DOI: 10.63527/1607-8829-2020-4-76-88

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THERMOELECTRIC DEVICE FOR NON-CONTACT COOLING OF THE HUMAN EYES

The paper presents the results of the development of a thermoelectric device for non-contact cooling of the human eyes. The device is designed for the treatment of acute and chronic eye diseases, reducing intraocular pressure, reducing pain and inflammation of the eye. The developed thermoelectric medical device makes it possible to cool the eye structures without contact, which will allow developing and implementing the technology of controlled local therapeutic hypothermia in ophthalmology. The design features of the device, the principle of its operation and technical characteristics are described. Bibl. 22, Fig. 2, Tabl. 1.
Key words: thermoelectric device, non-contact cooling, hypothermia of the human eye.

Introduction

Therapeutic hypothermia consists in artificially lowering the patient's body temperature by forcibly removing heat from the body (general hypothermia) or internal organs (local hypothermia) for therapeutic purposes.

Local therapeutic hypothermia is successfully employed in various fields of medicine. For example, cold cardioplegia is used to protect the heart tissue during cardiac surgery performed in the conditions of artificial circulation, which allows to uniformly reduce the temperature of the

myocardium to (+8÷10 °C) [1]. Craniocerebral hypothermia is used to prevent hypoxia of brain structures during neurosurgery, as well as in newborns born with severe asphyxia [2]. In reconstructive surgery on renal vessels or kidney transplantation, local hypothermia can protect its tissues from hypoxia and prevent the development of renal failure in the postoperative period [3].

In ophthalmology, local hypothermia of the eye structures can also be used to solve some therapeutic problems. Thus, J.M. Katsimpris suggests using local cooling of the eye to combat intraocular inflammation [4]. Local therapeutic hypothermia can be used to reduce intraocular pressure [5]. After local cooling in the eye there is an increase in blood supply to the vascular tract, increased pulse volume and blood flow velocity, which can be used for anti-ischemic purposes in ophthalmic diseases [6]. Local hypothermia during vitreoretinal eye surgery can lead to decreased fibrin production and reduced bleeding [7].

Artificial local contact hypothermia is a fairly simple way to achieve a decrease in intraocular temperature and, unlike general hypothermia, is free from the risk of severe complications from the internal organs, and therefore its use looks promising. There are different ways of local cooling of the eye. During intraocular surgery, local hypothermia of the eye can be created by lowering the temperature of irrigation solutions [8]. A decrease in the temperature of the intraocular media of the eye is possible, both when cooling directly the outer surface of the cornea, and when exposed to cold through closed eyelids. For contact cooling of the structures of the eye, one can use, for example, an ice pack applied to the eyelids [9]. The development of special thermoelectric devices for local contact cooling of the eye allows more efficient and controlled use of the beneficial effects of therapeutic hypothermia for the treatment of ophthalmic diseases [10, 11].

It is known that the heat transfer by the surface tissues of the human body, including the structures of the eye, to the environment is carried out mainly by radiation in the form of electromagnetic waves in the infrared spectrum (wavelength 3-50 μm with a peak of 9.6 μm), i.e. in the areas of long-wave infrared radiation [12]. Thus, at room temperature (+21 ÷ +23 °C) and relative humidity (within 40-60%) about 60% of heat is removed from the human body by radiation. About 20% of heat is removed by evaporation and 15 -20% - by convection. Conduction is situational and depends on the contact of the body with objects in the environment [13]. Thus, the above features of heat transfer of the human body create certain opportunities for cooling the surface structures of the body by non-contact means. Further research in this direction is required to develop the technology of artificial non-contact controlled local hypothermia of the eye and assess the feasibility of its use in the treatment and prevention of ophthalmic diseases.

Therefore, the *purpose of this work* is to develop a design and manufacture an experimental prototype of a thermoelectric device for non-contact cooling of the human eyes.

Design and technical characteristics of the device

At the Institute of Thermoelectricity of the NAS and MES of Ukraine within cooperation agreement with the State Institution "The Filatov Institute of Eye Diseases and Tissue Therapy of the NAMS of Ukraine", a thermoelectric device was developed for non-contact cooling of the human eyes (Fig.1). The technical characteristics of the device are given in Table 1.

