L.I. Anatychuk[1, 2], O.I. Ivaschuk[3], R.R. Kobylianskyi[1, 2], I.D. Postevka[3], V.Yu. Bodiaka[3], I.Ya. Gushul[3]

[1]Institute of Thermoelectricity, 1, Nauky str., Chernivtsi, 58029, Ukraine;
[2]Yu. Fedkovych Chernivtsi National University,
2, Kotsiubynskyi str., Chernivtsi, 58012, Ukraine;
[3]Higher state educational institution of Ukraine "Bukovinian State Medical University",
2, Theatre sq.,Chernivtsi, 58002, Ukraine

THERMOELECTRIC DEVICE FOR TEMPERATURE AND HEAT FLUX DENSITY MEASUREMENT "ALTEC-10008"

This paper presents the design, operating principle and specifications of thermoelectric device developed for temperature and heat flux density measurement which involves connection to personal computer for saving, processing and visualization of measurement results in real-time mode.
The results of experimental research on heat release of implanted breast neoplasm of trial rat as a function of neoplasm progression stage are presented. It is established that the results obtained can be used for development of a method for early diagnostics of breast cancer.
Key words: thermoelectric sensor, temperature, heat flux density, breast cancer, diagnostics of oncologic diseases.

Introduction

For the investigation of local human heat release much promise is held by semiconductor thermoelectric heat flux sensors [1 – 11] which combine miniature size, high sensitivity, parameter stability in a wide operating temperature range and are matched with state-of-the-art recording equipment [12 – 17]. The use of such sensors enables one to get high locality and precision of heat flux metering. This, in turn, provides insight into characteristics of objects under study and their detailed analysis for the purpose of early detection of human organism inflammatory processes and oncologic diseases.

An important factor in the investigation of human heat fluxes with the aid of thermoelectric sensors is precision and speed of signal recording. Early developments of signal recorders [3 – 9] have a relatively high measurement error, large overall dimensions, low speed and no self-contained power supplies. Further developments in this direction resulted in creation of modern electronic recorders with processing of information from thermoelectric heat flux sensors [18 – 20] which have internal memory for saving of measurement results and self-contained power supplies. However, the disadvantages of such devices are the impossibility of connection of several thermoelectric sensors, the absence of simultaneous temperature and heat flux density measurement and the absence of real-time connection to personal computer for processing, saving and visualization of measurement results. Moreover, the data on correlation between heat release and the level of health is still insufficient [21 – 27].

Therefore, *the purpose of this work* is development of a multi-channel thermoelectric device for temperature and heat flux density measurement and investigation with its help of heat release of implanted breast neoplasm of trial rat depending on neoplasm progression stage.

Device design and specifications

Thermoelectric device for temperature and heat flux measurement "ALTEC - 10008" was developed at the Institute of Thermoelectricity of the National Academy of Sciences and Ministry of Education and Science of Ukraine under the agreement on cooperation with Bukovinian State Medical University of the Ministry of Public Health of Ukraine. The device is intended for a simultaneous measurement of temperature and heat flux density on human body surface by contact method, allowing early diagnostics of inflammatory processes and oncologic diseases. Device appearance and specifications are presented in Fig. 1 and Table 1, respectively.

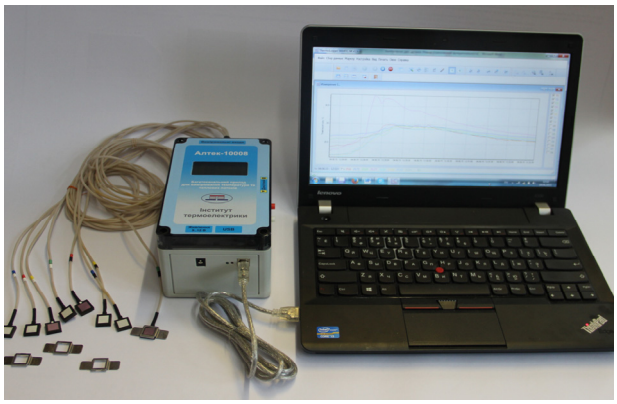

Fig. 1. Appearance of thermoelectric device for temperature and heat flux density measurement "ALTEC-10008".

Table 1.

