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Research article

RISK FACTORS ABLE TO CAUSE METEOROLOGICAL RESPONSES FROM THE IMMUNE SYSTEM IN PATIENTS WITH BRONCHIAL ASTHMA IN SEA MONSOON CLIMATE

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Assessing the characteristics of interseasonal meteorological responses from the immune system remains a controversial scientific problem. The aim of the study was to determine the intensity and nature of the seasonal meteorological responses from the immune system in healthy individuals and patients with bronchial asthma (BA) living in Vladivostok when exposed to favorable and unfavorable weather conditions.

The objects of the study were the immune system indicators and climatic factors selected in a single spatiotemporal aspect. Four hundred and fifty people were examined, of which 160 people were included in the control group and 290 in the group of people with BA. Based on the information-entropy analysis, the seasonal level of meteorological responses was estimated by determining the difference in values ($R_{conditional} – R_{without\ \%}$). Using the conditional entropy indicator ($R_{conditional\ \%}$) made it possible to estimate the favorable and pathogenic nature of the seasonal impact exerted by climatic factors.

In Vladivostok, weather conditions have the most active effect on the immune system of patients with bronchial asthma, decreasing by 20–30 % from winter to autumn and again sharply increasing by winter, which is the most dangerous period of the year for patients with bronchial asthma. The healthy population of the city has a peak meteorological reaction in winter. Unfavorable and favorable weather conditions are characterized by different levels of impact. In general, the climate in Vladivostok has a predominantly pathogenic orientation for the entire city population. For patients with bronchial asthma, winter and spring are the most unfavorable periods. The immune system of people with bronchial asthma has been shown to actively react to the temperature regime, namely, to low temperatures in winter and to high temperatures with high humidity in summer. By autumn, an increase in health-improving properties of the climate is observed, especially for healthy people.

Keywords: *bronchial asthma, healthy individuals, monsoon climate, weather conditions, meteorological immune response, seasonal changes, immune system, information-entropy analysis.*

Diseases of the respiratory system are largely weather-dependent. About 10 % of the global population suffers from such pathologies [1–4]. As the global climate is changing rapidly, assessing meteorological responses in patients with respiratory diseases, taking interseasonal favorable and unfavorable climatic conditions into account, remains a controversial scientific problem [5, 6].

The immune system as a most significant homeostatic one occupies the leading place in generating adaptive responses to weather exposures [2, 5, 7]. Weather exposure is proven to be able to induce an immune response in the human body, especially in people with respiratory diseases. This response manifests itself either through greater immune reactivity or depressed cellular and humoral components of the immunity [1, 8, 9]. Sensitivity of the immune system changes in different seasons and depends on the ratio between favorable and unfavorable weather conditions. Therefore, seasonality is an important environmental factor, which influences immune responses in addition to specific genetic factors. It can affect variations in incidence rates

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and severity of immune-mediated diseases [10, 11].

At present, pathways responsible for maintaining seasonal variations have not been fully studied. Day length and outdoor temperature can be considered environmental signals able to coordinate seasonal phenotypes of the immune system [12, 13]. These factors induce changes in immune reactivity of the body, which, on one hand, are markers of exposure to unfavorable weather conditions, but on the other hand, they support subsequent development of a disease, aggravate an already present one or make it chronic [11, 14]. Certain success has been made in assessing peculiarities of effects produced by weather exposures on the immune system of patients with respiratory diseases as regards extreme air temperatures, high humidity and drastic interday changes in meteorological parameters [5, 15]. Favorable weather conditions largely depend on regional specificity of interseasonal changes in climate and weather factors. Monsoon climate is typical for Vladivostok, which means considerable interseasonal and interday changes in meteorological parameters [7, 16]. Unfavorable weather conditions in the southern Far East include high humidity combined with drastic fluctuations in air temperatures, frontal and circulatory changes in the atmosphere, strong winds, low air temperatures in winter, and stuffy air in summer as a non-specific irritator for the immune system of patients with respiratory diseases. Favorable weather conditions in the region mean absence of any extreme deviations in meteorological parameters [5, 14].

