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Thermography and Thermometry in Medicine. The Importance and use of Non-invasive Methods in the Diagnostics of Certain Diseases

Thermography and thermometry are modern diagnostic methods that are currently increasingly used in medical research due to their sufficient information content and non-invasiveness. The paper examines the possibilities of thermography in modern medical diagnostics, analyzes the literature on thermographic and thermometric research methods, and identifies the main areas of application of the method in medicine. The biophysical aspects of thermography, physiological and physical factors that influence the formation of thermographic and thermometric diagnostics have been identified.

Key words: temperature, thermography, thermometry, heat flux, infrared radiation, thermal diagnostics.

Introduction

Thermography, thermometry. From the name of this method it follows that the criterion, the main diagnostic parameter, is none other than heat, body temperature, which doctors even under Hippocrates attached great importance to in diagnosing diseases. The great Arab scientist Abu Ali Ibn Sina wrote that "fever" is a symptom of diseases that occur for a variety of reasons.

Thermography and thermometry as diagnostic methods allow determining the temperature of biological tissue by thermal radiation, by analyzing the temperature changes of the corresponding areas of biological tissue [1]. This method is minimally invasive and very often remote, that is, it can be used in cases of diagnostics and treatment of a large number of diseases, even those when other research methods are simply impossible, that is why it is used quite often, as a result of which it has become so popular and relevant. The main areas of use of the thermography method in medicine are oncology, angiology, gastroenterology, and rheumatology. It is possible to formulate the main directions of thermographic and thermometric research methods in medicine: studying the thermographic picture of various

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areas of the body in healthy people; primary selection of patients, based on the dynamics of thermographic examinations; identification of the dynamics of pathological processes: progression of tumor growth exacerbation and remission of chronic diseases, improvement of the condition under the influence of medications; assessment of innervation and blood flow in the study area; monitoring the results of coronary circulation correction during surgical interventions; express method for diagnosing emergency conditions [1-3].

Biophysical aspects of thermography and thermometry

The thermal radiation of the human body lies in the infrared region of the spectrum with an absorption coefficient of 0.90. Therefore, the law for a completely black body (with an absorption coefficient of 1) can be applied to the infrared radiation of the human body, with a known margin of error.

According to the Stefan-Boltzmann law, the energy luminosity of an absolutely black body is directly proportional to the fourth power of its absolute temperature (in this case, we mean energy luminosity, i.e. the total energy emitted from a unit of surface area per unit of time over all wavelengths at a given temperature).

According to Planck's formula, the distribution of radiation energy over wavelengths is the same for all absolutely black bodies and is expressed by a curve that has a maximum (for absolutely black bodies with $T = 300°\mathrm{K}$ (27 °C), the position of the spectral maximum corresponds to a wavelength of 9.66 μm) [1, 3].

The wavelength corresponding to the maximum radiation energy of absolutely black bodies is determined by Wien's law, according to which this maximum shifts towards the short-wave part of the spectrum with a rise in temperature.

Therefore, infrared radiation is proportional to the fourth power of the absolute temperature of the human body. The body temperature remains constant within extremely narrow temperature limits and is equal to 36°±1 with a certain daily rhythm [1, 3, 4].

Constancy of body temperature is achieved due to the existence of a thermal balance in the body, caused by the heat accumulated by the body, the heat production of metabolism, radiation heat loss, evaporation, convective heat transfer and energy spent on performing mechanical work [2]. The body temperature field is formed due to physical and physiological factors.

The physical factors that influence the formation of a thermographic picture are determined by:

1. Convection – a value determined by heat loss at an air velocity of 1 m/s. Convective heat transfer is also characterized by the Grashof number – a parameter that relates the velocity and mass of the air flow to the skin temperature, the kinematic viscosity of the air. Convection is minimal at an air velocity of 0.1 m/s (natural convection). In thermographic studies, it is recommended to approach this value [3].

2. Evaporation – heat loss through evaporation, which is determined by the degree of skin moisture, the saturated vapor pressure at a given skin temperature, and the water vapor pressure in the ambient air [3].

3. Radiation – radiant energy, which is proportional to the emissivity of the skin and the fourth power of its absolute temperature. It depends on heat loss, skin temperature, and ambient temperature [3].

