Method for Assessing Blood Flow in Segments of the Eye using Multichannel Rheoophthalmography

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Abstract: The paper presents the issue of studying changes and redistribution of the blood flow level in different segments of the eye using the electrical impedance method - rheoophthalmography. There are described and considered the quantitative values using this method for the posterior segment of the eye and the retrobulbar segment of the eye. Based on the obtained data, an algorithm for differentiation of disease stage for research groups with myopia is proposed. The principle of its operation is described. The prospects for increasing the efficiency of the developed algorithm are considered.

1 INTRODUCTION

Any changes in the blood supply to any organ or tissue of the human body entail changes in its functioning. It is also true for the human eyes (Schmetterer L., 2012). The blood supply to the eye covers both the area of the ciliary body in the anterior segment of the eye and the area of the sclera in the posterior segment of the eye. Determination of the blood supply level to the eye segments is of interest for many problems of ophthalmic diagnostics (Golzan S.M., Avolio A., et al., 2012; Michelson G., Gründler A., et al., 1994). It is known that in ocular pathologies, in particular myopia, the level of blood flow in different segments of the eye changes. In this regard, particular interest to the ophthalmologist is a study on the changes and redistribution of blood flow in the eye segments (Kunin V.D., Svirina T.A., 2002). This is especially true for a group of patients with low myopia, who are indicated for further therapy and correction.

Electrical impedance diagnostics is one of the non-invasive methods for assessing the state of blood flow in different areas of the human body with minimal impact on it (Cybulski G., 2011; Vasilyeva R.M., 2017; Bodo M., 2010). This diagnostic method makes it possible to form diagnostic information about the pulse blood filling of the investigated body area, as well as information about the biomechanical properties of blood vessels and the level of blood flow in them. The electrical impedance method is based on recording the changes in total resistance during probing tissues with high-frequency and low-amplitude current. Currently, there are several rheoophthalmographic (ROG) techniques for examining the eye (Avetisov E.S., Katsnel'son L.A., et al., 1967; Lazarenko V.I., Kornilovsky I.M., et al., 1999). The most atraumatic of them is the technique of transpalpebral rheoophthalmography (TP ROG), in which electrodes are applied to the closed upper eyelid (Luzhnov P.V., Shamaev D.M., et al., 2017; Luzhnov P.V., Shamaev D.M., et al. 2018). The study of the eye blood flow during the progression of myopia was carried out, the possibility of using this technique for the early diagnosis of blood supply disorders in myopic children was shown (Luzhnov P.V., Shamaev D.M., et al. 2017; Sokolova I.V., Yarullin K.K., et al., 1977). A feature of signal analysis of myopic patients concerns mainly the anterior segment of the eye.

In the general case, to assess the eye blood flow during diagnosis, it is possible to operate with three integral values of the blood flow level (Kiseleva A.A., Luzhnov P.V., et al., 2020): in the anterior segment of the eye, in the posterior segment of the eye, and also in the retrobulbar segment of the eye

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(as input value relative to the eye). It is necessary to develop a diagnostic algorithm for such a differential assessment of blood flow in different parts and take into account changes in the level of blood flow in each segment of the eye, and the ratio of these changes between segments.

2 MATERIALS AND METHODS

The method of electrical impedance diagnostics allows an integral assessment of the blood flow state in the eye vessels. At the same time, most other diagnostic methods are based on determining the blood filling of the eye vessels differentially. Electrical impedance diagnostics makes it possible to quantify blood supply not in individual arteries, but in the vascular system of the eye as a whole. The TP ROG technique allows a quantitative assessment of blood supply at a level corresponding to the anterior segment of the eye. It is achieved due to the positioning peculiarities of the TP ROG electrodes system (Luzhnov P.V., Shamaev D.M., et al. 2017). Multiple electrodes systems should be used to diagnose blood flow in multiple parts of the eye. The areas of study corresponding to the anterior, posterior and retrobulbar regions are shown in Fig.1. The corresponding positioning schemes for the ROG measuring electrodes are shown in the figure on the right.

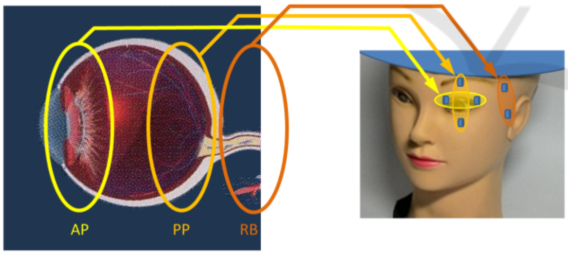

Figure 1: The areas of study corresponding to the anterior (AP), posterior (PP) and retrobulbar (RB) parts in the multichannel rheoophthalmography technique.

