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New opportunities for studying the oxygen saturation of blood hemoglobin in capillaries and tissues

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Abstract. A new method of express diagnostics of the health state based on the results of non-invasive measurements of the pulse waveform, pulse values, blood pressure, and oxygen saturation of blood vessels and tissues is considered. The feature of these measurements is that they can be carried out both in the hospital and at home (a person can implement them independently). To measure tissue oxygen saturation, a new optical hardware-software complex has been developed, which is compact and portable. The results of experimental studies of various people are presented.

Keywords: oxygen saturation, pulse wave, blood, tissues

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Материалы конференции
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Новые возможности изучения насыщения кислородом гемоглобина крови в капиллярах и тканях

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Аннотация. Рассмотрен новый метод экспресс-диагностики состояния здоровья, основанный на результатах неинвазивных измерений формы пульсовой волны, значений пульса, артериального давления, насыщения кислородом сосудов и тканей. Особенность этих измерений в том, что их можно проводить как в стационаре, так и дома (человек может осуществить их самостоятельно). Для измерения насыщения тканей кислородом разработан новый оптический программно-аппаратный комплекс, отличающийся компактностью и портативностью. Представлены результаты экспериментальных исследований различных людей.

Ключевые слова: насыщение кислородом, пульсовая волна, кровь, ткани

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Introduction

In recent years, for many reasons, the issues of express diagnostics of the functional state of human health in various situations have received increased attention [1, 2]. In contrast to the many methods of express diagnostics, pulse oximetry has not exhausted its possibilities for obtaining additional information about the state of human health in various situations, the potential of which has yet to be fully explored [3–7].

One of the new solutions for obtaining additional information about human health is using new optical systems we developed [8] to register pulse wave signals and tissue oximetry simultaneously. We process them with the combination of diagnostic information into a database and compare them with data obtained earlier by other methods [8, 9]. It allows obtaining additional health information in a short time, using new equipment and techniques, both for measuring and processing the recorded signals to interpret the integral signal.

Materials and Methods

The main goal of all work in this area is to increase the reliability of data on the state of the human body, which are obtained after processing the results of measuring pulse waves and changes in tissue oxygen saturation. To successfully achieve the primary target, we have developed a combined system for express diagnostics of the state of human health. Its block diagram is shown in Fig. 1.

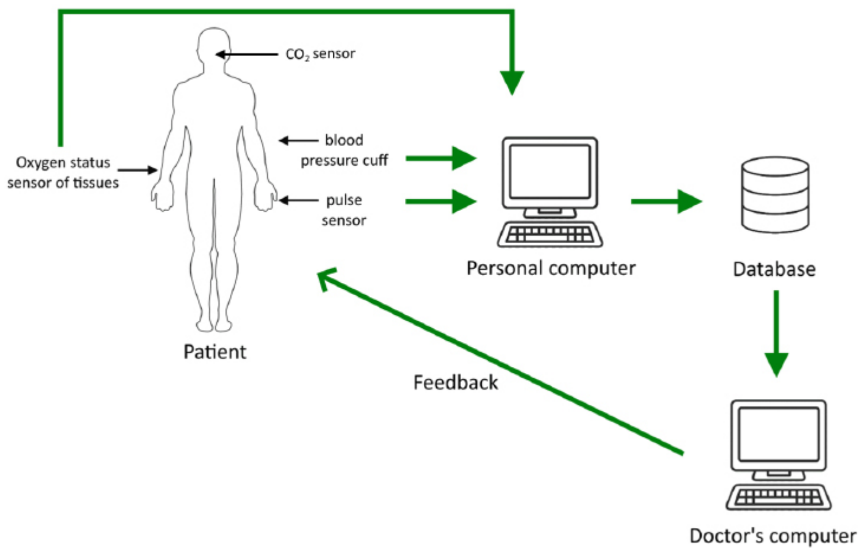

Fig. 1. Scheme for monitoring the state of human health in express mode

An optical sensor developed by us for registering a pulse wave and an optical system for studying tissue oximetry, and a standard device for measuring pressure are placed at three points on the hands to carry out measurements. For breath control, a CO_2 sensor is used. It should be noted that, unlike many previous studies, all measurements are carried out synchronously.

We have developed the following technique to identify additional information in the pulse wave signal, dividing it into six intervals (2 correspond to the rising front, 2 to the falling front, and 2 to the locality of the maxima). One dependence is used to describe the rising fronts of the pulse wave, and another is used for the falling front. In addition, unlike previous studies, we propose to use a separate function to study the neighborhoods of two maxima [9]. A separate function for studying the maxima is necessary because the change in the nature of the pulse waveform and the parameters of the steps in the presence of some diseases in a person, for example, angina pectoris or arrhythmia, requires a more detailed consideration of this part of the pulse wave (in the locality of both maxima).

To obtain additional information about the oxygen state of tissues and the processes occurring in the microcirculatory bed under study, we developed a multichannel system that operates in a wide range of optical radiation from 410 to 940 nm. A multichannel integrated optic spectrum analyzer registers and processes the reflected laser radiation. We used 18 channels with laser radiation of different wavelengths. Each channel has a spectral bandwidth of 20 nm. As radiation sources in the developed layout of the optical system, 3 SMD LEDs of varying glow colors were used: cold white, red, and infrared. SMD-type LEDs have some advantages: the small size of the LED, low cost, and long service life. Although the white LED is not a source of a broadband emission spectrum (as, for example, incandescent lamps), the white SMD LED emits a fairly wide region of the visible range from blue to red light (range from 450 to 660 nm) with a pronounced dip in the blue-green color (approximately 500 nm).

