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ABSTRACT

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PROSPECTS OF USING INFRARED THERMOGRAPHY IN THE DIFFERENTIAL DIAGNOSIS OF BRONCHOPULMONARY PATHOLOGICAL CONDITIONS

Introduction. The search for new non-invasive diagnostic methods for detecting pathological changes in the bronchopulmonary system is a pressing issue in modern medical diagnostics, gaining even greater significance during the COVID-19 pandemic. Existing clinical and morphological diagnostic methods for the differential diagnosis of viral and viral-bacterial pneumonia often require significant time for data acquisition and processing. There is substantial scientific and practical interest in developing a differential diagnostic method using remote infrared thermography to identify patients with viral and viral-bacterial pneumonia and to study the characteristics of thermographic visualization of the pulmonary system under various pathological conditions. This method allows for a rapid and non-invasive identification of the nature of the pathology.

Purpose of the study. To obtain thermal images of the posterior projection of the lungs in individuals with a history of bronchopulmonary pathology; to analyze the obtained thermographic images and oscillographic temperature distributions in the areas of interest; and, based on this information, to develop a method for the differential diagnosis of pathological states of the bronchopulmonary system.

Materials and methods. The study utilized a domestically developed thermograph with a temperature sensitivity of 0.07 °C developed by the V.E. Lashkaryov Institute of Semiconductor Physics of the NAS of Ukraine, featuring a cooled focal plane array and the ThermoVisio base test software, as well as a FLIR SYSTEM ThermaCAM E300 thermograph. Observations and control of thermal fields were conducted in the 3 ÷ 5 µm and 8 ÷ 14 µm ranges.

Results. Thermographic images and oscillographic temperature profiles of the posterior lung projection were obtained for various

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bronchopulmonary diseases. The analysis and processing of these images and distributions revealed significant differences in thermographic visualizations and oscillograms depending on the pathogenic agent. It was demonstrated that infrared thermography enables differential diagnosis of respiratory tract lesions. In conjunction with other clinical and laboratory methods, thermography simplifies the diagnostic search and treatment strategy.

Conclusions. A method for the differential diagnosis of bronchopulmonary pathological states using remote infrared thermography has been developed. The implementation of this thermal imaging method allows for the investigation of temperature pattern distributions in the posterior lung projection. It was found that thermographic visualization of the lung projection in patients with COVID-19-associated pneumonia lacks the clear inflammatory focus areas characteristic of viral-bacterial pneumonias of other etiologies. Infrared thermography is a promising method for detecting bronchopulmonary diseases caused by various pathogens.

Keywords: thermography, bronchopulmonary system, gradient, temperature, coronavirus infection.

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ПЕРСПЕКТИВНІСТЬ ЗАСТОСУВАННЯ МЕТОДУ ІНФРАЧЕРВОНОЇ ТЕРМОГРАФІЇ У ДИФЕРЕНЦІЙНІЙ ДІАГНОСТИЦІ ПАТОЛОГІЧНИХ СТАНІВ БРОНХОЛЕГЕНЕВОЇ СИСТЕМИ

Вступ. Пошук нових неінвазивних діагностичних методів виявлення патологічних змін бронхолегеневої системи відноситься до актуальних питань сучасної медичної діагностики, важливість яких підвищилась під час пандемії COVID-19. Розроблені та впроваджені клініко-морфологічні діагностичні методи для диференційної діагностики вірусної та вірусно-бактеріальної пневмонії потребують досить тривалого часу для отримання та опрацювання результатів обстеження. Науковий і практичний інтерес представляє розробка методу диференційної діагностики із застосуванням дистанційної інфрачервоної термографії для виявлення хворих на вірусну та вірусно-бактеріальну пневмонію, дослідження особливостей термографічної візуалізації легеневої системи при різних патологічних станах. Цей метод надає можливість швидко та неінвазивно виявити характер патології.

Мета дослідження. Отримати тепловізійні зображення задньої проєкції легень осіб, які мали в анамнезі бронхолегеневу патологію; проаналізувати отримані термографічні зображення та осцилографічні розподіли температури в зоні інтересу; на базі отриманої інформації розробити метод диференційної діагностики патологічних станів бронхолегеневої системи.

