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Occupational Hazards in the Mining Industry: A Focus on Chrysotile Asbestos Exposure and Health Outcomes

Mohammad Abdullah Al Zubair Naim[1]* & Raju Ahmed[2]*

[1]*Division of Nephrology, Department of Medicine, University of Tennessee Health Science Center, Memphis, TN, United States*

[2]*College of Public Health, University of Iowa, Iowa City, IA, United States*

* *These authors have equally contributed to this article.*

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Corresponding author:

Mohammad Abdullah Al Zubair Naim

Email mnaim@uthsc.edu

Abstract: Notwithstanding notable advancements in occupational health and safety over the past century, occupational injuries and illnesses occur frequently worldwide. Mining is among the highest-risk occupational environments, exposing workers to acute and chronic health problems. This narrative review explores research evidence of different mining-related hazards, with a special focus on asbestos exposure. Mineworkers more commonly face biological, chemical, physical, ergonomics, and psychological hazards than other industries. Exposure to respiratory particles like silica and coal dust contributes to respiratory diseases like pneumoconiosis, silicosis, chronic obstructive pulmonary disease (COPD), and other lung diseases. Due to the physically demanding nature of the work and poor ergonomics, the risk of musculoskeletal disorders (MSDs) occurring in soft tissues and surrounding body structures is high in mineworkers. Despite technological advancement and safety precautions, the mining industry remains a high-risk workplace with disproportionately higher rates of occupational injuries. Routine exposure to carcinogens results in a high risk of stomach and lung cancers. Chrysotile is the most used asbestos in the mining industry, causing asbestosis and mesothelioma. While some countries have introduced regulations to limit or phase out the use of asbestos, asbestos is still used in many countries. Studies are warranted to investigate the immediate and long-term health effects and potential risk factors. Essential preventive measures, consistent enforcement of safety standards, and accessible healthcare are essential to ensure overall well-being.

Keywords: Occupational health; mineworkers; asbestos exposure; chrysotile; respiratory diseases; occupational cancer; workplace safety; mining injuries

Introduction

Occupational illnesses include physical or psychological illnesses that are primarily caused by the work environment or related activities, often resulting in significant disruption, disability, or death (1). A wide range of health problems can be caused or worsened by work conditions, which include respiratory issues like asthma and pneumoconiosis, musculoskeletal disorders, mental health challenges such as stress and depression, and various forms of cancers (2). Despite notable advancements in occupational health and safety over the past century, an estimated 317 million nonfatal occupational injuries and 321,000 occupational fatalities still occur globally each year (3). These injuries and illnesses vary depending on the type of occupation and the specific hazards involved, such as chemical, biological, or physical hazards (4, 5).

Mining is one of the highest-risk occupational environments characterized by numerous hazards, exposing workers to conditions that can lead to both acute and chronic health problems (5). Generally, mineworkers have a significantly higher prevalence of occupational diseases compared to the general working population, including exposure to harmful particulates such as silica dust, coal dust, metals-containing dust, diesel particulate matter, and industrial noise (6). The working conditions in mines, including exposure to dust, chemicals, physical strain, and poor ergonomic practices, contribute significantly to the higher morbidity and mortality rates in mining workers (5). Mining operations also expose workers to risks such as rock falls, equipment accidents, and exposure to harmful substances. In addition to that, the continued use of outdated equipment and mining techniques exacerbates the risk of accidents and toxic exposures (7). The risks associated with mining can vary considerably depending on several factors, including the type of mining (e.g., underground vs. surface), the mineral being extracted (e.g., coal, copper), exposure levels and their temporal change, and the geographical context in which the operation occurs (6).

Despite the regulatory frameworks and safety protocols in the mining sector, incidents remain common and occur at significantly higher rates compared to other employment sectors (8). Key determinants that influence safety in mining include geological complexity, regulatory enforcement, technological development, and environmental conditions such as extreme temperatures or seismic activity. Studies found that mines with robust safety regulations and modern technologies generally experience lower injury rates (9). Therefore, understanding and addressing the specific risks associated with different mining environments is crucial for improving the safety of mineworkers.

This review aims to explore the evidence obtained from research on mining-related injuries, with a special focus on asbestos exposure. The review highlights the need for improved safety measures, worker training, and enforcement of regulations to mitigate risks and enhance workplace safety in the mining industry.

Occupational hazards in mining industry

Occupational hazards fall into several categories-biological, chemical, physical, ergonomics, and psychological (5), with a variable magnitude of prevalence across different sectors, regions, and individuals. While every occupation entails the risk of injury from occupational hazards, the mining industry is one of the most hazardous occupations compared to other sectors (6).

