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THERMOELECTRIC DEVICE FOR MEASUREMENT OF INTRAOCULAR TEMPERATURE

This paper presents the results of development and experimental research on a multi-channel thermoelectric device intended for measurement of intraocular temperature. The operating principle, design and technical characteristics of such device, as well as its advantages over known world analogs are given. The method for the intraocular introduction of thermoelectric measuring probes and the method for measurement of intraocular temperature have been developed in an in vivo experiment. With the aid of the elaborated device the regularities of temperature distribution in different sections of the rabbit eye have been determined in an in vivo experiment.

Key words: thermoelectric device, measuring probe, intraocular temperature, rabbit eye.

Introduction

It is known that physicochemical processes in a sound eye, as well as hemo- and hydrodynamic parameters of the eye are in direct relationship to temperature of intraocular media [1 – 3]. However, the issue of temperature distribution in different sections of the human and animal eye remains to be studied.

There are contact and noncontact methods of measuring eye temperature. Noncontact measurement methods (for instance, infrared thermography) allow recording only the temperature of the outer surface of the eye, the temperature of intraocular media remaining unknown [4]. A number of devices and measuring probes have been developed in the world for recording the temperature of biological tissues and liquids. Some of them have been employed for contact measurement of intraocular temperature [5 – 7]. However, the existing devices and measurement methods have considerable disadvantages. First, the use of measuring probes of high thermal conductivity materials results in appreciable temperature measurement errors. Second, proposed methods of surgical approach produce a considerable impact on the intraocular temperature recorded [8].

Therefore, *the purpose of the paper* is to develop a thermoelectric device for contact measurement of intraocular temperature and to determine in experiment the regularities of temperature distribution in different parts of the rabbit eye.

Thermoelectric temperature measuring device

Thermoelectric device for measurement of intraocular temperature has been developed at the Institute of Thermoelectricity of the NAS and MES of Ukraine in the framework of cooperation agreement with the Filatov Institute of Eye Diseases and Tissue Therapy of the NAMS of Ukraine [9].

The device is intended for measurement of the temperature of biological object tissues and investigation of the dynamic thermal processes occurring in the organs of biological objects.

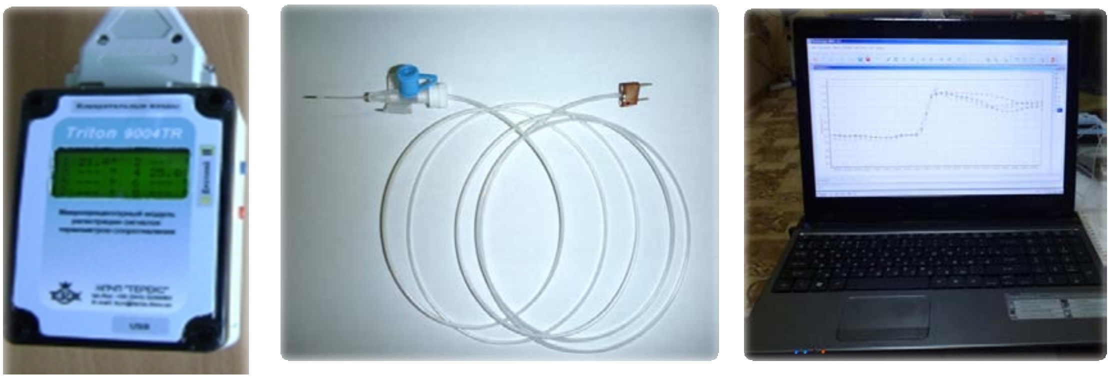


Fig. 1. Outside view of thermoelectric device for measurement of intraocular temperature.

