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APPLICATION OF THE INFRARED THERMOGRAPHY METHOD IN DIAGNOSIS OF RAYNAUD`S PHENOMENON

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Ключові слова: *феномен Рейно, термографія, градієнт температури, супутні захворювання, цукровий діабет*

Abstract. Application of the infrared thermography method in diagnosis of Raynaud`s phenomenon. Zabolotnyi D.I., Loboda T.V., Dunaievskyi V.I., Kotovskyi V.Y., Timofeiev V.I., Nazarchuk S.S. *The development of modern diagnostic medicine, the important task of which is the use of non-invasive methods for detecting a disease without impact of radiation exposure, has led to the spread of the method of infrared thermography, which allows to quickly and informatively identify pathological conditions of a person within a single examination. The main complaints characteristic of Raynaud's phenomenon are associated with cold, hyperemia, edema, and a feeling of paresthesia in the limbs. A significant number of scientific works have been devoted to the study of the Raynaud's phenomenon, where basically, examples of manifestations of Raynaud's phenomenon are given in the form of a violation of the microcirculation of the distal parts of limbs. Comprehensive studies of the combination of Raynaud's phenomenon with concomitant diseases, according to the authors, are insufficiently covered. The application of sophisticated modern laboratory diagnostic methods to detect this disease is nonspecific and burdensome for the patient. Thermographic diagnostics within one examination reveals both the presence of signs of Raynaud's phenomenon and concomitant somatic diseases. This paper presents the results of many years' thermographic research, demonstrating the variety of manifestations of the Raynaud's phenomenon. For the first time, it has been shown that patients with signs of Raynaud's phenomenon, as a rule, have concomitant somatic diseases, which should be the subject of research of specialists in different medical fields to determine the relationship of Raynaud's phenomenon with the identified diseases. The results of visualization of thermoasymmetries of the skin of various pathological conditions during a complex thermographic examination were obtained, which greatly simplify the diagnostic search and understanding the complexity and danger of Raynaud's phenomenon. Of particular importance are the results of work for the differential diagnosis of complications of diabetes mellitus – diabetic foot syndrome. The paper presents some results of thermographic examinations of patients with signs of Raynaud's phenomenon and identified pathological changes in the body.*

Реферат. Застосування методу інфрачервоної термографії в діагностиці феномену Рейно. Заболотний Д.І., Лобода Т.В., Дунаєвський В.І., Котовський В.Й., Тимофеєв В.І., Назарчук С.С. *Розвиток сучасної діагностичної медицини, важливим завданням якої є застосування неінвазивних методів виявлення захворювання без впливу променевого навантаження, привів до поширення методу інфрачервоної термографії, який дозволяє оперативно та інформативно в рамках одного обстеження виявити патологічні стани людини. Основні скарги,*

які викликає феномен Рейно, пов"язані з похолоданням, гіперемією, набряклістю та відчуттям парестезії в кінцівках. Питанню вивчення феномену Рейно присвячена значна кількість наукових праць, у яких, переважно, наведені приклади проявів феномену Рейно у вигляді порушення мікроциркуляції дистальних відділів кінцівок. Комплексні дослідження поєднання феномену Рейно із супутніми захворюваннями, на думку авторів, висвітлені недостатньо. Застосування складних сучасних лабораторно-діагностичних методів для виявлення цього захворювання є неспецифічними та обтяжливими для пацієнта. Термографічна діагностика в межах одного обстеження дозволяє виявити як наявність ознак феномену Рейно, так і супутні соматичні захворювання. У цій роботі представлені результати багаторічних термографічних досліджень, що демонструють різноманітність проявів феномену Рейно. Уперше показано, що в пацієнтів з ознаками феномену Рейно, як правило, спостерігається наявність супутніх соматичних захворювань, які повинні стати предметом дослідження фахівців різних медичних напрямків для визначення взаємозв'язку феномену Рейно з виявленими захворюваннями. Отримані результати візуалізації термоасиметрій шкірного покриву різних патологічних станів під час комплексного термографічного обстеження, які значно спрощують діагностичний пошук та надають розуміння складності й небезпечності феномену Рейно. Особливого значення набувають результати роботи для диференційної діагностики ускладнення цукрового діабету - синдрому діабетичної стопи. У роботі викладені окремі результати термографічних обстежень пацієнтів з ознаками феномену Рейно та виявленими патологічними змінами в організмі.

In the medical literature, Raynaud's phenomenon (RPh) is interpreted as a spasm of small arteries of the distal parts of the limbs, rarely – the tip of the nose, tongue, arterial blood circulation at the level of the finger arteries, which is based on disorders of the regulation of the tone of vessels of the microcirculature [1, 2, 3, 4].

The clinical and medical and social problem of RPh is due to the significant spread of the disease. According to WHO, this disease occurs in 21% of women and 16% of men; the peak incidence occurs in the 2-3 decades of life. Predominantly RPh occurs in young women, while angiospasm is expressed both in the upper and lower limbs, and the pulsation of the main arteries is preserved [2, 5].

