

Association of Total and Hazardous Work Experience With the Structure of Registered Occupational Diseases in Kazakhstan: A Retrospective Descriptive Study, 2018–2023

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ASSOCIATION OF TOTAL AND HAZARDOUS WORK EXPERIENCE WITH THE
STRUCTURE OF REGISTERED OCCUPATIONAL DISEASES IN KAZAKHSTAN: A
RETROSPECTIVE DESCRIPTIVE STUDY, 2018–2023

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Annotation. Occupational diseases remain a significant medical and social problem, particularly in industries characterized by long-term exposure to hazardous workplace factors. The number of studies describing the long-term structure of occupational pathologies in relation to work experience remains limited in Kazakhstan.

Objective. To characterize the distribution of occupational diseases in 2018-2023 according to age, total and hazardous work experience, and occupational group.

Study design. A retrospective descriptive study based on the analysis of all newly registered cases of occupational diseases. The study was not designed to estimate the population-level risk, did not include control groups, and reflects only the structure of identified cases.

Materials and methods. A total of 593 cases of occupational diseases were analyzed. The descriptive statistics, analysis of distribution by age, work experience, occupation, and nosological categories were performed. Group comparisons were performed using the χ test², and associations between quantitative variables were assessed using Spearman's correlation coefficient. Regression models were used exclusively for within-sample association assessment and were not interpreted as risk estimates.

Results. The majority of cases were identified among workers aged 40-59 years with work experience of ≥ 20 years. The most prevalent nosological forms were dust-related lung diseases, vibration disease, and occupational hearing loss. The association between the length of work experience and the distribution of nosological forms was observed, as well as between occupational groups and types of diseases.

Conclusions. The structure of occupational pathology is characterized by a predominance of cases among workers with long professional experience. The findings reflect the distribution of occupational diseases among registered cases and may serve as a basis for improving early detection systems and preventive programs.

Keywords: occupational diseases; work experience; hazardous workplace factors; risk factors; working conditions; occupational risk groups; occupational epidemiology.

Background. Occupational morbidity remains one of the most significant challenges in occupational health, exerting a direct impact on workers' health, work capacity, and the economic sustainability of enterprises and healthcare systems. According to the World Health Organization (WHO) and the International Labour Organization (ILO), more than 160 million employees worldwide develop work-related diseases each year, and approximately 2.4 million deaths are attributed to occupational conditions. These figures position occupational diseases among the leading preventable causes of loss of work ability globally. In Kazakhstan, the issue is particularly relevant due to the high proportion of employment in sectors such as mining, metallurgy, construction, and mechanical engineering which are characterized by persistent exposure to noise, vibration, industrial dust, chemical agents, and heavy physical workloads. According to national statistics, dust-related respiratory diseases, vibration disease, occupational hearing loss, and musculoskeletal disorders occupy leading positions in the structure of occupational pathology. These diseases are typically associated with long-term exposure to harmful factors and are frequently detected at advanced stages, when chronic changes have already developed. The duration of occupational exposure is a key factor of risk in the development of occupational diseases. The most of pathology forms emerge after 10-20 years of exposure to harmful occupational factors and reach the maximum of severity with work experience exceeding 25 years. Despite this well-established relationship, comprehensive long-term studies examining the association between total work experience, hazardous work experience, and the structure of occupational morbidity using large datasets are still lacking in Kazakhstan. The absence of systematic long-term analytical research limits the development of effective preventive programs, leads to delayed diagnosis, underestimation of occupational diseases, and worsens the quality of planning of events regarding the occupational health and efficient resource allocation. Thus, analysis of occupational pathology in relation to work experience and working conditions is a necessary step toward evidence-based improvement of prevention systems, early detection strategies, and reduction of the burden of occupational diseases in Kazakhstan.

Epidemiological context. Occupational diseases constitute a significant contribution to the global burden of diseases while remaining one of the major causes of chronic disability among industrial workers. According to the WHO and ILO estimates, more than 160 million work-related cases of disease are registered annually worldwide, although the true prevalence is likely higher due to underdiagnosis and variability in diagnostic criteria. The most common forms of occupational pathology include respiratory diseases, noise-induced hearing loss, vibration disease, musculoskeletal disorders, and conditions related to chemical and aerosol exposure. Regions with developed heavy industry exhibit the highest burden of occupational morbidity. Central Asia, including Kazakhstan, demonstrates a stable occupational disease structure typical of countries with extensive mining, metallurgical activities. Dust-related lung diseases, vibration disease, and occupational hearing loss have remained the leading nosological entities for several decades. National reports indicate that hundreds of new occupational disease cases are identified annually in Kazakhstan, with the most vulnerable groups comprising underground miners, metallurgical workers, and machine operators exposed to sustained vibration, noise, dust, adverse microclimates, and physical overload. A substantial proportion of newly registered cases occurs among workers aged over 40–45 years with work experience exceeding 20–25 years, supporting the cumulative effect of harmful occupational exposures. An additional challenge influencing the epidemiological situation is the limited detectability of occupational diseases. Delayed diagnosis, restricted access to specialized occupational health services, variability in the quality of periodic medical examinations, and inconsistent interpretation of workplace exposure contribute to underestimation of true disease prevalence. Overall, the epidemiological situation in Kazakhstan reflects global trends: occupational diseases remain persistently prevalent among workers subjected to prolonged exposure to multiple harmful factors. This underscores the need for systematic analysis of long-term data, identification of high-risk groups, and optimization of preventive interventions.

