International Journal of Basic & Clinical Pharmacology
Filander KN et al. Int J Basic Clin Pharmacol. 2026 May;15(3):582-588
http://www.ijbcp.com
pISSN 2319-2003 | eISSN 2279-0780

DOI: https://dx.doi.org/10.18203/2319-2003.ijbcp20261079

Review Article

Occupational respiratory disorders: global exposure patterns, surveillance, preventive strategies, intervention, effectiveness and emerging innovations

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Received: 10 March 2026
Accepted: 10 April 2026

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ABSTRACT

Occupational respiratory disorders remain a significant global public health burden due to continuous exposure to airborne hazards across various industries. This narrative review synthesizes global exposure patterns, surveillance systems, preventive strategies, intervention effectiveness, and emerging innovations in occupational respiratory health. A comprehensive narrative review was conducted using peer-reviewed literature and reports from international organizations, including the World Health Organization (WHO), International Labour Organization (ILO), National Institute for Occupational Safety and Health (NIOSH), and European Agency for Safety and Health at Work (EU-OSHA). Mining, construction, agriculture, and manufacturing industries exhibit the highest exposure risks. Surveillance and preventive measures vary substantially across income regions, with high-income countries adopting advanced monitoring and engineering controls. Emerging technologies, such as wearable sensors and artificial intelligence, are increasingly integrated into occupational health systems. Occupational respiratory diseases are largely preventable through enhanced surveillance, exposure control strategies, worker education, and technological innovations. Strengthening global occupational health systems is essential to reducing the burden of respiratory morbidity and mortality.

Keywords: Occupational respiratory disorders, Workplace exposure, Occupational health and safety, Global comparison surveillance systems, Preventive strategies, Emerging innovations

INTRODUCTION

Occupational respiratory disorders continue to pose a major challenge to global public health systems. World Health Organization (WHO), International Labour Organization (ILO), and National Institute for Occupational Safety and Health (NIOSH) have jointly advanced occupational health and safety through systematic reviews and surveys.[1] WHO's estimated health workforce shortage decreased.[2] According to international estimates, millions of workers are exposed daily to airborne hazards capable of causing acute and chronic respiratory disease.[3] Despite decades of regulatory progress, occupational lung diseases remain underdiagnosed and underreported, particularly in regions with limited occupational health infrastructure.[4,5] This review provides a comprehensive synthesis of global evidence, emphasizing exposure patterns, disease mechanisms, preventive strategies, and innovations aimed at reducing occupational respiratory risk.[2]

GLOBAL OCCUPATIONAL EXPOSURE PATTERNS

Workplace exposure to respiratory hazards varies considerably by industry, occupation, and geographic region. Mining and quarrying are characterized by high levels of respirable crystalline silica and coal dust.[6] A disproportionately large work-related burden of disease is observed in the WHO African **r**egion (for DALY), South-East Asia **r**egion, and the Western Pacific **r**egion (for deaths), males, and older age groups.[7] Construction workers encounter silica, asbestos in older structures, and diesel exhaust. Agricultural workers are exposed to organic dusts, endotoxins, pesticides, and animal allergens.[5] Current and former farmers represent 63.9% of the rural cohort but account for 88.1% of those with high VGDF exposure in their last job.[8]

This indicates that associations between respiratory health and high VGDF exposure may predominantly stem from farming activities, highlighting the need to investigate exposure-response relations in both experienced and inexperienced farmers. Manufacturing workers may be exposed to metal fumes, solvents, isocyanates, and other chemical sensitizers.

Several studies have reported stronger exposure–disease associations in women, potentially due to biological susceptibility or lower exposure thresholds.

Rural residents demonstrated higher occupational exposure levels compared to urban populations, even among individuals without farming experience. This distribution enables future investigation of exposure–response relationships between VGDF exposure and obstructive respiratory outcomes such as chronic bronchitis and airflow limitation. Cumulative exposure over time remains the most important determinant of chronic respiratory disease development.[6,8]

These findings highlight the urgent need for targeted preventive interventions and policy enforcement in high-risk industries. The provision of personal protective equipment and improvement of working environments by the government, industry owners, and other stakeholders are crucial in reducing occupational respiratory symptoms. Additionally, prioritizing occupational health and safety training for industry workers can help prevent and mitigate the impact of occupational respiratory diseases.

Table 1: Major occupational airborne exposures and associated respiratory outcomes.

