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RESEARCH OF THE TEMPERATURE PATTERNS DISTRIBUTION OF PATHOLOGICAL CONDITIONS OF THE KNEE JOINTS

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Orthopedic pathology of the knee joints occupies a leading position in the frequency of occurrence among degenerative-dystrophic diseases of the musculoskeletal system. An important aspect of the problem is the timely diagnosis of the disease using simple and affordable radiodiagnostic methods. Studies of the distribution of temperature patterns of pathological conditions of knee joints of various etiologies were performed using the method of infrared thermography with the use of a domestic thermographic complex, which has the function of obtaining oscillographic images of temperature patterns of various areas of the surface of the skin of a biological object. The article elaborates and presents the results of long-term thermographic studies of structural and functional changes in the knee joints. Temperature gradients of asymmetric hypothermic or hyperthermic areas were determined, and oscillographic distributions in the zones of interest were obtained. The analysis of sections of temperature patterns is an important diagnostic criterion for assessing the pathological condition of the knee joints, which greatly simplifies planning an appropriate individual treatment program. Thermographic visualization of knee joints with various manifestations of lesions allows for the reliable and informative enrichment of complex diagnostics of the musculoskeletal system, the provision of an assessment of the effectiveness of treatment, and the safe monitoring of it.

Key words: temperature patterns, thermography, oscillographic thermal section, temperature gradient, knee joints.

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ДОСЛІДЖЕННЯ РОЗПОДІЛУ ТЕМПЕРАТУРНИХ ПАТЕРНІВ ПАТОЛОГІЧНИХ СТАНІВ КОЛІННИХ СУГЛОБІВ

Ортопедична патологія колінних суглобів займає лідируючу позицію за частотою виникнення серед дегенеративно-дистрофічних захворювань опорно-рухової системи. Важливим аспектом проблеми постає своєчасне діагностування захворювання з використанням простих та доступних методів променевої діагностики. Дослідження розподілу температурних патернів патологічних станів колінних суглобів різної етіології виконувались за допомогою методу інфрачервоної термографії із застосуванням вітчизняного термографічного комплексу, який має функцію отримання осцилографічних зображень температурних патернів різних ділянок поверхні шкірного покриву біологічного об'єкту. Результати довготривалих термографічних досліджень структурно-функціональних змін колінних суглобів опрацьовані та представлені в статті. Визначені градієнти температури асиметричних гіпо- чи гіпертермічних ділянок та отримані осцилографічні розподіли в зонах інтересу. Аналіз зрізів температурних патернів є важливим діагностичним критерієм оцінки патологічного стану колінних суглобів, що значно спрощує планування відповідної індивідуальної лікувальної програми. Термографічна візуалізація колінних суглобів з різними проявами уражень дозволяє надійно й інформативно збагатити комплексну діагностику скелетно-м'язевої системи, надати оцінку ефективності лікування й безпечно здійснювати його моніторинг.

Ключові слова: температурні патерни, термографія, осцилографічний термозріз, градієнт температури, колінні суглоби.

The study is a fragment of the research project "Improving the method of diagnosis, treatment and rehabilitation of complications and unsatisfactory results of anterior cruciate ligament plastic surgery", state registration No. 0119U003162.

Osteoarthritis (OA) is one of the most serious and widespread diseases, accounting for 80 % of the total structure of joint pathologies [2, 3].

The incidence of OA among adults varies from 8 to 29 % and is the third most common diagnosis made by general practitioners in older patients [12].

The reasons are primarily related to an increase in the life expectancy of the population, hypodynamia, excess body weight, a decrease in bone density, and a number of other factors that lead to traumatization and deformation of the joints. As the world population ages, [2, 5] it is estimated that degenerative joint diseases such as OA will affect at least 130 million people worldwide by 2050. The most common localization of this pathological process, accompanied by loss of temporary incapacity and disability, is the knee joint.

Gonarthrosis is one of the most urgent problems of modern orthopedics and is accompanied by persistent pain syndrome, a progressive violation of the supporting and kinematic function of the lower limb with disability. From a review of literary sources, it is known that gonarthrosis is registered in 50.6–

54.5 % of cases among patients with dystrophic diseases of the large joints of the lower limb and in 86 % of cases in persons of working age and in 6.5–14.6 % of cases it leads to disability [5].

