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Peculiarities of the body component composition and microcirculation of qualified divers

Peculiaridades de la composición de los componentes corporales y de la microcirculación de los buceadores cualificados

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Abstract. One of the important aspects of improving the effectiveness of training qualified divers is understanding the peculiarities of body component composition and the state of microcirculation. The aim of this study was to investigate the component body composition and microcirculation peculiarities of qualified divers diving from different types of gymnastic equipment. The study sample included 30 qualified divers, consisting of 17 girls and 13 boys aged 13 to 18 years. Body composition was assessed using bioimpedance analysis, and the functional state of the microcirculatory system was evaluated through laser Doppler flowmetry. The results indicated that divers who utilized the 10-meter tower exhibited a statistically significant decrease in adipose tissue content and an increase in fat-free mass and relative muscle mass compared to athletes in other diving disciplines. Additionally, a high level of tissue perfusion and microvascular reactivity was observed among the athletes. These findings are crucial for assessing and enhancing the training effectiveness of qualified diving athletes.
Keywords: springboard, diving tower, capillary blood flow, adipose tissue.

Resumen. Uno de los aspectos importantes para mejorar la eficacia del entrenamiento de buceadores cualificados es comprender las peculiaridades de la composición corporal y el estado de la microcirculación. El objetivo de este estudio fue investigar la composición corporal y las peculiaridades de la microcirculación de buceadores cualificados que se lanzan desde diferentes tipos de equipos de gimnasia. La muestra del estudio incluyó a 30 buceadores cualificados, compuesta por 17 chicas y 13 chicos de entre 13 y 18 años. La composición corporal se evaluó mediante bioimpedancia, y el estado funcional del sistema microcirculatorio se evaluó a través de la flujometría láser Doppler. Los resultados indicaron que los buceadores que utilizaban la torre de 10 metros mostraban una disminución estadísticamente significativa en el contenido de tejido adiposo y un aumento en la masa libre de grasa y la masa muscular relativa en comparación con los atletas de otras disciplinas de buceo. Además, se observó un alto nivel de perfusión tisular y reactividad microvascular entre los atletas. Estos hallazgos son cruciales para evaluar y mejorar la eficacia del entrenamiento de los atletas de buceo cualificados.
Palabras clave: trampolín, torre de salto, flujo sanguíneo capilar, tejido adiposo.

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Introduction

In modern conditions, diving is a sport that involves diving from a springboard and diving tower with a variety of rotations and entering the water with the head or feet. Even though this sport belongs to aquatic disciplines, the athlete performs the main technical elements of the jump in the air – before the contact with the water surface. Diving requires very good physical fitness, coordination of movements, and courage because the flight speed at the moment of diving can exceed 50 km/h. An incorrectly performed entry into the water, especially when diving from a 10-meter tower, can cause serious injuries, bruises, and fractures (Gulevich & Geychenko, 2019; Mu et al., 2023). Training interventions or environmental conditions (e.g., high-pressure water environments in diving) could influence microvascular adaptations.

To achieve high sports performance, it is necessary to develop a set of physical qualities and functional features: strength, agility, flexibility, endurance, neuromuscular coordination, general endurance, etc. (Popova, 2020; Sedochenko et al., 2022; Solikhin, et al., 2024). The expression of these qualities largely depends on the intensity of blood circulation in the muscles and throughout the body. One of the components of the circulatory system is the microvasculature, where metabolic processes between blood and tissues are directly realized. Regular physical loads that the athlete's body is subjected to cause a number of structural and functional modifications of the microcirculation system, which are aimed at maintaining the optimal level of oxygenation of skeletal muscles (Báez-Suárez & Moreham, 2024). The reactivity of various links in the microcirculatory system is one of the mechanisms of urgent and long-term adaptation (Cracowski & Roustit, 2020; Hendrickse & Degens, 2019; Robinson et al., 2018).

The study of skeletal muscle microcirculation is an informative method for assessing the level of adaptation and physical fitness of athletes (Ma et al., 2022). Explosive strength necessary for successful diving depends not only on the functioning of the microvasculature but also on the component body composition of athletes (Rausavljević et al., 2012), the assessment of which is widely used to study the somatic status and to determine the effectiveness of training loads.

