

NORMATIVE FRAMEWORKS AND INTERNATIONAL EVIDENCE ON WORK UNDER HYPOBARIC HYPOXIA IN HIGH-ALTITUDE ENVIRONMENTS: A COMPARATIVE ANALYSIS

A. K. Saktapov^{1*}, D. V. Vinnikov¹, A. Y. Ualiyeva¹, Z. V. Romanova¹,
N. N. Aitambayeva², L. Z. Nazarova², G. Z. Akhanov³, O. Z. Mukanova⁴

¹ NJSC «Al-Farabi Kazakh National University», Kazakhstan, Almaty

² Kazakhstan's Medical University «KSPH», Kazakhstan, Almaty

³ NJSC «S. D. Asfendiyarov Kazakh National Medical University», Kazakhstan, Almaty

⁴ Mangystau Central District Hospital, Health Department of Mangystau Region,
Kazakhstan, Mangystau Region

*Corresponding author

Abstract

Relevance. High-altitude work involves exposure to hypobaric hypoxia and risks of altitude illness, sleep and cognitive disturbances, and cardiovascular complications. Differences in national regulatory requirements hinder harmonisation of workers' medical assessments.

Objective. To compare selected Russian, Kazakhstani and Kyrgyz regulatory acts relevant to medical examinations for high-altitude work and assess their concordance with international guidance and scientific evidence.

Materials and Methods. Three national regulatory acts and three international clinical documents from the Wilderness Medical Society, European Society of Cardiology and British Thoracic Society were analysed. A structured narrative review using Scopus and Web of Science included 23 scientific publications in the qualitative synthesis.

Results. The Russian document addresses reduced pressure and reduced oxygen partial pressure in technologically maintained environments, but its applicability to natural high-altitude settings is not explicitly defined. The Kazakhstani document does not identify hypobaric hypoxia as a distinct harmful occupational factor. The Kyrgyz document covers selected occupations in high-altitude and remote areas. Within the provisions reviewed, no integrated system of altitude-specific risk stratification, validated occupational fitness criteria and explicit categories of restriction was identified. International clinical guidance addresses relevant risks but does not constitute an occupational fitness regulatory standard. Selected forms of haemorrhoids and hernias are included in the Kazakhstani and Kyrgyz documents; their regulatory context must be distinguished from contraindications specifically attributable to hypobaric exposure.

Conclusion. National requirements would benefit from clearer definitions of occupational exposure to hypobaric hypoxia and individual, task-specific fitness assessment. International guidance may inform regulatory revision when adapted to occupational settings.

Keywords: altitude, hypoxia, occupational health, occupational exposure, physical examination, risk assessment, legislation as topic.

Introduction

High-altitude environments are characterised by an altitude-dependent reduction in barometric pressure and oxygen availability. Barometric

pressure decreases from approximately 101.3 kPa (760 mmHg) at sea level to 75.0 kPa (563 mmHg) at 2,500 m and 61.6 kPa (462 mmHg) at 4,000 m, corresponding to reductions of approximately 26 %

and 39 %, respectively [1-3]. Although the oxygen fraction remains constant at approximately 20.9 %, the humidified inspired oxygen partial pressure (PIO₂) decreases from approximately 19.9 kPa (149 mmHg) at sea level to 14.4 kPa (108 mmHg) at 2,500 m and 11.6 kPa (87 mmHg) at 4,000 m, resulting in hypobaric hypoxia [1-3]. These pressure estimates are approximate and depend on atmospheric conditions; the humidified inspired values assume a water-vapour pressure of approximately 6.3 kPa at 37 °C.

Acute acclimatisation begins within minutes and includes increased pulmonary ventilation, sympathetic activation with elevations in heart rate and cardiac output, and hypoxic pulmonary vasoconstriction leading to increased pulmonary arterial pressure [1-4]. Over subsequent days to weeks, plasma-volume contraction and erythropoietin-mediated erythropoiesis increase haemoglobin concentration [1-3]. The magnitude of the haematological response varies with altitude, exposure duration and population characteristics [5]. Although these responses support tissue oxygen delivery, they may also increase physiological strain, particularly in individuals with pre-existing cardiovascular, respiratory, haematological or neurological disorders [2-5].

The physiological effects of hypobaric hypoxia have measurable functional and clinical consequences. In unacclimatised individuals, a commonly cited approximate rule of thumb is that maximal oxygen uptake (VO₂max) decreases by 1 % for every 100 m of ascent above 1,500 m, corresponding to estimated reductions in aerobic capacity of approximately 10 % at 2,500 m and 25 % at 4,000 m [6]. These estimates are illustrative rather than universal and do not directly quantify occupational performance. Arterial oxygen saturation progressively decreases with altitude and frequently falls below 90 % at approximately 3,000–3,500 m and above, although individual values vary according to acclimatisation, health status and exposure conditions [1]. Following rapid ascent, acute mountain sickness has been reported in approximately 20-25 % of individuals at around 2,500 m and in 40–50 % of trekkers and climbers near 4,000 m [7]. These reductions in oxygenation and aerobic capacity may impair physical work capacity and potentially affect safety during physically demanding or safety-critical tasks. They are particularly relevant to workers in mining, construction, transport, rescue and military occupations

who may experience prolonged, repeated or intermittent high-altitude exposure.

To reduce occupational risks, national regulatory frameworks establish preliminary and periodic medical examinations for workers exposed to harmful or hazardous working conditions. However, the regulatory approaches of Russia, Kazakhstan and Kyrgyzstan differ in their terminology, scope, examination requirements and lists of medical contraindications [8-10]. The Russian framework lists reduced pressure of air or gas environments and reduced oxygen partial pressure in relation to occupational environments in which such pressure must be maintained according to the applied work technology; its applicability to natural high-altitude work is not explicitly defined [8]. The Kazakhstani framework regulates medical examinations for hazardous work but does not identify hypobaric hypoxia as a distinct harmful occupational factor [9]. The Kyrgyz framework explicitly includes specified work performed at hydrometeorological stations and communication facilities located in high-altitude, remote and difficult climatic areas and provides contraindications for those occupational settings [10]. The Kazakhstani and Kyrgyz lists also include conditions such as haemorrhoids and hernias [9; 10]. In Kazakhstan, these conditions appear in general or other occupational categories, including work at height, which must be distinguished from natural high-altitude exposure [9]. However, these conditions are not identified as altitude-specific contraindications in the international clinical guidance included in the present comparison [11-13].

