R.R. Kobylianskyi, *Cand. Sc (Phys &Math)* [1,2]
A.V. Prybyla, *Cand. Sc (Phys &Math)* [1,2]
I.A. Konstantynovych, *Cand. Sc (Phys &Math)*[1,2]
V.V. Boychuk [2]

[1]Institute of Thermoelectricity of the NAS and MES of Ukraine, 1 Nauky str., Chernivtsi, 58029, Ukraine;
[2] Yuriy Fedkovych Chernivtsi National University, 2 Kotsiubynskyi str., Chernivtsi, 58000, Ukraine
e-mail: anatych@gmail.com

RESULTS OF EXPERIMENTAL RESEARCH ON THERMOELECTRIC MEDICAL HEAT FLOW SENSORS

The paper presents the results of experimental studies and medical tests of local heat release of the human body using a thermoelectric medical heat flow sensor. The study was conducted in the intensive care and surgical departments of the Vyzhnytskyi Central District Hospital. The device uses a multi-element thermoelectric sensor with high sensitivity and accuracy in a wide temperature range. Medical tests have confirmed that inflammatory processes are accompanied by increased heat release in certain areas, even if the general body temperature remains normal. At the same time, with oncological diseases and thrombosis, there is a reduced heat release in the corresponding parts of the body. The obtained results show the potential of using thermoelectric heat flow sensors for early diagnostics of various pathological conditions, including inflammation and oncological processes. The introduction of thermoelectric heat meters into medical practice will provide an accessible and effective tool for detecting diseases at early stages, which will significantly simplify diagnostic procedures and increase their effectiveness.
Key words: heat flow sensor, thermoelectric heat meter, local heat release, diagnostics of diseases, thermoelectric sensor, body heat release, early diagnostics, inflammatory processes, oncological diseases.

Introduction

The human body has its own thermoregulation system capable of maintaining a stable body temperature regardless of external or internal changes. This creates conditions in which the general body temperature is not always an indicator of existing pathological processes. For example, local inflammatory processes may not lead to an increase in the general body temperature due to the active work of the body's thermoregulatory devices, which is why such conditions may remain hidden during routine temperature measurements. However, these processes are accompanied by increased local thermal release, which can be easily detected using superconductor thermoelectric heat flow sensors [1–3]. These devices are distinguished by high accuracy in measured heat flows and are widely used in medical diagnostics.

In Ukraine, cancer is one of the main causes of mortality among the population. According to the National Cancer Registry of Ukraine, there has been an increase in the incidence of cancer in recent years. In particular, in 2023, more than 200,000 new cases of cancer diagnosis were registered, which shows an increasing trend. The most common types of cancer include breast cancer, lung cancer, stomach cancer, and prostate cancer.

Mortality from oncological diseases in Ukraine remains high (Fig. 1), which is due to insufficient early diagnostics and limited access to modern treatment methods. The survival rate of patients depends on the stage of the disease at the time of diagnostics. Early diagnostics significantly increases the chances of successful treatment and improves the prognosis.