The phenomenon was first described by the French physician Maurice Raynaud in 1862 and defined as local limb asphyxia. Subsequently, two options for determining the form of the disease were identified: primary Raynaud's disease (RD) and secondary RPh.

Despite the fact that RPh was discovered more than 100 years ago, clinicians are faced with a growing list of questions regarding the etiology and pathogenetic nature of RPh [6, 7].

In the modern interpretation, the classification of various forms of RPh is divided into a number of signs of local, regional, segmental origin, the combination of RPh with systemic diseases, it is proposed to use the term "Raynaud's syndrome" to interpret vascular diseases, and the term "Raynaud's phenomenon" to interpret various systemic pathologies [8, 9].

At the conference (2011), which was organized by the Vascular Medicine Section of The Royal Society of Medicine, it was recommended to use the term "Raynaud's phenomenon" instead of "Raynaud's syndrome" and "Raynaud's disease" due to the lack of consensus among specialists [3].

According to the classification of the above society, primary and secondary risk factors are distinguished. In the absence of symptoms of the underlying disease, primary RPh is diagnosed, which occurs in approximately 80% of cases and is characterized by the absence of structural changes or minimal damage to the walls of blood vessels.

Secondary RPh is associated with certain diseases, mainly with systemic connective tissue diseases (vasculitis, arteritis), vascular diseases (atherosclerosis, peripheral arterial disease), hematological disorders, and neurovegetative causes. During secondary RPh, changes in small and large vessels occur depending on the disease that caused the aforementioned syndrome [3, 8, 9, 10].

The issue of objective diagnosis of microcirculation disorders at the level of the distal parts of the upper and lower limbs is complicated.

To date, a wide range of modern laboratory and instrumental diagnostic methods are used to examine patients with signs of this pathology: capillaroscopy; laser Doppler flowmetry; ultrasound color Doppler scanning; angiography and magnetic resonance angiography; plethysmography.

Most of the proposed methods for studying microcirculation are nonspecific, burdensome for the patient, and often do not provide an answer to the questions about the cause of the disease. Incorrect diagnosis of the cause of the disease leads to inadequate treatment, severe disability in young patients of working age [6, 12]. Therefore, the development and improvement of diagnostic principles and standards of the disease is an urgent problem in medicine.

Among modern diagnostic methods, infrared thermography (ITh) is the most accessible and quite informative diagnostic method of radiation diagnostics, which allows studying the pathogenetic mechanisms of the development of peripheral vascular disorders [9, 13, 14].

The use of ITh when examining patients makes it possible to objectively confirm the presence of circulatory disorders at the level of the microcirculature and assess its degree. Thermographic

detection of circulatory disorders in the lower limbs in most patients is observed in combination with other risk factors – varicose veins (VrV), the presence of ulcers, macroangiopathy.

Ambiguous conclusions can be drawn in patients with diabetes mellitus (DM). Failure of capillary circulation is one of the leading factors in the development of gross trophic disorders such as diabetic foot syndrome (DFS). If the manifestation of RPh does not have serious consequences, then the microcirculatory circulation disorder in the lower limbs in patients with DM can lead to such a difficult outcome as amputation of the phalanges of the fingers or even the whole foot [15, 16].

The purpose of this work is to provide capabilities of infrared thermography for diagnosing manifestations of RPh in combination with somatic pathologies and local vegetative-vascular disorders.

MATERIALS AND METHODS OF RESEARCH

In this work, we used a domestic thermograph with a matrix photodetector with a temperature sensitivity of 0.07°C, developed by the Institute of Semiconductor Physics V.Ye. Lashkaryova National Academy of Sciences of Ukraine. The observation and control of thermal fields was carried out in the range of 3-5 μm. Before the thermographic examination, the patients did not undergo thermal procedures, they did not take drugs that affect blood circulation and metabolic processes. Patients were forbidden to smoke 4 hours before the examination, as this is important for the study of peripheral blood flow, they were also subject to adaptation within 30 minutes to the conditions of the thermography room where the temperature was maintained at 22.0±1°C. The examination began from the front part and ended with the lower limbs, fixing the thermographic images in the PC memory of the corresponding parts of the body surface. A detailed description of the methodology for conducting thermographic studies is set out in the work [17].

The research was conducted in accordance with the principles of bioethics set out in the WMA Declaration of Helsinki – "Ethical principles for medical research involving human subjects" and "Universal Declaration on Bioethics and Human Rights" (UNESCO).

RESULTS AND DISCUSSION

Fig. 1 shows the classic thermographic visualization of the manifestation of RPh, namely: "cold" tip of the nose (A), circulatory disorders of the distal parts of the upper and lower limbs (B, C, D), which is possibly associated with morphological changes in the autonomic ganglia.