Rationale and research gap. Studies examining the influence of professional exposure duration on the risk of developing occupational diseases confirm that length of service is one of the key factors

in the formation of chronic occupational pathology. A study among workers in the aluminum industry showed that lifetime cumulative exposure to sulfur dioxide and fluorides is a statistically significant predictor of reduced lung function (FEV1/FVC ratio). The effect is observed even at exposure levels below established international occupational exposure limits (OELs), which highlights the role of exposure duration as an independent risk factor [1]. International studies consistently demonstrate that increasing duration of exposure to occupational hazards - such as noise, vibration, dust aerosols, chemical substances, and physical overload - raises the likelihood of developing respiratory diseases, musculoskeletal disorders, hearing impairment, and peripheral nervous system conditions. The international literature studied the next occupational groups in most detail: miners and workers in the mining industry (pneumoconioses, chronic obstructive pulmonary disease (COPD), dust bronchitis); metallurgical workers and welders (dust-related diseases, chronic intoxications, thermal injuries); operators of vibration-intensive machinery (vibration disease and vascular–neurological disorders); workers in environments with noise levels ≥ 85 dBA (occupational hearing loss); construction workers (musculoskeletal injuries, chronic physical overload). Most international studies indicate a clear relationship between disease risk and duration of occupational exposure, especially when exposure exceeds 10–15 years. Work experience is important not only because of its duration, but also because of the timing of the first exposure to a harmful factor, as many severe diseases have a long latency period [2]. Even after exposure has ceased (due to retirement or a change of occupation), the risk of developing diseases such as silicosis remains, which makes occupational history and past work experience essential data for diagnosis [3]. Work experience (often correlated with age) also influences the pattern and severity of injuries. Trend analysis in Ontario showed that the incidence of severe injuries (fractures and dislocations) increases among workers with longer work experience, especially among women aged 55 years and older [4, 5]. However, a substantial proportion of these studies are limited to individual enterprises or narrowly defined occupational groups, which reduces the possibility of extrapolating their findings to large working populations. In Central Asian countries, including Kazakhstan, research on occupational pathology is much less extensive. Available

publications are generally based on descriptions of individual enterprises, reports from occupational health services, or case series. Comprehensive studies that simultaneously analyze total and hazardous work experience, occupational affiliation, nosological structure, and temporal dynamics using large samples are extremely rare. As a result, a significant scientific and practical gap remains—the lack of long-term analytical studies that make it possible to assess how the duration of occupational exposure influences the structure of occupational morbidity at the regional or national level. The present study addresses this gap by offering an analysis of a large archive-based dataset and by examining work experience, occupation, and nosology within a unified descriptive epidemiological framework. The scientific novelty of this study is defined by a number of features that distinguish it from existing research in the field of occupational pathology in Kazakhstan and Central Asia.

1. Analysis of the complete set of registered cases over a six-year period. For the first time at the regional level, all officially registered cases of occupational diseases for 2018–2023 were analyzed, ensuring a high level of coverage and eliminating the selection bias typical of studies conducted at individual enterprises.
2. Standardized and cleaned database. A unified structured database was created, including age, total work experience, hazardous work experience, occupation, and diagnosis. The following procedures were performed: deduplication; correction of data entry errors; format normalization; handling of missing values; and unification of nosological categories. Such databases are virtually absent in Kazakhstan.
3. Comprehensive analysis of work experience as a key factor of occupational risk. Unlike most local studies, work experience is considered not as a single variable but as an integrated indicator of long-term exposure, encompassing total work experience, hazardous work experience, age–experience relationships, and distribution across occupations. This approach allows for a deeper assessment of the contribution of exposure duration to the structure of occupational diseases.

4. First systematic comparison of occupational, age-related, and nosological profiles using a large dataset. The study demonstrates which nosologies are most characteristic of specific occupations, how work experience is distributed within occupational groups, and how the epidemiological profile of occupational pathology is formed.
5. Exclusion of inappropriate statistical models and application of valid analytical methods. In contrast to the previous version, which employed logistic and Poisson regression without sufficient theoretical justification, the revised study uses appropriate methods for comparing categories, trend analysis without model overfitting, and correlation analysis that accounts for data structure. This enhances the scientific validity of the findings.
6. Addressing a significant information gap in occupational epidemiology in Kazakhstan. In the context of a lack of long-term national studies, this work provides a systematic understanding of the structure of occupational morbidity and its relationship with work experience, which is important for preventive programs and for improving occupational health and safety standards.

Research hypothesis. An increase in total and hazardous work experience is statistically associated with a higher prevalence of occupational diseases characteristic of long-term exposure to harmful workplace factors, which is reflected in changes in the nosological structure of occupational pathology among workers with different lengths of occupational exposure.

Aim of the study. To assess the impact of total and hazardous work experience on the structure of occupational diseases among workers in various industries based on the analysis of all registered occupational disease cases from 2018 to 2023.

To achieve the stated aim, the following objectives were defined:

1. To characterize the structure of occupational diseases registered between 2018 and 2023, with distribution by age, total and hazardous work experience, occupation, and nosological categories.

2. To assess the distribution of total and hazardous work experience among affected workers and identify their statistical associations with age and occupational affiliation.
3. To determine the relationship between the structure of occupational pathology and the duration of occupational exposure, including analysis by work experience categories and leading nosological forms.
4. To analyze occupational risk groups by identifying professions and types of activities most strongly associated with prolonged exposure to harmful workplace factors and characteristic forms of occupational disease.

Methods. The study was conducted as a retrospective descriptive epidemiological analysis based on the complete set of archival data on registered occupational disease cases from 2018 to 2023. This design allows for the assessment of the structure of occupational pathology and its association with the duration of occupational exposure without the formation of control groups or intervention in the case registration process. Unlike cohort or case–control studies, a retrospective descriptive design does not aim to estimate population-level disease risk. Instead, it focuses on analyzing distributions, identifying statistical patterns within the registered cases, and examining associations between work experience, age, occupation, and nosological categories. The use of the full dataset of officially registered cases minimizes selection bias and enables a comprehensive characterization of occupational morbidity across multiple industrial sectors.

Study period and setting. The study was based on archival data on occupational diseases registered in the Republic of Kazakhstan between 1 January 2018 and 31 December 2023. This time frame allows for the assessment of long-term characteristics of occupational pathology, evaluation of the stability of nosological structures, and identification of patterns related to the duration of occupational exposure. The analysis included cases registered across various regions and industrial sectors of Kazakhstan, including mining, metallurgy, mechanical engineering, transportation,

construction, and industrial maintenance. The use of nationwide data ensures representativeness and reflects actual sectoral and regional characteristics of occupational morbidity.

Data sources Data were obtained from archival records documenting occupational disease cases among workers in Kazakhstan during the study period. The database was compiled using the following primary sources:

1. Notifications of newly diagnosed occupational diseases containing information on occupation, diagnosis, work experience, working conditions, and medical history.
2. Registries of primary occupational disease cases, including data on registration dates, industrial sector, age, and other key characteristics.
3. Annual reports on combined occupational pathology and summary tables describing occupational disease distribution by industry, worker category, and type of occupational hazard.

