

CHARACTERISTICS OF MICROCIRCULATORY PARAMETERS OF BOYS AND GIRLS ACCORDING TO LASER DOPPLER FLOWMETRY (LDF)

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ABSTRACT

The method of laser doppler flowmetry is one of the relevant and informative ways to study the state of the microcirculation.

The aim of the work was to conduct a comparative analysis of the microcirculatory system of boys and girls according to laser Doppler flowmetry (LDF).

Materials and methods. The study involved 128 second-year students of the Medical Institute of the North-Eastern Federal University named after M.K. Ammosov. All individuals were of Yakut ethnicity. The boys' group consisted of 44 people, the girls' group consisted of 84 people. The state of microcirculation and the functioning of its regulatory mechanisms were assessed by laser Doppler flowmetry (LDF) using two identical single-channel portable LASMA PF analyzers (SPE "LAZMA", Moscow). The measurement was carried out on the lower third of the right and left forearms for 5 minutes.

Results. Significant intergroup differences in microcirculatory parameters between the examined boys and girls were established. The results showed significant sex differences in the state of the microcirculatory system: the boys recorded higher values of shunt blood flow (1.71 ± 0.13) and a large amplitude of fluctuations due to vascular endothelial activity (0.04 ± 0.01). The girls had significantly lower shunt blood flow (1.34 ± 0.07) and endothelial activity (0.01 ± 0.01). At the same time, the levels of nutritional blood flow, as well as the activity of neurogenic and myogenic regulatory mechanisms, were similar in both sexes. A group of people with a low level of respiratory fluctuations in blood flow prevailed among the subjects (68.2 % of boys and 73.8 % of girls). And the indicators of cardiac fluctuations in blood flow were at a normal or reduced level and also did not depend on gender.

Conclusion. The study highlights the need to take into account the age and gender characteristics of the microcirculatory system in the diagnosis and monitoring of diseases of the cardiovascular system, especially in young people living in the extreme climatic conditions of Yakutia.

Keywords: microcirculation, LDF, boys, girls, Yakutia

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ХАРАКТЕРИСТИКА ПОКАЗАТЕЛЕЙ МИКРОЦИРКУЛЯТОРНОГО РУСЛА ЮНОШЕЙ И ДЕВУШЕК ПО ДАННЫМ ЛАЗЕРНОЙ ДОППЛЕРОВСКОЙ ФЛОУМЕТРИИ (ЛДФ)

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РЕЗЮМЕ

Метод лазерной доплеровской флоуметрии является одним из актуальных и информативных способов изучения состояния микроциркуляторного русла.

Целью работы явилось проведение сравнительной характеристики показателей микроциркуляторного русла юношей и девушек по данным лазерной доплеровской флоуметрии (ЛДФ).

Материалы и методы исследования: В исследовании приняли участие 128 студентов второго курса Медицинского института Северо-Восточного федерального университета им. М.К. Аммосова. Все обследованные были якутской национальности. Группа юношей состояла из 44 человек, группа девушек из 84 человек. Состояние микроциркуляции и функционирование ее регуляторных механизмов оценивали методом лазерной доплеровской флоуметрии (ЛДФ) с помощью двух одинаковых одноканальных портативных анализаторов «ЛАЗМА ПФ» (ООО НПП «ЛАЗМА», Москва). Измерение проведено на нижней трети правого и левого предплечий, запись велась в течение 5 минут.

Результаты. Установлены достоверные межгрупповые различия в показателях микроциркуляторного русла между обследованными юношами и девушками. Полученные результаты показали значимые половые различия в состоянии микроциркуляторного русла: у юношей зафиксированы более высокие значения шунтового кровотока ($1,71 \pm 0,13$) и большая амплитуда колебаний, обусловленных активностью эндотелия сосудов ($0,04 \pm 0,01$). У девушек же отмечались достоверно меньшие показатели шунтового кровотока ($1,34 \pm 0,07$) и активности эндотелия ($0,01 \pm 0,01$). При этом уровни нутритивного кровотока, а также активность нейрогенных и миогенных механизмов регуляции были сходны у представителей обоих полов. Среди обследуемых преобладала группа лиц с низким уровнем дыхательных колебаний кровотока (68,2 % юношей и 73,8 % девушек). А показатели сердечных колебаний кровотока находились в нормальном или сниженном уровне и также не зависели от пола.

Заключение. Исследование подчеркивает необходимость учитывать возрастные и половые особенности показателей микроциркуляторного русла при диагностике и мониторинге заболеваний сердечно-сосудистой системы, особенно у молодых людей, проживающих в экстремальных климатических условиях Якутии.

