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(REVIEW ARTICLE)

Occupational exposure patterns and respiratory disease manifestations in industrial workers across multiple manufacturing sectors

Christianah Oluwabunmi Ayodele [1], Oluwafemi Sheriff Yekinni [2,*], Esther Oludele Olaniyi [3], and Chukwuebuka Francis Udokporo [4]

[1] *Department of Nursing, Western Governors University, Millcreek, Utah, United State of America.*
[2] *Department of Health Science, Western Illinois University, Illinois, United State of America.*
[3] *Department of Health Promotion and Education, College of Medicine, Faculty of Public Health, University of Ibadan, Nigeria.*
[4] *School of Medicine, St.George's University, St. George, Grenada.*

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Abstract

Occupational respiratory diseases remain a significant concern in industrial settings, particularly within various manufacturing sectors. Workers are frequently exposed to a range of airborne contaminants, including dust, fumes, gases, and vapors, which can lead to various respiratory conditions. This comprehensive review examines the patterns of occupational exposures and their correlation with respiratory disease manifestations among industrial workers across multiple manufacturing sectors. Through detailed analysis of industry-specific exposure levels in textile, rubber, chemical, and steel manufacturing, the review identifies prevalent respiratory diseases such as byssinosis, occupational asthma, chronic obstructive pulmonary disease (COPD), and pneumoconiosis. Risk factors influencing disease severity, including duration and intensity of exposure, use of personal protective equipment, smoking habits, and pre-existing health conditions, are thoroughly evaluated. The review explores current mitigation strategies encompassing engineering controls, administrative measures, and robust training programs aimed at reducing occupational respiratory hazards. Additionally, it highlights emerging innovations in prevention and management, including artificial intelligence-driven monitoring systems and novel protective equipment. By synthesizing this comprehensive assessment, the paper aims to provide evidence-based recommendations for effective preventive measures to safeguard worker health and reduce the socioeconomic burden associated with occupational respiratory diseases.

Keywords: Occupational respiratory diseases; Pneumoconiosis; Chronic obstructive pulmonary disease; Manufacturing

1. Introduction

Occupational respiratory diseases encompass a wide range of conditions resulting from the inhalation of hazardous substances in the workplace. These diseases pose significant health risks to workers and can lead to substantial socioeconomic burdens [1, 2]. Understanding the specific exposure patterns within various manufacturing sectors is crucial for developing targeted interventions and preventive strategies.

The prevalence of occupational respiratory diseases varies across different industries, influenced by the nature of materials handled and processes employed [3]. For instance, workers in the textile industry are at risk of developing by missions, also known as "brown lung disease," caused by inhalation of cotton, flax, or hemp dust. This condition is

* Corresponding author: Oluwafemi Sheriff Yekinni.

characterized by chest tightness, coughing, and wheezing, particularly at the beginning of the workweek a phenomenon referred to as "Monday fever" [4, 5].

In the construction and mining industries, occupational exposure to crystalline silica is prevalent, leading to silicosis a fibrosing interstitial lung disease. Long-term exposure can also contribute to chronic obstructive pulmonary disease (COPD) and lung cancer. Similarly, workers in rubber manufacturing are exposed to various chemicals, including solvents and curing agents, which can cause respiratory irritation and sensitization, potentially leading to chronic respiratory conditions [6].

The burden of occupational respiratory diseases extends beyond individual health, impacting productivity and imposing economic costs on healthcare systems. A comprehensive literature review demonstrated a substantial occupational burden for multiple respiratory conditions not typically considered work-related, reinforcing the need for effective preventive measures. Primary preventive interventions aimed at reducing exposure levels in the workplace remain pivotal for eliminating the occupational lung disease burden [7, 8]

This review examines the patterns of occupational exposures and their correlation with respiratory disease manifestations among industrial workers across multiple manufacturing sectors. By analyzing industry-specific exposure levels, prevalent respiratory diseases, and existing mitigation strategies, the review seeks to highlight trends in occupational respiratory health risks and recommend effective preventive measures.

2. Occupational Exposure Patterns in Manufacturing Sectors

Occupational exposure patterns in manufacturing sectors are intricately linked to the materials utilized and the processes employed, resulting in distinct health risks for workers across various industries [9]. In the textile industry, workers are susceptible to byssinosis, colloquially known as "brown lung disease," which arises from inhaling cotton, flax, or hemp dust [10]. This condition manifests as chest tightness, coughing, and wheezing, particularly at the start of the workweek a phenomenon termed "Monday fever." Despite advancements in industrial hygiene, byssinosis persists, especially in regions where occupational health standards may be less stringent [11].