Exposure agent	Primary industries	Associated respiratory outcomes
Crystalline silica	Mining, construction	Silicosis, COPD, lung cancer
Coal dust	Coal mining	Coal workers' pneumoconiosis
Asbestos	Construction, shipyards	Asbestosis, mesothelioma
Organic dust	Agriculture	Hypersensitivity pneumonitis
Isocyanates	Manufacturing	Occupational asthma

MAJOR OCCUPATIONAL RESPIRATORY DISORDERS

Occupational respiratory disorders encompass a broad spectrum of diseases, ranging from non-malignant conditions such as pneumoconiosis and occupational asthma to malignant diseases including lung cancer and mesothelioma.[6] Occupational airborne exposure was weakly related to the incidence of respiratory disorders when assessed by JEM. Silicosis remains a global concern due to continued silica exposure in both formal and informal sectors.[6,7] Coal workers' pneumoconiosis is still a major concern in industrially developing countries and in some long-industrialized countries.[6] Occupational asthma is among the most frequently reported work-related respiratory diseases in surveillance systems.[4] A large and bewildering variety of occupational agents have been reported as potential antigens in hypersensitivity pneumonitis, and new occupational agents continue to be identified.[6] The epidemiological evidence supporting the occupational contribution of exposure to a wide variety of workplace dusts, fumes, or gases to the causation of COPD continues to accrue.[6,8] The risk of pneumococcal infection is increased in welders and probably others with occupational exposure to metal fumes; the risk could extend to other respiratory infections.[6] Many occupational respiratory diseases are irreversible, highlighting the critical importance of prevention.[6,9]

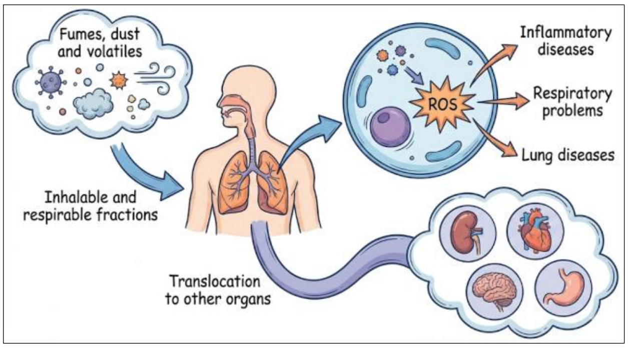

Figure 1: Pathophysiological pathways linking occupational exposure to respiratory disease.

SCREENING AND SURVEILLANCE SYSTEMS

Effective surveillance systems are essential for early detection and prevention of occupational respiratory disorders.[4,5] Screening typically involves periodic health examinations, spirometry, chest imaging, and symptom questionnaires.[5] High-income countries often maintain mandatory disease registries, whereas surveillance in many low- and middle-income countries remains fragmented or absent. Digital surveillance platforms are increasingly being adopted to improve data quality.[10] Surveillance of respiratory health shows inconsistencies across respiratory disease categories, with different methods and intervals by workplace sector. Frequently used instruments consist of a respiratory survey, pulmonary function assessments, imaging studies, immune biomarkers, and signs of airway inflammation. The majority of questionnaires are based on altered formats of BMRCQ, CDPH/ATS, IUATLD, or NHANESII. Although they are commonly used, issues regarding reliability, sensitivity, and specificity have been highlighted, and additional standardization and validation against health outcomes are necessary. Differences in employee oversight after surveillance breakdowns vary across companies and sectors.[9]

Although lung function indicators, specifically FEV1 and FVC, are commonly utilized in health monitoring, uncertainties persist about determining abnormality thresholds, particularly for younger employees.[8] Suggested solutions involve applying designated percentiles instead of a constant FEV1/FVC threshold of 0.7. The longitudinal analysis of FEV1 reduction necessitates additional research; tools such as SPIROLA may assist in interpreting data. Crucial benchmarks for referring patients to specialists must be set, and enhancing spirometry precision is vital to detecting early occupational respiratory conditions.

While some studies challenge the significance of lung function in monitoring, reliable evidence backs its incorporation with questionnaires as objective assessments.[11] Tests such as bronchial hyper-responsiveness are not as well-defined. Currently, the regular use of exhaled nitric oxide (eNO) in health monitoring is not advised, although upcoming research may shed light on its possible advantages.

Standard chest X-rays are not recommended beyond particular high-risk sectors, emphasizing the necessity for more non-invasive but effective methods. Immunological indicators demonstrate potential in specific situations, like platinum refining. Mathematical models are being developed to improve predictions of workers' risks for sensitization and disease advancement. Significantly, the review faced constraints, likely omitting pertinent studies, and concentrated primarily on respiratory health monitoring rather than on broader occupational disease causes.