The device is designed to treat acute and chronic eye diseases, reduce intraocular pressure, alleviate pain and inflammatory processes in the human eye. The developed thermoelectric medical device allows non-contact cooling of the structures of the eye, which will make it possible to develop and implement the technology of non-contact controlled local therapeutic hypothermia in ophthalmology [8, 14 - 20]. Such a device is original and has no analogues in the world.



Fig.1. Experimental prototype of thermoelectric device for non-contact cooling of the human eyes: 1 – thermoelectric cooling modules, 2 – electronic control and power supply unit

The device consists of two main functional units: a cooling device based on thermoelectric cooling modules 1 and an electronic control and power supply unit 2 (Fig. 1). The cooling device is made on the basis of the Peltier thermoelectric modules 1 [21, 22] and is designed to cool two metal surfaces located in close proximity to the surface of the human eyes. Due to the exchange of radiant energy between these surfaces, the surface of the human eye is cooled by several degrees Celsius. The degree of cooling of the eye surface depends on the temperature of the metal heat exchange surfaces and the duration of the procedure. The temperature of the eye surface during cooling is controlled by a non-contact thermometer. To increase the efficiency of radiation heat transfer, the metal cooling surfaces are blackened. Cooling of the hot sides of TE cooling modules is carried out by an external liquid circuit, which is connected to the water supply network. On the back panel of the cooling device there are liquid heat exchangers (made of highly thermally conductive material - copper) with fittings for connecting the water supply network. Water

consumption in the cooling circuit of the hot sides of TE cooling modules is small - enough 2-3 l/min at a water temperature of up to 20 ºC. In addition, the cooling device is placed on a tripod, which makes it possible to adjust its height and, accordingly, to select the individual placement of the cooling surfaces of the TE cooling modules in close proximity to the surfaces of the human eye.

Table 1

Technical characteristics of the device

№	Technical characteristics of the device	Parameter values
1.	Range of setting and maintenance of working temperatures	(-25 ÷ +10) °C
2.	Temperature stabilization error, not more	1 ºC
3.	Temperature measurement error, not more	1 ºC
4.	Cooling the hot side of TE cooling module	liquid, from the water supply network
5.	Supply voltage (50 Hz AC)	220 ± 10 V
6.	Electric power of the device, not more	150 W
7.	Setting the exposure time	(1 ÷ 10) min
8.	Overall dimensions of cooling device	(160 × 235 × 50) mm
9.	Overall dimensions of electronic control and power supply unit	(100 × 240 × 250) mm
10.	The ability to cool each eye separately at a common set temperature	+
11.	Availability of protection against mains voltage	+
12.	Length of hoses for liquid cooling of TE cooling modules	3 m
13.	Device weight	1.5 kg
14.	Time of reaching temperature mode by the device	10 min
15.	Time of continuous operation of the device	48 h

Electronic unit 2 provides power and control of thermoelectric modules in order to maintain the temperature values set by the operator, forms the necessary time intervals for temperature exposure, selects the temperature effect on the patient's eyes (right eye, left eye, both eyes), and also protects the patient from being damaged by the mains voltage in an emergency.

On the front panel of the electronic unit 2 there are "ON", "RIGHT EYE", "LEFT EYE" toggle switches, a programmable microprocessor thermostat with an electronic display for setting and visualizing temperature values, a "HOLD TIME" switch, a "START" button.

On the rear panel of the electronic unit 2 there is a protective cut-out device, a connector for connecting a cooling device, a cord for connecting to a 220 V mains, a fuse 5 A.

In addition, the design of the device provides for the mounting of the cooling device on the ophthalmological table. After connecting water from the water supply network to the cooling device and connecting the electronic unit 2 to a 220 V mains, the device is ready for operation.

In an emergency, if mains voltage appears on the metal parts of the device, the protective cut-out device will operate and the device will be completely disconnected from the voltage. After eliminating the emergency, the protective cut-out device on the rear panel of the electronic unit 2 must be switched on again.