Матеріали та методи. В роботі застосовувався вітчизняний термограф з температурною чутливістю 0,07 °С розробки Інституту фізики напівпровідників ім. В. Є. Лашкарьова НАН України з охолоджувальним матричним фотоприймачем та базовою тестовою програмою для тепловізійної системи ThermoVisio, а також

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термограф ThermaCAM E300 FLIR SYSTEM. Спостереження та контроль теплових полів здійснювалось в діапазоні 3 ÷ 5 та 8 ÷ 14 мкм.

Результати. Отримані термографічні зображення та осцилографічні температурні зрізи задньої проєкції легень захворювань бронхолегеневої системи. Здійснений аналіз та обробка термографічних зображень й отриманих осцилографічних розподілів температури. Виявлені суттєві відмінності термографічних візуалізацій та осцилограм в залежності від патогенного збудника. Показано, що застосування методу інфрачервоної термографії дозволяє здійснювати диференційну діагностику уражень дихальних шляхів. Термографія в комплексі з іншими клінічними та лабораторними методами дозволяє спростити діагностичний пошук та стратегію лікування.

Висновки. Розроблений метод диференційної діагностики патологічних станів бронхолегеневої системи із застосуванням дистанційної інфрачервоної термографії. Впровадження тепловізійного методу надає можливість досліджувати розподіл температурних патернів тепловізійних зображень задньої проєкції легень. Виявлено, що термографічна візуалізація проєкції легень хворих на пневмонію, асоційовану з COVID-19, не має чітких ділянок вогнищ запалення, які є характерними для вірусно-бактеріальних пневмоній іншої етіології.

Використання інфрачервоної термографії є перспективним методом у виявленні захворювань бронхолегеневої системи різними патогенними збудниками.

Ключові слова: термографія, бронхолегенева система, градієнт, температура, коронавірусна інфекція.

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ABBREVIATIONS

IRT – Infrared Thermography
SC – Skin Cover
CT – Computed Tomography

INTRODUCTION

In the 21st century, pneumonia remains a critical medico-social issue. This is primarily due to its high prevalence, significant disability and mortality rates, and substantial economic costs [1]. According to 2023-2024 data [2], 4.8 million people contracted influenza and other acute respiratory infections (ARIs), with a relative incidence rate of 13,391.1 per 100,000 population – a 22.7 % increase over the previous season. Currently, ARI incidence figures include COVID-19, which, while gradually becoming a routine respiratory infection, still retains specific characteristics. The incidence of ARIs and COVID-19 remains a pressing issue; for instance, according to the Ministry of Health of Ukraine, 125,438 cases of influenza, COVID-19, and ARIs were registered in a single week (December 1–7, 2025).

Despite recent advances in diagnostic methods and pharmaceuticals, the detection and treatment of bronchopulmonary diseases remain challenging due to the reduction in clinical manifestations of major pathogenetic syndromes [3, 4, 5]. Among existing radiation diagnostic methods, IRT is one of the most accessible and is widely used globally, particularly in technologically advanced countries.

The thermographic diagnostic method allows for the detection of pathological changes in a biological object (BO) related to thermal balance disruption. The BO body temperature remains constant within a very narrow range of (36.6 ± 1.0) °C. Significant heat is produced within the BO due to exothermic biochemical processes in cells and tissues, as well as energy release from DNA and RNA synthesis. This heat is distributed via blood and lymph circulation, which levels temperature gradients. Venous blood, which cools minimally in the lungs and circulates through the systemic circuit, is considered the warmest, maintaining optimal temperature in tissues and organs [6, 7].

During illness, the circulatory system is disrupted. Changes arise from increased metabolism; for example, in an area of inflammation, blood perfusion and subsequent thermal conductivity increase, which is visualized on a thermogram as zones of thermal asymmetry. Visualized temperature fields provide diagnostic information about peripheral blood flow and deep-seated processes in tissues and organs. The value of the temperature gradient between an area of increased or decreased radiation and an intact area on a thermographic image holds significant diagnostic weight. The unique diagnostic capabilities of thermography led the authors to apply IRT to the differential diagnosis of bronchopulmonary pathologies.

The unprecedented global challenge of the 2019 coronavirus infection caused by the SARS-CoV-2 virus remains a central topic today [8]. The scale of the pandemic necessitated active study of all its aspects, primarily the clinical features of lung damage. Coronaviruses are emerging infectious agents with etiological, pathogenetic, and clinical features that are not yet fully understood [9, 10].

