

<https://doi.org/10.47183/mes.2026-508>



ASSESSMENT OF CELLULAR AND HUMORAL IMMUNE RESPONSES IN MILITARY PERSONNEL IN THE ARCTIC UNDER LONG-TERM EXPOSURE TO ENVIRONMENTAL AND OCCUPATIONAL FACTORS

Rofail S. Rakhmanov^{1✉}, Denis A. Narutdinov², Elena S. Bogomolova¹, Sergey A. Razgulin¹

¹ Privolzhsky Research Medical University, Nizhny Novgorod, Russia

² Prof. V.F. Voyno-Yasenetsky Krasnoyarsk State Medical University, Krasnoyarsk, Russia

Introduction. When carrying out professional activities or living for a long time in the extreme conditions of the Far North, the risk of developing immunopathological conditions increases.

Objective. To assess cellular and humoral immune responses in military personnel deployed to the Arctic.

Materials and methods. The study involved 60 contracted military personnel (mean age: 37.3 ± 3.1 years) stationed in the Far North, with the median deployment duration reaching 7 [5; 9] years. This cohort, comprising individuals in medical categories 1 and 2, underwent evaluation during their annual routine medical examination in the summer. IgA, IgM, and IgG levels were quantified by gel electrophoresis using SAS-1plus and SAS-2 equipment. B and T lymphocytes (including T helper and T killer cells), NKT cells, activated NK cells, and NK lymphocytes were determined by flow cytometry with the CELL-DYN RUBY analyzer (MAPSS technology). Cell immunophenotyping (to identify lymphocyte subpopulations, NK cells, etc.) was performed using fluorescently labeled monoclonal antibodies against CD3, CD4, CD8, CD19, and CD16/56. Nonspecific adaptive reactions were profiled according to Garkavi's method based on the percentage of blood lymphocytes. Occupational health assessment of working conditions was carried out in accordance with Guidelines R 2.2.2006-05. Statistical analysis was performed using IBM SPSS Statistics 6.1.

Results. Analysis of leukocyte differentials showed that in 54 (90%) military personnel, the median band neutrophil percentage (0.5 [0.3; 0.8]) was statistically significantly below the reference range. According to Garkavi's profiling of nonspecific adaptive responses, a "training reaction" was identified in 33 (55.0%) participants, "calm activation" in 22 (36.7%), and "increased activation" in only 5 (8.3%). Analysis of humoral immunity revealed greater variability in individual IgM levels; in 11.7% of cases, values were reduced to 0.22–0.24 g/L. Parameters of T-cell immunity showed multidirectional changes: the proportions of T, NKT, and NK cells were decreased in 21 (35.0%), 14 (23.3%), and 7 (11.7%) participants, respectively, while elevated NK-cell percentages were observed in 30 (50.0%) military personnel. Within the T-lymphocyte pool, the proportion of cytotoxic T cells (T killer cells) was reduced in 16 (26.7%) subjects, while in 29 (48.3%) individuals these values exceeded the physiological norm. The working conditions of the military personnel involved exposure to a complex of adverse occupational and environmental factors, including significant physical dynamic and static loads, high sensory and emotional stress, and irregular shift work with night rotations.

Conclusions. Adaptation to the extreme Arctic environment varies individually and depends on the body's adaptive capacity. The immune response in military personnel stationed in the Arctic — characterized by cellular immune imbalance, compromised humoral immunity, and developing immunoglobulin deficiency — along with deployment conditions, underscores the need for a comprehensive health status assessment in this cohort. This enables early detection of abnormalities and supports the planning and implementation of targeted preventive measures.

Keywords: Arctic; contracted military personnel; years of service; living and working conditions; leukocytes; humoral and cellular immunity; non-specific adaptive reactions

For citation: Rakhmanov R.S., Narutdinov D.A., Bogomolova E.S., Razgulin S.A. Assessment of cellular and humoral immune responses in military personnel in the Arctic under long-term exposure to environmental and occupational factors. *Extreme Medicine*. 2026. <https://doi.org/10.47183/mes.2026-508>

Funding. The study was conducted without sponsorship.

Compliance with the ethical principles. The study was approved by the local ethics committee of the Privolzhsky Research Medical University (Minutes No. 4 dated 14 Mar. 2022). All participants signed informed consent to participate in the study and for the use of anonymized medical data.

Potential conflict of interest. The authors declare no conflict of interest.

AI tools use. The authors declare no AI tools were used in the preparation of this article.