Block-diagram of the device

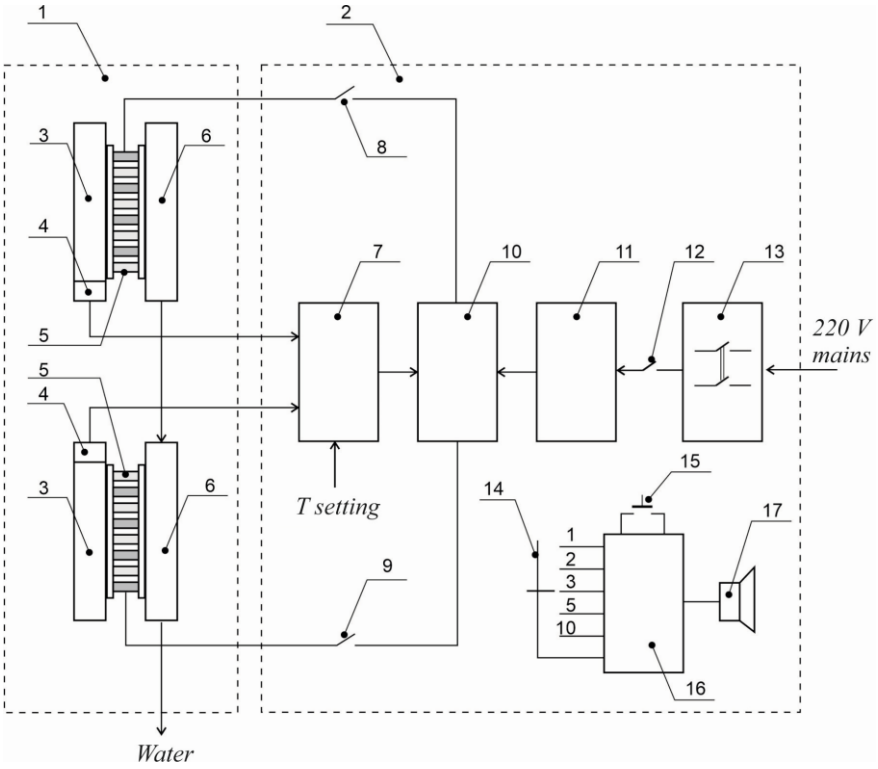


Fig.2. Block-diagram of thermoelectric device for non-contact cooling of the human eyes:
1 – cooling device, 2 – electronic control and power supply unit, 3 – cooling surface, 4 – temperature sensor, 5 – thermoelectric cooling module, 6 – liquid heat exchanger, 7 – programmable microprocessor thermostat, 8 – "LEFT EYE" toggle switch, 9 – "RIGHT EYE" toggle switch, 10 – power control unit of TE cooling module, 11 – power supply unit, 12 – "MAINS" toggle switch– switching of device to a 220 V mains, 13 – protective cut-out device,14 –"HOLD TIME" switch, 15 – "START" button, 16 – timer, 17 – buzzer.

The block-diagram of thermoelectric device for non-contact cooling of the human eyes is given in Fig.2, where 1 is a cooling device, 2 is an electronic control and power supply unit, 3 is a cooling surface, 4 is a temperature sensor, 5 is a thermoelectric cooling module, 6 is a liquid heat exchanger, 7 is a programmable microprocessor thermostat, 8 is a "LEFT EYE" toggle switch, 9 is a "RIGHT EYE" toggle switch, 10 is power control unit of TE cooling module, 11 is power

supply unit, 12 is a “MAINS” toggle switch– switching of the device to a 220 V mains, 13 is a protective cut-out device, 14 is a “HOLD TIME” switch, 15 is a “START” button, 16 is a timer, 17 is a buzzer.

The principle of operation of the device

The principle of operation of the device consists in non-contact cooling of the human eyes in order to treat acute and chronic eye diseases, reduce intraocular pressure, alleviate pain and inflammation.