Table 2: Comparison of occupational respiratory surveillance systems by region.

Region	Surveillance coverage	Reporting mechanism	Limitations
High-income	Comprehensive	Mandatory registries	Latency of disease
Middle-income	Partial	Mixed reporting	Under-reporting
Low-income	Limited	Passive reporting	Lack of infrastructure

Evidence supports integrating lung function testing with structured questionnaires for improved detection.[5,12] Prevention frameworks emphasize early detection and hazard removal.[9] Surveillance coverage differs substantially by income level and infrastructure capacity.[2,4]

PREVENTION AND CONTROL STRATEGIES

Prevention of occupational respiratory disorders follows the hierarchy of controls, prioritizing elimination and substitution of hazardous agents, followed by engineering controls such as local exhaust ventilation. Administrative controls and personal protective equipment serve as supplementary measures. Evidence consistently demonstrates that reliance on PPE alone is insufficient without upstream controls.[9]

Occupational lung diseases include pneumoconioses, nonspecific airway diseases, hypersensitivity pneumonitis, toxic gas inhalation disorders, byssinosis, and occupational asthma. Accurate estimation of the burden of occupational respiratory diseases remains challenging due to limited surveillance data and underreporting. Strengthening regulatory frameworks and ensuring compliance with occupational exposure limits could substantially reduce the incidence of work-related respiratory disorders.[13]

Primary prevention strategies focus on eliminating or substituting hazardous agents and implementing engineering controls. Secondary prevention includes health surveillance programs aimed at early disease detection and intervention. Worker education and training are essential components of occupational health programs to promote safe practices and reduce exposure risks.

Employers should implement dust control measures, including ventilation systems and process modifications, to reduce exposure to silica and coal dust. Occupational asthma prevention remains challenging, particularly in small enterprises with limited occupational health infrastructure. Establishing specialized referral systems for occupational asthma diagnosis and management is recommended. Additionally, worker education on smoking cessation and chemical exposure risks is crucial, as smoking can exacerbate occupational respiratory diseases.

Further research is required to quantify exposure levels, characterize dose–response relationships, and develop effective mitigation strategies for occupational airborne hazards. Further research is required to quantify occupational exposure levels and develop effective mitigation strategies for airborne contaminants.

Longitudinal cohort studies are necessary to evaluate the long-term health effects of occupational airborne exposures. Longitudinal cohort studies are necessary to elucidate the long-term health effects of occupational airborne exposures.

Additional studies are required to investigate the etiology and prevention of byssinosis. Existing data on occupational exposure are often outdated or inconsistent, limiting accurate risk assessment. Emerging materials, such as fibrous glass and mineral wool, warrant further investigation due to potential respiratory health risks.[13] Continuous research is required to quantify exposure levels and evaluate long-term health outcomes associated with novel industrial materials.

In conclusion, comprehensive multifaceted approaches involving regulation, education, research, and surveillance are critical to mitigating occupational lung diseases and protecting worker health. Addressing these challenges will require concerted efforts across multiple sectors to establish safer working environments and improve respiratory health outcomes.

Table 3: Hierarchy of controls applied to respiratory hazards.

Control level	Examples	Effective-ness
Elimination/ substitution	Process change	Very high
Engineering	Ventilation, enclosure	High
Administrative	Work rotation	Moderate
PPE	Respirators	Variable

EFFECTIVENESS OF OCCUPATIONAL HEALTH AND SAFETY INTERVENTIONS

Multicomponent occupational health and safety interventions have been shown to reduce exposure levels, improve respiratory symptoms, and lower disease incidence. Engineering controls provide the most sustained benefits, while training and education enhance compliance. Economic evaluations suggest that preventive interventions are cost-effective when considering reduced healthcare costs and productivity losses.

OHS training positively influences worker behaviours, contributing to safer practices.[13] However, the evidence regarding its impact on health outcomes, such as reductions in symptoms or illnesses, is insufficient. The review suggests that although substantial health improvements should not be anticipated solely from OHS training, continued delivery of such training is recommended due to its positive effects on worker practices. Additionally, the review investigated whether higher engagement training methods (involving interactive approaches like simulations) have a greater effect than lower engagement methods (such as lectures). While training is essential in fostering OHS competencies like hazard recognition and control, the effectiveness of various training methods requires further examination.