Ключевые слова: микроциркуляция, ЛДФ, юноши, девушки, Якутия

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INTRODUCTION

One of the key aspects of cardiovascular system function is microcirculation. Disturbances at the level of the microcirculatory bed play a crucial role in the pathogenesis of a wide range of diseases, from arterial hypertension and diabetes mellitus to chronic heart failure and autoimmune vasculitides.

One of the most informative and modern approaches for assessing microcirculation is laser Doppler flowmetry (LDF) [1–3]. This method is based on recording the intensity of light scattering reflected by moving erythrocytes, which allows determination of blood flow velocity and volume in the smallest blood vessels [4]. In studies utilizing LDF various parameters are recorded that characterize blood circulation at the microcirculatory level, such as the microcirculation index, reactivity indices, flow velocity, and signal variability [5, 6]. By obtaining objective quantitative data, a comprehensive analysis of the functional status of microcirculation can be conducted, including assessment of its response to external stimuli and identification of potential abnormalities.

Interpretation of microcirculatory parameters requires consideration of various individual and population factors, primarily sex and age, as well as climatic and geographic conditions of residence [7–9]. Extreme continental climate of Yakutia, characterized by prolonged periods of low temperatures, sharp fluctuations in atmospheric pressure, and specific light conditions, creates specific requirements on cardiovascular function, particularly the microcirculation. Establishing differences in sex-specific microcirculatory parameters can lead to the personalization of strategies for early diagnosis, prevention, and management of cardiovascular disease. To date, no studies on the microvascular bed using LDF in young individuals have been conducted in the Republic of Sakha (Yakutia). This highlights the significance and originality of this research.

AIM

To conduct a comparative analysis of microcirculatory parameters in young males and females using laser Doppler flowmetry (LDF).

MATERIALS AND METHODS

The study was conducted at the Medical Institute of M.K. Ammosov North-Eastern Federal University (NEFU) in April and May 2025. A total of 128 second-year students, who were of Yakut ethnic origin, participated in the study, including 44 males and 84 females. All participants met the following inclusion criteria: absence of chronic cardiovascular and autoimmune diseases, as well as acute pathological conditions at the time of the examination. Participation in the study was voluntary, and it was carried out only after obtaining written informed consent

from each participant. The study received approval from the local ethics committee of the Medical Institute of M.K. Ammosov (Protocol No. 5, dated February 14, 2024).

The status of microcirculation and the functioning of its regulatory mechanisms were evaluated using laser Doppler flowmetry (LDF), employing two identical single-channel portable LASMA PF analyzers (SPE LAZMA, Moscow), in accordance with the requirements of Roszdravnadzor (Resolution No. 660/2018). To assess microcirculatory parameters, sensors were attached to the lower third of the right and left forearms of the subjects. During the recording of blood perfusion, the subjects were in a state of physical and psychological rest. The arms were placed at heart level, and the study was conducted at least 2 hours following meals and physical activity. Each measurement lasted 5 minutes, and the temperature in the testing environment was maintained at $23 \pm 2^\circ\text{C}$.

The processing of the acquired LDF signals was carried out using specialized software. Based on the acquired data, quantitative parameters were calculated. The following parameters were recorded: the integrated perfusion index (M, perfusion units, p.u.) and the coefficient of variation (CV, %) that characterize microcirculatory variability. The component level of microcirculation was determined by the parameters of nutritional (Mnutr) and shunt (Mshunt) blood flow. Wavelet analysis was used to evaluate the amplitude-frequency spectrum of microcirculation oscillations and calculate the amplitude characteristics of the main rhythms of microvascular blood flow regulation: endothelial (Ae), neurogenic (An), myogenic (Am), respiratory (Ar), and cardiac (Ac). After measurement completion, the software of the instrument automatically generated a report indicating perfusion, variability, and regulatory parameters. In the forearm area, the following parameters were considered within the normal range: M – 3.5 to 9.5 p.u., Mshunt – 2.0 to 6.0 p.u., Mnutr – 1.5 to 3.5 p.u., KV – 6.0 to 11.0 %, Ae – 0.1 to 0.2 p.u., An – 0.12 to 0.35 p.u., Am – 0.2 to 0.35 p.u., Ar – 0.15 to 0.25 p.u., Ac – 0.15 to 0.35 p.u.