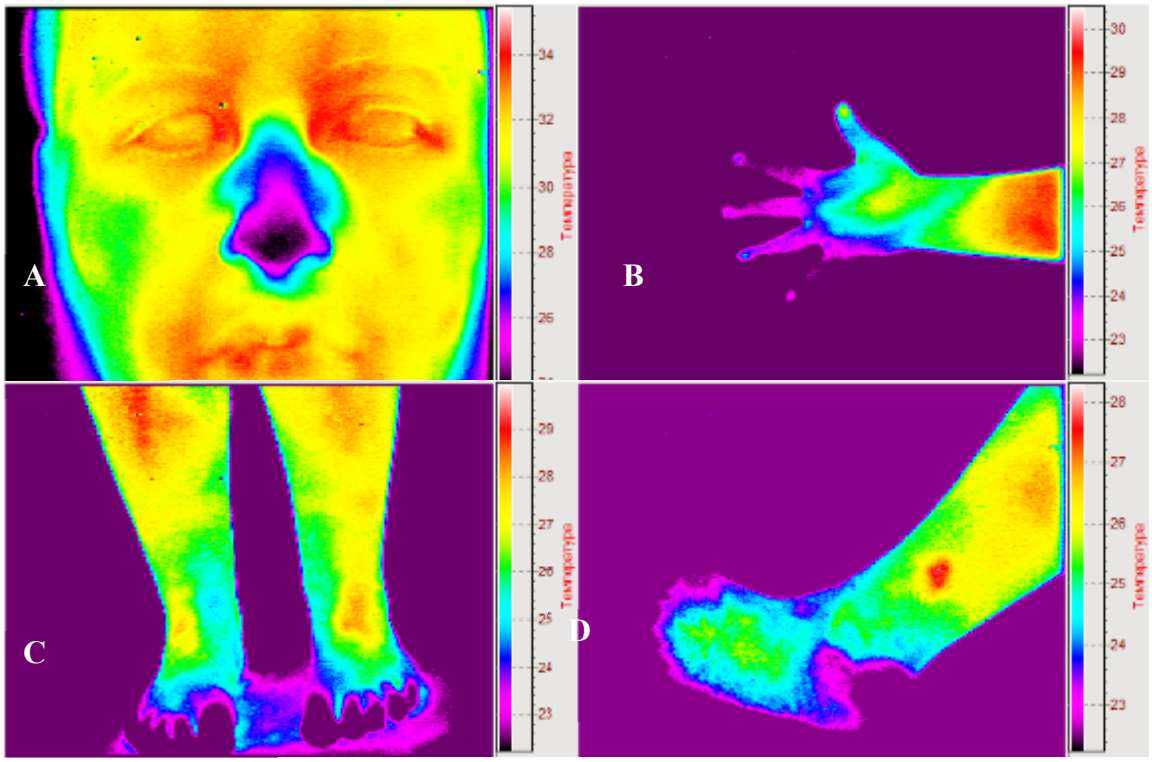

Fig. 1. Classic thermographic image of a patient with RPh.
A typical thermographic picture – decrease in temperature in the zone of the tip of the nose (A), hands and feet (B, C, D)

Depending on the degree of development of the disease, the temperature gradient in cold zones can range from -0.6°C to -5.1°C and higher. The greatest temperature gradient is observed in patients close to the presence of the so-called "thermal amputations" of the hand or lower limb. Based on the processing of the obtained results, the authors proposed to introduce a gradation of the severity of the manifestation of the RPh according to the magnitude of the temperature gradient. The results are presented in the Table.

Degrees of manifestation of Raynaud's phenomenon by the magnitude of the temperature gradient (ΔT°C) and their percentage distribution

Degrees of manifestation of RPh	Temperature gradient (ΔT°C) *	%
1	0.6-1.1	8.4
2	1.2-2.0	15.6
3	2.1-3.0	25.7
4	3.1-5.0	40.2
5	5.1 and more	10.1
Total		100

Note. * The thermographic norm is the value of the temperature gradient, not exceeding 0.5°C.

Based on the thermograms worked out in order to demonstrate the manifestations of 1-5 degrees of RPh, respectively, (Fig. 2) thermograms with circulatory disorders in the distal parts of the upper limbs are given. On the thermograms, there is a gradual increase in the temperature gradient until the so-called "thermal amputation" of the hand appears.

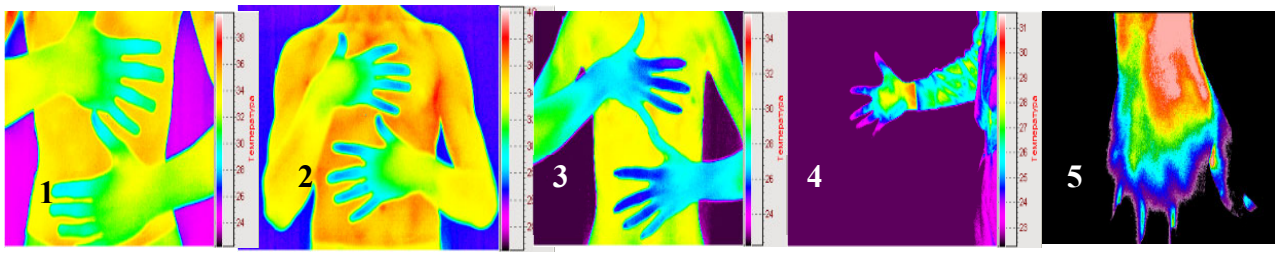

Fig. 2. Thermograms of the distal parts of the upper limbs with different degrees of manifestation of RPh (1 - 1st; 2 - 2nd; 3 - 3rd; 4 - 4th; 5 - 5th)

