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Physiological Dynamics of the Rheological Properties of Erythrocytes in Young Men Involved In Swimming

Vladimir Yu. Karpov[1], Svetlana Yu. Zavalishina[1]*, Maxim V. Eremin[1], Mikhail N. Komarov[1], Alexander V. Dorontsev[2] and Victor I. Sharagin[3]

[1]Faculty of Physical Education, Russian State Social University, 129226, Moscow, Russia.
[2]Department of Physical Education, Astrakhan State Medical University, 414000, Astrakhan, Russia.
[3]Department of Physical Culture and Fundamentals of Life Safety, Moscow State University of Psychology and Education, 127051, Moscow, Russia.
*Corresponding Author E-mail: svetlanazsyu@mail.ru

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The parameters of erythrocytes largely determine the processes of blood movement through small vessels and metabolism in tissues. The study included 37 young men who during the past life showed low muscle activity and, at their own request, started regular swimming lessons 3 times a week. The control group consisted of 42 young men who, before being included in the study, went in for swimming for at least 5 years at least 3 times a week. Traditional hematological, biochemical and statistical research methods were used. Weakly physically trained young men before the start of swimming had an increased amount of altered forms of erythrocytes in the blood, which negatively affected their microcirculation. After six months of swimming in the blood of young men, the level of arachidonic acid derivatives normalized, the content of cholesterol molecules and acyl hydroperoxides in erythrocytes decreased, and phospholipids increased in their membranes. In the blood of swimmers, the number of discoid erythrocytes increased and the number of erythrocytes with an altered shape decreased. The control group, which had a long experience in swimming, was characterized by a high preservation of the shape of erythrocytes and an optimum of biochemical parameters taken into account. By the end of the observation, the novice swimmers showed the output of erythrocyte and biochemical parameters to the level of the control group.

Keywords: Adolescence; Erythrocytes; Erythrocyte surface properties; Muscle activity; Swimming.

The modern population of developed countries very often has weak and irregular muscle activity[1,2]. This leads to the early appearance of various pathologies[3,4]. This pattern has been observed in various categories of the population, and a relationship has been found between low physical activity and deterioration in the general health of the working population[5,6]. In the presence of weak daily physical activity in young people, the functionality of internal organs is significantly reduced, chronic diseases are formed and episodes of temporary disability become more frequent for a number of reasons[7,8]. A persistent decrease in muscle activity leads to the rapid progression of the existing pathology and the early development of its complications[9,10].

Weak daily muscle activity very early begins to negatively affect hematological parameters[11]. Under these conditions, additional functionally unfavorable changes occur that

contribute to the weakening of the body[12,13]. A low level of physical fitness even in adolescence can lead to microrheological disorders, causing a tendency to hypoxia in the internal organs[14]. The oxygen deficiency formed under these conditions inhibits protein synthesis in all cells of the body[15]. The emerging conditions contribute to the creation of a pronounced vasospasm, which inhibits the activity of all cells[16]. It has long been established that under conditions of low muscle activity, conditions often arise that lead to an increase in blood pressure with the risk of arterial hypertension in the near future[17,18]. Under these conditions, the rheological characteristics of the main population of blood cells, erythrocytes, often deteriorate. Developing even at a young age, this situation can contribute to the formation of any pathology[19,20]. Due to the pronounced negative effect on the body of weak muscle activity, it seems important to continue the search for options for eliminating physical inactivity, which contribute to the optimization of hematological blood parameters in young men who have long-term low physical activity.

A very promising option for increasing physical activity is swimming, which can have a strong stimulating effect on the body[21]. Swimming training had a healing effect on a healthy body and on those with pathology[22,23]. The existing different variants of swimming lessons have always demonstrated very positive effects on various hematological parameters[24,25]. However, the influence of this variant of physical training on the rheological properties of the erythrocytes of the youthful organism has not yet been finally revealed.

Purpose of the study: to find out the dynamics of the surface properties of erythrocytes in physically inactive young men who started regular swimming lessons.

