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Photometric methods for assessing the state of the light sensitivity of the visual system and its light-sensitivity changes in terms of hemodynamic disorders

Abstract. *In this article, the data of a quantitative estimation of the visual system light sensitivity of healthy people and the light-sensitivity changes in eyes of patients with arterial hypertension and ischemic optic neuropathy are given. Diagnostic usefulness of the photometric methods for assessing the state of the light sensitivity are discussed.*

Streszczenie. *W artykule opisano metody fotometryczne pozwalające określić aktualny stan układu wzrokowego zdrowego człowieka pod względem czułości na bodźce świetlne. Opisane metody pozwalają diagnozować zmiany czułości wzroku pacjentów z nadciśnieniem naczyń układu wzrokowego oraz neuropatią nerwów wzrokowych. Przedstawiono wyniki badań eksperymentalnych przeprowadzonych podanymi metodami. (**Fotometryczne metody oszacowania poziomu czułości świetlnej układu wzrokowego i jej zmian wskutek zaburzeń hemodynamicznych**).*

Key words: photometric methods, photometric diagnostics of the visual system, computer medical diagnostics.
Słowa kluczowe: metody fotometryczne, diagnostyka fotometryczna układu wzrokowego, komputerowa diagnostyka medyczna.

Introduction

It is well known that the hemodynamic abnormalities in the retina caused by atherosclerosis, diabetes, hypertension and other vascular diseases cause a decrease in visual function and a development of retinal degenerative process. There are several methods used for the assessment of blood flow in the retinal vessels: laser Doppler flowmetry, fluorescent angiography, optical coherence tomography, and digital photographic recording followed by an analysis of vascular pattern. Each of these methods exhibits its advantages and disadvantages. The laser Doppler flowmetry allows only a qualitative description of local blood flow comparing parallelly the assessments in two areas: one being under investigation, and the other as reference. Fluorescent angiography is applied to evaluate the size of vessels, the speed of fluorescent solution filling, and the structural integrity of the vascular wall. The optical coherence tomography allows to measure the thickness of the choroid in order to reveal the presence of edema and signs of vascular tissue neoplasm. The photographic recording is used for getting a picture and making a close and subtle analysis of the vascular tree of the central retinal artery and vein. Ophthalmologists and other specialists have gained a long-term experience in applying such important indicators of eye microcirculation estimation as: the diameter of the arteries, veins and micro vessels, the density of the vascular network, the nature of the vascular branching, the vascular wall condition and blood rheology, according to the nature of the movement of red blood cells and their aggregation (the "sludge" phenomenon), the signs of edema, and a number of other indicators, using the methods of ophthalmoscopy, biomicroscopy, fluorescent angiography etc.

The data concerning retinal vessels and blood flow state obtained using the modern research methods are very important for the disease diagnostic at the stage of morphological changes. However, those data do not allow to assess whether the blood flow in the vessels of microcirculatory bed is sufficient for ensuring the visual functions, and cannot be used for early, preclinical disease detecting. Such estimation is complicated because the efficiency of the main processes of the transcapillary exchange of substances between the blood and cells of the retina (diffusion, filtration, vesicular and other modes of transport) depends on many factors. The most critical factors are: the volume and linear flow velocity, the ratio of hydrostatic and oncotic pressures of blood extracellular fluid, blood rheology, the total surface area and the permeability of walls of the effective capillaries, the gradients of concentration, osmotic pressure, gas tension, the outflow of venous blood, and others. Obviously, the estimate of their combined influence on the processes of transcapillary exchange is practically impossible.

In regard to that, a rapid development of quantitative methods for microvascular circulation assessment and other indicators of microcirculation, has begun. The popularity of the method of digital photography and video of retinal vessels, and the vessels of bulbar conjunctiva, with subsequent processing of images using special computer programs as well as reasonably accurate measurement of vessel diameter, the thickness of their walls, and the nature of their reactions to various influences began to grow.

The emergence of quantitative methods for assessing the microcirculation allowed the researchers to start resolving the question how the state of microcirculation affects the function of tissues and organs for which it is estimated [1-3]. Given that the blood flow in the vessels of microcirculation is a major factor in the normal exercise of tissue functions, the simultaneous assessment of the microcirculation and tissue function could be an important way to determine the sufficiency or insufficiency of blood flow in the microcirculatory bed for the metabolic needs of tissues.

