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Complex of Thermoelectric Equipment for Diagnostics and Treatment of Ophthalmological Diseases

The article presents the prospects for the use of new models of thermoelectric equipment developed to solve some urgent problems of ophthalmology, in particular the justification and implementation of the technology of controlled local artificial hypothermia of the eye in vitreoretinal surgery. Thermoelectric devices for measuring intraocular temperature, epibulbar temperature, and heat flux on the surface of the eye were demonstrated, which allow for comprehensive perioperative monitoring of thermal processes in the eye during vitreoretinal surgery. The design of new thermoelectric devices is also described, which provide active cooling/heating of irrigation fluid or eye structures, and which create opportunities for controlling thermal intraocular processes both intraoperatively and in the pre- and postoperative periods.

Keywords: thermoelectric cooling, irrigation fluid, surgery, ophthalmology.

Introduction

Advances in thermoelectric science, thanks to advances in materials science and device design, open up new prospects for the practical use of thermoelectric energy conversion. Research into new materials with higher thermoelectric characteristics, continuous improvement of production processes to achieve greater thermoelectric conversion efficiency, expand the potential areas of application of thermoelectric devices [1–3].

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Recently, thermoelectric technologies, which can directly convert thermal energy into electrical energy and vice versa using the Seebeck effect and the Peltier effect, have attracted increasing attention in the field of biomedicine [4, 5]. Thus, thermoelectric sensors, which are capable of converting thermal energy generated as a result of biological activity into electrical signals, can be integrated into clinical diagnostic systems, facilitating health monitoring [6]. Thermoelectric modules, which provide active cooling/heating by transferring thermal energy using electricity, can be used for localized cooling and heating of biological tissues, fluids, and medical devices under precise temperature control [7–9].

Today, due to the progressive development of the latest technologies in various fields of science and technology, there is a growing trend of introducing innovative approaches into the medical field, in particular ophthalmology [10]. In ophthalmological science, there is a need for modern solutions both for the development of new possibilities for early and objective diagnosis of eye diseases, and for their effective therapy and minimally invasive surgery.

Thus, today the “golden” standard of treatment for patients with various ophthalmological pathologies (proliferative diabetic retinopathy, penetrating eye injuries, retinal detachment) is vitreoretinal surgery. Despite the constant improvement of surgical technologies, there are a number of unresolved problems that reduce the effectiveness of surgical treatment [8]. One of the important problems of vitreoretinal surgery is that during the surgery, irrigation fluid is injected into the middle of the eye, usually at room temperature, i.e. much lower than the temperature of the intraocular media [11], and monitoring of the intraocular temperature and the temperature of the irrigation solutions is not performed. Thus, ophthalmic surgery is accompanied by artificial uncontrolled (often prolonged) deep hypothermia of intraocular structures with their subsequent rapid uncontrolled warming after the cooling stage. Rapid uncontrolled changes in intraocular temperatures that occur during surgery create significant risks of damage to the structures of the eye, as well as the occurrence of undesirable vascular reactions during the operation, which may also be accompanied by complications [12]. In this case, the surgeon usually does not have the ability to control the temperature of the irrigation fluid entering the eye and influence the temperature of the intraocular environment.

An important problem of vitreoretinal surgery can also be the risk of developing inflammatory complications in the postoperative period [13]. Currently, only the laser photometry method allows objectively assessing the presence and determining the degree of intraocular inflammation at the early subclinical stage [14]. However, the widespread use of this technology is limited due to the need to provide departments with complex and expensive equipment. The search for other accessible and reliable means of early objective diagnosis of intraocular inflammation remains an urgent task of ophthalmology. It is known that inflammation of the eye tissues, which can be a dangerous complication of surgical intervention and requires emergency measures, is often accompanied by ocular hyperthermia [14]. To date, significant progress has been made in the creation of thermoelectric means of measuring heat flux (HF), which is an important indicator of the intensity of heat exchange and allows for improved assessment of the functional state of biological objects [15–17]. Modern thermoelectric HF sensors are characterized by compactness, high sensitivity, accuracy and speed [16]. Therefore, recording temperature and HF changes caused by inflammation seems promising and can be used for early objective diagnosis of postoperative intraocular inflammation. And to combat intraocular inflammation, some authors suggest using local cooling of the eye [18].