Physiological factors that influence the formation of a thermographic picture

In the human body, as a result of exothermic biochemical processes in cells and tissues, as well as due to the release of energy associated with the synthesis of DNA and RNA, a large amount of heat is produced (50 – 100 kcal/gram) [6, 9]. This heat is distributed inside the body by the circulation of blood and lymph. Blood circulation equalizes temperature gradients. Blood is capable of intensive heat exchange between the central and peripheral areas of the body due to its high thermal conductivity which does not change with the nature of movement. Venous blood is the warmest. It cools little in the lungs and, spreading throughout the large blood circulation, maintains the optimal temperature of tissues, organs and systems. The temperature of the blood flowing through the skin vessels decreases by 2-3 degrees. In pathology, the circulatory system is disrupted. Changes occur because increased metabolism, for example, in the area of the inflammatory process increases blood perfusion and, accordingly, thermal conductivity, which is reflected on the thermogram by the appearance of a hyperthermia area.

Skin temperature has its own clearly defined topography [1, 3, 7]. The lowest temperature (23 – 30 °C) is found in the distal extremities, the tip of the nose, and the auricles. The highest temperature is in the armpits and axillary areas, in the perineum, neck area, cheeks. Daily fluctuations in skin temperature average 0.1 – 0.3 °C and depend on a number of physiological and psychosomatic factors.

In a healthy person, the temperature distribution is symmetrical about the midline of the body. Violation of this symmetry is the main criterion for thermographic and thermometric diagnostics of diseases. The quantitative expression of thermal asymmetry is the magnitude of the temperature difference.

The main causes of temperature asymmetry are:

1.Congenital vascular pathology, including vascular tumors.

2.Vegetative disorders leading to disruption of the regulation of vascular tone.

3.Circulatory disorders due to trauma, thrombosis, embolism, vascular sclerosis.

4. Venous stasis, retrograde blood flow.

5. Inflammatory processes, tumors, which cause increased metabolic processes [2].

6. Changes in tissue thermal conductivity due to edema, increase or decrease in the subcutaneous fat layer [1, 4].

It is necessary to note two main points of view on the causes of local hyperthermia: it is believed that the increase in temperature of the body area in malignant tumors is caused by an increase in the metabolism of malignant cells (R. Lawson), the other point is that the cause of hyperthermia is, first of all, an increase in the dynamics of blood circulation (V.L. Tabern, A. Dol).

Thermal asymmetry, in itself, is not an unconditional factor of pathology. There is the so-called physiological thermal asymmetry, which differs from pathological in a smaller temperature difference for each individual part of the body. Speaking about different variations of skin temperature in normal and pathological conditions, it is necessary to remember that all these processes occur in the whole organism and are under the control of neurohumoral regulation. Thermoregulatory reactions in the human body are controlled by the hypothalamus [1, 3, 7, 14]. Reactions that increase heat loss are regulated by the anterior hypothalamus (they cause deep breathing, sweating, and peripheral vasodilatation). Reactions aimed at the production and preservation of heat (vasoconstriction) are due to the action of the posterior hypothalamus. The occurrence of certain reactions is associated with the stimulation of two groups of receptors: peripheral and central (located in the hypothalamus itself and near it). From them, impulses spread along afferent pathways to the hypothalamus, and from there, along somatic and autonomic pathways, they spread to the executive organs, regulating sweating, vascular and muscle tone.

Studies have established a relation between specific areas of the cerebral cortex and corresponding areas of the skin. Cortical actions can, under certain conditions, cause inadequate vascular reactions. Thus, in the inhibited state of the higher parts of the central nervous system, thermoregulatory reactions are activated, directed against overheating. On the contrary, in the excited state of the higher parts of the central nervous system, reactions are provoked, which cause an increase in heat-generating processes. In addition to central mechanisms, there are also local thermoregulation mechanisms. The skin, thanks to a dense network of capillaries, which are under the control of the autonomic nervous system and are able to significantly expand or completely close the lumen of the vessels, and change its size within wide limits, is a very good heat exchange organ and regulator of body temperature [1, 3, 5, 6].