In the rubber manufacturing sector, employees encounter a myriad of chemicals, including solvents and curing agents, that can irritate the respiratory system and lead to sensitization, potentially culminating in chronic respiratory ailments [12,13]. Notably, occupational exposures in this industry have been associated with an elevated risk of cancers such as leukemia, lymphoma, and malignancies of the urinary bladder, lungs, and stomach. The intricate and evolving nature of exposure mixtures in rubber manufacturing poses challenges in pinpointing specific causative agents, underscoring the necessity for comprehensive exposure assessments and robust preventive measures [14].

Within the chemical manufacturing industry, workers may be exposed to substances like Bisphenol A (BPA), utilized in producing polycarbonate plastics and epoxy resins. Studies have highlighted the potential for occupational exposure to this endocrine-disrupting compound, emphasizing the need for vigilant monitoring and the implementation of stringent safety protocols to safeguard workers from potential health effects associated with chemical agents [15, 16].

Industries employing per- and polyfluoroalkyl substances (PFAS), such as electronics, plastics, textiles, and construction, present unique exposure risks due to the hydrophobic and lipophobic properties of these chemicals [17]. Occupational exposure to PFAS can occur in facilities that produce these chemicals and in manufacturing settings where they are integral to industrial processes, such as the chrome plating industry [18, 19]. Workers handling PFAS-containing products, including firefighters using PFAS-based foams and ski technicians applying PFAS-containing waxes, are also at risk. Exposure pathways encompass inhalation, ingestion, and dermal contact, with studies indicating higher blood PFAS levels in occupationally exposed individuals compared to the general population

Furthermore, exposure to airborne contaminants in industries such as steel manufacturing is considered a risk factor for pulmonary diseases and pathological changes in airways [20]. Suspended metals, dust, and toxic gases in steelwork may increase the risk of respiratory symptoms related to diseases such as pneumoconiosis, bronchial asthma, COPD, and cancers [21]. Implementing appropriate ventilation systems and personal protective equipment is crucial to mitigate these risks.

3. Respiratory disease manifestations

Occupational respiratory diseases manifest in various forms, primarily influenced by the type and duration of exposure to hazardous substances in the workplace [22]. One prevalent condition is occupational asthma, characterized by variable airflow limitation and airway hyper-responsiveness due to workplace exposures [23]. It is the most commonly diagnosed occupational lung disease, with symptoms including wheezing, coughing, and shortness of breath. These symptoms often exacerbate during the workweek and may improve during weekends or vacations, highlighting the direct impact of occupational environments on respiratory health. Exposure to substances such as dust, chemicals, and molds can trigger this condition [24, 25].

Chronic obstructive pulmonary disease (COPD), encompassing chronic bronchitis and emphysema, can also be caused or exacerbated by occupational exposures to dust, fumes, and chemicals. Approximately 14% of COPD cases are attributable to workplace exposures, with certain industries such as mining and manufacturing posing higher risks [26, 27]. Notably, a significant proportion of individuals with COPD have never smoked, underscoring the critical role of occupational factors in the disease's etiology.

Pneumoconiosis refers to a group of interstitial lung diseases caused by the inhalation of mineral dust, leading to lung fibrosis. Common types include silicosis, resulting from silica dust exposure, and asbestosis, from asbestos fibers [28]. These conditions are prevalent among workers in mining, construction, and manufacturing industries where such dust exposure is significant [29].

Hypersensitivity pneumonitis is an inflammatory syndrome of the lung caused by repetitive inhalation of organic dust and certain chemicals, leading to an immune response in the alveoli. It is commonly observed in agricultural and textile workers exposed to dust from moldy hay, bird droppings, or contaminated humidifiers. Symptoms include cough, shortness of breath, and fever, which may become chronic with continued exposure [30,31].

4. Risk factors influencing disease severity

The severity and progression of occupational respiratory diseases are influenced by several interrelated factors, including the duration and intensity of exposure to hazardous substances, the use of personal protective equipment (PPE), smoking habits, and pre-existing health conditions [32].