Thermoelectric device specifications

№	Device specifications, measurement unit	Value
1.	Number of probes, pcs.	8
2.	Probe dimensions, mm	14 × 14 × 3
3.	Probe configuration	Temperature sensor, heat flux sensor
4.	Temperature sensor type	Thermistor
5.	Temperature sensor dimensions, mm	2.2 × 2 × 0.7
6.	Heat flux sensor type	Thermocouple thermopile
7.	Thermopile dimensions, mm	10 × 10 × 3
8.	The length of probe connecting wires, m	1.5
9.	Electronic recorder type	TRITON 9004TC A
10.	Temperature measurement range, °C	0 ÷ + 50
11.	Temperature measurement accuracy, °C	0.05
12.	Heat flux density measurement range, W/cm^2	$5 \cdot 10^{-5} \div 10^{-1}$
13.	Electronic recorder speed, s	3 ÷ 5
14.	Electronic recorder supply: a) mains AC/DC-adapter, V b) three galvanic elements AA, V	 220/5 4.5
15.	Possibility of real-time display of measurement results on electronic recorder	+
16.	Possibility of real-time display of measurement results on personal computer	+
17.	Possibility of real-time saving measurement results on microSD memory card	+

The device is composed of electronic control unit and 8 identical thermoelectric probes. Electronic control unit is a 16-channel microprocessor module for electric signal recording based on Triton-9004TCA recorder. Device can be powered in two ways: three galvanic elements of the type AA (4.5 V) or external power supply of voltage 5 V (mains AC/DC-adapter (220/5 V), USB-port of personal computer or laptop). With a simultaneous connection to device of external power supply and galvanic elements, the latter are recharged.

The device is fully-autonomous, i.e. measurement results are shown on display in real-time mode and saved on microSD memory card with given time interval. Moreover, for convenience of processing and analysis of measurement results the device involves data transfer through USB interface to personal computer by means of specially elaborated software program.

Thermoelectric probe comprises self-contained temperature sensor (thermistor) and thermocouple heat flux sensor. The thermoelectric probe is schematically shown in Fig. 2.

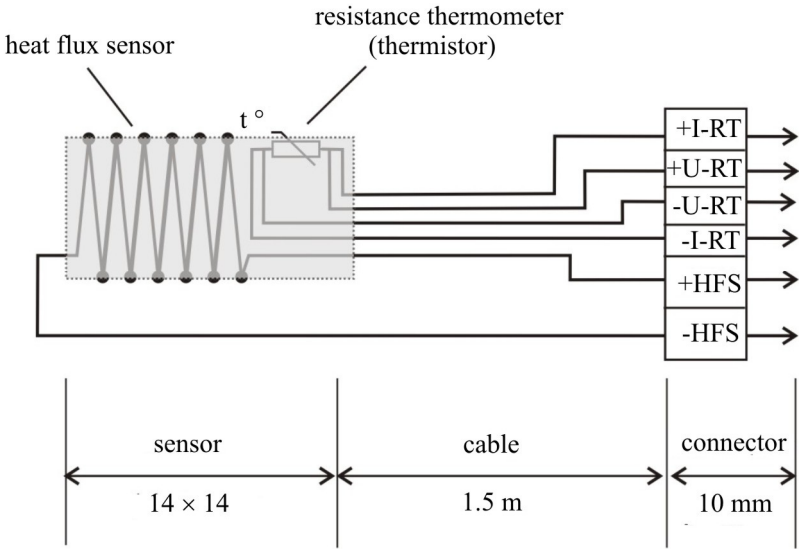

Fig. 2. Schematic of thermoelectric probe.

Heat flux sensor is a tightly packed thermopile of thermocouple elements made of high-performance semiconductor materials based on *Bi – Te* [1]. The intervals between thermocouple elements are filled with epoxy compound, and thermopile working surfaces are hermetically sealed by ceramic plates. Full hermetic state of thermoelectric probes allows their thorough disinfection. For convenient replacement of thermoelectric probe it is connected to electronic control unit. Thermoelectric probes are fastened to object under study by means of frames with the lobes made of food grade stainless steel.

Experiment description

The experiment was carried out on 48 pubertal nonlinear rats of average age, of weight at least 180 g, female sex that had never been pregnant.

All trial animals were divided into two groups – comparative and main. The main group comprised 32 rats which were implanted with Geren's carcinoma in the area of location of the abdominal mammary gland by injection of cell suspension (Fig. 3).

Fig. 3. Neoplasm of left abdominal mammary gland of trial rat (10-th day after injection of Geren's carcinoma cell suspension).

