}$
The micro-circulation index (M) value, perfusion units	19.8±1.3	18.3±1.1	0.026
Mean square deviation of the amplitude of fluctuations in blood movement (σ), perfusion units	1.56±0.13	1.51±0.17	0.034
Coefficient of variation, (Kv), %	10.3±1.6	10.9±1.4	0.017
Endothelial regulation component (Ae), perfusion units	0.6±0.1	0.7±0.1	0.054
Myogenic regulation component (Am), perfusion units	0.7±0.1	0.8±0.1	0.674
Neurogenic regulation component (An), perfusion units	1.1±0.1	1.0±0.1	0.393
Respiratory regulation component (Ar), perfusion units	0.5±0.02	0.3±0.01	0.041
Heart rhythm regulation component (Ac), perfusion units	0.8±0.03	0.6±0.02	0.047
Indicator of oxidative metabolism (IOM), perfusion units	3.7±0.2	3.6±0.3	0.629
Saturation (Spo2), %	97.3±0.7	98.6±0.6	0.061

When analyzing the spectral components of blood flow fluctuations, it was found that in boys and girls, respiratory and cardiac mechanisms are the predominant component of blood flow regulation, that is, passive factors that form outside the micro-circulation system. It is more realized in young men. The analysis of the tone-forming mechanisms revealed no differences in the active factors of the micro-circulatory tone formation between students of different sexes, $p > 0.05$. At the same time, the amplitude of the active links is observed less, in contrast to the passive components of regulation. Among the passive links of blood micro-circulation, the neurogenic component of regulation prevails in both boys and girls. It indicates the modulation of smooth muscle elements of the cardiovascular system by the sympathetic nervous system. The contributions of myogenic rhythm to blood micro-circulation play a role, which synchronize spontaneous contractions of the smooth muscles of the vascular wall and endothelium-dependent component of regulation, expressed in the formation of vascular cells of one of the vasodilation – nitric oxide factors. Thus, the dynamics of the amplitude components indicates their balance in ensuring the regulation of blood flow, but this is mainly realized with the help of passive components. It indicates a slight decrease in the outflow of blood from the bed and an increase in the inflow of arterial blood against the background of a decrease in vascular tone.

When analyzing saturation, it was found that in boys this indicator was $97.3 \pm 0.7\%$, in girls – $98.6 \pm 0.6\%$, $p=0.061$. This indicates an increase in blood oxygen saturation in girls, while the indicators are within the norm. In both groups, there are normative values of tissue metabolism (IOM), while no statistical differences were found among boys and girls, $p=0.629$. It indicates a satisfactory relationship between the flow of oxygenated blood into the capillary bed and its utilization in tissues. After monitoring the heart rate, this indicator in boys was 72.1 ± 16.3 bpm, in girls – 76.3 ± 14.5 bpm (fig. 2), and systolic blood pressure – in boys 129.6 ± 19.4 mmHg, and in girls - 125.4 ± 21.3 mmHg. It is generally consistent with the variability of micro-circulation indicators and the activity of blood flow regulation mechanisms.

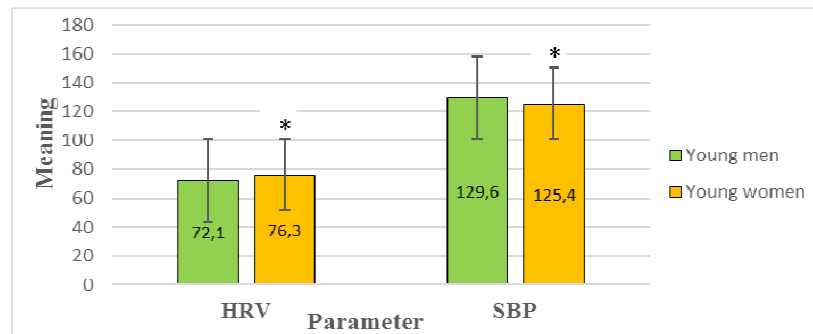


Fig. 2. The value of heart rate and systolic blood pressure indicators
(«*») - differences in indicators between boys and girls are not statistically significant, $p > 0.05$)

The data obtained during the study of blood micro-circulation in students can be used for dynamic monitoring of students' of a special medical group health status. In case of significant deviations of the results from the norm, the information is transmitted to specialists of the Institute of Pediatrics of the University Clinic to resolve the issue of additional examination and further algorithm for constructing PE classes. If necessary, the correction of motor activity and the mode of educational and daily activities is carried out.