Although the mining industry accounts for just 1% of the global workforce, it accounts for approximately 8% of all fatal workplace accidents (10). Mineworkers experience some of the highest rates of occupational injuries and illnesses across all industries, primarily due to their inherently hazardous and labor-intensive physical environments and exposure to toxic substances. Compared to the general working population, the mining industry has a higher percentage of manual laborers, putting them at different occupational exposures than occupations. A national study by Robinson et al. (2023), which compared mineworkers to six other groups of manual laborers-based industries in the United States, found that mineworkers had a higher crude prevalence of hypertension, moderate-to-severe hearing loss, lower back, neck, leg, and joint pain (6).

Common mining-related health issues and injuries

Respiratory diseases

Exposures to various respirable particulates have been linked to chronic occupational diseases in mineworkers, with excessive inhalation of silica and coal dust, as well as other particulates, contributing to various respiratory diseases and health-related issues. A study of more than 2,500 former US coal mineworkers found that over half had abnormal lung function, often due to prolonged exposure to coal dust (11).

Pneumoconiosis, commonly called ‘black lung disease,’ is a dust-induced occupational lung disease prevalent among mineworkers, particularly those working in coal mines (12). A 23-year follow-up study on US coal mineworkers found a direct correlation between the duration of coal dust exposure and the severity of pneumoconiosis, confirming that more prolonged exposure significantly increased disease progression and mortality risk (13).

Mineworkers exposed to high levels of silica dust are at a significantly increased risk of developing silicosis, a progressive disease that often leads to debilitating respiratory failure (14). A cross-sectional study by Cowie et al. (1991) investigating gold mineworkers in South Africa reported a higher prevalence of silicosis-associated pulmonary dysfunction, with dyspnea on exertion linked to the duration of underground exposure and the concentration of dust exposure in the workplace (15).

Another respiratory disorder with a notably higher prevalence among mineworkers than the general population is chronic obstructive pulmonary disease (COPD), which is developed as a result of long-term exposure to mining dust and fumes. Other reported respiratory symptoms and disorders include bronchitis, chronic bronchitis, chronic cough, and chronic phlegm (16). Table 1 furnishes the frequencies of different mine dust lung diseases reported by Resources Safety and Health Queensland (Australia) in 2024.

Mineworkers in the US, particularly coal mineworkers, were found to have increased odds of death from pneumoconiosis, lung cancer, and COPD compared to the rest of the population, caused by the respirable coal mine dust (17).

Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) are soft tissue disorders and surrounding structures in the neck, shoulders, elbows, wrists, and lower back (18). These are among the most widespread occupational health problems in the mining industry (19). MSDs accounted for 32% of all non-fatal injuries among full-time US workers in 2014 (20). A meta-analysis by Rabiei et al. (2021) examining the prevalence of MSDs among mineworkers around the world reported MSDs to be one of the most common reported occupation-related disorders, with a prevalence of 50.39% in the upper back and 16.03% in the knees (19). Over 65% of underground coal mineworkers in Eastern India complained of MSD pain, with the highest, approximately 58%, of the pain identified in the lower back (21).

There are a number of occupational risk factors contributing to the development of MSDs in mining workers due to the physically demanding nature of mining work, such as poor ergonomics, including repetitive movements, heavy lifting, and awkward postures (22). The use of vibrating tools and machinery in mining is another significant risk factor for MSDs. Vibration and ergonomic exposures were found to be associated with MSDs of the neck and shoulder (22). It was also reported that prolonged exposure to hand-arm vibration is associated with conditions such as hand-arm vibration syndrome and rotator cuff syndrome among mineworkers (22).

Occupational Injuries

The mining industry, despite advancements in workplace safety, continues to remain a high-risk workplace with disproportionately higher rates and severity of occupational injuries (7). The physical environment of mines is characterized by confined spaces, heavy machinery, and the potential for structural failures, contributing to the higher likelihood of occupational injuries.

The US Bureau of Labor Statistics (2023) reported incidence rates for non-fatal occupational injuries in the mining sectors to be 130 per 10,000 full-time employees in 2023 (23). An investigation into the Australian mining sector by Jones et al. (2013) in 2019 found that there were a total of 837 reported injuries, including 658 severe cases (three fatalities) and 179 minor injuries, highlighting the ongoing risks mineworkers face (24). The authors reported sprains and strains (69%) as the most recorded injury, followed by fractures (10%), lacerations (6%), crushing injuries (5%), bruises and contusions 4%, and dislocations and displacements 2%. Other injuries include amputations, punctures, chemical effects, bites, foreign bodies, loss of consciousness, thermal burns, and flash and arc burns (24).