Three international clinical documents provide relevant evidence for evaluating these national regulations. The Wilderness Medical Society (hereinafter – WMS) guideline addresses the prevention and treatment of acute altitude illness [11]. The European Society of Cardiology (hereinafter – ESC) recommendations evaluate altitude-related risks in individuals with pre-existing cardiovascular disease [12]. The British Thoracic Society (hereinafter – BTS) statement provides guidance for individuals with respiratory disorders exposed to hypobaric conditions during air travel [13]. These documents were not developed specifically for occupational medical screening and should therefore not be treated as direct regulatory standards. Nevertheless, comparison with these documents can help determine whether national contraindications are broadly consistent with contemporary clinical evidence and

identify potential gaps, differences in clinical emphasis and restrictions for which altitude-specific evidence remains limited.

Objective. To compare selected normative legal acts of Russia, Kazakhstan and Kyrgyzstan relevant to medical examinations for high-altitude work and to assess their concordance with relevant international clinical guidance and contemporary scientific evidence.

Materials and methods

This study combined a comparative analysis of selected national regulatory acts with a narrative review of scientific literature on hypobaric hypoxia and high-altitude work. The analysis examined the scope of occupational medical examinations and medical contraindications and considered their relationship to international clinical guidance and available physiological, clinical and occupational evidence.

Three national regulatory acts were examined: Order No. 29n of the Ministry of Health of the Russian Federation dated 28 January 2021 [8]; Order No. KP ДСМ-131/2020 of the Acting Minister of Health of the Republic of Kazakhstan dated 15 October 2020 [9]; and Resolution No. 225 of the Government of the Kyrgyz Republic dated 16 May 2011 [10]. The comparison covered terminology describing hypobaric exposure or high-altitude work, occupational categories, examination frequency, required specialists and investigations, medical contraindications, and provisions for permanent, temporary or conditional restrictions. Particular attention was paid to distinguishing natural high-altitude exposure from technologically maintained low-pressure environments and work at height. Findings were limited to the provisions examined and did not represent an exhaustive assessment of the three national legal systems.

The national provisions were compared with three international clinical documents: the Wilderness Medical Society guideline on acute altitude illness [11], the European Society of Cardiology recommendations for individuals with pre-existing cardiovascular conditions [12], and the British Thoracic Society statement on air travel for passengers with respiratory disease [13]. These documents were used to identify relevant clinical risks and assessment approaches. Their applicability was interpreted in relation to their intended populations and exposure settings; they were not treated as legally binding occupational fitness standards.

The reference set comprised 29 documents: three national regulatory acts, three international clinical documents and 23 additional scientific publications published between 2011 and 2025. The scientific literature included original human studies, systematic reviews, a meta-analysis, narrative reviews, editorial commentary and task-specific occupational recommendations. These sources provided evidence and context concerning physiological adaptation, exercise capacity, cardiovascular and respiratory outcomes, haematological conditions, neurological and functional performance, ophthalmological findings and employment outcomes. Original empirical findings were distinguished from clinical interpretation and recommendations.

For empirical studies, the synthesis considered study design, population, altitude, duration and pattern of exposure, reported outcomes and relevance to occupational settings. Findings from workers were distinguished from those involving travellers, permanent high-altitude residents or patients with chronic disease. Publications reporting different outcomes from the same trial or cohort were treated as complementary reports rather than independent replication. Reported numerical findings were interpreted with regard to the study population, outcome definition and statistical uncertainty.

Evidence was synthesised descriptively and organised into clinical and regulatory domains for comparison with the selected national provisions. Quantitative pooling was not undertaken because the sources differed substantially in design, population, exposure and outcomes. The literature component was a narrative review; no formal study-level risk-of-bias assessment or evidence grading was performed. Interpretation therefore considered methodological limitations, consistency of findings and directness of applicability to high-altitude work. Clinical measurements and diagnostic thresholds were not regarded as validated occupational fitness criteria unless their applicability to the relevant occupation and exposure setting had been established.

Results

The comparative analysis identified differences across twelve regulatory and clinical domains: recognition of hypobaric exposure; cardiovascular, respiratory, haematological, neurological and ophthalmological risks; haemorrhoids and hernias; examination frequency and investigation requirements; restriction categories; hypoxic challenge or altitude-simulation testing; supplemental oxygen

assessment; and quantitative occupational fitness criteria.

The three selected national regulatory documents differed substantially in how they defined the relevant occupational exposure. The Russian framework listed reduced pressure of air or gas environments and reduced oxygen partial pressure in relation to workplaces where such conditions are technologically maintained. It did not explicitly establish natural high-altitude work as a separate occupational category [8]. The Kazakhstani framework regulated medical examinations for hazardous occupations but did not identify hypobaric hypoxia or natural high-altitude exposure as a distinct harmful occupational factor [9]. The Kyrgyz framework explicitly covered specified work at hydrometeorological stations and communication facilities located in high-altitude, remote and difficult climatic areas and provided contraindications applicable to these occupational settings [10].

Within the provisions reviewed, cardiovascular, respiratory and neurological disorders were addressed in all three national documents. Although individual provisions include disease-specific qualifications, no unified decision pathway explicitly tailored to natural high-altitude exposure was identified. No altitude-specific haematological thresholds were identified. Ophthalmological contraindications were present in the national documents, but their explicit linkage to high-altitude work differed; no separate high-altitude-specific ophthalmological provision was identified in the Kazakhstani document [8–10].

A direct comparison of examination frequency, required specialists and investigation panels was limited by the absence of an equivalent natural high-altitude occupational category in the Russian and Kazakhstani documents. The Kyrgyz provisions were linked to specified high-altitude and remote occupations, whereas the Russian and Kazakhstani requirements were organised according to broader harmful factors or categories of work [8–10]. Within the provisions reviewed, no requirements were identified for hypoxic challenge testing, altitude-simulation testing or formal assessment of supplemental oxygen requirements as components of fitness assessment specifically for natural high-altitude work. No validated high-altitude-specific occupational thresholds were identified in these provisions based on oxygen saturation, exercise capacity, haemoglobin concentration or previous altitude tolerance.

Cardiovascular risks

Cardiovascular disorders were included among the contraindications in all three selected national documents. Within the provisions reviewed, no integrated altitude-specific risk-stratification pathway comparable in scope to the ESC recommendations was identified [8–10; 12].

