4. Крупаткин, А.И. Функциональная диагностика микроциркуляторно-тканевых систем: Колебания, информация, нелинейность. Руководство / А.И. Крупаткин, В.В. Сидоров. – М. : ЛЕНАНД, 2016. – 496 с.

5. Изменения микроциркуляции крови как показатель адаптации к регулярным физическим нагрузкам у спортсменов / В.И. Сысоев [и др.] // Теория и практика физической культуры. – 2008. – № 6. – С. 66-70.

УДК 535.8; 577.352.336; 577.325.3

Луговцов А.Е., Незнанов А.И., Каданова И.М., Гурфинкель Ю.И., Шин С., Приезжев А.В.

МИКРОРЕОЛОГИЯ И МИКРОЦИРКУЛЯЦИЯ КРОВИ В НОРМЕ И ПРИ ПАТОЛОГИИ

Аннотация. Сердечно-сосудистые и метаболические заболевания, такие как артериальная гипертензия и сахарный диабет, могут приводить к нарушению микрореологии и микроциркуляции крови. Используя in vitro методы диффузного рассеяния света, лазерной дифрактометрии, захвата и манипуляции лазерной ловушкой, а также in vivo метод цифровой капилляроскопии, было показано, что у пациентов с артериальной гипертензией и сахарным диабетом способность эритроцитов агрегировать повышена по сравнению с контрольной группой.

Ключевые слова: агрегация, деформируемость, эритроциты, артериальная гипертензия, сахарный диабет.

Lugovtsov A.E., Neznanov A.I., Kadanova I.M., Gurfinkel Yu.I., Shin S., Priezzhev A.V.

BLOOD MICRORHEOLOGY AND MICROCIRCULATION IN NORM AND PATHOLOGY

Summary: Cardiovascular and metabolic diseases such as artherial hypertension and diabetes mellitus can lead to impairment of

blood microrheology and microcirculation. Using in vitro measurement techniques of diffuse light scattering, laser diffractometry, laser trapping and manipulation and in vivo digital capillaroscopy we showed that in arterial hypertensive and diabetes mellitus patients, the ability of red blood cells (RBCs) to aggregate is enhanced relative to the control group.

Keywords: aggregation, deformability, red blood cells, artherial hypertension, diabetes mellitus.

INTRODUCTION

Nowadays the number of people suffering from diabetes mellitus and cardiovascular diseases (arterial hypertension, coronary heart disease) increases rapidly mainly due to unhealthy nutrition and lifestyle. Diabetes mellitus (DM) is a metabolic disease characterized by high blood sugar levels over a prolonged period. Arterial hypertension (AH) is a long-term medical condition in which the blood pressure in the arteries is persistently elevated. These diseases can lead to severe alterations of vitally important systems of the human organism including the cardiovascular system and resulting in damage to blood vessels and capillaries, impairment of blood hemorheology and microcirculation. Enhanced aggregation of RBCs is one of key factors, which determines the blood flow and thereby affects the blood rheology [1]. The ability of RBCs to deform in shear flow conditions is the second major property that affects blood microcirculation. Alterations in these properties lead to changing the blood viscosity and, as a consequence, to changes in capillary blood flow. This can lead to significant impairment of blood function, which increases a risk of occurrence of vascular concomitant diseases, and even the mortality. The main goal of this work is to assess the deformability and aggregation properties, forces of pair aggregation of RBCs drawn from patients suffering from AH, DM and from healthy donors using *in vitro* techniques of diffuse light scattering, laser diffractometry, laser trapping and manipulation and estimate the blood cappilary velocity by *in vivo* digital capillaroscopy.