Studies have shown that high performance in springboard diving requires the development of high power during the jump, which is achieved through a combination of muscular strength, body coordination, balance of the athlete, and low body mass index (Janura et al., 2016; Oggiano & Sætran, 2009; Rausavljević et al., 2012; Tønnessen et al., 2016). It has also been shown that changes in body fat content are important for the performance of springboard diving (Ostachowska-Gąsior et al., 2021). However, at present, there is no data on the peculiarities of the body component composition of qualified divers from different types of equipment. There is no data on the state of microcirculation of divers either. This information is of great practical importance, as it is an important factor in controlling the effectiveness of training loads, rehabilitation measures, and nutritional correction necessary to improve the efficiency of training of qualified divers.

The aim of the study was to investigate the component body composition and microcirculatory peculiarities of qualified divers performing diving from different types of equipment.

Materials and Methods

The study included 30 qualified divers (17 girls and 13 boys aged 13 to 18 years), diving from different types of equipment (springboard, 5-meter tower (individual diving, synchronized diving); 10-meter tower (individual diving)). The levels of sportsmanship of the participants included candidate masters of sports, masters of sports, and masters of sports of the international class.

The study was conducted on the basis of the Voronezh State Academy of Sports (Voronezh, Russia) according to the agreement on scientific cooperation between the Federal State Budgetary Educational Institution of Higher Education "Voronezh State Academy of Sports" and the State Budgetary Educational Institution of Higher Education "Dmitry Sautin Diving School of Olympic Reserve". The study design and its ethical compliance were approved by the State Budgetary Institution of Additional Education of the Voronezh Region "Olympic Reserve Sports School for Diving named after D. Sautin," as well as the Russian Federation of Diving. These organizations confirm the theoretical and practical significance of the research conducted. Furthermore, the study adhered to all relevant ethical guidelines, including obtaining informed consent from all participants, ensuring participant confidentiality, and maintaining transparency throughout the research process.

It is known that bioimpedance analysis of body composition is one of the modern methods of morphological and functional diagnostics in sports medicine (Ishiguro et al., 2006). A distinctive feature of this analysis is the possibility of operational examination of athletes both during a separate training session and at the stages of the training cycle. The data allow the specialists to evaluate the level of physical fitness of athletes in the monitoring mode.

The total and segmental body composition was assessed by bioimpedancemetry using Tanita BC 418 MA fat analyzer scales. The measurement is based on the generation of a weak electric current by the scale to assess the body's electrical resistance, which depends on the distribution of different tissue types in the body. The Tanita body composition analyzer measures body composition using 8 electrodes with a high-frequency direct current source (50 kHz,500 μA). During the research, the scales were placed on a stable, vibration-free surface. To ensure the accuracy of the measurements, the following protocols were observed:

- The research was conducted at an ambient temperature of 22-24°C and relative humidity of 30%-80% between 8:00 and 9:00 AM.
- Athletes stood barefoot on the scale with clean feet.
- Hand-held electrodes were always held with both hands (clean palms).
- The participants stood upright, ensuring their hands did not touch their thighs.
- No mobile phones or other sensors that could affect the readings were present during the measurements.

To prevent distortion of the results due to possible dehydration or overhydration, the measurements were conducted on an empty stomach, with the participants having emptied their bladders immediately before the study. Additionally, no high-intensity training or excessive consumption of food and liquids occurred the day prior to the measurements.

Such parameters as body fat content (FAT, kg and %), fat-free mass (FFM, kg), relative muscle mass (PPM, kg), and total body water (TBW, kg) were analyzed.

Studies of the functional state of the microvasculature in divers were performed using a laser capillary blood flow analyzer LAKK-01 (SPE "Lazma", Russia). Measurements were performed in the Zakharin-Ged zones for the heart on the outer surface of the right forearm, located along the midline 4 cm above the base of the ulnar and radial styloid processes. This site is poor in arteriolo-venular anastomoses, so it reflects nutritive blood flow to a greater extent (Krupatkin & Sidorov, 2016). LDF-gram recording was performed for 10 minutes in the red range of laser radiation (wavelength $\lambda = 630$ nm, probing thickness was about 1 mm).

To assess the intensity of microcirculation, the following parameters were analyzed: the microcirculation index (MI) (p.u.), the averaged maximum amplitudes of endothelial (Ae, p.u.), neurogenic (An, p.u.), myogenic (Am, p.u.), respiratory oscillations (Ad, p.u.) and cardiorhythms (Ac, p.u.), the shunt index (SI), the neurogenic (NT), myogenic (MT), and general vascular tone, the total volumetric flow (TVF, p.u./mmHg), the total nutritive flow (TNF, p.u./mmHg), and the total shunt flow (TSF, p.u./mmHg) (Krupatkin, 2005).

