A Comprehensive Review of Airborne Metal Exposures and Their Impact on Nurses' Health: Analyzing Occupational Risks and Preventive Measures

Fatimah Abdullah Ahmad Alsaanonah[1], Marwa Ahmed Ali Al Turki[1], Layla Zaki Ali Ashour[1], Mariam Habib Abdullah Alhakeem[1], Zahra Fahmi Ahmed Aman[1], Fatimah Ali Hassan Alzakariya[1], Zammal Mana Zammal Almansour[1], Amal Jaber Yahya Dawsh[1], Reem Khelaiwi Matrook Almutairi[2], Hawraa Mohammed Abdulwahab Alsalem[2], Mansour Rashad Alaqeel[3], Manouer Khalid Abdullah Alsubaie[4]

[1]*Nurse, Dhahran Eye Specialist Hospital, Saudi Arabia*
[2]*Nursing Technician, Dammam Medical Complex, Saudi Arabia*
[3]*National Guard Hospital, Patient Care Technician, Saudi Arabia*
[4]*Doha Health Center, Nursing Health Assistant, Saudi Arabia*

Abstract: This comprehensive review explores the impact of airborne metal exposures on nurses' health, focusing on the occupational risks associated with healthcare settings. Nurses, as the backbone of healthcare systems, are exposed to various environmental pollutants, including metals, during routine clinical activities. This review critically examines the sources of airborne metals, such as those generated by medical equipment and patient treatments, and discusses the potential health effects, particularly respiratory and neurological disorders. The evidence presented highlights the significance of these exposures, which have been under-recognized despite their growing presence in healthcare environments. The review also identifies the gaps in existing literature, especially regarding the specific risks faced by nurses, and proposes preventive measures, including enhanced monitoring, the use of personal protective equipment (PPE), and the adoption of safer medical technologies. By addressing these challenges, the review aims to improve nurse safety and contribute to the development of more effective health protection policies in healthcare settings.

Keywords: airborne metal exposures, nurses' health, occupational risks, healthcare safety, preventive measures, respiratory effects, neurological effects, medical equipment, health monitoring, personal protective equipment (PPE), healthcare environments.

1. Introduction

Healthcare systems around the world are dealing with unprecedented challenges. Nurses, the backbone of the healthcare systems, are faced with scaling demands for care and exposure to new risks. While the global focus has been on infectious agents, there is a growing concern over other airborne contaminants, including metals, in clinical environments. The recent spike in metal exposures, especially in large hospitals, is alarming. Investigating the sources and health impacts of such exposures is critical for nursing and wider healthcare safety. Metal exposures in healthcare are an under-recognized menace, often dismissed as negligible. Yet, evidence is emerging that airspace sharing with patients undergoing metal-assisted

treatments jeopardizes care providers. High-risk procedures liberate metals into the air. Newly nanoparticulated, these metals readily penetrate deep into the respiratory and circulatory systems, with detrimental effects. Recent discoveries link sick healthcare workers with aerosolized metals, prompting the need for systemic investigations (Johannes van den Heever, 1996).

Nurses, most suffering metal-associated ailments, face the greatest risk, yet are the least studied. Focusing on nurses, the most vulnerable yet least attended group, is vital for wider public safety and confidence in healthcare systems. Recent discoveries at one hospital showcase the criticality of the issue, which, if not recognized and addressed, could undermine patient safety and public trust, threatening the foundations of the healthcare system. The objective is to critically examine existing knowledge on airborne metal exposures and their impact on health, specifically on nurses, outlining the challenges and opportunities. An overview of the current understanding of occupational risk from airborne metal exposures is provided, along with evidence of associated health impacts, focusing on nurses, the group most studies neglect. Recognizing the problem, current knowledge gaps and crucial unexplored areas are highlighted, serving as a basis for future investigations. The significance of the research lies in improving the understanding of airborne metal exposures and their impact on nurse health, potentially enabling the development of preventative measures and interventions, benefiting care providers, healthcare systems, and patients alike.

1.1. Background and Rationale of the Study

Healthcare practices have historically incorporated metals and metal-containing substances in a multitude of forms, from basic elements to complex compounds. The direct application of metals in healthcare spans a broad time frame, applying to ancient, meditative, and religious healing practices involving metals or metal-based compounds, such as gold and silver. Considerations of metal applications in healthcare have evolved over time, influencing new practices so as to maintain the safety of patients, staff, and the public. However, some healthcare practices may generate airborne metal exposure, challenging the safety of healthcare workers who are more likely to come in contact with such airborne metals, such as nurses and nurse assistants (Johannes van den Heever, 1996). The gradual emergence of new practices resulting in airborne metal exposure in healthcare settings underscores the importance of a more focused inquiry into such occupational exposure.