A meta-analysis comprising 12 high-altitude studies with 834 participants and 18 low-altitude studies with 710 participants found that mean systolic pulmonary artery pressure was 25.3 mmHg (95 % CI: 24.0–26.7) at high altitude, compared with 18.4 mmHg (95 % CI: 17.1–19.7) at low altitude. Mean arterial oxygen saturation was 90.4 % (95 % CI: 89.3–91.5) at high altitude and 98.1 % (95 % CI: 97.7–98.4) at low altitude ($p < 0.001$ for both comparisons) [14]. The pooled estimates therefore differed by 6.9 mmHg for systolic pulmonary artery pressure and by 7.7 percentage points for arterial oxygen saturation between the high- and low-altitude groups.

These values were derived primarily from apparently healthy permanent high-altitude residents and therefore cannot be interpreted as occupational fitness thresholds. Nevertheless, they provide quantitative reference values illustrating the haemodynamic and oxygenation changes associated with prolonged high-altitude exposure [14].

Direct occupational evidence from Kyrgyzstan was provided by a prospective cohort of 569 employees screened before employment at a gold mine located at 3,800–4,500 m and followed until January 2022. During 5,190 person-years of observation, 23 workers developed a cardiovascular condition resulting in unfitness for work, corresponding to a cumulative incidence of approximately 4 %. Increasing age (HR per one-year increase 1.13; 95 % CI: 1.06–1.22) and body mass index (HR per 1 kg/m² increase 1.18; 95 % CI: 1.04–1.34) were independently associated with cardiovascular disease leading to unfitness for work [15]. The relatively low cumulative incidence should be interpreted in the context of pre-employment selection and the healthy-worker effect. Nevertheless, the findings suggest that age and adiposity may help identify workers requiring closer cardiovascular assessment and follow-up. The absence of a comparable low-altitude occupational control group limits attribution of these outcomes specifically to hypobaric exposure.

The ESC recommendations identify symptomatic pulmonary hypertension, unstable cardiovascular disease and poorly controlled heart failure as conditions associated with increased risk during altitude exposure [12]. Although cardiovascular contraindications were present in all three national documents, and some provisions considered disease severity or functional impairment, no integrated altitude-specific pathway for distinguishing stable disease from conditions at high risk of decompensation was identified in the provisions reviewed [8-10].

Respiratory disorders and functional capacity

Respiratory diseases were included in all three national frameworks, but only the Kyrgyz framework explicitly linked selected respiratory contraindications to specified high-altitude and remote occupations.

A randomised trial with 176 patients with moderate-to-severe chronic obstructive pulmonary disease (hereinafter – COPD) in the intention-to-treat analysis evaluated adverse health effects during a two-day stay at 3,100 m. Altitude-related adverse health effects occurred in 68 of 90 patients receiving placebo (76 %) and 42 of 86 patients receiving preventive acetazolamide (49 %). The hazard ratio was 0.54 (95 % CI: 0.37–0.79; $p < 0.001$), and the number needed to treat to prevent one adverse event was four (95 % CI: 3–8) [16]. These findings indicate a substantial risk of clinically relevant adverse effects among patients with COPD at 3,100 m, despite a baseline peripheral oxygen saturation of at least 92 %. The outcome was a composite of altitude-related adverse health effects, including severe hypoxaemia, acute mountain sickness and other events requiring medical intervention or descent; it should not be interpreted as the incidence of acute mountain sickness alone.

In an exercise-performance substudy of the parent randomised trial, 103 patients with COPD were included in the per-protocol analysis [17]. Mean values are presented with standard deviations. Maximal work rate in the acetazolamide group decreased from 105 ± 27 W at 760 m to 91 ± 25 W at 3,100 m, while maximal oxygen uptake decreased from 18.0 ± 4.8 to 15.5 ± 3.7 mL·min⁻¹·kg⁻¹ ($p < 0.001$ for both changes). Corresponding reductions in the placebo group were from 107 ± 34 to 97 ± 28 W and from 18.9 ± 6.0 to 17.2 ± 5.0 mL·min⁻¹·kg⁻¹ [17]. Depending on the treatment group and outcome, these changes represented reductions of approximately 9–14 % in maximal exercise capacity. Between-group differences

in the altitude-induced reductions in maximal work rate and maximal oxygen uptake were not statistically significant [17].

Because the parent trial and its exercise-performance substudy involved patients with COPD rather than occupational cohorts, their findings cannot be directly generalised to healthy workers. However, these reports provide quantitative evidence of reduced exercise capacity and an increased risk of clinically relevant adverse effects during short-term high-altitude exposure in selected patients with COPD [16; 17].

Evidence from a Kyrgyz occupational cohort further demonstrates the importance of considering modifiable workplace exposures alongside hypobaric hypoxia. Among 109 healthy gold-mine workers employed at approximately 4,000 m and followed with annual pulmonary function testing for five years, the estimated lung-function slope was a decline of 115 ± 9 mL per year (estimate $\pm$ standard error) before extensive workplace smoking restrictions were implemented. During the subsequent period following implementation of these restrictions, the estimated slope changed to an increase of 178 ± 20 mL per year (estimate $\pm$ standard error) ($p < 0.001$ for both slopes) [18]. Because this was an observational study, the change cannot be attributed exclusively to the smoking restrictions. The study provides occupational evidence that changes in workplace tobacco-smoke exposure may influence longitudinal lung-function measurements; however, its observational design does not establish causality or isolate the independent effect of high-altitude exposure.

Haematological conditions

Within the selected national provisions, no explicit high-altitude-specific contraindications were identified for severe anaemia, sickle cell disease or excessive erythrocytosis [8–10]. The reviewed clinical literature nevertheless identified impaired oxygen transport and excessive erythrocytosis as relevant concerns during high-altitude exposure.

In the diagnostic framework for chronic mountain sickness, excessive erythrocytosis has traditionally been defined as a haemoglobin concentration of ≥ 21 g/dL in men and ≥ 19 g/dL in women [19]. These thresholds form part of the diagnostic framework for chronic mountain sickness in high-altitude residents rather than validated occupational fitness limits. Nevertheless, no altitude-specific haemoglobin or haematocrit thresholds or dedicated haematological

assessment pathway was identified in the national provisions reviewed [8-10].

Neurological and functional effects

General neurological contraindications were included in all three selected national documents. Some provisions considered disease severity, functional impairment or clinical stability. However, no integrated neurological assessment pathway explicitly tailored to natural high-altitude exposure was identified in the provisions reviewed. In particular, no high-altitude-specific occupational clearance thresholds based on seizure control, time since stroke, neurological stability, postural control or cognitive and visuomotor performance were identified [8-10].

