



ORIGINAL ARTICLES. SPORT

Influence of physical load of maximum aerobic power on hemodynamics and morpho-biochemical changes in erythrocytes in female volleyball players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

DOI: <https://doi.org/10.34142/HSR.2022.08.01.03>

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How to Cite

Popel SL, Śliwiński Z. Influence of physical load of maximum aerobic power to hemodynamics and morpho-biochemical changes of erythrocytes of volleyball players. *Health, Sport, Rehabilitation*. 2022;8(1):39-51. <https://doi.org/10.34142/HSR.2022.08.01.03>

Abstract

Purpose: to study the types of cardiohemodynamic response of the organism and morpho-biochemical changes of erythrocytes of peripheral blood of volleyball players to physical activity of maximum aerobic capacity.

Material and methods In 18 highly qualified volleyball players aged 22.0±0.60 years, cardiohemodynamics (by functional methods), functional changes (by biochemical methods) and the structure of erythrocytes (using scanning electron microscopy) were studied before and after the maximum (3.5 W/kg of body weight) of physical activity.

Results. It was found that maximal physical activity causes significant changes in cardiohemodynamics, which result in morphological rearrangement of peripheral blood erythrocytes (increase in erythrocyte deformation index) and closely correlate with biochemical changes (decrease in ATP concentration and increase in magnesium concentration in erythrocytes). Possible mechanisms of realization of features of reaction of an organism of volleyball players to physical activity of the maximum aerobic power depending on type of regulation of blood circulation and morpho-biochemical changes of erythrocytes of peripheral blood are discussed.

Conclusions. Physical activity of maximum aerobic power in highly qualified female volleyball players reveals the typological features of the cardiohemodynamic response of the body of volleyball players, which is expressed by conformational changes in peripheral blood erythrocytes and depends on the concentration of individual macroelements in these cells and on the type of cardiohemodynamics.

Key words: volleyball players, types of blood circulation, macronutrients, physical activity, erythrocytes



Анотація

Попель С.Л., Слівінські З. Вплив фізичного навантаження максимальної аеробної потужності на гемодинаміку і морфо-біохімічні зміни еритроцитів у волейболісток

Мета: вивчити типи кардіогемодінамічного реагування організму та морфо-біохімічні зміни еритроцитів периферичної крові волейболісток на фізичне навантаження максимальної аеробної потужності.

Матеріал і методи. У 18 волейболісток високої кваліфікації у віці $22,0 \pm 0,60$ років досліджено кардіогемодинаміку (функціональними методами), функціональні зміни (біохімічними методами) та структуру еритроцитів (за допомогою скануючої електронної мікроскопії) до і після максимального (3,5 Вт/кг маси тіла) фізичного навантаження.

Результати. Встановлено, що максимальне фізичне навантаження викликає істотні зміни кардіогемодинаміки, які залежать від морфологічної перебудови еритроцитів периферичної крові (збільшення індексу деформації еритроцитів) і тісно корелюють з біохімічними змінами (зменшення концентрації АТФ і збільшення концентрації магнію в еритроцитах). Обговорюються можливі механізми реалізації особливостей реакції організму волейболісток на фізичне навантаження максимальної аеробної потужності в залежності від типу регуляції кровообігу і морфо-біохімічних змін еритроцитів периферичної крові.

Висновки. Фізичне навантаження максимальної аеробної потужності у волейболісток високої кваліфікації виявляє типологічні особливості кардіогемодінамічного реагування організму волейболісток, що виражається конформаційними змінами еритроцитів периферичної крові та залежить від концентрації окремих макроелементів у цих клітинах та від типу кардіогемодинаміки.

Ключові слова: волейболістки, типи кровообігу, макроелементи, фізичне навантаження, еритроцити

Аннотация

Попель С.Л., Сливински З. Влияние физической нагрузки максимальной аэробной мощности на гемодинамику и морфо-биохимические изменения эритроцитов у волейболисток

Цель: изучить типы кардиогемодинамического реагирования организма и морфо-биохимические изменения эритроцитов периферической крови волейболисток на физическую нагрузку максимальной аэробной мощности.

Материал и методы. У 18 волейболисток высокой квалификации в возрасте $22,0 \pm 0,60$ лет исследовано кардиогемодинамику (функциональными методами), функциональные изменения (биохимическими методами) и структуру эритроцитов (с помощью сканирующей электронной микроскопии) до и после максимальной (3,5 Вт/кг массы тела) физической нагрузки.