Effects produced by natural climatic conditions on systemic immune processes are hard to examine due to methodological difficulties in identifying specific features of an immune response. The widespread correlation method is not always revealing in systemic studies, especially when examining poorly compared human and environmental systems with weak correlations, as a rule, not higher than $r = 0.5$ [16, 17]. Stronger correlations are observed in experimental and clinical studies when examined objects are compared with each other directly or in population and group studies with maximum possible approximation of Human and Environment systems in the same spatiotemporal aspect [7]. It is well-known that interactions between the most complicated systems 'Human' and 'Climate' generate information noise as a process of entropy development in these interactions[1] [18–20]. Use of information-entropy analysis makes it possible to detect even weak dependence trends by assessing levels of uncertainty and randomness of processes occurring in each system or when they interact with each other [18–20]. **The aim of this study** was to determine the intensity and nature of seasonal meteorological responses from the immune system in healthy individuals and patients with bronchial asthma (BA) living in Vladivostok when exposed to favorable and unfavorable weather conditions.

Materials and methods. Research objects were represented by peripheral blood immunity parameters identified in healthy people and BA patients residing in Vladivostok. Climatic parameters were fixed in the unified spatiotemporal aspect. Over 2013–2024, 450 people were examined (their average age was 56.5 ± 4.8 years), who had been living in Vladivostok for ≥ 10 years. Of them, 160 people were included in the control group (conditionally healthy people) and 290 in the group of BA patients, the disease having mild severity and partially controlled clinical course. BA was diagnosed in accordance with the Global Strategy for Bronchial Asthma Treatment and Prevention, Federal Clinical Guidelines on Bronchial Asthma Diagnostics and Treatment, and the International Classification of Diseases, 10th revision (ICD-10). The following exclusion criteria were applied: acute communicable diseases, chronic diseases in the exacerbation phase, chronic heart failure in decompen-

[1] Teoriya informatsii v meditsine: respublikanskii mezhvedomstvennyi sbornik nauchnykh rabot [Information theory in medicine: republican interdepartmental collection of research works]. In: Associated Professor V.A. Bandarin ed. Minsk, "Belarus" Publ., 1974, 269 p. (in Russian).

sation, or contacts with adverse and hazardous occupational factors. The study was accomplished in conformity with the requirements fixed in the WMA Declaration of Helsinki (2013 Revision) and approved by a local ethics committee (the meeting protocol No. 1 dated January 08, 2024). All participants provided their informed voluntary consent.

The immunological profile of the examined groups is provided in Table.

Cellular immunity indicators (BD Multitest 6-color TBNK, USA) were measured by flow cytometry (BD FACS Canto II, USA); cytokine levels in blood serum (tumor necrosis factor α (TNF-α), interferon γ (IFN-γ), interleukin 4 (IL-4), IL-6, IL-10, IL-17A with the Cytometric Bead Array, BD, USA). Phagocytic and oxidative activity of neutrophils was measured by using commercial kits PHAGOTEST (BD, USA) and BURSTEST (PHAGOBURST) (BD, USA).

Six meteorological parameters were selected according to data provided by Primorskii Center on Hydrometeorology and Environmental Monitoring (Primgidromet) including wind speed and direction, precipitations, air temperature, air humidity, and atmospheric pressure, which corresponded to a day and time when patients were being examined. These parameters were selected bearing seasonality and their benign or adverse effects in mind. We selected days when meteorological parameters were unfavorable for people (drastic interday contrasts in air temperatures > 6 °C, atmospheric pressure changeability > 5 mbar, and wind speed > 3 m/sec). Unfavorable weather also included days with rains, snow, and other weather events, high air humidity > 60 %, stuffy days (high air humidity > 60 % with an air temperature > +20 °C), low air temperatures in winter < -18 °C and high wind speeds. Slight interday changes in meteorological parameters within safe hygienic standards were taken as favorable [5, 21, 22].

All data were statistically analyzed with STATISTICA 10.0 software package for Windows OS. The results were given as median values (*Me*) and quartiles (*Q25*, *Q75*). The obtained distributions were checked for normalcy using Kolmogorov – Smirnov test. Homogeneity of variance was estimated using Levene's test. Significance of intergroup differences was estimated using Mann – Whitney test. Critical level of significance (*p*) in testing hypotheses was taken as < 0.001, < 0.01, and < 0.05.