During the study, the LASMA PF device simultaneously recorded local skin temperature in the forearm area. This allowed the thermal component to be taken into account when interpreting microcirculatory parameters [10]. The data obtained provided a comprehensive assessment of the baseline state of the microvascular bed and the functional activity of the neurohumoral and metabolic regulatory systems.

Statistical analysis was conducted using SPSS-22 software. Mean (M), standard deviation (SD), median (Me), and interquartile range [Q_{25} ; Q_{75}] were calculated. The normality of the distribution was assessed using the Kolmogorov-Smirnov test. Depending on the distribution type, parametric (Student's *t*-test) and non-parametric (Mann-Whitney U-test) methods were employed for intergroup comparison. The significance of differences between relative parameters was determined using Pearson's chi-square (χ^2) test. Differences were considered statistically significant at $p < 0.05$.

RESULTS

The results of microcirculatory parameters in young males and females obtained using LDF were analyzed. The parameters recorded by the LASMA-PF device are presented in Table 1.

A significant intergroup difference was observed in shunt blood flow values. The mean shunt blood flow was significantly higher in males ($p = 0.034$). The amplitude of blood flow oscillations, determined by the endothelial mechanism of vascular tone regulation, was also significantly higher in males ($p = 0.039$).

Analysis of microcirculation level distribution showed that in males, normal microcirculation was recorded in 52.3 % of cases, while reduced microcirculation was observed in 47.7 %, although this difference was not statistically significant. Similar distribution patterns were observed in females, with normal microcirculation occurring in 42.9 % and reduced level in 57.1 % of cases. The mean local skin temperature of the forearm was $32.22 \pm 1.65^\circ\text{C}$ in males and $32.09 \pm 1.56^\circ\text{C}$ in females.

Levels of nutritional and shunt blood flow are presented in Table 2.

Table 3 presents data on the amplitude of blood flow oscillations, as determined by endothelial, neurogenic, and myogenic mechanisms of vascular tone regulation, in young males and females.

During the study, differences in the amplitude of blood flow oscillations that are determined by endothelial, neurogenic, and myogenic mechanisms of vascular tone regulation were recorded in young males and females of Yakut ethnicity. The levels of respiratory and cardiac blood flow oscillation amplitudes for both groups are presented in Table 4.

DISCUSSION

The level of the microcirculatory bed showed no sex differences. A comparison of our data with the results of Parshakova V.E. et al. (2024) [11] revealed that the absolute index of microcirculation (M) was lower in both

TABLE 1
INDICATORS OF MICROCIRCULATION OF THE FOREARM OF BOYS AND GIRLS OF YAKUT ETHNICITY

Parameter	Males (n=44)		Females (n=84)		p
	M±SD	Me [Q ₂₅ ;Q ₇₅]	M±SD	Me [Q ₂₅ ;Q ₇₅]	
M, p.u.	3.67±1.23	3.37 [2.86; 4.16]	3.73±2.24	3.41 [2.79; 4.15]	p=0.630
Mnutr, p.u.	2.15±1.12	1.80 [1.33; 2.50]	2.37±2.91	1.87 [1.32; 2.68]	p=0.972
Mshunt, p.u.	1.68±0.85	1.50 [1.02; 2.0]	1.41±1.27	1.39 [0.91; 1.87]	p=0.034
Sigma	0.55±0.39	0.41 [0.29; 0.69]	0.48±0.33	0.38 [0.28; 0.55]	p=0.298
CV, %	14.72±9.05	11.85[9.51; 17.66]	12.92±5.77	11.13 [9.19; 15.09]	p=0.278
Ae, p.u.	0.04±0.07	0.02 [0.01; 0.36]	0.002±0.04	0.001 [0.0; 0.30]	p=0.039
An, p.u.	0.17±0.16	0.12 [0.07; 0.22]	0.17±0.15	0.13 [0.08; 0.20]	p=0.819
Am, p.u.	0.23±0.21	0.16 [0.11; 0.27]	0.21±0.15	0.17 [0.11; 0.29]	p=0.843
Ar, p.u.	0.17±0.18	0.11 [0.08; 0.18]	0.13±0.11	0.09 [0.07; 0.15]	p=0.090
Ac, p.u.	0.20±0.12	0.18 [0.12; 0.21]	0.18±0.11	0.15 [0.11; 0.21]	p=0.390
T, C°	31.85±1.65	32.14[30.31; 33.23]	31.96±1.56	31.86 [30.95; 33.10]	p=0.580

TABLE 2
DISTRIBUTION OF BOYS AND GIRLS BY LEVELS OF NUTRITIONAL AND SHUNT BLOOD FLOW

Parameter	Level	Males (n=44)	Females (n=84)
Nutritional blood flow	Normal	23 (52.3)	48 (57.1)
	Increased	8 (18.2)	8 (9.6)
	Reduced	13 (29.5)	28 (33.3)
Shunt blood flow	Normal	13 (29.5)	15 (17.9)
	Reduced	31 (70.5)	69 (82.1)

groups groups (3.67 ± 1.23 and 3.73 ± 2.24 p.u. vs. 5.2 ± 1.0 p.u.). Neither study found any significant difference in this parameter between males and females.