The formation of a unified analytical database involved several sequential stages. Initially, data were imported from multiple formats (Microsoft Excel files, PDF documents, and scanned tables) and converted into machine-readable form. During technical preparation, all datasets were standardized into a unified structure while preserving original variables and attributes. Subsequently, data cleaning procedures were applied, including correction of technical errors, removal of partially completed records, and elimination of invalid values. Deduplication was performed to remove repeated records referring to the same worker or disease case. Formats for dates, occupational titles, and diagnostic categories were unified. Data from all sources were then merged into a single harmonized dataset suitable for statistical analysis. The final dataset comprised 593 occupational disease cases and included detailed variables such as age, occupation, total and hazardous work experience, disease category, type of occupational exposure, and year of diagnosis.

Inclusion criteria. Only records that met the following criteria were included in the study: newly registered cases of occupational diseases confirmed in accordance with established procedures and documented in official records; availability of key information required for analysis (diagnosis or nosological group, occupation, total work experience, hazardous work experience, and age). In addition, the data had to be complete, structured, logically consistent, and suitable for standardization and analysis. The registration period for occupational disease cases covered January 1, 2018, to December 31, 2023.

Exclusion criteria. Records that did not meet established data quality requirements or lacked the information necessary for valid statistical analysis were excluded from the study. This was essential to ensure the reliability of the findings and to improve the overall quality of the final sample. Exclusion criteria included duplicate records identified through comparison of key parameters (diagnosis, occupation, work experience, year of registration). Duplicates were removed after verification of data originality. Records with missing critical information were also excluded, including absence of a diagnosis or nosological group, lack of occupational data, missing information on total work experience, or missing age data. In addition, records containing incorrect or illogical values were excluded, such as negative or implausible values of age or work experience, inconsistencies between age and length of service, and obvious formatting errors (for example, misplacement of age and year of registration fields). Records with critical structural deficiencies that made standardized processing impossible were likewise excluded.

Cohor structure description. Since the study is based on the complete set of newly registered cases of occupational diseases for 2018–2023, the unit of analysis was a single confirmed case of occupational pathology, including individual worker characteristics and parameters of occupational exposure. To ensure analytical transparency, the data were structured into several categorical groups reflecting the key parameters of the impact of occupational factors:

1. Grouping by total work experience. Total work experience was considered an indicator of the duration of professional activity. The following categories were formed: <10 years;

10–19 years; 20–24 years; 25–29 years; ≥ 30 years. This distribution makes it possible to distinguish intervals corresponding to different depths of cumulative exposure to harmful factors.

2. Grouping by hazardous work experience. Where data on hazardous work experience were available, a similar categorization was applied: <10 years; 10–19 years; 20–24 years; 25–29 years; ≥ 30 years. This enables comparison of levels of occupational exposure within the study sample.
3. Age groups. Age at the time of diagnosis was classified into standard epidemiological categories: <30 years; 30–39 years; 40–49 years; 50–59 years; ≥ 60 years. This allows assessment of the combined influence of age and duration of work experience.
4. Occupational groups. Occupations were aggregated into broader groups according to the nature of work performed and the types of exposures involved, such as underground mining occupations, metallurgy and high-temperature production, construction trades, machine operators and operators of vibration-intensive equipment, and mechanical and technical occupations. This aggregation facilitates identification of sector-specific patterns.
5. Nosological categories. Diagnoses were grouped into standard nosological categories, including dust-related lung diseases, non-dust-related respiratory diseases, vibration disease, occupational hearing loss, musculoskeletal disorders, and combined occupational pathology. This ensured data comparability and appropriate distribution across categories.

Outcome (dependent) variables and exposure (independent) variables were defined for the study. The main outcomes were groups of occupational diseases identified on the basis of a standardized nosological classification. Individual diagnoses were aggregated into broader categories, namely: dust-related lung diseases (anthracosilicosis, pneumoconiosis, chronic dust bronchitis, and occupationally induced chronic obstructive pulmonary disease), non-dust-related diseases of the respiratory system, vibration disease (vascular–neurological and neurosensory forms),

occupational hearing loss associated with noise exposure, musculoskeletal disorders resulting from occupational load (osteoarthritis, radiculopathies, chronic myofascial overload), and combined occupational pathology in cases where two or more occupationally related diagnoses were present simultaneously. These variables were used to analyze the structure of occupational pathology and its associations with work experience, age, and occupational category.

The following variables were selected as exposure factors (independent variables):

1. Worker age, a quantitative variable measured in years; the following categories were additionally defined: <30; 30–39; 40–49; 50–59; ≥60 years;
2. Total work experience, a quantitative variable measured in years, categorized as: <10; 10–19; 20–24; 25–29; ≥30 years;
3. Hazardous work experience, a quantitative variable measured in years, categorized as: <10; 10–19; 20–24; 25–29; ≥30 years;
4. Occupation or occupational group, where individual occupations were aggregated based on the nature of exposure factors into the following groups: underground mining occupations; metallurgical and high-temperature production; construction trades; operators and drivers of vibration-intensive machinery; technical and maintenance occupations.
5. Year of disease registration. This variable was used to analyze temporal trends in the distribution of indicators but not for risk estimation, as data on the size of the workforce by industry were not available.

To ensure the validity of the analysis, all variables underwent preliminary data processing according to the procedures outlined below. Age and year of birth were derived as the difference between the year of diagnosis registration and the year of birth, and the resulting values were checked for logical consistency with work experience. Work experience variables were transformed as follows: original entries expressed in formats such as “23 years 8 months” were converted into decimal form by transforming months into fractions of a year (12 months = 1 year), yielding, for

example, 23.67 years. All values were screened for implausible or inconsistent entries, including discrepancies between age and work experience (e.g., work experience exceeding age). Such records were excluded from the study. For diagnostic classification, the full diagnostic formulations were reduced to standardized nosological categories suitable for statistical analysis.

Statistical analysis included descriptive statistics, group comparisons, logistic regression, correlation analysis, and assessment of statistical significance. At the first stage of analysis, descriptive statistics were performed to characterize the study sample and the key variables. For quantitative data, the mean, standard deviation (SD), median, and, where appropriate, the interquartile range (IQR) were calculated. For categorical variables—including age groups, occupational categories, total and hazardous work experience categories, and groups of occupational diseases—absolute frequencies (n) and relative frequencies (%) were determined. This stage of the analysis provided an overall epidemiological description of the cohort and made it possible to identify the dominant categories of work experience, age, and nosological groups.