Table

Immunological profile of the examined people

Indicators	Bronchial asthma, n = 290	Control, n = 160
T-lymphocytes ($CD3^+$), %	39.6 (35.8–41.9), $p = 0.062$	45.6 (41.1–47.6)
T-helpers ($CD3^+CD4^+$), %	34 (31.8–39.2), $p = 0.069$	40.2 (37.1–45.6)
B-lymphocytes ($CD3^-CD19^+$), %	9.6 (8.7–10.2), $p = 0.044$*	13.1 (11.2–14.8)
Natural killers ($CD16^+CD56^+$), %	11.4 (9.2–14.6), $p = 0.04$*	17.5 (15.3–19.7)
T-cytotoxic cells ($CD3^+CD8^+$), %	16.4 (13.4–18.2), $p = 0.02$*	22.6 (19.1–25.8)
CD4/CD8 index, a.u.	1.3 (1.22–1.43), $p = 0.008$**	1.7 (1.56–1.85)
Tumor necrosis factor-α, pg/ml	67.2 (64.1–76.8), $p < 0.001$***	46.3 (43.2–48.9)
Interferon-γ, pg/ml	91.4 (87.2–96.3), $p = 0.086$	103.5 (91.6–122.7)
Interleukin-4, pg/ml	98.1 (84.6–109.1), $p = 0.044$*	77.9 (69.2–81.0)
Interleukin-6, pg/ml	93.1 (83.9–96.7), $p < 0.001$***	38.2 (35.7–39.0)
Interleukin-10, pg/ml	27.5 (21.7–32.8), $p = 0.084$	32.4 (30.1–35.7)
Interleukin-17A, pg/ml	907.2 (852.0–964.2), $p < 0.001$***	378.4 (360.0–395.1)
Neutrophil phagocytic activity, %	58.7 (52.6–65.9), $p = 0.052$	65.0 (57.4–71.6)
Phagocytic reserve, a.u.	0.8 (0.76–0.84), $p < 0.001$***	1.2 (1.18–1.29)
Nitroblue tetrazolium test, %	8.0 (7.78–8.2), $p = 0.022$*	13.0 (11.4–15.1)
Reserve of nitroblue tetrazolium test, a.u.	0.82 (0.79–0.85), $p = 0.008$**	1.31 (1.28–1.42)

Note: p shows significant differences between bronchial asthma and control; * means $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$; a.u. means arbitrary units.

Data on the immune system and climatic parameters were analyzed using the information-entropy analysis. Information redundancy (R %) was used as a criterion to determine reliability of information transfer. That is, the higher is the information redundancy, the more reliable is information transfer; on the contrary, a decline in R % indicates growing system randomness and uncertainty of processes[2] [22].

Initially, unconditional entropy $R_{uncond\,\%}$ was calculated, which described uncertainty and randomness of ongoing processes in the immune system. The algorithm for calculating the unconditional entropy $R_{uncond\,\%}$ value included the following:

1) calculating the probability (p_i), which allowed transferring all initial data into relative values: $pi = \frac{i}{\sum i}$;

2) estimating the entropy value H, using the Shannon's formula:

$$H = -\sum_{i=1}^{i} p_i \ \log_2 p_i \ ;$$

3) determining the information redundancy coefficient (R %): $R\,\% = (1 - \frac{H_{actual}}{H_{max}})$, which compared the actual entropy H to the maximum possible one, the latter depending on the number of initial components (immune indicators and meteorological factors).

Next, conditional entropy $R_{cond\,\%}$ was found, which allowed estimating uncertainty of the immune system upon exposure to meteorological factors. This conditional entropy was established relying on the probability (p) of combining values in the climatic and immune systems:

$$p(A/B) = p(A) \cdot (p(A)p(B)),$$

where A is the immune system, B is climate, with subsequent establishment of entropy (H) and information redundancy R % in the combined variant of probabilities. The difference between the conditional and unconditional entropy ($R_{cond} - R_{uncond\ \%}$) described the level of meteorological sensitivity in the city population per seasons. Analysis of the conditional entropy ($R_{cond\,\%}$) in healthy people and BA patients under favorable and unfavorable weather conditions made it possible to estimate pathogenicity and health-improving capacity of climatic conditions.

Results and discussion. The information redundancy coefficient ($R_{cond\,\%} - R_{uncond\,\%}$) was determined per seasons in healthy participants and BA patients based on the calculations of the complex response in the immune system indicators upon exposure to the analyzed meteorological parameters (Figure 1).