MATERIALS AND METHODS

The study was supported by the local ethics committee established at the Russian State Social University (protocol 15 dated May 11, 2020). The study was conducted from mid-May 2020 to December 2020.

The study group consisted of 37 young men (mean age 20.2±0.6 years). The participants in the study had an average height and normal body weight, their body mass index averaged 19.8±0.42 kg/m2. All of them were university students located in the city of Moscow (Russia) and had a fairly balanced diet. Prior to the start of the study, all the young men in the study group did not experience regular muscle exercise. After being taken into the study, they began regular swimming lessons at least 3 times a week. The duration of one swimming lesson was at least 40 minutes. The control group consisted of 42 healthy young men with an average age of 19.5±1.1 years. These surveyed regularly visited the pool at least 3 times during the week for at least 5 years. The duration of each of their swimming lessons was at least 40 minutes.

The content of thromboxane B_2 and 6-keto-prostaglandin $F_{1á}$ molecules was determined in the plasma of those examined using the EnzoLifescience (USA) enzyme immunoassay kit. In the composition of erythrocytes after their washing and resuspension, the cholesterol level was assessed using the enzymatic colorimetric method. For this, a set of reagents from Vital Diagnosticum (Russia) was used. In washed and resuspended erythrocytes, the content of phospholipids was estimated by the amount of phosphorus present in them[26]. The intensity of lipid peroxidation of erythrocyte structures was determined after their washing and resuspension by assessing the content of malondialdehyde and acyl hydroperoxides in them[27].

In the blood of the examined using light phase-contrast microscopy, the number of erythrocytes having a discoid shape and the number of erythrocytes having an altered shape were determined.

The observation group was examined three times: initially and after three and six months of regular swimming lessons. The control group was examined once.

Statistical processing of all the results obtained in the study was carried out using Student's t-test.

RESULTS

In physically untrained young men, when taken into the study, there was a violation of the optimum levels in the blood of metabolites of arachidonic acid. The concentration of thromboxane

B2 in their blood was higher than the control level by 34.5% ($p<0.01$), while the level of 6-keto-prostaglandin F1á was less than the same value in the control group by 15.6% ($p<0.05$) (table).

At the beginning of the observation, in the membrane structures of erythrocytes in the young men of the study group, the amount of cholesterol was higher than in the control by 17.0%, and the initial content of total phospholipids in them was lower than the control level by 13.4% ($p<0.05$). In the erythrocytes of physically inactive young men, the initial levels of acyl hydroperoxides and malondialdehyde significantly exceeded the values in the control group by 35.5% and 37.1%, respectively.

Fig. 1. Normally shaped erythrocytes

At the beginning of the observation in the blood of the young men of the study group, the number of erythrocytes with a normal shape was lower than in the control by 15.6% ($p<0.05$) (table). At the same time, in this group, the initial number of erythrocytes with a reversibly and irreversibly transformed form exceeded the control level by 47.3% and 7.3 times, respectively ($p<0.01$).

Against the background of regular swimming lessons in the blood of the young men of the study group, there was a decrease in the severity of the imbalance of arachidonic acid derivatives. By the end of the observation in the plasma of these young men, the amount of thromboxane B_2 decreased by 35.4% ($p<0.01$). At the same time, the level of 6-keto-prostaglandin $F_{1á}$ in their blood during the study increased by 15.1% ($p<0.05$).

In the membrane structures of erythrocytes after six months of swimming in the young men of the study group, a decrease in cholesterol content occurred by 17.0%. This was accompanied by an increase in the content of phospholipids in their