Thus, perioperative monitoring of eye heat exchange is an important condition for increasing the safety of long-term vitreoretinal surgery. To solve the above-mentioned problems in the field of vitreoretinal surgery and obtain a comprehensive understanding of the thermal processes occurring in the tissues of the eye during surgery and in the postoperative period, the development and implementation of high-precision medical equipment for measuring temperature and heat fluxes for ophthalmological needs is relevant. It is also important to create medical equipment that will provide new opportunities to influence the thermal processes of the eye both during surgery to create optimal conditions for its conduct, and in the postoperative period to improve the results of surgical intervention. The implementation of these tasks will provide justification and implementation of the technology of controlled artificial local hypothermia of the eye in the practice of ophthalmology.

The purpose of the presented work is to demonstrate the possibilities of using thermoelectric technologies to solve some current problems in ophthalmology.

2. Thermoelectric equipment for ophthalmology

The Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine, within the framework of a cooperation agreement with the State Institution "Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine", developed the following thermoelectric equipment for use in ophthalmology: 1) a thermoelectric device for measuring intraocular temperature during vitreoretinal surgery; 2) a thermoelectric device for measuring temperature and heat flux on the surface of the eye; 3) a thermoelectric device for controlling the temperature of irrigation fluid during ophthalmic operations; 4) a thermoelectric device for contact cooling of the eye, 5) a thermoelectric device for contactless cooling of the eye.

2.1. Thermoelectric device for measuring intraocular temperature

The thermoelectric device designed for vitreoretinal surgery consists of a microprocessor temperature recording module, thermocouple measuring microprobes, a docking device, and a computer with software for recording and visualizing temperature readings in real time (Fig. 1) [19].

For the specified device, the temperature sensors were made on the basis of L-type thermocouples (chromel-copel). The thermocouple is placed inside a standard polytetrafluoroethylene cannula (outer diameter of the measuring probe 0.6 mm, length 19 mm). The diameter of the working part of the probe allows it to be used intraoperatively through a standard surgical port for vitrectomy (Fig. 2). The device can be used to measure temperatures in the range from −10 °C to +120 °C with a measurement error of ± 0.08 °C.

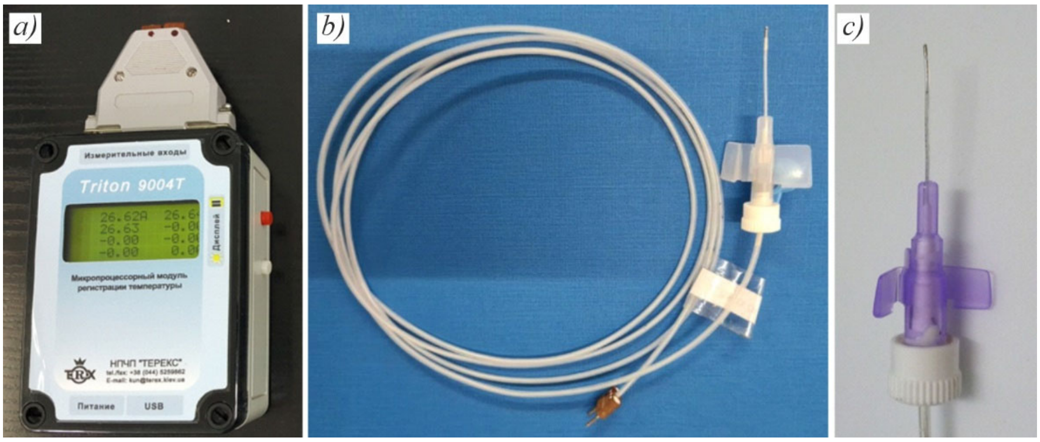

Fig. 1. Appearance of a thermoelectric device for measuring intraocular temperature. a). Microprocessor temperature recording module. b). Flexible thermocouple measuring probe. c). Measuring probe in a standard housing made of polytetrafluoroethylene cannula (outer diameter of the measuring probe 0.6 mm, its length 19 mm)

The developed device is multi-channel. The measuring probes are connected to the microprocessor temperature recording module via a docking device using a plug. The docking module has 4 connectors, to which up to 4 microprobes can be connected simultaneously. The temperature recording module is connected to the docking device using a DB-37f connector. The sockets in the docking device are mounted on a copper heat concentrator, which also houses a precision temperature sensor (platinum resistance thermometer), which measures the temperature of the "cold" ends of the thermocouples (reference temperature).