Indirect quantitative evidence of altitude-related functional impairment was identified in patients with COPD exposed to 3,100 m. In a randomised study of 45 patients, the placebo group demonstrated increases in directional error of 2.5° (95 % CI: 2.2–2.7) during visuomotor adaptation, 5.3° (95 % CI: 4.6–6.1) during immediate recall and 5.8° (95 % CI: 5.0–6.7) during post-sleep recall compared with measurements at 760 m ($p < 0.001$ for all comparisons) [20].

In another randomised study involving 127 patients with COPD, the centre-of-pressure path length increased from 28.8±9.7 cm at 760 m to 30.0±10.0 cm at 3,100 m in the placebo group ($p = 0.002$). Multivariable analysis confirmed an altitude-associated increase of 0.98 cm (95 % CI: 0.39–1.58; $p = 0.001$), indicating deterioration in postural control [21].

These studies involved patients with COPD rather than workers with neurological disorders and therefore provide indirect evidence only. The documented changes in visuomotor performance and postural control may be relevant to safety-critical tasks involving vehicle operation, machinery, balance or fall hazards [20; 21]. However, the findings do not establish the risk associated with specific neurological diagnoses or provide validated neurological or functional thresholds for occupational screening. Statistical changes in these test outcomes do not, by themselves, establish an increased incidence of occupational accidents.

Ophthalmological risks

Ophthalmological contraindications were present in the national documents, but no separate

high-altitude-specific ophthalmological provision was identified in the Kazakhstani document [8-10]. Quantitative occupationally relevant evidence was available from a prospective observational study of 54 security personnel referred with ocular complaints following high-altitude exposure. High-altitude retinopathy was diagnosed in 28 individuals (51.9 %). Reported abnormalities included 15 retinal arterial or venous occlusions and seven cases of central serous chorioretinopathy. The mean exposure altitude was 14,716 ft (approximately 4,485 m), and the mean duration of stay was 11.2 weeks [22].

The proportion of affected individuals should not be interpreted as prevalence among all high-altitude workers because participants were referred specifically for ocular complaints. The study therefore documents a spectrum of retinal pathology in a clinically selected group of symptomatic personnel but does not provide an estimate of risk among all high-altitude workers.

Haemorrhoids and hernias

Selected forms of haemorrhoids and hernias were listed among the contraindications in the Kazakhstani and Kyrgyz documents [9; 10]. In Kazakhstan, the relevant provisions concern general contraindications or other occupational categories, including work at height; their inclusion should not be interpreted as a specific contraindication to natural high-altitude exposure [9]. These conditions were not identified as altitude-specific contraindications in the WMS, ESC or BTS documents [11-13]. In a prospective cohort of workers newly employed at a Kyrgyz high-altitude gold mine, haemorrhoids diagnosed during pre-employment screening were associated with premature employment discontinuation for any reason (adjusted HR 1.32; 95 % CI: 1.01–3.75) [23]. Smoking (HR 1.55; 95 % CI: 1.10–2.17), lowland residence (HR 1.95; 95 % CI: 1.31–2.90) and obesity (HR 1.71; 95 % CI: 1.01–2.88) were also associated with reduced employment survival [23]. The assessed outcome was employment retention rather than altitude-related morbidity; therefore, the findings do not establish haemorrhoids as a pathophysiological contraindication to hypobaric exposure.

The principal differences between the national regulatory frameworks and the corresponding international guidance and supporting scientific evidence are summarised in Table 1.

Table 1. Comparison of national regulatory frameworks with international guidance and supporting scientific evidence regarding hypobaric exposure

Domain	Russia [8]	Kazakhstan [9]	Kyrgyzstan [10]	International guidance and supporting evidence
Recognition of hypobaric exposure	Reduced pressure and reduced oxygen partial pressure recognised for technologically maintained environments; applicability to natural high-altitude work not explicitly defined	Hypobaric hypoxia not identified as a distinct harmful factor	Specified work in high-altitude, remote and difficult climatic areas recognised	Hypobaric exposure addressed by WMS, ESC and BTS, although not as an occupational regulatory category
Cardiovascular risks	General contraindications	General contraindications	General contraindications	Condition-specific clinical guidance for pre-existing cardiovascular disease [12]; quantitative physiological estimates are available but are not validated occupational thresholds [14]
Respiratory diseases	Broadly included	Broadly included	Selected respiratory contraindications explicitly linked to specified high-altitude and remote occupations	Individual assessment recommended; COPD studies demonstrate increased clinical risk and reduced exercise capacity at 3,100 m [13, 16, 17]
Haematological disorders	No altitude-specific criteria	No altitude-specific criteria	No altitude-specific criteria	Excessive erythrocytosis recognised as clinically relevant; traditional CMS thresholds are Hb ≥ 21 g/dL in men and ≥ 19 g/dL in women [19]
Neurological and functional risks	General contraindications	General contraindications	General contraindications	No universal occupational clearance thresholds; studies indicate impaired visuomotor performance and postural control at 3,100 m in patients with COPD [20, 21]
Ophthalmological risks	Partially recognised	General ophthalmological contraindications present; no separate high-altitude-specific provision identified	Selected conditions recognised for specified occupational settings	Retinal pathology associated with high-altitude exposure is supported by observational evidence, but uniform screening criteria are unavailable [22]

Table continued

Domain	Russia [8]	Kazakhstan [9]	Kyrgyzstan [10]	International guidance and supporting evidence
Haemorrhoids and hernias	Not included as altitude-specific contraindications	Selected forms included in general or other occupational categories, including work at height; no distinct high-altitude category	Selected forms included for the occupational settings reviewed	Not identified as altitude-specific contraindications in WMS, ESC or BTS guidance; one occupational cohort associated haemorrhoids with premature employment discontinuation, but not with altitude-related morbidity [11–13, 23]
Examination frequency and investigation requirements	No directly comparable requirements identified for natural high-altitude work	No distinct hypobaric-exposure category assigning a specific examination schedule or investigation panel	Requirements linked to specified high-altitude and remote occupations	No universal occupational examination schedule provided [11–13]
Restriction categories	No integrated altitude-specific pathway with explicit restriction categories identified in the provisions reviewed	Disease-specific qualifications present; no integrated altitude-specific pathway identified	No integrated altitude-specific pathway with explicit restriction categories identified in the provisions reviewed	Condition-specific individual assessment is supported, but these documents are not occupational regulatory standards [11–13]
Hypoxic challenge or altitude-simulation testing	Not specified	Not specified	Not specified	BTS recommends hypoxic challenge testing for selected patients with respiratory disease; it is not a universal occupational screening test [13]
Supplemental oxygen assessment	Not specified	Not specified	Not specified	Considered for selected individuals with respiratory or cardiopulmonary disease [12, 13]
Quantitative occupational fitness thresholds	Not provided	Not provided	Not provided	No universally validated occupational thresholds; task-specific criteria have been proposed [25]. Other numerical indicators mainly concern clinical populations or residents [14; 16; 17; 19–22]

Source: Authors' comparative analysis of the national regulatory documents of Russia, Kazakhstan and Kyrgyzstan [8–10], international clinical guidance [11–13], and supporting scientific evidence [14; 16; 17, 19–23]. Note: the national categories are not directly equivalent. Work at height in the Kazakhstani document includes climbing work above 2 m and is distinct from natural high-altitude exposure [9]. «Not specified» indicates that no explicit high-altitude-specific requirement was identified in the provisions reviewed; it does not imply absence of all relevant national requirements.