The proposed device works as follows (Fig. 2). The operator connects the liquid heat exchangers 6 with the help of hoses to the water supply network, opens the water tap and controls the flow of water through the corresponding heat exchangers. Connects the electronic unit 2 to a grounded outlet and turns it on. Then turns on the "MAINS" toggle switch 12. On the digital indicator of the programmable microprocessor temperature controller 7, the current temperature of the cooling surfaces 3 will be displayed in red, and the value of the set temperature will be displayed in blue. Using the buttons on the thermostat, the operator sets the required cooling temperature (the value is selected experimentally). Then the operator turns on cooling the right eye with the “RIGHT EYE" toggle switch 8, or cooling the left eye with the "LEFT EYE" toggle switch 9, or selects the cooling both eyes together. Only after choosing the appropriate toggle switches 8, 9 will the cooling surfaces 3 begin to cool down. After 5 - 10 minutes, the temperature of surfaces 3 stabilizes and equals the set temperature. After that, the patient is placed in front of the cooling device 1 so that his eyes were at a distance of 1-5 cm from the cooling surfaces 3. Then the operator selects the required exposure time (temperature exposure time) with the "HOLD TIME" switch 14 and presses the "START" button 15. After the expiry of the holding time, an audible signal sounds from the buzzer 17. The procedure can be ended at this point or extended by pressing the START button again. On the case of the cooling device 1, on top for clarity, there are LED indicators of the operation of the cooling surfaces 3.

The specified device is simple, compact and reliable in operation, which allows a doctor or medical worker to use it without special training, having previously read the instructions. Thus, the technical advantages of such a device include: non-contact cooling of the surface of the human eye in real time, the ability to set and maintain the required temperature with a resolution of ±1 °C and the safety of the device.

The introduction of such a device into medical practice will be of great social and economic importance, as it will reduce the risk of ophthalmic complications, preserve the viability of patients' eye structures and ensure the provision of highly qualified care in specialized medical institutions and in extreme conditions. This, in turn, will provide appropriate conditions for preserving people's health, increase the efficiency and quality of medical care in the health care system and will become a significant contribution to the development of new domestic medical thermoelectric equipment.

It should be noted that to confirm the efficiency of the device, develop the method for treatment and clinical trials, the developed experimental prototype of device for non-contact cooling of the human eyes was transferred to the State Institution "The Filatov Institute of Eye Diseases and Tissue Therapy of the NAMS of Ukraine" within cooperation agreement. The results of clinical trials of the device will be the subject of subsequent publications on this topic.

The device is designed to treat acute and chronic eye diseases, reduce intraocular pressure, alleviate pain and inflammation of the eye. The developed thermoelectric medical device makes it possible to cool the eye structures without contact, which will allow developing and implementing the technology of controlled local therapeutic hypothermia in ophthalmology.

Conclusions

1. For the first time, a design was developed and an experimental prototype of a thermoelectric device for non-contact cooling of the human eyes was manufactured. The device is designed to treat acute and chronic eye diseases, reduce intraocular pressure, alleviate pain and inflammatory processes in the human eye. The proposed device has no analogues in the world.
2. The developed thermoelectric medical device makes it possible to carry out non-contact controlled cooling of the human eye surface in the temperature range (-25 ÷ +10) °C and in the future will allow the development and implementation of the technology of artificial non-contact controlled local therapeutic hypothermia in ophthalmology.

References

1. Fisk R.L., Gelfand E.T., Callaghan J.C. (1977). Hypothermic coronary perfusion for intraoperative cardioplegia. *Ann Thorac Surg*, 23, 58-61.
2. McDowall D.G. (1971). The current usage of hypothermia in British neurosurgery. *Br J Anaesth*, 43, 1084 – 1087.
3. Wickham J.E., Hanley H.G., Joekes A.M. (1967). Regional renal hypothermia. *Br J Urol*, 39, 727 – 743.
4. Katsimpris J. M., Xirou T., Paraskevopoulos K., et al. (2003). Effect of local hypothermia on the anterior chamber and vitreous cavity temperature: in vivo study in rabbits. *Klin. Monbl. Augenheilkd*, 220 (3), 148-151.
5. Chanchikov G.F., Zavolskaya Z.P., Bereznikova V.I. (1978. Vliianiie umerennoi lokalnoi hipotermii na ophtalmotonus, zritelnyie funktsii i gidrodinamiku glaz bolnykh glaukomoi [Influence of moderate local hypothermia on intralocular tension, visual functions and hydrodynamics of patients ill with glaucoma]. *Oftalmologicheskii Zhurnal - J. Ophthalmology*, 8, 594-597 [in Russian].
6. Lazarenko V.I., Chanchikov G.F., Kornilovskii I.M., Gaidabura V.G. (1976). Vliianiie umerennoi