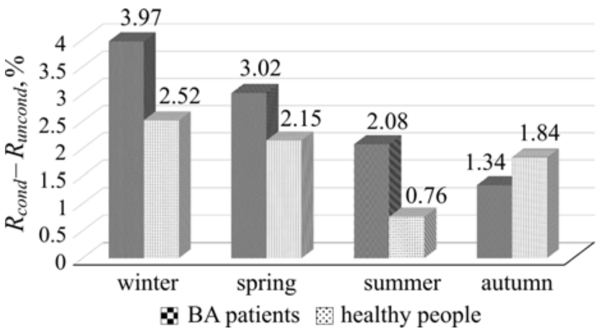

Figure 1. Meteorological response ($R_{cond\,\%} - R_{uncond\,\%}$) of the immune system influenced by seasonal climatic changes in Vladivostok

Comparative analysis revealed a significant meteorological response from the immune system for different groups of the examined participants. In BA patients, an active meteorological response was detected in winter-spring and summer seasons. The maximum meteorological response was detected in healthy people in winter (Figure 1).

In general, inter-seasonal differences in the integral meteorological response were examined based on analyzing the value of the indicator $R_{cond\,\%}$, which described the conditional entropy considering both favorable and unfavorable weather types. The value of the conditional entropy ($R_{cont\,\%}$) quite clearly

[2] Teoriya informatsii v meditsine: respublikanskii mezhvedomstvennyi sbornik nauchnykh rabot [Information theory in medicine: republican interdepartmental collection of research works]. In: Associated Professor V.A. Bandarin ed. Minsk, "Belarus" Publ., 1974, 269 p. (in Russian).

pointed at the determinative relationship between the immune system state and the number of unfavorable weathers in BA patients and healthy people. The greatest negative effects are produced on people by unfavorable weather in winter (in BA patients, $R_{cond\,\%}$ = 13.8; in healthy people, $R_{cond\,\%}$ = 9.3) and spring (in BA patients, $R_{cond\,\%}$ = 9.4; in healthy people, $R_{cond\,\%}$ = 6.0) (Figure 2). The lowest effects are produced by unfavorable weather *on BA patients* in autumn ($R_{cond\,\%}$ = 5.0); *on healthy people,* in summer ($R_{cond\,\%}$ = 2.7) and autumn ($R_{cond\,\%}$ = 3.5).

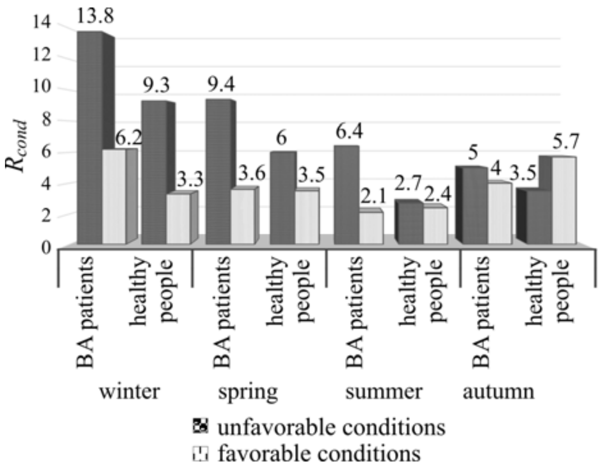

Figure 2. Interseasonal effects produced by unfavorable and favorable weather conditions on the immune system in healthy people and BA patients

Favorable weather conditions affect the immune system considerably weaker (by 2–2.5 times) in winter and spring. As a result, the maximum health-improving response to favorable weather conditions is detected in BA patients in winter ($R_{cond\,\%}$ = 6.2) and autumn ($R_{cond\,\%}$ = 4.0); in healthy people, in autumn ($R_{cond\,\%}$ = 5.7) and spring ($R_{cond\,\%}$ = 3.5).

Given the ongoing global climate change, investigating peculiar effects produced on natural climatic conditions on the immune system is an important issue that has not been given enough attention. Within investigating climate-induced effects, certain success has been reached in estimating regional peculiarities of body responses mostly to extreme air temperatures, high humidity, strong winds and drastic changes of meteorological parameters in neighboring days [4, 23].