Discussion

The present analysis identified substantial differences between the selected regulatory acts of Russia, Kazakhstan and Kyrgyzstan in their recognition of hypobaric exposure, medical contraindications and altitude-specific criteria. Although all three frameworks require medical examinations for hazardous work, no integrated risk-stratification pathway for natural high-altitude work was identified in the provisions reviewed [8-10]. The principal gap was the limited adaptation of existing contraindications to the physiological and functional demands of high-altitude work. This distinction matters when interpreting regulatory omissions, because general medical examinations and disease-specific restrictions may still apply.

Several factors may explain these differences. The documents were developed within distinct legal and occupational-health systems: the Kyrgyz resolution was adopted in 2011, and the Kazakhstani and Russian orders in 2020 and 2021, respectively [8-10]. Their structure relies primarily on lists of harmful factors, occupations and diseases. Broad diagnostic categories may therefore serve several occupational safety purposes and should not automatically be interpreted as restrictions specifically attributable to hypobaric hypoxia.

The international evidence base also remains heterogeneous. Although some studies concern miners, rescue personnel and military personnel, much of the clinical evidence originates from travellers, patients with chronic diseases or permanent high-altitude residents [24-27]. Differences in altitude, exposure duration, shift schedules, acclimatisation, workload and worker selection hinder the development of universal occupational fitness thresholds and may partly explain reliance on broad diagnostic categories.

The Russian and Kyrgyz frameworks recognise different exposures. The Russian document addresses reduced pressure and oxygen partial pressure in technologically maintained environments, whereas the Kyrgyz document covers specified occupations in high-altitude, remote and difficult climatic areas [8; 10]. The Kazakhstani document does not identify hypobaric hypoxia as a distinct harmful occupational factor [9]. These differences limit direct comparison and application to natural high-altitude work. Recognition of an exposure category alone does not ensure adequate clinical assessment: no integrated pathway combining altitude-specific risk

stratification and explicit restriction categories was identified.

The Kazakhstani framework requires examinations for hazardous work without a separate hypobaric hypoxia category [9]. In practice, the absence of a dedicated category may leave the relationship between anticipated exposure and required investigations unclear. This may complicate the selection of investigations before high-altitude work and increase reliance on broad disease categories or clinical judgement. Such discretion could lead to inconsistent decisions, unnecessary exclusion of stable workers or inadequate assessment of susceptibility to hypoxaemia. These potential effects were not directly evaluated. The analysis therefore identifies possible consequences of regulatory ambiguity rather than demonstrating differences in the quality of decisions between institutions.

Haemorrhoids and hernias must be interpreted within the occupational categories covered by the provisions [9; 10]. In Kazakhstan, general contraindications and restrictions for physically demanding work or work at height should not be conflated with hypobaric exposure [9]. These conditions were not identified as altitude-specific contraindications in the WMS, ESC or BTS documents [11-13]. Heavy workload, acute complications and limited surgical access may explain restrictions in remote occupations, but these remain hypotheses. A Kyrgyz cohort associated haemorrhoids with premature employment discontinuation for any reason, rather than altitude-related morbidity [23]. This does not establish causality or justify automatic exclusion. Assessment should consider severity, recent complications, workload and access to care.

Recommendations for alpine helicopter rescue personnel support task-specific screening that considers cardiovascular fitness, workload, environmental exposure and operational safety [25]. Although developed for mountain rescue rather than mining, they illustrate the value of adapting assessment to occupational demands. They include permanent and temporary restrictions and proposed quantitative fitness criteria [25]. These recommendations are distinct from the three clinical documents in the primary comparison, and their cut-offs are not universally validated for other high-altitude occupations.

All three national frameworks include cardiovascular contraindications, sometimes qualified by severity or functional impairment. However, no integrated pathway relating these factors to natural

high-altitude exposure was identified [8-10]. ESC recommendations provide condition-specific guidance for pre-existing cardiovascular disease but were developed for altitude exposure rather than occupational screening [12].

Occupational and population-based findings support cardiovascular assessment without establishing exclusion thresholds. In the Kyrgyz cohort, increasing age and body mass index were associated with cardiovascular disease leading to unfitness for work; the low incidence may reflect pre-employment selection and the healthy-worker effect [15]. The meta-analysis found higher systolic pulmonary artery pressure and lower oxygen saturation among high-altitude residents, but its pooled estimates cannot serve as occupational fitness criteria [14]. These findings support closer assessment of multiple risk factors without automatic exclusion based on isolated measurements. Their practical relevance depends on the worker's clinical status and exposure conditions, and neither association proves that hypobaric hypoxia independently caused the observed cardiovascular outcomes.

A systematic narrative review of 31 occupational studies suggested increased cardiovascular risk during long-term intermittent hypoxia, particularly among miners and military personnel [27]. Obesity, socioeconomic conditions and lifestyle may confound these associations. The evidence supports surveillance but does not establish an exclusion threshold. A cardiovascular review described potentially increased risk above approximately 2,500 m through hypoxaemia, sympathetic activation and hypoxic pulmonary vasoconstriction [28]. Responses depend on disease stability, altitude, ascent profile and exposure duration, supporting individual assessment rather than exclusion by diagnosis alone.

Trials in selected patients with COPD demonstrated adverse effects and reduced exercise capacity at 3,100 m, but these findings do not establish occupational exclusion thresholds [16; 17]. Low-altitude resting assessment may not fully predict stability or functional capacity during hypobaric exposure. Assessment should consider baseline oxygen saturation, disease control, exercise tolerance, workload and previous altitude responses. Hypoxic challenge testing and supplemental oxygen assessment, described by BTS for air travel, may help in selected cases but should not be routine for all workers [13]. Pulse oximetry may complement assessment, although evidence does not support a universal

saturation threshold for occupational clearance or prediction of altitude illness [29].