In order to identify adaptation reserves of the microcirculatory system, an occlusion test was performed according to the standard method (Krupatkin & Sidorov, 2016). When interpreting the results of the occlusion test, the authors evaluated the capillary flow reserve (CFR, %), the time to reach the maximum microcirculation index after occlusion (Tmax, s), and the time of blood flow half-recovery (T1/2, s). To identify the peculiarities of microcirculation in divers, the obtained data were compared with the data of the control group, which consisted of healthy, non-sporting boys and girls aged 16–18 years without microhemodynamic disorders (Krupatkin & Sidorov, 2016). Measurements were performed at an ambient temperature of 22–25°C, between 08:30 and 09:30, after at least eight hours of fasting.

The obtained data were analyzed by conventional methods of variation statistics with the assessment of the reliability of different empirical samples by Student's test.

At the beginning of the study, the required number of measurements to ensure the accuracy and reliability of the results was determined. The number of measurements depends on the variability of the studied characteristic, expressed by the coefficient of variation ($V_{\%}$), the accuracy of the study, expressed by the precision indicator ($P_{\%}$), and the accepted probability of the result, assessed by the reliability index (t_d). The number of observations was calculated using the following equation:

$$n = \frac{t_d^2 \cdot V_{\%}^2}{P_{\%}^2}, \quad (1)$$

where $V_{\%}$ is the coefficient of variation, $P_{\%}$ is the precision indicator, and t_d is the reliability index.

In sports physiology, it is generally accepted that a sufficient level of experimental reliability is ensured with a coefficient of variation within 15–17% and a precision indicator not exceeding 5%. The reliability index for a 0.90 probability of results is equal to 1.6. According to Equation 1, 30 observations are required for each series of experiments:

$$n = \frac{17^2 \cdot 1.6^2}{5^2} = 28.9 \approx 30$$

Based on this, the sample size consisted of 30 athletes.

To determine the statistical significance of differences between means, Student's t-test was applied. This test is a one-parameter family of absolutely continuous distributions, used to assess how likely it is that the true mean lies within a given range. The initial data followed a normal distribution.

As an example, we consider the difference in the amplitude of endothelial oscillations between the control group and springboard divers (Table 2). The significance of the difference was calculated as the difference between the mean values divided by the square root of the sum of the squared errors:

$t = (0.34–0,29)/\sqrt{0,4^2+0,4^2}$

After performing the calculations, the t-value was found to be 0.89. The degrees of freedom were 30. Comparing the obtained t-value (0.89) with the critical value at $p=0.05$ (2.042), we conclude that the observed differences are not statistically significant ($p>0.05$).

This method was used to calculate the significance of all the studied indicators.

Results

The study of the athlete microcirculation peculiarities showed a higher level of tissue perfusion in divers compared to the control group. In males, it was higher on average by 85.5%, and in females – by 116% (Table 1), which indicated high volume perfusion of the microcirculation system of athletes.

Table 1.
Main microcirculation parameters of divers

Parameter	Control	Diving Tower	Springboard
Males			
Microcirculation index (MI), p.u.	5.36 ± 0.12	9.87 ± 1.44	10.02 ± 1.49
Neurogenic tone (NT), CU	2.71 ± 0.12	2.67 ± 0.23	1.99 ± 0.28
Myogenic tone (MT), CU	4.34 ± 0.61	2.95 ± 0.27	2.01 ± 0.30
General tone, CU	7.05 ± 0.56	5.62 ± 0.52	4.00 ± 0.57
Shunt index (SI), CU	1.62 ± 0.27	1.04 ± 0.19	1.01 ± 0.02
Females			
Microcirculation index (MI), p.u.	3.98 ± 0.26	8.55 ± 2.40	8.65 ± 1.15
Neurogenic tone (NT), CU	2.53 ± 0.08	2.57 ± 0.73	2.22 ± 0.32
Myogenic tone (MT), CU	4.30 ± 0.47	2.72 ± 0.45	2.23 ± 0.65
General tone, CU	6.83 ± 0.40	5.29 ± 1.06	4.44 ± 0.93
Shunt index (SI), CU	1.71 ± 0.23	1.16 ± 0.33	0.98 ± 0.21

In order to determine endogenous influences on the microcirculation index, amplitude-frequency analysis of LDF-gram was performed. It was revealed that the amplitudes of endothelial oscillations in males and females did not differ significantly from the control group. At the same time, the amplitudes of neurogenic, myogenic, and respiratory oscillations, as well as cardiorhythms, exceeded the control values. Significant differences in the An and Am indices in males between the "springboard" and "diving tower" groups were revealed. No such differences were observed in females (Table 2). Thus, the amplitudes of microvascular oscillations (except for endothelial oscillations) are higher in athletes than in people not engaged in sports.