Dicussion

The most important task of professional educational institutions, along with the training of qualified specialists, is to protect the students' health (Li, 2022). This problem is especially relevant for students with various somatic diseases, which worsen not only the quality of life, but also reduce the effectiveness of training specialists (Gerber et al., 2017; Hollis et al., 2017; Glazkova et al., 2020). One of the important directions of improving the students' health is the use of physical culture and wellness technologies (Momot et al., 2020; Mozolev, 2020).

The process of adaptation of the students' body to educational and training activities can be accompanied by significant changes on the part of some morphofunctional systems of the body. Especially these changes concern the cardiovascular system, as a key one in performing physical activity (Surovegina et al., 2023). Therefore, it is necessary to monitor the state of the heart and blood vessels, including monitoring the blood micro-circulation state. It is due to the fact that micro-circulation can act as an early marker of changes caused by shifts in central hemodynamics affecting the reserve capabilities of the body (Bocharin et al., 2022). Recently, the study of the capillary bed state and its regulatory components has not lost relevance when monitoring the activity of the cardiovascular system in various segments of the population (Hendriks-Balk et al., 2022). For this purpose, one of the available methods of noninvasive screening is used - laser Doppler flowmetry based on optical probing of tissues with laser radiation (Fedirko, & Garkava, 2016; Connor, & Carvalho, 2019).

According to our data, it was found that when using laser Doppler flowmetry, the blood micro-circulation index in boys turned out to be 8.2% higher relative to girls, and the value of the mean square deviation (flax) of the blood flow fluctuations amplitude is also recorded at a higher value in males. The value of the coefficient of variation is observed higher in girls, which also implies an improvement in their micro-circulation state. When analyzing the spectral analysis of the components, the predominant component of regulation is the passive mechanisms of blood flow regulation (respiratory and cardiac), however, in girls their role is somewhat less relative to boys. In general, there is a balance of amplitude components in ensuring the blood flow regulation. When observing the indicator of oxidative metabolism, there were no statistical differences between boys and girls and a satisfactory relationship between the intake of oxygenated blood into the capillary bed and its utilization in tissues. Blood oxygen saturation in students is also within the limits of normative values. The variability of micro-circulation parameters and mechanisms of regulation of blood flow and vascular tone is consistent with the normative values of heart rate and systolic blood pressure, differentiated by gender.

The peculiarity of the blood micro-circulation system is that it can be one of the first to react to external effects on the body. This feature makes it possible to use the results of its determination for an early assessment of the body's reserve capabilities state and the human health level (Martusevich et al., 2022; Bocharin et al., 2022). Especially such a timely diagnosis of the functional characteristics of the body is necessary for young students who have various somatic diseases and they are assigned to a special medical group. The assessment of blood micro-circulation allows the teaching staff of the Physical Culture departments to individualize the curricula of PE classes for students assigned to a special medical health group.

Conclusions

When monitoring the blood micro-circulation state in students using laser Doppler flowmetry, a relative weakening of arterial vascular tone and an increase in blood volume in arterioles in young men, as well as a deeper modulation of blood flow in them, was found. At the same time, the value of the coefficient of variation shows an improvement in the state of micro-circulation in girls. It is realized in the mechanisms of ensuring vascular tone, where neurogenic and endothelial components of regulation are observed in girls, in boys – an increase in passive links of micro-circulation, which indicates a decrease in blood outflow from the bed, an increase in arterial blood flow and a decrease in vascular tone. In girls, there is an increase in blood oxygen saturation, as well as a higher indicator of heart rate and systolic blood pressure. The studied parameters indicate an increase in tension in the regulation of the cardiovascular system in male students.

Pronounced changes in blood micro-circulation occur among the first signs of the body's response to the effects of various factors, which allows using the results of its determination at the early stages of assessing the state of reserve capabilities and the level of human health. This makes it possible to make individual adjustments to the educational process of physical education of students at the early stages of the onset of the disease and increases the effectiveness of wellness technologies.

Conflicts of interest. The authors declare no conflict of interest.

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