Altitude-specific haematological assessment is relevant because severe anaemia impairs oxygen transport, whereas excessive erythrocytosis may increase viscosity and accompany chronic mountain sickness [19]. Diagnostic thresholds for permanent residents are not validated occupational fitness limits. Population, altitude and exposure pattern must therefore inform any proposed quantitative criteria. Distinguishing diagnostic criteria from fitness criteria is particularly important when translating findings from long-term residents to workers undergoing repeated or short-term exposure.

Neurological contraindications were present in all three frameworks, but no integrated pathway tailored to natural high-altitude exposure was identified [8-10]. Studies demonstrated impaired visuo-motor performance and postural control in patients with COPD at 3,100 m [20; 21]. These outcomes may matter for driving, machinery operation and tasks involving balance or fall hazards. However, evidence from selected clinical populations supports individual assessment, not categorical exclusion or universal neurological thresholds.

Ophthalmological conditions were addressed nationally, but no separate high-altitude-specific provision was identified in the Kazakhstani document [8-10]. Findings in symptomatic security personnel document retinal vascular and other ocular pathology after altitude exposure; selection prevents estimation of prevalence or occupational risk [22]. New ocular symptoms nevertheless warrant timely ophthalmological assessment.

These differences may increase reliance on individual judgement, produce inconsistent decisions or unnecessary exclusion of stable workers, and leave unlisted risk factors insufficiently assessed. The absence of explicit restriction and reassessment pathways may also limit reconsideration after treatment, acclimatisation or changes in exposure. These are hypotheses for practice and policy evaluation: actual clearance decisions, unnecessary exclusion and surveillance effectiveness were not measured.

International guidance can inform clinical interpretation but requires adaptation before incorporation into occupational regulations. WMS addresses acute altitude illness [11], ESC addresses pre-existing cardiovascular disease [12], and BTS addresses respiratory disease during air travel [13]. None specifically determines fitness for prolonged, repeated

or intermittent high-altitude work. Their value lies in identifying clinical domains and assessment approaches rather than legally applicable contraindications. Adaptation should preserve the distinction between preventing acute altitude illness, managing chronic disease during exposure and assessing the demands of a specific occupation.

A potential model could combine clearly defined absolute contraindications with conditional assessment of stable disease. Relevant factors include altitude, ascent rate, exposure duration and pattern, workload, medical access, oxygenation, functional capacity and previous altitude tolerance [24-26]. Pre-employment assessment could be complemented by acclimatisation planning, symptom monitoring, periodic surveillance and emergency procedures. Hypoxic challenge testing or oxygen assessment could be reserved for selected cardiopulmonary cases when results would influence fitness decisions. Prospective occupational evaluation would be needed to determine whether such an approach improves consistency, protects worker health and avoids unnecessary restrictions.

Several limitations require consideration. Only three selected acts were examined, rather than all national requirements for high-altitude work. Differences in terminology and scope limited comparison between natural altitude, technologically maintained low pressure and work at height. The literature component was a structured narrative review without formal risk-of-bias assessment or evidence grading. Searches were limited to Scopus and Web of Science; contextual publications may have introduced selection bias. Much evidence concerned travellers, residents or patients rather than workers. Reports from the same trial or cohort did not provide independent replication [15-17; 23]. Occupational studies also differed in altitude, exposure schedules, selection and outcomes [24-27]. Healthy-worker selection, co-exposures and limited comparators restrict causal interpretation. Numerical findings illustrate risks but do not establish occupational thresholds. Clearance effectiveness and the predictive validity of proposed criteria were not evaluated. Subsequent regulatory amendments and evidence may change the comparison; adoption dates alone do not establish the currency of the provisions analysed.

Conclusion

The selected regulatory acts of Russia, Kazakhstan and Kyrgyzstan differ in their explicit

coverage of occupational hypobaric exposure. The Russian provisions address technologically maintained low-pressure environments, the Kyrgyz provisions cover specified occupations in high-altitude and remote areas, and the Kazakhstani document does not identify hypobaric hypoxia as a distinct harmful occupational factor. No integrated fitness-assessment pathway specifically designed for natural high-altitude work was identified within the provisions analysed.

These findings support clearer definitions of occupational hypobaric exposure and individual fitness assessment that considers altitude, exposure pattern, physical workload and clinical stability. International clinical guidance and task-specific occupational recommendations may inform this approach, but their applicability to different working conditions requires evaluation. Prospective occupational studies are needed to validate fitness criteria and assess their effects on worker health and safety before clinical indicators are adopted as regulatory thresholds.

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БИІК ТАУЛЫ АЙМАҚТАҒЫ ГИПОБАРИЯЛЫҚ ГИПОКСИЯ ЖАҒДАЙЫНДАҒЫ ЕҢБЕК ҚЫЗМЕТІНЕ ҚАТЫСТЫ НОРМАТИВТІК НЕГІЗДЕР МЕН ХАЛЫҚАРАЛЫҚ ДЕРЕКТЕР: САЛЫСТЫРМАЛЫ ТАЛДАУ

**А. К. Сактапов^{1*}, Д. В. Винников¹, А. Е. Уалиева¹, Ж. В. Романова¹,
Н. Н. Айтамбаева², Л. З. Назарова², Г. Ж. Аханов³, О. Ж. Муканова⁴**

¹ «Әл-Фараби атындағы Қазақ Ұлттық университеті» КЕАҚ, Қазақстан, Алматы

² «ҚДСЖМ» Қазақстандық медицина университеті, Қазақстан, Алматы

³ «С. Д. Асфендияров атындағы Қазақ ұлттық медицина университеті» КЕАҚ, Қазақстан, Алматы

⁴ Маңғыстау облысының денсаулық сақтау басқармасының «Маңғыстау орталық аудандық ауруханасы», Қазақстан, Маңғыстау облысы

**Корреспондент автор*

Аңдатпа

Өзектілігі. Биік таулы жағдайларда жұмыс істеу гипобариялық гипоксияның әсерімен және биіктік ауруының, ұйқы мен когнитивтік функциялар бұзылыстарының, жүрек-қан тамыр асқынуларының қаупімен байланысты. Ұлттық нормативтік талаптардың айырмашылықтары жұмыскерлерді медициналық тексеру тәсілдерін үйлестіруді қиындатады.