Geren's carcinoma cell suspension was prepared by elimination of the latter from the other animal. The carcinoma was minced to fragments of size from 0.05 to 1.0 mm, with elimination of connective tissue elements. Also, cleaning in phycolous gradient was performed, in an effort to remove cell debris, elements of blood, mucus, connective tissue cells and large fragments. For transplantation a specimen of daily cells culture in culture medium was used, with their content $4 \cdot 10^8$ in 1 ml.

The main group was divided into two subgroups. In the first subgroup of animals, temperature and heat flux sensor was arranged in the projection of pathologically unchanged tissues of the abdominal mammary gland, in the second group – in the projection of carcinoma. The comparative group comprised 16 intact animals for which temperature and heat flux sensor was arranged in the projection of the abdominal mammary gland tissue.

For the purpose of measurement of heat flux from the abdominal mammary gland, the animal was fixed lying on its back. Heat flux sensor was fixed to skin by means of two simple interrupted stitches, the said area having been preliminarily shaved and treated with 70 % alcohol (Fig. 4).

Fig. 4. Arrangement and fixation by simple interrupted stitches of thermoelectric temperature and heat flux sensors in the projection of the abdominal and inguinal mammary glands tumor.

Temperature and heat flux density on the skin surface of mammary gland of trial rats was measured for 5 minutes, from the 8^{th} to 16^{th} day after tumor implantation. Said dates of experimental

investigations are caused by the size of implanted neoplasm, as well as by the beginning of destructive processes in the latter. In the course of experimental investigations air temperature in the room was within 20 ÷ 21 ºC. For the comparative group animals, temperature and heat flux density measurement was performed with thermoelectric sensor arranged horizontally on the skin in the projection of the abdominal mammary gland.

The experiment was carried out in the vivarium of Bukovinian State Medical University in conformity with the national requirements of "General ethical principles of animal experimentation" (Ukraine, 2011) that are consistent with provisions of "European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes" (Strasbourg, 1985).

Mercy killing of laboratory rats was done according to ethical standards and effective recommendations in heavy sedation state by injection of excess amount of drug in conformity with the law of Ukraine № 3447-1 of 21.02.2006 "On the protection of animals from cruelty".

Experimental results

In Table 2 are listed the results of experimental studies on heat flux density of trial rat mammary gland. The results obtained point to definitely lower values of heat flux density for the main group animals during the whole observation period. The figures of heat flux density for the animals of the first subgroup of the main group are definitely higher than the figures of the second subgroup during the entire investigation period. In both subgroups of the main group there is a definite reduction of heat flux density after the 8^{th} to 10^{th} day of observation.

Table 2.

Dynamics of heat flux density of trial rat mammary neoplasm depending on the term after tumor implantation (M ± m), mW

Term after tumor implantation	Animal group		
	The main group $n = 32$		Comparative group $n = 16$
	Первая подгруппа	Вторая подгруппа	
the 8^{th} to 10^{th} day	19.26 ± 0.31 $p < 0.001$	15.07 ± 0.30 $p < 0.001$; $p_1 < 0.001$	28.99 ± 0.60
the 11^{th} to 13^{th} day	17.93 ± 0.31 $p < 0.001$*	13.08 ± 0.26 $p < 0.001$; $p_1 < 0.001$*	
the 14^{th} to 16^{th} day	13.65 ± 0.32 $p < 0.001$*	9.17 ± 0.38 $p < 0.001$; $p_1 < 0.001$*	

Notes: n – number of observations; p – with respect to comparative group; p_1 – with respect to the first subgroup of the main group; * – reliable on the 8^{th} to 10^{th} day of observation.

Evaluating the results of experimental studies on skin surface temperature in the projection of trial rat mammary gland, one should note definitely lower temperature values for the main group animals during the whole observation period (Table 3). The skin surface temperature in the projection of mammary gland for animals of the first subgroup of the main group is definitely higher than for animals of the second subgroup. There is a definite reduction of skin surface temperature in the projection of mammary gland for the main group animals during the whole investigation period with a reliable difference on the 14^{th} to 16^{th} day.

Table 3.

Dynamics of skin surface temperature of trial rat mammary neoplasm depending on the term after tumor implantation (M ± m), ºC

Term after tumor implantation	Animal group		
	The main group $n = 32$		Comparative group $n = 16$
	The first subgroup	The first subgroup	
the 8th to 10th day	25.45 ± 0.58 $p < 0.001$	22.90 ± 0.31 $p < 0.001$; $p_1 < 0.001$	31.50 ± 0.63
the 11th to 13th day	24.98 ± 0.42 $p < 0.001$	22.33 ± 0.36 $p < 0.001$; $p_1 < 0.001$	
the 14th to 16th day	24.11 ± 0.30 $p < 0.001$*	21.72 ± 0.40 $p < 0.001$; $p_1 < 0.001$*	

Notes: n – number of observations; p – with respect to comparative group; p_1 – with respect to the first subgroup of the main group; * – reliable on the 8th to 10th day of observation.

