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The contribution of weather factors to seasonal variations in oxygen partial density in different climatic zones

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ABSTRACT

BACKGROUND: Currently, there is growing concern about changes in the oxygen content in the surface air layer. There are weather classifications where the determining meteotropic effect affecting human health is the value of oxygen partial density, but among these types of weather, hyperoxia situations are not considered, although in a number of studies attention has been drawn to the negative impact on human health of high oxygen content in inhaled air. Taking into account the combination of periodic and aperiodic components of weather factors, it seems relevant to assess their intraannual variations in different climatic zones and determine their contribution to the formation of seasonal rhythms of partial oxygen density.

AIM: To assess the contribution of weather factors of the subarctic and subtropical climatic zones to the seasonal dynamics of the partial oxygen density in the atmospheric air.

MATERIALS AND METHODS: Wavelet analysis was used for mathematical analysis of weather changes. Signal analysis was performed in the plane of wavelet coefficients (scale–time–level). The statistical significance of rhythms was estimated by multiple (5000) random permutations of the levels of the original time series.

RESULTS: In the Subarctic region, the annual rhythm of partial oxygen density is modulated by the insertion intra-annual rhythms of weather factors, in the subtropics, the rhythm of partial oxygen density is determined by constant low-amplitude rhythms of weather factors. The population of the North is exposed to hyperoxia during the five winter months and hypoxia in the summer. In the Limpopo province of South Africa, hypoxia occurs during the wet season (November to May), which, according to the medical weather classification, requires medical supervision.

CONCLUSION: Considering the presence of aperiodic components in the dynamics of weather factors, mathematical data processing requires the use of methods that evaluate changes in the spectral composition of a time series over time. We recommend supplementing medical weather classifications with such items as "hyperoxic day" and "hyperoxic" weather type.

Keywords: extremeweather; oxygen; hypoxia; hyperoxia; North.

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Сезонные вариации парциальной плотности кислорода в различных климатических поясах

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АННОТАЦИЯ

Обоснование. В настоящее время растёт озабоченность учёных изменением содержания кислорода в приземном слое воздуха. Существуют классификации погод, где определяющим метеотропным воздействием, влияющим на здоровье человека, является величина парциальной плотности кислорода. Однако эти типы погоды не учитывают состояние гипероксии, хотя есть данные о негативном воздействии на здоровье человека высокого содержания кислорода во вдыхаемом воздухе. Представляется актуальным оценить сочетание периодических и апериодических компонентов погодных факторов и их внутригодовые вариации в различных климатических поясах и определить их вклад в формирование сезонных ритмов парциальной плотности кислорода.

Цель. Оценить вклад погодных факторов субарктического и субтропического климатических поясов в сезонную динамику парциальной плотности кислорода в атмосферном воздухе.

Материалы и методы. Для математического анализа изменений погоды применён вейвлет-анализ. Анализ сигналов производили в плоскости wavelet-коэффициентов (масштаб–время–уровень). Статистическую значимость ритмов оценивали путём многократной (5000) случайной перестановки уровней исходного временно́го ряда.

Результаты. В субарктическом регионе годовой ритм парциальной плотности кислорода модулируется вставочными внутригодовыми колебаниями погодных факторов; в субтропиках вариабельность парциальной плотности кислорода определяется постоянными низкоамплитудными ритмами этих же факторов. Население Севера испытывает воздействие гипероксии в течение пяти зимних месяцев и гипоксии — летом. В провинции Лимпопо (ЮАР) в течение влажного сезона (с ноября по май) наблюдается гипоксия, которая в соответствии с медицинской классификацией погоды требует медицинского контроля.

Заключение. С учётом апериодических составляющих в динамике погодных факторов в математической обработке данных необходимо применение методов, которые оценивают изменения спектрального состава временно́го ряда со временем. Медицинские классификации погод рекомендуем дополнить такими пунктами, как «гипероксический день» и «гипероксический» тип погоды.

Ключевые слова: экстремальные погодные условия; кислород; гипоксия; гипероксия; Север.