Limitations of full joint functioning, persistent pain syndrome, and decreased quality of life determine the need for an in-depth approach to the study of diagnostic information of methods of radiographic visualization of knee joint pathologies [10, 14].

As a rule, it is not difficult to study the structural and functional state of the knee joints with a detailed clinical picture when both joints are affected. Significant problems arise in the diagnosis of OA at the early preclinical stage of the disease.

To diagnose the condition of the knee joints, the following methods of radiographic diagnostics are used: radiography (RG), computed tomography (CT); ultrasound diagnostics (US), magnetic resonance imaging (MRI), three-phase osteoscintigraphy (3-phOSG), thermography.

Each of the above diagnostic methods has both its advantages and disadvantages. The significant radiation load on the patient, requiring a certain period of time before the subsequent examination, significant cost and insufficient information content, especially in the early stages of the pathological process, necessitated the use of infrared thermography (ITG).

Remote thermal imaging allows for assessing functional changes in the disease in dynamics (both during the initial examination and directly during the treatment) and visualizing soft and periarticular tissues of the joint. The ability to measure the temperature in any area of the lesion allows assessing the severity of the disease by its value.

ITG, combined with other clinical methods of radiation diagnostics, is widely used in modern world medicine and allows the identification of the anatomical area of pathological changes long before the manifestation of clinical symptoms to determine the activity and nature of the processes. Visualized temperature fields provide diagnostic information about the state of peripheral blood flow and the deep processes occurring in the body.

Thermography has diagnostic capabilities that are inherent in this method and occupies a special place among other types of radiation diagnostics [1, 4, 6], and that is why the authors used the ITG method to solve problems in studying structural and functional changes in the musculoskeletal system of the process and its prevalence, as well as the nature of changes in thermal patterns - inflammation, microcirculation disorders [9, 15].

Special scientific and practical developments on the issue of studying pathological changes in the knee joints are devoted to individual diseases [9, 11]. There is no data on the combination of the identified pathological conditions of the knee joints of various etiologies with thermographic visualization and temperature patterns on the surface of the knee joints.

The author of the work [7] draws attention to the emergence of certain difficulties in diagnosing OA in the early stages, especially in patients with monogonarthrosis, since there is a discrepancy between the clinical symptoms and radiographic signs of the disease. These difficulties are quite successfully overcome with the help of ITG.

The purpose of the study was to investigate thermographic visualization of pathological changes in the knee joints of various etiologies and the diagnostic information content of blood supply in the lower extremities, to link the identified changes with patterns of thermal fields by types of disease, to obtain oscillographic temperature distributions in the area of interest.

Materials and methods. The work used a domestic thermograph with a temperature sensitivity of 0.07° C developed by the V.Ye. Lashkaryov Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine with a cooling matrix photodetector and a basic test program for the TherrmoVisio thermal imaging system, as well as a TherraCAM E300 FLIR SYSTEM thermograph. Observation and control of thermal fields was carried out in the range of 3÷5 and 8÷14µm. The program codes were implemented in the Delphi programming language in the Borland Delphi 7 development.

When registering the results of thermographic studies (personal thermographic card of the patient), the program uses the properties of the Microsoft Word document to create a template and inserts them into the corresponding field of the text editor, and also adds a set of special commands necessary for working with IR images (the ability to insert a text comment, a photograph of the patient, his IR images, the necessary thermal profile, a table of results, etc.) and various research tools. The diagnostic information obtained in this way can be stored as an electronic card in the Basic IR Photo template for further operational analysis, observation and forecasting of the dynamics of the functional state.

The examination was carried out during inpatient and outpatient treatment at the municipal non-profit enterprise “Kyiv City Clinical Hospital No. 12” and the State Institution “Institute of Traumatology

and Orthopedics” of the National Academy of Medical Sciences of Ukraine. The patients’ ages ranged from 25 to 82 years, the overwhelming majority of patients were women (76 %), and the patients' weight ranged from 55 to 80 kg, depending on age and gender. There was no special division of patients into groups, the total number was 183 people. The temperature measurement error was $\pm 0.07^{\circ}\text{C}$.