Effects produced by climatic conditions are largely determined by regional conditions. Monsoon climate is typical for Vladivostok involving seasonal changes in the atmospheric circulation: winds from the continent prevail in winter whereas winds from the ocean are usual for summer. In spring, powerful air masses from the continent (Siberian anti-cyclone with high atmospheric pressure) are destroyed and replaced with humid air from the Pacific Ocean with low atmospheric pressure; the opposite situation occurs in autumn. Therefore, stable weather with low temperatures, strong winds, low humidity and precipitations is typical for winter; in summer, rainy weather is typical with sometimes weak winds, high air temperatures and humidity. Weather tends to be rather changeable in transitional seasons including drastic interday changes in wind speed and direction, atmospheric pressure, humidity and other meteorological parameters [7, 16, 22].

Accumulative data indicate that heat or cold waves and temperature fluctuations may create elevated risks of respiratory mortality and morbidity. Changes in the air temperature are a risk factor able to exacerbate bronchial asthma. In addition, heating in winter may increase indoor air dryness and considerable differences between indoor and outdoor temperatures can also have a rather adverse effect on BA patients [3, 4]. Exposure to cold air leads to growing granulocyte and macrophage counts, induces mucociliary dysfunction, damages the epithelial barrier, and remodels the airways involving combined eosinophilic and neutrophilic inflammation. Cold stress induces changes in the metabolic rate, sympathetic activity, fat acid oxidation, energy homeostasis and immune responses [9, 24, 25]. Temperature stress may promote repolarization of the T-helper immune response towards Th2 phenotype [26, 27].

For human body, creating protection from cold involves high metabolic costs since heat is mostly produced due to mitochondrial oxidative metabolism. Activation of pathways for receiving heat (cellular oxidative metabolism, muscle contractions) or losing it (sweating, greater blood inflow to skin) creates elevated loads on immune and metabolic resources [1]. The key role in perceiving and transferring temperature signals belongs to the transient receptor potential (TRP) channels, which excite sensory nerves in the airways thereby inducing abnormal physiological and pathological responses in the respiratory system. A recent study has shown that activation of TRPM8 in bronchial epithelial cells upon cold exposure has led to a considerable increase in expression of important genes responsible for regulating cytokines and chemokines including IL-1α, -1β, -4, -6, -8, -10 and -13, GM-CSF and TNF-α [8, 28].

In addition, some recent studies have also shown several processes in the immune system to be associated with creation of a specific immune profile depending on a season. Multicentered studies have revealed that more than 400 protein-encoding mRNA genes in leucocytes have seasonal expression profiles; the cellular structure of blood also changes depending on a season. A significant correlation with seasonal changes is typical for production of cytokines, $CD4^+$ and $CD8^+$ sub-populations of T-cells. The immune system has been shown to have a pro-inflammatory trascriptome profile with elevated levels of soluble receptor IL-r and C-reactive proteins in winter [10, 12].

For BA patients, similar dynamics is unfavorable addition to the already existing inflammatory background. In summer, high air temperatures combined with high air humidity create an elevated meteorological burden for BA patients whereas seasonal conditions produce quite sparing effects on healthy people. A relationship has been detected between asthma exacerbations and interday air temperature changeability. A 1 °C rise in an interday temperature range is largely associated with a growing number of visits to emergency wards by BA patients [23, 29]. Autumn has an opposite effect on healthy people and BA patients in Vladivostok since meteorological responses in healthy people are more intense than those in BA patients. Given that autumn is the most favorable season in this region due to the longest duration of stable, warm and sunny days, positive meteorological responses can be assumed among the city population. However, a drastic transition from a mild meteorological response in autumn to the maximum intensive one in winter can create a high risk of BA exacerbations when weather turns to winter cold temperatures.

The number of favorable and unfavorable weathers creating seasonal peculiarities of meteorological responses makes it possible to estimate either pathogenic or health-improving effects on the immune system in BA patients. The indicator $R_{cond\,\%}$, which described conditional entropy, was used as a calculation unit; it allowed for negentropy occurring upon direct exposure to weather conditions. Analysis of the $R_{cond\,\%}$ values has revealed the climate in Vladivostok to be unfavorable for BA patients in any season but especially so in winter and spring due to low air temperatures and strong winds. Meteorological responses in BA patients become less pathogenic only in autumn, which indicates that this season is somewhat favorable for them. Health-improving effects produced by favorable weather are detected in all seasons through the year but they are less pronounced. Thus, the lowest $R_{cond\,\%}$ value for BA patients was detected in summer.