To study the anterior segment of the eye, it is advisable to use the TP ROG technique (Luzhnov P.V., Shamaev D.M., et al. 2017), which proved itself in the diagnosis of various stages of myopia in children and adolescents (Luzhnov P.V., Shamaev D.M., et al., 2015; Iomdina E.N., Luzhnov P.V., et al., 2014). To study the posterior segment of the eye, the method was previously used to determine blood flow parameters in groups of patients with glaucoma. For the study of the input blood flow, the method (Bodo M., 2010; Sokolova I.V., Yarullin K.K., et al., 1977) is known, which was used for the study of cerebral circulation. In our work, the data on TP ROG diagnostics were taken from (Luzhnov P.V., Shamaev D.M., et al., 2015). ROG signals for the posterior and retrobulbar segments were recorded in groups of patients with various degrees of myopia.

To register the electrical impedance signals of the ROG, a two-channel tetrapolar measurement technique was used. For each channel, two pairs of electrodes were used: two current and two measuring. The axis of electrodes symmetry of the posterior segment was located vertically (the first channel). The measuring electrodes were located along the edge of the orbit above and below the eye. The distance between them was 4.5 cm. Measuring electrodes of the second channel were located at the temple. The distance between the measuring electrodes was 2.5 cm. The second channel probing area included the area of the ophthalmic and internal carotid arteries. In the study we used standard self-adhesive electrodes for functional diagnostics. The distance between the electrodes was controlled by measuring the distance between their centers, or the attachment points of the lead cable. The frequency of the probing current was 100 kHz, the amplitude was 3 mA. Two-channel registration of the ROG signals with a sampling rate of 200 Hz was carried out. Then the ROG signals were filtered.

The primary analogue filtering was carried out using a combined bandpass filter with cutoff frequencies of 0.15 Hz and 100 Hz. It allowed selecting the component of the ROG signal, which reflected the process of pulse blood filling. Its amplitude was determined by the rheographic index (RI). The second component of the signal, called the base impedance (BI), was formed by a low-pass filter with a cutoff frequency of 0.15 Hz and reflected the level of general blood filling in the examined part of the eye.

Thus, the ROG signal was available for calculations for each patient, from which the RI and BI values could be determined. The average values of RI and BI for the study group were also calculated. Then it was possible to calculate the relative changes in these parameters comparing the study and the control groups. Based on these data, it became possible to build an algorithm for diagnosing and determining the blood supply disorders specific for the stage of the myopic process. This sequence implied the algorithm development for assessing blood flow in one part of the eye and the subsequent comparison of the data obtained in different parts of the eye using the signals analysis from multichannel ROG.

At the first step of the algorithm, one recorded signal was processed. In our work, the duration of the ROG signal was chosen to be 20 seconds. During this period, with calm breathing, several complete breathing cycles passed. It eliminated the influence of breathing phases on the one signal processing result. The computation started with a contour analysis of the ROG signal. The contour analysis used automatic detection of the onset of the systole phase with a period of rapid blood filling. It was used the threshold method used on the first derivative of the signal. The second point of the contour analysis was the systolic wave amplitude. It was determined by the position of the signal local extremum. The value of the RI amplitude was determined by the difference in the levels of these points. Then this stage of the algorithm was repeated for all whole periods of cardiac cycles presented in the analyzed signal record.

At the next step of the algorithm, the amplitude of the ROG signal was determined as the arithmetic mean of the amplitudes of all pulse waves included in the 20-second recording period. The RI value determined in this way corresponded to one value of the BI, since the BI change in time during the recording of the ROG signal was negligible. One ROG signal was represented by the resulting RI-BI score pair. For the second channel, the calculation was done using the same step. As a result, there were two pairs of RI-BI values for a two-channel ROG recording in a single patient study. One pair characterized the posterior segment of the eye, the other pair characterized the retrobulbar segment of the eye.

The obtained values were averaged for the entire group of studies. The resulting averaged value made it possible to assess the change of the indicators value in comparison with a certain value (for example, the norm). It also allowed comparing the diagnostic results in different groups. To visualize such comparison, the resulting parameters were presented graphically on the RI-BI plane. This presentation of the results made it possible to analyze the obtained diagnostic data. In addition, on the RI-BI plane, it became possible to build an algorithm for differentiation by disease stages.