In order to reveal the contribution of myogenic and neurogenic factors to the general vascular tone, the value of neurogenic and myogenic microvascular tone was determined. A decrease in neurogenic tone value relative to the control by 26.5% was found only in springboard divers (males). In other cases, the differences were statistically insignificant. The values of myogenic tone in males were reduced by 32% ("tower") and 53.7% ("springboard"), in females – by 36.7% ("tower") and 48% ("springboard") in comparison with the control (Table 1). Male tower divers had higher general microvascular tone (5.62 ±0.52 CU) than springboard divers (4.00±0.57 CU). In females, statistically significant differences in this parameter depending on the type of diving were not revealed (Table 1). It was shown that the main blood flow in divers was carried out through nutritive capillaries with a low proportion of shunt blood flow (shunt index SI fluctuated between 1.16±0.33 and 0.98±0.21). A decrease in general vascular tone was revealed, primarily due to the myogenic component.

Table 2.
Average distribution of amplitudes of blood flow rhythms in divers

Parameter	Control	Diving Tower	Springboard
Males			
Amplitude of endothelial oscillations (Ae), p.u.	0.29 ± 0.04	0.32 ± 0.03	0.34 ± 0.04
Amplitude of neurogenic oscillations (An), p.u.	0.39 ± 0.03	0.36 ± 0.04	0.59 ± 0.04
Amplitude of myogenic oscillations (Am), p.u.	0.21 ± 0.02	0.35 ± 0.04	0.57 ± 0.05
Amplitude of respiratory oscillations (Ar), p.u.	0.12 ± 0.02	0.18 ± 0.02	0.22 ± 0.01
Amplitude of cardiorhythms (Ac), p.u.	0.13 ± 0.01	0.20 ± 0.02	0.24 ± 0.02
Females			
Amplitude of endothelial oscillations (Ae), p.u.	0.28 ± 0.03	0.33 ± 0.04	0.35 ± 0.02
Amplitude of neurogenic oscillations (An), p.u.	0.34 ± 0.04	0.41 ± 0.03	0.45 ± 0.04
Amplitude of myogenic oscillations (Am), p.u.	0.20 ± 0.03	0.32± 0.04	0.44 ± 0.05
Amplitude of respiratory oscillations (Ar), p.u.	0.11 ± 0.01	0.19 ± 0.02	0.25 ± 0.03
Amplitude of cardiorhythms (Ac), p.u.	0.12 ± 0.02	0.20 ± 0.02	0.21 ± 0.02

The authors calculated the total volume flow (TVF), total nutritive flow (TNF), and total shunt flow (TSF). In males, TVF was significantly higher than in the control group and was 0.0189±0.003 p.u./mmHg (tower divers) and 0.0297±0.004 p.u./mmHg (springboard divers). The total nutritive blood flow in divers also exceeded the control values. Intergroup differences were revealed: in springboard divers, TNF was 68.8% higher than in tower divers (Table 3).

In girls, the values of TVF and TNF also exceeded the control values, but no significant differences were found between the springboard and tower divers. Low values of TSF should be noted in athletes of different diving disciplines (Table 3).

Table 3.
Total volume, nutritive and shunt blood flow values in divers

Parameters	Control	Diving Tower	Springboard
Males			
Total nutritive flow (TNF), p.u./mmHg	0.0058±0.001	0.018±0.003	0.029±0.002
Total shunt flow (TSF), p.u./mmHg	0.0041±0.001	0.0009±0.00004	0.0007±0.00003
Total volumetric flow (TVF), p.u./mmHg	0.0099±0.002	0.0189±0.003	0.0297±0.004
Females			
Total nutritive flow (TNF), p.u./mmHg	0.0031±0.0004	0.011±0.0009	0.011±0.0008
Total shunt flow (TSF), p.u./mmHg	0.0021±0.0005	0.002±0.0001	-
Total volumetric flow (TVF), p.u./mmHg	0.0052±0.001	0.013±0.001	0.011±0.0009

To assess the functional reserves of the microcirculation system in divers, a 3-minute occlusion test was performed, the results of which were used to determine the capillary flow reserve (CFR, %), the time to reach the maximum microcirculation index after occlusion (Tmax), and the time of blood flow half-recovery (T1/2). The results of the occlusion test are presented in Table 4.