Table 1

Specificationsof thermoelectric device
for measurement of intraocular temperature

№	Technical characteristics	Value
1.	Temperature measurement range	(-10° ÷ +120) °C
2.	Temperature measurement accuracy	± 0.05°C
3.	Number of temperature measurement channels	4
4.	Temperature recording period	from 4 s to 2 h
5.	Dimensions of temperature measuring microprobes	22 G and 24 G
6.	Temperature measurement in real-time mode	+
7.	Time of continuous operation of device from fully charged batteries	100 h
8.	Device power supply: Li-Ion battery 950 mA/h mains adapter AC220V/DC12V, 1A	 + +
9.	Charging of batteries from USB interface	+
10.	Type of interface for data exchange with PC	USB
11.	Geometric dimensions of microprocessor temperature recording module	(125 × 90 × 60) mm
12.	Geometric dimensions of docking device	(70 × 55 × 25) mm
13.	Device weight	0.5 kg

The device consists of a microprocessor temperature recording module, thermocouple measuring microprobes, a docking device, as well as a computer with software for visualization and recording of temperature in real-time mode. By means of USB-cable the results of temperature measurement can be passed to a personal computer. The outside view of the thermoelectric device is given in Fig. 1.

Microprobe temperature sensors are based on *L*-type thermocouples (chromel-copel) [10, 11]. The sensor probe is arranged in a case of standard cannula made of polytetrafluoroethylene. Thermocouple junction is welded to heat concentrator of medical stainless steel and fixed at the end of cannula needle. Thermocouple leads pass from cannula to a cable 1.5 m long and end in a plug. The cable and cannula joint is sealed with a medical silicon sealant which is chemically neutral and permits thermal or chemical sterilization of device (as a standard medical instrument).

With the aid of a plug through the docking device the microprobe is connected to a microprocessor temperature recording module. The docking module has 4 sockets to which up to 4 microprobes can be connected simultaneously. The docking device of temperature recording module is connected by means of DB-37f connector. Sockets in the docking device are mounted on a copper heat concentrator which also accommodates a precision temperature sensor (platinum resistance thermometer). It is used to measure the temperature of “cold” thermocouple ends – the reference temperature. A diagram of microprobes connection to microprocessor temperature measuring device is shown in Fig. 2.

The plugs of the microprobes and the sockets of the docking device have polarity marks. To reduce the level of crosstalk, the unused inputs of the meter are shorted with pegs – individual plugs with shorted pins.

