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Spectroscopic Non-Invasive Method For Monitoring Glucose Concentration In Human Blood.

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ABSTRACT

In order to avoid serious complications, people with diabetes have to take samples of their blood "for sugar" periodically. Therefore, the importance of developing a method for non-invasive determination of blood glucose is obvious. The proposed method relates to spectroscopic ones and is based on the measurement of the intensity of the absorbed light when it passes through the blood-containing organ of a person. Such methods are known for a long time, but so far it has not been possible to solve the problem of allocating a fraction of the light absorbed by glucose. We consider the possibility of determining the proportion of light absorbed by glucose by multiple measurements of the intensity of the absorbed light at a large number of wavelengths in the near IR area of the spectrum, as well as processing the data using a mathematical apparatus developed for this purpose, including the formation and solution of a system of linear equations with the number of unknown, not less than the number of light-absorbing components in the blood-containing organ through which light is transmitted. The estimation of the method by determining the convergence of the solution of the system of equations is given, as well as the requirements for refining the spectral characteristics of the absorption of some of the absorbing components are formulated.
Keywords: diabetes mellitus, noninvasive method, system of linear equations, convergence of the solution

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INTRODUCTION

Currently, diabetes is one of the most common diseases, which today is considered incurable and accompanies a person all his life. In order to avoid serious complications, people with diabetes are forced to adhere to a special regime of life and nutrition and take samples of their blood “for sugar” periodically, or rather to determine the amount of sugar. Naturally, blood sampling (or biomaterial) is accompanied by some difficulties, such as; it is necessary to have constantly available not only a glucometer, but also test strips, and also to ensure sterility during the procedure. As it is necessary to check the concentration of sugar in the blood several times a day, there are a number of inconveniences. Therefore, the importance of developing a device and method for non-invasive determination of blood glucose is obvious.

Now in the scientific literature you can find a large number of more or less reasonable proposals on the principles of operation and construction of devices that allow without blood sampling to determine the concentration of glucose in the patient’s blood. These proposals can be divided into two large groups – based on non-optical methods and based on optical methods.

One of the simplest methods is to compare temperatures measured in different organs of the patient’s body [1]. The method is based on a linear relationship between the concentration of glucose and the temperature difference of insulin-dependent and insulin-independent parts of the body. The concept of the method is that some organs of the human body absorb glucose without the help of insulin, i.e. they are insulin-independent. These include brain cells, lens, retina, nerve endings. For nutrition other tissue and organs with glucose insulin is required. With a lack of insulin in the body the level of glucose in the blood increases, this leads to increased work of insulin-dependent tissues, accompanied by the release of heat and fever. In this case, insulin-dependent tissues do not receive enough glucose, and their biological activity will be reflected in lower temperatures.

Another example of a non-optical non-invasive method of glucose determination is based on the measurement of acetone concentration exhaled by a human, which correlates with glucose content [2]. The acetone present in exhaled air continuously at 1-3mg/m^3; the concentration of acetone in the urine is identified semi-quantitative and has little diagnostic value.

We also note the study of Indian scientists who created a method for determining the glucose content on the signal of plethysmogram with verification by electromagnetic method [3]. The method includes the use of a multisensor system and processing of the data obtained using multidimensional linear regression technologies and artificial neural networks. Achieving high accuracy is prevented by fluctuations in skin moisture and body temperature.

Optical methods for determining blood glucose levels among non-invasive methods are considered to be the most promising [4, 5]. These methods include photoacoustic, polarimetric, spectroscopic methods, as well as methods of Raman spectroscopy and optical coherence tomography. However, the most promising optical methods are spectrometric ones. They allow you to get some information about the content of various impurities in the blood, including glucose. Research in this area is quite extensive and considerable research experience has already been accumulated [6, 7].