Comparative statistical methods were used to assess differences between categories of work experience, age groups, and nosological forms. Pearson's χ^2 test was applied to analyze differences between categorical variables, for example, the distribution of disease groups across categories of work experience or occupational groups. The Mann–Whitney U test was used to compare two independent groups when quantitative data did not follow a normal distribution. The Kruskal–Wallis test was applied to compare three or more independent groups, such as work experience categories across different diagnostic groups. These methods were selected in consideration of the distributional characteristics of the variables, including deviations from normality and heterogeneity of variances, and are consistent with WHO and CDC recommendations for the analysis of epidemiological data

To analyze the impact of total and hazardous work experience on the risk of developing specific nosological forms, multivariable models were applied. Logistic regression was used to estimate the odds ratios (ORs) for the occurrence of specific groups of occupational diseases

depending on age, total work experience, hazardous work experience, occupation, and industry. Stepwise adjustment was employed in the models to control for potential confounding factors. Poisson regression and binomial regression were used to analyze temporal trends in occupational morbidity over the period 2018–2023. These models made it possible to assess changes in the frequency of detected occupational diseases over time, examine the relationship between work experience categories and year of registration, and evaluate both linear and non-linear temporal trends. Poisson models are recommended by the ECDC and CDC for the analysis of disease incidence and morbidity dynamics.

Correlation analysis was conducted to assess relationships between key quantitative variables. Pearson's correlation coefficient was used when variables followed a normal distribution, while Spearman's rank correlation coefficient was applied for ordinal scales or in cases of non-normal distribution. This analysis made it possible to determine the strength of associations between age and total work experience, age and hazardous work experience, total and hazardous work experience, and work experience and the probability of specific types of occupational diseases. These analyses supported the cumulative nature of occupational exposure and identified statistically significant relationships. Across all statistical procedures, a standard significance level of $p < 0.05$ was applied as the criterion for statistical significance, and 95% confidence intervals (95% CI) were used to assess the precision of risk estimates (ORs, RRs, regression coefficients). All calculations were performed using Python 3.10 (packages: pandas, numpy, scipy, statsmodels) and Microsoft Excel 2021. Python 3.10 served as the primary analytical environment, with pandas used for data processing and structuring, numpy for numerical computations, scipy for statistical tests, and statsmodels for statistical modeling. Microsoft Excel 2021 was used for initial data structuring, verification of record accuracy, format control, and preparation of tables for import into the analytical environment. The use of Python 3.10 ensured reproducibility of the analysis, transparency of statistical procedures, and standardized processing of large datasets.

Results. The study included 593 newly registered cases of occupational diseases confirmed in accordance with established procedures during the period 2018–2023. The dataset contained information on workers’ age, total and hazardous work experience, occupational affiliation, and nosological form of disease. The age of affected workers ranged from 22 to 67 years. The mean age was 50 ± 6.8 years (median: 51 years), with the main body of observations concentrated in the mature working-age group (IQR: 46–55 years). The age-group distribution confirms the cumulative nature of occupational pathology: 78.2% of cases were diagnosed in individuals older than 40 years, and the peak incidence (46.2%) was observed in the 50–59-year age group. The mean total work experience was 28 years (median: 27 years), with more than 74% of workers having ≥ 20 years of service. A strong positive correlation was identified between age and total work experience ($r = 0.82$; $p < 0.001$), as well as between age and hazardous work experience ($r = 0.77$; $p < 0.001$), characterizing age as a marker of cumulative exposure to harmful occupational factors.

The demographic and work-experience characteristics of the registered occupational disease cases are summarized in Table 1.

[Insert Table 1 here]

Table 1. Sample characteristics by age and work experience.

Characteristics	Group / Indicator	Number, n	Proportion, %	Mean	Standard deviation (SD)	Median	Interquartile range (IQR)
Age	Generalized measures	593	100	50	6,8	51	46–55
Age	<30 years	4	0,70	28,3	1,0	28,5	27–29
Age	30–39 years	71	12,00	36,0	2,6	36	34–39

Characteristics	Group / Indicator	Number, n	Proportion, %	Mean	Standard deviation (SD)	Median	Interquartile range (IQR)
Age	40–49 years	190	32,00	45,1	3,0	45	42–48
Age	50–59 years	274	46,20	54,9	2,9	55	52–57
Age	≥60 years	54	9,10	61,0	1,1	61	60–62
Total work experience	Generalized measures	593	100	28	7,1	27	22–32
Total work experience	<10 years	18	3,00	7,8	1,6	8	6–9
Total work experience	10–19 years	134	22,60	15,2	2,7	15	13–18
Total work experience	20–24 years	147	24,80	22,4	1,4	22	21–24
Total work experience	25–29 years	152	25,60	27,3	1,3	27	26–29
Total work experience	≥30 years	142	24,00	34,6	3,1	33	31–37
Hazardous work experience	Generalized measures	593	100	24,5	6,2	24	20–29

Characteristics	Group / Indicator	Number, n	Proportion, %	Mean	Standard deviation (SD)	Median	Interquartile range (IQR)
Hazardous work experience	<10 years	26	6,80	8,1	1,7	8	7–9
Hazardous work experience	10–19 years	138	35,90	15,4	2,6	15	13–18
Hazardous work experience	20–24 years	132	34,40	22,3	1,3	22	21–24
Hazardous work experience	25–29 years	57	14,80	27,4	1,4	27	26–29
Hazardous work experience	≥30 years	31	8,10	34,1	2,7	33	31–37

Mean values, standard deviations, medians, and IQRs for total and hazardous work experience were calculated based on the subsample of individuals with valid quantitative work experience data; $n = 593$ represents the total cohort size.

The industrial profile of the sample is characterized by the predominance of underground mining occupations (39%) and the metallurgical sector (18%). The leading nosological forms are dust-related lung diseases (43.2%), of which pneumoconioses account for 59%. Vibration disease represents 23.9% of all cases and is predominantly associated with exposure to local vibration (71%).

Occupational hearing loss accounts for 16.5% of cases. A statistically significant association was identified between occupation and type of pathology ($\chi^2 = 147.8$; $p < 0.001$). Specifically, dust-related diseases predominate among miners (58%), whereas vibration disease is most prevalent among machinery operators (54%). Data on hazardous work experience were not available for all cases of occupational morbidity; however, among the available observations, a distribution similar to that of total work experience was observed. The majority of workers had prolonged hazardous work experience exceeding 20 years.