Nervous connections between the skin and internal organs are realized in the form of viscerocutaneous reflexes, proceeding according to the type of axon-reflexes, segmental or projection reflexes. Impulses from internal organs are directed along afferent pathways to the anterior and lateral horns of the spinal cord, and from there are transmitted to the surface through effector sympathetic preganglionic and postganglionic fibers. These connections are most clearly manifested in pathology, when persistent skin zones with altered sensitivity, trophism, impaired vascular, secretory and other reactions arise. Under the influence of various factors in humans (along with congenital segmental viscerodermal connections), an additional system of projection skin-visceral relationships with numerous, including vascular and trophic processes is formed [1 – 3, 9]. As a result, human skin turns into a wide zone, reflecting to one degree or another the processes occurring in the internal organs [1, 3, 8],

Skin temperature may have a mosaic character due to temperature heterogeneities of internal organs or even individual areas of a particular organ. It is necessary to pay attention to the high thermal insulating properties of the skin, which, due to the numerous subcutaneous capillary network, prevents the contact transfer of thermal action inside the body and in the reverse direction. All these general and local mechanisms of thermoregulation have an impact on physical and physiological factors, ultimately determining the features of skin thermal radiation, and accordingly, the nature of the thermographic picture [3, 4, 11].

Among the methods of thermal diagnostics, it is necessary to highlight infrared thermography [4], which is based on non-contact remote registration of the thermotopography of the skin of the human body by its own thermal radiation, caused by various physiological and biochemical processes in the tissues of the body. The main advantages of infrared thermography are as follows:

1. Complete harmlessness and no contraindications to examinations.
2. The human body is not exposed to radiation or damage, so multiple examinations are possible in a short period of time.
3. Complete cleanliness during operation or storage of thermographic equipment.
4. Quite accurate topical diagnostics of foci of inflammation, neoplasms, necrosis and other local manifestations of various diseases.
5. The possibility of simultaneous, sequential examination of all organs and systems of the human body.
6. The compatibility with other diagnostic methods [1, 3, 12, 15].

The determination of the difference in body surface temperature during thermography is carried out by two methods: in one case, liquid crystal indicators are used, the optical properties of which are very sensitive to small temperature changes, the other method is technical and based on the use of thermal imagers. The thermography method is objective, simple and absolutely harmless, with no contraindications [3, 5]. Therefore, in this case, the use of thermoelectric modules becomes very important and relevant, allowing for high-quality, prompt, non-invasive measurement of temperature differences in the individual areas of the skin, promptly carrying out diagnostic operations to identify possible human diseases.

Infrared remote thermography and thermometry [4, 6, 16] are the most common thermography methods that provide an image of the thermal relief of the body surface and the temperature in any area. This technique makes it possible to record violations of infrared radiation in cases of: changes in vascular tone (disorders of vegetative innervation, reflex changes in tone); local circulatory disorders (injuries, thrombosis, vascular sclerosis); venous blood flow disorders (stasis, backflow of blood in case of insufficiency of venous valves); local changes in heat production (inflammatory foci, tumors); changes in tissue thermal conductivity (edema, tissue compaction, changes in fat content) [1, 4].

Cardiology and angiology. Today, thermographic studies have found use in the diagnosis of vascular pathology (diagnosis of acute and chronic diseases of arteries and veins, chronic and venous insufficiency, varicose veins, arteriovenous anastomoses, aneurysms of the arteries of the extremities, diabetic angiopathies). In healthy people, the thermographic picture of the lower extremities is characterized by a symmetrical temperature distribution, and in their diseases, thermal asymmetry occurs, primarily in the distal parts of the lower extremities. With the help of thermographic examination, it is possible to detect the presence of superficial varicose veins [1, 9]. The method of their detection is based on the fact that in case of insufficiency of the perforating vein valves, there is a reverse flow of blood from the deep veins to the superficial ones. Since the temperature in the deep veins is higher, the result is an increase in the temperature of the skin areas adjacent to the superficial veins [1, 2, 18].