Metals are pivotal in the current development of healthcare technology. Healthcare technologies, necessitating the use of metals, guarantee the proper delivery of healthcare services and the safety of patients. However, certain healthcare technologies may generate airborne metal exposure. Observations of elevated metal concentration in the air before and after the use of such healthcare technologies implicate metal-related aerosol bio-generation. Such metal-related aerosol bio-generation could challenge the safety of healthcare workers, similar to the bioparticle-aerosol bio-generation induced by healthcare technologies that have been the focus of attention among researchers and regulators. In reference to airborne bioparticle exposure, respiratory-related health issues and sensitivity have been found among nurses, pointing to occupational risks similar to those posed by airborne metal exposure. Extensive research has been conducted on healthcare technology-induced airborne bioparticle exposure; in contrast, research addressing healthcare technology-induced airborne metal exposure remains scant. (Weber & Prietl, 2021)

Despite the growing use of metal-containing healthcare technologies, studies directly addressing occupational exposure to airborne metals among healthcare workers are lacking. Nevertheless, inquiries into occupational airborne metal exposure beyond the healthcare sector indicate that such exposure is related to health-related issues similar to those in the healthcare sector. Upward trends in nurse- and nurse-assistant-relevant, healthcare-technology-induced, health-related issues in the review of health-record databases point to the need for an in-depth inquiry into the aerosols generated by metal-containing healthcare technologies and nurses'

occupational exposure to such aerosols. Such inquiry is warranted and timely, not only to fill the gaps in existing literature but also to assist regulators and relevant policymakers in identifying the weaknesses in the enforcement of organizational policies and in augmenting protective measures.

2. The Role of Nurses in Metal Exposure

This section explores the specific roles nurses have in healthcare settings that can expose them to airborne metals. Metal exposure comes from health treatments for the patients, procedures performed on the nurses themselves, or management of medical equipment used by patients emitting medical particles. Fume metals generated by lasers, X-ray tube targets, and CT scan tubes in healthcare produce airborne metal particles. Those generally are close to handling body laboratory specimens by nurses too, which have risks of metal exposure (Johannes van den Heever., 1996). Other studies containing one or a few participating nursing processes found an increase in metals on nurses' breathing zones, e.g., handling metal-contaminated patients or cleaning processes. This exposure pathway needs further exploration of the activities involved to clarify which can pose exposure risks. In addition, the differences in metal levels across auditing settings suggest that attention should focus on determining the types of objects or the settings where nurses operate that may expose them to metals.

The interaction of nurses with equipment possibly contaminated with metals comes as a significant focus. The previous studies were silent regarding what nursing practices might interact with equipment leading to exposure, although this exposure pathway was highlighted. A deeper exploration of these roles is essential for understanding the pathway of exposure. Another aspect for deeper discussion is environmental health risks and concerns related to nursing practices. Although indirect roles, infectious wastes handling by cleaning or transferring between wards provide a pathway for pollutant exposure similar to the conducting metal studies, estimating the risk remains challenging. This section paves the way to find mitigation strategies through prevention discussion in later parts.

2.1. Occupational Settings and Tasks Putting Nurses at Risk

Health professionals, in general, are challenged with physical, chemical, and psychological hazards, and demographic characteristics such as age and educational level play a significant role in their vulnerability to these hazards. Nursing is considered a stressful profession throughout the world, with high demands and low control, long shifts, and exposure to several stressors, which may result in compromised physical and mental health. Health hazards can adversely affect the quality of health services, as well as socio-economic development. Nurses are the largest workforce in the health service industry and play a vital role in the health care delivery system of every country (Gezehy Amare et al., 2021).

The major areas in which nurses perform hazardous tasks include injection, cleaning, patient care, bed making, cleaning and dressing of wounds, medication administration, and performing operations. During these activities, healthcare providers are exposed to many types of occupational hazards. Contaminated needles, other sharp instruments, and contaminated blood or body fluids expose healthcare providers to blood borne pathogens. Noise from medical equipment and poor working environment, bulky equipment, and ill-fitted working furniture could cause physical stress. Use of disinfectants, chemicals, and exposure to patient’s drugs could cause chemical hazards. Slip and fall accidents while carrying heavy equipment, jungling with many tasks and patients, and during night shifts pose risks to physical safety.