Результаты. Показано, что физическая нагрузка максимальной аэробной мощности вызывает существенные изменения кардиогемодинамики, которые зависят от морфологической перестройки (увеличение индекса деформации эритроцитов периферической крови) и тесно коррелируют с биохимическими изменениями (уменьшение концентрации АТФ и увеличение концентрации магния в эритроцитах). Обсуждаются возможные механизмы реализации особенностей реакции организма волейболисток на физическую нагрузку максимальной аэробной мощности в зависимости от типа регуляции кровообращения и морфо-биохимическими изменениями эритроцитов периферической крови.

Выводы. Физическая нагрузка максимальной аэробной мощности у волейболисток высокой квалификации выявляет типологические особенности кардиогемодинамического реагирования организма волейболисток, что выражается конформационными изменениями эритроцитов периферической крови и зависит от концентрации отдельных макроэлементов в этих клетках и от типа кардиогемодинамики.

Ключевые слова: волейболистки, типы кровообращения, макроэлементы, физическая нагрузка, эритроциты



Introduction

The determining parameter of different types of cardiohemodynamics is the cardiac index [1]. Determining this indicator helped to identify reserves of functional capabilities of students [2], in the selection of training tactics for men and women during long-term health running [3], as well as wrestlers of different ages [4].

The range of its oscillations in healthy people is divided into several types of cardiohemodynamics [1]. However, this heterogeneity is due to the level of autonomic regulation [4] and is the norm of somatic health of people of all ages [5], including students of different sexes [6].

Exercise, especially maximum aerobic power, can cause changes not only in central cardiohemodynamics [4], but also creates the conditions for disruption of erythrocyte hemostasis [7]. Such changes in erythrocytes are determined by biochemical and macronutrient imbalance, which affects their ability to deform [8]. Among the factors that determine the deformation capacity of erythrocytes, the intracellular concentration of magnesium and calcium ions is of vital importance [7]. Knowledge of the value of their content in erythrocytes is important because the interaction of 2,3-diphosphoglycerate and adenosine triphosphate (ATP) with hemoglobin is largely regulated by these ions. Magnesium is known to bind to the 2,3-diphosphoglycerate molecule to increase the ability of hemoglobin to retain intracellular oxygen [9]. The number of intracellular magnesium and calcium ions has a significant effect on the level of cardiohemodynamics [3] and largely depends on the type of autonomic regulation of heart rate [10]. In many works [7, 8, 9, 11, 12, 13, 14] conducted in recent years for the main purpose of the study, the authors point to the establishment of correlations between the level of maximum exercise and changes in cardiohemodynamics and its dependence on morphological adjustment of peripheral blood erythrocytes (increase in erythrocyte deformity index) and biochemical similar results in the field of medical and biological support of modern physical culture and sports.

Modern high-achievement sports are characterized by intense training and competitive loads. For quality management of sports training in these conditions it is extremely necessary to assess the current functional state of the body and regular monitoring of the health of athletes [15]. Thus, we need simple, accessible, but at the same time, objective, highly informative and specific research methods that would verify these processes before the

manifestations of fatigue and overtraining [16]. In general, this task relates to the field of laboratory control over the state of fitness of athletes [13, 15, 17]. However, among the wide range of parameters that are determined in medical and biological research, taking into account the realities of the training process in qualified athletes, it is necessary to identify those that will provide fairly objective information about functional status and physical performance at one time or another [18, 19], and such a study can be performed quickly [20]. Such a "window" into the athlete's body, in our opinion and in accordance with the views of other researchers [21, 22], are erythrocytes, as highly specialized non-nuclear blood cells with a limited lifespan (approximately 90-120 days), specialized before all on the delivery of oxygen to working organs and tissues. It is known that the oxygen transport capacity of erythrocytes is determined primarily by the concentration of hemoglobin in them and the partial pressure of oxygen. At full oxygen saturation ($PO_2 = 90$ mm Hg), each gram of hemoglobin localized exclusively in erythrocytes can transport 1.34 ml of oxygen [19, 23, 20, 24]. Thus, for an athlete whose hemoglobin level in the blood averages $150 \text{ g} \cdot \text{l}^{-1}$, oxygen transport capacity reaches 200 ml of oxygen per liter of arterial blood; in women, this value is approximately 10% less due to the lower content of erythrocytes [23, 24]. Oxygen is released from hemoglobin when blood flows through a capillary bed [25]. Morphofunctional features of erythrocytes are largely related to their size and deformability of their cytoskeleton [26], so they easily penetrate through capillaries 3-4 μm in size, although they have a diameter almost twice as large [27, 28]. This relatively small lumen from 3 to 6 mm is characterized, including capillaries of muscle tissue [29]. Under normal conditions, the erythrocyte in a stationary state has a biconcave shape "torus", when the diameter of the discocytes is 7.3-7.8 μm . This form is determined by the membrane rather than the intracellular content of erythrocytes. The erythrocyte volume is 85-95 femtoliters (1 fl = 10^{-15} l). In the peripheral blood of a healthy person, the number of discocytes of the correct shape is approximately 85%, and discocytes of modified shape, with one or multiple protrusions, ridges, spines, etc. can reach 12-13%. The increase in the content of erythrocytes in the blood with an abnormally altered form is accompanied by a deterioration in the passage of these cells in the lumen of the microvessel [30, 31, 32]. It is with these well-known sports physiologists and specialists in the field of laboratory diagnostic data, in our field of vision was an erythrocyte, which contains hemoglobin. The starting point of the working hypothesis of the study was the possibility