Мақсаты. Ресейдің, Қазақстанның және Қырғызстанның биік таулы жағдайларда жұмыс істейтін жұмыскерлерді медициналық тексеруге қатысты жекелеген нормативтік құқықтық актілерін салыстыру және олардың халықаралық ұсынымдар мен ғылыми деректерге сәйкестігін бағалау.

Материалдар мен әдістер. Үш ұлттық нормативтік құқықтық акт және Wilderness Medical Society, European Society of Cardiology және British Thoracic Society ұйымдарының үш халықаралық клиникалық құжаты талданды. Scopus және Web of Science дерекқорларында іздеу арқылы құрылымдалған нарративтік шолу жүргізілді; сапалық синтезге 23 ғылыми жарияланым енгізілді.

Нәтижелер. Ресейлік құжат технологиялық жолмен қамтамасыз етілетін ортадағы төмен қысым мен оттегінің төмен парциалдық қысымын қарастырады, алайда оның табиғи биік таулы жағдайларға қолданылуы нақты белгіленбеген. Қазақстандық құжатта гипобариялық гипоксия дербес зиянды өндірістік фактор ретінде көрсетілмеген. Қырғызстандық құжат биік таулы және шалғай аудандардағы жекелеген кәсіптерді қамтиды. Қарастырылған ережелерде биіктікке тән қауіптерді стратификациялауды, кәсіби жарамдылықтың валидтелген өлшемдерін және нақты белгіленген шектеу санаттарын біріктіретін бірыңғай алгоритм анықталмады. Халықаралық клиникалық ұсынымдар тиісті қауіптерді қарастырады, бірақ кәсіби жарамдылықты реттейтін нормативтік стандарт болып табылмайды. Қазақстандық және қырғызстандық құжаттар геморрой мен жарықтардың жекелеген түрлерін қамтиды; бұл шектеулердің нормативтік мәнмәтінін гипобариялық әсерге тікелей байланысты қарсы көрсетілімдерден ажырату қажет.

Қорытынды. Гипобариялық гипоксияның кәсіби әсерін нақтылау және жұмыс міндеттерін ескере отырып, жарамдылықты жеке бағалау қажет. Халықаралық ұсынымдар кәсіби жағдайларға бейімделген кезде нормативтік талаптарды қайта қарауға негіз бола алады.

Түйін сөздер: теңіз деңгейінен биіктік; гипоксия; жұмыскерлердің денсаулығы; кәсіптік әсер; физикалық тексеру; тәуекелді бағалау; заңнама.

НОРМАТИВНЫЕ ОСНОВЫ И МЕЖДУНАРОДНЫЕ ДАННЫЕ О ТРУДОВОЙ ДЕЯТЕЛЬНОСТИ В УСЛОВИЯХ ГИПОБАРИЧЕСКОЙ ГИПОКСИИ НА ВЫСОКОГОРЬЕ: СРАВНИТЕЛЬНЫЙ АНАЛИЗ

А. К. Сактапов^{1*}, Д. В. Винников¹, А. Е. Уалиева¹, Ж. В. Романова¹,
Н. Н. Айтамбаева², Л. З. Назарова², Г. Ж. Аханов³, О. Ж. Муканова⁴

¹ НАО «Казахский национальный университет им. аль-Фараби», Казахстан, Алматы

² Казахстанский медицинский университет «ВШОЗ», Казахстан, Алматы

³ НАО «Казахский национальный медицинский университет
им. С. Д. Асфендиярова», Казахстан, Алматы

⁴ «Мангистауская центральная районная больница» Управления здравоохранения Мангистауской
области, Казахстан, Мангистауская область

*Корреспондирующий автор

Аннотация

Актуальность. Работа в высокогорных условиях сопряжена с воздействием гипобарической гипоксии и риском высотной болезни, нарушений сна и когнитивных функций, сердечно-сосудистых осложнений. Различия национальных нормативных требований затрудняют согласование подходов к медицинскому обследованию работников.

Цель. Сравнить отдельные нормативные правовые акты России, Казахстана и Кыргызстана, относящиеся к медицинским осмотрам работников в высокогорных условиях, и оценить их соответствие международным рекомендациям и научным данным.

Материалы и методы. Проанализированы три национальных нормативных правовых акта и три международных клинических документа Wilderness Medical Society, European Society of Cardiology и British Thoracic Society. Проведён структурированный нарративный обзор с поиском в Scopus и Web of Science; в качественный синтез включены 23 научные публикации.

Результаты. Российский документ предусматривает пониженное давление и пониженное парциальное давление кислорода в технологически поддерживаемых условиях, однако его применимость к природному высокогорью прямо не определена. В казахстанском документе гипобарическая гипоксия не выделена как самостоятельный вредный производственный фактор. Кыргызский документ охватывает отдельные профессии в высокогорных и отдалённых районах. В рассмотренных положениях не выявлен единый алгоритм, объединяющий высотную стратификацию риска, валидированные критерии профессиональной пригодности и явно определённые категории ограничений. Международные клинические рекомендации рассматривают соответствующие риски, но не являются нормативными стандартами профессиональной пригодности. Казахские и кыргызские документы включают отдельные формы геморроя и грыж; нормативный контекст этих ограничений следует отличать от противопоказаний, непосредственно связанных с гипобарическим воздействием.

Выводы. Необходимы уточнение определения профессионального воздействия гипобарической гипоксии и индивидуальная оценка пригодности с учётом рабочих задач. Международные рекомендации могут содействовать пересмотру требований при адаптации к профессиональным условиям.

Ключевые слова: высота над уровнем моря, гипоксия, здоровье работников, профессиональное воздействие, физикальное обследование, оценка риска, законодательство.

АВТОРЛАР ТУРАЛЫ

Сактапов Акылбек Кенгесович – әл-Фараби атындағы ҚазҰУ Эпидемиология, биостатистика және дәлелді медицина кафедрасының аға оқытушысы; e-mail: akylbekzone@mail.ru; ORCID: <https://orcid.org/0000-0003-4337-1779>.

Винников Денис Владимирович – м.ғ.д., профессор, әл-Фараби атындағы ҚазҰУ, Денсаулық және қоршаған орта ғылыми-зерттеу зертханасы меңгерушісі; e-mail: denisvinnikov@mail.ru; ORCID: <https://orcid.org/0000-0003-0991-6237>.

Уалиева Алия Ержановна – PhD, әл-Фараби атындағы ҚазҰУ, Эпидемиология, биостатистика және дәлелді медицина кафедрасының қауымдастырылған профессоры; e-mail: aualiyeva9@gmail.com; ORCID: <https://orcid.org/0000-0002-4776-1988>.