In the developed hardware-information complex, a novelty is the possibility of simultaneous registration of radiation backscattered in tissues at once at eighteen wavelengths of the visible and near-infrared ranges of optical radiation in real-time with a wireless connection to a computer, which allows recording measurements both at rest and when the patient performs functional and physical activity.

Results and Discussion

Patients of different age groups are studied, and their pulse waves are analyzed using improved previously developed formulas [9]. The improvement consists in considering several local maxima in the pulse wave (from 1 to 3), which occurred in patients and some empirical corrections in coefficients. Fig. 2, as an example, presents the results of the registration of pulse waves from people of different age groups.

During the study, patients held their breath for a minute, and after that observed for about 2 minutes. An example of the received results is presented in Fig. 3.

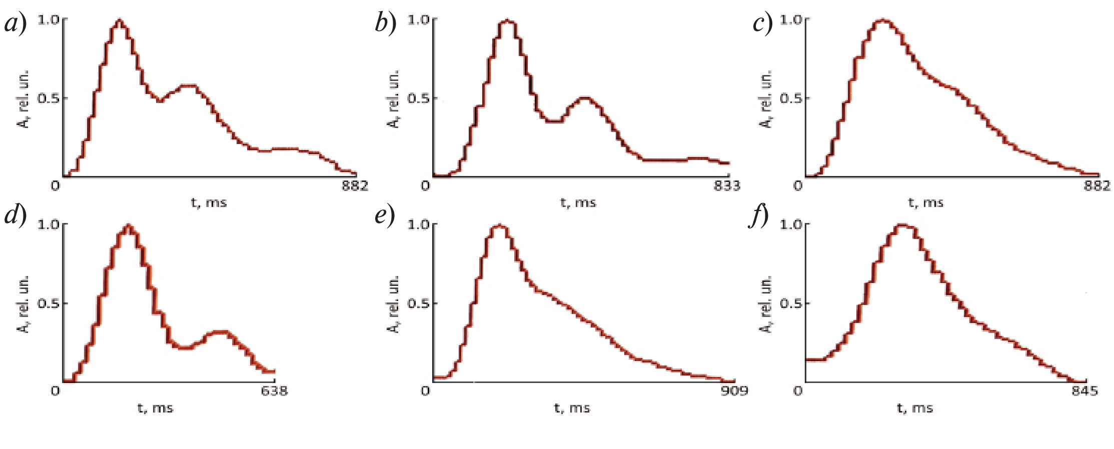

Fig. 2. One period of the pulse wave of patients. Age of male patients: 20 years old (*a*), 30 years old (*b*), 56 years old (*c*). Age of female patients: 22 years (*d*), 28 years (*e*), 40 years (*f*)

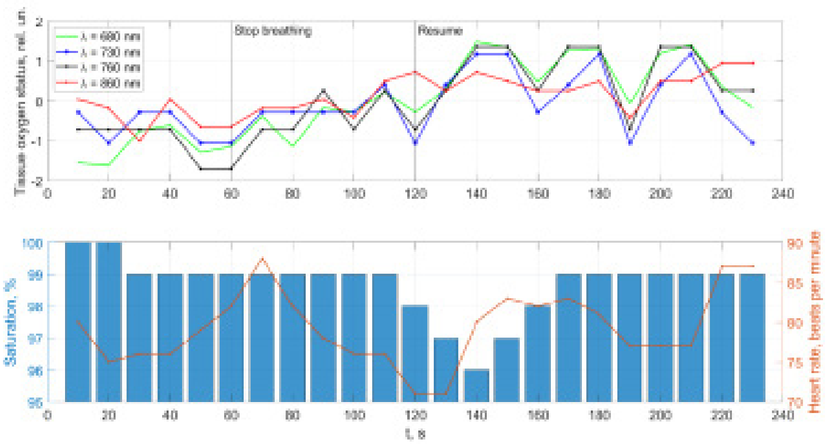

Fig. 3. Results of oxygen saturation for one of the patients

The results are collected and analyzed for 30 patients. Analysis showed that the new system makes it possible to detect minor deviations in pulse waveforms and tissue oxygen saturation problems, which were sometimes hard to do on the previously used equipment. After that, the results were compared with the patient's history and clinical study. In most cases, problems were confirmed.

Conclusion

Comparing data on human health obtained using the new methods and devices with examination data on certified clinical equipment showed a high degree of agreement. It confirms the validity of the methods and optical devices we developed for the integrated monitoring of the work of the human cardiovascular system. Some further investigations are needed to connect deviations with worse health states for different reasons.

The advantage of the developed system over those previously used for express diagnostics is the ability to detect progressive destructive changes in the blood supply in real-time. And also to compare these results with the dynamics of changes in the pulse wave. Previously, similar studies using other methods were carried out at different points in time (a person's condition could change, especially if the interval between measurements was long). As a result, the information was difficult to compare, which led to errors. In our case, all measurements are carried out simultaneously, making it possible to help determine the onset of vascular disease and pathological changes in the human body. It is needed to provide early medical intervention and prevent the transition of diseases to the chronic stage. In addition, rapid monitoring of the state of microcirculation and basic hemodynamic parameters will help control the treatment process and, in the future, may increase the number of cases of timely seeking qualified medical care, which will reduce the number of complications after the disease, as well as reduce the time of patients' stay in hospitals.

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