3. Common Airborne Metals in Healthcare Environments

Common Airborne Metals in Healthcare Environments Healthcare environments are designed to ensure that nurses and patients feel safe and comfortable. Special attention is paid

to training nurses to properly handle medications and potentially hazardous materials while protecting patients' health. However, these arrangements may not consider the airborne metals that constantly permeate healthcare workplaces, exposing nurses. Given the heavy workload nurses endure in caring for patients with chronic diseases, an analysis of the airborne metals in healthcare environments is essential. This analysis helps identify contaminants that can harm health and discusses preventive measures. Nurses may be exposed to various airborne metals, some of which are common in other workplaces but are rarely considered in the healthcare field. Airborne metals are divided into three groups. The first group consists of metals commonly found in environmental samples, such as antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc. Among them, airborne cadmium, chromium, copper, manganese, and nickel are classified as probable human carcinogens or may negatively affect human development based on hazard identification in epidemiological studies. The second group includes metals that can come from medical equipment or materials, such as cobalt, iron, lanthanum, neodymium, palladium, platinum, sodium, and titanium, primarily found in personal exposure samples. These metals are generally considered harmless to health; however, preventing them from becoming airborne is advisable since they can cause adverse health effects under special circumstances. The third group consists of metals used in healthcare procedures, such as barium, lead, and mercury, which are rarely airborne in healthcare workplaces unless an accident happens. This categorization of airborne metals helps identify the types of metals concerning health and safety in occupational settings. Focusing on healthcare workplaces, the most concerned airborne metals are lead, mercury, and cadmium. These metals can adversely affect not only nurses' health but also patients' safety. Although lead and mercury have been gradually removed from healthcare materials, cadmium is still used in some medical devices. As a result, these metals are some of the most legally regulated contaminants in healthcare workplaces, although only accidental exposures are considered. Recently, awareness of preventing airborne contaminants in healthcare environments has increased since these workplaces have been designed to ensure patients' safety from airborne bio-contaminants. However, it is also essential to raise awareness regarding airborne metals. Preventive measures are mainly focused on the accidental exposure of damaged healthcare equipment containing hazardous metals but don’t include routine healthcare procedures that can generate airborne metals. An overview of common airborne metals in healthcare workplaces helps stimulate discussion regarding the need for preventive measures against these contaminants. To provide basic knowledge, the properties of each metal and the health effects caused by occupational exposure are presented. Lead is a bluish-gray metal and is considered hazardous and toxic to health when ingested or inhaled. Determining the sources of exposure to lead from dust particles found in the environment can help promote educational programs to prevent exposure to lead from dust. The toxicity of lead is primarily due to its interference with calcium transport pathways. Manganese is a silvery metal used in several industries, such as steel and battery manufacturing. An increase in worldwide battery usage in smartphones, tablets, and electric vehicles can lead to higher manganese exposure among workers. Manganese oxide exposure has been linked to respiratory symptoms such as cough and wheezing. Exposure to manganese can cross the blood-brain barrier and result in altered neurotransmission and neurotoxicity. Cadmium is a soft, malleable, silvery-white metal that is commonly used in industrial applications such as batteries, pigments, coatings, and electroplating. The main route of exposure to cadmium is inhalation and/or ingestion. Hazardous health effects due to cadmium include irritation of the respiratory tract, lung edemas, emphysema, and proteinuria. The emergence of new and innovative healthcare technologies may introduce new contaminants into healthcare settings. (Emami et al., 2024)(Mohankumar et al.2024)(Burnase et al.2022)(Fadeev et al.2024)(Abdulaziz et al.2022)(Maring et al.2023)(Kodali et al., 2024)

3.1. Lead

Lead is one of the most common airborne metals encountered by health workers. On account of its damaging effects on human health, it is classified as an undesirable metal by the World Health Organization. Due to an inability of the atmosphere to dissipate its presence, it has risen to prominence as a hazardous air pollutant. Moreover, it figures amongst the top contaminants posing threats to humans (Faith Motaung, 2021). The risk of exposure to lead in the hospital environment mainly comes from the medical instruments employed for diagnosis and treatment of patients. Additionally, older hospitals may also have lead paint or plumbing which could pose a risk. Other significant sources of lead exposure include clinical activities involving blood sampling, acetic acid, pharmaceuticals preparation, fluoroscopy, etc. Exposure to lead can cause a plethora of health impairments, some asymptomatic and others critically symptomatic. Lead is a potent neurotoxin. It induces apoptosis in neurons by augmenting the accumulation of intracellular calcium ions and oxidative stress. Chronic exposure in adults can lead to diminished neurocognitive functions, seizures, peripheral neuropathy, weakness, and abnormalities in electromyography and nerve conduction. The blood lead levels in nurses attending to lead poisoned children significantly exceeded the reference level. However, monitoring of airborne lead in the hospital atmosphere was absent. There are no studies ascertaining the risk of lead exposure to nursing staff although they are deliberately involved in blood collection activities and care of pediatric patients undergoing fluoroscopy. Keeping nursing responsibilities in view, it is vital to analyze the interaction of lead exposure with nursing duties.