Романова Жанна Витальевна – м.ғ.к., әл-Фараби атындағы ҚазҰУ, Эпидемиология, биостатистика және дәлелді медицина кафедрасының қауымдастырылған профессоры; e-mail: Zhanna.Romanova@kaznu.kz; ORCID: <https://orcid.org/0000-0002-9551-2505>.

Айтамбаева Надира Нурбековна – «ҚДСЖМ» Қазақстандық медицина университеті, Қоғамдық денсаулық және әлеуметтік ғылымдар кафедрасының аға оқытушысы; e-mail: aitambaeva.nadira@gmail.com; ORCID: <https://orcid.org/0000-0001-5869-1789>.

Назарова Ләйла Зәуірбекқызы – «ҚДСЖМ» Қазақстандық медицина университеті, Эпидемиология, биостатистика және дәлелді медицина кафедрасының аға оқытушысы; e-mail: laila-nazar92@mail.ru; ORCID: <https://orcid.org/0000-0003-2084-2806>.

Аханов Гани Жайшылыкович – PhD, С. Д. Асфендияров атындағы ҚазҰМУ қауымдастырылған профессоры; e-mail: ahanovgj@gmail.com; ORCID: <https://orcid.org/0009-0006-3760-9831>.

Муканова Орынгуль Жоламановна – Маңғыстау облысы денсаулық сақтау басқармасының «Маңғыстау орталық аудандық ауруханасы», директордың емдеу ісі жөніндегі орынбасары; e-mail: mukanova.o_gol@mail.ru; ORCID: <https://orcid.org/0009-0000-1028-0825>.

ОБ АВТОРАХ

Сактапов Акылбек Кенгесович – старший преподаватель кафедры эпидемиологии, биостатистики и доказательной медицины, КазНУ им. аль-Фараби; e-mail: akylbekzone@mail.ru; ORCID: <https://orcid.org/0000-0003-4337-1779>.

Винников Денис Владимирович – д.м.н., профессор, заведующий научно-исследовательской лабораторией здоровья и окружающей среды, КазНУ им. аль-Фараби; e-mail: denisvinnikov@mail.ru; ORCID: <https://orcid.org/0000-0003-0991-6237>.

Уалиева Алия Ержановна – PhD, ассоциированный профессор кафедры эпидемиологии, биостатистики и доказательной медицины, КазНУ им. аль-Фараби; e-mail: aualiyeva9@gmail.com; ORCID: <https://orcid.org/0000-0002-4776-1988>.

Романова Жанна Витальевна – к.м.н., ассоциированный профессор кафедры эпидемиологии, биостатистики и доказательной медицины, КазНУ им. аль-Фараби; e-mail: Zhanna.Romanova@kaznu.kz; ORCID: <https://orcid.org/0000-0002-9551-2505>.

Айтамбаева Надира Нурбековна – старший преподаватель кафедры общественного здоровья и социальных наук, Казахский медицинский университет «ВШОЗ»; e-mail: aitambaeva.nadira@gmail.com; ORCID: <https://orcid.org/0000-0001-5869-1789>.

Назарова Ләйла Зәуірбекқызы – старший преподаватель кафедры эпидемиологии, биостатистики и доказательной медицины, Казахский медицинский университет «ВШОЗ»; e-mail: lailanazar92@mail.ru; ORCID: <https://orcid.org/0000-0003-2084-2806>.

Аханов Гани Жайшылыкович – PhD, ассоциированный профессор, КазНМУ имени С. Д. Асфендиярова; e-mail: ahanovgj@gmail.com; ORCID: <https://orcid.org/0009-0006-3760-9831>.

Муканова Орынгуль Жоламановна – заместитель директора по лечебной части Мангистауской центральной районной больницы Управления здравоохранения Мангистауской области; e-mail: mukanova.o_gol@mail.ru; ORCID: <https://orcid.org/0009-0000-1028-0825>.

ABOUT THE AUTHORS

Saktapov Akylbek – Senior Lecturer of the Department of Epidemiology, Biostatistics and EBM, al-Farabi KazNU; e-mail: akylbekzone@mail.ru; ORCID: <https://orcid.org/0000-0003-4337-1779>.

Vinnikov Denis – PhD, Professor, Head of the Research Laboratory of Health and Environment, al-Farabi KazNU; e-mail: denisvinnikov@mail.ru; ORCID: <https://orcid.org/0000-0003-0991-6237>.

Ualiyeva Aliya – PhD, Associate Professor of the Department of Epidemiology, Biostatistics and EBM, al-Farabi KazNU; e-mail: aualiyeva9@gmail.com; ORCID: <https://orcid.org/0000-0002-4776-1988>.

Romanova Zhanna – PhD, Associate Professor of the Department of Epidemiology, Biostatistics and EBM, al-Farabi KazNU; e-mail: Zhanna.Romanova@kaznu.kz; ORCID: <https://orcid.org/0000-0002-9551-2505>.

Aitambayeva Nadira – Senior Lecturer of the Department of Public Health and Social Sciences, Kazakhstan's Medical University «KSPH»; e-mail: aitambaeva.nadira@gmail.com; ORCID: <https://orcid.org/0000-0001-5869-1789>.

Nazarova Laila – Senior Lecturer of the Department of Epidemiology, Biostatistics and EBM, Kazakhstan's Medical University «KSPH»; e-mail: lailanazar92@mail.ru; ORCID: <https://orcid.org/0000-0003-2084-2806>.

Akhanov Gani – PhD, Associate Professor, S. D. Asfendiyarov Kazakh National Medical University; e-mail: ahanovgj@gmail.com; ORCID: <https://orcid.org/0009-0006-3760-9831>.

Mukanova Oryngul – Deputy Director for Medical Affairs at «Mangystau Central District Hospital» of the Health Department of Mangystau Region; e-mail: mukanova.o_gol@mail.ru; ORCID: <https://orcid.org/0009-0000-1028-0825>.

Author Contributions: Conceptualization: A.K. Saktapov, D.V. Vinnikov and A.Y. Ualiyeva; investigation: A.K. Saktapov, D.V. Vinnikov, Z.V. Romanova and L.Z. Nazarova; formal analysis: A.K. Saktapov, D.V. Vinnikov, Z.V. Romanova, N.N. Aitambayeva, L.Z. Nazarova, G.Z. Akhanov and O.Z. Mukanova; interpretation of findings: A.K. Saktapov, D.V. Vinnikov and L.Z. Nazarova; writing-original draft preparation: A.K. Saktapov, A.Y. Ualiyeva and N.N. Aitambayeva.

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