The nature of the development of risk factors is multifactorial; neurogenic, vascular, mediator, and immune mechanisms play an important role. Local tissue ischemia with the possible development of dystrophy, soft tissue necrosis, which is observed in RPh, can occur either due to a violation of the regulation of vascular functions by the sympathetic nervous system, or due to increased formation of vasoconstrictor substances in the process of autoimmune inflammation [6].

Fig. 3 shows thermograms of patients who, during a thermographic examination with classic symptoms of RPh (A, B, C), had hypothermia of the upper lobe of the thyroid gland (TG) and hyperthermia of the right breast (D, indicated by arrows, respectively); hypothermia in the area of the gastrointestinal tract (GIT) – gastritis, duodenal ulcer according to clinical studies (E); VrV of the left lower limb is represented by uneven saccular dilatation of the veins, accompanied by valve failure and impaired blood flow (F).

Inflammatory process in the maxillary cavities – (Fig. 4A), hypothermia of the projection zone of the left lobe of the thyroid gland (shown by the arrow, B), circulatory disorders in the distal parts of the upper limb (C), VrV of the lower limbs (D, E), thermal amputation of the phalanges of the fingers of the left and right foot (F), observed in the patient with RPh.

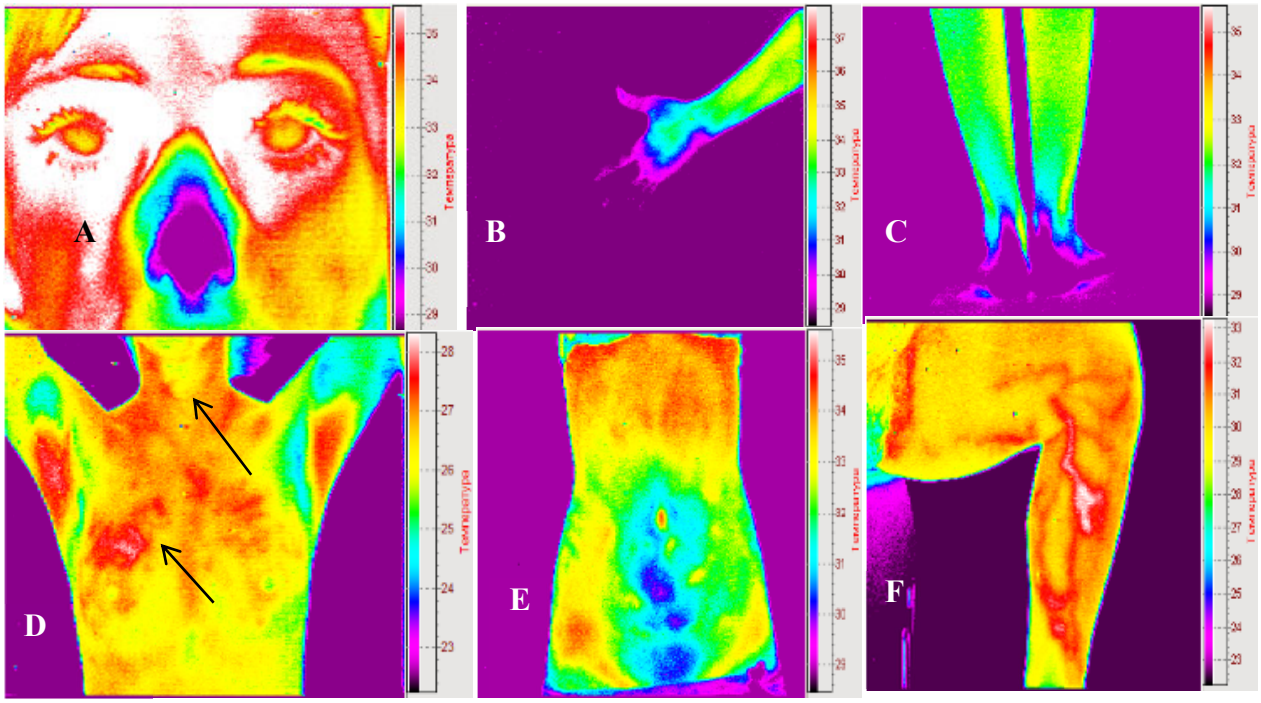

Fig. 3. Detection of pathological changes in the body of patients with signs of risk factors

Vascular component affecting thermographic imaging is one of the main factors affecting the thermal image. The study of temperature changes in the thyroid gland, which has significant vascularization, the pathological process in the maxillary cavities, in the tissues of the lower limbs in VrV, will provide new diagnostic information.

