Measuring Blood Flow Velocity Using a Developed Small-Size Optical Sensor

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***Abstract* — This work is devoted to the creation of a small-sized mobile optical sensor for studying the speed of blood flow, as well as measuring the speed of blood flow on it. Using the developed device, test studies were carried out on relatively healthy volunteers aged 19 to 22 years old and on a patient with liver cirrhosis. Using the formulas given in the theoretical part, the correlation time and blood flow velocity were calculated. The results are compared with the values obtained in previous works, as well as with the values measured using a commercial device LAZMA PF. This is necessary to evaluate the functioning of the created device and the possibility of using it in medical centers.**

Keywords — speckle correlation analysis, microcirculation, laser, correlation function, blood flow velocity

I. Introduction

Capillaries play an important role in the circulatory system. They deliver oxygen and eliminate metabolites. The flow through the capillary network changes due to changes in any part of the circulatory system [1]. Thereby, the state of the microvasculature is significant for the metabolism and perfusion of tissue cells. Impaired microcirculation is one of the first signs of many diseases, therefore non-invasive methods for assessing the condition of the microvasculature are important for the early diagnosis [2-4]. It is especially essential to monitor the state of microcirculation in liver diseases, as well as in other diseases [5, 6].

To study the velocity of blood flow, there are various optical methods. In this work, the method of speckle correlation analysis is used, its advantages are non-invasiveness, quickly effectiveness and it also does not require complex technical equipment. This method is based on determining the flow velocity by analyzing the dynamics of the interference pattern formed when laser radiation is scattered from an inhomogeneous probed area [7]. Currently, devices designed to study blood microcirculation have several disadvantages, including the use of equipment difficult to transport, for example, an oscilloscope, the lack of test measurements on people, carrying out contact measurements [8], calculation of blood flow velocity in relative units [9], because in some medical and scientific manuals the blood flow velocity is defined in mm/s. In this regard, the development of a measuring set and method that allows obtaining data on blood flow velocity remains relevant. The goal of the work is to create a small-sized and mobile optical device based on speckle correlation analysis method for studying the speed of blood flow, as well as to develop an experimental technique and carry out appropriate measurements on the developed sensor.

II. Development of a Mesuring Complex

Most of biological objects are optically inhomogeneous and rough, so, illuminating coherent light reflected from such objects forms speckle structures [7, 10]. The change in realizations of speckle structures is determined by the speed of movement of the scattering object. The greatest interest for measuring blood flow velocity is the backscattered radiation from red blood cells. The recorded intensity of the backscattered laser light represents a signal with random characteristics, having the properties of a random signal. The autocorrelation function of such a signal makes it possible to establish a connection between the correlation time and the blood flow velocity. This first function is an exponential autocorrelation function:

$$G(\tau) = e^{\left(-\frac{\tau^2}{\tau_c^2}\right)}. \quad (1)$$

The correlation time τ_c is determined by the level 1/e from the maximum of the autocorrelation function $G(\tau)$ and is described by the relation:

$$\tau_c = \frac{K}{|v|}, \quad (2)$$

where v is the speed of the scattering object, and the proportionality coefficient K is determined by the parameters of the optical scheme: the beam waist width, the width and curvature of the wave front, the distance from the scattering object to the observation plane.

The developed optical device is based on the theoretical calculations given above. This device allows you to calculate the correlation time, with which you can calculate the speed of blood flow and draw a conclusion about the state of the microvasculature.

The optical sensor contains a single-mode semiconductor laser with wavelength 650 nm, a collecting lens with focal length 50 mm, an optical fiber, a photomultiplier model H11706-01 from HAMAMATSU, and an analog-to-digital converter representing an L-CARD data acquisition board. The unit is connected to a personal computer using a USB cable. Installation size: length 24 cm, width 16 cm, height 12 cm.

Laser radiation passes through a collecting lens to focus the beam and hits an area of skin. Radiation scattered on red blood cells is recorded by a photomultiplier model using an optical fiber. Next, the signal is sent to an analog-to-digital converter, digitized, and transmitted to a personal computer for further research. Using the program written in Python, an autocorrelation function is constructed, and the correlation time is calculated, from which the blood flow velocity is founded out. The time of one measurement is 30 seconds.