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不同气候带内局部氧气密度的季节变化

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摘要

论证。当前，科学家们对地球近地面大气层中氧气含量的变化感到日益担忧。在一些天气分类中，影响人类健康的决定性气象效应是局部氧气密度值。尽管有证据表明吸入空气中的高浓度氧气会对健康产生不利影响，但是，这些类型的天气并不算是高氧条件。 评价气候因素中的周期性和非周期性成分的组合及其在不同气候带内的年内变化，并确定这些因素对形成季节性局部氧气密度节律的贡献，显然是迫切的需求。

目的。评估亚北极气候区和亚热带气候区的气象因素对大气空气中局部氧气浓度季节动态变化的贡献。

材料和方法。应用小波分析法对气候变化进行数学分析。信号分析在小波系数的平面（尺度-时间-等级）中进行。通过在原始时间序列水平上的多次（5000）随机排列评估了节律的统计意义。

结果。在亚北极地区，局部氧密度的年节律受气候因素的插入式年内波动调节；在亚热带地区，局部氧密度的变化由这些因素的恒定低幅节律决定。 北方的居民在冬季的五个月里会受到多氧症的影响，而在夏季则会受到少氧症的影响。 在南非林波波省，根据天气的医学分类，需要医学监测，在潮湿季（11月至5月）会出现低氧症。

结论。考虑到气候因素动态中的非周期成分，在数学数据处理中必须应用的方法，应能够评估时间序列的频谱成分随时间的变化。我们建议在天气的医学分类中增加“多氧日”和“多氧”天气类型等项目。

关键词： 极端天气条件；氧气；低氧症；多氧症；北方。

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BACKGROUND

The human body is exposed to various weather and geophysical factors, including temperature, humidity, atmospheric pressure, solar irradiance, magnetic activity, and air composition [1–3]. The intensity of biotropic effect depends on the magnitude of these factors and also their periodic and aperiodic changes over time [4]. Long-term exposure to high temperatures can lead to hyperthermia and related conditions, such as tachycardia, hypertension, hypotension, headaches, convulsions, and electrolyte imbalances [5]. Exposure to low temperatures can result in various functional changes that negatively affect health [6, 7]. For example, 33 types of conditions have been identified where acute exposure to cold can be a causative (etiological) factor for primary dysfunction and a definitive determinant for other pathological processes (pathogenetic factor), which contribute to their progression and poorer outcomes.

High humidity exacerbates the adverse effects of both high and low temperatures. High humidity affects pulmonary ventilation and alveolar–capillary oxygen diffusion [8]. Water vapor is involved in maintaining the partial oxygen density (POD) of inhaled air and in heat transfer processes. Atmospheric pressure significantly impacts many functions of the human body, including gas exchange and circulatory system function [9].

There are growing concerns about changes in the oxygen content of ground-level air [10, 11]. Several weather classification systems use POD as a determinant of human health. These classifications identify four types of weather conditions: hypoxic, spastic, indifferent, and hypotensive, which may or may not require medical supervision [12, 13].

Situations with increased oxygen content are not considered. However, several works have demonstrated that high oxygen levels negatively affect human health and well-being [14], even at high latitudes [15].

Taking into account the combination of periodic and aperiodic components of weather factors, it seems relevant to assess their intra-annual variations in different climatic zones, and determine their contribution to the formation of seasonal POD rhythms.

The study **aimed** to assess the contribution of weather factors of the subarctic and subtropical climatic zones to the seasonal changes of POD in the atmospheric air.

MATERIALS AND METHODS

The weather undergoes both periodic and aperiodic changes, so wavelet analysis was used for mathematical analysis of weather changes [16]. The wavelet coefficient plane (scale–time–level) was used to evaluate signals [17]. The wavelet transform illustrates over-time changes in the spectral structure of a time series. It can be used to track abrupt weather shifts, such as cyclones with associated atmospheric fronts, and their impact on stable weather rhythms [4].

The following time series parameters were evaluated: mean level (mesor, M ± m), rhythm amplitude (A, arbitrary units), periods of stable and transient (quantized) rhythms (days per month), the coefficient of variation (c_v, %), and the coefficient of synchronization (r, arbitrary units). The statistical significance of rhythms was estimated by multiple (5000) random permutations of the levels of the original time series. The reported *p*-value indicates the percentage of cases in which the energy of the extracted frequency component of the original series exceeded that of the permuted series.

The following parameters were evaluated using daily means to assess weather variations throughout the year: ambient air temperature (T, °C); atmospheric pressure (P, mm Hg); relative humidity (φ, %), and POD (g/m^3).