The most common clinical manifestation of SARS-CoV-2 is bilateral pneumonia – a viral diffuse alveolar injury with microangiopathy.Clinicians have shown that typical CT signs of viral pneumonia usually include bilateral lesions characterized by nodular changes or small areas of lung tissue consolidation, primarily in the postero-basal segments [11, 12].

In severe cases, the virus can affect up to 50 % of the lungs within 24-48 hours [13, 14]. Patients suffer from oxygen deficiency, leading to damage in other internal organs and systems (CNS, endocrine, immune, heart, kidneys, GI tract).

Given the severity of COVID-19, rapid and safe differential diagnosis between primary viral pneumonia, bacterial pneumonia, and other diseases involving proliferative lung changes is highly relevant.

COVID-associated pneumonia shares many similarities with common infectious pneumonia, yet clinicians have identified critical differences [15, 16]. While X-rays can detect lung infiltrates, CT provides a more accurate picture but involves higher costs and significant radiation exposure.

Since no single criterion exists to definitively distinguish viral from bacterial pneumonia, a comprehensive assessment of clinical, laboratory, and instrumental data is recommended.

The implementation of IRT significantly expands the instrumental base for detection and monitoring [6, 17].

As part of differential diagnosis, thermography enables the identification of areas of local hyperthermia and thermal asymmetry on the skin surface of the posterior lung projection.

RESEARCH OBJECTIVE

The objective of the study was to obtain thermal images of the posterior projection of the lungs in individuals with a history of bronchopulmonary pathology; to analyze the obtained thermographic images and oscillographic temperature distributions within the region of interest; and, based on the acquired data, to develop a method for differential diagnosis of pathological conditions of the bronchopulmonary system.

MATERIALS AND METHODS

A domestic thermograph with a temperature sensitivity of 0.07 °C, developed at the V. Ye. Lashkaryov Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine, equipped with a cooled matrix photodetector and basic testing software for the ThermoVisio thermal imaging system, was used in this study. Additionally, the ThermaCAM E300 FLIR Systems thermograph was employed.

Observation and monitoring of thermal fields were performed in the $3 \div 5$ μm and $8 \div 14$ μm spectral ranges. Software code implementation was carried out using the Delphi programming language in the Borland Delphi 7 development environment.

The patients' ages ranged from 20 to 80 years. No specific grouping according to disease type, age, or sex was performed. Statistical processing of the study results was conducted using test software developed for thermal imaging systems.

Thermographic examination of patients covered the period both before the emergence of the COVID-19 pandemic and during its spread. Respiratory tract pathology was identified through comprehensive thermographic examination as well as through analysis of patients’ medical history during hospitalization and outpatient treatment.

The following conditions were clinically verified in medical institutions and subsequently visualized thermographically: cronic obstructive bronchial diseases – 39 patients, viral-bacterial pneumonia – 44 patients, COVID-associated pneumonia – 42 patients.

The study was conducted in accordance with the bioethical principles outlined in the Helsinki Declaration “Ethical Principles for Medical Research Involving Human Subjects” and the “Universal Declaration on Bioethics and Human Rights” (UNESCO).

During the study, different patterns of thermographic visualization of pulmonary pathologies were identified, which constituted the subject of this research.

RESULTS

The authors investigated the characteristics of thermographic visualization of inflammatory processes in the respiratory tract resulting from pathogenic factors and developed a thermographic method for the differential diagnosis of viral and viral-bacterial pneumonia.

A characteristic thermographic indicator of the absence of pathological changes is symmetry of the thermographic image with a temperature gradient (ΔT) not exceeding 0.5 °C between symmetrical areas of the examined surfaces, corresponding to physiological thermographic norms.

Thermographic visualization of the posterior lung projection without pathological thermal asymmetry is shown in Figure 1.