Climatic conditions in Vladivostok create a substantial burden on healthy people as well due to unfavorable weather conditions, especially in winter and spring. Summer has the lowest adverse effect on healthy people, which gives evidence of summer peculiarities of monsoon climate being within adaptation capabilities of a healthy person. Autumn is the most favorable season with high health-improving effects for healthy people due to intensified compensatory-adaptive responses [7, 22].

Conclusion. Use of information-entropy analysis has made it possible to estimate the intensity and nature of meteorological responses from the immune system in Vladivostok population upon exposure to monsoon climate. In BA patients, meteorological immune responses have been established to grow by 20–30 % during a year with a drastic increase by winter, which is the most dangerous season for them. By autumn, an increase in health-improving properties of the climate is observed. Healthy people in Vladivostok tend to have weaker meteorological responses in winter, spring and summer, while their meteorological sensitivity grows in autumn. Analysis of meteorological responses in healthy people has revealed an insignificant rise beyond safe ranges in winter, which indicates there are developing adaptive responses of the immune system upon weather exposures. Effects produced by unfavorable and favorable weather conditions on the immune system in BA patients have been established to be different throughout a year. Temperatures are a risk factor for the immune system in BA patients, namely, low air temperatures in winter and high ones together with high air humidity in summer.

In general, the climate in Vladivostok has a predominantly pathogenic orientation for BA patients and, to a lesser extent, for healthy people. BA patients are especially susceptible in winter, spring and summer. Autumn is the most favorable season for the entire city population, especially for healthy people due to immune responses in them having a health-improving effect.

Our findings make it possible to develop preventive activities aimed at mitigating effects produced by weather conditions on patients with bronchial asthma, especially given the ongoing global climate change.

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References

1. Maloney E., Duffy D. Deciphering the relationship between temperature and immunity. *Discov. Immunol.*, 2024, vol. 3, no. 1, pp. kyae001. DOI: 10.1093/discim/kyae001
2. Magomedova Z.S., Kagramanova Z.S. Literaturnyi obzor. Sovremennye predstavleniya o funktsional'nykh osobennostyakh immunnoi sistemy [Literature review. Modern ideas about functional features of the immune system]. *Nauchnoe obozrenie. Meditsinskie nauki*, 2016, no. 2, pp. 68–80. Available at: https://science-medicine.ru/ru/article/view?id=851 (May 16, 2025) (in Russian).
3. Zhou Y., Pan J., Xu R., Lu W., Wang Y., Liu T., Fan Z., Li Y. [et al.]. Asthma mortality attributable to ambient temperatures: A case-crossover study in China. *Environ. Res.*, 2022, vol. 214, pt 4, pp. 114116. DOI: 10.1016/j.envres.2022.114116
4. Zhao Y., Huang Z., Wang S., Hu J., Xiao J., Li X., Liu T., Zeng W. [et al.]. Morbidity burden of respiratory diseases attributable to ambient temperature: a case study in a subtropical city in China. *Environ. Health*, 2019, vol. 18, no. 1, pp. 89. DOI: 10.1186/s12940-019-0529-8
5. Uyanaeva A.I., Rassulova M.A., Maksimova G.A. Sovremennye tekhnologii otsenki klimata i pogody dlya mediko-meteorologicheskogo prognozirovaniya [Up-to-date technologies of climate and weather assessment for medical-meteorological forecasting]. *Voprosy kurortologii, fizioterapii i lechebnoi fizicheskoi kul'tury*, 2018, vol. 95, no. 2–2, pp. 134 (in Russian).
6. Vasilenko A.M., Agasarov L.G., Sharipova M.M. The physical methods for the prevention and management of weather-dependent pathological reactions (a literature review). *Voprosy kurortologii, fizioterapii i lechebnoi fizicheskoi kul'tury*, 2016, vol. 93, no. 5, pp. 58–65. DOI: 10.17116/kurort2016558-65 (in Russian).
7. Veremchuk L.V., Vitkina T.I., Mineeva E.E., Kondratyeva E.V. Assessing short-term weather-induced immune response in Russian far east residents with respiratory diseases. *Russian Open Medical Journal*, 2023, vol. 12, no. 2, pp. e0203. DOI: 10.15275/rusomj.2023.0203
8. Liu H., Hua L., Liu Q., Pan J., Bao Y. Cold Stimuli Facilitate Inflammatory Responses Through Transient Receptor Potential Melastatin 8 (TRPM8) in Primary Airway Epithelial Cells of Asthmatic Mice. *Inflammation*, 2018, vol. 41, no. 4, pp. 1266–1275. DOI: 10.1007/s10753-018-0774-y
9. Liao W., Zhou L., Zhao X., Song L., Lu Y., Zhong N., Yang P., Sun B., Zhang X. Thermoneutral housing temperature regulates T-regulatory cell function and inhibits ovabumin-induced asthma development in mice. *Sci. Rep.*, 2017, vol. 7, no. 1, pp. 7123. DOI: 10.1038/s41598-017-07471-7