of indirect assessment of oxygen transport capacity of blood and, consequently, aerobic capacity, by studying changes in the characteristics of erythrocytes, which are the only possible unique oxygen-carrying cells in athletes.

There are only some works that study the types of hemodynamics depending on the morpho-biochemical state of erythrocytes [23, 24]. However, it is not clear what is the ratio of such types in healthy people [33, 34]. Data from some authors indicate the same proportion of different types of cardiohemodynamics [3]. Other studies have noted the predominance of one [12, 32], which also depends on a person's age [35] and gender [36]. At the same time, scientists ignore the question of their origin [37] and the peculiarities of such a reaction to physical activity of maximum aerobic power [38, 39] in athletes depending on their age [5, 40], sex [41] and specialization [42]. .

Hypothesis. It is assumed that in athletes with different types of cardiohemodynamics, the reaction to exercise of maximum aerobic power may be due to changes in macronutrient composition and deformation capacity of erythrocytes.

The aim of the work is to study the peculiarities of cardiohemodynamic reaction of volleyball players' body to physical activity of maximum aerobic capacity depending on morpho-biochemical features of peripheral blood erythrocytes.

Material and methods

Participants

The study involved 18 volleyball players aged 20.0 ± 0.6 years, who gave written consent to participate in the study, which ensures compliance with the requirements of the Declaration of Helsinki. The total experience of volleyball for participants was 20-25 years. Volleyball players were selected as follows: a prerequisite for participation in the study was the presence of sports qualifications in the past not less than a candidate for master of sports (winners of competitions not lower than the region and Ukraine) and regular training for the last 10 years 3-4 times a week. The study was conducted on the basis of sports clubs "University of PNU", Ivano-Frankivsk Ukraine.

All participants were informed about the purpose of the study and gave written consent to participate in the study, which was conducted in accordance with the Helsinki Declaration of the WMA - Ethical Principles of Medical Research for Human Subjects, 2013.

Procedure

The study used physical activity of maximum aerobic power of 3.5 W / kg body weight, which was performed on a Kettler ergometer (Germany), and the determination of cardiohemodynamic parameters was carried out using a computer cardiographic system "CardioLab +" "KHAI-MEDICA". Ukraine).

Cardiohemodynamic changes during urgent adaptation to maximal aerobic exercise were assessed by cardiac index, systolic, diastolic, and mean arterial pressure, as well as changes in heart rate, stroke, and circulatory volume. The energy characteristics of cardiac activity [10] and myocardial oxygen demand were determined by the value of the double product [15, 16,].

Morpho-biochemical methods of erythrocyte analysis

To study the morpho-biochemical changes of erythrocytes, capillary blood was taken according to the protocol for determining the level of glucose in blood plasma before and 5 minutes after exercise at maximum aerobic capacity. The concentration of hemoglobin was studied by standard cyanomethemoglobin method [17], the number of erythrocytes was detected by a unified counting method in the Goryaev chamber, hematocrit was determined by micromethod using standard heparinized capillaries [18], the concentration of adenosine triphosphate in Javerbaum et al., Adenosine diphosphate (ADP) and adenosine monophosphate (AMP) - according to the method of Bergmeyer [7].

Morphological studies of erythrocytes were performed in a scanning electron microscope "JEOL-25M-T220A" (Japan) according to conventional methods [21].