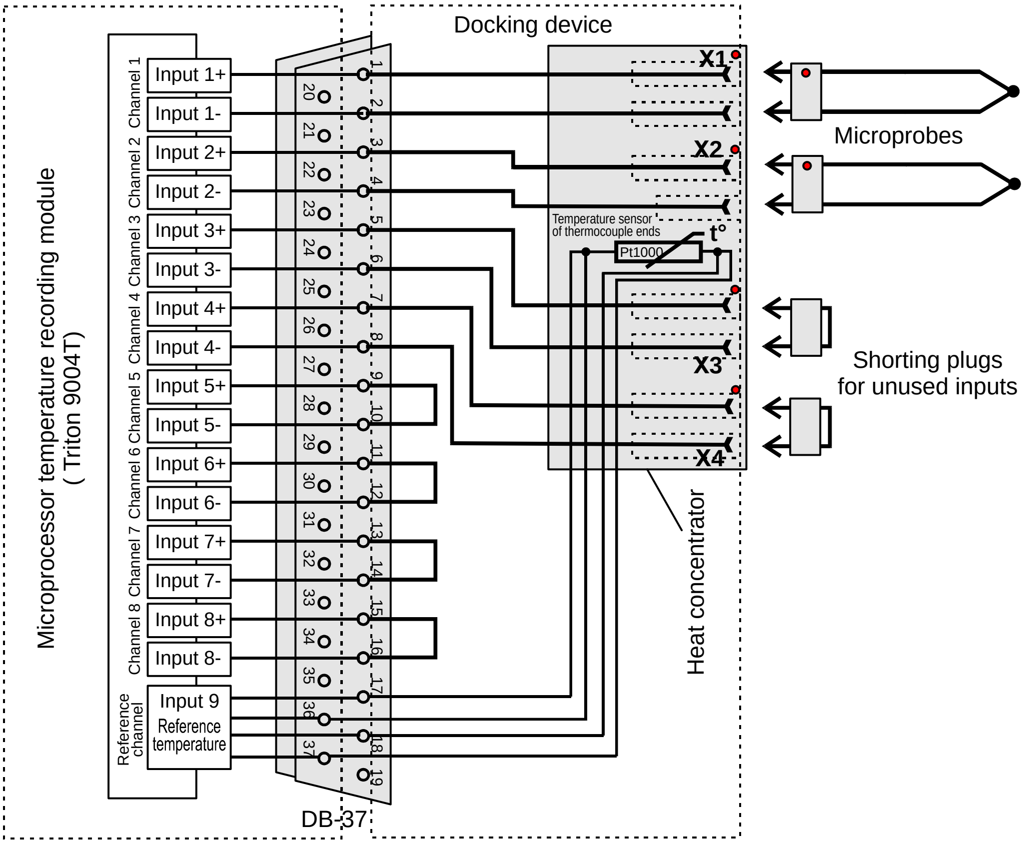


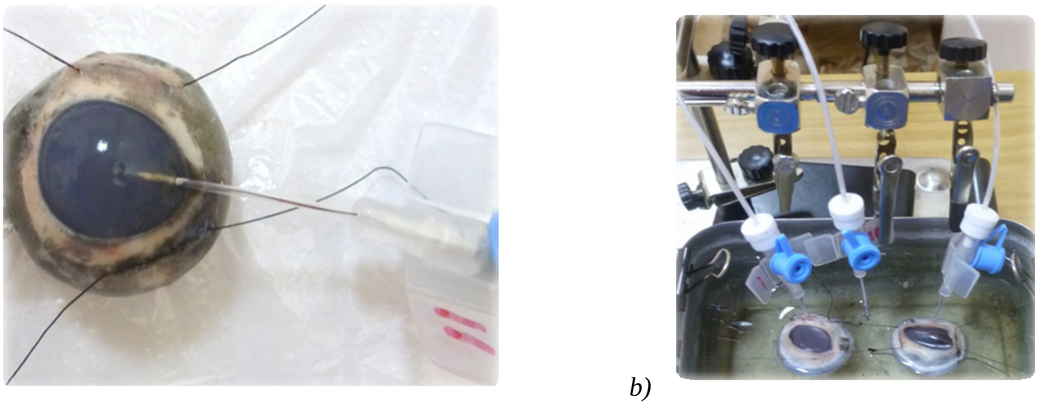
Fig. 2. Diagram of microprobes connection to thermoelectric temperature measurement device.

Microprocessor temperature recording module is based on Triton-9004T device that has an 8-channel 24-digit analog-to-digital converter (ADC). This temperature meter employs the first 4 channels, and the rest of the channels are shorted. If necessary, they can be “unshorted” and used for further measurement with another 4 channels. Maximum input voltage of measuring channel is ± 1.17 V. Temperature recording module is powered from a storage battery, and can also operate on mains adapter or powered from USB-cable with a joint work with computer. This adaptor is used for charging of storage battery. Device battery is also recharged from personal computer.

The specific feature of microprocessor temperature recording module is a possibility to set individually the sensitivity for each channel depending on thermocouple type. The device can measure temperature with the assigned time interval in the range from 4 s to 2 hours. The measured results are recorded in a non-volatile memory. The device memory capacity is 50 thousand cells. Programming of channels of microprocessor recording module and information readout is done by means of a personal computer through USB-cable.

