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Case Report

Features of the Development of Childhood Glaucoma and the Possibilities of its Treatment

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Abstract

Annotation Glaucoma is an ophthalmological disease that is detected at birth or during life, where its development without treatment leads to severe consequences - blindness. Cases of partial or complete loss of visual functions in children due to increased intraocular pressure (IOP) are increasingly being detected, and this figure is constantly increasing in Eastern European countries (1-2 cases per 2500 newborns are registered). The appearance of this disease, its course and complications depend on the intraocular pressure, which at birth is 9-12 mm Hg. st., and later increases, reaching a maximum of 22-45 mm Hg. st. already in adulthood. Therefore, it is necessary to monitor IOP even in the early stages of development of the child's body.

Timely detection of the disease in the early stages of is an extremely important problem in glaucoma and allows you to use drug treatment with a positive effect. In childhood, during growth, the parameters of the eye change, including the thickness of the eye membrane, its elasticity, which have a significant impact on the pressure distribution and the possibility of glaucoma. The authors conducted a simulation of the impact of changes in the thickness of the eye membrane on the distribution of stresses, which can lead to the occurrence of glaucoma.

During the modeling process, it was determined that within the thickness of the eye membrane of 0.1-0.3 mm and the pressure of 9-14 mm Hg. optimal tension of less than 100 kPa is provided. Raising IOP values more than 21 mm Hg. leads to a sharp increase in tension (>150 kPa) and the progressive development of glaucoma. Recommendations include preventive examination, IOP control when the thickness of the eye membrane changes, possible stages of drug and surgical treatment

Keywords: childhood glaucoma; intraocular pressure; eye tension; drainage devices

Introduction

In children's ophthalmology, there are some cases of partial or complete loss of visual functions in children, which is characterized by an increase in intraocular pressure (IOP) and due to changes in the conditions of exposure to eye diseases, this figure is constantly increasing in European countries [1,2]. In the future, ophthalmologists predict blindness in tens of millions of people worldwide, 25% of them due to glaucoma, including children. In glaucoma, visual impairment significantly reduces the level of information perception and aggravates the pathological condition with progressive death of ganglion cell axons, which causes complete loss of the visual field. Some well-known modern methods of treating glaucoma are the following: drug therapy, laser therapy and surgical implantation of drainage devices, which provide the necessary rate of the intraocular fluid removal (normally it is 2-2.5 μl/min) almost stably. It is known that the implantation of drainage devices in glaucoma is performed after unsuccessful previous attempts at conservative treatment and due to a decrease in the speed of movement and insufficient outflow of intraocular fluid through the trabecular meshwork of the eye [3-5].

For an adult, the average values of the eye parameters are characterized by the following values:

1. Intraocular pressure 14-16 mm Hg.

2. Minute volume of moisture 2 mm3/min.

3. Coefficient of ease of outflow 0.2-0.3 mm3/min.

4. Becker coefficient 60-70

Normal IOP values for children are lower than for adults: the norm for newborns is approximately 9-11 mm Hg, and by the age of 4-5 this figure increases to 14 mm Hg. Therefore, with a constant increase in IOP, which can often occur, before a planned surgery, it is necessary to carry out an individual selection of implants with reasonable parameters for an individual patient. The main clinical sign of glaucoma in children is a significant increase in IOP (more than 22 mm Hg and above), and in some cases even low pressure in this range may be considered unacceptable. The detection of IOP leads to the action of high pressure on the conjunctivaand, accordingly, on the optic nerve [4-6]. This creates a force that changes the shape and stretches the thin conjunctiva. In these conditions, tension is defined as the ratio of pressure to the actual size of the conjunctivaon which it acts. It should be noted that performing surgery and installing a regulating valve, for example, of the Ahmed type, is a complex process that can be used if the use of drug therapy has not achieved results and further deterioration of the child's vision is noted. Making a decision to perform surgery as the only option to prevent vision loss in a child depends on many factors: the choice of the valve and the use of high-quality material elements, checking the modes of its timely operation (the magnitude of the pressures of its opening and closing), the mandatory technological inspection on special stands, etc. [7,8]. It is also important to correctly assess the state of the eye during its functioning and the magnitude of the tension level in it. The purpose of this study is to conduct modelling of the child's conjunctivatension at different pressure parameters and sizes of the eye conjunctivathickness in order to further take it into account in the period before surgery [9]. Modeling provides the opportunity to obtain information about the stresses that arise depending on the thickness of the eye shell and intraocular pressure, thereby ensuring the prediction of more accurate design or selection of the implant. Additional check of the implant for operability, using the author's automated system, allows to increase the efficiency of surgical intervention in the child's eye.