Thermography is used to assess the activity of vasodilators in the conservative treatment of limb diseases, as well as to determine the impact of surgical interventions on the dynamics of blood circulation [3, 9]. In the latter case, thermography is used to assess the degree of restoration of blood circulation after bypass or prosthetic replacement of the affected vessel. The role of the method in assessing blood flow after surgery such as deep femoral artery plasty [4] is very important (this is due to the fact that when the superficial femoral artery is damaged, there is no pulse in the arteries of the feet and it is impossible to palpate to judge the restoration of blood circulation in this case). Thermography is effective in monitoring the effectiveness of laser therapy in impaired arterial blood circulation of the extremities. A significant place in the thermographic diagnosis of vascular pathology is occupied by the study of diabetic angiopathies (obliterating atherosclerosis, diabetic microangiopathy) [3]. Vascular lesions of the lower extremities are mainly diagnosed by thermography from the moment of the appearance of clinical symptoms, most often when the capillaries are affected by a specific diabetic process and atherosclerosis of medium and large arterial vessels is combined [3, 5].

The thermography method can also be used to assess the effectiveness of drugs used for peripheral circulatory disorders, diabetic polyneuritis. Fig. 1 and Fig. 2 below show an illustrative use of the thermography method. The diagrams show how informative and useful this remote method of measurements and diagnostics is.

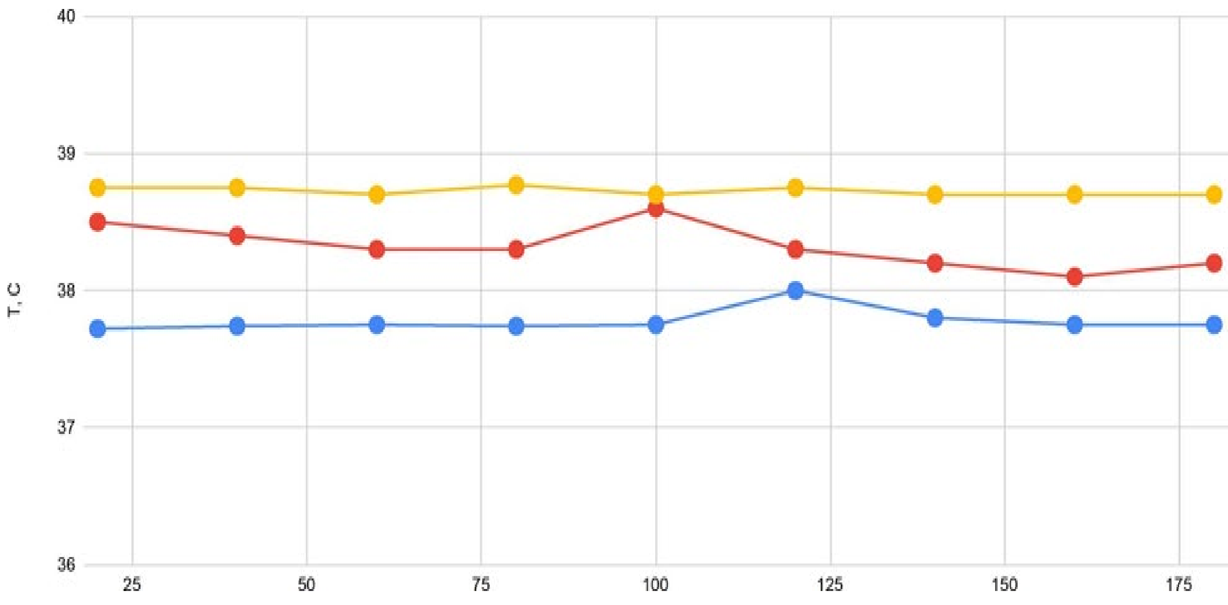

Fig. 1. Temporal change in temperature of the left lung (as the more affected) during the period of drug treatment. Total study time is 3 hours, with an interval of 20 minutes, comparative graph is 3 days (bottom curve is the 3rd day, middle

Thermography itself has proven to be an effective method in the differential diagnosis of renovascular hypertension. It can help resolve the question of what is causing the hypertension: narrowing (occlusion) of the renal artery, an adrenal tumor, or the hypertension itself. In case of narrowing or occlusion of the renal artery, asymmetry of the temperature topography of the kidney area is observed with a decrease in temperature on the affected side; in case of tumor processes of the adrenal glands, hyperthermia of the corresponding area is observed, associated with increased metabolism of degenerated tissues; in case of hypertension, no changes in temperature distribution are detected.