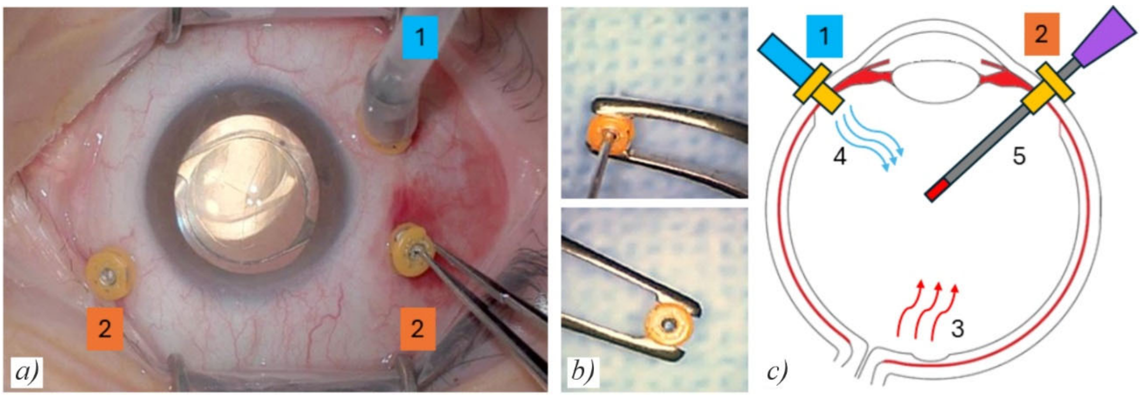

Fig 2. Procedure for intraoperative measurement of intraocular temperature. A. Operating field with established surgical ports for insertion of instruments into the eye (2) and irrigation cannula (1). B. Surgical ports. C. Schematic representation of the eye during surgery: heat flux directed from the choroid towards the anterior segment of the eye (3); irrigation fluid (4) entering the eye through the irrigation cannula (1); flexible thermocouple measuring probe (5) inserted into the vitreous cavity through the surgical port (2)

The microprocessor module for temperature recording is based on the Triton-9004T device, which has an 8-channel 24-bit analog-to-digital converter. This temperature meter uses 4 channels, and the other 4 channels can be used additionally. The maximum input voltage of the measuring channel is ±1.17 V. The temperature recording module is powered by a rechargeable battery or can be powered by a mains adapter. The rechargeable battery is charged using this adapter. The battery can also be charged and the device can be controlled from a computer via a USB cable. To work with the multi-channel temperature measurement module, the ThermoLogger version 2.0 program (TEREX, Ukraine) was used. It allows for real-time measurements and reading of data from the memory block. The measurement results are displayed on the screen using a graph and table, which can be saved, exported, and printed.

The developed device provides the ability to set the sensitivity separately for each channel of the microprocessor module depending on the type of thermocouples. The thermoelectric device can measure the temperature during a given time interval in the range from 4 seconds to 2 hours. Data on the measurement results are recorded in non-volatile memory. The device's memory capacity is 50 thousand cells. Programming of the microprocessor module channels is performed using a computer.

2.2. Thermoelectric device for measuring temperature and heat flux density on the surface of the eye

The developed device for determining the HF density of the eye consists of an electronic control unit and a thermoelectric HF sensor. The appearance of such a device is shown in Fig. 3 [20].

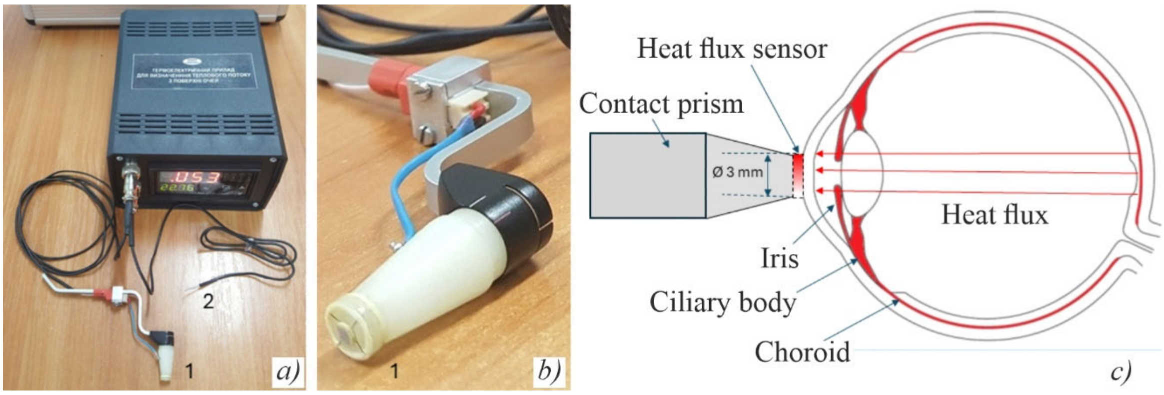

Fig. 3. Thermoelectric device for determining the temperature and HF density of the eye. a). Electronic control unit with HF sensor (1) and temperature sensor (2). b). Thermoelectric HF sensor (diameter 3 mm) mounted on a contact prism. c). Schematic representation of the position of the contact prism with the HF sensor relative to the patient's eye