✉ Rofail S. Rakhmanov raf53@mail.ru

Received: 16 Apr. 2026 **Revised:** 16 June 2026 **Accepted:** 30 June 2026 **Online first:** 16 Sep. 2026

УДК 613.12:613.646:612.112.9:612.42

ОЦЕНКА КЛЕТОЧНЫХ И ГУМОРАЛЬНЫХ ИММУННЫХ РЕАКЦИЙ У ВОЕННОСЛУЖАЩИХ В АРКТИКЕ ПРИ ДЛИТЕЛЬНОМ ВЛИЯНИИ ФАКТОРОВ СРЕДЫ ОБИТАНИЯ И ТРУДОВОГО ПРОЦЕССА

Р.С. Рахманов¹, Д.А. Нарутдинов², Е.С. Богомолова¹, С.А. Разгулин¹¹ Приволжский исследовательский медицинский университет, Нижний Новгород, Россия² Красноярский государственный медицинский университет им. профессора В.Ф. Войно-Ясенецкого, Красноярск, Россия

Введение. При осуществлении профессиональной деятельности или длительном проживании в экстремальных условиях районов Крайнего Севера возрастает риск развития иммунопатологических состояний.

Цель. Оценка реакции факторов клеточного и гуморального иммунитета у военнослужащих, осуществляющих профессиональную деятельность в условиях Арктики.

Материал и методы. Исследование проведено с участием 60 человек (средний возраст $37,3 \pm 3,1$ года), проходящих службу по контракту в условиях Крайнего Севера (медианная длительность профессиональной деятельности в данных условиях достигала 7 [5; 9] лет). Изучение показателей выполнено у лиц 1-й и 2-й групп здоровья в ходе ежегодного планового медицинского обследования в летний период. Методом гелевого электрофореза на оборудовании «SAS-1plus» и «SAS-2» оценивали уровни IgA, IgM, IgG. Методом проточной цитометрии на анализаторе CELL-DYN RUBY с технологией MAPSS определяли В- и Т-лимфоциты (в т.ч. Т-хелперы, Т-киллеры), TNK-клетки, активированные NK-клетки, NK-лимфоциты. Для иммунофенотипирования клеток (определения субпопуляций лимфоцитов, NK-клеток и др.) применяли моноклональные антитела CD3, CD4, CD8, CD19, CD16/56, меченные флуоресцентными красителями. По процентному содержанию лимфоцитов крови оценивали состояние неспецифических адаптационных реакций организма по Л.Х. Гаркави. Гигиеническая оценка условий труда проведена с использованием Руководства Р 2.2.2006-05. Статистическая обработка проведена с помощью пакета прикладных программ IBM SPSS Statistica 6.1.

Результаты. При анализе лейкоцитограммы у 54 (90%) военнослужащих медианное значение палочкоядерных нейтрофилов было статистически значимо меньше 0,5 [0,3; 0,8] референтных значений. При оценке неспецифической адаптационной реакции организма у 33 (55,0%) участников тип адаптационной реакции был определен как «тренировка», у 22 (36,7%) — как «спокойная активация» и только у 5 (8,3%) — как «повышенная активация». При рассмотрении гуморального звена иммунитета у военнослужащих уровни IgM отличались большей вариабельностью индивидуальных значений; у 11,7% его уровни снижены до 0,22–0,24 г/л. Показатели Т-клеточного звена иммунитета характеризовались разновекторными изменениями: снижением доли Т-лимфоцитов у 21 (35,0%) участника, снижением TNK-лимфоцитов у 14 (23,3%), снижением NK-лимфоцитов у 7 (11,7%), а повышением у 30 (50,0%) военнослужащих. В структуре Т-лимфоцитов доля Т-киллеров снижена у 16 (26,7%) испытуемых; у 29 (48,3%) человек показатели превышали границы физиологической нормы. Условия труда военнослужащих характеризовались воздействием комплекса неблагоприятных факторов производственной среды и трудового процесса, обусловленных значительными физическими динамическими и статическими нагрузками, высоким сенсорным и эмоциональным напряжением, режимом профессиональной деятельности с нерегулярной сменностью и работой в ночное время.

Выводы. Процесс адаптации к воздействию экстремальных климатических факторов Арктики носит индивидуальный характер и зависит от адаптационных возможностей организма человека. Как сами показатели, отражающие особенности иммунного ответа у военнослужащих в Арктике (дисбаланс в клеточном звене иммунитета, недостаточность гуморального звена иммунной защиты и развивающийся дефицит иммуноглобулинозащиты), так и условия военно-профессиональной деятельности определяют важность комплексной оценки состояния здоровья контингента для обеспечения раннего выявления отклонений и формирования информационной базы для планирования и проведения профилактических мероприятий.