The POD, also defined as the weight oxygen content, is directly proportional to atmospheric pressure minus the partial pressure of water vapor and inversely proportional to air temperature: O_2=83×(P–φ)/T. This correlates with the partial oxygen pressure in inhaled and alveolar air, depending on physical characteristics [18, 19].

To minimize the effects of helio-geophysical factors on the weather, 2007 was selected as the reference year. It was the quietest year of Solar Cycle 23, with a minimum monthly mean smoothed sunspot number of 2.2. Table 1 shows the duration of each actual season in the regions that were evaluated.

Khanty-Mansiysk is located at the coordinates 61° N, 69° E. It has a sharply continental climate which is characterized by severe, long winters with strong winds and snowstorms. Cold weather returns in spring, and late spring and early autumn frosts are common. The typical duration of the seasons is as follows: autumn:[1] September 5 to October 11 (36 days); winter: October 12 to April 27 (200 days); spring: April 28 to June 9 (42 days); summer: June 10 to September 4 (87 days). Apparent changes in photoperiod occur throughout the year. The shortest daylight duration, 5 hours and 32 minutes, is recorded on December 22. In contrast, during the summer white nights, daylight reaches 19 hours and 17 minutes.

Polokwane is the capital of the Polokwane municipality, the Capricorn District Municipality, the Limpopo province in South Africa. It is located at 23° S, 29° E.

Summer in Limpopo lasts from November to March (~5 months). Most of the annual precipitation falls during this season. Daytime temperatures are 25–40°C or higher. Autumn (April, May) is a transitional season, characterized by moderate temperatures and lower precipitation. Daytime temperatures are 20–30°C, and precipitation is significantly lower. Winter lasts from June to August (~3 months). There is virtually no precipitation. Spring, the transition period from dry to wet season, lasts approximately two months (September and October). The temperature fluctuates between 20°C

[1] Khanty-Mansiysk Center for Hydrometeorology and Environmental Monitoring. Available at http://www.ugrameteo.ru Accessed on November 7, 2024.

Table 1. Duration of actual seasons of the year in Khanty-Mansiysk (Russia) and Polokwane (South Africa)

Khanty-Mansiysk

August	September	October	November	December	January	February	March	April	May	June	July
Summer	Autumn	Winter						Spring			Summer

Polokwane

August	September	October	November	December	January	February	March	April	May	June	July
Winter	Spring		Summer						Autumn		Winter
Dry season		Wet season							Dry season		

and 35°C. The province receives abundant sunshine throughout the year, especially in winter. There are minor seasonal variations in photoperiod, with an approximate difference of three hours (10 hours and 39 minutes on June 22 versus 13 hours and 36 minutes on December 22).[2]

RESULTS

Table 2 shows the average annual values, amplitude of variations, and coefficient of variation for temperature, atmospheric pressure, relative humidity, and POD in Khanty-Mansiysk and Polokwane.

Although the average annual POD values in Khanty-Mansiysk and Polokwane do not differ significantly (see Table 2), reliable seasonal differences are observed (Fig. 1). The lowest POD values occur in the summer months in both the northern and southern hemispheres. However, POD in Khanty-Mansiysk varies more, with a coefficient of variation of 5.22% (ranging from 260 g/m^3 in summer to 330 g/m^3 in winter). In contrast, POD in Polokwane varies by only 2.39% throughout the year (ranging from 260 g/m^3 in summer to 290 g/m^3 in winter).

A wavelet analysis of the POD variations in Khanty-Mansiysk found two transient [20] rhythms, or abrupt weather shifts [21]: 101.1 days/4.65 arbitrary units/0.001[3] and 135 days/2.99 arbitrary units/0.001 lasting from January to June (winter/spring). A POD spectrogram was compared with spectrograms of other weather variables, and comparable transient rhythm durations were documented for variations of T (101.1 days), P (75.3 days), and φ (68.3 days). Abrupt shifts in humidity were demonstrated for 19.0 and 17.3 days. A correlation analysis of weather factor variations and the POD in Khanty-Mansiysk indicates strong positive relationships between the POD/T (r=0.924) and moderate positive relationship between POD/P (r=0.318) and POD/φ (r=0.386) ratios.