The age and work-experience profile of the occupational groups and their leading nosological categories are presented in Table 2.

[Insert Table 2 here]

Table 2. Profile of the study sample by age, work experience across occupational groups, and the proportion of leading nosological categories.

Occupational group	Mean age (years)	Mean work experience (years)	Leading nosological category	Proportion of leading nosological category (%)
Underground mining occupations	51,2	29,8	Dust-related lung diseases	58
Machinery operators and operators of vibration-intensive equipment	50,1	26,8	Vibration disease	54
Repair and technical occupations	49,7	25,9	Vibration disease	26
Metallurgy and thermal production occupations	49,5	27,4	Dust-related lung diseases	31

Occupational group	Mean age (years)	Mean work experience (years)	Leading nosological category	Proportion of leading nosological category (%)
Repair and technical occupations	48,3	24,6	Musculoskeletal disorders	34

The leading nosological forms correspond to the most prevalent occupational hazards – dust, noise, and vibration. Most cases are diagnosed in mature and pre-retirement age groups after prolonged exposure to harmful production factors. Thus, the mean work experience at the time of diagnosis was 30.1 years for dust-related lung diseases, 26.4 years for vibration disease, 25.6 years for occupational hearing loss, 22.8 years for musculoskeletal disorders, and 21.7 years for non-dust-related respiratory diseases. The sample characteristics demonstrate a predominance of middle-aged and older workers, a high prevalence of long total and hazardous work experience, a clearly defined industrial structure, and a nosological pattern typical of the industrial sector. These features provide the basis for subsequent analyses of the relationships between work experience, occupation, and nosology. Analysis of comorbid (combined) occupational pathology, identified in 3% of workers, showed that the most frequent combinations were dust-related disease with vibration disease, vibration disease with occupational hearing loss, and dust-related disease with musculoskeletal disorders. Occupational groups in which combined pathology was most commonly observed included underground drivage workers, longwall miners, operators of mining machinery, and drilling operators. The highest proportion of combined pathology was observed among workers aged 50–59 years. Mean hazardous work experience in cases of combined pathology was ≥ 20 years, and no cases of combined pathology were identified among workers with work experience < 15 years. Combined occupational pathology serves as an indicator of prolonged and intensive exposure and reflects the

multifactorial nature of occupational hazards. Such cases require targeted preventive measures and enhanced medical surveillance.

Binary logistic regression. Model 1 examined the probability of developing dust-related occupational diseases (0 = no, 1 = yes). Dust-related occupational diseases constituted the majority of cases in the study sample; therefore, binary logistic regression was used to identify factors associated with their occurrence.

The factors associated with a dust-related diagnosis among registered occupational disease cases are presented in Table 3.

[Insert Table 3 here]

Table 3. Distribution of factors associated with the development of dust-related diseases.

Predictor	OR (odds ratio)	95% CI	p-value
Total work experience (per additional 5 years)	1,42	1,28–1,58	<0.001
Hazardous work experience (per additional 5 years)	1,31	1,19–1,47	<0.001
Underground mining occupations (vs others)	3,85	2,71–5,47	<0.001
Age (per additional 10 years)	1,14	1,03–1,28	0.011

Logistic regression showed that working in underground conditions increased the odds of developing dust-related diseases by 3.85 times (95% CI: 2.71–5.47). Each additional 5 years of hazardous work experience increased the probability of disease by 31% (OR = 1.31).

Associations between selected occupational factors and the distribution of occupational disease nosologies are presented in Table 4.

[Insert Table 4 here]

Table 4. Factors influencing the distribution of occupational disease nosologies.

Diagnostic category	Factor	OR	95% CI	p-value
Dust-related diseases	Underground work	4.72	3.01–6.85	<0.001
	Total work experience ≥ 25 years	2.16	1.53–3.23	<0.001
Vibration disease	Operators of vibration-intensive equipment	5.84	3.90–8.72	<0.001
	Hazardous work experience ≥ 20 years	1.78	1.24–2.54	0.002

Diagnostic category	Factor	OR	95% CI	p-value
Occupational hearing loss	Metallurgy	3.41	2.12– 5.46	<0.001
	Age $\geq$ 50 years	1.67	1.10– 2.54	0.015
Musculoskeletal disorders (MSDs)	Repair and technical occupations	3.22	1.95– 5.11	<0.001

Multinomial logistic regression. Model 2 assessed the probability of developing different types of occupational diseases, with non-dust-related respiratory diseases used as the reference (baseline) category. Each nosological group demonstrated a distinct occupational linkage: dust-related diseases were associated primarily with underground work, vibration-related diseases with operators of vibration-intensive equipment, noise-related pathology with metallurgy, and disorders related to physical load with construction work.

Poisson regression. Poisson regression was not applied to model disease risk, as data on the size of the exposed workforce were unavailable, but rather to model the number of concurrent occupational diagnoses (0–3 or more). Model 3 examined the number of diagnoses (0–3) as a function of age and work experience.

The results of the Poisson regression model for the number of concurrent occupational diagnoses are presented in Table 5.

[Insert Table 5 here]

Table 5. Poisson regression – number of occupational diseases by age, total and hazardous work experience.

Predictor	IRR	95% CI	p-value
Hazardous work experience (per additional 5 years)	1.22	1.09–1.37	<0.001
Total work experience (per additional 5 years)	1.15	1.04–1.28	0.005
Age (per additional 10 years)	1.11	1.03–1.22	0.009

Poisson regression confirmed that an increase in hazardous work experience by 5 years was associated with a 22% increase in the frequency of concurrent diagnoses (IRR = 1.22; $p < 0.001$).

The main patterns observed during the period from 2018 to 2020 indicate a steady decline in the number of registered occupational disease cases. The most pronounced decrease occurred in 2020, when the number of cases fell by 23% (from 220 to 170), which was statistically significant based on the rate ratio (RR). This decline is likely attributable to restrictions during the COVID-19 pandemic and a temporary reduction in access to occupational health examinations, rather than to a genuine improvement in working conditions, as the mean work experience of affected workers remained consistently high (approximately 28 years).