In males, CFR values did not differ from the control. In females, CFR was on average 71.2% higher than in the control group and 51.9% higher than in males. No significant differences were found between the springboard and tower divers. It is noteworthy that CFR in females was on average 50% higher than in males (Table 4).

The time to reach the maximum microcirculation index after occlusion (Tmax) in athletes was lower by 56% compared to the control, which indicates high microvascular reactivity. The time of blood flow half-recovery (T1/2) was significantly reduced only in female athletes (Table 4).

It is known that the determination of body composition benchmarks for elite athletes is important for the physical training of high-performance athletes (Ackland et al., 2012).

There are no published data on the analysis of the body composition of highly qualified divers with regard to sex and type of diving disciplines. For this reason, the authors studied the distribution of different types of tissues in the body of athletes. The analysis of the distribution of different types of tissues in the body of athletes revealed an increase in the amount of fat mass in % in females compared to males in all types of diving disciplines. At the same time, no statistically significant differences were revealed in values of absolute content of fat mass in the body of athletes of different sexes associated with a tendency to a higher content of this type of tissue in females in comparison with males (Tables 5, 6). At the same time, a significant decrease in the amount of fat mass in the body was found in 10-m tower divers compared to athletes performing diving from other equipment (Tables 5, 6).

Table 4.
Main parameters of the occlusion test in divers

Parameters	Control	Diving Tower	Springboard
Males			
CFR, %	164.2±19.0	133.6±23.9	169.2 ±27.7
Tmax, s	32.5±5.2	40.14±7.2	26.1±0.7
T ½, s	25.9±3.0	32.8 ±4.3	26.6±0.6
Females			
CFR, %	132.7±14.4	224.0±43.6	230.5±17.6
Tmax, s	30.5±3.5	14.42±2.6	17.3±2.1
T ½, s	35.0±5.1	19.6±3.9	21.5±5.0

In order to increase the reliability of determining the model characteristics of athletes, a comparative analysis of the studied indicators was carried out in diving athletes who had the rank of a candidate for master of sports and master of sports. Masters of sports showed lower values of relative and absolute amounts of adipose tissue in the body in comparison with athlete candidates for master of sports of both sexes for all types of diving disciplines (Tables 5, 6). Moreover, in females of higher qualification, a tendency to increase the amount of adipose tissue in % relative to males was revealed, but these differences were not statistically significant.

The amount of fat-free mass and water mass in males exceeds those in females. The maximum fat-free mass and water mass were found in 10-m tower divers (Tables 5, 6).

Table 5.
Ratio of different tissue types in the body of qualified divers (individual diving)

Parameters	Springboard		5m Diving Tower		10m Diving Tower
	Males	Females	Males	Females	Males
Candidates for master of sports					
FAT, %	15.7 ± 1.1	21.6 ± 2.3	15.3 ± 0.8	21.3 ± 2.1	9.5 ± 1.2
FAT mass, kg	9.7 ± 0.5	10.8 ± 1.3	9.8 ± 0.7	11.2 ± 0.9	7.3 ± 0.9
FFM, kg	45.1 ± 1.7	43.3 ± 1.7	42.4 ± 2.9	38.9 ± 1.7	43.4 ± 3.7
TBW, kg	31.4 ± 1.3	27.9 ± 1.8	31.0 ± 1.7	28.5 ± 1.3	32.1 ± 3.1
Masters of sports					
FAT, %	13.7 ± 0.7	15.6 ± 1.9	12.9 ± 0.9	15.3 ± 1.7	6.1 ± 0.9
FAT mass, kg	7.1 ± 0.7	7.5 ± 1.1	7.3 ± 0.9	8.1 ± 1.2	5.3 ± 1.2
FFM, kg	49.0 ± 1.7	48.7 ± 2.7	49.4 ± 2.3	48.9 ± 2.7	56.4 ± 2.3
TBW, kg	34.3 ± 1.7	33.7 ± 1.9	34.7 ± 1.5	35.0 ± 2.7	41.1 ± 2.9