Prolonged and high-intensity exposure to respiratory hazards significantly elevates the risk and severity of disease manifestation. For instance, workers in industries such as mining and construction, where inhalation of dust, fumes, and chemicals is prevalent, are at heightened risk for developing chronic obstructive pulmonary disease (COPD) and other respiratory conditions. The cumulative effect of long-term exposure can lead to progressive lung damage, underscoring the importance of monitoring and controlling exposure levels in occupational settings [33, 34].

The proper use of PPE is crucial in mitigating exposure to harmful substances in the workplace. Inadequate or improper use of equipment such as respirators can lead to higher exposure levels and an increased risk of disease [35]. For example, during emergency situations where PPE usage may be compromised, workers can experience significant exposure to toxic substances, leading to long-term health disorders, including respiratory diseases. This highlights the necessity for rigorous training and enforcement of PPE protocols to protect workers effectively.

Smoking exacerbates the effects of occupational exposures and significantly increases the risk of developing respiratory diseases. Tobacco smoke is a well-established risk factor for chronic respiratory conditions, and when combined with occupational hazards, it can lead to more severe disease progression [36]. Notably, a considerable proportion of COPD cases are attributed to occupational exposures, particularly among individuals who have never smoked, underscoring the compounded risk that smoking introduces [37].

Workers with pre-existing respiratory conditions are more susceptible to occupational respiratory hazards, leading to more severe health outcomes. Chronic respiratory diseases can be caused or exacerbated by exposure to occupational agents, and individuals with existing conditions may experience accelerated disease progression or increased vulnerability to additional respiratory complications [38, 39]. This emphasizes the importance of tailored workplace interventions and health monitoring for at-risk populations to mitigate further health deterioration.

5. Mitigation strategies

Implementing effective mitigation strategies is essential to protect workers from respiratory hazards in occupational settings. A comprehensive approach encompasses engineering controls, administrative measures, proper use of personal protective equipment (PPE), and robust training and education programs.

Engineering controls serve as the first line of defense by reducing or eliminating exposure to airborne contaminants at their source. Improving ventilation systems is a fundamental strategy; ensuring that heating, ventilation, and air conditioning (HVAC) systems meet recommended air exchange rates can significantly lower the concentration of airborne pathogens and pollutants [40, 41]. For instance, during the COVID-19 pandemic, enhancing building ventilation was identified as a critical measure to reduce the spread of respiratory infections. Additionally, implementing dust suppression methods, such as water sprays or local exhaust ventilation, can effectively control particulate matter in industries like mining and construction [42, 43]. Enclosing processes that generate hazardous substances further prevents their release into the workplace environment, thereby safeguarding workers' respiratory health.

Administrative controls complement engineering measures by modifying work practices and policies to minimize exposure risks. Implementing work rotation schedules can limit the duration individuals are exposed to hazardous environments, thereby reducing cumulative exposure [44]. Regular health screenings are vital for early detection of respiratory conditions, enabling timely interventions and preventing disease progression. For example, monitoring lung function through spirometry can help identify early signs of occupational lung diseases, allowing for prompt medical response and adjustments to work assignments.

The proper use of personal protective equipment (PPE) is crucial in shielding workers from inhalation hazards. Providing appropriate PPE, such as N95 respirators, and ensuring workers are trained in their correct usage, maintenance, and limitations is essential [44, 45]. Respirators must be properly fitted to each individual to ensure an effective seal and optimal protection. Inadequate or improper use of PPE can lead to higher exposure levels and increased disease risk, underscoring the importance of comprehensive training and adherence to safety protocols [46].

Training and education are foundational components of an effective respiratory protection program. Educating workers about potential hazards, safe work practices, and the correct use of control measures fosters a culture of safety and proactive health management [47]. Regular training sessions, updates on new safety protocols, and open communication channels encourage workers to engage actively in their health and safety. A well-informed workforce is better equipped to recognize hazards, comply with safety measures, and contribute to a safer work environment [48].

6. Future work

Advancements in the prevention and management of occupational respiratory diseases necessitate ongoing research and innovation. Future studies should focus on identifying emerging occupational hazards resulting from technological and industrial developments, as these changes can introduce new respiratory risks to workers [49]. For instance, the integration of nanomaterials in various industries has raised concerns about potential respiratory health effects, highlighting the need for continuous monitoring and assessment.