lokalnoi hipotermii na hemo- i hidrodinamicheskiie pokazateli zdorovykh glaz [Influence of moderate local hypothermia on the hemo-and hydrodynamic parameters of healthy eyes]. *Oftalmologicheskii Zhurnal - J. Ophthalmology*, 6, 419-422 [in Russian].

7. Jabbour N.M., Schepens C.L., Buzney S.M. (1988). Local ocular hypothermia in experimental intraocular surgery. *Ophthalmology*, 95, 1685-1690.
8. Anatychuk L., Pasechnikova N., Naumenko V., Kobylianskyi R., Nazaretyan R., Zadorozhnyy O. (2020). Prospects of temperature management in vitreoretinal surgery.*Ther. Hypothermia Temp. Manag*. https://doi.org/10.1089/ther.2020.0019
9. Shif L.V., Taratynova A.V., Neiman V.A., Angelova N.V. (1981). Primeneniie lokalnoi gipotermii pri ostrom pristupe glaukomy i glaukome v terminalnoi stadii, oslozhnivsheisia bolevym sindromom [The use of local hypothermia in an acute attack of glaucoma and glaucoma in the terminal stage, complicated by pain]. *Oftalmologicheskii Zhurnal - J. Ophthalmology,* 3, 187-188 [in Russian].
10. Anatychuk L.I., Pasechnikova N.V., Naumenko V.O., Zadorozhnyi O.S., Nazaretian R.E., Havryliuk M.V., Tiumentsev V.A., Kobylianskyi R.R. (2019). Thermoelectric device for hyperthermia of the human eye. *J.Thermoelectricity*, 3, 64-73.
11. Anatychuk L. I., Pasechnikova N. V., Naumenko V. O., Zadorozhnyi O. S., Danyliuk S. L., Havryliuk M. V., Tiumentsev V. A., & Kobylianskyi R. R. (2020). Thermoelectric device for contact cooling of the human eye. *Physics and Chemistry of Solid State*, 21(1), 140-145.
12. Vail Yu.S., Varanovskii Ya.M. (1969). *Infrakrasnyie luchi v klinicheskoi diagnostike i mediko-biologicheskikh issledovaniiakh [Infrared rays in clinical diagnostics and biomedical research]*. Leningrad: Meditsina [in Russian].
13. Avetisov S.E., Novikov I.A., Lutsevich Ye.E., Reyn E.S. (2017). Primeneniie termografii v oftalmologii [The use of thermography in ophthalmology]. *Vestnik oftalmologii – Bulletin of Ophtalmology*, 6, 99-104 [in Russian].
14. Anatychuk L.I., Pasechnikova N.V., Zadorozhnyi O.S., Kobylianskyi R.R., Havryliuk M.V., Nazaretian R.E., Mirnenko V.V. (2015). Thermoelectric device for measurement of intraocular temperature. *J.Thermoelectricity*, 3, 31-40.
15. Anatychuk L.I., Pasechnikova N.V., Zadorozhnyi O.S., Nazaretian R.E., Mirnenko V.V., Kobylianskyi R.R., Havryliuk N.V. (2015). Originalnoie ustroistvo i podkhody k izucheniiu raspredeleniia temperatury v razlichnykh otdelakh glaza [Original device and approaches to studying the temperature distribution in different parts of the eye]. *Oftalmologicheskii Zhurnal - J. Ophthalmology,* 6, 50-53 [in Russian].
16. Anatychuk L.I., Pasechnikova N.V., Kobylianskyi R.R., Havryliuk N.V., Naumenko V.A., Mirnenko V.V. Nazaretian R.E., Zadorozhnyi O.S. (2016). Termoelektricheskiie datchiki dlia registratsii vnutriglaznoi temperatury [Thermoelectric sensors for registration of intraocular temperature]. *Sensorna elektronika i mikrosystemni tekhnologii - Sensor Electronics and Microsystem Technologies*, 13(3), 30-38 [in Russian].