To compare different forms of erythrocytes and assess the level of their morphological conformation, the erythrocyte deformation index was calculated by the formula: $IDE = A - B / B$, where A is the total number of erythrocytes, B is the number of irreversibly altered erythrocyte forms, B is the number of inversely altered erythrocyte forms. The low level of conformational ability of erythrocytes is determined at values of erythrocyte deformation index from 1.6 to 2.5, medium - in the range of 2.6-3.9, high - at 4.0-6.0.

To determine the electrolyte composition of erythrocytes in a muffle furnace at t 800 Co ash was 2 ml of erythrocyte mass. The ash was pressed, after which the surface of the mold was sprayed with carbon (≈ 10 nm). Determination of erythrocyte



concentration of macronutrients such as sodium (Na), potassium (K), iron (Fe), magnesium (Mg) and calcium (Ca) was performed using a computer program "SELMI" and a prefix for energy-dispersive X-ray microanalysis EDAR "On the REMMA-102E scanning electron microscope (SELMI, Ukraine) with an accelerating voltage of 20 kV in the energy range from 960 to 19600 kiloelectron-volts (keV).

Statistical analysis

Statistical processing of quantitative indicators was performed using the computer software package "Statistica 6.0" [43]. Data are presented as arithmetic mean \pm standard deviation ($M \pm SD$). The obtained results were not subject to the law of normal distribution according to the Kolmogorov-Smirnov criterion, therefore the statistical significance of the intergroup difference was estimated using the Mann-Whitney test and the nonparametric Kruskal-Wallis test using the nonparametric Spearman correlation coefficient. The difference was considered statistically significant at a bilateral level of $p < 0.05$.

To determine the significance of the impact of qualitative value of the erythrocyte deformation index on the functional state of the cardioregulation system, a nonparametric analysis of variance of heart rate variability was performed both before and after exercise at maximum aerobic capacity.

Results

Studies have shown that at rest in volleyball players is the heterogeneity of different types of cardiohemodynamics. According to the typological analysis, 7 (38.9%) volleyball players had a hypokinetic type, 6 (33.3%) had a eukinetic type, and 5 (27.8%) subjects had a hyperkinetic type of cardiohemodynamics.

Volleyball players with a hyperkinetic type of cardiohemodynamics had significantly higher heart rates, heart rate, stroke and minute blood volume, and double the product ($p < 0.05$). In volleyball players with hypokinetic type of cardiohemodynamics, the initial values were the lowest, and in volleyball players with eukinetic type of cardiohemodynamics, these indicators occupied an intermediate position.

It was found that in volleyball players with hyperkinetic type of cardiohemodynamics, a

significant increase in systolic blood pressure reaches a maximum by the end of the first minute of exercise of maximum aerobic power. As for volleyball players with hypokinetic and eukinetic types of cardiohemodynamics, their systolic blood pressure, reaching a maximum in the second minute of exercise, does not change until the end of the test. The increase in systolic blood pressure during exercise of maximum aerobic capacity was mainly due to an increase in stroke volume and did not depend on the type of cardiohemodynamics. However, in volleyball players with hypokinetic type of cardiohemodynamics, the septic index increased 2.82 times, while in volleyball players with hyperkinetic type of cardiohemodynamics increased 3.09 times ($p < 0.05$).

In all volleyball players, the average blood pressure changes significantly after the first minute of exercise of maximum aerobic capacity, which occurs due to increased heart rate and statistically significant decrease in double the product ($p < 0.05$).

During restitution, the tendency to normalize all cardiohemodynamic parameters was manifested in the first minute of the recovery period only in volleyball players with eukinetic type of cardiohemodynamics, while in volleyball players with hypokinetic and hyperkinetic type of cardiohemodynamics, the probability of differences persists.

After physical activity of maximum aerobic power, all volleyball players have a statistically significant increase in hematocrit and hemoglobin level ($P < 0.05$). However, in the hypokinetic type of cardiohemodynamics, the increase in hematocrit and hemoglobin level occurs against the background of increasing the number of erythrocytes due to the development of hemoconcentration, while volleyball players with eukinetic type of cardiohemodynamics have a decrease in erythrocytes. In volleyball players with hyperkinetic type of cardiohemodynamics, exercise of maximum aerobic capacity causes an increase in the number of erythrocytes in the largest volume (on average by $15.3 \pm 0.11\%$, $p < 0.05$).

When studying the indicators of energy metabolism, it was found that volleyball players have reduced ATP content and increased concentration of AMP (Table 1).