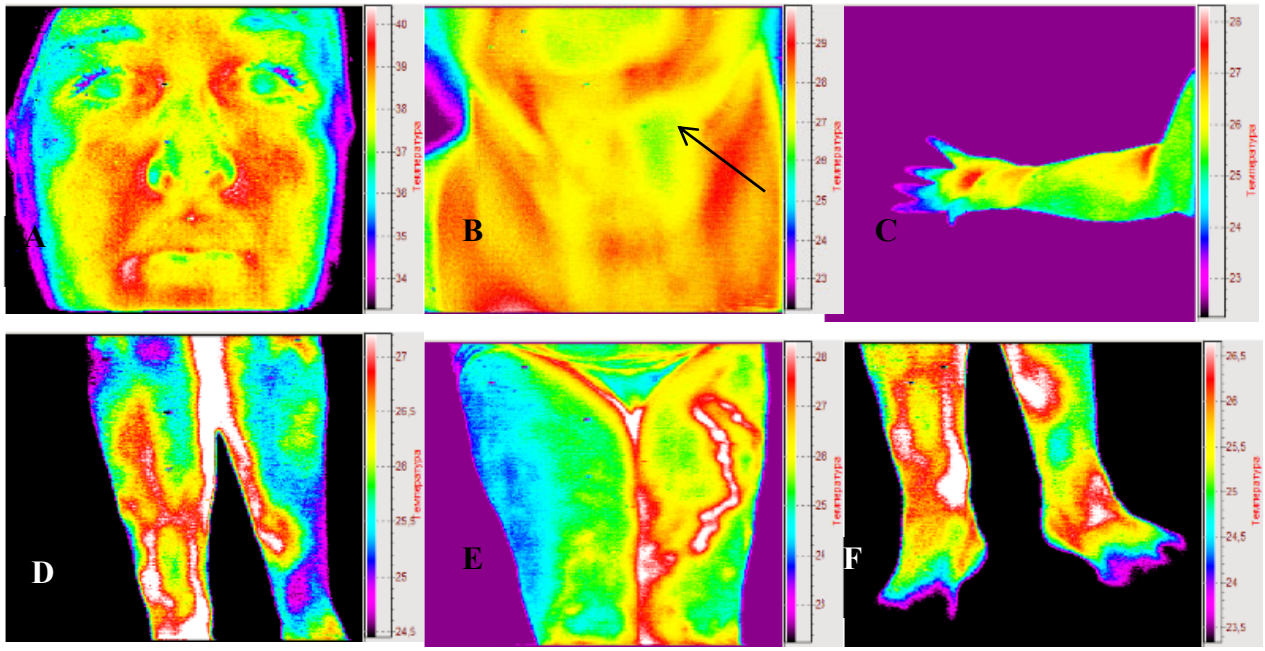

Fig. 4. Concomitant diseases in combination with manifestations of risk factors

The combination of risk factors with concomitant diseases is shown in Fig. 5. The temperature gradient of the tip of the nose is -5.29°C. Fig. 5B, C, D demonstrates the so-called effect of "thermal amputation" of the upper and lower limbs. The zone of hypothermia of the right knee joint is

clearly visualized (Fig. 5E), which indicates functional changes. Pathological changes of the hip joint are shown in Fig. 5F. The temperature gradient in the area is shown by the arrow -1.97°C. Hyperthermia of the upper lobe of the thyroid gland on the left and hyperthermia of the lower lobe of the thyroid gland on the right are shown in Fig. 5G. Temperature gradients in the zones are indicated by arrows 1 and 2 +0.84°C and +1.18°C, respectively. Hyperthermia of the posterior projection of the lungs – thermographic visualization of bronchitis – is shown in Fig. 5H; hypothermia of the left breast (Fig. 5I) is a thermographic visualization of mastopathy manifestations.

Thus, thanks to a comprehensive thermographic examination with minimal costs and the absence of harmful and burdensome radiation exposure, an objective informative model of the state of health has been obtained.