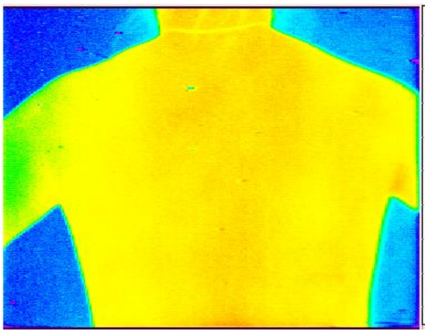

Figure 1. Posterior projection of the lungs without pathological thermal asymmetry. *(The temperature gradient does not exceed 0.1–0.2 °)*

Inflammatory processes in the bronchi represent one of the most common diseases of the bronchopulmonary system. Their symptoms require close attention from both patients and physicians. Timely diagnosis and adequate treatment are effective methods for preventing the development and progression of obstructive bronchial changes and chronic obstructive pulmonary disease.

Figure 2 presents thermographic visualization of the posterior lung projection with areas of pronounced hyperthermia. The temperature gradients indicated by arrows are: ΔT_{2-1} = +0.79 °C; ΔT_{3-1} = +0.89 °C (Fig. 2, A); and ΔT_{2-1} = +1.38 °C; ΔT_{3-1} = +0.86 °C (Fig. 2, B); the examinations were performed during inpatient treatment on the second day after hospitalization.

Clinical verification confirmed: chronic obstructive bronchitis (Fig. 2, A) and chronic bronchitis in the exacerbation phase (Fig. 2, B).

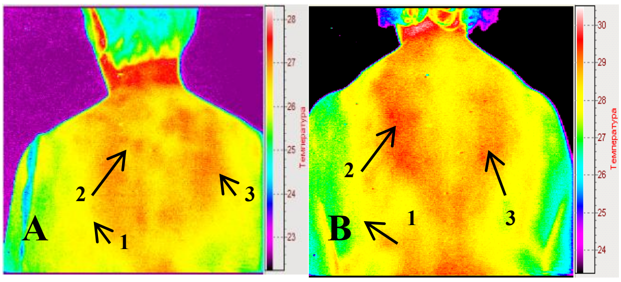

Figure 2. Thermographic visualization of chronic obstructive bronchitis (A) and chronic bronchitis in the exacerbation phase (B). (*Note: arrow 1 - indicates an intact area*)

Figure 3 shows: thermographic visualization of acute bronchitis (A) and the corresponding oscillographic thermosection (B); bilateral pneumonia and its thermosection (C, D - respectively). The maximum temperature difference of the inflammatory process in the bronchi (Fig. 3, A) was +1.89 °C. Hyperthermia in the region of the upper lung lobes showed maximum temperatures ranging from +2.31 °C to +2.76 °C (Fig. 3, C).

The oscillographic temperature distribution for acute bronchitis corresponds to a Gaussian distribution (Fig. 3, B), whereas the thermosection of bilateral pneumonia shows two distinct temperature maxima, reflecting the temperatures of the upper lung lobes (Fig. 3, D).

The presented thermograms of the posterior lung projection make it possible to obtain thermographic examination results with differentiation of detected pathologies**.**

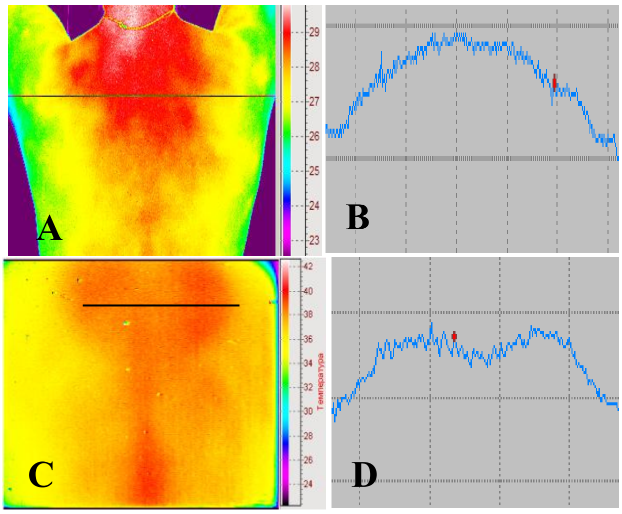

Figure 3. Thermographic image of acute bronchitis (A) and oscillographic thermosection (B); bilateral pneumonia (C) and oscillographic thermosection (D)

Visualization of the posterior lung projection with clearly defined hyperthermic zones (Fig. 4, A) was performed using software improved by the authors, which enables thermographic images with maximum informational value (Fig. 4, B, C).