Integrating artificial intelligence (AI) and real-time monitoring systems could revolutionize workplace hazard detection and early disease intervention, enabling more proactive approaches to occupational health [50, 51]. AI-driven diagnosis and monitoring in respiratory care is an emerging field that aims to improve the detection and treatment of respiratory diseases using smart wearable devices and real-time data analysis [52, 53]. For example, AI systems can collect and classify bio signals such as cough, body temperature, and airflow, providing accurate and timely diagnosis of respiratory illnesses, including COVID-19, asthma, and COPD.

Research into the long-term health outcomes of workers exposed to complex mixtures of airborne contaminants is essential to develop comprehensive risk assessment models [54]. New occupational agents with unknown respiratory health effects are constantly introduced to the market, necessitating periodic health surveillance among exposed workers to detect early signs of adverse respiratory effects [55,56]. Additionally, the aging workforce, many of whom have pre-existing respiratory conditions, poses new challenges in diagnosing and managing occupational lung diseases [57,58].

Exploring the effectiveness of novel protective equipment and engineering controls will contribute to more robust preventive strategies. For instance, the development of a low-cost 'smart mask' capable of analyzing the wearer's breath

to detect signs of diseases like lung conditions and inflammation due to COPD and asthma offers an accessible method for real-time health monitoring [59, 60]. This innovation addresses challenges in current breath-analysis methods by providing efficient and immediate analysis of breath biomarkers.

7. Conclusion

Occupational respiratory diseases (ORDs) remain a significant concern in industrial environments, primarily due to prolonged exposure to airborne contaminants. These diseases not only impair workers' health but also lead to increased absenteeism, reduced productivity, and substantial economic burdens on healthcare systems. Addressing this issue necessitates a comprehensive understanding of exposure patterns, disease manifestations, and the implementation of effective risk reduction strategies. Identifying and mitigating exposure patterns is paramount in preventing ORDs. Industries must conduct thorough assessments to pinpoint specific airborne hazards inherent in their operations. For instance, workers in construction and mining are often exposed to silica dust, leading to conditions like silicosis and chronic obstructive pulmonary disease (COPD). Recognizing such patterns enables the development of targeted interventions to reduce exposure.

Understanding the manifestations of respiratory diseases is crucial for early detection and management. Occupational asthma, COPD, pneumoconiosis, and hypersensitivity pneumonitis are among the common respiratory ailments linked to workplace exposures. Early identification of symptoms allows for timely medical interventions, potentially halting disease progression and improving quality of life for affected workers. Implementing effective risk reduction strategies requires a multifaceted approach. Engineering controls, such as improved ventilation systems and dust suppression methods, are fundamental in minimizing airborne contaminants. Administrative measures, including work rotation schedules and regular health screenings, further mitigate risks. Ensuring the proper use of personal protective equipment (PPE) is vital; employers must provide appropriate PPE and comprehensive training on its correct usage. Fostering a culture of safety through continuous education empowers workers to engage proactively in their health management.

Collaboration among all stakeholders' policymakers, industrial leaders, occupational health professionals, and employees is essential to effectively address the challenges posed by ORDs. Regulatory bodies should establish and enforce stringent exposure limits and safety standards. Employers must invest in safety infrastructure and training programs, while workers should adhere to safety protocols and participate actively in health initiatives. Such collective efforts not only reduce the incidence of occupational respiratory diseases but also enhance overall productivity and worker well-being in industrial settings.

Recommendations

To effectively mitigate the impact of occupational respiratory diseases, a comprehensive and proactive approach is essential. Employers should prioritize the implementation of stringent workplace regulations and advanced engineering controls, such as enhancing ventilation systems and adopting effective dust suppression techniques, to minimize workers' exposure to airborne contaminants. Regular health screenings are crucial for the early detection of respiratory conditions, enabling timely interventions and reducing the progression of diseases. Comprehensive training programs that educate workers about potential hazards, safe work practices, and the correct use of personal protective equipment (PPE) are vital in fostering a culture of safety and proactive health management. Ensuring the availability and proper use of appropriate PPE, such as respirators, is imperative; employers must provide training on correct usage, maintenance, and understanding the limitations of such equipment. Collaboration among employers, workers, occupational health professionals, and regulatory bodies is imperative to establish and maintain effective preventive measures, ensuring a safe and healthy work environment.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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