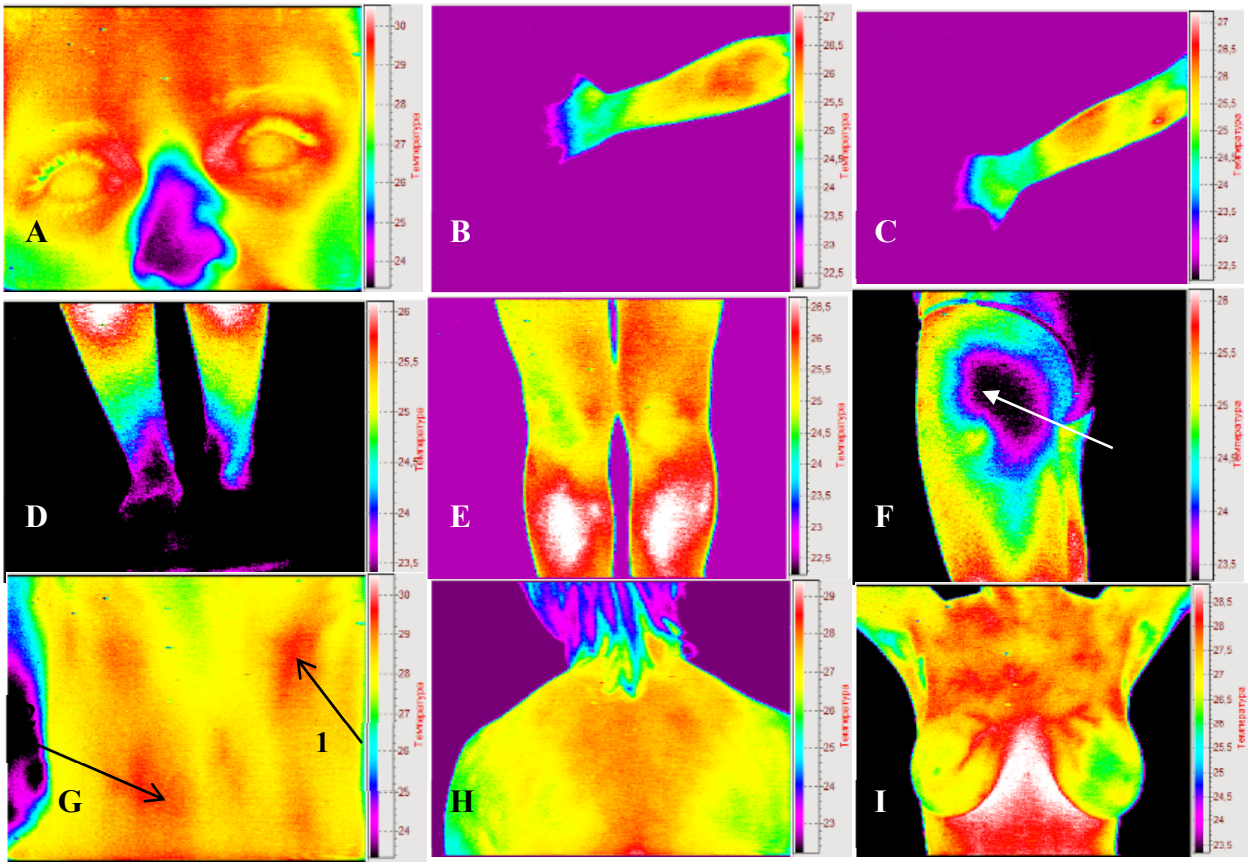

Fig. 5. Hypothermia of the tip of the nose (A); "thermal amputation" of the upper (B, C) and lower (D) limbs; arthrosis of the right knee joint (E); deforming arthrosis of the left hip joint (F); hyperthermia of the upper lobe of the thyroid gland on the left and the lower lobe on the right (indicated by arrows 1, 2, respectively, (G); bronchitis (H); hypothermia of the left breast (I)

Combination of RPh manifestations (Fig. 6A, B) with severe somatic diseases, namely: chronic obstructive bronchitis in the acute phase (C), hypothermia of the left breast with a temperature gradient ΔT=-1.5°C (D), hyperthermia of the projection zone of the kidneys (E) is shown in Fig. 6.

Thermographic visualization of spasm of thermoregulatory vessels – the tip of the nose, impaired blood supply to the distal parts of the upper limb, impaired blood circulation of II, III and IV fingers of the lower left limb and II finger of the right limb are shown in Fig. 7. The temperature gradient of the affected phalanges of the foot of the left limb is -1.62°C, right -2.93°C. The identified selective circulatory disorder in the distal lower limbs is characteristic of DM disease, which has been clinically verified.

According to the foregoing, there is much in common in the manifestations of RPh and lower limb lesions in patients with DM. In RPh, we usually observe a spasm of small arteries of the distal limbs, which is also inherent in patients with diabetes – a violation of the main blood flow in the arteries of the lower limbs of varying severity, which also leads to spasm of the distal parts of limbs.