After a large amount of studies of the retinal vessels and limbal conjunctiva in diseases of the visual system, it became apparent that the microcirculation disturbance is not only accompanied by a decrease of visual functions, but also can be an indirect indicator of hemodynamic disorders in cerebral vessels [3]. By the development of research on of the eye microcirculation indicators it has been found that the connection between the hemodynamic disorders in the retinal vessels and widespread consequences in form of vascular diseases can happened [3-5]. It has been shown that the presence of retinal microvascular malfunction increases the risk of ischemic stroke, disorders of coronary blood flow, and faster progression of hypertension. These observations became the basis for hypothesizing that there is systemic disease of arterioles, and they underlie the assumptions that the retinal and scleral microvascular state

may be a status marker of the vessels in other organs and tissues [6].

Since the implementation of the visual functions requires significant investment of metabolic energy, it is not surprising that its most important indicator, i.e. light sensitivity, depends on the blood vessels in the retina and brain. It is known that the highest density of blood capillaries is characteristic for the central fovea of retina, where the main consumers of oxygen, i.e. photoreceptors and other cell, are concentrated. It is an important indicator of visual functions.

Methods

The purpose of this study was to examine the state of the light sensitivity of the visual system and its changes in disorders of hemodynamics, to determine the possibility of using the threshold and colour contrast sensitivity indicators as markers of the blood flow in the vessels of the visual system.

For this reason, the computerized setup and dedicated program software were elaborated [7]. The investigations have shown that the monitors based on cathode-ray tubes have more stable reproducibility characteristics for a given brightness, especially at moderate values of brightness. Therefore, a monitor based on cathode-ray tube is used in the setup. The brightness of illumination of R, G and B elements is calibrated, and then is reproduced with an error less than 5 %.

In order to determine the threshold of light and colour contrast sensitivity of the visual system, a modified principle of computer perimetry was applied.

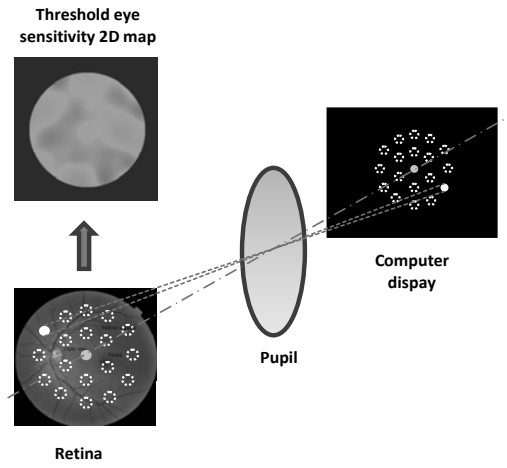

Fig.1. Optical scheme illustrating the method of determination of the eye's threshold sensitivity (in the Figure, the sensitivity of rods in the green regions is decreased)

The contents of the method can be illustrated on the example of threshold sensitivity of rods in Fig. 1. During investigations the controlling program chooses consecutively (at random) the coordinates of luminous point according to two-dimensional matrix of stimuli location. These points illuminate in some place of the monitor in the shape of 2×2 mm^2 squares the brightness of which increases linearly during 6 s. Optical elements of the eye form the image of these points on the retina surface. For each point, according to the measured time intervals from the onset of increasing the brightness until the instant of patient's fixation, the colour map of threshold sensitivity is drawn.

Before investigations, the patient is kept in the conditions of dark adaptation for 15 min. All sources of any radiation in the dark room are eliminated. The background radiation of the monitor at the absence of the image is kept at minimum value (approximately 0.1 cd/m^2). The monitor is placed 20 cm from a patient's eyes and his head is fixed on a support. After 15 minutes the illuminating points appear at random areas of the monitor which are determined by the matrix of points displacement. These points appear within the solid angle confined by the straight line from the eye's centre at the angle 20^0 to the direction of sight fixation. The brightness of these points is increased linearly. During the investigation of the colour contrast sensitivity the colour of appearing points is red. The patient watches continuously the spot 2x2 mm, twinkling at short intervals in the monitor central area, a minimum illumination intensity of which was produced (as illumination at a subject's face) on the level about $1.1 \cdot 10^{-6}$ Lx, and at the maximum illumination intensity – about $4.1 \cdot 10^{-5}$ Lx. As soon as the patient notices the appearing spot within his peripheral vision he is obligated to register this instant by pressing the "Enter" key.

In order to study the light sensitivity threshold of rods for the dark adapted subjects, a black backgrounded screen of the monitor was offered for detecting the same white object of a minimum brightness; the person's face illumination level was $1 \cdot 10^{-7}$ Lx, while at a maximum level - $5 \cdot 10^{-7}$ Lx.

After the testing has been finished, the two-dimensional map of the retina sensitivity based on the results of the measurements is drawn. On this map the location of each point of the two-dimensional matrix of points is labelled with the value of the reaction time interval. Then the number of points within the fovea area is about 10 points of the whole set displayed.

Together with the light sensitivity, the state of microvascular vessels was estimated by ophthalmoscopic examination of the fundus as well as according to the analysis of the retinal and bulbar conjunctival vascular tree in digital photo and video.