Table 1

The content of adenyl nucleotides in peripheral blood erythrocytes in volleyball players with different types of hemodynamics (M ± SD)

Indicator	Hypokinetic type of cardiohemodynamics (n=6)	Eukinetic type of cardiohemodynamics (n=7)	Hyperkinetic type of cardiohemodynamics (n=5)
ATP, mmol / l	1.46±0.18 [#]	1.87±0.14	1.12±0.33 ^{*#}
ADP, mmol / l	0.68±0.34 [#]	1.17±0.36	0.79±0.42 [#]
AMP, mmol / l	1.4±0.45 [#]	0.89±0.12	1.68±0.63 [#]
ATP/ADP	2.22±0.46 [#]	1.62±0.23	1.62±0.91 [*]
ADP x AMP/ATP	0.74±0.61 [#]	0.56±0.11	1.31±1.07 ^{*#}

Notes: * - marked statistic significance of the difference in indicators in comparison with volleyball players with hypokinetic type of cardiohemodynamics, # - in comparison with indicators of volleyball players with eukinetic type of cardiohemodynamics (p < 0,05).

The most pronounced changes in the studied parameters were registered in volleyball players with hyperkinetic type of cardiohemodynamics. This is confirmed by data on changes in spectral parameters in volleyball players with different types of

cardiohemodynamics. It was found that in volleyball players with hyperkinetic type of cardiohemodynamics most spectral and temporal indicators of heart rate variability differed significantly from similar parameters of volleyball players with eukinetic and hypokinetic type of cardiohemodynamics (Tables 2, 3).

Table 2

Values of heart rate variability of volleyball players with different types of blood circulation and the value of erythrocyte deformation index to physical activity of maximum aerobic productivity, (M ± SD, n = 18)

Indicator	Type of blood circulation regulation / erythrocyte deformation index level		
	Hypotonic / low	Eukinetic / low	Hyperkinetic / average
Heart rate beats per minute	78.1±1.53	71.9±1.43	70.6±1.94
The average duration of the RR interval, ms	0.78±0.04	0.85±0.03	0,88±0.02
SDNN, ms	0.05±0.001	0.06±0.002	0.06±0.006
RMSSD, ms	0.05±0.003	0.05±0.001	0.06±0.012
pNN50, %	27.1±4.57	30.1±1.87	31.7±7.11
TF, ms ²	4003.1±305.33 [*]	4427.3±247.19	5414.9±1281.6 [*]
VLF, ms ²	1093.9±54.31 [*]	1610.5±81.63	1902.8±58.32 [*]
LF, ms ²	1103.3±47.85 [*]	1345.5±92.74	1744.8±52.44 [*]
HF, ms ²	1194.2±66.14 [*]	1081.9±101.32	1089.4±427.08
LF/HF	1.4±0.12 [*]	1.7±0.15	2.4±0.42 [*]
pLF, %	50.7±1.35 [*]	57.4±1.42	64.4±4.32 [*]
pHF, %	49.2±1.04 [*]	42.6±1.02	35.7±4.33 [*]

Notes: * - in comparison with volleyball players with eukinetic type of cardiohemodynamics the difference is probable at p < 0, LF - spectrum power in the low frequency range; HF - spectrum power in the high frequency range; RMSSD - root mean square difference between the duration of R-R intervals; SDNN - standard deviation of R-R intervals; SDANN - standard deviation of the difference between successive R-R intervals; PNN50 - the proportion of consecutive R-R intervals, the difference between which exceeds 50 ms; TF - total spectrum power; VLF - spectrum power in the very low frequency range.

Table 3

Values of heart rate variability of volleyball players with different types of blood circulation and the value of the erythrocyte deformation index after exercise of maximum aerobic productivity, ($M \pm SD$, $n = 18$)