In the subtropical climate zone, the annual POD variations have two transient rhythms: 83.1 days/2.11 arbitrary units/0.002 and 23.2 days/0.69 arbitrary units/0.035. However, unlike in the subarctic climate zone, the high-amplitude rhythm with a period of 83.1 days was observed as two abrupt weather shifts, which occurred during the wet (summer) season (January–March and October–December), and the low-amplitude, but a significant rhythm with a period of 23.2 days was observed during the dry season peak (June–July), respectively (Fig. 1). In contrast to the transient rhythm in the subarctic climate, the air temperature in the subtropical zone was characterized by a stable, low-amplitude, three-month rhythm (101.1 days/1.46 arbitrary units/ 0.003).

Variations in atmospheric pressure are characterized by the stable, high-amplitude (2.46 arbitrary units) rhythm with a period of 101.1 days (0.001), as well as by short-term (transient) rhythms with the periods of 21.0 (0.001), 34.4 (0.001), and 50.9 (0.015) days. These rhythms peaked in the middle of the dry season (May–August). The humidity showed a stable rhythm with the period of 83.1 days (0.001) and the peak during the entire dry season. The relationship between the POD and weather factors in the subtropical climate zone was moderately positive: POD/T (r=0.627), POD/P (r=0.489), and POD/φ (r=0.351).

DISCUSSION

An analysis of the chronobiological features of POD variations has revealed that the annual POD rhythm in the subarctic climate zone is modulated by transient, intra-annual weather patterns. These factors contribute differently to the resulting POD by season. Over time, the transient rhythms of POD, air temperature, and humidity coincide, primarily in the winter. In the summer, however, POD depends more on the short-period transient rhythms of atmospheric pressure. The intra-annual range of the parameters is quite high (c_v=5.22% compared with 2.7% in Moscow [15]). An analysis of POD variations throughout the year reveals stable seasonal changes in the subarctic climate zone, such as hyperoxia in winter and hyperthermic hypoxia in summer.

In the subtropical climate zone, a rigid rhythm of POD changes (c_v=2.39%) with a low mesor is observed. This suggests an unfavorable, oxygen-based weather type, which can be caused by stable, low-amplitude weather patterns [12]. The higher POD (rhythm with a period of 23.2 days) in May to June of the dry season is caused by short-term variations in atmospheric pressure. The subtropical climate zone

[2] Green Book: Adapting South African Settlements to Climate Change. Available at https://greenbook.co.za Accessed on November 7, 2024.

[3] Hereinafter: period / amplitude / significance.

Table 2. Average annual values, amplitude of fluctuations and coefficient of variation of temperature, atmospheric pressure, relative humidity, partial oxygen density in the cities of Khanty-Mansiysk and Polokwane

Parameters	M±m	A	c_v
Khanty-Mansiysk			
Temperature (°C)	0,84±13,86	192,74	1641,15
Atmospheric pressure (mmHg)	1012,34±10,16	1024936,77	1,00
Relative humidity (%)	77,75±10,31	6151,88	13,27
Partial oxygen density (g/m^3)	283,24±14,79	80445,13	5,22
Polokwane			
Temperature (°C)	17,77±4,36	334,77	24,52
Atmospheric pressure (mmHg)	1021,29±4,24	1043051,72	0,41
Relative humidity (%)	63,28±14,41	4212,23	22,77
Partial oxygen density (g/m^3)	274,22±6,55	75237,27	2,39

Note. M — average level; m — standard error; A — oscillation amplitude (conventional units); c_v— variation coefficient (%).