17. Anatychuk L.I., Pasechnikova N.V., Zadorozhnyi O.S., Kobylianskyi R.R., Nazaretian R.E., Mirnenko V.V., Havryliuk N.V. (2016). Ustroistvo dlia intraokuliarnoi termometrii i osobennosti raspredeleniia temperatury v razlichnykh otdelakh glaza krolika [A device for intraocular thermometry and features of temperature distribution in various chambers of the rabbit's eye]. *Zhurnal Natsionalnoi Akademii Medychnykh Nauk Ukrainy - J. of the National Academy of Medical Sciences of Ukraine*, 22(1), 103-108 (in Russian].
18. Anatychuk L.I.., Pasechnikova N.V., Kobylianskyi R.R., Prybyla A.V., Naumenko V.O., Zadorozhnyi O.S., Nazaretian R.E., Mirnenko V.V. (2017). Computer simulation of thermal processes in human eye. *J.Thermoelectricity*, 5, 41-58.
19. Anatychuk L.I., Pasechnikova N.V., Naumenko V.O., Zadorozhnyi O.S., Havryliuk M.V., Kobylianskyi R.R. (2018). Thermoelctric device for determination of heat flux from the surface of eyes. *J.Thermoelectricity*, 5, 52-67.
20. Anatychuk L.I., Pasechnikova N.V., Naumenko V.A., Zadorozhnyi O.S., Kobylianskyi R.R., Havryliuk N.V. (2019). Termoelektricheskoie ustroistvo dlia oftalmoteplometrii i osobennosti registratsii plotnosti teplovogo potoka glaza cheloveka [Thermoelectric device for ophthalmothermometry and features of registration of heat flux density of the human eye]. *Oftalmologicheskii Zhurnal - J. Ophthalmology,* 3, 45-51 [in Russian]. http://doi.org/10.31288/oftalmolzh201934551
21. Anatychuk L.I. (1979). *Termoelementy i termoelektricheskiie ustroistva. Spravochnik (Thermoelements and thermoelectric devices. Handbook).* Kyiv: Naukova Dumka [in Russian].
22. Anatychuk L.I. (2003). *Termoelektrichestvo. T.2. Termoelektricheskiie prepbrazovateli energii [Thermoelectricity. Vol.2. Thermoelectric power converters].* Kyiv-Chernivtsi: Institute of Thermoelectricity [in Russian].

Submitted 30.07.2020

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ТЕРМОЕЛЕКТРИЧНИЙ ПРИЛАД ДЛЯ БЕЗКОНТАКТНОГО ОХОЛОДЖЕННЯ ОЧЕЙ ЛЮДИНИ

У роботі наведено результати розробки термоелектричного приладу для безконтактного охолодження очей людини. Прилад призначений для лікування гострих і хронічних захворювань ока, зниження внутрішньоочного тиску, зменшення больового синдрому та запальних процесів ока. Розроблений термоелектричний медичний прилад дає можливість безконтактно охолоджувати структури ока, що дозволить розробити та впровадити технологію контрольованої локальної терапевтичної гіпотермії в офтальмології. Наведено особливості конструкції приладу, принцип роботи та його технічні характеристики. Бібл. 22, рис. 2, табл. 1.

Ключові слова: термоелектричний прилад, безконтактне охолодження, гіпотермія ока людини.

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ТЕРМОЭЛЕКТРИЧЕСКИЙ ПРИБОР ДЛЯ БЕСКОНТАКТНОГО ОХЛАЖДЕНИЯ ГЛАЗ ЧЕЛОВЕКА

В работе приведены результаты разработки термоэлектрического прибора для бесконтактного охлаждения глаз человека. Прибор предназначен для лечения острых и хронических заболеваний глаза, снижение внутриглазного давления, уменьшение болевого синдрома и воспалительных процессов глаза. Разработанный термоэлектрический медицинский прибор дает возможность бесконтактно охлаждать структуры глаза, что позволит разработать и внедрить технологию контролируемой локальной терапевтической гипотермии в офтальмологии. Приведены особенности конструкции прибора, принцип работы и его технические характеристики. Библ. 22, рис. 2, табл. 1.