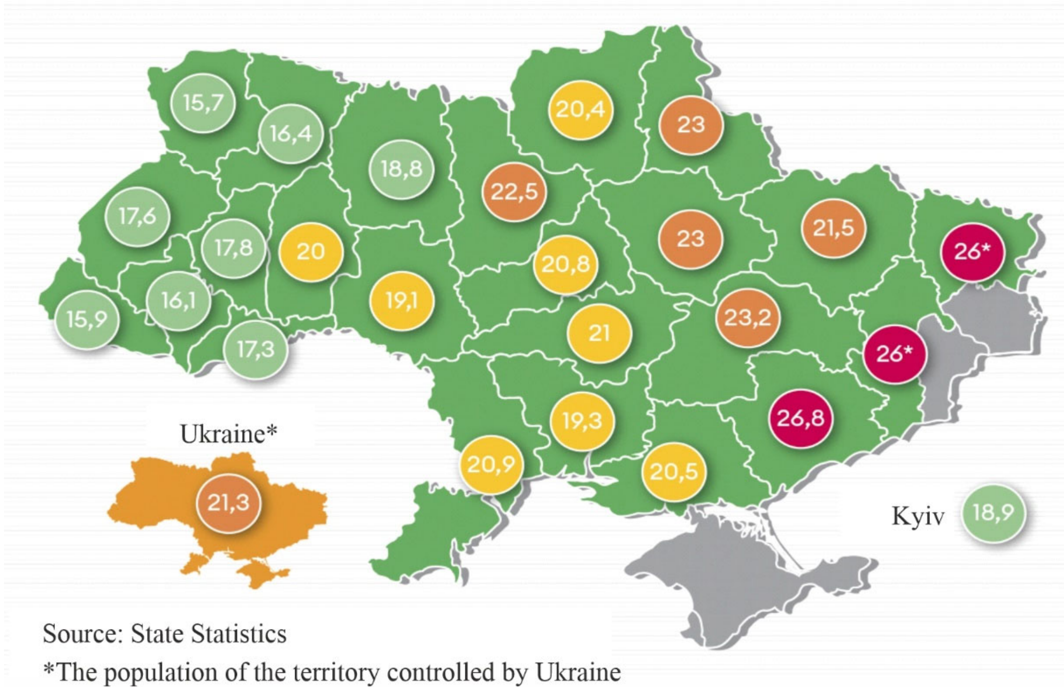

Fig. 1. The number of deaths from oncological diseases in Ukraine per 10,000 population in 2020.

The importance of early diagnostics cannot be overstated. Timely detection of oncological diseases allows us to prevent the progression of the disease, apply effective treatment methods and reduce mortality. To achieve these goals, it is necessary to improve screening methods, raise awareness among the population and ensure access to quality medical services.

Considering the above, constant improvement of the system of diagnostics and treatment of oncological diseases is critically important for improving the general situation in medical diagnostics in Ukraine.

Analysis of the literature. The paper [4] presents the development of a highly sensitive thermoelectric semiconductor heat flow sensor, specially created for medical and biological research, in particular, for measuring heat flows from the surface of the human body. This paper presents the results of using such sensors for the diagnostics and treatment of joint diseases and establishes that it is the heat flow density that is the key parameter that best reflects the degree of expression of inflammatory processes in the human body.

In addition, a heat meter designed to detect oncological diseases of the mammary glands was developed in [5, 6]. Such a device allows diagnosing tumors at early stages, thanks to the analysis of changes in the heat production of mammary gland tissue. Also, a medical thermoelectric heat meter [7] was developed at the Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine, which is used to measure the density of heat flow from the body surface in order to detect inflammatory processes, assess the state of the body in extreme conditions and determine the permissible level of physical activity.

The accuracy and speed of recording signals from thermoelectric sensors are key factors in measuring heat flows from the human body using medical heat meters [8 – 12]. In [13 – 15], modern electronic systems for recording signals from such sensors were developed, which allows monitoring the thermal state of the body in real time.

Studies of the influence of thermoelectric heat meters on the recording of heat flows from human skin were conducted in [16 – 21]. Using computer simulation, the features of using these devices to study local heat release in real operating conditions were analyzed [22, 23]. In [24 – 29], modern multichannel thermoelectric devices were developed that allow real-time measurement of both the temperature and the density of heat flows of the human body, and a method for calibrating thermoelectric sensors for medical purposes was presented [30 – 32].

However, to date, the correlation between the readings of thermoelectric heat flow sensors and the general state of human health has not been sufficiently studied. Therefore, the purpose of this work is to determine the local heat release of the human body using a thermoelectric heat meter for early diagnostics of diseases.

1. Method of measurement

Gradient semiconductor heat flow sensors, which work on the basis of the "auxiliary wall" principle [1, 2] (Fig. 2), are actively used to determine the heat release of the object under study.

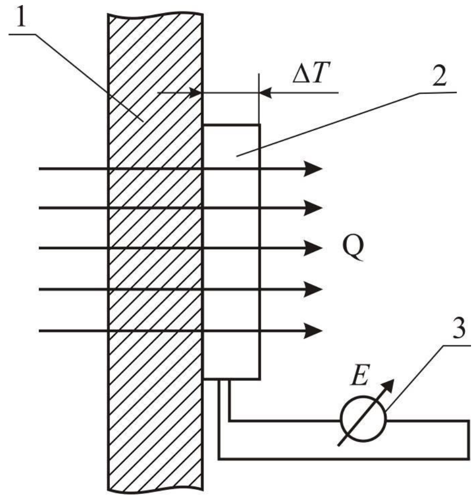

Fig. 2. "Auxiliary wall" method:
1 – surface under study, 2 – gradient heat meter; 3 – galvanometer.