Hyperthermic zones of the posterior lung projection were detected during thermographic examination with the following temperature gradients: $\Delta T_{2\text{-}1}$ = +1.24 °C; $\Delta T_{3\text{-}1}$ = +1.07 °C; $\Delta T_{4\text{-}1}$ = +0.78 °C (Fig, 4, A). Radiological examination confirmed a bilateral focal inflammatory process.

Oscillographic thermosections were obtained in different hyperthermic areas corresponding to the projections of the left and right lungs (Fig. 4, B, C). Oscillograms demonstrate two temperature maxima, marked as 1 and 2 along the analyzed lines.

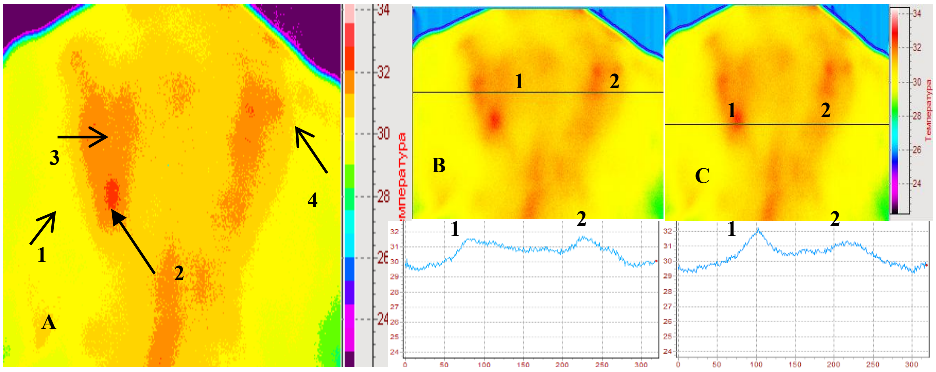

Figure 4. Posterior lung projection (A); oscillographic temperature distribution along lines (B, C)

Diseases of the bronchopulmonary system that are not always detected by other imaging diagnostic methods can be visualized using IRT.

Figure 5 shows a thermogram of the posterior lung projection with hyperthermic areas showing a temperature gradient of +(0.66 ÷ 0.71) °C, which represents a slight excess of physiological norms.

The patient's history included a pulmonary inflammatory process three years prior.

Thermographic images of lung projections in patients with a history of COVID-19 showed different thermographic patterns (Fig. 6, A, B).

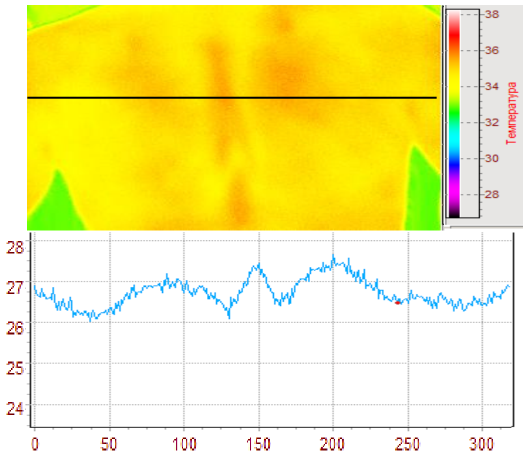

Figure 5. Posterior projection of the lungs and thermal section in the hyperthermia zone

Figure 6, A presents a thermogram obtained six months after coronavirus infection complicated by lower-lobe inflammation. Hyperthermia of the skin surface over the lung projection is visualized without clear delineation of the inflammatory zone. Maximum temperature values: left lung: +0.97 ÷ 1.17 °C; right lung: +0.51 ÷ 0.55 °C; the thermographic visualization of the posterior lung projection characteristic of a patient who had recovered from COVID-19 is demonstrated in Fig. 6, B.

The thermogram of the posterior projection of the lungs after COVID-19 with a complication – community-acquired bilateral pneumonia and the thermosection relative to the line are shown in Fig. 7.