Ключевые слова: Арктика; военнослужащие по контракту; стаж работы; условия обитания и труда; лейкоциты; гуморальный и клеточный иммунитет; неспецифические адаптационные реакции

Для цитирования: Рахманов Р.С., Нарутдинов Д.А., Богомолова Е.С., Разгулин С.А. Оценка клеточных и гуморальных иммунных реакций у военнослужащих в Арктике при длительном влиянии факторов среды обитания и трудового процесса. *Экстремальная биомедицина*. 2026. <https://doi.org/10.47183/mes.2026-508>

Финансирование. Исследование выполнено без спонсорской поддержки.

Соответствие принципам этики. Исследование одобрено локальным этическим комитетом ФГБОУ ВО «ПИМУ» Минздрава России (протокол № 4 от 14.03.2022). Все участники подписали информированное согласие на участие в исследовании, а также использование обезличенных медицинских данных.

Потенциальный конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

Использование инструментов ИИ. Авторы заявляют, что при подготовке статьи не использовали инструменты искусственного интеллекта.

✉ Рахманов Рофаиль Салыхович raf53@mail.ru

Статья поступила: 16.04.2026 **После доработки:** 16.06.2026 **Принята к публикации:** 30.06.2026 **Online first:** 16.09.2026

INTRODUCTION

Individuals stationed in the Far North are exposed to a combination of non-specific (bioclimatic), specific (helio-geophysical), and psychosocial factors. Prolonged

exposure to these factors can exhaust the body's adaptive responses, resulting in pathological conditions and chronic stress [1–4]. Chronic stress initially activates and subsequently suppresses the immune response by altering the secretion of pro-inflammatory

and anti-inflammatory cytokines by immune cells. This immunosuppression predisposes individuals to various disease states and may ultimately lead to somatic pathology [5].

The body's protective responses are inextricably linked to the risk of developing immunopathological conditions driven by cellular and humoral immune pathways [6]. For example, under extreme winter conditions, permanent residents of the Arctic Kola Peninsula were found to exhibit decreased neutrophil phagocytic activity, lymphopenia, and T-helper cell depletion [7–9]. Some authors [10] reported cellular immune stress in women, associated with insufficient apoptotic activity and increased cytotoxic T-cell activity. Elevated cell-mediated cytotoxicity alongside impaired phagocytic defence was observed in both nomadic and sedentary populations living in the tundra, as well as in shift workers in the northern seas [11]. This shift reflects a depletion of regulatory reserves, increasing the risk of impaired T-lymphocyte function and the development of secondary, environmentally induced immune imbalances. A chronic stress response with concomitant cellular and humoral immune dysregulation was observed in non-indigenous populations residing long-term in the Arctic [12].

Several authors [13, 14] report adverse changes in the immune system of military personnel during professional adaptation. It stands to reason that long-term service may detrimentally affect health status due to the combined effects of living conditions and occupational factors, impairing the body's immune response.

The study aimed to assess cellular and humoral immune responses in military personnel deployed to the Arctic.

MATERIALS AND METHODS

The study enrolled 60 contracted military personnel stationed in the Arctic. The mean age of the participants was 37.3 ± 3.1 years, and the median duration of Arctic deployment was 7.0 [5; 9] years.

Inclusion criteria were: Arctic deployment for at least 6 months; absence of acute diseases or exacerbation of chronic conditions; and no prior use of immunomodulating agents or dietary supplements. Exclusion criteria were: refusal to participate; presence of acute diseases or exacerbation of chronic conditions; or being on leave.

This cohort, comprising individuals in medical categories 1 and 2, underwent evaluation during an annual routine medical examination in summer. The subjects traveled by air to Dudinka, where blood samples were drawn the following morning into vacuum tubes (LabVac) at the Taymyr Interdistrict Hospital. Within 3 hours, the samples were delivered without freezing to the Central Research Laboratory of the Krasnoyarsk State Medical

University for a complete blood count, leukocyte differential analysis using an automated Abbott hematology system (USA), and evaluation of cellular and humoral immunity.

Non-specific adaptive reactions were assessed based on blood lymphocyte percentages using Garkavi's method [15]. Participants were classified as follows:

- “training reaction”: 20–27.5%;
- “calm activation”: 28–34%;
- “enhanced activation”: 34.5–44%;
- “overactivation”: >44%.

Serum levels of IgA, IgM, and IgG were determined via gel electrophoresis using SAS-1plus and SAS-2 equipment (HELENA, UK). Protein fractions, including immunoglobulins, were visualized by staining with Amido Black dye (Cresol, Russia); pyronin B (Sinopharm Chemical Reagent Co., Ltd., China) was used to control albumin migration, enabling clear identification of the precipitation lines after electrophoresis.