This method consists in measuring the change in temperature ΔT along the heat flow Q on the "auxiliary plane" (plate) located on the surface of the object under study. Due to the Seebeck effect, a thermoelectric power E arises in the thermopile used as an "auxiliary wall", proportional to the temperature difference between its faces. This allows the thermopile to be pre-calibrated and the thermoelectric power value to be used to determine the heat flow density.

The temperature distribution $T(r)$ in the thermoelements of the auxiliary plate can be found by solving the differential equation of thermal conductivity in the quasi-stationary approximation, written in the isotropic situation for the legs of n- and p-type [1, 2]:

$$\nabla(\kappa\nabla T)+\frac{i^2}{\sigma}-Ti\nabla\alpha=0, \quad (1)$$

where κ, σ, α are thermal conductivity, electric conductivity and thermoEMF of legs material, i is electric current density.

The solution of the differential equation (1) makes it possible to determine the temperature distribution $T(r)$ and specific heat flows $q(r)$ from the relationship:

$$q(r)=\alpha iT-\kappa\nabla T=0. \quad (2)$$

The amount of heat flow on the surface of the plate is determined by the ratio:

$$Q=\int_S q(r)ds, \quad (3)$$

where S is free surface of the plate.

Ratios (1) – (3) make it possible to determine the relationship between the heat flow and the temperature distribution on the surface of the plate. In the case of small temperature differences, which are often encountered in engineering applications, the heat flow value is determined by averaging the parameters of relations (1) – (3) from the following equation [1, 2]:

$$Q=\frac{\lambda}{l}\cdot S\cdot\Delta T, \quad (4)$$

where Q is the value of the measured heat flow, λ is the effective coefficient of thermal conductivity of the "wall" – the primary heat flow converter, l is the thickness of the "wall", S is the surface area of the plate, ΔT is the average temperature difference between the heat exchange sides of the "wall", which is measured by the battery of thermoelements of the primary converter.

The quantities λ, l, S have constant values, and the ratio $\frac{\lambda}{l}\cdot S=C$ is a fixed characteristic of the sensor determined through experiment. In this case, the heat flow is calculated by the formula:

$$Q=C\cdot\Delta T. \quad (5)$$

Therefore, this method involves placing a heat flow sensor on the object being studied, obtaining readings from the heat meter in a steady state, and measuring the thermoelectric force (thermoEMF) of the heat meter.

2. Operating principle and structure of a thermoelectric heat flow sensor

The recorder is designed to measure and automatically record temperature and DC voltage, ambient temperature (room temperature). The general appearance of the device is shown in Fig. 3.

When developing the electronic indicator, special attention was paid to its reliability and low cost, which provides the possibility of wide implementation of thermoelectric heat flow sensors in medical practice.

Before carrying out measurements, it is necessary to fulfill the following requirements, in particular, to determine the temperature of the human body T_{body}, °C. For each measurement of the heat flow on the surface of the human body, the same conditions should be ensured:

- ambient temperature T_{room},°C
- vertical or horizontal arrangement of thermoelectric heat flow sensor on the surface of the body;
- body position during measurement.

a) *b)*

Fig. 3. Appearance of heat flow (voltage) and temperature measuring and recording devices. a – measuring device version with a heat flow sensor; b – measuring device version with temperature sensors.

When developing the electronic indicator, special attention was paid to its reliability and economic availability, which contributes to the widespread introduction of thermoelectric heat flow sensors in medicine.

3. Results of experimental studies

Experimental studies of the thermoelectric medical heat flow sensor were carried out in the intensive care and surgical departments of the Vyzhnytskyi Central District Hospital. The results of the conducted studies are presented below in Fig. 4 – 7 for various patient diagnoses.

The first stage of the tests was the study of postoperative processes accompanied by increased values of heat flow density of inflamed areas of the human body. This is especially noticeable when analyzing heat flows on the surface of the human body in the area of the liver when diagnosing a patient with cirrhosis of the liver (ascites) (Fig. 4). It should be noted that the patient's body temperature before and after the operation was $T = 36.6$ °C.

From Fig. 4 it is clear that after the operation the heat release in the liver area stabilized, the inflammatory process stopped and the patient is recovering.