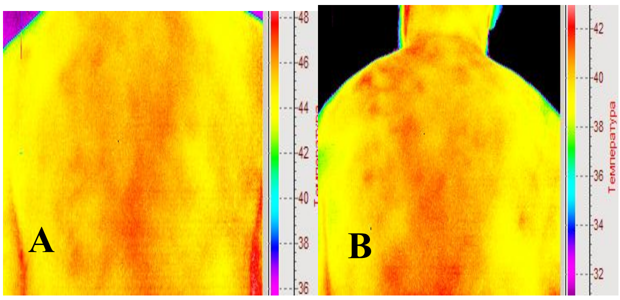

Figure 6. Thermographic visualization of the posterior projection of the lungs after a previous COVID-19 infection (A, B)

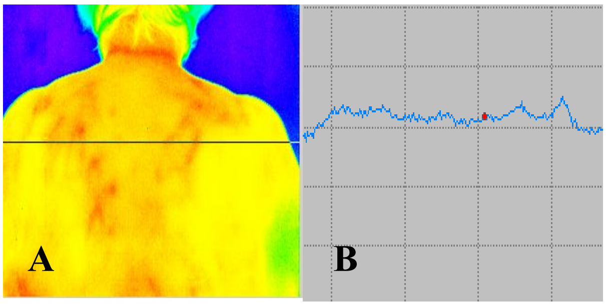

Figure 7. Posterior projection of the lungs: community-acquired bilateral pneumonia (A), thermosection relative to the line (B)

Figure 8 presents a thermogram of the posterior projection of the lungs (with a history of prior COVID-19 infection) and an oscillographic thermosection relative to the line. Hyperthermic areas are visualized with temperature gradients of +1.26 °C for the left lung and +1.16 °C for the right lung.

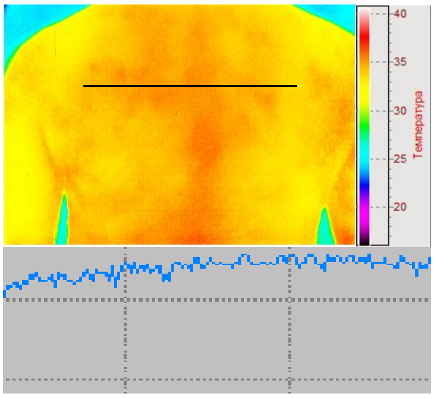

Figure 8. Posterior projection of the lungs and oscillographic temperature distribution relative to the line

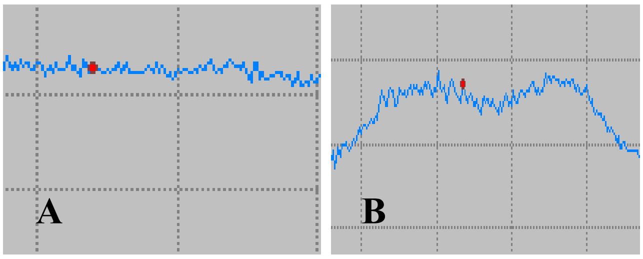

Figure 9. Thermoprofiles of COVID-19-associated pneumonia (A) and viral-bacterial pneumonia (B)

Figure 9 shows temperature thermoprofiles obtained after COVID-19-associated pneumonia (A) and pneumonia caused by other pathogenic factors (B).In thermoprofile (A), the absence of areas with clearly expressed localized temperature increase is observed; thermoprofile (B) is characterized by the presence of zones of maximum temperature, which are typical for viral-bacterial pneumonia not associated with COVID-19.

DISCUSSION

It has been shown that the thermographic image of the thermal fields of the lungs in patients after COVID-19 differs from the thermographic visualization of the lungs after bacterial or viral pneumonia not associated with COVID-19. According to the authors, this is related to changes in the intensity of infrared radiation from lung tissues, which undergo different structural pathological changes as a result of the action of the pathogenic agent.

According to the authors [12, 18], in COVID-19 infection inflammatory changes are observed in the form of numerous round “ground-glass” opacities of various sizes, which are located peripherally or basally. On thermograms, these opacities are visualized as separate hyperthermic areas.

One of the characteristic radiological signs of COVID-associated pneumonia is the “ground-glass opacity” sign – areas of reduced transparency of the lung parenchyma that have low density; against the background of “ground glass,” vessels and bronchi can be differentiated because they have a denser structure. Parenchymal consolidation is an area, often of irregular shape, that is denser than the “ground-glass” zone; therefore vessels and bronchi are not visualized. Consolidation is also caused by the accumulation of exudate in the alveolar spaces, which is characteristic of pneumonia of bacterial origin and affects the nature of infrared radiation of the skin surface of the posterior lung projection.