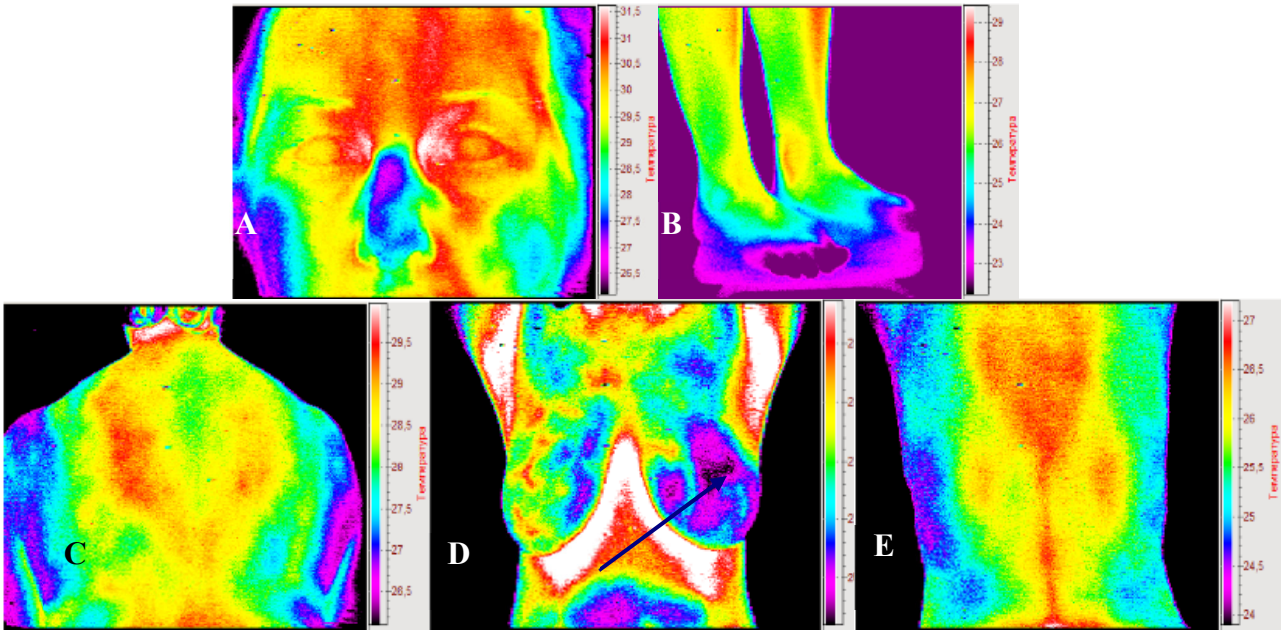

Fig. 6. Thermographic visualization of RPh (A, B) and concomitant diseases: chronic obstructive bronchitis in the acute phase (C), hyperthermia of the posterior projection of the lungs: ΔT of the projection of the left lung +1.33°C, the right one +0.58°C; hypothermic areas of the left breast (D); hyperthermia of the projection zone of the kidneys (E) with a temperature gradient on the right +0.81°C, on the left +0.65°C