For the presented thermoelectric device, a miniature thermoelectric HF sensor was developed and manufactured using a special patented technology of the Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine. The thermoelectric micromodule with dimensions of 2 mm × 2 mm × 0.5 mm contains 100 crystals of *n*- and *p*-type conductivity with dimensions of 0.17 mm × 0.17 mm × 0.4 mm made of a highly efficient thermoelectric material based on Bi_2Te_3. The thermoelectric micromodule is placed between two ceramic plates based on Al_2O_3 with a diameter of 3 mm and a thickness of 0.1 mm each, and the side surface is sealed using a special sealant. Thus, the diameter and height of the manufactured HF sensor are 3 mm and 0.7 mm, respectively.

The thermoelectric sensor is mounted on a specially manufactured contact prism, which can be installed in a standard mount for contact prisms of the Goldmann applanation tonometer and docked with slit lamps of various manufacturers. The contact prism is designed in such a way that it can be removed for disinfection after examining the patient. The contact surface of the sensor is made atraumatic (with smoothed edges). The thermoelectric HF sensor (diameter 3 mm) is located in the center of the working surface of the contact prism (diameter 7 mm), and between them there is a structurally provided optical control zone, which allows you to accurately install the thermoelectric sensor on a specific area of the ocular surface.

The developed device is multi-channel. In the electronic unit, the device has a separate HF measurement channel, which is designed to accurately measure the voltage generated by the thermoelectric HF sensor. The thermoelectric HF sensor was calibrated and the conversion factor of the value of the generated voltage of the thermoelectric sensor into a physical quantity in units of HF density (mW/cm^2) was determined. The resolution of the voltage measurement channel is ± 1 μV, which allows for measurements with maximum accuracy. The HF density measurement range is from 0.01 mW/cm^2 to 50 mW/cm^2. The HF density measurement error corresponds to ± 5 %. The device also has a temperature measurement channel, which is designed for high-precision temperature measurement by a thermoelectric thermocouple sensor in the range from 0 °C to 50 °C with a sensitivity of 0.01 °C, as well as an ambient temperature measurement channel. The digital microcontroller is designed to control the measurement channels, as well as to normalize and convert the generated signals into physical quantities.

The thermoelectric device for determining the density of HF from the surface of the eye is made in the form of an autonomous device with a battery power source, which allows for high-precision measurements of heat fluxes and temperatures of biological objects by the contact method. Due to galvanic isolation from the mains, safe and effective use of the device in ophthalmological practice is ensured. The low voltage of the autonomous power source (no more than 4.5 V) does not pose a threat of electric shock to any biological object under study.

2.3. Thermoelectric device for controlling the temperature of irrigation fluid during ophthalmic surgeries

The thermoelectric device provides both the possibility of thermoelectric heating and cooling of the irrigation fluid during ophthalmic surgical interventions. The device for controlling the temperature of the irrigation fluid contains two main functional units – a metal cooling/heating unit and a control and power supply unit. The physical model of the cooling/heating unit of the developed device is shown in Fig. 4 [21].

Using the Comsol Multiphysics program (COMSOL, Inc., USA), a computer model of a device for controlling the temperature of the irrigation fluid was built. The computer model allowed calculating the temperature distribution in the irrigation fluid flux during its heating and cooling at different fluid velocities, module cooling capacity, etc. A typical temperature distribution along the fluid flux was calculated, taking into account that the fluid flux rate during surgery varies from 0 to 20 cm^3/min, and the length of the medical tube from the cooling/heating unit to the eye does not exceed 50 cm. The irrigation fluid itself is a balanced salt solution BSS (Alcon Laboratories, Inc., USA) with almost identical rheological parameters to distilled water.