B lymphocytes, T lymphocytes (including T helper and T killer cells), NKT cells, activated NK cells, and NK lymphocytes were determined via flow cytometry on a CELL-DYN RUBY analyzer (Abbott, USA) using MAPSS (Multi-Angle Polarized Scatter Separation) technology for optical cell analysis with laser excitation. The analyses employed the following reagents: Diluent/Focus reagent (USA), Leukocyte Lysing Agent (Shenzhen Dymind Biotechnology Co., Ltd., China), and hemoglobinolytic agent (USA). Cell immunophenotyping (determination of lymphocyte subpopulations, NK cells, etc.) was performed using CD3, CD4, CD8, CD19, and CD16/56 monoclonal antibodies labeled with fluorescent dyes (FITC, PE, and APC; Vector, Russia), as well as cell fixation and permeabilization solutions. The immunoregulatory index was calculated as the ratio of T-helper ($CD4^+$) to T-killer ($CD8^+$) cells and evaluated against reference ranges¹.

An occupational health assessment was performed in accordance with Guidelines R 2.2.2006-05 to classify working conditions based on workplace hazards, harmful environmental factors, and the severity and intensity of the workload².

Statistical analysis was performed using IBM SPSS Statistics 6.1 (USA). Normality of distribution was assessed with the Kolmogorov–Smirnov test. Normality of distribution was assessed using the Kolmogorov–Smirnov test. For parametric data, the mean values and standard deviations ($M \pm SD$) were calculated, while for non-parametric data, the median (M_e) and interquartile range [Q_1 ; Q_3] were used.

RESULTS AND DISCUSSION

Leukocyte differential analysis showed that all parameters, except for the neutrophil percentage, were within

¹ Yarets Yul. Interpretation of immunogram results. Gomel: Republican Scientific and Practical Center for Radiation Medicine and Human Ecology; 2020.

² Guidelines for the hygienic assessment of occupational environment factors and the labor process. Criteria and classification of working conditions. R 2.2.2006-05.

normal limits. In 54 (90%) military personnel, the median band neutrophil percentage was 0.5 [0.3; 0.8], which was statistically significantly below the reference values; only in 6 (10.0%) individuals was it at the lower reference limit. A reduced percentage of segmented neutrophils was observed in 7 (11.7%) participants, and in another 5 (8.3%) the values were at the lower limit of the reference interval (Table 1).

Our findings are consistent with those of Kabbani et al. [11], who reported a decreased proportion of segmented neutrophils in 23.08% of nomadic and settled men in the Far North; reductions occurred four times more frequently than increases. Additionally, neutropenia was observed in the subjects studied by the authors of [7] during winter.

Neutrophilic leukocytes drive phagocytosis and produce interferon, cationic proteins, lysosomal enzymes, and lactic acid, which exert bacteriostatic and bacteriolytic effects [16]. Reduced neutrophil counts are most commonly associated with deficiencies in vitamins B12 and B9 and key minerals (iron and copper), likely due to increased micronutrient requirements in the Far North³ [17, 18]. Compounding this problem, the standard military ration was found to be deficient⁴ in several micronutrients, including vitamins A, C, B₁, B₂, and PP, as well as calcium [19, 20]. Furthermore, water sourced from melted snow or ice is characterized by low mineralization; however, prior analyses [21] revealed trace amounts of magnesium, calcium, sodium, potassium, manganese, copper, zinc, and iron in drinking water samples.

In study [12], the long-term resident non-indigenous population of the Subarctic (≥ 10 years) exhibited increased neutrophil percentages compared to residents

of the favorable climate zone of Western Siberia, along with decreased monocyte and lymphocyte proportions. In contrast to our findings, a comparative study [9] reported a higher incidence of leukocytosis, lymphocytosis, neutrophilia, monocytosis, eosinophilia, and basophilia among subjects exposed to similar climatic conditions. However, the authors did not report the season of data collection, the specific occupational cohort, or the duration of exposure to extreme northern conditions [9, 12].

Profiling of non-specific adaptive reactions revealed a “training reaction” in 33 (55.0%) military personnel, a “calm activation” reaction in 22 (36.7%), and an “enhanced activation” reaction in only 5 (8.3%) individuals.

According to Garkavi’s method [15], “training” and “calm activation” reactions reflect the body’s response to threshold-level stressors (homeostasis maintained within the lower half of the reference range) and moderate-intensity stressors (homeostasis within the upper third of the reference range), respectively. This indicates adaptation of the participants to the living conditions in the Arctic.

Humoral immunity analysis in military personnel revealed that mean IgM, IgA, and IgG levels were within reference limits. However, individual IgM levels exhibited greater variability: in 7 (11.7%) individuals, concentrations were reduced to 0.22–0.24 g/L; in 4 (6.7%) participants, levels were at the lower reference limit. This may indicate a compromised first line of defense (Table 2).