Table 6.
Ratio of different tissue types in the body of qualified divers (synchronized diving)

Parameters	Diving Tower		Springboard	
	Males	Females	Males	Females
Candidates for master of sports				
FAT, %	15.8 ± 1.9	23.2 ± 1.8	15.7 ± 1.1	21.2 ± 2.3
FAT mass, kg	9.1 ± 1.2	11.1 ± 0.9	9.8 ± 0.9	11.3 ± 1.3
FFM, kg	42.9 ± 2.7	41.5 ± 2.2	41.4 ± 2.3	37.5 ± 1.9
TBW, kg	30.8 ± 1.9	27.2 ± 0.9	30.0 ± 1.2	27.2 ± 1.9
Masters of sports				
FAT, %	12.8 ± 1.3	16.2 ± 1.8	12.7 ± 2.1	16.2 ± 2.3
FAT mass, kg	7.1 ± 1.2	8.3 ± 0.9	6.3 ± 0.9	8.3 ± 1.3
FFM, kg	49.8 ± 2.7	48.5 ± 2.3	48.4 ± 2.3	46.5 ± 2.9
TBW, kg	35.8 ± 1.9	33.2 ± 0.9	35.0 ± 1.2	33.2 ± 1.9

An analysis of the segmental body composition of athletes showed a decrease in the amount of fat and an increase in the fat-free and relative muscle mass in the lower limbs of males compared to those of females (Tables 6, 7). Within diving disciplines, statistically significant differences in tissue distribution in the lower limbs were revealed only in 10-m tower divers in comparison with athletes performing other types of diving. They were characterized by the minimum content of fat tissue and the maximum amount of fat-free and relative muscle mass in the lower limbs (Tables 7, 8).

In the upper limbs of athletes, a tendency to decrease the amount of adipose tissue was revealed in males compared to females, but these differences were not statistically significant. The content of fat-free and relative muscle mass in the upper limbs was significantly higher in males compared to females (Tables 6, 7). Moreover, higher values of these parameters were found in 10-m tower divers. In representatives of other types of diving, statistically significant differences in the distribution of different types of tissues in the upper limbs were not revealed (Tables 7, 8).

Table 7.
Segmental body composition of qualified divers (individual diving)

Parameters	Springboard		5-m diving tower		10-m diving tower
	Males	Females	Males	Females	Males
left lower limb					
FAT mass, kg	2.0 ± 0.2	2.4 ± 0.1	1.9 ± 0.2	2.5 ± 0.2	1.4 ± 0.3
FFM, kg	8.3 ± 0.3	6.3 ± 0.4	7.6 ± 0.3	6.3 ± 0.2	9.4 ± 0.5
PMM, kg	7.9 ± 0.5	5.9 ± 0.3	7.2 ± 0.2	5.9 ± 0.4	9.0 ± 0.3
right lower limb					
FAT mass, kg	2.0 ± 0.2	2.5 ± 0.2	1.9 ± 0.2	2.3 ± 0.1	1.3 ± 0.4
FFM, kg	8.0 ± 0.4	6.5 ± 0.3	7.3 ± 0.2	6.3 ± 0.1	9.2 ± 0.4
PMM, kg	7.6 ± 0.3	6.1 ± 0.2	7.9 ± 0.4	5.9 ± 0.3	8.7 ± 0.3
left upper limb					
FAT mass, kg	0.5 ± 0.2	0.7 ± 0.3	0.5 ± 0.2	0.7 ± 0.2	0.4 ± 0.1
FFM, kg	2.4 ± 0.1	1.8 ± 0.2	2.2 ± 0.1	1.7 ± 0.2	3.1 ± 0.3
PMM, kg	2.2 ± 0.2	1.7 ± 0.2	2.0 ± 0.1	1.6 ± 0.2	2.9 ± 0.1
right upper limb					
FAT mass, kg	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.7 ± 0.2	0.4 ± 0.2
FFM, kg	2.4 ± 0.3	1.5 ± 0.2	2.1 ± 0.1	1.6 ± 0.3	3.0 ± 0.2
PMM, kg	2.3 ± 0.3	1.4 ± 0.2	2.0 ± 0.3	1.5 ± 0.2	2.9 ± 0.2
body					
FAT mass, kg	2.9 ± 0.5	3.6 ± 0.3	2.5 ± 0.3	3.9 ± 0.2	2.0 ± 0.3
FFM, kg	25.9 ± 0.3	23.0 ± 0.5	24.3 ± 0.4	22.8 ± 0.3	28.6 ± 0.5
PMM, kg	24.9 ± 0.3	22.0 ± 0.5	23.7 ± 0.5	21.8 ± 0.4	27.5 ± 0.3