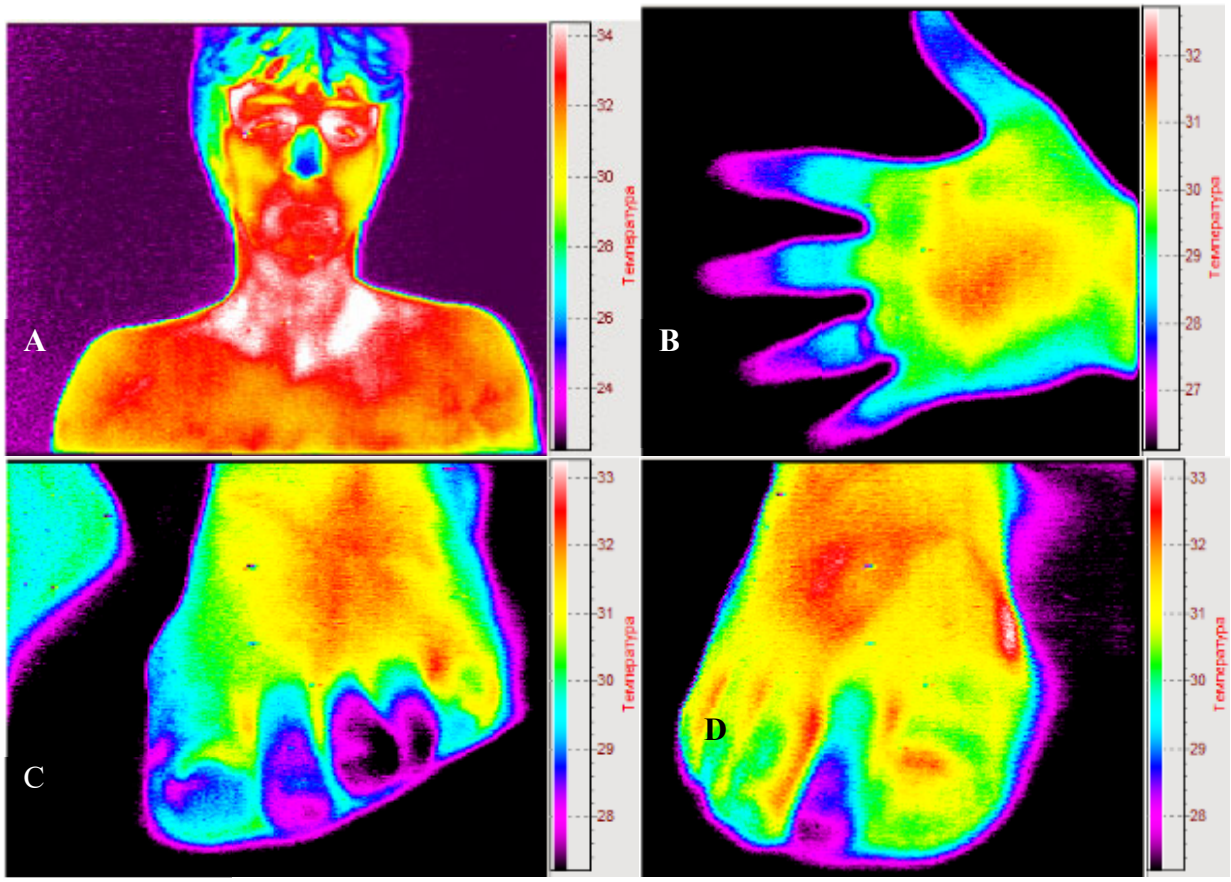

Fig. 7. Thermographic visualization of spasm of thermoregulatory vessels in a patient with DM

As noted, the clinical signs of RPh are circulatory disorders of the peripheral blood circulation due to local arterial spasm, the development of trophic circulatory disorders of organs and systems. Thermographic visualization of RPh is characterized by the presence of spasm of thermoregulatory vessels – the tip of the nose, angiospasm in the distal parts of the upper and lower limbs.

An analysis of the results of a comprehensive examination of patients with the use of ITh showed that RPh is usually accompanied by concomitant somatic diseases. It has been established that RPh can exist both as an independent disease and as a manifestation of other pathological conditions. The results of data processing are shown in the diagram (Fig. 8).

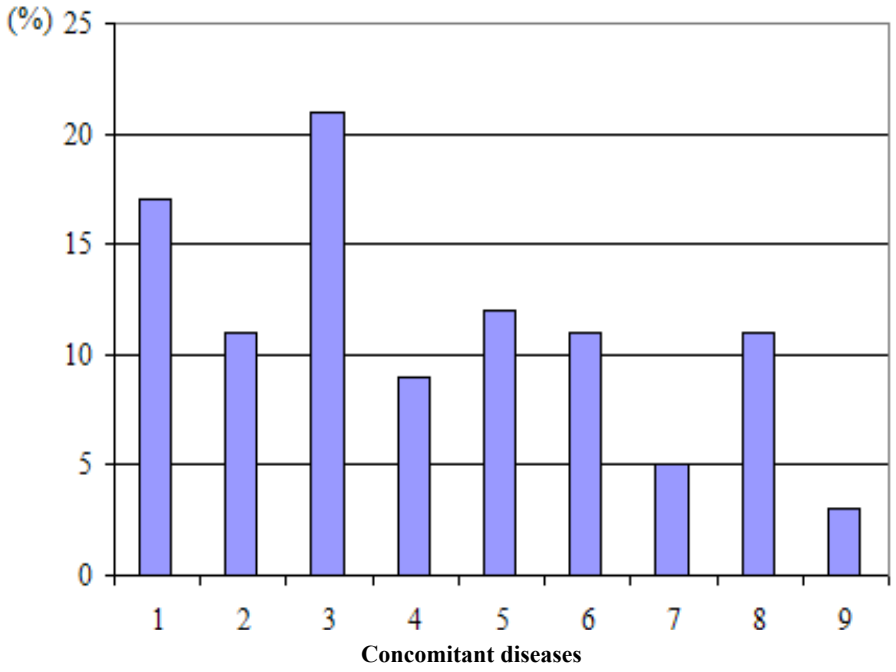

Fig. 8. Distribution of the percentage of identified concomitant diseases:
(1 - no concomitant diseases were detected, 2 - thyroid diseases, 3 - diseases of the bronchopulmonary system, 4 - pathologies of the mammary glands, 5 - gastrointestinal disorders, 6 - VrV, 7 - kidney diseases, 8 - violation of the musculoskeletal system, 9 - DM)

Analysis of the obtained results allows us to present a complex thermographic combination of manifestations of risk factors of RPh with various somatic diseases, which allows us to assess the state of health within the limits of thermography.

Of particular importance are studies of patients with DM, who have severe microcirculation disorders, leading to significant metabolic changes in tissues. Thermographic visualization of the pathological manifestation of DM has a number of common features in terms of RPh. The introduction of thermographic diagnostics allows timely differentiation of risk factors between manifestations of threatening complications of diabetes, such as diabetic polyneuropathy and diabetes.

CONCLUSIONS

The results of the performed thermographic studies showed that:

4. Infrared thermography is an effective diagnostic method for the rapid detection of manifestations of Raynaud's phenomenon and allows you to assess the severity of the disease according to the gradation of the manifestation of Raynaud's phenomenon proposed by the authors according to the magnitude of the temperature gradient.
5. Within the same diagnostic examination, infrared thermography allows you to simultaneously obtain thermographic images of both signs of Raynaud's phenomenon and concomitant somatic pathologies.

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