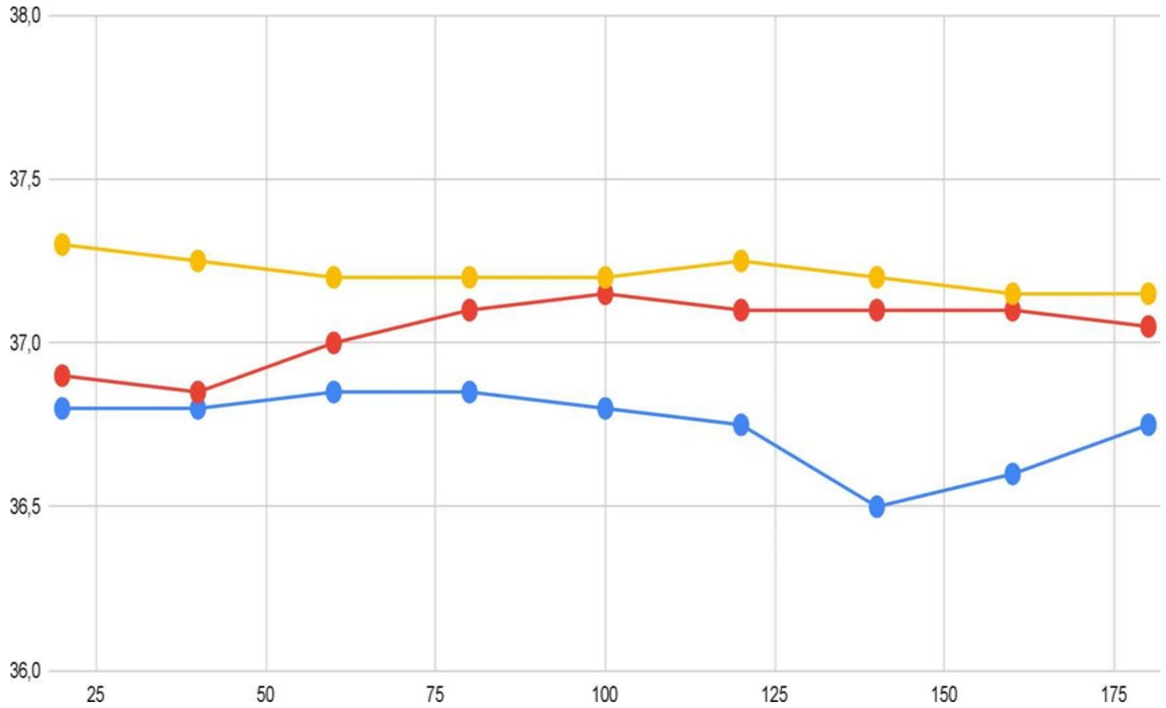

Fig. 2. Rheumatoid arthritis of the joints. Temporal change in temperature during medical treatment. Total study time is 3 hours with an interval of 10 minutes. Comparative graph is 5 days. Lower curve is the 5th day of the study; middle curve is the 3rd day of the study; upper curve is the 1st day of the study

Pulmonology. Since the lungs are protected by a kind of barrier – the chest, which does not allow thermal energy coming from the internal organs to pass through, the result of thermographic studies largely depends on many conditions: the patient's age, the characteristics of the tumor's blood supply, the condition of the lung tissue surrounding the tumor (presence or absence of emphysema), the presence of fluid in the pleural area (cancerous pleurisy, reflex effects on the vessels). Currently, thermosemiotics of lung cancer and benign tumors has been developed. The latter are distinguished by clearer boundaries of the luminescence area and a smaller temperature difference (up to 1.5 °C instead of 2 – 3 °C in malignant neoplasms) [19, 21]. Each of the lung diseases has its own specific signs on thermograms. For pneumonia, the homogeneity of the inflammatory process area is characteristic, for pulmonary emphysema - fine-grained hyperthermia, in patients with acute pneumonia in the initial stage, thermal asymmetry of the thermal field is detected, which is expressed in the appearance of a hyperthermia zone.