Before the thermographic examination, patients did not undergo thermal procedures or take medications that affected blood circulation and metabolic processes. Patients were prohibited from smoking 4 hours before the examination, as this is important for the study of peripheral blood flow, and they were subject to adaptation to the conditions of the thermography room, where the temperature was maintained at $22.0 \pm 1^{\circ}\text{C}$.

The study was conducted in accordance with the principles of bioethics set out in the Helsinki Declaration, “Ethical Principles for Medical Research Involving Humans”, and the “General Declaration on Bioethics and Human Rights” (UNESCO).

Processing of thermograms and further actions to formalize the results of thermographic studies were performed using the ThermoVisio program, which was improved by the authors and allowed thermographic images with removed background noise and oscillographic thermal sections in real temperature values to be obtained.

Results of the study and their discussion. One of the main indices of the human body's condition is temperature. At the initial stages of the disease, a change in temperature is observed, manifested in the appearance of hypo- or hyperthermia zones of the skin and the formation of new thermal patterns that can be associated with nonlinear thermal effects in biological tissues. Visualized temperature fields provide diagnostic information about blood flow and deep processes occurring, particularly in the joints.

The authors of the work present thermographic visualization and oscillographic temperature distributions of thermal patterns of the most common pathological conditions of the knee joints.

A characteristic thermographic sign of the absence of pathological changes is the symmetry of the thermographic image with a temperature gradient (ΔT), which does not exceed 0.5°C of the compared symmetrical zones of the studied surfaces, corresponding to the physiological thermographic norm values.

Fig. 1 shows a thermographic image and oscillographic temperature distribution (thermosesis) of the anterior projection line of the knee joints without pathological changes (A).

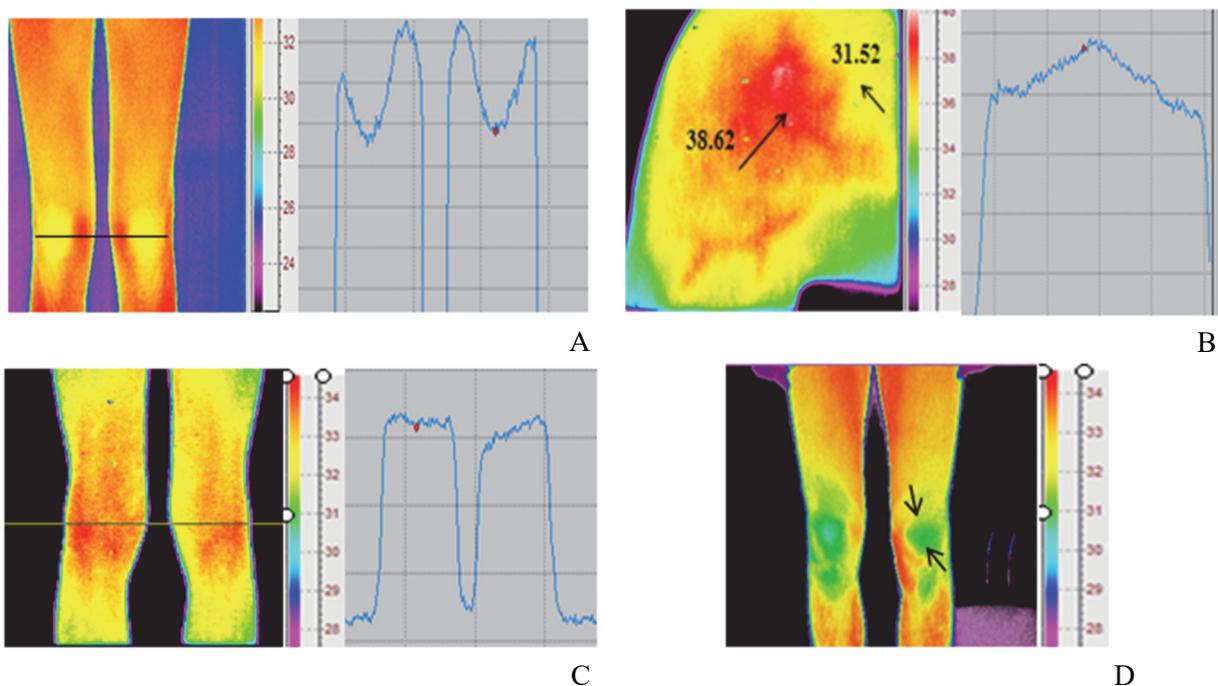


Fig. 1. Thermographic visualization of the anterior projection of the knee joints without signs of pathological changes with oscillographic temperature distribution according to the line (A); hematoma of the knee joint with an oscillographic temperature peak of the inflammation focus (B); left-sided hemarthrosis of the knee joint (posterior projection with temperature distribution oscillogram (C); paracapsular rupture of the medial meniscus of the left knee joint (D).