Summarizing the results of experimental investigations, it should be noted that in the case of malignant state of trial rat mammary gland one can observe definitely lower mode and median values of temperature and heat flux density as compared to intact animals. The said figures are definitely lower in tumorous mammary gland compared to intact one in the organism of the same animal. Progression of mammary gland tumor is characterized by a definite reduction of the mode and median values of heat flux density and skin surface temperature, though the latter is characterized by less pronounced changes, as testified by unreliable difference on the 11th to 13th day of observation.

Thus, heat flux density and skin surface temperature in the projection of mammary gland malignant neoplasm have definitely lower values decreasing with the latter growth. The results obtained can be used for the development of a method for early detection of breast cancer. Introduction to medical practice of the thermoelectric device for temperature and heat flux density measurement "Altec-10008" will yield a simple and cheap method for early detection of inflammatory processes and oncologic diseases.

Conclusions

1. A multi-channel thermoelectric device was developed and manufactured for a simultaneous contact measurement of temperature and heat flux density of human body surface which involves connection to personal computer for saving, processing and visualization of measurement results in real-time mode.
2. It was experimentally established that the value of heat flux density and skin surface temperature of tumorous mammary gland is lower compared to intact one and is reduced with neoplasm growth. The results obtained can be used for the development of a method for early detection of breast cancer.
3. The proposed device is promising for the monitoring of temperature and thermal state of human organism, enabling early detection of inflammatory processes, oncologic diseases and express diagnostics during mass preventive examination of patients.

References

1. L.I.Anatychuk, *Thermoelements and Thermoelectric Devices: Reference Book* (Kyiv:Naukova Dumka, 1979), 768 p.
2. O.A.Geraschenko, *Foundations of Heat Flux Measurement* (Kyiv: Naukova Dumka, 1971), p.192.
3. L.I.Anatychuk, N.G.Lozinsky, P.D.Mykytyuk and Yu.Yu.Rozver, Thermoelectric Semiconductor Heat Meter, *Instruments and Experimental Techniques* **5**, 236 (1983).
4. L.I.Anatychuk, L.P.Bulat, D.D.Gutsal and A.P.Myagkota, Thermoelectric Heat Meter, *Instruments and Experimental Techniques* **4**, 248 (1989).
5. R.B.Ladyka, D.N.Moskal and V.D.Didukh, Semiconductor Heat Meters in Arthropathy Diagnostics and Treatment, *Meditsinskaya Tekhnika* **6**, 34 – 35 (1992).
6. R.B.Ladyka, O.N.Dakalyuk, L.P.Bulat and A.P.Myagkota, Use of Semiconductor Heat Meters in the Diagnostics and Treatment, *Meditsinskaya Tekhnika* **6**, 36 – 37 (1996).
7. B.M.Demchuk, L.Ya.Kushneryk, and I.M.Rublenyk, Thermoelectric Sensors for Orthopedics, *J.Thermoelectricity* **4**, 80 – 85 (2002).
8. A.A.Ascheulov, A.V.Klepikovskyi, L.Ya.Kushneryk, A.O.Rarenko, and V.I.Cherchenko, Patent of Ukraine № 53104 A, Sensor for Preliminary Diagnostics of Inflammatory Processes in Mammary Glands, Yu.Fedkovych Chernivtsi Nastional University, Application № u2002031955; Filed 12.03.2002; Publ. 15.01.2003, Bul. № 1.
9. A.A.Ascheulov, L.Ya.Kushneryk, Thermoelectric Device for Medico-Biological Express-Diagnostics, *Tekhnologiya i Konstruirovaniye v Elektronnoi Apparature* **4**, 38 – 39 (2004).
10. B.M.Demchuk, R.R.Kobylyansky, and A.V.Prybyla, Primary Thermoelectric Converters Based on Semiconductor Materials for Gradient Het Meters, *The 31-st International and 10-th European Conference on Thermoelectrics* (2012, Aalborg, Denmark), P. 277.
11. L.I.Anatychuk, R.R.Kobylyanskii, Thermoelectric Converters for Gradient Heat Meters, *Proceedings of XIII Interstate Workshop "Thermoelectrics and Their Applications"* (Saint-Petersburg, November 13 – 14, 2012), pp. 440 – 444.
12. L.I.Anatychuk, R.R.Kobylyanskii, *Patent of Ukraine № 71619*, Thermoelectric Medical Heat Meter, Application № u 2011 14007; filed 28.11.11; publ. 25.07.12, Bul. № 14.
13. L.I.Anatychuk, R.R.Kobylyanskii, *Patent of Ukraine № 72032*, Thermoelectric Sensor for Temperature and Heat Flux Measurement, Application № u 2011 14005; filed 28.11.11; publ. 10.08.12, Bul. № 15.
14. P.D.Mykytyuk, R.R.Kobylyanskii, and T.V.Slepenyuk, *Patent of Ukraine № 73037*, Thermoelectric Medical Device, Application № u 2012 01922; filed 20.02.12; publ. 10.09.12, Bul. № 17.
15. L.I.Anatychuk, R.R.Kobylyanskii, *Patent of Ukraine № 78619*, Method for Determination of Heat Flux Density, Application № u 2012 11018; filed 21.09.12; publ. 25.03.13, Bul. № 6.
16. L.I.Anatychuk, *Patent of Ukraine № 79929,* Thermoelectric Converter of Heat flux for Gradient Heat Meters, Application № 2012 11857; filed 15.10.12; publ. 13.05.13, Bul. № 9.
17. L.I.Anatychuk, R.R.Kobylianskyi, and I.A.Konstantinovich, Calibration of Thermoelectric Heat Flux Sensors, *Proc. of XV International Research and Practical Conference "Current Information and Electronic Technologies", Vol.2* (Odessa, Ukraine, May 26 – 30, 2014), P. 30 – 31.
18. V.S.Gischuk, Electronic Recorder of Signals from Human Heat Flux Sensors, *J.Thermoelectricity* 4, 105 – 108 (2012).
19. V.S.Gischuk, Electronic Recorder with Processing Signals from Heat Flux Thermoelectric Sensor, *J.Thermoelectricity* 1, 82 – 86 (2013).