Discussion. The results of this study, based on the analysis of 593 newly registered cases of occupational diseases in the Republic of Kazakhstan during 2018–2023, made it possible to identify key patterns characterizing the current structure of occupational pathology in industrial sectors. First, a pronounced age-related concentration of occupational diseases was identified. More than 78% of all cases were diagnosed in workers older than 40 years, with the peak incidence observed in the 50–59-year age group. This finding reflects the long latency period of occupational disease development and the cumulative nature of exposure to harmful occupational factors. Work experience should be considered not as a linear indicator, but through the perspective of cumulative exposure and latency

period. It serves as a reliable predictor for both acute traumatic events (through changes in job tasks and age) and long-term disabling diseases (such as cancer, COPD, and silicosis). The analysis of work experience makes it possible to move from recording occupational accidents to predictive management of occupational risks [6]. Second, work experience, both total and hazardous, was found to be a determining factor in the development of occupational pathology. The majority of affected workers had a total work experience of ≥ 20 years (approximately 74%) and a hazardous work experience of ≥ 15 –20 years. Modeling demonstrated a strong statistical association ($\rho = 0.91$) between total and hazardous work experience, indicating the persistent nature of occupational exposure in mining, metallurgical industries. Third, the occupational structure of the sample was dominated by underground miners, metallurgical workers, operators of vibration-intensive equipment, and construction workers, which corresponds to the prevailing exposure profile - dust aerosols, noise, vibration, and physical overload. A fourth key finding concerns the nosological structure of occupational diseases. The leading nosological forms were dust-related lung diseases (43.2%), vibration disease (23.9%), and occupational hearing loss (16.5%). Together, these three groups accounted for more than two thirds of all occupational pathology and fully correspond to the dominant harmful factors in the analyzed industrial sectors. Logistic regression models confirmed the statistical significance of clear occupation–nosology associations. For example, underground work increased the odds of developing dust-related diseases by almost fourfold ($OR = 3.85$), while vibration-intensive occupations increased the probability of vibration disease more than fivefold ($OR = 5.84$). Finally, additional analysis showed that combined occupational pathology, although relatively rare (3%), characterizes a group of workers exposed to the most severe occupational conditions. These workers had the longest hazardous work experience, older age, and the most demanding working environments, predominantly in underground settings.

Overall, the findings of this study are consistent with both international and national data on occupational morbidity in the mining and heavy industrial sectors. Similar patterns have been reported in epidemiological studies conducted in the Republic of Kazakhstan, which also emphasize

the leading role of the mining and metallurgical industries in the overall structure of occupational diseases and highlight the importance of a centralized occupational hygiene system. The predominance of respiratory diseases, vibration-related disorders, occupational hearing loss, and musculoskeletal diseases among workers in mining enterprises corresponds to occupational morbidity profiles described worldwide for miners, drillers, tunnel construction workers, and operators of heavy mining equipment in the coal and ore-mining industries. A key conclusion of this study is the cumulative nature of occupational risk exposure. The leading role of dust-related lung diseases and occupational chronic obstructive pulmonary disease identified in this cohort is comparable with international estimates demonstrating a high prevalence of pneumoconiosis and dust-induced bronchitis among workers in the mining and metallurgical industries. Similarly, the substantial proportion of vibration disease and occupational hearing loss among workers exposed to mechanical vibration and industrial noise reflects well-established concepts regarding the spectrum of occupational pathology under conditions of intensive industrial production. Clinical observations among miners in Kazakhstan also indicate that occupational hearing loss predominantly develops in underground workers with long exposure histories and is often diagnosed at moderate or advanced stages, pointing to delayed detection of noise-induced disorders. Overall, the structure of occupational diseases identified in this cohort does not contradict global data and confirms the universal impact of physical and chemical risk factors, despite regional specificities. Differences from some international studies, in which work-related skin diseases, occupational cancers, and chemical poisonings constitute a substantial proportion of morbidity, can be explained by the industrial profile of the region, characterized by the predominance of underground mining operations and a high level of mechanization. The statistically significant decrease in the number of newly registered cases observed in 2020 ($RR = 0.77$; 95% CI: 0.63–0.94) diverges from trends reported in some countries, and the most plausible explanation for this phenomenon lies in organizational factors. These include disruptions in routine medical examinations of workers and reduced access to diagnostic services during the COVID-19 pandemic. Similar organizational and expert-related factors—such as the

quality of referrals for occupational disease assessment and the completeness of periodic medical examinations—are widely recognized as key determinants of disease detection and registration in Kazakhstan. Comparable effects of “hidden” occupational vulnerability have been demonstrated in international studies showing sharp increases in excess mortality and morbidity in specific occupational sectors during the COVID-19 period [7]. This effect starkly exposed inequalities that require remediation, as a safe and healthy working environment constitutes the foundation of effective preventive interventions [8, 9]. Particular attention should be given to the finding that, in the logistic analysis, hazardous work experience of ≥ 20 years did not demonstrate a statistically significant increase in the risk of respiratory diseases specifically when compared with other types of occupational pathology (OR = 0.70; 95% CI: 0.47–1.04). International studies often report a stronger association between prolonged exposure to dust-related factors and respiratory diseases; however, in the present cohort, long hazardous work experience represents a common background for nearly all types of occupational pathology, thereby reducing differences between diagnostic groups. This discrepancy with some published data underscores the importance of accounting for the sectoral structure of employment and the combined effects of multiple occupational hazards—noise, vibration, physical overload, and dust exposure—which contribute to polymorbid occupational pathology. The association between total and hazardous work experience and the development of occupational diseases can be explained by a combination of pathophysiological and hygienic mechanisms reflecting prolonged exposure to harmful factors. Chronic occupational exposure leads to the accumulation of functional impairments and irreversible tissue damage, which may manifest clinically only after many years. Dust-related lung diseases, including pneumoconiosis and occupational chronic obstructive pulmonary disease (COPD), result from sustained inhalation of mineral and coal dust, leading to chronic inflammation, damage to the alveolar epithelium, activation of fibroblasts, and progressive pulmonary fibrosis. These processes are cumulative in nature and typically require more than 15–20 years of exposure for clinically apparent disease to develop. Disease severity is influenced not only by exposure duration but also by dust concentration,

composition, and workforce heterogeneity [10]. Vibration disease likewise exhibits a pronounced cumulative pattern. Prolonged vibration exposure disrupts microcirculation, induces vascular dysfunction, and damages peripheral nerves and the musculoskeletal system. Clinically significant forms usually emerge after 10–15 years of intensive exposure, while severe manifestations tend to develop after 20–25 years. Occupational hearing loss results from long-term exposure to noise levels exceeding 85 dBA, leading to damage of cochlear hair cells, oxidative stress, and progressive auditory dysfunction. Musculoskeletal disorders develop under conditions of chronic physical load, including heavy lifting and work in constrained postures, resulting in degenerative changes that evolve over decades. Combined occupational pathology reflects simultaneous exposure to multiple risk factors and was predominantly observed among workers with the longest duration of hazardous employment (≥ 25 years), confirming the cumulative and synergistic nature of occupational risks.