Thermographic visualization and oscillogram of the inflammatory focus of the subcutaneous hematoma of the knee joint as a result of injury are shown in Fig. 1, B. Clinically, rather blurred fluctuation boundaries are determined, which complicates the evacuation of the hematoma. The

performed thermographic examination revealed an increase in the number of color patterns characterizing the intensity of blood flow in the vessels; the focus of the temperature increased to 38.62°C , the temperature gradient is $+3.1^{\circ}\text{C}$, which simplified the search for a place for a possible puncture of the hematoma.

The thermogram of left-sided hemarthrosis of the knee joint with temperature distribution along the line is shown in fig. 1, C. According to the results of thermographic visualization, thermal asymmetry of the knee joints is observed; the size of the patterns determines the scale of micro- and macroheterogeneity; the range of visualized temperature is $30\div 34^{\circ}\text{C}$. Homogeneous hyperthermia zone with $\Delta T^{\circ}\text{C}$ “knee joint-hip” from $+1.5^{\circ}\text{C}$ to $+2.2^{\circ}\text{C}$.

A typical thermographic picture of damage to the medial meniscus of the left knee joint is shown in fig. 1, D. Thermographic examination reveals a change in temperature along the medial surface of the left joint compared to the symmetrical zone by 3°C (32.1°C and 29.1°C , respectively) and a decrease in heat generation in the damage zone. This condition may be due to a reaction of the synovial capsule of the damaged joint due to a paracapsular rupture of the medial meniscus of the left knee joint.

Thermographic visualization of OA as one of the most common chronic diseases of the musculoskeletal system demonstrates the versatility and diversity of the detected superficial pathological foci of inflammation.

The thermogram (Fig. 2, A) shows the detected active hyperthermia zone of the knee joint surface, corresponding to the verified clinically right-sided OA. The $\Delta T^{\circ}\text{C}$ value between the active zone indicated by arrows 1 and 2 is $+2.35^{\circ}\text{C}$, corresponding to subclinical inflammation. ITG permits determining the process's activity, its prevalence, and the nature of the accompanying changes in the extremities, in this case, circulatory disorders – varicose veins (DVV).

Hyperthermia in the area of the right knee joint and periarticular tissues, confirming the right-sided arthrosis with the temperature distribution oscillogram are shown in Fig. 2, B. The temperature gradient between the right and left knee joints is $+1.28^{\circ}\text{C}$, corresponding to the oscillogram's hyperthermic peak.