A decade-long investigation by Chen et al. (2012) that examined the trends of coal mine accidents in China, although reported a significant decrease in accidents and fatalities after 2005 compared to earlier periods, the absolute number of registered coal mine fatalities in 2010 was still high (n= 2,433) (25).

Notwithstanding technological advancements and stricter safety protocols, mining remains one of the most injury-prone industries globally, highlighting the need for improved hazard control, comprehensive worker training, and effective emergency preparedness.

Cancers

Mineworkers are routinely exposed to a wide range of hazardous substances, many of which are known or suspected carcinogens. Long-term exposure to these agents significantly elevates the risk of various cancers. A meta-analysis by Alif et al. (2022), investigating cancer and mortality in coal mine workers, reported an increased risk of stomach cancers among mineworkers (standardized mortality ratio: 1.11, 95% CI 0.97 to 1.35) (26).

In addition, mineworkers are at a higher risk of developing lung cancers compared to the general population. A large Scandinavian registry study identified mineworkers as having a high occupational risk for lung cancer, largely due to exposure to silica dust and radon daughters, as well as other airborne carcinogens such as arsenic, chromium (VI), asbestos, polycyclic aromatic hydrocarbons (PAHs), diesel exhaust, and nickel (27).

However, epidemiological studies reported conflicting results on lung cancer among coal mineworkers. Hosgood and colleagues investigated the association between coal mining and lung cancer in China, observing an elevated lung cancer risk among coal mineworkers compared to non-coal miners (28). On the contrary, Brown and colleagues, who investigated the occurrence of cancer in a cohort of coal mineworkers in Australia, suggested that the coal industry in the New South Wales does not appear to be a general risk of cancer (29). Such discrepancies underscore the importance of modifiable factors. The type of mineral extracted, level and duration of exposure, and co-factors such as smoking play a critical role in modulating cancer risk in mining populations. Smoking, in particular, is known to have a synergistic effect with workplace carcinogens, amplifying the overall risk of respiratory cancers (30). Studies demonstrated smoking mediated the relationship between asbestos and lung cancer among mineworkers (31).

These findings highlight the need for region-specific occupational health monitoring and targeted cancer prevention strategies for mineworkers.

Chrysotile asbestos exposure and consequences

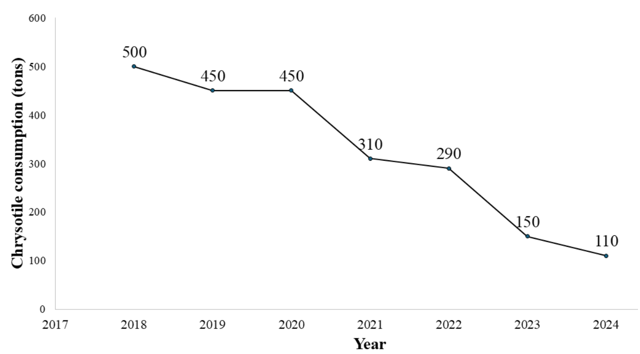
One of the major occupational hazards in the mining industry is airborne environmental pollution within the mines, primarily in the form of toxic dust, gases, fumes, and vapors. Among these, the inhalation of fine particulate matter, especially asbestos fibers, poses a significant health risk to miners. Asbestos refers to a group of naturally occurring fibrous minerals that have been widely used in industrial applications for their durability, heat resistance, and insulating properties. Chrysotile, known as white asbestos, is the most commercially used asbestos globally (32).

The mining and processing of asbestos have had severe health consequences for mineworkers, particularly those who are frequently exposed to airborne asbestos fibers during extraction and processing. Fibers deposited in the lung parenchyma lead to a progressive inflammation of the tissues, resulting in a fibrotic response that impairs gas exchange, resulting in asbestosis, a potentially fatal lung disorder that may cause progressive dyspnea and respiratory failure (33).

Chrysotile belongs to the serpentine mineral group and is classified as a carcinogen by international health authorities due to its strong association with mesothelioma, a rare and aggressive cancer affecting the mesothelium, the protective lining of several internal organs (34). Mesothelioma is often diagnosed at an advanced stage, which limits the treatment options and results in poor survival. A study on cancer mortality of a historical cohort of 30,445 mineworkers who worked for more than 30 years in the chrysotile mine and its enrichment factories in Russia confirmed that exposure to dust containing chrysotile increased the risk of cancer development in a dose-dependent manner (35).