This study is supported by a large and representative sample of 593 newly diagnosed and officially confirmed cases of occupational diseases across major industrial sectors. The use of verified archival data minimizes subjective bias, while the five-year observation period (2018–2023) allows for the assessment of temporal trends, including the impact of the COVID-19 pandemic. The application of standardized diagnostic categories and advanced statistical methods enhances internal consistency and external comparability with international data. Nevertheless, several limitations must be acknowledged. The absence of denominator data on the total number of exposed workers precludes calculation of true incidence rates and standardized risk estimates. Variability and incompleteness of archival records, particularly regarding the duration of hazardous work, limit the depth of exposure analysis. In addition, data on individual-level factors such as smoking status, comorbidities, and use of personal protective equipment were not available, restricting the ability to establish causal relationships. Despite these limitations, the findings remain robust and informative for understanding patterns of occupational morbidity. Night shift work and/or shift work, which is also a major occupational risk factor affecting 15–30% of the global workforce, could not be assessed in our study due to the lack of such data [11]. The results have substantial practical implications for occupational

hygiene policy and industrial risk management in Kazakhstan. The identified age- and exposure-related thresholds can serve as a basis for developing targeted medical surveillance strategies, while the predominance of diseases associated with dust, noise, and vibration exposure confirms the need to prioritize engineering and organizational control measures. These findings are consistent with national strategies aimed at strengthening prevention, early detection, and rehabilitation in the field of occupational hygiene [12]. Future research should integrate occupational disease registries with workforce denominator data to enable direct risk estimation and standardized comparisons. Studies incorporating quantitative exposure measurements, early biomarkers, and longitudinal designs would further improve understanding of disease progression and support evidence-based prevention strategies [13].

Prolonged employment under hazardous working conditions leads to a cumulative effect, whereby the risk of developing pathology increases proportionally with the duration of exposure. Studies indicate that in the energy sector, the risk of musculoskeletal and skin diseases begins to increase significantly after 10 years of work [14]. For diseases of the circulatory system, the critical threshold is approximately 14 years, while for disorders of the nervous system it reaches 30 years of continuous employment. Among workers exposed to electromagnetic fields (EMF), the risk of meningioma is considered acceptable up to 20 years of exposure; however, after 30 years it becomes moderately hazardous, necessitating strict limitations on contact duration. In the construction sector, the highest prevalence of biomechanical (82%) and physical risks (76%) has been documented, leading to the early development of disabling conditions [8]. In the healthcare sector, length of service correlates with increased psychosocial stress (90%) and biological risks (69%) [15]. International studies likewise emphasize the importance of early detection of stress-related manifestations and the implementation of effective preventive strategies to preserve both physical and mental health [16, 17].

To minimize the consequences of prolonged hazardous work experience, international practice and scientific evidence highlight a комплексный подход, включающий законодательные, медицинские и технические меры. At the legislative and socioeconomic level, this includes the implementation of paid sick leave without risk of job loss, living wage policies to reduce excessive workload, and social protection for vulnerable groups [18]. Medical and preventive strategies involve individual exposure monitoring through dosimeters, interdisciplinary screening with the inclusion of oncologists and biomarker assessment for long-term workers, and psychosocial support programs aimed at reducing allostatic load. Technical and hygienic measures focus on automation and modernization of labor-intensive processes, as well as improved engineering controls and strict compliance with personal protective equipment (PPE) [19]. Evidence shows that as cumulative work experience increases, the structure of morbidity shifts from acute injuries to chronic, systemic, and neoplastic diseases, which requires a transition from reactive treatment to proactive risk management and limitation of exposure duration. In this context, the results of the study and the analysis of current technological solutions emphasize the need to develop a unified state-level, risk-oriented digital platform for occupational safety management in Kazakhstan. The existing digital infrastructure should be expanded through the integration of occupational health data and sanitary-hygienic monitoring systems. The integration of medical examination results, sick leave records (ICD-10), and occupational history would allow automatic identification of high-risk zones and repeated injury patterns, as well as establish links between accidents and specific equipment or gaps in worker training. In addition, digital monitoring of personal protective equipment (PPE) use can detect critical mismatches between existing hazards and actual protection practices. The application of GIS technologies, as demonstrated in emergency medical service studies in Astana, provides opportunities to identify spatial clusters of occupational risks and optimize resource allocation [20, 21]. Furthermore, external factors such as the COVID-19 pandemic have shown a direct relationship between industrial activity levels and injury rates. Therefore, the development of predictive analytics based on production monitoring data (noise, vibration, dust) and medical indicators will enable not

only a reduction in occupational injuries but also the creation of personalized occupational pathways based on work experience and risk profiles. The implementation of such systems will ensure a shift from passive control to active, data-driven management of occupational risks at the national level.

Conclusions. The present study made it possible to comprehensively characterize the structure of occupational diseases among workers in Kazakhstan's industrial sector over a five-year period and to identify key patterns in the development of occupational pathology under conditions of prolonged exposure to harmful factors. Analysis of 593 newly registered cases showed that occupational diseases predominantly develop among older workers and are closely associated with long total and hazardous work experience, reflecting the cumulative nature of occupational exposure. The peak incidence was observed in the 50–59-year age group, and more than 70% of affected workers had a total work experience of 20 years or more. The nosological structure was dominated by dust-related lung diseases, vibration disease, and occupational hearing loss, which corresponds to the prevailing hazard profiles in the mining, metallurgical, and construction industries. Occupation emerged as a leading determinant of the type of occupational disease: miners were predominantly affected by dust-related diseases, operators of vibration-intensive equipment by vibration disease, and metallurgical workers by occupational hearing loss. These associations were confirmed by regression models and are consistent with findings from international studies. Similar patterns have been reported in international sector-specific research on occupational exposures, as well as in studies conducted in Kazakhstan, where adverse working conditions have been associated with increased morbidity of the respiratory, cardiovascular, and nervous systems. The regression relationships identified in this study align well with international evidence demonstrating that job demands are key drivers of health deterioration, whereas workplace resources can mitigate negative effects and enhance occupational safety. In a large meta-analysis, Nahrgang J.D. and colleagues showed that risks and hazards are persistent predictors of burnout and unsafe behavior, while a supportive work environment remains a universal protective factor across industries. In the context of Kazakhstan, these findings indicate that even in the presence of persistently high levels of physical occupational hazards, there is

substantial potential to reduce occupational morbidity through organizational interventions and the development of a strong safety culture.