Table 8.
Segmental body composition of qualified divers (synchronized diving)

Parameters	Diving Tower		Springboard	
	Males	Females	Males	Females
left lower limb				
FAT mass, kg	1.9 ± 0.3	2.5 ± 0.2	1.9 ± 0.1	2.7 ± 0.2
FFM, kg	7.9 ± 0.2	6.2 ± 0.3	7.6 ± 0.4	6.1 ± 0.3
PMM, kg	7.7 ± 0.3	5.8 ± 0.4	7.2 ± 0.2	5.7 ± 0.3
right lower limb				
FAT mass, kg	2.0 ± 0.2	2.8 ± 0.3	1.9 ± 0.3	2.8 ± 0.4
FFM, kg	7.9 ± 0.2	6.4 ± 0.3	7.3 ± 0.5	6.4 ± 0.2
PMM, kg	7.6 ± 0.3	6.5 ± 0.3	7.9 ± 0.3	6.0 ± 0.4
left upper limb				
FAT mass, kg	0.5 ± 0.3	0.7 ± 0.1	0.5 ± 0.2	0.8 ± 0.2
FFM, kg	2.3 ±0.2	1.7 ± 0.2	2.2 ± 0.1	1.7 ± 0.1
PMM, kg	2.1 ±0.3	1.6 ± 0.1	2.0 ±0.1	1.6 ± 0.2
right upper limb				
FAT mass, kg	0.7 ± 0.3	0.6 ± 0.2	0.6 ± 0.3	0.7 ± 0.1
FFM, kg	2.3 ± 0.3	1.6 ± 0.3	2.1 ± 0.3	1.6 ± 0.2
PMM, kg	2.3 ± 0.3	1.5 ± 0.2	2.1 ± 0.3	1.5 ± 0.1
body				
FAT mass, kg	2.8 ± 0.3	4.0 ±0.3	2.5 ± 0.3	4.1 ± 0.4
FFM, kg	25.1 ± 0.3	22.6 ± 0.5	23.9 ± 0.4	22.6 ± 0.2
PMM, kg	24.0 ± 0.5	21.6 ± 0.3	24.1 ± 0.3	21.6 ± 0.5

The analysis of the composition of the athletes' bodies showed the predominance of relative muscle, fat-free mass, and a decrease in adipose tissue in males compared to females. The minimum amount of fat and the maximum content of fat-free and relative muscle mass were found in 10-m tower divers compared to athletes of other types of diving (Tables 7, 8).

Discussion

The analysis of the obtained data on the peculiarities of microcirculation in divers indicates that regular physical loads result in significant adaptations in the microvasculature of athletes, likely due to long-term muscular activity. Divers are characterized by a high index of microcirculation and total blood flow, suggesting increased blood inflow into the microvasculature. This increase in microcirculation can be attributed to both a higher number of functionally active capillaries and a reduction in microvascular tone (mainly due to decreased myogenic component activity). Maintaining a high level of perfusion is essential for divers, as it ensures optimal tissue oxygenation and metabolite delivery, which are critical for endurance during exercise (Szanto et al., 2021).

Supporting these findings, previous research has shown that physical fitness significantly enhances microvascular function. Studies such as Montero et al. (2015) and Franzoni et al. (2004) highlight that athletes exhibit superior microvascular function compared to sedentary individuals, largely due to increased nitric oxide (NO) availability, which improves endothelial function and microcirculatory responses. These results align with the elevated microvascular reactivity observed in our divers, where increased oscillation amplitudes and blood flow reflect robust microvascular performance in response to physical training.

Furthermore, physical fitness and age are key factors influencing microvascular adaptation in divers. As Franzoni et al. (2004) noted, regular exercise helps counteract age-related declines in endothelial function, promoting sustained microcirculatory health even in older athletes. In our study, the high capillary density observed in young divers can be explained by the developmental phase of microcirculatory networks, as suggested by Krupatkin and Sidorov (2016), where a significant increase in capillary density occurs during adolescence due to hormonal and growth-related changes.