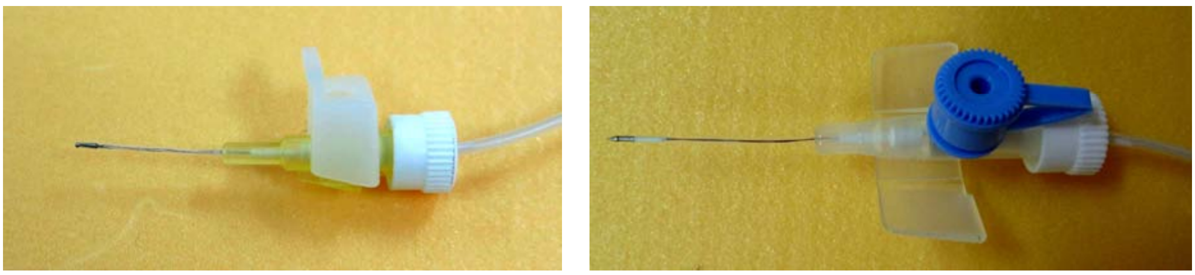
Experiment description

The thermoelectric device for measurement of intraocular temperature was tested in the Filatov Institute of Eye Diseases and Tissue Therapy of the NAMS of Ukraine. Its operating characteristics (temperature recording speed, measured temperature range, measurement error) were studied in an *ex vivo* experiment on 10 isolated pig eyes (Figs. 3). The optimal properties of thermoelectric measuring probes were tried out (Fig. 4), namely material, diameter, length, method of insertion, fixation and temperature recording. To simulate natural thermal effect of choroid, the experiment was carried out under bath water temperature 39 °C.



a) *b)*

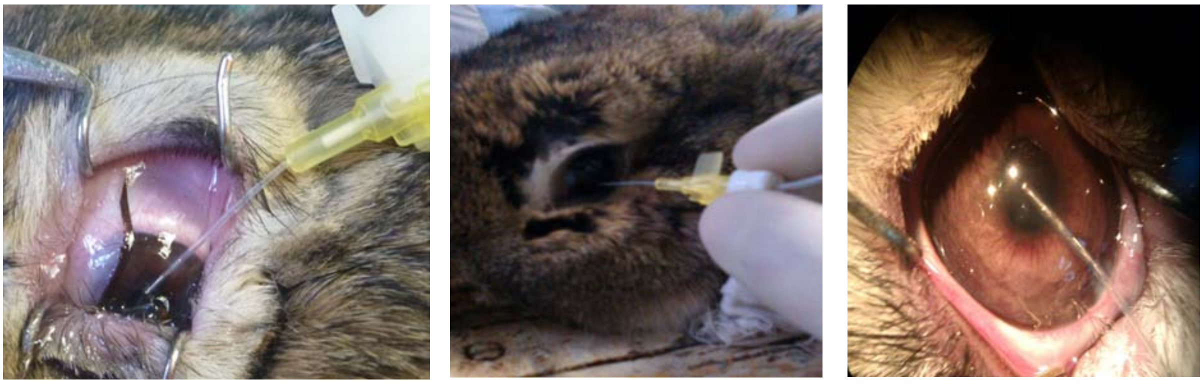
Fig.3 a, b. An ex vivo experiment on the isolated pig eyes.



a) *b)*

Fig.4. Thermoelectric measuring probes for contact measurement of eye temperature:
a) gauge 24G (outer diameter of measuring probe needle 0.7 mm, length 19 mm);
b) gauge 22G (outer diameter of measuring probe needle 0.8 mm, length 25 mm).