Immunoglobulins IgM, IgA, and IgG are integral components of humoral immunity and are classified as natural (innate) and adaptive (immune or induced) [22–25]. Under normal conditions, IgM is the first immunoglobulin

Table 1. Leukocyte profile of the examined cohort, n = 60

Parameter	Parameter values	
	Reference range ⁵	Observed values
Leukocytes ¹ , ×10 ⁹ /L	3.9–10.6	6.5 ± 0.56
Band neutrophils ² , %	1–6	0.5 [0.3; 0.8]*
Segmented neutrophils ¹ , %	40–72	45.3 ± 3.43
Eosinophils ² , %	1–5	2.8 [1.8; 3.7]
Basophils ² , %	0–1	0.5 [0.2; 0.8]
Lymphocytes ² , %	18–45	27.6 [25.4; 31.7]
Monocytes ¹ , %	2–10	6.2 ± 1.66

Table prepared by the authors using their own data

Note. ¹ — data are presented as arithmetic mean and standard deviation ($M \pm SD$); ² — data are presented as median and interquartile range ($M_e [Q_1; Q_3]$); * — statistically significant differences ($p \leq 0.05$) compared to reference values.

³ Knott L. Neutropenic patients and neutropenic regimes neutropenia oncology. URL: <https://patient.info/doctor/neutropenic-patients-and-neutropenic-regimes>

⁴ Decree of the Government of the Russian Federation No. 946 of 29.12.2007, «On food supply for military personnel and certain other categories of persons, as well as on the provision of feed (products) for regular animals of military units and organizations in peacetime».

⁵ Kishkun AA. Guidelines for laboratory diagnostic methods. Moscow: GEOTAR-Meditsina; 2007.

Table 2. Serum immunoglobulin concentrations

Immunoglobulin class	Immunoglobulin levels	
	Reference range ⁶	Observed values (n = 60)
IgA, g/L	0.7–4.0	2.47 ± 0.54
IgM, g/L	0.4–2.3	0.53 ± 0.09
IgG, g/L	7.0–16.0	9.57 ± 0.69

Table prepared by the authors using their own data

Note. Data are presented as mean and standard deviation ($M \pm SD$).

Table 3. Cellular immunity profile, (n = 60)

Parameter	Parameter values			
	Observed values, %	Reference range ⁷	Observed values, cells/ μ L	Reference range ⁸
B lymphocytes ¹ , CD3 ⁺ CD19 ⁺	11.6 [8.4; 13.3]	9.1–12.4	237.8 [215.9; 295.8]	100–500
T lymphocytes ² , CD3 ⁺ CD45	68.9 ± 5.1	66–75	1372.7 ± 245.6	700–2100
T helper cells ² , CD3 ⁺ CD4	41.9 ± 6.9	35.4–46.6	868.4 ± 228.2	300–1400
T killer cells ² (cytotoxic) CD3 ⁺ CD8	26.2 ± 6.1	20.8–26.8	476.1 [380.9; 544.1]	200–900
Natural killer T cells ² CD3 ⁺ CD16/56 ⁺	2.7 ± 0.6	2.5–5.8	95.6 ± 40.2	5–200
Immunoregulatory index ²	observed value: 1.68 ± 0.44 reference range: 1.4–2.1			
Activated natural killer cells ¹ CD3 ⁺ CD8 ⁺	2.46 [1.47; 2.9]	0.8–2.3	41.2 [24.9; 48.7]	18–150
NK-lymphocytes (natural killer cells) ² CD3 ⁺ CD16 ⁺ 56	19.6 ± 6.6	8.8–17.1	320.9 [167.9; 401.2]	90–600

Table prepared by the authors using their own data

Note. ¹ — data are presented as median and interquartile range (M_e [Q_1 ; Q_3]); ² — data are presented as arithmetic means and standard deviations ($M \pm SD$).

secreted during a humoral response. Given that all study participants were healthy, the IgM pool likely consisted of natural immunoglobulins.

Our data diverge from those reported by other authors. For instance, in study [12], long-term Subarctic residents exhibited reduced IgG and IgA serum levels, whereas IgM concentrations did not differ statistically from those in the comparison group from the favorable climate zone of Western Siberia.

Mean relative (%) and absolute B-lymphocyte counts were within reference limits. However, in 20 (33.3%) individuals, the percentage of B lymphocytes was decreased, suggesting insufficient cell generation, whereas in 25 (41.7%) participants, values exceeded the upper reference limit, likely reflecting increased cell formation. Notably, this elevation did not affect immunoglobulin

secretion. These findings indicate a potential risk for impaired immunoglobulin output in the humoral immune response [26].