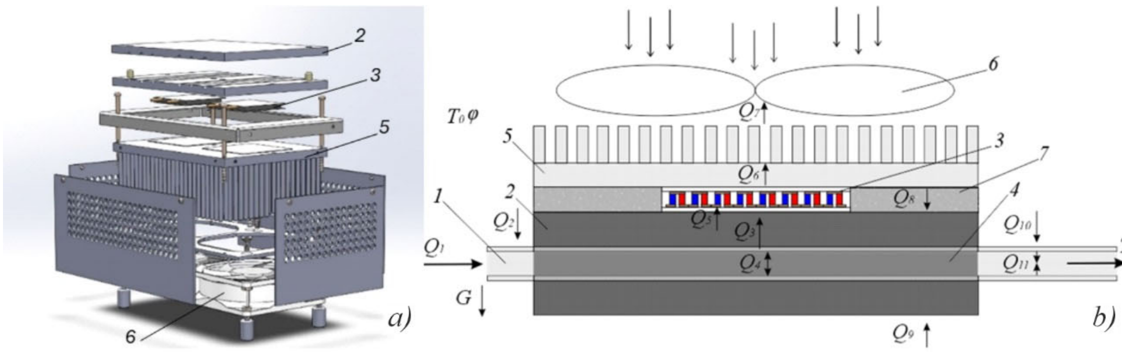

Fig. 4. a). b). Physical model of the cooling/heating unit of a thermoelectric device for controlling the temperature of irrigation fluid during ophthalmic surgeries:1 – medical tube; 2 – metal cooling/heating unit; 3 – thermoelectric module; 4 – steel tube; 5 – heat sink; 6 – fan; 7 – thermal insulation. b). Thermal processes during cooling of irrigation fluid. T_0, φ – temperature and relative humidity; G – gravitational force; Q_1 – heat flux entering the cooling unit together with the liquid; Q_2 – heat inleak to the inlet of the cooling unit from the environment;Q_3 – heat flux removed from the steel tube to cooling unit plates; Q_4 – heat flux removed from the liquid to the steel tube; Q_5 – cooling capacity of thermoelectric module; Q_6 – heat removed from the hot side of thermoelectric module; Q_7 – heat removed from the heat sink to the environment; Q_8 – heat inleak from the hot side of the heat sink to the cooling unit; Q_9 – heat inleak from the environment to the cooling unit; Q_{10} – heat inleak from the environment to the medical tube; Q_{11} – heat inleak from the medical tube to the cooled liquid; T_1 – temperature of the cooled liquid

The simulation results showed that to ensure the required liquid cooling conditions (temperature of about 15 °C at an ambient temperature of 25 °C), one thermoelectric module of the Altec-22 type is quite sufficient. For the given case, the following input parameters were used: air temperature and temperature of the incoming irrigation liquid – 25 °C, air humidity – 40 %, liquid flux rate – 4 ml/min, cooling capacity of the thermoelectric module – 8.2 W. Fig. 5 shows the results of computer simulation, in particular the temperature distribution in the cooling/heating unit and the medical tube.

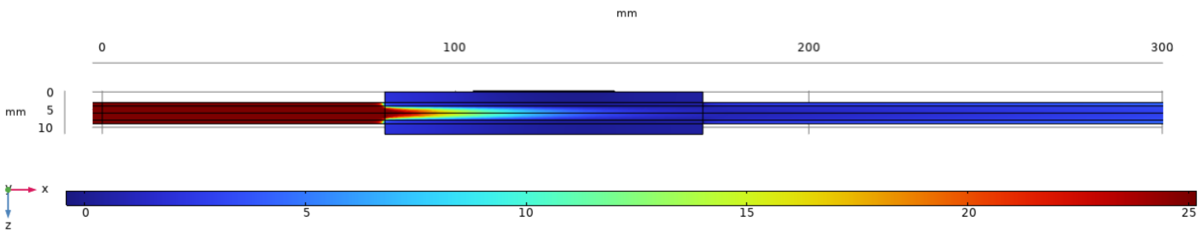

Fig. 5. Temperature distribution along the irrigation fluid flux obtained by computer simulation using the Comsol Multyphysics program

The development of a thermoelectric device for controlling the temperature of irrigation fluid provides for the possibility of intraoperative regulation of its temperature by both heating and cooling, which ensures the achievement of the required depth of hypothermia of intraocular structures during ophthalmic operations. The possibility of fulfilling medical and technical requirements for achieving the required temperature of irrigation fluid using thermoelectric equipment has been theoretically and experimentally confirmed.

2.4. Thermoelectric device for contact cooling of the eye

The developed device (Fig. 6) consists of two main functional components: 1) a cooling liquid heat exchanger made of a highly thermally conductive material (copper), which provides cooling of the ocular surface upon contact with it directly or through closed eyelids; 2) a thermoelectric electronic cooling, control, and power unit based on a microprocessor temperature controller RE-202 (“Termoprylad”, Ukraine). The thermoelectric cooling unit contains a thermoelectric Peltier module, liquid heat exchangers, and a circulation pump [22].

Fig. 6. Appearance of the device for contact cooling of the eye. a). Thermoelectric electronic cooling, control and power unit. b). Coolant heat exchanger

The Peltier thermoelectric module is designed to cool or heat a liquid circulating in an external circuit. The hot side of this thermoelectric module is cooled by an internal liquid circuit connected to the water supply network. The circulation pump ensures the circulation of the liquid coolant in the external circuit. The power supply unit is designed to power the thermoelectric module from the electrical network. The RE-202 thermostat measures the temperature from internal and external thermoresistive sensors and generates control signals for the control circuit. In turn, the control circuit controls the thermoelectric module according to a given program in order to maintain the operating temperatures set by the operator.