Seventeen studies targeting employee health behaviours assessed various outcomes, including tobacco use, weight management, and chronic disease incidence. Nine studies reported favourable effects, while three indicated mixed results, and two showed no effects. Four integrated interventions focused on injury prevention related to musculoskeletal disorders (MSDs), with mixed outcomes on MSD prevalence. Three studies evaluated organizational health/safety (OHS) management, with improvements in some safety climate aspects but not all. Four high-quality studies indicated positive effects on the psychosocial work environment, improving job quality, reducing occupational stress, and depression symptoms.[13] Nine studies regarding cost-related outcomes were inconclusive, with five reporting favourable effects on absenteeism. Two studies comparing integrated health promotion (HP) with standard HP revealed better participation and smoking cessation rates in integrated settings, while other outcomes, like BMI, showed no additional benefits from intensive interventions.

COMPARATIVE GLOBAL ANALYSIS OF EXPOSURE CONTROL STRATEGIES AND INNOVATIONS

Marked disparities exist between countries and regions in their capacity to control occupational respiratory hazards.[2,4] High-income regions typically enforce stringent exposure limits and invest in advanced monitoring technologies. Middle-income regions demonstrate uneven implementation, while low-income regions often lack regulatory enforcement.[1,2] International frameworks aim to harmonize standards, but contextual adaptation remains necessary.

EMERGING INNOVATIONS IN OCCUPATIONAL RESPIRATORY HEALTH

Technological innovations are transforming occupational respiratory health. Wearable sensors enable real-time exposure monitoring, while artificial intelligence supports predictive risk modeling. Incorporating AI in occupational health and safety provides advantages like improved safety and productivity via predictive maintenance and immediate risk evaluation.[10] Nonetheless, disadvantages encompass ethical issues, data privacy matters, and the necessity for regulatory adherence. Work organizations need to reconcile innovation with honoring workers' rights, investing in employee education, developing AI skills, and partnering with solution providers to effectively create a safe environment that merges AI with human creativity. Smart personal protective equipment and digital health platforms improve compliance and data integration. However, equitable access to these technologies remains a challenge.

The suggested maturity model (MM) stresses the incorporation of occupational health and safety (OHS) with Industry 4.0 technologies to improve worker safety.[14] This combination utilizes big data, AI, IoT, and robotics to enhance risk detection, accident avoidance, and operational effectiveness. Real-time data analysis allows for hazard identification and behavior tracking via wearables, whereas automation minimizes worker exposure to dangers. The MM evaluates organizational maturity in accordance with ISO 45001 standards, offering a systematic framework for safety adaptation in evolving environments. Important contributions consist of a versatile evaluation instrument for maturity assessment, the connection of maturity criteria with Industry 4.0 principles, and emphasis on both operational and behavioral aspects of leadership.[14] Future studies might investigate wider uses and improvements of the model.

Table 4: Global comparison of occupational respiratory exposure control and innovation.

Region	Exposure limits	Control measures	Surveillance strength	Innovations
High-income	Strict	Engineering-focused	Strong	AI, wearables
Middle-income	Moderate	Mixed controls	Moderate	Digital pilots
Low-income	Weak	PPE-based	Limited	Emerging tools
Global frameworks	Guideline-based	Best practices	Variable	Knowledge platforms

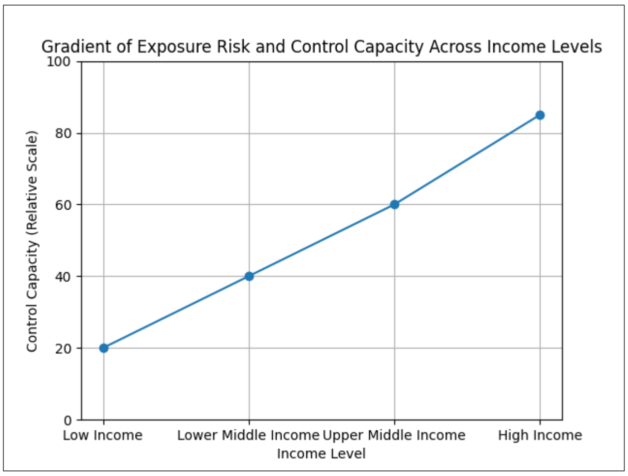

Figure 2: Global disparities in occupational respiratory risk and control capacity.

Technologies such as building information modeling (BIM), radio frequency identification (RFID), and augmented reality (AR) are recognized for their efficiency in sectors like construction. Therefore, incorporating these technologies is essential for enhancing workplace health and safety standards across different sectors.

The combination of AI and wearable technologies is a significant trend in ergonomic research, providing enhanced and immediate posture tracking across diverse work settings.[10] Recent studies show that these technologies not only enable the early identification of high-risk postures but also offer feedback that can enhance ergonomics practices in real-time. AI-driven tools specifically facilitate more objective and scalable ergonomic evaluations, making them ideal for larger workplaces where manual posture observation might be unfeasible. Wearable technology and exoskeletons provide assistance for risky activities, greatly minimizing workers' physical stress and improving overall safety and efficiency.