In an *in vivo* experiment, on 11 chinchilla rabbits (22 eyes) (age 1 year, weight 3.5 - 4 kg) prior to the anesthetic management of the rabbit the outer surface temperature of cornea and conjunctiva was measured (Fig. 5). Cornea temperature was measured by direct contact of probe tip to central part of the outer surface of cornea up to recording of constant temperature data. After that the temperature was recorded with the measuring probe placed into lower conjunctival fornix, and then into upper conjunctival fornix. After the anesthetic management of the rabbit the temperature was measured again on the outer surface of cornea and in conjunctival fornices, and then, on formation of surgical approach, the temperature was measured in the ocular anterior chamber, in the anterior, medial and posterior sections of vitreous humor, in retina/choroid, in subtenon space. The measuring probe was introduced into the anterior chamber through tunnel paracentesis 0.7 mm. The probe was introduced into vitreous humor through sclerotomy of diameter 0.6 mm in the projection of flat part of ciliary body 2 – 3 mm away from limbus. The probe was introduced into subtenon space through conjunctival incision in the upper internal quadrant. Moreover, measurements were made of the rabbit rectal temperature, the temperature and relative air humidity in the room.



a) *b)* *c)*

Fig.5 a,b,c. An in vivo experiment on chinchilla rabbits.

The work with experimental animals was performed in conformity with the “European Convention for the Protection of Verterbrate Animals” used for research and other scientific purposes (Strasbourg, 1986) and the Law of Ukraine “On Protection of Cruelty to Animals” (2006).

Results of experimental research

In an *ex vivo* experiment it was established that the elaborated device permits temperature measurement in real-time mode (with data display as graphic images) in the range from -10°C to +120°C simultaneously by 4 thermal probes with measurement error up to ± 0.05°C. In so doing, the difference in readings of 4 thermal probes was not more than 0.04°C.

During the first stage, in an *ex vivo* experiment, on the isolated pig eye the method of measuring temperature in the ocular anterior chamber, in the anterior, media and posterior sections of the vitreous humor, retina/choroid, as well as the on the outer surface of cornea by proposed device was adapted for application *in vivo*. The method of intraocular introduction of thermal probes (into anterior chamber, into vitreous humor) on the isolated eye was developed. Then, using the elaborated device, at constant water bath temperature on the average 39 ± 0.5°C and ambient temperature 23.5 ± 0.6°C, the temperature was measured in the sections of the eye. Maximum intraocular temperature was recorded in the posterior section of vitreous humor at contact with retina and made 38.5 ± 0.8°C. With the probe displacement from the posterior to medial section of vitreous humor the temperature was reduced to 38 ± 0.6°C, and with the probe displacement to anterior section of vitreous humor – to 37 ± 0.7°C. The temperature in the anterior chamber proved to be lower that that of the vitreous humor and made 35 ± 0.8°C, which is due to the contact of cornea to the environment, whereas water bath simulates the role of retina, forming and maintaining the constancy of intraocular temperature. Thus, in an *ex vivo* experiment the hypothetic temperature distribution in different sections of the eye was demonstrated.

During the next stage, in an *in vivo* experiment, the method of application of the elaborated device was worked out for measuring temperature of the outer surface of cornea and conjunctiva, in the ocular anterior chamber, in the anterior, medial and posterior sections of the vitreous humor, retina/choroid, as well as in the subtenon space of the rabbit eye. The research was performed at an average ambient temperature 23.8 ± 0.6°C, an average relative air humidity 80.7 ± 1.6 %, and an average rectal temperature of the rabbit 38.73 ± 0.94°C. The temperature of different sections of the eye recorded in the experiment is represented in Table 2.

Table 2

Temperature distribution in different sections of the rabbit eye

Eyball and ocular adnexa section	Average value of *t* *, °C ± SD
lower conjunctival fornix	37.65 ± 0.70
upper conjunctival fornix	36.82 ± 0.66
outer surface of cornea	34.41 ± 0.80
ocular anterior chamber	35.97 ± 0.73
anterior section of vitreous humor	36.96 ± 0.77
medial section of vitreous humor	37.40 ± 0.87
posterior section of vitreous humor	37.50 ± 0.88
retina/choroid	37.64 ± 0.87
subtenon space	37.78 ± 0.77

* *t* – temperature data obtained after the anesthetic management of the rabbit.