10. Ter Horst R., Jaeger M., van de Wijer L., van der Heijden W.A., Janssen A.M.W., Smeekens S.P., Brouwer M.A.E., van Cranenbroek B. [et al.]. Seasonal and Nonseasonal Longitudinal Variation of Immune Function. *J. Immunol.*, 2021, vol. 207, no. 2, pp. 696–708. DOI: 10.4049/jimmunol.2000133

11. Gruzdeva A.Yu., Saltykova M.M., Bobrovnitskiy I.P., Balakaeva A.V., German S.V. The influence of seasons on the development of exacerbations of the most common diseases of the circulatory system. Gender and age peculiarities. *Gigiena i sanitariya*, 2019, vol. 98, no. 8, pp. 839–844. DOI: 10.18821/0016-9900-2019-98-8-839-844 (in Russian).

12. Dopico X.C., Evangelou M., Ferreira R.C., Guo H., Pekalski M.L., Smyth D.J., Cooper N., Burren O.S. [et al.]. Widespread seasonal gene expression reveals annual differences in human immunity and physiology. *Nature Communications*, 2015, vol. 6, pp. 7000. DOI: 10.1038/ncomms8000

13. Wyse C., O'Malley G., Coogan A.N., McConkey S., Smith D.J. Seasonal and daytime variation in multiple immune parameters in humans: Evidence from 329,261 participants of the UK Biobank cohort. *iScience*, 2021, vol. 24, no. 4, pp. 102255. DOI: 10.1016/j.isci.2021.102255

14. Saltykova M.M., Bobrovnitskii I.P., Banchenko A.D. Main aspects of studying the influence of meteotropic reactions. *Rossiiskii zhurnal vosstanovitel'noi meditsiny*, 2018, no. 4, pp. 19–24 (in Russian).

15. Davis R.E., Hondula D.M., Sharif H. Examining the diurnal temperature range enigma: why is human health related to the daily change in temperature? *Int. J. Biometeorol.*, 2020, vol. 64, no. 3, pp. 397–407. DOI: 10.1007/s00484-019-01825-8

16. Veremchuk L.V., Vitkina T.I., Mineeva T.T., Antonyuk M.V. Predicting the response of the lung function in patients with chronic obstructive pulmonary disease under the influence of climate-technogenic factors. *Byulleten' fiziologii i patologii dykhaniya*, 2021, no. 82, pp. 53–61. DOI: 10.36604/1998-5029-2021-82-53-61 (in Russian).

17. Vitkina T.I., Veremchuk L.V., Mineeva E.E., Gvozdenko T.A., Antonyuk M.V., Novgorodtseva T.P., Grigorieva E.A. The influence of weather and climate on patients with respiratory diseases in Vladivostok as global health implication. *J. Environ. Health Sci. Eng.*, 2019, vol. 17, no. 2, pp. 907–916. DOI: 10.1007/s40201-019-00407-5

18. Botoeva N.K. Informatsionno-entropiinyi analiz v otsenke vliyaniya meteofaktorov na bol'nykh gipertonicheskoi bolezn'yu [Information-entropy analysis in evaluating meteorological factors' impact on patients with hypertension]. *Mezhdunarodnyi zhurnal prikladnykh i fundamental'nykh issledovanii*, 2010, no. 12, pp. 34–35. Availible at: https://applied-research.ru/ru/article/view?id=970 (May 16, 2025) (in Russian).