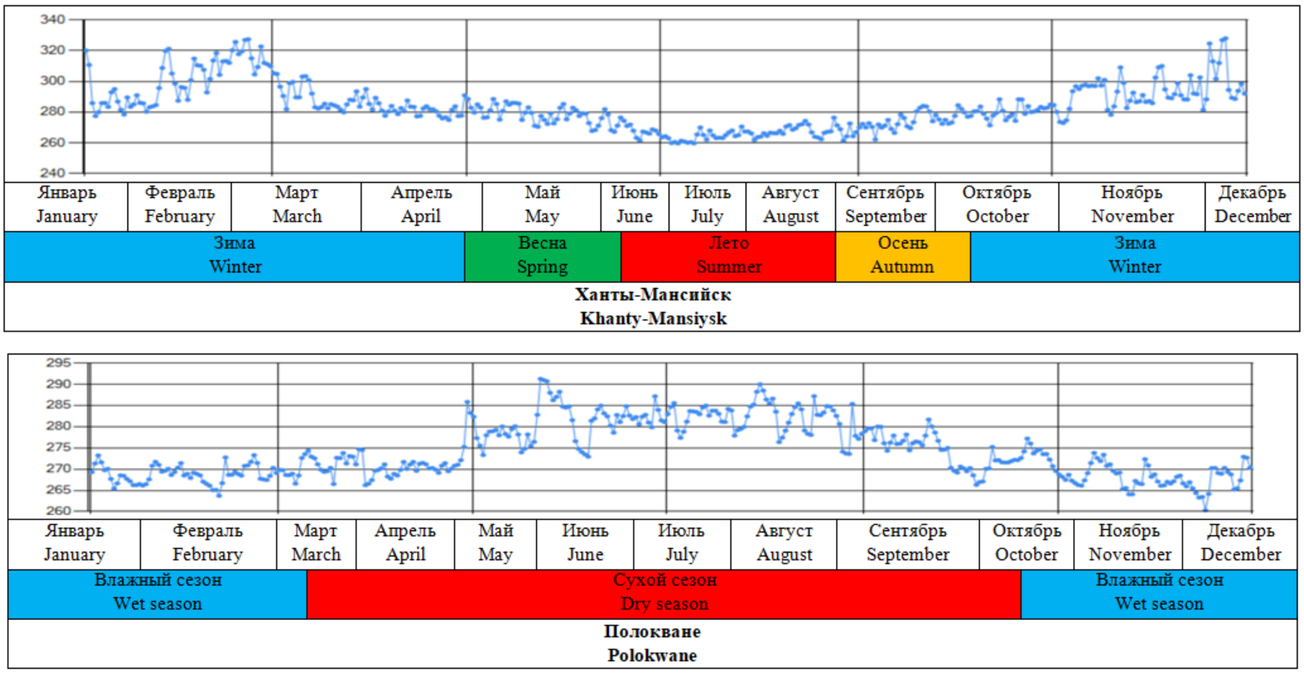

Fig. 1. Dynamics of the partial oxygen density in Khanty-Mansiysk and Polokwane: the abscissa axis is the value of the partial oxygen density (g/m^3), the ordinate axis is months and seasons.

is characterized by hypoxia throughout the year, with a slight increase in POD during the dry season.

Transient seasonal rhythms predominate in the north, whereas stable, low-amplitude rhythms predominate in the south throughout the year. This results in rigid subtropical and apparent seasonal subarctic POD rhythms.

From a clinical point of view, a quantitative classification of weather conditions includes three oxygen-based types of weather: positive, with POD of approximately 285±5 g/m^3; conditionally negative, with POD of 270–280 g/m^3; and negative, with POD of less than 270 g/m^3 [19]. A medical weather classification proposed by Grigoryev [12, 18] categorizes weather types as requiring either intensified (POD = 289–260 g/m^3) or intensive (POD <260 g/m^3) medical monitoring, as opposed to the very positive type (POD >315 g/m^3). This classification is based solely on these factors, with no consideration given to the effects of higher POD (hyperoxia), as mentioned by some authors [15].

Oxygen is essential for life. However, like any medicine, it has both positive and toxic biological effects. The pathophysiology of hyperoxia is associated with higher levels of reactive oxygen species (ROS), which can easily react with surrounding biological tissues, affecting lipids, proteins, and nucleic acids. Hyperoxia may impair antioxidant protection. ROS cause oxidative stress. An activated alveolar capillary endothelium is characterized by increased adhesiveness. This leads to the accumulation of cell populations, such as neutrophils, which produce ROS. Higher ROS levels cause hyperpermeability, coagulopathy, collagen deposition, and other irreversible alveolar changes [22].

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Zhuravlev [23] hypothesized that physical factors primarily act by influencing free radical processes. The author classified all factors by the process of free radical generation into three main groups: 1) factors initiating free radical oxidation: ionizing radiation, ultraviolet rays, ultrasound, and higher POD (oxygen therapy); 2) factors inhibiting free radical oxidation: peloid therapy, hydrogen sulfide baths, and lower POD; 3) factors indirectly affecting free radical oxidation: various currents, visible and infrared radiation, microwaves, etc. [24].