So, the *in vivo* experiment has confirmed the existence of temperature gradient between different sections of the eye. Thus, temperature gradient between the outer surface of cornea and ocular anterior chamber has made 1.56°C, between the outer surface of cornea and retina – 3.23°C, between the outer surface of cornea and subtenon space – 3.37°C (Fig. 6).

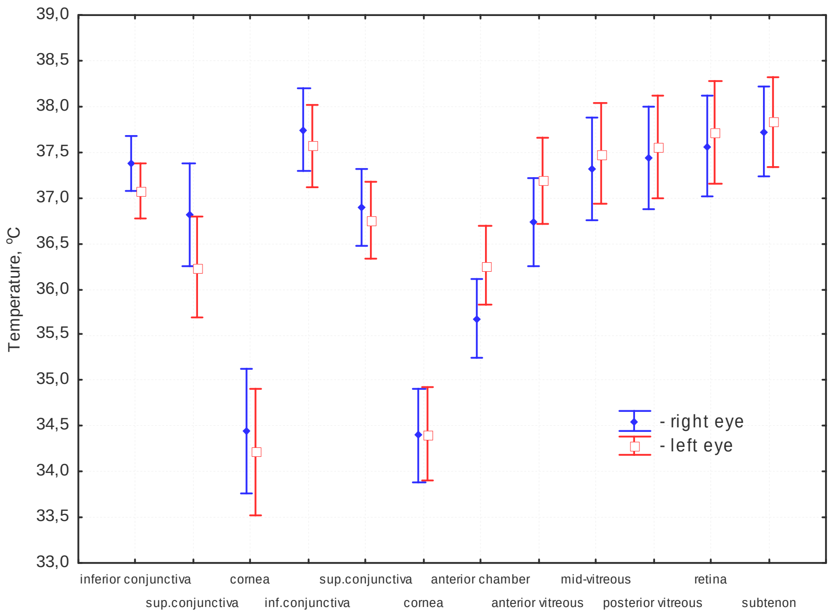


Fig. 6. Temperature in different sections of the rabbit eye.

When analyzing the obtained results it was marked that no essential differences in the temperature of the right and left eyes of experimental animals were revealed. These observations refer both to the outer sections of the rabbit eye where measurements were performed (lower conjunctival fornix, upper conjunctival fornix, outer surface of cornea), and the inner sections of the rabbit eye (anterior chamber, different sections of vitreous humor, retina/choroid, subtenon space). Hence, it can be stated that the temperature in all the sections of the right and left eye of the same experimental animal does not differ essentially. Moreover, these results confirm the reproducibility of temperature measurements performed by the elaborated thermoelectric device.

Further analysis of the obtained results revealed high correlation between the temperature of conjunctival fornices and intraocular temperature in vitreous humor, retina and subtenon space. Thus, high correlation was revealed between the temperature of lower conjunctival fornix and retina temperature ($r = 0.857$, $p = 0.000$), as well as the temperature in subtenon space ($r = 0.86$, $p = 0.000$). Presumably this observation can be explained by the well-defined vascularity of conjunctiva and superficial arrangement of vessels in it. Also, high correlation was revealed between the temperature in the anterior section of vitreous humor and the temperature of retina ($r = 0.92$, $p = 0.000$), as well as between the temperature in the anterior section of vitreous humor and in the subtenon space ($r = 0.88$, $p = 0.000$).

At the same time, it was mentioned that the temperature of the outer surface of cornea less correlates with the intraocular temperatures recorded in the anterior chamber, vitreous humor, retina and subtenon space. Thus, low correlation was observed between the temperature of cornea and that of retina ($r = – 0.13$, $p = 0.57$). The obtained results are obviously attributable to the nonvascular structure of eye cornea and a direct contact between the outer surface of cornea and the environment. It is known that the temperature of the outer surface of cornea is very variable and strongly dependent on the ambient temperature, air motion velocity and air humidity.