The obtained results of thermographic studies correlate with the findings of studies [19, 20].

As a result of the conducted work, it was found that regardless of the time elapsed since the disease, changes are visualized in the form of zones of thermal asymmetry of the skin surface of the posterior projection of the lungs.

The processed and analyzed results of the study are presented in the Table 1.

Table 1 – Processed and analyzed results of the study

№	Types of diseases			
1.	Bronchial inflammation	Exacerbation phase of chronic bronchitis	Chronic obstructive bronchitis	Acute bronchitis
1.1.	Temperature gradients	ΔT +(0.86 ÷ 1.38) °C	ΔT +(0.79 ÷ 0.89) °C	ΔT +(1.89) °C
1.2.	Thermographic visualization of the posterior lung projection	Hyperthermia zones with defined lung contours	Areas of pronounced hyperthermia in the upper and lower lobes without lung contour delineation	Hyperthermia zones with defined lung contours
1.3.	Oscillographic temperature distribution	The graphical representation of the oscillographic temperature distribution for bronchial inflammation corresponds to a Gaussian distribution.		
2.	Pulmonary inflammation	Exacerbation phase	Residual effects	
2.1.	Temperature gradients	ΔT +(0,78 ÷ 1,24) °C; ΔT +(2,31 ÷ 2,76) °C	ΔT +(0,66 ÷ 0,71) °C	
2.2.	Thermographic visualization of the posterior lung projection	Hyperthermia of the posterior lung projection with clearly defined contours	Hyperthermic areas with a slight excess above physiological norms; lung projection zones have no clear contours	
2.3.	Oscillographic temperature distribution	The graphical oscillographic temperature distribution has a symmetrical shape corresponding to a Gaussian curve	The shape corresponds to the oscillographic temperature distribution as during the exacerbation phase, but the height of the maximum is insignificant	
3.	COVID-associated pneumonia	Residual effects.		
3.1.	Temperature gradients	ΔT +(0,97 ÷ 1,17) °C; ΔT +(0,51 ÷ 0,55) °C; ΔT +(1,26 ÷ 1,17) °C		
3.2.	Thermographic visualization of the posterior lung projection	Hyperthermic point-like areas of the posterior lung projection without clearly defined contours		
3.3.	Oscillographic temperature distribution	In the thermosection, areas of elevated temperature of a diffuse nature are visualized		

CONCLUSIONS

1. A method for differential diagnosis of pathological conditions of the bronchopulmonary system using remote infrared thermography has been developed.

2. The obtained thermal images of the skin surface of the posterior lung projection and the oscillographic temperature distributions depend on the type of pathogenic agent. It has been shown that the oscillographic temperature distribution of bronchial inflammation and pneumonia not associated with COVID-19 has a symmetrical form corresponding to a Gaussian curve.

3. On the skin surface of the posterior lung projection after COVID-19-associated pneumonia, thermography visualizes scattered areas of elevated temperature without defined lung contours; on the oscillographic thermosection, separate areas of elevated temperature are observed that correspond to the hyperthermic zones on the thermogram.

4. The use of infrared thermography in pulmonology makes it possible to perform differential diagnosis of diseases and to monitor the effectiveness of therapeutic measures, in combination with other clinical methods, in order to prevent the development and progression of obstructive changes in the respiratory tract.

PROSPECTS FOR FUTURE RESEARCH

The implementation of the thermographic method of radiation diagnostics is a promising direction of modern diagnostic medicine for detecting pathological conditions of the bronchopulmonary system.

The infrared thermography method is of particular importance for the differential diagnosis of inflammatory processes of the respiratory system in pregnant women, children, and military personnel.

ETHICAL CONSIDERATIONS

The study was conducted in accordance with the bioethical principles outlined in the Helsinki Declaration "Ethical Principles for Medical Research Involving Human Subjects" and the "Universal Declaration on Bioethics and Human Rights" (UNESCO).

AUTHOR CONTRIBUTIONS

All authors made a substantial contribution to the development of both the initial and the revised versions of this article. They bear full responsibility for all aspects of the work and for resolving issues related to the accuracy or integrity of the presented information.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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