Theoretical studies of modeling the distribution of tension in the shell of the child's eye tension

It is known that the size of a child's eye at birth is on average 16.2 mm. By the 1st year of life it increases to 19.2 mm, and at the age of 15 it is equal to 23 mm, which is already practically approaching the average size of an adult's eye, namely 24 mm. Since the shape of the child'sconjunctivais not perfectly spherical (Figure. 1), its radius of curvature is variable: it increases from the front to the back and in the central part of the cornea its radius of curvature is approximately 7 mm, on the periphery of the cornea it is already 9 mm, in the anterior part of the sclera - 11 mm, and in its posterior part - 12 mm.

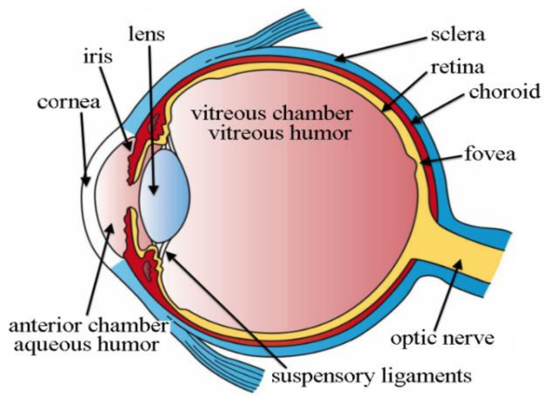

Figure 1: Human eye anatomy

Also, the thickness of the sclera is not the same in different areas: in the posterior pole of the eye it is almost 1 mm, near the edge of the cornea - 0.6 mm. [5].

Considering the above parameters of the eye, we can proceed to the modelling of tensions.

Since the wall thickness of the spherical conjunctiva of the eye (Figure. 2) is much smaller than the radius of its curvature, to calculate the tension per unit area of the cross-sectional area of the TS eye conjunctiva, it is advisable to use the Young-Laplace formula, where all the necessary values can be taken into account - the parameters of the intraocular pressure, the parameters of the conjunctiva and the cornea:

$$T_s = \mathrm{P}r_k / 2d \quad (1)$$

where Pis intraocular pressure (IOP); r_k – radius of curvature of the cornea of the eye; d – thickness of the eye conjunctiva

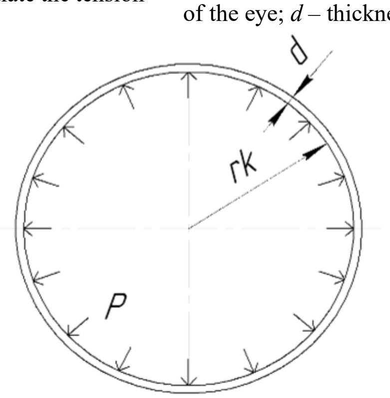

Figure 2: Image of tension action in the spherical conjunctiva

Since the shape of a child's eye is elliptical, to calculate the tension per unit of the cross-sectional area $T\varphi$it is necessary to apply a more accurate formula (2) that uses clarifying coefficients, which provides more accurate results:

$$T_{\varphi}=\frac{P}{2bd}\sqrt{r^{2}(b^{2}-a^{2})+a^{4}}\ , \qquad (2)$$

where: P is intraocular pressure (IOP); a – larger diameter of the conjunctiva; b – smaller diameter of the conjunctiva; d – thickness of the conjunctiva; r – coefficient determined from the ratio:

$$r=\sqrt{\frac{a^{4}}{2(b^{2}-a^{2})}}\ , \text{ at}(a>b), \qquad (3)$$

where a and b – are the larger and smaller radiuses of the conjunctiva, respectively.