Ключевые слова: термоэлектрический прибор, бесконтактное охлаждение, гипотермия глаза человека.

References

1. Fisk R.L., Gelfand E.T., Callaghan J.C. (1977). Hypothermic coronary perfusion for intraoperative cardioplegia. *Ann Thorac Surg*, 23, 58-61.
2. McDowall D.G. (1971). The current usage of hypothermia in British neurosurgery. *Br J Anaesth,* 43, 1084 – 1087.
3. Wickham J.E., Hanley H.G., Joekes A.M. (1967). Regional renal hypothermia. *Br J Urol*, 39, 727 – 743.
4. Katsimpris J. M., Xirou T., Paraskevopoulos K., et al. (2003). Effect of local hypothermia on the anterior chamber and vitreous cavity temperature: in vivo study in rabbits. *Klin. Monbl. Augenheilkd*, 220 (3), 148-151.
5. Chanchikov G.F., Zavolskaya Z.P., Bereznikova V.I. (1978. Vliianiie umerennoi lokalnoi hipotermii na ophtalmotonus, zritelnyie funktsii i gidrodinamiku glaz bolnykh glaukomoi [Influence of moderate local hypothermia on intralocular tension, visual functions and hydrodynamics of patients ill with glaucoma]. *Oftalmologicheskii Zhurnal - J. Ophthalmology*, 8, 594-597 [in Russian].
6. Lazarenko V.I., Chanchikov G.F., Kornilovskii I.M., Gaidabura V.G. (1976). Vliianiie umerennoi lokalnoi hipotermii na hemo- i hidrodinamicheskiie pokazateli zdorovykh glaz [Influence of moderate local hypothermia on the hemo-and hydrodynamic parameters of healthy eyes]. *Oftalmologicheskii Zhurnal - J. Ophthalmology*, 6, 419-422 [in Russian].
7. Jabbour N.M., Schepens C.L., Buzney S.M. (1988). Local ocular hypothermia in experimental intraocular surgery. *Ophthalmology*, 95, 1685-1690.