T-cell immunity markers (CD3 lymphocytes and their subpopulations) and NK lymphocyte counts were within reference limits (Table 3).

However, individual T-, NKT-, and NK-cell profiles exhibited marked variability. T-lymphocyte percentages were decreased in 21 (35.0%) participants and elevated in 14 (23.3%). NKT-lymphocyte proportions were reduced in 14 (23.3%) subjects. NK-lymphocyte proportions were decreased in 7 (11.7%) and increased in 30 (50.0%) military personnel.

The T-lymphocyte profile showed that the percentage of T helper cells was reduced in 16 (26.7%) participants and exceeded the upper reference limit in 14 (23.3%).

⁶ Krasteleva IM, Zubovskaya ET, Dalnova TS, Khodyukova AB, Gushchinskaya MK, Grin OR. Clinical and laboratory parameters in pediatrics (reference intervals): educational and methodological guide. Minsk: BelMAPO; 2020.

⁷ Yarets Yul. Interpretation of immunogram results. Gomel: Republican Scientific and Practical Center for Radiation Medicine and Human Ecology; 2020.

⁸ Ibid.

Concurrently, the T killer (cytotoxic) cell percentage was decreased in 16 (26.7%) subjects but exceeded the reference limit in 29 (48.3%) military personnel, indicating a predominance of cytotoxic lymphocytes in the T-cell pool.

Elevated cytotoxic T-cell activity in northern regions has also been documented by other authors [10, 11]. For example, a winter-period study [7] revealed that 37% of subjects exhibited T-helper cell deficiency accompanied by decreased neutrophil phagocytic activity. Similarly, approximately one-third of our cohort showed T-helper cell deficiency within the blood T-cell pool, aligning with these earlier observations.

This imbalance between T helper and T killer cells shifted the immunoregulatory index outside the reference intervals in 28 (46.7%) military personnel. The index was reduced in 31.7% of participants and elevated in 15.0%, indicating dysregulation of cellular immunity (Table 4).

Occupational health evaluation revealed that military personnel were exposed to a combination of adverse environmental and occupational factors. The primary health risk factors were associated with heavy physical workloads, including runway maintenance, snow harvesting for domestic and drinking water supply, and routine household tasks. These activities induced substantial dynamic and static physical strain, characterized by: moving loads over a distance of up to 5 m per shift (33.750 kg × m; Class 3.1); performing a single manual lift and carry of a 17 kg load (Class 3.1); manually lifting a total mass of 715 kg from the floor during each hour of the shift (Class 3.2); maintaining static load while holding a weight (Class 3.1); and enduring forced working postures with 425 trunk bends per shift (Class 3.2).

The performed tasks were associated with high sensory and psychological loads (Class 3.2), including concentrated observation for more than 75% of the working

time, display screen monitoring, high responsibility for the safety of others, and irregular shift schedules with night work. Based on occupational health assessment criteria, the working conditions of the military personnel were classified as harmful (Class 3.3).

CONCLUSIONS

- 1. Long-term residence and service under extreme Arctic conditions negatively affect the reserve capacities of military personnel, resulting in immune system restructuring manifested by shifts in humoral and cellular defense mechanisms. The cellular immune response is characterized by reduced proportions of band neutrophils (90.0%) and segmented neutrophils (11.7%), as well as decreased proportions of B cells (75.0%), T cells (58.3%), NKT cells (23.3%), and NK cells (61.7%). Additionally, a reduced immunoregulatory index was observed in 46.7% of military personnel.
- 2. Humoral immune deficiency in military personnel is driven by reduced IgM levels (18.4%), likely stemming from an imbalance in the B-cell immune response. This developing immunoglobulin deficiency may indicate the onset of immunosuppression, attributable to both the Far North environment and the nature of military duties.
- 3. Non-specific adaptive reactions, determined by lymphocyte percentages, indicate adaptation of the military personnel to these living conditions: “training” was observed in 55.0% and “calm activation” in 36.7% of participants.
- 4. According to occupational health assessment criteria, the working conditions of military personnel were classified as harmful (Class 3) due to exposure to adverse environmental and occupational workload factors. The leading health risk factors for this cohort included high physical, psychological, and sensory loads, as well as an irregular work–rest schedule with non-standard shifts and night work.