Table 1. Digital results obtained during the study

Hematological indicators	Started sailing, n=37, M±m			Control, n=42, M±m
	sailing start	3 months sailing	6 months sailing	
Total erythrocyte phospholipids, µmol/10^{12} erythrocytes	0.67±0.010 p<0.05	0.70±0.014 p<0.05	0.75±0.008 p_1<0.05	0.76±0.012
Erythrocyte cholesterol, µmol/10^{12} erythrocytes	1.03±0.015 p<0.05	0.96±0.016 p<0.05	0.88±0.009 p_1<0.05	0.88±0.016
6-keto-prostaglandin $F_{1\alpha}$, pg/ml	85.3±0.53 p<0.05	92.0±0.32 p<0.05	98.2±0.28 p_1<0.05	98.6±0.39
Thromboxane B_2, pg/ml	191.7±0.52 p<0.01	168.7±0.61 p<0.05	141.5±0.46 p_1<0.01	142.5±0.68
Malondialdehyde in erythrocytes, nmol/10^{12} erythrocytes	1.81±0.007 p<0.01	1.55±0.010 p<0.05	1.31±0.008 p_1<0.01	1.32±0.032
Erythrocyte acyl hydroperoxides, D_{233}/10^{12} erythrocytes	3.97±0.012 p<0.01	3.40±0.017 p<0.01	2.92±0.022 p_1<0.01	2.93±0.017
Irreversibly altered erythrocytes, %	8.8±0.10 p<0.01	4.8±0.08ð<0.01 p_1<0.05	1.2±0.07 p_1<0.01	1.1±0.12
Reversibly altered erythrocytes, %	13.7±0.17 v<0.01	11.0±0.15ð<0.01 p_1<0.05	9.6±0.19 p_1<0.01	9.3±0.18
Erythrocytes are discoid, %	77.5±0.26 p<0.05	84.2±0.29 p<0.05	89.2±0.34 p_1<0.05	89.6±0.16

Note: p - reliability of differences in indicators in the study group and in the control group; p1 - the reliability of the dynamics of indicators in the study group compared with the baseline.

erythrocytes by 11.9% ($p<0.05$). At the same time, by the end of the observation, the content of acyl hydroperoxides in the membrane structures of erythrocytes in the young men involved in swimming decreased by 35.9% ($p<0.01$) and the concentration of malondialdehyde decreased by 38.2% ($p<0.01$).

Under the conditions of regular swimming lessons in the blood of young men of the study group, an increase in the level of erythrocyte-discocytes by 15.1% compared with the initial level ($p<0.05$) was noted (table). The numbers of reversibly transformed erythrocytes and erythrocytes with an irreversibly changed shape in their blood after half a year of swimming decreased by 42.7% ($p<0.01$) and 7.3 times ($p<0.01$), respectively.

DISCUSSION

Previously, it was noted that weak physical activity is always accompanied by the appearance of many dysfunctions and various pathologies [28]. At the same time, in the modern world, physical activity is less and less in demand, and diseases associated with physical inactivity are becoming more common. Under these conditions, maintaining the physiological norm throughout the human body throughout his life becomes a difficult task, which should be solved with the use of regular dosed physical activity [29]. A special role in the long-term maintenance of health is played by the stable preservation of the optimum parameters of the blood, including the normal characteristics of its erythrocytes (Figure 1).

It has been precisely clarified that weak muscle activity causes the development of disturbances in the microrheological characteristics of cells in the blood and, first of all, its erythrocytes. Excessive lipid peroxidation in erythrocyte membranes, which is characteristic of hypodynamia, leads to damage to their membranes, which significantly weakens their functions[30]. The situation that has arisen is further aggravated by the lipid imbalance in erythrocyte membranes that is very often formed under conditions of physical inactivity, which also negatively affects their functioning[31]. Changes in the amount of phospholipids and cholesterol content noted in the erythrocytes of young men with low physical activity are biologically very undesirable[32]. The current situation violates the selective permeability of erythrocyte membranes and weakens the functionality of membrane proteins, including as a result of changes in their secondary and tertiary structure. All this negatively affects the exchange

Fig. 2. Swimming lessons in the pool

of ions and macroelements through the surface membranes of the main part of erythrocytes in the blood[33].