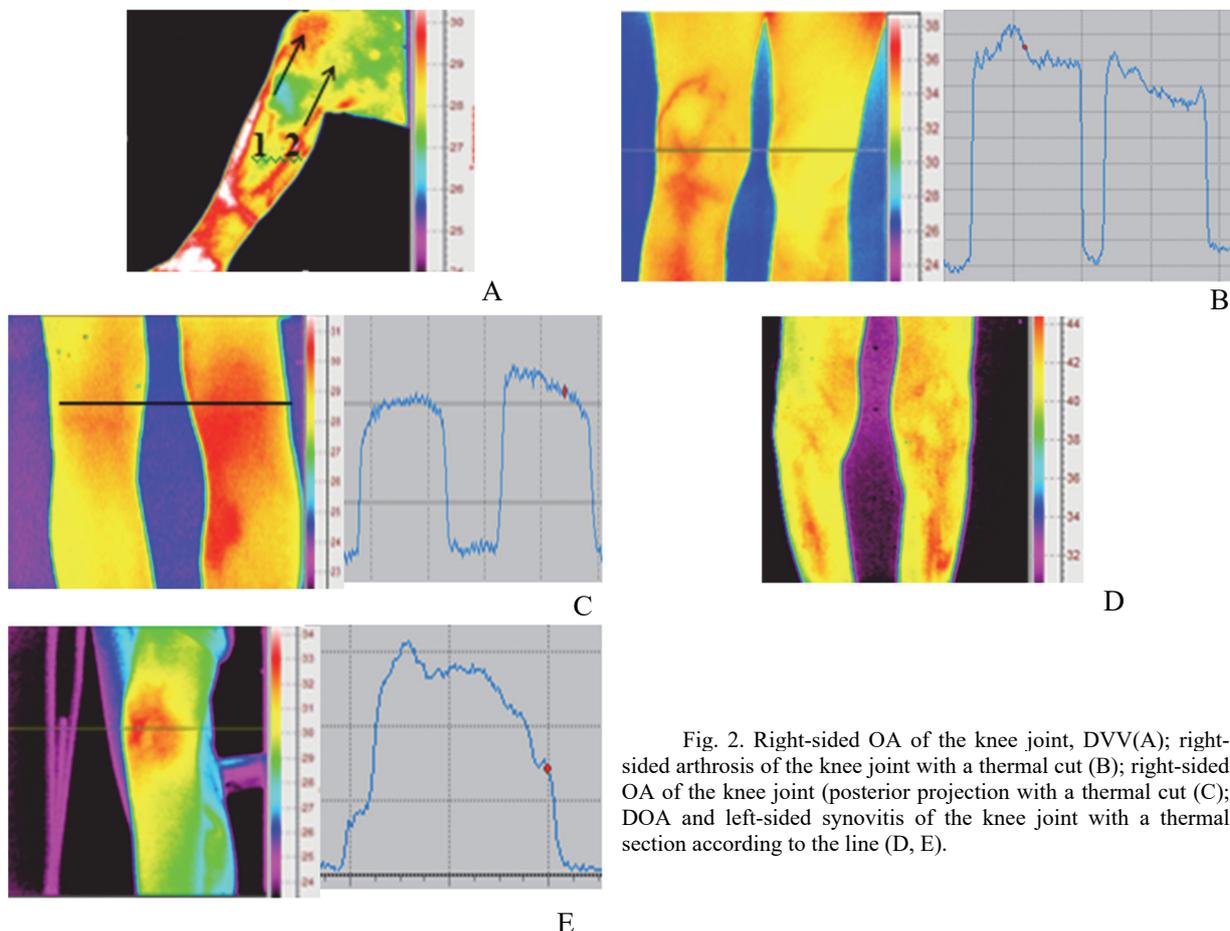


Fig. 2. Right-sided OA of the knee joint, DVV(A); right-sided arthrosis of the knee joint with a thermal cut (B); right-sided OA of the knee joint (posterior projection with a thermal cut (C); DOA and left-sided synovitis of the knee joint with a thermal section according to the line (D, E).

Thermographic visualization of right-sided knee OA in the acute phase of the disease and the oscillographic temperature distribution is shown in Fig. 2, C; $\Delta T^{\circ}\text{C}$ right-left knee joint is $+0.72^{\circ}\text{C}$ and

+1.73°C, respectively. Qualitative analysis of the thermogram shows an increase in the area of the thermal pattern during an exacerbation of the disease. In deforming osteoarthritis (DOA), damage to the articular cartilage is associated with the development of synovitis, which, in turn, intensifies the degenerative processes.

Thermographic representation of DOA of the knee joints with left-sided synovitis and temperature distribution along the measurement line using the “oscilloscope” mode of the thermograph in Fig. 2, D, E. The temperature in the center of the inflammation focus is 32.10°C, nearby – 28.93°C; $\Delta T^{\circ}C=+3.17^{\circ}C$.

Using the temperature distribution results allows us to determine the center of the inflammation focus, which allows us to make appropriate adjustments when making decisions on therapeutic measures. During thermographic examination of the knee joints, the condition of the lower limbs is analyzed. In most cases, circulatory disorders of various etiologies are characteristic.

Occlusive vascular lesions of the extremities are one of the most common pathological changes in the human peripheral arterial system.

Fig. 3, A shows a thermogram of the lower limbs, characteristic of right-sided occlusion of the femoral artery in combination with clinically verified DOA and the temperature distribution relative to the line. Numbers 1 and 2 indicate the temperature distribution on the thermal section – the right and left knee joint, respectively. Thermographic examination of the lower limbs before endoprosthetics allows for more adequate planning of surgical intervention and avoidance of intraoperative complications.