Combined occupational pathology occurs relatively rarely; however, its presence indicates the maximum intensity and duration of exposure to harmful factors. Workers with combined diagnoses have the longest work experience and belong to the most heavily burdened occupational groups. The findings have high practical relevance. They make it possible to optimize preventive measures, strengthen control of working conditions in high-risk groups, adjust medical surveillance programs, and develop more precise regulatory approaches to occupational risk assessment. The age- and work experience-based thresholds identified in this study can be used to personalize dispensary follow-up and medical monitoring. Overall, this work provides a scientifically grounded basis for further research in the field of occupational pathology and may serve as a foundation for improving occupational health services, modernizing systems of industrial control, and developing more effective preventive strategies. For example, the expert assessment of the causal relationship between an occupational disease and job duties is conducted in accordance with the relevant regulatory legal act [22]; however, with respect to combined occupational pathology, existing regulations provide only general references to the multifactorial nature of causation. During the expert assessment process, a causal relationship between occupational disease and working conditions is established, which forms the basis for prevention, case registration, social protection of affected workers, and the development of measures to improve working conditions.

The study confirms that occupational morbidity in Kazakhstan has a pronounced cumulative character. Length-of-service thresholds are observed in more than 74% of all cases among workers with ≥ 20 years of service, while the mean work experience of affected workers is approximately 28 years. The peak of newly diagnosed cases occurs in the 50–59-year age group (46.2% of cases), indicating a long latent period in the development of chronic occupational changes. The identified peak of first diagnoses at ages 50–59, combined with a mean work experience of about 28 years, is

consistent with contemporary concepts of the “slow” formation of work-related diseases, as described in reviews of modern occupational pathology [23]. The longest mean work experience (29.8 years) and hazardous work exposure were observed among workers in the mining industry, which directly correlates with the predominance of dust-related diseases. Occupational risk management policy faces systemic barriers that distort the true epidemiological picture. A gap exists between actual and registered morbidity due to limited access to occupational health services and variability in the quality of periodic medical examinations. The statistically significant reduction in case registration in 2020—by 23% compared with 2018—was not related to improved working conditions but rather to the COVID-19 pandemic, which restricted medical examinations. This highlights the vulnerability of the official reporting system. A transformation of preventive policy is required through the integration of work experience data into risk management systems, enabling a shift toward a targeted health protection model. Differentiated monitoring—specifically, the identified threshold of ≥ 20 years of service—should serve as a legal trigger for enhanced medical surveillance, including expanded spirometry, audiometry, and vibrosensory testing. This approach aligns with the *Total Worker Health*TM concept, which integrates occupational safety with health promotion and applies stratified preventive strategies for different risk groups [24]. In sectors with the highest accumulation of risks (e.g., underground operations), priority should be given to the implementation of automated systems and remote control technologies to physically remove workers from zones of hazardous exposure. The presence of two or more diagnoses—combined occupational pathology—occurs among workers with ≥ 25 years of service and should be used as a criterion of critical exposure requiring immediate job rotation to safer positions. Although rare, these cases are clinically significant and should be regarded as markers necessitating not only medical intervention but also managerial decisions. This approach is consistent with modern views on primary prevention at the level of work processes rather than relying solely on individual monitoring [25]. Health policy in the industrial sector should be grounded in the understanding that disease type is statistically determined by occupation; for example, underground work leads to dust-related pathologies (OR = 3.85), while work with vibration

tools leads to vibration disease (OR = 5.84). Scientific substantiation of these associations enables the modernization of sanitary regulations and the updating of lists of hazardous occupations, thereby shifting the prevention system from a reactive to a truly preventive model.

List of abbreviations

CDC: Centers for Disease Control and Prevention

CI: Confidence interval

COPD: Chronic obstructive pulmonary disease

COVID-19: Coronavirus disease 2019

dBA: A-weighted decibels

ECDC: European Centre for Disease Prevention and Control

EMF: Electromagnetic fields

FEV1: Forced expiratory volume in one second

FVC: Forced vital capacity

GIS: Geographic information system

ICD-10: International Classification of Diseases, 10th Revision

ILO: International Labour Organization

IQR: Interquartile range

IRR: Incidence rate ratio

MSDs: Musculoskeletal disorders

NIOSH: National Institute for Occupational Safety and Health

OELs: Occupational exposure limits

OR: Odds ratio

PPE: Personal protective equipment

RR: Rate ratio

SD: Standard deviation

WHO: World Health Organization

Declarations

Ethics approval and consent to participate

This study was conducted as part of the project entitled “Assessment of ergonomic risk factors among workers in hazardous industries with the identification of work-related health problems and the provision of effective preventive measures.” The study was approved by the Local Ethics Committee of the Non-profit Joint Stock Company “Astana Medical University” on 7 November 2023, decision No. 5.

The study was based on retrospective analysis of archival records of registered occupational disease cases and did not involve direct contact with participants or any experimental intervention. All methods were performed in accordance with the relevant institutional and national ethical requirements and regulations.

Consent for publication

Not applicable. The manuscript reports aggregated study results and does not contain any identifiable personal data, images, or individual participant information.

Availability of data and materials

The datasets analysed during the current study are not publicly available because they contain sensitive occupational health information derived from archival records.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

AAM contributed to the conception and design of the study, interpretation of the findings, and preparation of the manuscript. AUA contributed to the scientific supervision of the study,

interpretation of occupational health findings, and critical revision of the manuscript. AOG contributed to data collection, database preparation, and manuscript revision. AIA contributed to the methodological design, interpretation of the results, and critical revision of the manuscript. AMM contributed to study coordination, supervision, interpretation of the findings, and critical revision of the manuscript. All authors read and approved the final manuscript.

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