Analysis of microcirculatory components revealed that the mean shunt blood flow was significantly higher in males ($p = 0.034$) compared to females. Furthermore, the amplitude of endothelium-dependent blood flow oscillations was also significantly higher in males ($p = 0.039$). These findings can be attributed to a combination of structural and physiological features: males typically have higher anthropometric measurements (height, weight, muscle mass, etc.), a faster metabolic rate, and a more extensive network of arteriovenous anastomoses. These features lead to increased shunt blood flow. It is known that decreased testosterone levels are associated with impaired vascular endothelial function [12].

Skin temperature was measured using an integrated thermosensor within the flowmeter measuring head and recorded simultaneously with the LDF signal. The local skin temperature on the forearm showed no significant difference between males ($32.22 \pm 1.65^\circ\text{C}$) and females ($32.09 \pm 1.56^\circ\text{C}$). Simultaneous temperature recording

improves the reliability of the data, as local skin temperature directly affects microvascular tone and consequently perfusion levels. Minor temperature fluctuations can influence vasomotor activity and potentially affect the accuracy of regulatory mechanism assessments.

A heterogeneous pattern was observed in terms of nutritional blood flow levels. A significant proportion of both males and females (52.3 % and 57.1 %, respectively) exhibited normal nutritional blood flow ($\chi^2 = 5.454$, $p = 0.020$; $\chi^2 = 22.134$, $p < 0.001$). However, individuals with reduced and increased nutritional blood flow values were also present. A significantly larger proportion of males ($\chi^2 = 5.002$, $p = 0.026$) and females ($\chi^2 = 24.257$, $p = 0.001$) had reduced shunt blood flow (70.5 % and 82.1 %, respectively). This can be explained by the structural characteristics of forearm skin, where arteriolo-venular anastomoses are rare in this area and located in deeper skin layers inaccessible to laser probe analysis. Consequently, forearm skin perfusion primarily reflects the nutritional aspect of microcirculation [13–15].

Both males and females exhibited a predominance of reduced blood flow oscillation amplitudes associated

TABLE 3

AMPLITUDE LEVELS OF BLOOD FLOW FLUCTUATIONS CAUSED BY DIFFERENT MECHANISMS OF VASCULAR TONE REGULATION IN BOYS AND GIRLS

Blood flow oscillation amplitude	Level	Males (n=44)	Females (n=84)	Pearson's χ^2 test; p
Endothelial mechanism	Normal	-	1 (1.2)	$\chi^2=0.522$; $p=0.471$
	Increased	6 (13.6)	1 (1.2)	$\chi^2=7.502$; $p=0.007$
	Reduced	38 (86.4)	82 (97.6)	$\chi^2=0.205$; $p=0.651$
Neurogenic mechanism	Normal	19 (43.2)	35 (41.7)	$\chi^2=0.011$; $p=0.917$
	Increased	7 (15.9)	12 (14.3)	$\chi^2=0.044$; $p=0.834$
	Reduced	18 (40.9)	37 (44.0)	$\chi^2=0.047$; $p=0.830$
Myogenic mechanism	Normal	9 (20.5)	23 (27.4)	$\chi^2=0.451$; $p=0.502$
	Increased	9 (20.5)	14 (16.7)	$\chi^2=0.194$; $p=0.660$
	Reduced	26 (59.1)	47 (56.0)	$\chi^2=0.032$; $p=0.859$