Oncology [2, 3, 20]. Currently, thermosemiotics of malignant breast processes has been qualitatively developed. The main thermographic signs of pathologies include local hyperthermia, asymmetry of the image structure, hyperthermia in the areola area, and deformation of the breast outline. The temperature difference at symmetrical points exceeding 1o C makes it possible to thermographically diagnose breast cancer (in the absence of acute purulent-inflammatory diseases). To improve the quality of thermographic diagnostics, functional medicinal, thermal and cold tests are used [1]. In order to enhance thermographic infrared radiation, it is realistic to use the glucose loading technique (malignant cells capture glucose and their energy balance increases, which is manifested by hyperthermia on the thermogram). In malignant tumors, a sharp increase in thermal asymmetry by 0.7 – 3 °C is noted [2, 4, 22].

Liver and biliary tract diseases. The most convincing thermographic picture is formed in chronic cholecystitis, secondary pancreatitis, which is expressed by a clear area of pronounced thermal asymmetry. Thermographic studies in diseases of the liver and biliary tract allow a deeper assessment of the nature of the inflammatory process, its localization and severity in patients with cholecystitis and chronic hepatitis in the acute phase [1, 2].

Arthrology. Thermographic studies are also effectively used in the diagnosis of bone and joint lesions. A thermographic sign of rheumatoid arthritis is joint hyperthermia [1], which reliably indicates the presence of inflammation. The degree of intensity of this hyperthermia is directly proportional to the stage of development of the disease [1-3, 23]. There are also a number of joint diseases in which the pathological process is characterized by the appearance of areas of hypothermia on the thermographic picture. These include ankylosing spondylitis, various deforming arthrosis, scleroderma.

In conclusion, it should be emphasized that thermography is successfully used for:

a) differential diagnostics of various thyroid diseases;

b) detection of inflammatory processes in the kidneys (pyelonephritis), malignant tumors of the renal parenchyma;

c) detection of inflammatory processes in the kidneys (pyelonephritis), malignant tumors of the renal parenchyma;

d) assessing the effectiveness of anti-inflammatory therapy and determining the optimal dose of drugs.

Conclusion

Non-invasive diagnostic methods such as thermography and thermometry significantly facilitate the differential diagnosis of cardiovascular diseases and provide objective data on the state of the autonomic nervous system. The capabilities of thermography are not limited to the detection of various diseases, but in some cases they also allow us to establish the etiology of the pathological process. Thermography makes it possible to increase the reliability of the diagnosis of the disease, obtain a true picture of the distribution of heat on the skin surface, determine the shape and area of the area with impaired blood circulation, and observe the dynamics of the intensity of infrared radiation during functional and drug tests. Using the method, it is possible to conclude about the presence of inflammatory processes in the vascular bed and functional changes in blood flow, and to carry out early diagnostics of vascular damage. All this makes thermography and thermometry an integral part of a comprehensive examination of patients with cardiovascular system pathology. Thus, thermography and thermometry are methods of functional diagnostics based on the registration of infrared radiation of the human body. The distribution and intensity of thermal radiation are normally determined by the peculiarities of physiological processes occurring in the body, both in superficial and deep tissues and organs. Various pathological conditions are characterized by thermal asymmetry and the presence of a temperature gradient between the zone of increased and decreased radiation, which is reflected in the thermographic image. This fact has important diagnostic and practical significance, as confirmed by numerous clinical studies.

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Термографія та термометрія в медицині. Значення та використання неінвазивних методів при діагностиці низки захворювань

Термографія та термометрія – сучасні діагностичні методи, які на даний час все більше застосовуються в медичних дослідженнях у зв`язку з достатньою інформативністю та неінвазивністю. У роботі розглянуто можливості термографії в сучасній медичній діагностиці, проведений аналіз літератури на тему термографічних та термометричних методів дослідження, визначено основні напрямки застосування методу в медицині. Визначено біофізичні аспекти термографії, фізіологічні та фізичні фактори, які впливають на формування термографічної та термометричної діагностики.

Ключові слова: температура, термографія, термометрія, тепловий потік, інфрачервоне випромінювання, термодіагностика.

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