19. Zubatkina I.S., Dobrodeeva L.K., Malachova M.Y., Kryzhanovskiy E.V., Zubatkina O.V. Entropy as a parameter for the immune state estimation. *Original'nye issledovaniya*, 2012, vol. 4, no. 1, pp. 57–61 (in Russian).

20. Zilov V.G., Kirichuk V.F., Fudin N.A. Experimental justification of the chaos hierarchical organization in nervous-muscular physiology. *Vestnik novykh meditsinskikh tekhnologii*, 2019, vol. 26, no. 1, pp. 133–136. DOI: 10.24411/1609-2163-2019-16375 (in Russian).

21. Yakovlev M.Yu., Saltykova M.M., Banchenko A.D., Fedichkina T.P., Nagornev S.N., Khudov V.V., Balakaeva A.V., Bobrovnitskii I.P. Osnovnye mekhanizmy, obuslavlivayushchie razvitie meteotropnykh reaktsii [Main mechanisms underlying the development of meteotropic reactions]. *Mezhdunarodnyi zhurnal prikladnykh i fundamental'nykh issledovanii*, 2018, no. 10, pp. 187–192. Available at: https://applied-research.ru/ru/article/view?id=12440 (May 16, 2025) (in Russian).

22. Rakhmanov R.S., Tarasov A.V. Adaptatsionnye reaktsii organizma pri vliyanii morskogo klimata na zdorov'e naseleniya v regionakh Rossii: monografiya [Adaptive responses of the human body under the impact of sea climate on health of Russian regional populations: a monograph]. Nizhnii Novgorod, OOO «Stimul-ST» Publ., 2018, 100 p. (in Russian).

23. Lei X., Liu L., Chen R., Liu C., Hong J., Cao L., Lu Y., Dong X. [et al.]. Temperature changes between neighboring days and childhood asthma: a seasonal analysis in Shanghai, China. *Int. J. Biometeorol.*, 2021, vol. 65, no. 6, pp. 827–836. DOI: 10.1007/s00484-020-02057-x

24. Yin Q., Wang J. The association between consecutive days' heat wave and cardiovascular disease mortality in Beijing, China. *BMC Public Health*, 2017, vol. 17, no. 1, pp. 223. DOI: 10.1186/s12889-017-4129-7

25. Han A., Deng S., Yu J., Zhang Y., Jalaludin B., Huang C. Asthma triggered by extreme temperatures: From epidemiological evidence to biological plausibility. *Environ. Res.*, 2023, vol. 216, pt 2, pp. 114489. DOI: 10.1016/j.envres.2022.114489

26. Sangkharat K., Mahmood M.A., Thornes J.E., Fisher P.A., Pope F.D. Impact of extreme temperatures on ambulance dispatches in London, UK. *Environ. Res.*, 2020, vol. 182, pp. 109100. DOI: 10.1016/j.envres.2019.109100

27. Xu R., Zhao Q., Coehlo M.S.Z.S., Saldiva P.H.N., Abramson M.J., Li S., Guo Y. Socioeconomic level and associations between heat exposure and all-cause and cause-specific hospitalization in 1,814 Brazilian cities: A nationwide case-crossover study. *PLoS Med.*, 2020, vol. 17, no. 10, pp. e1003369. DOI: 10.1371/journal.pmed.1003369

28. Millqvist E. TRP channels and temperature in airway disease–clinical significance. *Temperature (Austin)*, 2015, vol. 2, no. 2, pp. 172–177. DOI: 10.1080/23328940.2015.1012979

29. Fang J., Song J., Wu R., Xie Y., Xu X., Zeng Y., Zhu Y., Wang T. [et al.]. Association between ambient temperature and childhood respiratory hospital visits in Beijing, China: a time-series study (2013–2017). *Environ. Sci. Pollut. Res.*, 2021, vol. 28, no. 23, pp. 29445–29454. DOI: 10.1007/s11356-021-12817-w

Veremchuk L.V., Vitkina T.I. Risk factors able to cause meteorological responses from the immune system in patients with bronchial asthma in sea monsoon climate. Health Risk Analysis, 2025, no. 3, pp. 32–40. DOI: 10.21668/health.risk/2025.3.04.eng

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