Based on the above ratios (1-3), the authors have constructed graphs of the dependence of tensions on different conjunctiva thicknesses, taking into account the parameters of the child's eye at different IOPs. The distribution of tensions in the posterior segment of the conjunctiva on the conjunctiva thickness is given below (Figure. 3).

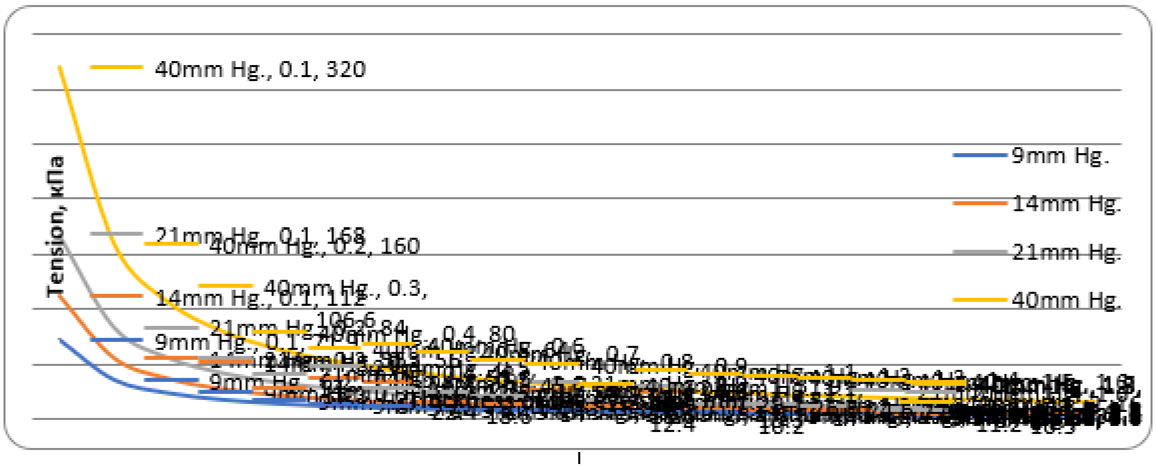

Figure 3: Dependence of the posterior conjunctiva tensions on its thickness, with a curvature radius of 12 mm for different IOP levels: 9 mm Hg; 14 mm Hg; 21 mm Hg; 40 mm Hg.

In the process of modelling, based on the calculations and results obtained, it can be stated that with IOP in the range of 9 mm Hg - 14 mm Hg (normal in children), optimal tension of less than 100 kPa is ensured. An increase in IOP values significantly more than 21 mm Hg leads to a rapid increase in tension (>150 kPa) and the creation of conditions for the development of glaucoma. So, in IOP from 21 mm Hg up to 40 mm Hg, the tension increases almost 2 times or more, especially with a conjunctiva thickness of less than 0.6 mm. In this mode, the process of glaucoma is diagnosed, which ultimately leads to damage to the optic nerve and, as a result, to the child's vision loss.

Technical support for preoperative testing of intraocular implants

As a result of the analysis of drainage devices, it was found that there is practically no possibility of individual selection of valves taking into account the characteristics of patients, including children. Therefore, the authors of [8,10]. developed an automated system for preoperative inspection and testing of drainage devices. The system provides the ability to take into account individual patient parameters, automatically record valve opening and closing pressures, allows checking the performance of valves over time, recording information about the testing process, and rejecting low-quality devices. The functional diagram of the automated system is shown in Figure 4