Table 4. Cellular immunity profile of the cohort (n = 60)

Parameter	Parameter values, %		
	Decrease	Within reference limits	Increase
T lymphocytes, CD3+CD45, including: T helper cells, CD3+CD4 T killer cells (cytotoxic) CD3+CD8	62.95 ± 1.71* 31.87 ± 1.57* 16.66 ± 1.89*	69.2 ± 2.5 35.4 ± 3.46 24.63 ± 1.66	77.32 ± 1.68* 52.13 ± 1.81* 32.38 ± 2.6*
Natural killer T cells CD3+CD16/56+	1.66 ± 0.33*	3.06 ± 0.37	0.0
Immunoregulatory index	1.28 ± 0.26*	1.75 ± 0.2	2.78 ± 0.62*
B lymphocytes	8.1 [7.05; 8.3]*	11.15 [10.2; 12.0]	14.3 [13.3; 15.0]
NK lymphocytes (natural killer cells) CD3+CD16+56	8.0 ± 0.33*	14.78 ± 3.23	25.69 ± 2.86*

Table prepared by the authors using their own data

Note. * — statistical significance of differences (p = 0.001) in the proportion of reduced values compared to reference values; ♦ — statistical significance of differences (p = 0.001) in the proportion of elevated values compared to reference values.

References

- Gudkov AB, Degtyareva GN, Shepeleva OA. Ecological and hygienic problems in Arctic territories of intensive industrial activity (review). *Public Health*. 2021;1(4):49–55 (In Russ.). <https://doi.org/10.21045/2782-1676-2021-1-4-49-55>
- Provorova AA, Smirennikova EV, Ukhanova AV. Population health in the Russian Arctic: problems, challenges. *Arctic and North*. 2024;55:161–81 (In Russ.). <https://doi.org/10.37482/issn2221-2698.2024.55.161>
- Bezmenova IN. Selection of informative genetic markers for assessment of adaptabilities of northerners: a review. *Public Health and Life Environment — PH&LE*. 2023;31(1):7–12 (In Russ.). <https://doi.org/10.35627/2219-5238/2023-31-1-7-12>
- Bagnetova EA, Malyukova TI, Bolotov SV. Adapting the human body to living conditions in the northern region. *Advances in Current Natural Sciences*. 2021;4:111–6 (In Russ.). <https://doi.org/10.17513/use.37616>
- Barrett TJ, Corr EM, Solingen CV, Schlamp F, Brown EJ, Koelwyn GJ, et al. Chronic stress primes innate immune responses in mice and humans. *Cell Reports*. 2021;36(10):109595. <https://doi.org/10.1016/j.celrep.2021.109595>
- Dzhumaeva GG. Human immunity: a systems analysis of innate and adaptive defense mechanisms. *Central Asian Journal of Academic Research*. 2026;4(1):9–16 (In Russ.). <https://doi.org/10.5281/zenodo.18480575>
- Balashova SN, Samodova AV, Dobrodeeva LK, Belisheva NK. Hematological reactions in the inhabitants of the Arctic on a polar night and a polar day. *Immunity, Inflammation and Disease*. 2020;8(3):415–22. <https://doi.org/10.1002/iid3.323>
- Dobrodeeva LK, Samodova AV, Balashova SN, Pashinskaya KO. Intercellular interactions in peripheral venous blood in practically healthy residents of high latitudes. *BioMed Research International*. 2021;7086108. <https://doi.org/10.1155/2021/7086108>
- Gubkina LV, Samodova AV, Dobrodeeva LK, Balashova SN, Pashinskaya KO. Features of cellular and humoral immune reactions in the inhabitants of the European North and the Arctic. *Yakut Medical Journal*. 2022;4:87–91 (In Russ.). <https://doi.org/10.25789/YMJ.2022.80.23>
- Morozova OS, Sergeeva TB, Shchegoleva LS. Cellular immunity in women aged 40–60 years living in the Far North. *Journal of Medical and Biological Research*. 2020;8(3):235–40 (In Russ.). <https://doi.org/10.37482/2687-1491-Z014>
- Kabbani MS, Filippova OE, Shashkova EYu, Men'shikova MV, Shchegoleva LS. Formation of cellular responses in the adaptive immune response of 40–60-year-old women living in Northern Russia. *Journal of Medical and Biological Research*. 2020;8(4):350–9 (In Russ.). <https://doi.org/10.37482/2687-1491-Z027>
- Zyryanov BN, Sokolova TF. Adaptation reactions and immunity in the migrant population of the Far North. *Scientific Bulletin of the Yamalo-Nenets Autonomous Okrug*. 2021;2(111):48–58 (In Russ.). <https://doi.org/10.26110/ARCTIC.2021.111.2.003>
- Churilov YuK, Moiseev YuB, Richey II. The state of immunological reactivity during the professional adaptation of flight personnel. *Military Medical Journal*. 2019;34021(4):42–6 (In Russ.).