Osteoporosis is a dangerous chronic disease in which the bone structure changes. Particular attention should be paid to osteoporosis of the knee joints, in which there is a gradual destruction of articular cartilage and knee tissue. An important aspect of successful treatment measures is timely diagnosis of the initial period of the disease. The ITG method allows visualizing asymmetric temperature zones for subsequent comprehensive diagnostic searches.

Fig. 3, B shows thermographic visualization of the lower limbs with a clinically verified diagnosis – osteoporosis of the knee joints with oscillographic temperature distribution. The presence of hypo- and hyperthermia zones of the lower limbs with a temperature difference of -1.81°C is observed. The obtained temperature indices according to the specified zones (1-2-3-4-5) of the left lower limb: 28.14°C; 27.93°C; 26.69°C; 28.79°C; 31.83°C.

Knee joint disease in young people can be caused by excessive physical activity or injuries, most often found in the military and athletes. As an example, Fig. 3, C and D show thermograms of the knee joints in young people (22 and 23 years old, respectively). The temperature distribution in the knee joint area is shown by arrows 1–2–3 in Fig. 3, C, respectively: 25.79°C, 26.24°C; 27.62°C; Fig. 3, D – 25.26°C; 26.41°C; 27.66°C. The temperature gradients are: $\Delta T_{1-3}=-1.83^{\circ}C$ (C); $\Delta T_{1-3}=-2.4^{\circ}C$ (D).

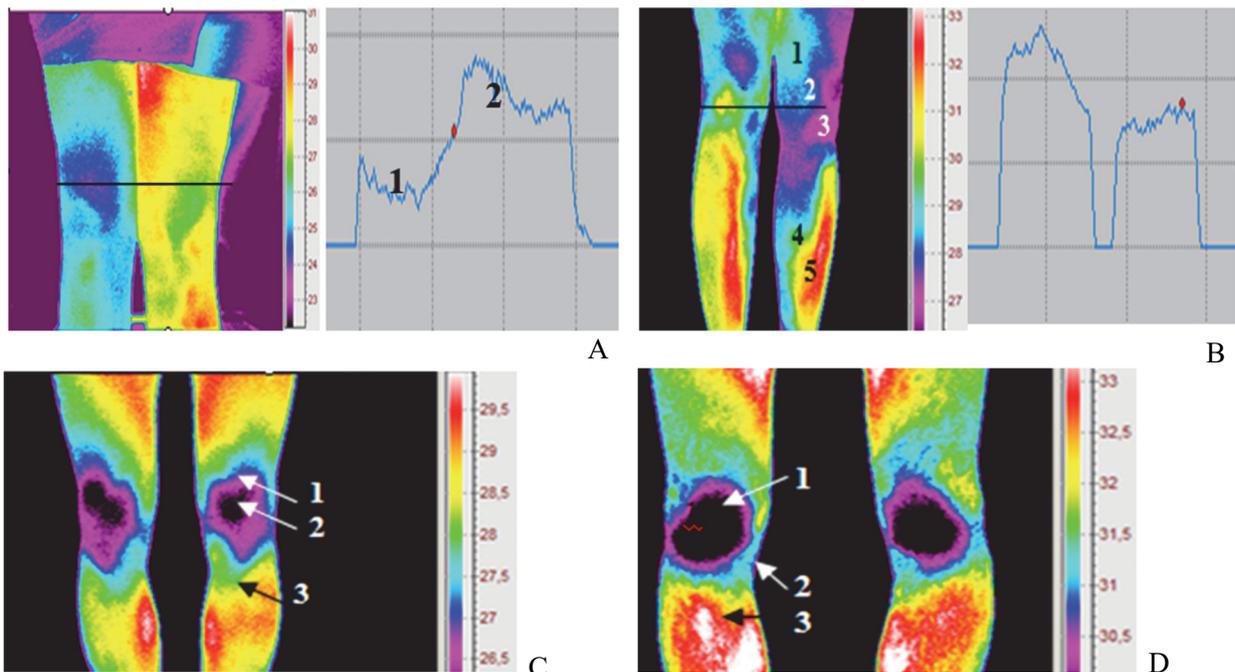


Fig. 3. Occlusion of the right femoral artery, DOA, oscillographic thermal section (A); osteoporosis of the knee joints, temperature distribution oscillogram (B); thermal asymmetry of knee joints (C, D).