Despite the well-established relationship between asbestos and mesothelioma, chrysotile is found in 95% of all asbestos mined today (32). However, global chrysotile consumption has significantly declined due to increased awareness of its health risks and regulatory bans in many countries. For example, figure 1 shows the domestic chrysotile consumption trend in the United States between 2018 to 2024 (36).

Figure 1: Domestic chrysotile consumption trend in United States between 2020 to 2024



Global policy initiatives in reducing asbestos-related health risks

Several countries have implemented successful policies to mitigate the occupational health risks associated with asbestos, particularly in the mining and construction sectors. These examples can inform more effective regulations in regions where asbestos exposure remains a significant concern:

1. *Australia:* A complete ban on all forms of asbestos was implemented in 2003. Prior to the ban, the country had already phased out the use of asbestos in construction materials and introduced national standards for asbestos removal. Post-ban, strict licensing systems for asbestos handling and removal, along with public awareness campaigns, significantly reduced occupational exposure and related diseases (37).
2. *European Union (EU):* In 2005, the EU banned chrysotile asbestos after years of concern over its health risks. Before that, member states such as France, Germany, and Sweden had already enacted national bans and initiated asbestos abatement programs in schools, public buildings, and older industrial sites. Additionally, the EU established directives for asbestos waste management to ensure the safe disposal of contaminated materials, thereby reducing the risks of secondary exposure to asbestos fibers (38, 39).
3. *Japan:* In the 1990s, Japan adopted a phased approach to banning asbestos, culminating in a total ban in 2012. In response to growing public concern and the surge in mesothelioma cases, they also introduced a compensation system in 2006 to support both occupationally and environmentally exposed individuals. Additionally, the government made significant investments in retrofitting public infrastructure to ensure the safe removal of asbestos-containing materials, aiming to prevent future exposures and protect public health (40).
4. *South Korea:* South Korea implemented a complete ban on asbestos in 2009. The national asbestos surveillance system in South Korea includes a registry for asbestos-exposed individuals and mandatory health monitoring for workers with a history of employment in asbestos-related industries. These initiatives have significantly strengthened early disease detection and long-term monitoring, enhancing prevention and compensation efforts for affected populations (41).
5. *Brazil:* In 2017, Brazil instituted a nationwide ban on commercial asbestos use. Authorities also began encouraging industries to adopt safer alternative materials and provided retraining programs to support workers transitioning out of asbestos-related jobs. These steps aimed to reduce future exposure risks while supporting affected communities through economic and occupational adjustments (42).

Occupational hazards: beyond physical harm

In the mining industry, some health problems develop silently over time upon long-term exposure to toxic dust and chemicals, severely impacting the daily well-being of workers. Diseases such as asbestosis and lung cancer lead to constant breathlessness, fatigue, and pain, making everyday tasks a challenge. These physical struggles often coexist with mental health issues like anxiety and depression (43).

Living with a long-term illness becomes financially overwhelming. Medical treatments can be expensive, and when workers are too sick to continue working, the loss of income puts enormous economic pressure on them and their families. Over time, many affected individuals become socially isolated, impairing their emotional health and quality of life (44).

Mineworkers facing long-term illnesses require support like access to counseling, mental health care, and programs that help them return to social life and work. Community-based efforts such as peer support groups, workplace mental health screenings, and financial assistance can make a real difference in helping affected workers cope and recover (45, 46).

Table 1. Reports of mine dust lung diseases (all mining) reported in 2024 in Queensland, Australia (47)

Lung disease	Cases (n)
Chronic Obstructive Pulmonary Disease (COPD)	101
Pneumoconiosis	8
Silicosis	15
Cancer	3
Other lung diseases	9
Multiple lung diseases	27

Conclusion

While the mining industry contributes significantly to global economies, it continues to pose substantial health and safety challenges for its workforce. Despite the improvement in the safety of the mining environment, the nature of the mining industry exposes mineworkers to various physical and environmental risks, potentially compromising their quality of life. Prospective studies are warranted to investigate the immediate and long-term physical and mental health effects and potential risk factors associated with those. Studies should also explore the complex interplay of physical, chemical, and organizational risks of mining workers. While some countries have introduced regulations to limit or phase out asbestos use, many permit it in various industries, including mining. Therefore, studies should underscore asbestos-related health risks in mining populations to influence policy decisions. Strategies to better protect the mineworkers include modernizing mining equipment, providing adequate personal protective equipment, and implementing regular medical screenings to detect health issues at an early, more treatable stage. Essential preventive measures, consistent enforcement of safety standards, and accessible healthcare will likely protect mineworkers from the potential and detrimental effects of occupational illnesses and improve their overall well-being.

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