The increased use of prolonged mechanical ventilation and hyperbaric oxygen therapy in anesthesiology and intensive care has made hyperoxia an urgent clinical concern. Even now, nearly 240 years after the discovery of oxygen, the medically safe upper limits and duration of high-fraction inspired oxygen remain unclear [25, 26].

Recently, hyperoxia has been used in hypoxic/hyperoxic training in sports [27] and clinical [28] practice. The effectiveness of this training is enhanced by alternating short periods of low oxygen with high oxygen pulses (exposure to a gas mixture containing 30% O_2 for 2–3 minutes) [29].

However, the dose–effect problem, considered one of the most critical aspects of free radical processes, remains largely unsolved. Levels of ROS and the antioxidant/prooxidant ratio can be used to objectively evaluate the impact of oxygen and other physical factors [30].

CONCLUSION

In the subarctic climate zone, the POD rhythm throughout the year is modulated by intra-annual transient rhythms of weather patterns, and these effects on POD vary from season to season. Over time, the transient rhythms of POD, air temperature, and humidity coincide, primarily in the winter. In the summer, however, POD depends more on the short-period transient rhythms of atmospheric pressure. The population of Khanty-Mansiysk is exposed to a changed gas environment throughout the year. Hyperoxia is observed for five months: November, December, January, February, and March. Normoxia is observed in April, May, and June (the spring component) and in September and October (the autumn component). Hyperthermic hypoxia is observed in July and August.

In the subtropical climate zone, stable, low-amplitude rhythms of weather patterns largely explain the detection of a rigid POD rhythm with a low mesor (coefficient of variation: 2.3%). The population of the Limpopo province experiences slightly different POD conditions during the dry season (May to September). However, according to the medical weather classification, hypoxia requires intensified medical monitoring during the wet season (November to May).

In the context of mathematical data processing, aperiodic components in weather pattern changes should be considered. To address this necessity, it is crucial to use methodologies that estimate temporal variations in the spectral structure of time series. In addition, it is recommended to use specific terms such as *hyperoxic day* and *hyperoxic weather type* to supplement medical weather classifications.

ADDITIONAL INFORMATION

Authors' contribution. O.N. Ragozin — a significant contribution to the concept and design of the study, editing and final approval of the manuscript; I.V. Radysh — editing and final approval of the manuscript; L. Muthelo — data analysis; E.Yu. Shalamova — preparation of the first version of the article; A.B. Gudkov — editing the first version of the article; E.R. Ragozina — a set of primary material; I.A. Pogonysheva — data analysis. All authors confirm that their authorship meets the international ICMJE criteria (all authors have made a significant contribution to the development of the concept, research and preparation of the article, read and approved the final version before publication).

Ethical expertise. The study was approved by the local ethics committee Khanty-Mansiysk State Medical Academy (conclusion No. 214 dated October 15, 2024).

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Generative AI. Generative AI technologies were not used for this article creation.

Provenance and peer-review. This paper was submitted to the journal on an unsolicited basis and reviewed according to the usual procedure. Two external reviewers, a member of the editorial board, and the scientific editor of the publication participated in the review.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. О.Н. Рагозин — существенный вклад в концепцию и дизайн исследования, редактирование и окончательное утверждение рукописи; И.В Радыш — редактирование и окончательное утверждение рукописи; Л. Мутэло — анализ данных; Е.Ю. Шаламова — подготовка первого варианта статьи; А.Б. Гудков — редактирование первого варианта статьи; Э.Р. Рагозина — набор первичного материала; И.А. Погонышева — анализ данных. Все авторы подтверждают соответствие своего авторства международным критериям ICMJE (все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией).

Этическая экспертиза. Проведение исследования одобрено локальным этическим комитетом Ханты-Мансийской государственной медицинской академии (заключение № 214 от 15 октября 2024 г.).

Источники финансирования. Отсутствуют.

Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов за последние три года, связанных с третьими лицами (коммерческими и некоммерческими), интересы которых могут быть затронуты содержанием статьи.

Оригинальность. При создании настоящей работы авторы не использовали ранее опубликованные сведения (текст, иллюстрации, данные).

Доступ к данным. Редакционная политика в отношении совместного использования данных к настоящей работе не применима, новые данные не собирали и не создавали.

Генеративный искусственный интеллект. При создании настоящей статьи технологии генеративного искусственного интеллекта не использовали.

Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внешних рецензента, член редакционной коллегии и научный редактор издания.

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