Let us consider in more detail the heat release on the surface of the human body for patient diagnoses – cirrhosis of the liver (ascites) and atrophic cirrhosis of the liver (Fig. 5). The figure shows that heat release in the area of the liver almost did not change with atrophic cirrhosis of the liver.

However, heat release in the intestine and spleen is reduced by 3 – 4 times due to blood stagnation in the portal vein (thrombotic condition).

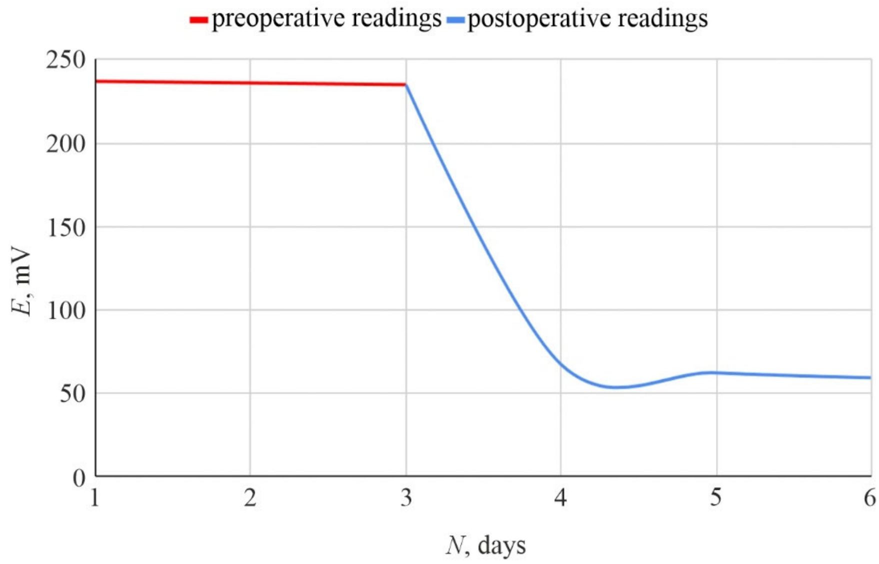

Fig. 4. Results of experimental studies of heat flows of the human body surface in the liver area with a patient diagnosed with liver cirrhosis (ascid).

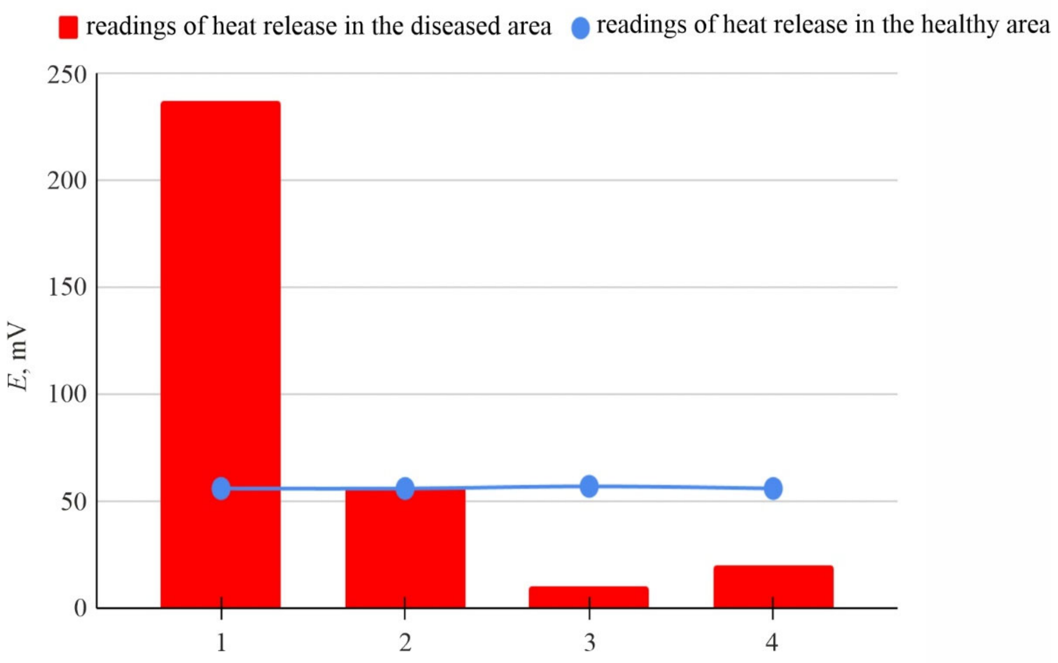

Fig. 5. Results of experimental studies of heat flows of the human body surface with a patient diagnosed with liver cirrhosis: 1 – liver cirrhosis (ascites); 2 – atrophic liver cirrhosis (liver readings); 3 – atrophic liver cirrhosis (intestine readings); 4 – atrophic liver cirrhosis (spleen readings).