Artificial intelligence technologies offer considerable benefits in algorithm-driven chest X-ray (CXR) assessment for developing nations, tackling the shortage of specialized radiologists. AI techniques aid in identifying occupational lung diseases from chest X-rays and are essential in assessing compensation claims for workers exposed to dust, minimizing delays caused by uncertain diagnoses such as silicosis. Recent developments, including the TBFE, indicate encouraging results in the detection of pneumoconiosis at early stages. As pneumoconiosis re-emerges in the U.S. and Australia, improved AI integration is crucial.[10,14]

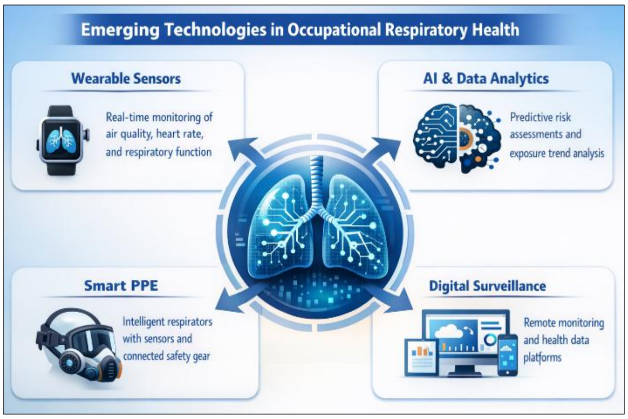

Figure 3: Emerging technologies in occupational respiratory health.

Through the examination of employee data and environmental factors, AI promotes anticipatory risk management, enabling organizations to alleviate hazards and enforce safety protocols efficiently, which ultimately decreases workplace injuries and enhances the health and safety of workers.

ROLE OF HEALTHCARE PROFESSIONALS

Healthcare professionals play a central role in the early detection, reporting, and management of occupational respiratory disorders.[3,5] Multidisciplinary collaboration among physicians, nurses, industrial hygienists, and pharmacists enhances prevention and continuity of care.

They identify hazards, provide clinical care, and implement preventive measures to protect employees.

Occupational health physicians and nurses conduct pre-employment exams, health surveillance, and return-to-work assessments while focusing on illness, injury management, and health promotion.[15]

Industrial hygienists specialize in controlling chemical, biological, and physical exposures to prevent chronic diseases.

Safety professionals enforce PPE use, conduct training, perform risk assessments, and ensure compliance with standards like infection control and emergency preparedness.[16]

In healthcare settings, they safeguard staff from biological risks, ergonomics issues, and psychosocial hazards, enhancing patient safety and system resilience.

These roles reduce accidents, support training on risks, and foster a safety culture through audits and policy advice.[16]

CHALLENGES AND FUTURE DIRECTIONS

Persistent challenges include underreporting, long disease latency, informal employment, and limited access to occupational health services.[1,2,17] Future directions should focus on strengthening surveillance, improving regulatory enforcement, and promoting international collaboration. Major obstacles in OHS management include inadequate infrastructure, limited availability of personal protective equipment, insufficient training programs, and weak regulatory enforcement. Healthcare workers indicated significant exposure to biological, chemical, and physical risks, worsened by insufficient institutional backing. Private sector establishments showed marginally improved resource availability but encountered similar regulatory shortcomings.[17]

Despite technical advances, several barriers to global occupational health remain.

Lack of standardization

There is a pressing need for uniform ergonomic standards across different industries (especially agriculture and healthcare).[4]

Adaptability

Future research must ensure that solutions are adaptable to diverse populations and specific task requirements.

Implementation

Moving from research to industry-wide adoption is the next critical step for practitioners.[2]

CONCLUSION

Occupational respiratory disorders remain a significant yet largely preventable global public health burden. Strengthening surveillance systems, enforcing occupational exposure regulations, promoting worker education, and integrating emerging digital technologies are critical to reducing morbidity and mortality. Future research should prioritize longitudinal exposure assessment, standardized global surveillance frameworks, and equitable implementation of innovative occupational health technologies.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

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Cite this article as: Filander KN, Julliyan DA, Naveena B, Abinaya S, Sheeba S. Occupational respiratory disorders: global exposure patterns, surveillance, preventive strategies, intervention, effectiveness and emerging innovations. Int J Basic Clin Pharmacol 2026;15:582-8.