The device has the following technical characteristics: temperature maintenance accuracy ± 0.2 ºC; discreteness of measured and set temperature ± 0.1 ºC; temperature measurement error, no more than ± 0.2 ºC; thermal load in the external circuit, no more than 20 W; total power consumption, no more than 120 W.

A mathematical model of bioheat transfer of the eye under conditions of local hypothermia was developed, with regard to its anatomical structure, thermophysical features, blood circulation and metabolic processes. The COMSOL Multiphysics® software package (COMSOL, Inc., USA) was used to develop a mathematical model of bioheat transfer. The dynamics of intraocular temperatures under conditions of local artificial heat removal and the target temperature of the eye surface were determined to achieve a potential therapeutic level of hypothermia using the developed thermoelectric device. The calculation of temperature and HF density distributions in the eye was carried out using the finite element method. Using object-oriented computer simulation, temperature and HF distributions in various structures of the eye were obtained (Fig. 7).

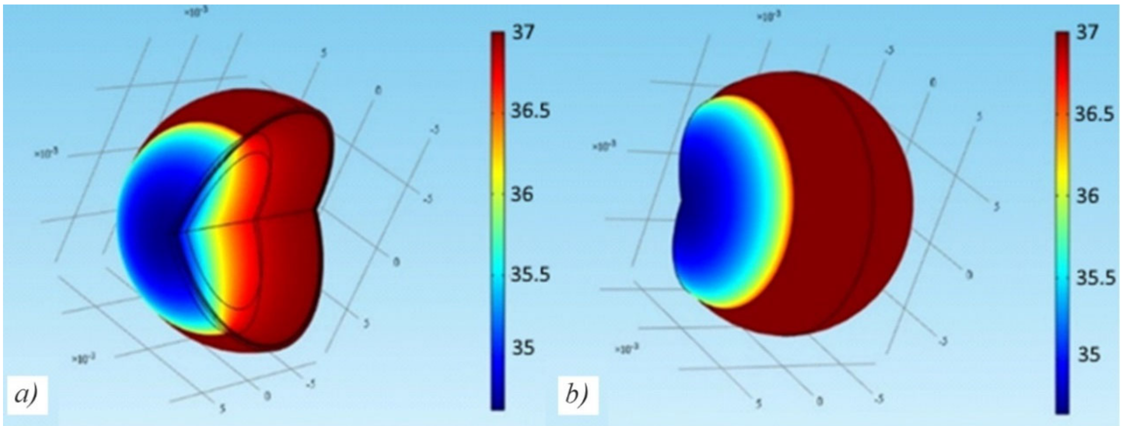

Fig. 7. Distribution of intraocular (a) and surface (b) eye temperature at an ambient temperature of 22 °C

The use of computer simulation has made it possible to establish that the necessary decrease in the temperature of the vitreous body and, accordingly, the retina by 1–2 °C is achieved by cooling the corneal surface to a temperature of 20 °C. Simulation of the bioheat transfer of the eye under conditions of its cooling by various methods has demonstrated that cooling the eye directly through the cornea can reduce the temperature of the retina to a therapeutic level.

2.5. Thermoelectric device for non-contact cooling of the eye

The developed device consists of two main functional units: a cooling device based on thermoelectric cooling modules and an electronic control and power supply unit (Fig. 8) [23].

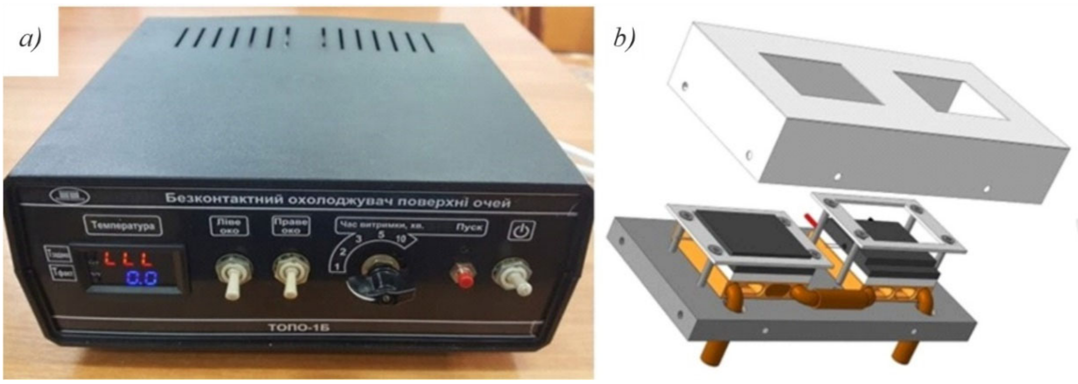

Fig. 8. Appearance of the developed thermoelectric medical device for non-contact cooling of the eyes. a). Electronic control and power supply unit. b). Cooling device with thermoelectric cooling modules