Fig. 6 shows a diagram of average readings of a thermoelectric heat flow sensor for healthy areas of the body.

The diagram (Fig. 6) shows that the readings of the thermoelectric heat flow sensor for healthy areas of the body vary within 50 – 70 mV. In some areas, such as the temple, the readings can reach 81 mV. This is due to the presence of the temporal artery, through which a large amount of blood passes, causing intense heat release. However, when measuring the heat flow in the shin and knee area, reduced heat generation was observed, which is probably due to the lower blood supply to these areas.

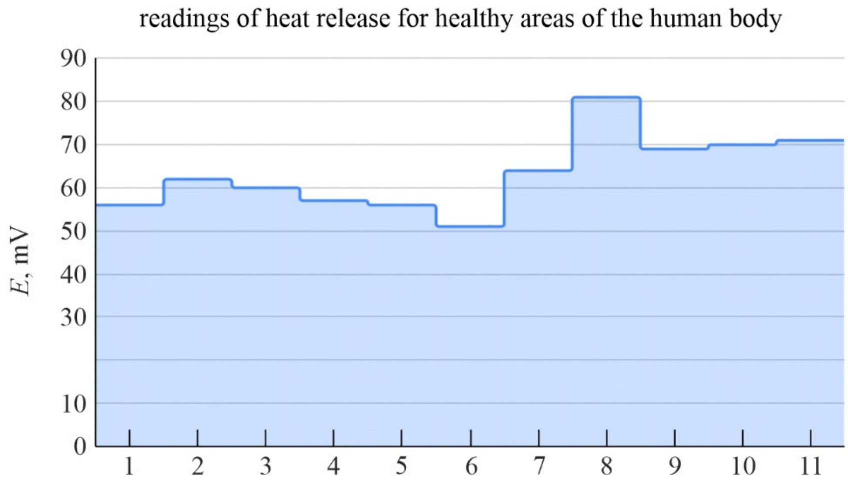

Fig. 6. Average readings of a thermoelectric heat meter for healthy areas of the human body: 1 – liver, 2 – pancreas, 3 – kidneys, 4 – intestines, 5 – spleen, 6 – knee joint, 7 – right shin, 8 – temples, 9 – heart, 10 – mammary gland, 11 – large intestine.

Fig. 7 shows a diagram of average readings of a thermoelectric heat flow sensor for diseased areas of the human body with different patient diagnoses.

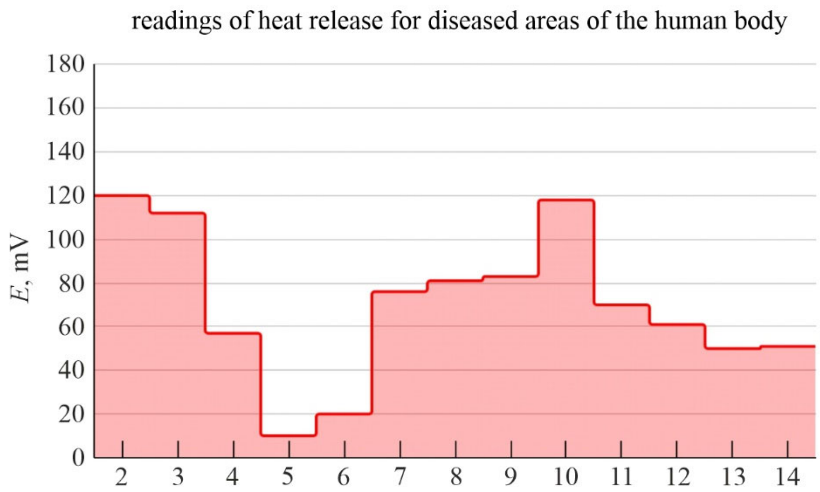

Fig. 7. Average readings of the thermoelectric heat meter for various patient diagnoses: 1 – liver cirrhosis (ascid); 2 – inflammation of the pancreas (pancreatonecrosis); 3 – inflammation of the kidneys (nephritis); 4 – atrophic cirrhosis of the liver (liver readings); 5 – atrophic cirrhosis of the liver (intestine readings); (spleen readings), 7 – rheumatoid arthritis (inflammation of the knee joint), 8 – trauma to the right shin, 9 – post-traumatic phlebothrombosis (concomitant diagnosis – suppurative hematoma on the right leg), 10 – stroke, 1, 12 – heart attack, 13 – benign breast tumor, 14 – tumor of ileocecal angle (readings in the colon area).