Measurement protocol consists of preparation, turning on the experimental device, connection the installation to the computer and launching the software, entering the installation parameters (sampling frequency, recording time), measurements of the pulse, placing a finger in a special recess and recording. When the measurements are finished, the sensor is turned off.

III. Experimental Results

To test the functioning of the installation, there was selected a group of conditionally healthy volunteers aged 19 to 22 years old. Blood flow velocity was measured for each volunteer for 30 seconds on the pad of the distal phalanx of the forefinger. Measurements were taken under normal conditions and during compression. It was necessary to determine if the clamping affects the recorded velocity of blood flow to understand how sensitive the sensor is to blood flow changes. The research results are shown in Fig. 1.

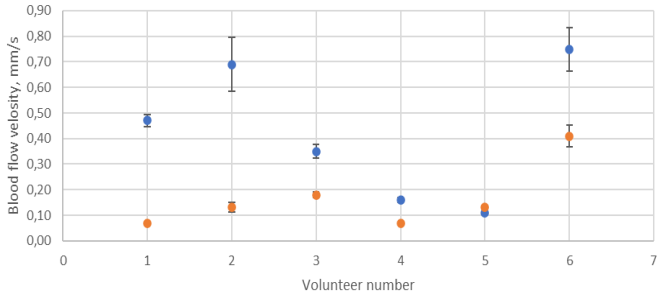

Fig. 1. Results of a study of blood flow velocity in 6 volunteers under normal conditions and during clamping

Orange points show the results taken during clamping and blue points show measurements under normal conditions. The error marked on the graph shows the amount of random measurement error calculated using the mean of 5 measurements, standard deviation, and confidence interval at the 95% confidence level. It can be noted that during the clamping, the speed of blood flow decreases due to pinching of the blood vessels. The optical device is sensitive to various conditions of the microcirculatory bed and can diagnose diseases that are characterized by a reduced blood flow velocity, for example, diabetes mellitus. Under normal conditions, the obtained blood flow velocity varies in the range from 0,1 mm/s to 0,75 mm/s, that is correlated with the results obtained in [7] considering the error.

After test experiments showing that the created optical device responds to changes in blood flow speed, measurements were carried out on a patient with cirrhosis of the liver. Measurements on the developed sensor took place on the pad of distal phalanx of the index finger of the right hand. There were also measurements obtained using a commercial LAZMA PF sensor on which blood microcirculation is determined indirectly by the optical characteristics of the probing area in relative units. Measurements with the commercial sensor took place on the forearm of the left hand. The patient was in a supine position during both experiments.

The progression of cirrhosis is characterized by significant changes in the intra- and extrahepatic microvasculature, leading to dysfunction. A dysfunctional microcirculation leads to regions of heterogeneous microvascular flow causing tissue hypoxia. This worsens microcirculatory dysfunction and ultimately leads to organ failure. The microcirculatory changes in cirrhotic patients are extensive and affect both the structure and dynamics of the blood vessels. Within the liver, these changes disrupt normal regulatory mechanisms, leading to increased vascular resistance and portal hypertension [6].

According to the description of the commercial device, it provides filtering of Doppler frequencies corresponding to erythrocyte velocities in the range of 0,8-4,5 mm/s, the blood flow microcirculation value should be 7-20 relative units with a permissible deviation of no more than ±20%. Average microcirculation value obtained using a commercial sensor was 3,71 perfusion units. So, the data obtained using the LAZMA PF sensor may not be informative. The velocity of blood flow measured using the created device is 0,06 mm/s. It is known that in patients with fibrosis or cirrhosis of the liver, the speed of blood flow in the microvasculature can decrease to 0,05 mm/s. This shows that the device is working properly.

IV. Conclusion

In this work was developed a small-sized mobile device to change the speed of blood flow, as well as an experimental technique for conducting research on the created device. Blood flow velocity measurements were carried out on apparently healthy volunteers. Analyzing the data obtained, it was revealed that the measurement results were within the normal range of blood flow velocity in the microvasculature. The blood flow velocity value was measured in a patient with liver cirrhosis and compared with the results obtained with a commercial sensor. The created optical device responds to changes in blood flow speed, that can make it possible to diagnose vascular complications at the initial stage. The main advantages of the developed device are the small size of the device, simple using and transporting, the ability to calculate the average blood flow velocity in physical units. Thus, the developed sensor has great potential for use in medical centers to study blood microcirculation.

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