The amplitudes of all types of oscillations in the microvasculature (except for endothelial oscillations) in divers were higher than in the control group. The increase in neurogenic oscillations was associated with reduced microvascular resistance, while myogenic oscillations were linked to heightened activity in precapillary sphincters and arterioles. The observed growth in respiratory oscillations was due to decreased microcirculatory pressure, and increased cardiorhythms were indicative of reduced overall tone in microvascular walls. These changes suggest increased perfusion in the athletes.

The shunt index in divers was lower than in the control group, indicating that most blood flow in athletes occurs through nutritive capillaries. Low CFR values in both male and female divers may be attributed to their young age and the specific demands of the sport. Aerobic training has been shown to enhance capillary networks, as demonstrated by Dvurekova (2018) and Meng et al. (2021). Furthermore, the microvasculature is dynamic and undergoes structural changes throughout ontogeny, with a marked increase in capillary density occurring after age 16, likely due to hormonal and growth-related factors (Krupatkin & Sidorov, 2016). High capillary density not only ensures adequate oxygenation but also accelerates muscle recovery after damage (Hendrickse & Degens, 2019).

The occlusion test results revealed a significant reduction in blood flow recovery time (Tmax) during post-occlusion hyperemia in the "springboard" group, suggesting high microvascular reactivity and the dominance of vasodilatory factors. In female divers, the shorter half-recovery time (T1/2) could be due to the rapid removal of anaerobic metabolic byproducts accumulated during occlusion, further indicating efficient microvascular function.

Statistically significant differences in some LDF parameters (such as neurogenic and myogenic oscillations, total nutritive flow, and blood flow recovery during hyperemia) were observed between the "tower" and "springboard" groups, particularly among young male athletes. These differences may reflect individual variability in microvascular adaptation based on the specific demands of each diving discipline.

The assessment of athletes' body composition revealed lower fat mass and higher fat-free and relative muscle mass in males compared to females, particularly in the lower limbs and trunk. Although there were no statistically significant differences in body composition across diving disciplines, 10-meter tower divers showed significantly lower fat content and higher fat-free and relative muscle mass compared to athletes in other diving categories.

Establishing a morphological model for qualified divers is critical for effective sports orientation, performance success, and professional longevity. Quantitative assessments of body composition and muscle characteristics are essential for coaches and sports physicians, as these parameters provide a foundation for designing training regimens that improve performance, achieve peak physical condition, and regulate body weight and active muscle mass in divers.

Conclusions

The analysis of the distribution of different types of tissues showed that lower values of fat mass and the predominance of fat-free and relative muscle mass were found in males compared to females. Divers from a 10-meter tower showed a statistically significant decrease in the content of fatty tissue and an increase in the amount of fat-free and relative muscle mass in the body compared to athletes of other diving disciplines.

The study of microcirculation peculiarities of divers showed a high level of tissue perfusion due to a decrease in the overall tone of microvessels and/or an increase in the number of functionally active capillaries. The main blood flow in the microvasculature goes through nutritive vessels, which contributes to a better supply of oxygen and energy substrates to muscle cells.

Regular physical loads, typical for diving, do not lead to the formation of a developed capillary network, as evidenced by the low values of reserve capillary blood flow (no more than 169.2 ±27.7% in males and 230.5 ±17.6% in females). The possible reason for the low values of reserve capillary blood flow is the young age of athletes.

Divers are characterized by high microvascular reactivity, including to metabolic stimuli. The main LDF parameters of microcirculation do not reliably differ in tower divers and springboard divers. Intergroup differences were revealed only in males in the following parameters: the amplitude of neurogenic oscillations and neurogenic and myogenic tones of microvessels, which, apparently, is associated with the individual characteristics of athletes.

Thus, laser Doppler flowmetry is an informative method of studying the microhemodynamics of athletes. The LDF method allows the specialists to determine the current state of the microvasculature, to identify possible functional disorders, and to assess the reactivity of microvessels in response to metabolic effects of an anaerobic character. This is necessary to determine the speed of recovery processes in the microvasculature in response to anaerobic loads. The establishment of reference parameters of microcirculation of highly qualified divers contributes to the improvement of the quality of sports selection at various stages of multi-year training.

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Conflicts of Interest

The authors declare no conflicts of interest.

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