Let us consider in more detail the possible reasons for changes in heat release in diseased areas of the human body in various diseases.

In liver cirrhosis (at the ascites stage), the patient's liver enlarges and fluid accumulates in the abdominal cavity. During this, inflammatory reactions occur, resulting in an increase in the heat flow of this area. In nephritis (inflammation of the kidneys) and pancreatic necrosis (inflammation of the pancreas), the interstitial tissue of the kidneys and pancreas is acutely affected, which is also accompanied by a significant increase in the heat release of this area.

A characteristic feature of atrophic liver cirrhosis is that the liver size decreases, and blood stagnation occurs around it in the portal vein system. At the same time, the heat flow of the intestine and spleen decreases several times compared to heat release in a healthy state.

Rheumatoid arthritis (inflammation of the knee joint) is characterized by a chronic inflammatory process of autoimmune nature, the final result of which is ankylosis (i.e. a person loses the ability to move). Naturally, such an inflammatory process is also accompanied by increased values of heat flow density, which has been experimentally confirmed using a thermoelectric medical heat meter.

Posttraumatic phlebothrombosis is a condition of a person after thrombosis. Due to limited accumulation of blood in tissues and formation of a cavity that contains liquid or coagulated blood and accumulation of microbes, such patients develop a suppurating hematoma. During this, inflammatory processes occur, accompanied by increased heat release. It is important to determine the presence of such inflammatory processes in the early stages in order to take priority measures to improve the patient's health.

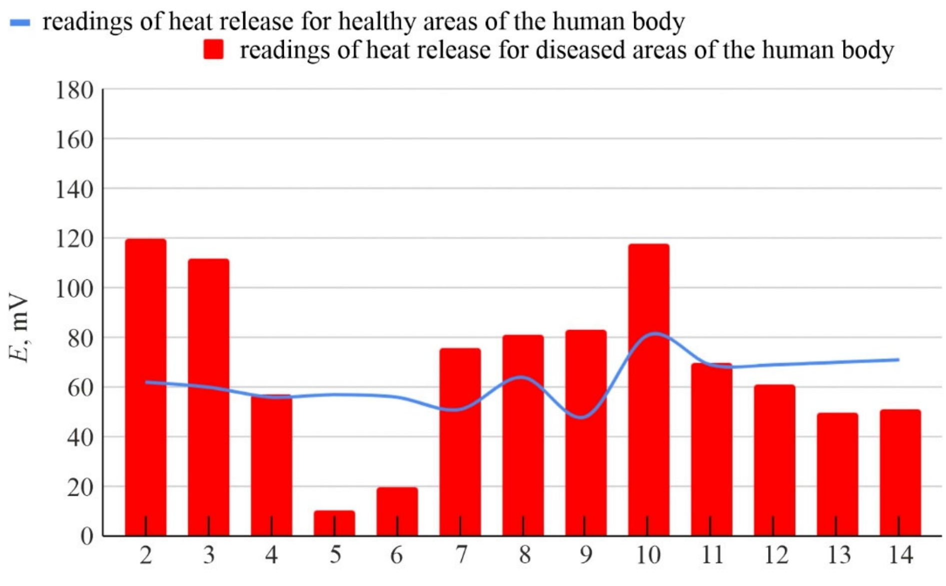

Fig. 8. Average readings of the thermoelectric heat meter for various patient diagnoses: 1 – liver cirrhosis (ascites), 2 – inflammation of the pancreas (pancreatonecrosis), 3 – inflammation of the kidneys (nephritis), 4 – atrophic cirrhosis of the liver (liver readings); 5 – atrophic cirrhosis of the liver (intestine readings), 6 – atrophic cirrhosis of the liver (spleen readings), 7 – rheumatoid arthritis (inflammation of the knee joint), 8 – right leg injury, 9 – post-traumatic phlebothrombosis (concomitant diagnosis – suppurative hematoma on the right leg), 10 – stroke, 11 – angina pectoris (readings in the heart area), 12 – heart attack, 13 – benign breast tumor; 14 – tumor of ileocecal angle (readings in the colon area).