20. V.S.Gischuk, Modernized Device for Human Heat Flux Measurement, *J.Thermoelectricity* 2, 91 – 95 (2013).
21. L.I.Anatychuk, R.R.Kobylianskyi, Research into the Effect of Thermoelectric Heat Meter on Human Heat Release Measurement, *J.Thermoelectricity* 4, 60 – 66 (2012).
22. L.I.Anatychuk, R.R.Kobylyanskii, 3D-Model for Determination of Thermoelectric Heat Meter Effect on the Accuracy of Human Heat Release Measurement, *Scientific Bulletin of Chernivtsi University: Collected Scientific Works. Physics. Electronics,* ***2****, issue 1* (Chernivtsi: Chernivtsi National University, 2012), p. 15 – 20.
23. L.I.Anatychuk, R.R.Kobylianskyi, Computer Design of Thermoelectric Heat Meter Readings under Real-Service Conditions, *J.Thermoelectrucity* 1, 53 – 60 (2013).
24. L.I.Anatychuk, R.G.Giba, and R.R.Kobylianskyi, Some Peculiarities of Using Medical Heat Meters in the Investigation of Local Human Heat Release, *J.Thermoelectricity* 2, 67 – 73 (2013).
25. O.I.Ivaschuk, I.K.Morar, R.R.Kobylianskyi, L.V.Nepelyak, and V.D.Deley, The Role of Abdominal cavity Heat Flux in the Monitoring of Acute Destructive Pancreatis, *Collection of Abstracts of Research and Practical Conference "Highlights of Surgery"* (Chernivtsi, Ukraine, 2013), P. 254 – 259.
26. L.I.Anatychuk, R.R.Kobylianskyi, and I.A.Konstantinovich, The Impact of a Thermoelectric Supply on the Accuracy of Temperature and Heat Flux Measurement, *J.Thermoelectricity* 6, 53 – 61 (2013).
27. R.R.Kobylianskyi, V.V.Boichuk, The Use of Thermoelectric Heat Meters in Medical Diagnostics, *Scientific Bulletin of Chernivtsi University: Collected Scientific Works. Physics. Electronics,* ***4****, issue 1* (Chernivtsi: Chernivtsi National University, 2015), p. 90 – 96.

Submitted 26.02.2016.