An increase in the number of erythrocytes with reversible structural changes and an increase in the number of irreversibly altered erythrocytes inevitably leads to an increase in the level of their aggregates in the blood, which disrupts the course of microcirculation in all tissues. Under these conditions, in the structures of the walls of the vessels of young men with poor physical fitness, the synthesis of many regulatory compounds, including those that affect the state of blood cells, was weakened. Under these conditions, in the blood of the physically untrained, a situation arose of a functional increase in the plasma of substances with a proaggregant effect. The intensification of the synthesis of thromboxane and the weakening of the formation of its antagonist prostacyclin created a discrepancy between the existing activity of arachidonic acid products in plasma and the needs of the body. The resulting disturbances in the rheological parameters of erythrocytes worsened the processes of blood movement through the vessels and inhibited metabolism throughout the body, including in the walls of blood vessels, which aggravated the situation.

To overcome the existing situation of complete recovery of the body of young men who had poor physical fitness, systematic swimming lessons were recommended (Figure 2).

As a result of regular swimming trainings, in all the boys of the study group, the level of fitness increased and the process of lipid peroxidation in erythrocytes weakened. This helped them to optimize their functions. The positive dynamics of erythrocyte parameters in those who started swimming training was also realized due to the optimization of the lipid composition of erythrocyte membranes. This situation created conditions for optimizing the properties of the membranes of erythrocytes circulating in the blood[34]. This was facilitated by the normalization of the content and ratio of phospholipids and cholesterol in the composition of erythrocyte membranes, which had a very positive effect on the function of membrane proteins. The found dynamics of the lipid composition also contributed to the improvement of the permeability and mechanical properties of erythrocyte membranes, thereby contributing to the intensification of metabolic processes in them[35].

In the course of regular swimming lessons in the blood of the young men of the study group, there was a gradual increase in erythrocytes with an optimal discoid shape. This phenomenon had biologically extremely positive consequences. This led to a decrease in the blood of young men who increased their physical activity, the number of erythrocytes with a changed shape and created conditions for the weakening of erythrocyte aggregation, which improved the blood supply to all tissues of their body[36,37,38].

CONCLUSION

Low muscle activity leads to a gradual increase in the number of erythrocytes with an impaired shape in the blood of young men. These changes can reduce the efficiency of their hemocirculation through the capillaries and weaken the metabolism. In previously physically untrained young men who started regular swimming lessons, the processes of lipid peroxidation were inhibited in the erythrocyte membranes and their lipid composition was optimized. Against the background of six-month swimming lessons, the level of normal-shaped erythrocytes in the blood increased to the control values. There is reason to believe that six months of swimming can optimize the rheological characteristics of erythrocytes in adolescence. Longer swimming sessions reinforce this result, which was noted in the control group. This contributes to the stable recovery of the young body and minimizing the appearance of various dysfunctions in it.

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Conflict of interest

No conflict of interest is declared.

Sources of financing

The study was conducted at the expense of the authors.

Ethics Committee Resolution

The study was approved by the local ethics committee of the Russian State Social University on May 11, 2020 (protocol [1]5).