TABLE 4

AMPLITUDE LEVELS OF RESPIRATORY AND CARDIAC FLUCTUATIONS IN BLOOD FLOW IN BOYS AND GIRLS

Blood flow oscillation amplitude	Level	Males (n=44)	Females (n=84)	Pearson's χ^2 test; p
Respiratory	Normal	8 (18.2%)	11 (13.1%)	$\chi^2=0.432$; $p=0.511$
	Increased	6 (13.6%)	11 (13.1%)	$\chi^2=0.006$; $p=0.941$
	Reduced	30 (68.2%)	62 (73.8%)	$\chi^2=0.075$; $p=0.785$
Cardiac	Normal	23 (52.3%)	38 (45.2%)	$\chi^2=0.200$; $p=0.655$
	Increased	7 (15.9%)	6 (7.1%)	$\chi^2=1.938$; $p=0.164$
	Reduced	14 (31.8%)	40 (47.6%)	$\chi^2=1.249$; $p=0.264$

with the endothelium (86.4 % and 97.6 %, respectively). A higher amplitude of blood flow oscillations mediated by the endothelial mechanism of vascular tone regulation was more common in males ($\chi^2 = 7.502$; $p = 0.007$). We suggest that the increased amplitude of endothelium-dependent blood flow oscillations in males may be due to a higher baseline vascular tone under the influence of androgens, requiring a stronger reactive release of nitric oxide for vasodilation in response to stimuli [16].

Assessment of blood flow oscillation amplitude, mediated by the neurogenic mechanism of vascular tone regulation, in Yakut males showed an approximately equal distribution between normal (43.2 %) and reduced (40.9 %) levels. A similar distribution was observed in the female group (41.7 % and 44.0 %, respectively). An increased level was seen in a significantly lower proportion of both males ($\chi^2 = 4.323$; $p = 0.038$) and females ($\chi^2 = 8.897$; $p = 0.003$). There were no statistically significant differences in the distribution of neurogenic regulation levels between the studied groups. This indicates a low level of sympathetic nervous system involvement in microcirculation regulation for both males and females. The myogenic mechanism also showed no significant sex differences, with reduced activity seen in the majority of males and females. Our study found that different regulatory mechanisms were equally involved, indicating a balanced and adaptable organization of vasomotor control in the group of young participants. Each mechanism made a comparable and balanced contribution to the regulation of microcirculation.

In the examined groups of males and females, a predominance of reduced respiratory blood flow oscillation amplitude was observed (68.2 % and 73.8 %, respectively). The amplitude of respiratory blood flow oscillations is an important indicator of venous outflow and overall autonomic regulation of the cardiovascular system. Cardiac blood flow oscillations reflect the transmission of the pulse wave from the large arteries to the microcirculatory bed and depend on several factors, including blood pressure, arterial wall stiffness, peripheral vascular resistance, and the state of capillary beds and tissue drainage [17]. Analysis of cardiac blood flow oscillation amplitude revealed that, in the majority of subjects, it was within normal or reduced ranges and did not statistically differ between males and females ($p > 0.05$). Increased levels were only observed in a small percentage of participants. This finding indicates that, despite known physiological differences between males and females (e.g., lower blood pressure and lower muscle mass in females), the transmission of pulse waves to the microcirculation is comparable between the two sexes. On the one hand, this could be seen as an indication of preserved arterial wall elasticity and appropriate peripheral resistance. However, on the other hand, the decreased amplitude, particularly in almost half of the female participants (47.6 %), could suggest more effective pulse wave attenuation in peripheral vessels. This is often associated with the vasodilative effect of estrogens. To verify this hypothesis, a study involving direct measurement of hormone levels would be required.

Numerous studies have demonstrated significant sex differences in microvascular perfusion parameters. Women generally exhibit higher perfusion indices and larger amplitudes of neurogenic oscillations than men, which can be attributed to the effects of estrogen on vasodilation, endothelial-dependent relaxation, and overall vascular reactivity. These findings are supported by studies in the literature [18, 19]. At the same time, studies have shown that men often exhibit signs of reduced microvascular reserve even at a younger age, which may explain their earlier manifestation of atherosclerotic and hypertensive complications compared to women.

CONCLUSION

Therefore, significant intergroup differences in microcirculatory parameters were observed between the examined males and females. Males exhibited higher mean shunt blood flow values and a greater amplitude of blood flow oscillations associated with vascular endothelial activity. Nevertheless, the distribution of nutritional blood flow levels and the levels of neurogenic and myogenic mechanisms for vascular tone regulation did not show significant differences between the sexes. Both males and females exhibited a predominance of decreased respiratory component parameters. Cardiac flow oscillation parameters fell within the normal or decreased range and were not dependent on sex.

These results highlight the importance of considering age and sex characteristics when assessing the state of the cardiovascular system and the microcirculatory bed, particularly in young people living in the extreme climatic conditions of Yakutia.

Conflicts of interest

The authors declare no conflicts of interest.

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