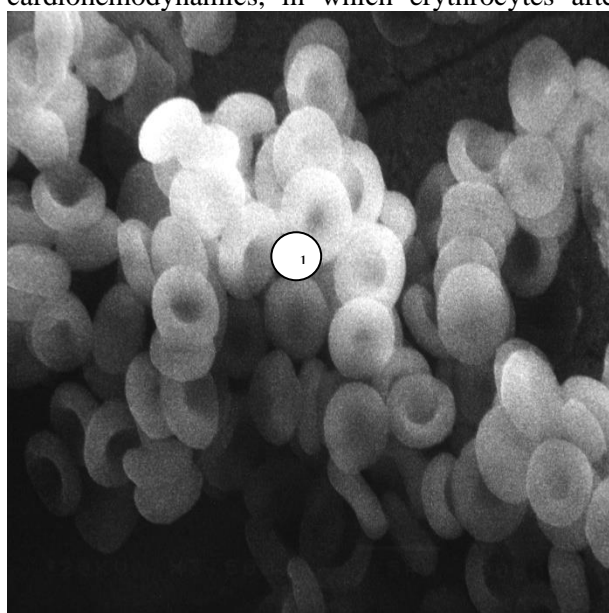
Indicator	Type of blood circulation regulation / erythrocyte deformation index level		
	Hypotonic / low	Eukinetic / low	Hyperkinetic / average
Heart rate beats per minute	90.8±3.06*	82.6±0.92	78.1±3.43
The average duration of the RR interval, ms	0.68±0.04*	0.74±0.02	0.78±0.04
SDNN, ms	0.05±0.001	0.05±0.001	0.05±0.001
RMSSD, ms	0.03±0.001*	0.04±0.001	0.05±0.001*
pNN50, %	18.7±5.53*	16.9±1.43	20.0±5.94*
TF, ms ²	2208.1±374.33*	3447.8±292.12	5282.6±117.24*
VLF, ms ²	689.1±105.47*	1298.5±181.63	1975.3±157.75*
LF, ms ²	581.2±92.12*	1112.9±77.51	1660.6±297.82*
HF, ms ²	588.8±142.64	649.0±66.33	1017.3±313.15*
LF/HF	1.8±0.32*	2.0±0.11	2.8±0.22
pLF, %	48.6±4.44*	62.9±1.53	65.6±5.44
pHF, %	51.4±4.42*	37.1±1.57	34.5±5.23

Note. see approx. to table 2.

The results of the calculation of the non-parametric Spearman correlation coefficient indicate that there is a probable positive relationship between individual indicators of heart rate variability and the value of the erythrocyte deformation index (see Table 3, mark *).

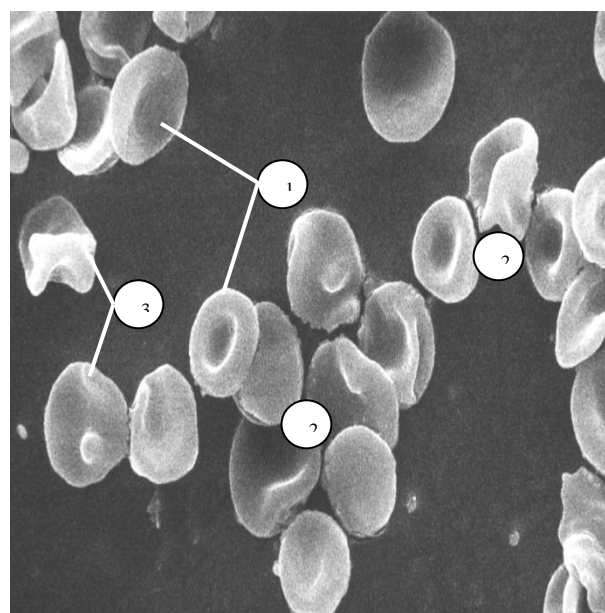
Along with these changes, there is a structural rearrangement of erythrocytes. Thus, in contrast to volleyball players with eukinetic type of cardiohemodynamics, in which erythrocytes after

exercise of maximum aerobic power remain almost unchanged (Fig. 1 a), volleyball players with hypokinetic type of cardiohemodynamics (Fig. 1 b) have some inversely reversed forms. whereas in the hyperkinetic type of cardiohemodynamics, along with a pronounced increase in irreversibly altered forms by 15.0% increases the aggregation capacity of erythrocytes ($p < 0.05$), which is manifested by an increase in the number of "adhesion threads" between individual cells (Fig. 1 c).



×1200

a



×1200

b

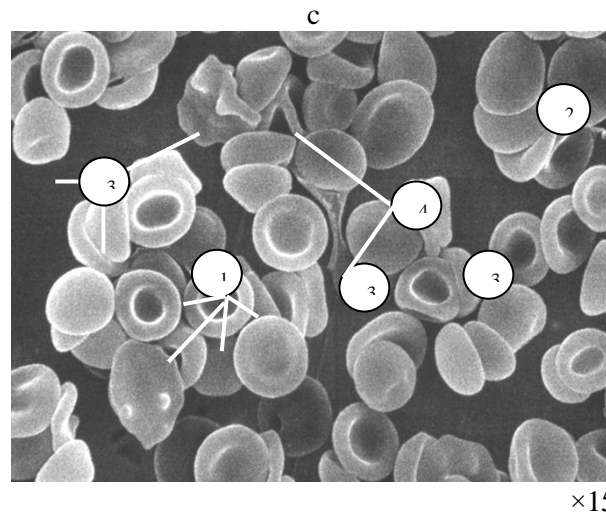


Fig. 1. Structural rearrangement of peripheral blood erythrocytes of volleyball players with eukinetic (a), hypokinetic (b) and hyperkinetic (c) types of hemodynamics after physical activity of maximum aerobic power: 1 - normal forms of erythrocytes (discocytes), 2 - inversely altered forms of erythrocytes, 3 - irreversibly altered forms of erythrocytes, 4 - "adhesion filaments". Scanning electron microscopy. Magnification: a - x 1200; b, c - x 1500