REFERENCES

1. Gundarov, I.A. The menace of demographic crisis of human resources in Russia and means of its overcoming. *Health Care of the Russian Federation, Russian journal*, **61(1)**, 5-10. (2017)
2. Makhov, A.S., Medvedev, I.N. Functional characteristics of physically unfit children with down syndrome. *Teoriya i Praktika Fizicheskoy Kultury,* **7** : 42. (2019)
3. Medvedev, I.N. Formation of hemostasiopathy in arterian hypertension and insulin resistance. *Prensa Medica Argentina,* **105(2)** : 1000348 (2019)
4. Vorobyeva, N.V., Khabibulina, T.V., Skripleva, E.V., Skoblikova, T.V., Zatsepin, V.I., Skriplev, A.V. Effect of Lipid-lowering Therapy and Regular Exercise on the Fibrinolytic System in Patients with Metabolic Syndrome. *Prensa Med Argent*, **105(1)**. DOI: 10.41720032-745X.1000327 (2019)
5. Oganov, R.G., Maslennikova, G.Ya. Mortality from cardiovascular and other chronic non-infectious diseases among the working-age population of Russia. *Cardiovascular therapy and prevention*, **3** : 4-8. (2002)
6. Medvedev, I.N. Problems of human nutritional behavior in modern society. *International Journal of Pharmaceutical Research*, **12** : 1357-1365. (2020)
7. Apanasenko, G.L., Popova, L.A. Medical valeology. Rostov-on-Don: "Phoenix", 248 p. (2000)
8. Medvedev, I.N., Karpov, V.Yu., Makurina, O.N., Eremin, M.V., Dorontsev, A.V., Sibgatulina, F.R., Ivanov, D.A. Functional reaction of the cardiovascular system to irritation of vestibular receptors in students engaged in different types of martial arts. *International journal of biology and biomedical engineering*, **16** : 96-104. (2022)
9. Makhov, A.S., Medvedev, I.N. Physiological characteristics of junior fot balers who stopped training six months ago. *Teoriya i Praktika Fizicheskoy Kultury,* **1** : 25. (2019)
10. Medvedev, I.N. Physiological Dynamics of Platelets' Activity in Aged Rats. *Annual Research & Review in Biology,* **18(2)** : 1-6. doi: 10.9734/ARRB/2017/36821 (2017)
11. Filippov, E.V., Petrov, V.S. Analysis of low physical activity among the able-bodied population of the Ryazan region (according to the Meridian-RO study). *Clinician*, **9(3)** : 22–27. (2015)
12. Shalnova, S.A., Deev, A.D., Oganov, R.G. Factors affecting mortality from cardiovascular diseases in the Russian population. *Cardiovascular therapy and prevention*, **4(1)** : 4-9. (2005)
13. Makhov, A.S., Medvedev, I.N. Functional basics of motivation of people with musculoskeletal disorders for adaptive sports practices. *Teoriya i Praktika Fizicheskoy Kultury*; **10** : 59. (2019)
14. Medvedev, I.N. Place and Possibilities of the Robotic System Lokomat in the Rehabilitation of Patients after Ischemic Stroke. *Biomedical & Pharmacology Journal,* **12(1)** : 131-140. http://dx.doi.org/10.13005/bpj/1621 (2019)
15. Makurina, O.N., Vorobyeva, N.V., Mal, G.S., Skripleva, E.V., Skoblikova, T.V. Functional Features of Hemocoagulation in Rats with Experimentally Formed Arterial Hypertension in Conditions of Increased Motor Activity. *Prensa Med Argent*; **104(6)**. DOI: 10.41720032-745X.1000323 (2018)
16. Medvedev, I.N., Gusev, A.V., Malyshev, A.V., Mikhailova, O.D., Garina, E.V., Petina, E. Sh., Tagirova, N.Dz. Influence of the Experience of Health-Improving Jogging on the Level of Functional Activity of Platelets in Men of the Second Mature Age. *Systematic Reviews in Pharmacy*, **11(8)** : 432-438. (2020)
17. Medvedev, I.N., Skoriatina, I.A. Effect of lovastatin on adhesive and aggregation function of platelets in patients with arterial hypertension and dyslipidemia. *Klinicheskaia meditsina*, **88(2)** : 38-40. (2010)
18. Makurina, O.N., Vorobyeva, N.V., Mal, G.S., Skripleva, E.V., Skoblikova, T.V. Functional Features of Hemocoagulation in Rats with Experimentally Formed Arterial Hypertension in Conditions of Increased Motor Activity. *Prensa Medica Argentina,* **105(8)** : 469-476. (2019)
19. Medvedev, I.N. The Effect of Complex Treatment on Platelet Aggregation Activity in Patients with Grade 3 Arterial Hypertension with Metabolic Syndrome. *Prensa Med Argent*, **104(6)**. DOI: 10.41720032-745X.1000325 (2018)
20. Medvedev, I.N. Microrheology of erythrocytes in arterial hypertension and dyslipidemia with a complex hypolipidemic treatment. *Russian Journal of Cardiology,* **4(144)** : 13-17. (2017)
21. Vasiliev, A.S., Vasiliev, N.N., Shentsov, A.N., Erokhina, N.N. Teaching students to swim at physical education lessons and the health-improving effect of swimming on health. *Modern issues of theory and practice of teaching at the university*, **18** : 182-189. (2015)