MATERIALS AND METHODS

The proposed method is spectroscopic and is based on the measurement of the intensity of the absorbed light as it passes through the blood-containing organ of a person at certain wavelengths [8]. Although this method has long been known, but still could not solve the problem of allocation of the share of light absorbed by glucose. In our method, we consider the possibility of determining the proportion of light absorbed by glucose by multiple measurements of the total intensity of the absorbed light at a large number of wavelengths in the near infrared area of the spectrum, as well as processing the experimental data using a specially designed for this purpose mathematical apparatus [9, 10], which includes the formation and solution of a system of linear equations with the number of unknown, no less than the number of light-absorbing components in the blood-containing organ through which light is transmitted.

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RESULTS AND CONSIDERATION

The Buger –Lambert - Ber law (1) was taken as the basis for determining the proportion of absorbed light in the blood.

$$I_0 = I(l) \cdot e^{k_\lambda l}$$, where (1)

I_0 –light intensity before transmission through the substance;
$I(l)$ –light intensity aftertransmission through the the substance;
k_λ – thesubstance absorption factor;
l – the substancethickness.

As this law is generally used only for the single-type substance (more precisely for a substance that has a certain thickness), it has been modified. Hence, our formula has taken the form:

$$I_0 = I \cdot e^{k_m \cdot n_m + k_p \cdot n_p + ... + k_z \cdot n_z}$$, (2)

where
k_m –theabsorption factor of a substance of type m at i-th wavelength;
n_m - the amount of substance of type m.
After a certain transformation, we obtain a simple linear equation:

$$k_m \cdot n_m + k_p \cdot n_p + ... + k_z \cdot n_z = \ln \frac{I_0}{I}$$ (3)

Then, for example, for a solution of glucose and water, the light absorption fraction formula has the form:

$$k_w \cdot n_w + k_g \cdot n_g = \ln \frac{I_0}{I}$$, where (4)

g- glucose,
w- water.

As any substance has its absorption factor at certain wavelengths and taking into account that there is no concept of substance thickness in the solution, the proposed formula allows us to measure the percentage of any substance in the solution.

Naturally, some substances can have the same absorption coefficients at certain wavelengths and to avoid such a case, it is proposed to carry out multiple measurements. As a result of multiple measurements, we have whole groups of systems of equations. The more systems, the more accurate the result is. However, this increases the process of solving these systems, which is not always a good solution. The main feature of the non-invasive method is not only obtaining results without biomaterial sampling, but also fast calculation.

Some substances at certain wavelengths have a maximum absorption coefficient as others at the same wavelengths have minimal, and even it tends to zero. So under certain conditions, at certain wavelengths, we can neglect some substances, which can greatly simplify the solution of a group of equations systems.

As mentioned earlier, the main test of our theory is the convergence of equations systems. As the most common method for determining the convergence of a system of linear algebraic equations is the Gauss method, we used it.

Also a good opportunity to verify quickly the correctness of our findings is the fact that the total percentage of all substances in the solution is 100. As the blood is a composite material and the entire biochemical composition of the blood is still not known (and different people have minor differences in the composition), the total percentage should not exceed 90-97%.

In a common sense, the convergence of equations systems is the definition of intersections of planes at one point. However, we do not have the coordinates of the plane (not the equations of the planes), but the coordinates of the functions, where the absorption coefficient of the substance on the i-th wavelength is plotted on one axis, and the intensity of the absorbed light on the i-th wavelength on the other axis. AS we are looking for the concentration of our substance, and it is unchanged - the functions will converge at one point. As the system of equations is nonuniform (free coefficients are not equal to zero), it is proposed to solve it by Gauss method, that is, by the method of sequential elimination of variables, when by means of elementary transformations the system of equations is reduced to an equivalent system of triangular form, from which all the variables of the considered system of equations are sequentially, starting with the latter (by number).

After calculating the amount of glucose in a percentage in the blood, we convert it into a liter/mole system and display the result.

CONCLUSION

As the beam of light pass not only through the blood, but also through part of the body, it will be necessary to take into account the substances in it. For example, in the earlobe substances such as melanin, epidermis and proteins contained in the tissues should be taken into account. Accordingly, the number of equations of the system and the number of wavelengths at which measurements are made will be increased. It will also be necessary to take into account the light scattering by proteins, which will require additional calculations and may affect the design of the device for summing the probing beam and the output of the transmitted beam.

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