Results and discussion

It was revealed that the colour contrast sensitivity of the visual system of healthy young people aged 18-30 was $(0.78 \pm 0.09) \cdot 10^{-5}$ Lx, and decreased with age. In the study of colour contrast sensitivity in 30 young people of the same age with high blood pressure (hypertension 1-2 degrees) within the same age range, it turned out that it was significantly reduced in comparison with healthy people, and was equal to $(0.9 \pm 0.2) \cdot 10^{-5}$ Lx (Fig.2). The study of bulbar conjunctival vessels in this group of subjects by digital video recording, revealed signs of predisposition to vasospasm and a positive correlation between the colour contrast sensitivity and the level of diastolic blood pressure. The light sensitivity threshold for healthy young men was $(2.4 \pm 0.3) \cdot 10^{-7}$ Lx and its value was also positively correlated with diastolic blood pressure (Fig. 3).

A significant reduction in colour contrast sensitivity of the visual system was found for 25 patients with acute ischemic optic neuropathy (AION) and for 26 patients with chronic ischemic optic neuropathy (CION) caused by impaired hemodynamics in the vessels of the optic nerve and retina due to atherosclerosis, high blood pressure, vasculitis, and vasospasm. The results of this study are presented in Table 1.

The comparative analysis of static visual acuity changes, colour-contrast sensitivity and condition of retinopathy in patients with ischemic optic neuropathy, indicates the absence of strict parallelism in their changes. Thus, for the most evident vascular changes and hemodynamic disturbances in the fundus in patients with CION the static visual acuity could be preserved or slightly reduced. The colour contrast sensitivity was less reduced than in patients with AION with the similar values of static

visual acuity, for which less evidenced changes in microvascular bed could be detected. Moreover, for some patients with CION and AION having unaltered static visual acuity and no changes in the microcirculatory vessels of the fundus, significant reduction in colour contrast sensitivity to red stimulus in the central visual field were detected.

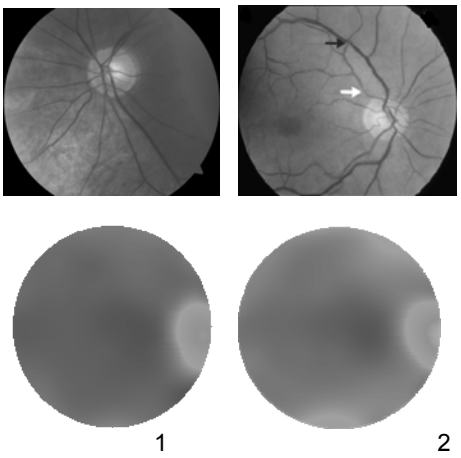

Fig.2. The colour contrast sensitivity: 1 – healthy young people; 2 – young people with arterial hypertension of I-II stages

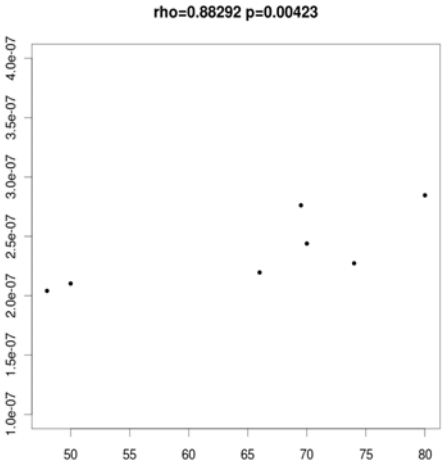

Fig.3. The relationship between the light sensitivity threshold and the diastolic arterial blood pressure

Table 1. The colour-contrast sensitivity indicators (Me (25% - 75%) in the central visual field for patients with ischemic optic neuropathy

The optic neuropathy type	The colour contrast sensitivity × 10^{-5} Lx
The healthy subjects (n=29)	0.89 (0.86-1.03)
The healthy subjects (n=29)	1.14 (0.93-1.41)*
The AION patients, (n=25)	2.28 (1.71-2.58)*
The CION patients, (n=26)	1.54 (1.3-1.83)*

* P <0.05 - compared with the healthy subjects,
** P <0.05 - compared with the healthy eye of patients.

The opposite case, when at the presence of the microcirculation disturbances, the fine visual function indices remained intact, was also observed.

Conclusions

The application of photometric methods to computer perimetry has shown a high effectiveness of the light sensitivity as a marker for the visual system indices in hemodynamic disorders [8]. The results of this study indicate the necessity for more detail studies aimed at identifying the relationship between parameters of visual function, blood flow in the microvessels and the retinal metabolism. Such studies could be carried out if a special integrated optoelectronic equipment would be available.

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