The generalized results of the identified structural and functional configurations of knee joints with temperature gradients are presented in Table 1.

Table 1

Distribution of temperature gradients of identified pathological configurations

Pathological changes in knee joints of traumatic origin		Degenerative-dystrophic changes of knee joints	
Identified pathologies	$\Delta T^{\circ}\text{C}^*$	Identified pathologies	$\Delta T^{\circ}\text{C}$
Hematoma of the knee joint	+3.1 $^{\circ}\text{C}$	OA, DVV	+2.35 $^{\circ}\text{C}$
Paracapsular tear of the medial meniscus	+3 $^{\circ}\text{C}$	Arthrosis of the knee joint OA, acute phase	+1.28 $^{\circ}\text{C}$ +(0.72÷1.73) $^{\circ}\text{C}$
Baker's cyst	+2.7 $^{\circ}\text{C}$	DOA, synovitis	+3.17 $^{\circ}\text{C}$
		Asymmetry of knee joints, OA	+1.7 $^{\circ}\text{C}$ -1.1 $^{\circ}\text{C}$
		Femoral artery occlusion, DOA	Not determined
		Psoriatic arthritis	+(1.7÷2.25) $^{\circ}\text{C}$
		Osteoporosis of knee joints	-1.81 $^{\circ}\text{C}$
		Vascular disorders	Not determined
		Hypothermia of knee joints	-1.83 $^{\circ}\text{C}$ -2.4 $^{\circ}\text{C}$

Note. *The thermographic norm is considered to be the value of the temperature gradient, which does not exceed 0.5 C.

The paper presents the results of a thermal imaging study of structural and functional changes in the knee joints that are most often encountered in medical practice. Oscillographic temperature patterns characterizing the severity of the identified traumatic injuries and degenerative-dystrophic changes are separately shown.

The issue of early detection of the disease is particularly important to prevent further progression of irreversible processes in the knee joints. The solution to this problem becomes possible through ITG as a sensitive instrumental method of radiation diagnostics for comprehensively obtaining diagnostic information [5, 9, 11].

The work has shown that using the ITG method allows for an expressive, painless and easy examination of the patient, the identification of pathological changes, and the timely initiation of treatment.

The thermograms obtained by the authors of this work are accompanied by an oscillographic temperature distribution and determination of the temperature gradient in the affected area, simplifying the diagnostic search. The paper presents the results of a comprehensive approach to analysing the obtained diagnostic information on pathological conditions of the knee joints.

For example, in the case of DOA, the degree of deformation of the affected joint can be determined using oscillogram data, and in the case of traumatic injury to the knee joint, the temperature distribution allows one to determine the epicenter of the lesion, simplifying the treatment.

An interesting result of the work was the identification of functional changes of unknown etiology in the knee joints of young people, which should be the subject of a detailed, comprehensive diagnostic examination.

During the work, a relationship was identified between circulatory disorders, which is related to the provoking factors of DOA development and can be one of the prerequisites for the occurrence of functional and degenerative changes in the knee joints, which was also reflected in the works [8, 13].

Conclusions

1. The work has shown that infrared thermography in diagnosing knee joint diseases is an effective and safe method of radiation diagnostics. Thermographic visualizations of various etiologies' pathological conditions of the knee joints were obtained.

2. Analysis of thermal field patterns and oscillographic temperature distributions permits the determination of the zone and maximum temperature of the affected area of the knee joint.

3. Thermographic visualization of microcirculation disorders in the lower extremities shows the activity of pathological processes.

4. Thermographic images of knee joints with various manifestations of lesions enrich the musculoskeletal system's comprehensive diagnostics, permitting the evaluation of treatment's effectiveness and monitoring it.

5. A promising direction of thermographic diagnostics, according to the authors, is the use for monitoring before and after surgical interventions on the lower extremities to determine the course of the regeneration process, as well as in determining the volume of surgical intervention in case of injuries to the lower extremities in military personnel.

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