The results of macroelement analysis testify in favor of increasing the deformation of erythrocytes in volleyball players with hyperkinetic type of cardiohemodynamics (Fig. 4). It was found that the content of calcium and magnesium in these volleyball players is 11.6% and 36.9% higher than in

volleyball players with eukinetic type of cardiohemodynamics and 23.7% and 45.6% more than in volleyball players with hypokinetic type of cardiohemodynamics.

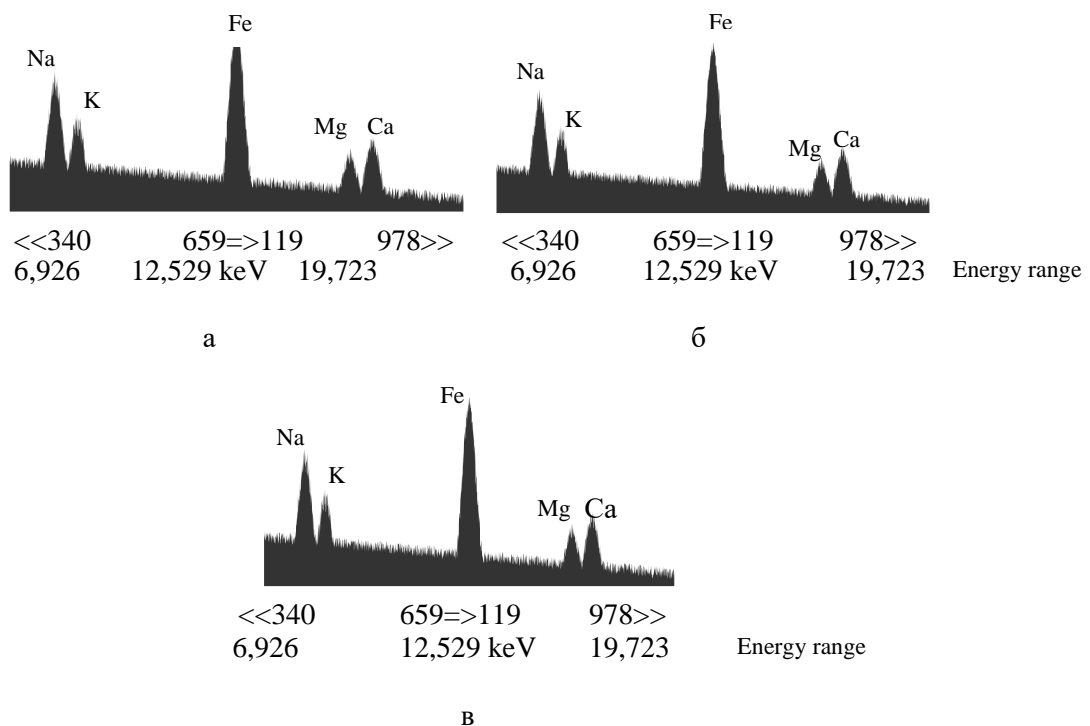


Fig. 3. Histogram of the distribution of the content of macronutrients in erythrocytes in volleyball players with hypokinetic (a), eukinetic (b) and hyperkinetic (c) types of cardiohemodynamics



Discussion

In assessing the adaptive potential of the human body depending on the amount of physical activity are actively used various morphofunctional indicators that are integrative and informative for their use in planning the training process and predicting the level of physical fitness of athletes [21, 45].

Recognized indicators of the influence of positive and negative factors are the index of the intensity of functional systems and indicators of heart rate variability [10, 46].

However, many aspects of this problem remain poorly understood. In particular, the system of hemocardioregulation provides a close relationship not only between the circuit of autonomic regulation and the organs of the cardio-respiratory system, but also requires consideration of the state of erythrocytes [13, 47]. Nevertheless, there is no data in the scientific literature on the study of this relationship and on changes in these components of the hemocardioregulation system during exercise of varying intensity.