It is known that myocardial infarction is accompanied by a sudden disruption of local cardiac blood circulation. However, it has been experimentally established that during a heart attack, there is no increase in heat release in the heart area. There are also no significant changes in heat generation in the heart area during angina, the symptoms of which are attacks of sudden pain behind the sternum due to acute insufficiency of blood supply to the myocardium. However, during a stroke (cerebral hemorrhage), heat release in the area of a person's temples increases significantly, since cerebral blood circulation is acutely disrupted, which leads to damage to brain tissue and disorders of its functions.

It is interesting that the areas of the human body affected by cancer are characterized by reduced heat release compared to similar healthy areas. For example, an area with a breast tumor (which has the form of a connective tissue tumor of a solid consistency) can have half the heat release. This indicates that, unlike inflammatory processes, cancer diseases are characterized by reduced heat release in the corresponding damaged areas of the human body.

After averaging the readings of the thermoelectric heat meter within each diagnosis, the results of experimental measurements can be presented in the following form (Fig. 8).

When analyzing the diagram shown in Fig. 8, we can conclude that in the presence of inflammatory processes, heat release in diseased areas increases, and in the presence of thrombotic processes and oncological diseases, heat release in the corresponding areas decreases significantly. This is due to a change in the metabolic activity of the affected areas of the human body.

Conclusions

1. Experimental studies and medical tests of the thermoelectric heat flow sensor were carried out in the intensive care and surgical departments of the Vizhnitsa Central District Hospital. It was found that inflammatory processes in the human body are accompanied by increased heat release in the corresponding areas even at normal human body temperature, while the presence of oncological diseases and thrombotic processes are characterized by reduced heat release values.
2. It has been established that thermoelectric heat flow sensors are promising for diagnosis in the early stages of cancer and inflammatory processes in the human body. The implementation of such sensors in medical practice will provide a simple and effective method of diagnosing various human diseases.

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Кобилянський Р.Р., *канд. фіз.-мат. наук* [1,2]
Прибила А.В., *канд. фіз.-мат. наук* [1,2]
Константинович І.А., *канд. фіз.-мат. наук* [1,2]
Бойчук В.В. [2]

[1] Інститут термоелектрики НАН та МОН України,
вул. Науки, 1, Чернівці, 58029, Україна;
[2] Чернівецький національний університет імені Юрія Федьковича,
вул. Коцюбинського 2, Чернівці, 58012, Україна
e-mail: anatych@gmail.com

РЕЗУЛЬТАТИ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ТЕРМОЕЛЕКТРИЧНИХ МЕДИЧНИХ СЕНСОРІВ ТЕПЛОВОГО ПОТОКУ

У роботі представлено результати експериментальних досліджень та медичних випробувань локального тепловиділення людського тіла за допомогою термоелектричного медичного сенсора теплового потоку. Дослідження проведено в реанімаційному та

хірургічному відділеннях Вижницької центральної районної лікарні. Пристрій використовує багатоелементний термоелектричний сенсор з високою чутливістю та точністю в широкому діапазоні температур. Медичні випробування підтвердили, що запальні процеси супроводжуються збільшеним тепловиділенням у певних зонах, навіть якщо загальна температура тіла залишається в нормі. Водночас, при онкологічних захворюваннях та тромбозах спостерігається знижене тепловиділення у відповідних ділянках тіла. Отримані результати демонструють перспективність застосування термоелектричних сенсорів теплового потоку для ранньої діагностики різних патологічних станів, включаючи запалення та онкопроцеси. Впровадження термоелектричних тепломірів у медичну практику забезпечить доступний та ефективний інструмент для виявлення захворювань на ранніх стадіях, що значно спростить діагностичні процедури та підвищить їхню ефективність.
Ключові слова: сенсор теплового потоку, термоелектричний тепломір, локальне тепловиділення, діагностика захворювань, термоелектричний датчик, тепловиділення тіла, рання діагностика, запальні процеси, онкологічні захворювання.

Література

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