Based on the obtained experimental results a schematic distribution of temperature in the rabbit eye was constructed (Figs. 7 – 8).

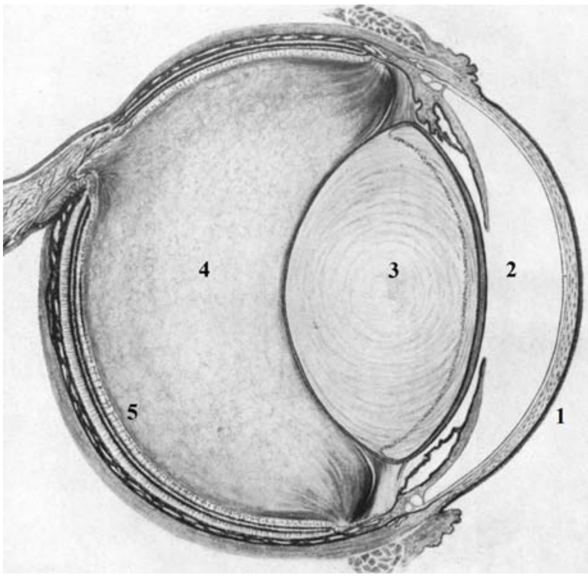


Fig. 7. Schematic of the rabbit eye:
1 – cornea, 2 – anterior chamber, 3 – lens,
4 – vitreous humor, 5 – retina.

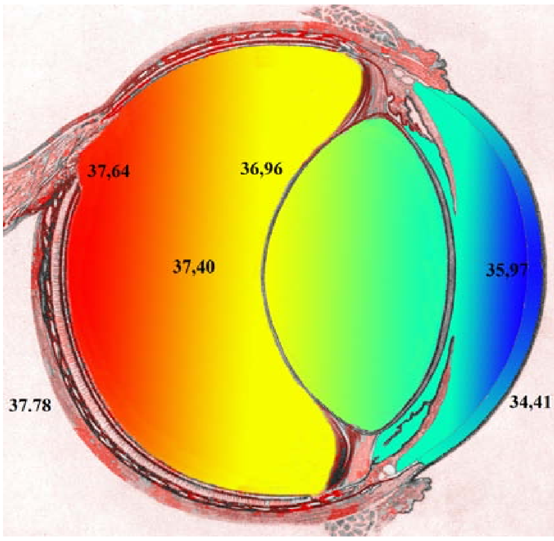


Fig. 8. Schematic of temperature distribution in the rabbit eye.

Discussion

In 1962 B. Schwartz and M. R. Feller published a paper dedicated to measurement of temperature in different eye sections of white New Zealand rabbits. For measuring the intraocular temperatures the authors employed a device based on a thermistor and several modifications of measuring probes. As a probe for recording the intraocular temperatures, a metal needle of length 7.62 cm and diameter 0.7 mm was used. Measurement in different eye sections was performed by gradual introduction of the probe through cornea, lens, vitreous humor and retina into the eye socket. The ambient temperature varied from 22 to 24°C, the relative air humidity was 33 – 53%. After the anesthetic management of seven experimental animals the average rectal temperature was 39.13°C. The work resulted in the following average figures: the temperature of the outer surface of cornea – 32.30 ± 0.49°C, lower conjunctival sac – 38.74 ± 0.54°C, anterior chamber – 32.98 ± 0.74°C, lens – 35.42 ± 1.0°C, medial section of vitreous humor – 36.56 ± 0.9°C, retina/choroid – 37.03 ± 0.86°C, socket – 37.68 ± 0.71°C [7].

In 1983 D. R. May with coauthors determined the effect of perfusion of anterior chamber with irrigating solutions of different temperature on temperature variations in the eye sections of Dutch rabbits. In this work they employed a thermocouple-based thermometer which is a metal probe with a blunt tip of diameter 0.64 mm and length 2.5 cm. Thermometer measurement error was ± 1°C. Air temperature was 25 °C. After the anesthetic management of experimental animals the average rectal temperature was 39.4°C. The authors represented the following average initial temperatures in the eye sections: anterior chamber – 32.5°C, anterior section of vitreous humor – 35.0°C, medial section of vitreous humor – 35.5°C, posterior section of vitreous humor – 36.6°C, retina – 36.8°C [5].