MATERIALS AND METHODS

In this work, complex laser-optics studies of the factors determining the capillary blood flow in patients suffering from AH

and DM were conducted. Laser aggregometry and diffractometry techniques, which are implemented in the laser aggregometer-deformometer device Rheoscan AnD-300 (Republic of Korea) [2], were used to conduct *in vitro* measurements of aggregation and deformability characteristics of the RBCs in big ensembles of cells. Several parameters were measured: RBC deformability index dependance on shear stress, hydrodynamic strength of RBC aggregates - critical shear stress (CSS), characteristic time of RBC aggregates formation, aggregation index (percentage of the RBC participating in the aggregation during first 10 seconds of spontaneous aggregation process) [3, 4]. Double-channeled optical tweezers were used for *in vitro* measuring the aggregation speed as well as interaction forces during RBC doublet formation on cellular level [5]. To visualize and quantitatively evaluate the capillary blood flow *in vivo* non-invasive capillaroscopy measurements in the nailfold vessels were conducted [3].

All in vitro measurements were performed with human blood drawn from patients with AH (102 people) and DM (22 people) and practically healthy volunteers – control (18 people). Blood samples were stabilized with EDTA to prevent blood from clotting. The measurements were performed within two hours after blood sampling.

RESULTS AND CONCLUSION

It was shown that in AH and DM patients, the ability of erythrocytes to deform is slightly reduced while the aggregation speed and forces of the cells interaction and CSS are significantly increased relative to the control group. The blood microcirculation in nailfold capillaries is impaired as well.

Basing on the obtained results one can conclude that laser aggregometry and optical trapping and manipulation are appropriate techniques for estimating the blood aggregation properties in whole blood samples and on the level of individual cells. We showed that the alterations of the parameters measured *in vivo* and *in vitro* for patients suffering from these diseases are interrelated. Good agreement between the results obtained with different techniques, and their applicability for the diagnostics of abnormalities of rheological properties of blood were demonstrated.

The work was supported by Russian Foundation for Basic Research (grant No. 19-52-51015).

REFERENCES

1. Baskurt O.K., Neu B., Meiselman H. Red blood cell aggregation. Boca Raton : CRC Press, 2019.

2. Shin S., Yang Y., Suh J.-S. Measurement of erythrocyte aggregation in a microchip stirring system by light transmission // Clin. Hemorheol. Microcirc. 2009. V. 41(3). PP. 197-207.

3. Lugovtsov A., Gurfinkel Y., Ermolinskiy P., Maslyanitsina A., Dyachuk L., Priezzhev A. Optical assessment of alterations of microrheologic and microcirculation parameters in cardiovascular diseases // Biomed. Opt. Express. 2019. V. 10. PP. 3974-3986.

4. Priezzhev A.V., Firsov N.N., Lademann J. Light backscattering diagnostics of RBC aggregation in whole blood samples // Handbook of Optical Biomedical Diagnostics, Editor V. Tuchin, Chapter 11 (PP. 651 – 674). Washington: SPIE Press, 2012.

5. Lee K., Khokhlova M.D., Lyubin E. V., Priezzhev A. V., Meglinsky I., Fedyanin A.A. Optical tweezers study of red blood cell aggregation and disaggregation in plasma and protein solutions // J. Biomed. Opt. 2016. V. 21. PP. 035001-1-035001–10.

УДК 535.8; 577.352.336; 577.325.3

А.Н. Семенов, Е.А. Ширшин, А.Е. Луговцов, П. Ермолинский, Б. Якимов, А. Муравьев, С. Шин, А.В. Приезжев

БИОФИЗИЧЕСКИЕ АСПЕКТЫ ВЗАИМОДЕЙСТВИЯ ФИБРИНОГЕНА И МЕМБРАНЫ ЭРИТРОЦИТОВ ПРИ ИХ АГРЕГАЦИИ: ОЦЕНКА С ОПТИЧЕСКИМИ МЕТОДАМИ

Аннотация: Механизмы индуцированной фибриногеном агрегации эритроцитов до конца не изучены. Одна из моделей предполагает адсорбцию молекул фибриногена на мембране эритроцитов, приводящую к сращиванию клеток в агрегаты. В данной работе мы представляем результаты оценки адсорбции