The cooling device is based on thermoelectric Peltier modules and is designed to cool two metal surfaces located in close proximity to the eye surface. Due to the exchange of radiant energy between these surfaces, the eye surface is cooled. The degree of cooling of the eye surface depends on both the temperature of the metal heat exchange surfaces and the duration of the procedure. The hot sides of the thermoelectric modules are cooled by an external liquid circuit connected to the water supply network. Liquid heat exchangers (made of highly thermally conductive material – copper) with fittings for connection to the water supply network are located on the rear panel of the cooling device. The water consumption in the cooling circuit of the hot sides of the thermoelectric modules is insignificant, 2–3 l/min is sufficient at a water temperature of up to 20 °C.

The electronic unit of the device provides power and control of thermoelectric modules to maintain the temperature values set by the operator, generates the necessary time intervals for temperature exposure, selects the temperature exposure to the patient's eyes (right eye, left eye, both eyes), and also protects the patient from damage by mains voltage in an emergency. In the event of an emergency, if mains voltage appears on the metal parts of the device, the protective shutdown device will operate and the power in the main device will be completely disconnected.

The device has the following technical characteristics: temperature stabilization error, no more than 1 ºC; temperature measurement error, no more than 1 ºC; cooling of the hot side of thermoelectric modules is liquid, from the water supply network; supply voltage (50 Hz AC network) 220 ± 10 V; electrical power of the device, no more than 150 W. The temperature of the eye surface during cooling is monitored by a non-contact thermometer or thermograph.

3. Prospects for the use of thermoelectricity in ophthalmology

The presented samples of thermoelectric equipment create new opportunities for solving some urgent problems of clinical and experimental ophthalmology, in particular, substantiation and implementation of the technology of controlled local artificial hypothermia of the eye in vitreoretinal surgery. For this purpose, devices were developed for measuring intraocular temperature, epibulbar temperature and HF on the surface of the eye, which allow for comprehensive perioperative monitoring of thermal processes of the eye during vitreoretinal surgery. And new thermoelectric devices that provide active cooling/heating of irrigation fluid or structures of the eye are a tool for controlling thermal processes both intraoperatively and in the postoperative period.

Previous studies have demonstrated the safety and reliability of the developed measuring devices and have expanded our understanding of the thermal processes occurring in the eye during all stages of ophthalmic intraocular surgery [24]. It has been confirmed that standard vitreoretinal surgery with room temperature irrigation fluid is performed under conditions of uncontrolled hypothermia of the eye, followed by rapid uncontrolled heating of the vitreous cavity after the cooling step [8, 11].

It is known that some patients after cataract, glaucoma, and vitreoretinal surgery experience a disruption of the blood-ophthalmic barrier due to subclinical inflammation, which can be confirmed by optical methods, such as laser photometry [25–27]. We have found an increase in the intensity of heat transfer of the operated eye in the postoperative period, associated with postoperative inflammation. It has been confirmed that the increase in the density of HF on the ocular surface recorded in the postoperative period may be a consequence of postoperative inflammation, concomitant increased blood circulation in the choroid of the eye and an increase in the intensity of heat transfer [8, 14, 28]. Preliminary data have been obtained that thermoelectric sensors measuring the density of HF on the ocular surface after vitreoretinal surgery allow for the rapid and safe detection of intraocular inflammation even at the subclinical level and its quantitative assessment [24].

Currently, our understanding of thermoregulation under controlled cooling of the whole body or individual organs and the therapeutic effects of hypothermia remains limited [29, 30]. Artificially lowering body temperature by forced heat removal from its surface (general hypothermia) or internal organs (local hypothermia) has been successfully used in various fields of medicine (cardiac surgery, intensive care) to increase protection against the damaging effects of ischemia/reperfusion, reduce the volume of tissue damage, and reduce patient mortality [31, 32]. Local hypothermia (cold cardioplegia) has been successfully used, for example, in cardiac surgery to protect the heart from ischemic injury, providing a still and bloodless surgical field, which allows for effective postischemic myocardial resuscitation [33]. Therefore, local hypothermia of the eye may be useful in reducing the negative effects of ischemia and inflammation in various ophthalmological pathologies, preventing complications both during intraocular surgery and in the postoperative period.