It should be noted that in these works use was made of high thermal conductivity metal probes. Moreover, in the work by D. R. May with co-authors, prior to temperature measurement, for irrigation/aspiration processes of the anterior chamber two punctures of the cornea were made with metal needles of diameter 0.7 and 0.8 mm, and then one of the punctures was widened with metal scissors up to 3 mm. From the experimental data (in vitro) and theoretical studies performed by I. Fatt and J. F. Forester in 1972 it is known that the temperatures of eye tissues recorded by metal probes can prove to be several degrees lower than the temperatures recorded by low thermal conductivity probes [8].

In our work, the temperature recorded in the ocular anterior chamber was 35.97°C and proved to be higher as compared to the data published before (32.5°C in the work by D. R. May and 33°C in the work by B. Schwartz) by about 3 – 3.5°C. Essential differences in temperatures recorded in ocular anterior chamber apparently are related to a small volume of humidity in the rabbit's ocular anterior chamber which is as low as 0.25-0.3 ml, as well as to a direct contact of the cornea to the environment. Therefore, introduction into anterior chamber of metal instrument at formation of surgical approach and metal measuring probe results in essential heat loss and recording of lower temperatures. In our work, measuring probe was made of low thermal conductivity polytetafluoroethylene, and a minimum surgical approach which is only necessary for the introduction of thermal probe was formed, which resulted in heat loss reduction at the moment of temperature measurement and recording of higher figures.

Heat loss is less appreciable when measuring temperature in vitreous humor, since its volume for the rabbit is 1 – 1.5 ml and there is no direct contact of vitreous humor to the environment. The temperature in the medial section of vitreous humor in our study was 37.4°C and was less different from the data reported by the above authors (35.5 and 36.56°C).

Therefore, the recorded intraocular temperatures are largely affected by the scope of surgical intervention at formation of access to different eye sections and by the application of surgical instruments made of high thermal conductivity materials. Moreover, considerable effect on the recorded data is produced by the material of probe for measurement of intraocular temperatures.

Conclusions

1. For the first time, a multi-channel thermoelectric device with computer software has been developed for recording and visualization of intraocular temperature, allowing high-precision measurements in real-time mode (in the temperature range of -10°C ÷ +120°C with measurement error ± 0.05°C).
2. For the first time, a thermoelectric measuring probe based on L-type thermocouples has been developed and manufactured in a case of standard cannula made of low thermal conductivity polytetrafluoroethylene, which allowed increasing the accuracy of measuring intraocular temperature through reduction of heat loss through the probe.
3. A method has been developed for measuring temperature of the outer surface of cornea and conjunctiva, in the anterior chamber, in the anterior, medial and posterior sections of vitreous humor, retina/choroid, in the subtenon space of the rabbit eye in an *in vivo* experiment.
4. Using the elaborated thermoelectric device, in an *in vivo* experiment the regularities of temperature distribution in different sections of the rabbit eye have been determined (lower conjunctival fornix – 37.65°C; upper conjunctival fornix – 36.82°C; cornea surface – 34.41°C; ocular anterior chamber – 35.97°C; anterior section of vitreous humor – 36.96°C; medial section of vitreous humor – 37.40°C; posterior section of vitreous humor – 37.50°C; retina/choroid – 37.64°C; subtenon space – 37.78°C at the ambient temperature 23.8°C). In an *in vivo* experiment high correlation has been revealed between the temperature of lower conjunctival fornix and retina temperature, as well as the temperature in the subtenon space of the rabbit eye.

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Submitted 05.07.2015.