- Rakhmanov RS, Bogomolova ES, Narutdinov DA, Razgulin SA, Potekhina NN, Evdokimov AV. Assessment of body adaptation state of military personnel in Arctic zone of Russia: comparative study. *Marine Medicine*. 2026;12(1):87–94 (In Russ.). EDN: [HVCBSBW](https://doi.org/10.35266/2949-3447-2024-4-9)
- Garkavi LKh. *Activation therapy: anti-stress reactions of activation and training and their use for health improvement, prevention, and treatment*. Rostov-on-Don: Rostov University Press; 2006 (In Russ.).
- Kisina TE, Vorobyeva NA. Extracellular traps: a new function of neutrophils and their role in inflammation and hemostasis. *Vestnik SurGU. Meditsina*. 2024;17(4):63–74 (In Russ.). <https://doi.org/10.35266/2949-3447-2024-4-9>
- Torrez M, Chabot-Richards D, Babu D, Lockhart E, Foucar K. How I investigate acquired megaloblastic anemia. *International Journal of Laboratory Hematology*. 2022;44(2):236–47. <https://doi.org/10.1111/ijlh.13789>
- Costanzo G, Sambugaro G, Mandis G, Vassallo S, Scuteri A. Pancytopenia secondary to vitamin B₁₂ deficiency in older subjects. *Journal of Clinical Medicine*. 2023;12(5):2059. <https://doi.org/10.3390/jcm12052059>
- Subbotina TI, Andrianov AI, Sorokoletova EF, Smetanin AL, Ishchuk YuV. The role of adequate food rationing in maintaining and improving the health of military personnel serving in the Arctic zone. *Bulletin of the Russian Military Medical Academy*. 2020;39(S3–5):169–72 (In Russ.). EDN: [VBQGF](https://doi.org/10.3390/jcm12052059)
- Rusakov EB, Artyukhova SI. On the prospects for the creation and production of bioproducts for nutrition of military personnel located in the Arctic. *Topical Biotechnology*. 2022;1:196–200 (In Russ.).
- Rakhmanov RS, Narutdinov DA, Bogomolova ES, Razgulin SA, Alikberov MKh, Nepryakhin DV. Assessment of the body response to snowmelt water consumption in military personnel serving in the arctic based on blood parameters. *Public Health and Life Environment — PH&LE*. 2023;31(7):48–54 (In Russ.). <https://doi.org/10.35627/2219-5238/2023-31-7-48-54>
- Zemskov AM, Zemskova VA, Bakuleva NI, Glagoleva AB, Shiryayev OYu. Immunoglobulins are the present and future of immunotherapy. *Scientific and Medical Bulletin of the Central Chernozem region*. 2021;86:61–72 (In Russ.). EDN: [FTJRMJ](https://doi.org/10.20514/2226-6704-2017-7-2-95-106)
- Vasilenko VV, Vinogradov DL, Burlakova AS. IgG4-associated pathology: state of the art. *Archives of Internal Medicine*. 2017;7(2):95–106 (In Russ.). <https://doi.org/10.20514/2226-6704-2017-7-2-95-106>
- Abokor AA, McDaniel GH, Golonka RM, Campbell C, Brahmandam S, Yeoh BS, et al. Immunoglobulin A, an active liaison for host-microbiota homeostasis. *Microorganisms*. 2021;9(10):2117. <https://doi.org/10.3390/microorganisms9102117>
- Gong S, Ruprecht RM. Immunoglobulin M: An ancient antiviral weapon — rediscovered. *Frontiers in Immunology*. 2020;11:1943. <https://doi.org/10.3389/fimmu.2020.01943>
- Ermakov EA, Nevinsky GA, Buneva VN. Immunoglobulins with non-canonical functions in inflammatory and autoimmune disease states. *International Journal of Molecular Sciences*. 2020;21(15):5392. <https://doi.org/10.3390/ijms21155392>

Authors' contributions. All authors confirm that their contributions meet the ICMJE criteria for authorship. The primary contributions are distributed as follows: Rofail S. Rakhmanov — study design and conceptualization, manuscript drafting; Denis A. Narutdinov — primary data collection, statistical processing; Elena S. Bogomolova — editing, article approval; Sergey A. Razgulin — literature and information search.

Authors:

Rofail S. Rakhmanov, Dr. Sci. (Med.), Professor, ORCID: <https://orcid.org/0000-0003-1531-5518>

Denis A. Narutdinov, Dr. Sci. (Med.), ORCID: <https://orcid.org/0000-0002-5438-8755>

Elena S. Bogomolova, Dr. Sci. (Med.), Professor, ORCID: <https://orcid.org/0000-0002-1573-3667>

Sergey A. Razgulin, Dr. Sci. (Med.), Associate Professor, ORCID: <https://orcid.org/0000-0001-8356-2970>