8. Anatychuk L., Pasechnikova N., Naumenko V., Kobylianskyi R., Nazaretyan R., Zadorozhnyy O. (2020). Prospects of temperature management in vitreoretinal surgery.*Ther. Hypothermia Temp. Manag*. https://doi.org/10.1089/ther.2020.0019
9. Shif L.V., Taratynova A.V., Neiman V.A., Angelova N.V. (1981). Primeneniie lokalnoi gipotermii pri ostrom pristupe glaukomy i glaukome v terminalnoi stadii, oslozhnivsheisia bolevym sindromom [The use of local hypothermia in an acute attack of glaucoma and glaucoma in the terminal stage, complicated by pain]. *Oftalmologicheskii Zhurnal - J. Ophthalmology,* 3, 187-188 [in Russian].
10. Anatychuk L.I., Pasechnikova N.V., Naumenko V.O., Zadorozhnyi O.S., Nazaretian R.E., Havryliuk M.V., Tiumentsev V.A., Kobylianskyi R.R. (2019). Thermoelectric device for hyperthermia of the human eye. *J.Thermoelectricity*, 3, 64-73.
11. Anatychuk L. I., Pasechnikova N. V., Naumenko V. O., Zadorozhnyi O. S., Danyliuk S. L., Havryliuk M. V., Tiumentsev V. A., & Kobylianskyi R. R. (2020). Thermoelectric device for contact cooling of the human eye. *Physics and Chemistry of Solid State*, 21(1), 140-145.
12. Vail Yu.S., Varanovskii Ya.M. (1969). *Infrakrasnyie luchi v klinicheskoi diagnostike i mediko-biologicheskikh issledovaniiakh [Infrared rays in clinical diagnostics and biomedical research]*. Leningrad: Meditsina [in Russian].
13. Avetisov S.E., Novikov I.A., Lutsevich Ye.E., Reyn E.S. (2017). Primeneniie termografii v oftalmologii [The use of thermography in ophthalmology]. *Vestnik oftalmologii – Bulletin of Ophtalmology*, 6, 99-104 [in Russian].
14. Anatychuk L.I., Pasechnikova N.V., Zadorozhnyi O.S., Kobylianskyi R.R., Havryliuk M.V., Nazaretian R.E., Mirnenko V.V. (2015). Thermoelectric device for measurement of intraocular temperature. *J.Thermoelectricity*, 3, 31-40.
15. Anatychuk L.I., Pasechnikova N.V., Zadorozhnyi O.S., Nazaretian R.E., Mirnenko V.V., Kobylianskyi R.R., Havryliuk N.V. (2015). Originalnoie ustroistvo i podkhody k izucheniiu raspredeleniia temperatury v razlichnykh otdelakh glaza [Original device and approaches to studying the temperature distribution in different parts of the eye]. *Oftalmologicheskii Zhurnal - J. Ophthalmology,* 6, 50-53 [in Russian].
16. Anatychuk L.I., Pasechnikova N.V., Kobylianskyi R.R., Havryliuk N.V., Naumenko V.A., Mirnenko V.V. Nazaretian R.E., Zadorozhnyi O.S. (2016). Termoelektricheskiie datchiki dlia registratsii vnutriglaznoi temperatury [Thermoelectric sensors for registration of intraocular temperature]. *Sensorna elektronika i mikrosystemni tekhnologii - Sensor Electronics and Microsystem Technologies*, 13(3), 30-38 [in Russian].
17. Anatychuk L.I., Pasechnikova N.V., Zadorozhnyi O.S., Kobylianskyi R.R., Nazaretian R.E., Mirnenko V.V., Havryliuk N.V. (2016). Ustroistvo dlia intraokuliarnoi termometrii i osobennosti raspredeleniia temperatury v razlichnykh otdelakh glaza krolika [A device for intraocular thermometry and features of temperature distribution in various chambers of the

rabbit's eye]. *Zhurnal Natsionalnoi Akademii Medychnykh Nauk Ukrainy - J. of the National Academy of Medical Sciences of Ukraine*, 22(1), 103-108 (in Russian].

18. Anatychuk L.I.., Pasechnikova N.V., Kobylianskyi R.R., Prybyla A.V., Naumenko V.O., Zadorozhnyi O.S., Nazaretian R.E., Mirnenko V.V. (2017). Computer simulation of thermal processes in human eye. *J.Thermoelectricity*, 5, 41-58.
19. Anatychuk L.I., Pasechnikova N.V., Naumenko V.O., Zadorozhnyi O.S., Havryliuk M.V., Kobylianskyi R.R. (2018). Thermoelctric device for determination of heat flux from the surface of eyes. *J.Thermoelectricity*, 5, 52-67.
20. Anatychuk L.I., Pasechnikova N.V., Naumenko V.A., Zadorozhnyi O.S., Kobylianskyi R.R., Havryliuk N.V. (2019). Termoelektricheskoie ustroistvo dlia oftalmoteplometrii i osobennosti registratsii plotnosti teplovogo potoka glaza cheloveka [Thermoelectric device for ophthalmothermometry and features of registration of heat flux density of the human eye]. *Oftalmologicheskii Zhurnal - J. Ophthalmology,* 3, 45-51 [in Russian]. http://doi.org/10.31288/oftalmolzh201934551
21. Anatychuk L.I. (1979). *Termoelementy i termoelektricheskiie ustroistva. Spravochnik (Thermoelements and thermoelectric devices. Handbook).* Kyiv: Naukova Dumka [in Russian].
22. Anatychuk L.I. (2003). *Termoelektrichestvo. T.2. Termoelektricheskiie prepbrazovateli energii [Thermoelectricity. Vol.2. Thermoelectric power converters].* Kyiv-Chernivtsi: Institute of Thermoelectricity [in Russian].

Submitted 30.07.2020