22. Kazyzaeva, A.S. Application of the game method in swimming lessons in groups of primary swimming training. *Issues of functional training in elite sport*, **3(1)** : 91-98. (2015)
23. Kireeva, O.V., Rasskazov, A.V. Sports swimming. Swimming methods. *Modern research and development*, **1(18)** : 191-192. (2018)
24. Yakub, I.Yu., Motorykina, A.A. Swimming and swimming test results. *Symbol of Science: International Scientific Journal*, **1-2** : 166-170. (2018)
25. Kamilova M.A. Types and styles of swimming, rescue measures in the process of swimming. *Pedagogical journal*, **9(2-1)** : 591-596. (2019)
26. Kolb, V.G., Kamyshnikov, V.S. Handbook of Clinical Chemistry. Minsk: Belarus publishing house, 367. (1982)
27. Volchegorsky, I.A., Dolgushin, I.I., Kolesnikov, O.L., Tseylikman, V.E. Experimental modeling and laboratory assessment of adaptive responses of the organism. Chelyabinsk: publishing house of the Chelyabinsk State Pedagogical University, 167. (2000)
28. Prilipko, N.S. The need for medical rehabilitation of the adult population of various age groups in stationary conditions. *Healthcare of the Russian Federation*, **1(60)** : 23-27. (2016)
29. Medvedev, I.N., Skoryatina, I.A. Pravastatin in correction of vessel wall antiplatelet control over the blood cells in patients with arterial hypertension and dyslipidemia. *Cardiovascular therapy and prevention*; **13(6)** : 18-22. (2014)
30. Makhov, A.S., Medvedev I.N. Role of coach in selection of exercises for athletes with disabilities based on physiological characteristics. *Teoriya i Praktika Fizicheskoy Kultury;* **8** : 62. (2019)
31. Medvedev, I.N. The Impact of Durable and Regular Training in Handto-hand Fighting Section on Aggregative Platelet Activity of Persons at the First Mature Age. *Annual Research & Review in Biology*, **15(2)** : 1-6. DOI: 10.9734/ARRB/2017/35048 (2017)
32. Vorobyeva, N.V., Medvedev, I.N. (2020) Functional platelet activity in Dutch newborn calves. IOP Conference Series: Earth and Environmental Science. 421, 022042. doi:10.1088/1755-1315/421/2/022042 (2020)
33. Tkacheva, E.S., Medvedev, I.N. Functional features of vascular hemostasis in piglets of milk and vegetable nutrition. IOP Conference Series: Earth and Environmental Science. 421, 022041. doi:10.1088/1755-1315/421/2/022041 (2020)
34. Medvedev, I.N. Physiological response of the rheological parameters of erythrocytes to regular physical exertion in individuals of the first mature age who are at risk of hemodynamic and metabolic disturbances. *International Journal of Pharmaceutical Research*, **11(4)** : 257-262. (2019)
35. Vorobyeva, N.V., Medvedev I.N. Functional activity of platelets in new-born calves of black-marked breed. *Bulgarian Journal of Agricultural Science*; **25(3)** : 570-574. (2019)
36. Pavlov, S.E., Kuznetsova, T.N. Some physiological aspects of sports training. Moscow: BACKGROUND, 55. (1998)
37. Karpov, V.Yu., Medvedev, I.N., Boldov, A.S., Sibgatulina, F.R., Fedorova, T.Y. Physiological Basis for the Use of Physical Activity in Conditions of Disorders of Carbohydrate and Lipid Metabolism. *Indian Journal of Public Health Research & Development*, **10(8)** : 1899-1903. (2019)
38. Medvedev, I.N., Plotnikov, A.V., Kumova, T.A. Rapid normalization of platelet hemostasis in patients with arterial hypertension and metabolic syndrome. *Russian Journal of Cardiology*, **2** : 43-46. (2008)