There are several methods of local cooling of the eye. Hypothermia of intraocular structures can be achieved by changing the temperature of the irrigation fluid during vitreoretinal surgery [8]. The feasibility of performing ophthalmic surgical interventions under hypothermia has been confirmed by various authors, but to date there is no consensus on the optimal temperature of the irrigation fluid and the level of intraocular hypothermia during surgery. Thus, Mauro et al. proposed a device that allows vitreoretinal surgical interventions under temperature control and is capable of heating the infusion fluid and air during surgery, maintaining their temperature in the range of mild or moderate hypothermia [34]. Other authors prefer to perform surgery under conditions of deep hypothermia, citing confirmation of the obtained beneficial effects [35–38]. In our opinion, it is advisable to use a mild level of hypothermia in the middle of the eye during vitreoretinal operations, since such conditions are safer for intraocular structures, especially during long interventions. The level of mild hypothermia can be achieved by heating the irrigation fluid before it enters the middle of the eye to a temperature higher than the ambient temperature [12]. It should be noted that the ability to control the temperature of irrigation solutions will allow using the beneficial effects of deep hypothermia during certain types of operations. To solve this problem, it is necessary to solve the issue of effective intraoperative cooling of the liquid. The use of thermoelectric devices in the mode of both heating and cooling of the irrigation liquid during surgery looks the most promising. The development of a thermoelectric device for controlling the temperature of the irrigation liquid provides the surgeon with the opportunity to influence the thermal processes of the eye during surgery [39].

Reducing the temperature of the external and internal structures of the eye can also be achieved by direct contact cooling of the ocular surface or through closed eyelids, which can be useful for combating, for example, postoperative inflammation [18]. For heat removal, ice packs or gel cold packs can be used, applied to the eyelids, or by irrigating the external surface of the eye with cooled solutions. However, this method is not reliable and controllable enough. Progress in biomedical engineering and new possibilities in thermoelectric science create the prospect of developing special thermoelectric devices for controlled and convenient local cooling of the eye. This will allow more effective use of the beneficial effects of hypothermia of eye structures for solving ophthalmological problems. It is also known that heat transfer from the surface tissues of the human body, including eye tissues, to the environment is carried out mainly (about 60 %) by infrared radiation [40]. Therefore, the above-mentioned features of heat exchange of the human body create certain opportunities for heat removal from the surface structures of the eye in a non-contact way, which requires additional study in the experiment and using mathematical simulation.

It should be noted that the prospect of using thermoelectric equipment for the implementation of the technology of controlled local artificial hypothermia of the eye in vitreoretinal surgery is not limited only to the intraoperative and postoperative periods. As a promising direction, the possibility of introducing the beneficial effects of cold preconditioning into vitreoretinal surgery can also be considered. Thus, the use of local hypothermia of the eye before surgery can contribute to the induction of neuroprotective mechanisms and create additional conditions for the protection of retinal cells from intraoperative ischemic and phototoxic damage [41].

4. Conclusions

1. Thermoelectric devices have been developed for measuring intraocular temperature, epibulbar temperature, and heat flux density on the surface of the eye, which allow for comprehensive perioperative monitoring of thermal processes in the eye during vitreoretinal surgery.
2. New thermoelectric devices have been created for active cooling/heating of irrigation fluid or ocular structures, which are a tool for controlling thermal processes in the eye both during vitreoretinal surgery and in the postoperative period.
3. New models of thermoelectric equipment for ophthalmology provide the implementation of the technology of controlled local artificial hypothermia of the eye in vitreoretinal surgery.

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Комплекс термоелектричного обладнання для діагностики та лікування офтальмологічних захворювань

У статті представлено перспективи використання нових зразків термоелектричного обладнання, розробленого для вирішення деяких актуальних завдань офтальмології, зокрема, обґрунтування та впровадження технології керованої локальної штучної гіпотермії ока в вітреоретинальну хірургію. Продемонстровано термоелектричні прилади для вимірювання внутрішньоочної температури, епібульбарної температури та теплового потоку на поверхні ока, які дозволяють здійснювати комплексний періопераційний моніторинг теплових процесів ока в ході вітреоретинальної хірургії. А також описано конструкцію нових термоелектричних приладів, які забезпечують активне охолодження/нагрівання іригаційної рідини або структур ока, та які створюють можливості для керування тепловими внутрішньоочними процесами як інтраопераційно, так і в перед- та післяопераційному періоді.

Ключові слова: термоелектричне охолодження, іригаційна рідина, хірургія, офтальмологія.

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