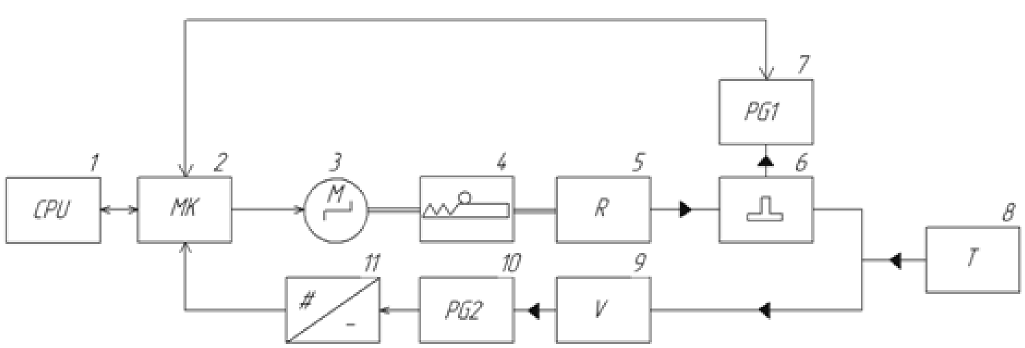

Figure 4: Block diagram of the implant testing device for IOP regulation

The device comprises a computer 1, a microcontroller 2 connected in series, a motor 3 with a worm gear 4, a reservoir with physiological saline solution 5, a 3-input splitter 6 with an electromechanical pressure meter 7 connected to it, pressure balancing tube 8, and implant 9 to the output of which is connected to the liquid detector 10 and ADC 11 connected to the input of the microcontroller 2, the second output of which is connected to the input of the computer 1. The device for testing implants for regulating intraocular pressure works as follows. First, the implant is connected to the cannula, then through the pressure tube 8 the system of connecting tubes and the reservoir 5 is filled with saline solution. On the computer 1, the mode of checking the presence of air inclusions in the system is set (the mode of "zero reference setting" of the measuring system), for which the microcontroller 2 generates a series of pulses of rotation of the rotor of the stepper motor 3, which slightly (by 3-5 units of mm Hg) increases the pressure in the tank 5 and the connection system with the help of the worm gear 4 and the existing air residues are squeezed out through the pressure balancing tube 7. The next step is the implant testing mode" for which the pressure tube 7 is closed, the microcontroller 2 generates a test sequence of pulses to rotate the rotor of the stepper motor 3 through the worm gear 4 connected to the piston of the saline tank 5, the pressure in the connection system increases step by step and is continuously monitored by a microelectromechanical pressure meter 7, the pressure level is constantly read by the microcontroller 2 and recorded in the computer memory in the form of a pressure graph. The pressure rises from zero to the value of operation of the implant under test. At the outlet of the implant there is a liquid that falls on the liquid detector 10. The signal of the detector 10 through the ADC 11 is converted into digital form and fed to the microcontroller 2, which stops the process of rotation of the rotor of the stepper motor 3. Information about the end of the testing process and the measured value of the pressure level of the implant from the microcontroller 2 and the electromechanical pressure meter 8 is transmitted and recorded in the computer memory. As a microcontroller used chip STM32F103RET6, microelectromechanical pressure meter ST Microelecronics LPS33HW is one of the functional units that provides the ability to automate the testing process. The microcontroller reads data from the meter via SPI interface and provides communication with a computer. The pressure measurement error is 0.075 mm Hg or 0.25% at the maximum pressure value in the tank.

Conclusions

1. Preventive control of intraocular pressure in childhood can prevent glaucoma with vision loss.

2. An increase in IOP to 11-14 mm Hg creates tension in the conjunctivawithin values up to 100 kPa, which becomes a signal for the use of more effective treatment methods.

3. Further increase in IOP (>14-21 mm Hg) with ineffective treatment and reaching tensions of more than 100 kPa is stopped by performing surgical intervention with the installation of a valve.

4. So, an increase in IOP above the norm in the treatment of glaucoma in childhood requires enhanced treatment or effective surgical intervention, as evidenced by publications of domestic and foreign authors and the results of calculations with graphical representations presented above.

5. The modern automated system for testing drainage devices developed by the authors allows for their preoperative testing and individual selection according to patient parameters, including in pediatric ophthalmology.

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