To test the developed algorithm on the basis of the department of refraction pathology, binocular vision and ophthalmoergonomics of Helmholtz National Medical Research Center of Eye Diseases, a study of the ROG signals of several groups of patients with myopia was carried out. Simultaneous registration of the ROG signals of the posterior and retrobulbar parts of the eye was carried out using a two-channel measuring transducer. During the examination, the patient was in a horizontal position at rest. In total, ROG signals were analyzed in 21 patients (42 eyes). When carrying out two-channel registration, 4 groups of patients were formed: conditionally healthy with normal vision (refraction more than - 1.0 diopter), a group with low myopia (from -1.0 to -3.0 diopters), a group with moderate myopia (from -3.0 up to - 6.0 diopters) and a group with high myopia (- 6.0 diopters and more). The first group included 6 subjects (11 eyes) with an average age of 23.7 years. The group with low myopia consisted of 7 people (13 eyes) with an average age of 14.0 years. The group with moderate myopia was 4 people (8 eyes) with an average age of 17.2 years. The group with high myopia consisted of 5 people (10 eyes) with an average age of 16.2 years. This study was performed in accordance with the Declaration of Helsinki and was approved by the Local Committee of Biomedical Ethics of the Helmholtz National Medical Research Center of Eye Diseases. A written informed consent was obtained from all participants.

3 RESULTS

The relative change in pulse blood filling in groups with myopia was determined as the difference between the mean value of the parameter in the myopic group and in the group with normal refraction (normal group), divided by the mean value of the parameter for the normal group. In this case, RI(PP) and BI(PP) determine the indicators for the posterior segment, RI(RB) and BI(RB) determine the indicators for the retrobulbar segment.

To use the developed algorithm, the norm group was used as a control group. The magnitude of the relative change was calculated as the difference between the mean parameter in the group and the mean parameter in the control group, normalized to the mean parameter in the control group (in percents). This value was determined for each channel separately. The calculation results are shown in Table 1.

Table 1: Relative change in parameters for two-channel registration of ROG signals in percents.

Myopia Degree	RI(PP)	BI(PP)	RI(RB)	BI(RB)
Low	4.1	22.4	5.0	29.5
Moderate	-6.0	-23.6	-9.7	-2.9
High	-2.6	10.0	-5.6	8.3

The result of the algorithm is presented graphically in Fig.2. For each patient of the groups with myopia, two values of diagnostic parameters were obtained, presented by a pair of points on the RI-BI plane.

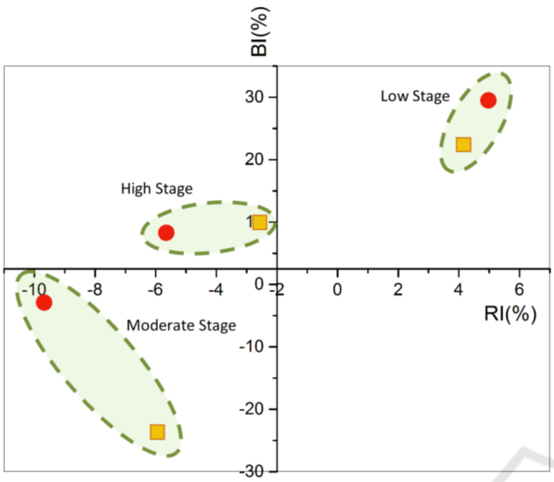

Figure 2: The diagnostic parameters, presented by a pair of points on the RI-BI plane for different stages of myopia.

Red markers on the graph (see Fig.2) show the parameters of the retrobulbar segment of the eye, orange markers show the parameters of the posterior segment of the eye.

4 DISCUSSION

The obtained results indicate a simultaneous increase in indicators in the temporal region and the region of the posterior segment of the eye for a low myopia. The points position on the graph with moderate myopia indicates an increase in the BI value against the background of a decrease in the blood supply to the posterior segment. In high myopia, it describes a decrease in the blood supply to the posterior segment of the eye with a simultaneous decrease in the total blood supply. This result suggests that with a low degree of myopia, a compensatory response from the vascular system is observed, which manifests itself in a relative increase in blood flow parameters.

In this work, the values of the control group were selected as the basis for the calculation results of the algorithm. However, the efficiency of the algorithm can be improved if other values are used as the origin of the RI-BI plane. It can be, for example, parameters reflecting blood flow in the anterior segment of the eye. The question of choosing the origin of coordinates to achieve maximum efficiency of the algorithm has not been fully resolved and requires further research, including other diagnostic methods, such as optical coherence tomography (Iomdina E.N., Kiseleva A.A., et al., 2020) for the posterior segment of the eye.

5 CONCLUSIONS

The use of the developed algorithm makes it possible to present for analysis and present graphically large data sets in multichannel ROG studies. The use of the algorithm for groups of patients with different myopia degrees showed the fundamental possibility of automatic differentiation according to the severity of the blood supply disorders. Along with the possibility of early diagnosis of these disorders, this will make it possible to study blood flow disorders of the eye in different segments with the possibility of quantitative comparison of these disorders. With the help of the developed algorithm, it becomes possible to implement it within the framework of one diagnostic technique for different ophthalmic diseases.

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The authors declare that they have no conflict of interest.

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