Aerobic exercise of different levels of intensity play an important role in shaping the overall endurance of the body, which is especially necessary when conducting volleyball competitions [21, 46]. It integrates a large number of processes that occur at different levels: from cellular and to the whole organism [10, 47]. However, as the results of modern scientific research show, the leading role in endurance research belongs to the identification of factors that contribute to the activation of energy metabolism and autonomic systems to ensure it - cardio-respiratory and humoral systems. At the same time, the study of cellular reactions during exercise in the process of training associated with increasing the overall endurance of the body of volleyball players [22, 48] and, in particular, erythrocytes [23, 49] are left out of consideration.

Erythrocytes, in this case, are a convenient object for this type of research, because they participate in the processes associated with maintaining homeostasis at the level of the whole organism [7, 10, 24, 50]. These cells, in addition to their inherent specific gas transport function, have the ability to participate in the regulation of acid-base status, water-electrolyte balance, microreological status of blood, binding and transfer of amino acids, lipids and toxins, which are formed in large quantities during intense exercise. . All this is of direct interest in the development of general endurance of the organism [25, 46, 50].

The study found that 57.0% of volleyball players with hyperkinetic type of cardiohemodynamics under the influence of exercise of maximum aerobic power have negative morphological changes in erythrocytes due to biochemical disorders and intracellular predominance of magnesium ions [11] and calcium [26]. The data show that volleyball players with a hyperkinetic type of cardiohemodynamics, in contrast to the eukinetic and hypokinetic types of cardiohemodynamics, have high demands on the mechanisms responsible for the energy supply of cardiac activity. This can be explained by the predominance of systolic blood pressure, which is accompanied in most cases by an increase in myocardial oxygen demand [27]. However, in contrast to volleyball players with hyperkinetic type of cardiohemodynamics with high myocardial oxygen demand in volleyball players with hypokinetic and eukinetic type of cardiohemodynamics, the work performed by the heart is more economical. Proof of this is the fact that they have higher absolute values of such indicators as heart rate, energy expenditure to move one liter of minute volume of blood, left ventricular contraction power and volumetric blood flow rate [2, 3, 5, 48].

According to a number of authors [5, 10, 13, 28], the body of people with different types of blood circulation responds to physical activity of maximum aerobic capacity by increasing the heart index. When comparing the values of the cardiac index during exercise of maximum aerobic capacity, there was a tendency to increase its values from hypokinetic to hyperkinetic type of blood circulation. Volleyball players with hyperkinetic type of cardiohemodynamics had the highest indicators of cardiac index during exercise of maximum aerobic power. Under such conditions, there is a violation of the structural integrity of erythrocytes, which in turn promotes their intravascular lysis and can lead to the development of anemia [26]. The presence of these changes, as a rule, has a negative impact on the level of physical health and athletic performance of volleyball players. This requires appropriate correction of the training process, as well as the elimination of negative consequences and the development and timely application of adequate measures to eliminate the development of possible pathological changes in the body of volleyball players.

Thus, the study showed that cardioregulation depends on such important typological features of human erythrocytes as their ability to deform and intracellular concentration of macronutrients. The obtained results can be used in practice for differentiated assessment of the functional state of



the organism depending on the ratio of the number of reversibly and irreversibly deformed erythrocytes under the influence of exercise of maximum aerobic capacity [26, 51].

Prospects for further research

Further research may be aimed at finding ways to improve the system of cardiohemodynamic control over the state of fitness of athletes of different qualifications.

Limitation

The study was conducted on qualified young volleyball players, so the data obtained relate only to the studied contingent. Additional research is needed to disseminate the data among volleyball players of other age and social groups, as well as among representatives of other sports.

Conclusion

There is a close correlation between the type of cardiohemodynamics and biochemical parameters

of the blood ($r = 0.83$), which determines a certain type of deformation of erythrocytes and their increased ability to aggregation. Therefore, the quantification of inversely and irreversibly altered forms of peripheral blood erythrocytes may be of practical importance for the use of this method of monitoring the condition of athletes in the training process.

Acknowledgments

The authors are very grateful to all the athletes and coaches who took part in the experiment.

The study was conducted on research on the Department of Sports and Pedagogical Disciplines of Vasyl Stefanyk Precarpathian National University for 2021-2026: "Organizational and methodological principles of sports and pedagogical technologies to improve the health of various groups" (№ state registration: 0114U002625).

Conflict of interest

The authors state that there is no conflict of interest.

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Received: 2022-01-05 Accepted: 2022-02-20 Published: 2022-03-25