The permissible exposure limit for lead is 50 μμg/m3 for an 8-hour work shift, which should not be exceeded. Effective engineering controls include lead-coated surfaces, routine cleaning of dust, wet mopping, exhaust ventilation systems, and enclosing leaded glass windows. Administrative controls include prohibition of lead-containing equipment in lunchrooms and dry methods of cleaning lead dust. Personal protective equipment includes surgical gowns, gloves, and masks. Admission of children with lead poisoning has been a routine in all hospitals involved in the study. A range of nursing duties involving blood collection, administering medications, and care during X-ray fluoroscopy help in exposure to airborne lead. By virtue of its higher density, airborne lead may primarily settle on the ground surface within 5 hours and up to 70% within 12 hours following solely an airborne mode of transportation. However, nursing duties involving transportation of the child between units may enhance exposure risks and therefore protective measures against airborne lead in nursing work environments are crucial. (Namungu et al.2021)(Weaver et al., 2024)(Simon et al., 2024)(Li et al., 2024)(Rana, 2023)(Guth et al.2022)(Read et al., 2022)

3.2. Mercury

Mercury represents another type of airborne metal that can be found in the healthcare setting, especially in laboratories and clinical environments. Mercury is often used to make thermometers, sphygmomanometers, and various other devices. Despite the availability of various substitutes, mercury-containing devices are still in use, including in healthcare facilities neglecting the hazards of mercury (Xu et al., 2020). When mercury devices break or are mishandled, exposure incidents can occur. Mercury is notorious for its toxicity. Soluble organic mercury compounds, such as methyl mercury, are extremely toxic to the nervous system. Inorganic mercury mainly affects the kidneys (Decharat et al., 2014). Several epidemiological studies have reported mercury-related health issues in healthcare workers, including nurses.

Healthcare facilities are considered as one of the workplace environments for nurses that have significant exposures to mercury. Outreach assessments of mercury in the workplace setting have been conducted, focusing on the awareness and presence of mercury in facilities. Several regulations restrict or prohibit the use of mercury in healthcare. However, the regulations are not effectively enforced, and improper disposal and handling still occur. Therefore, prioritizing efforts towards education and awareness is essential for nursing staff

about the risks of mercury. Regarding the global burden of mercury, most countries already support the Minamata Convention on Mercury, focusing on its phase-out in various sectors. To effectively prevent exposure incidents and over-occupational risks to nurses, mercury hazardous activities and limits should be specified. (Palathoti et al.2022)(Cheuyem et al.2023)(Kim et al.2021)(Tong et al.2021)(Teo et al.2021)(Kazapoe et al.2021)

3.3. Cadmium

Cadmium (Cd) is one of the pertinent airborne metals in health care exposure. Cadmium is found in the environment as the result of both natural and anthropogenic activities. Naturally, cadmium occurs as a mineral in association with zinc, lead, copper, gold, and silver ores and is released into the environment through weathering and volcanic activity (Matović et al., 2011). Anthropogenic sources include mining, nonferrous metals smelting, manufacture and disposal of nickel-cadmium batteries, pigments, and plastics as well as cigarette smoke. In health care settings, cadmium can be found in cleaning agents, medical equipment, and laboratory reagents. Acute cadmium exposure may occur from inhalation or ingestion, while chronic exposure may occur from contaminated food, air, soil, and smoking. Low-level chronic exposure from contaminated food is the most common route of cadmium exposure. Cadmium toxicity may affect almost every organ or system in the body, while the respiratory and renal systems are most affected. Cadmium is classified as a group 1 carcinogen by the International Agency for Research on Cancer (IARC) and the US Environmental Protection Agency (EPA). Even though cadmium does not have recognized occupational exposure limits in some countries, guidelines can be found for several health care settings. In facilities where cadmium is handled, health care workers should be trained and personal protective equipment (PPE) should be correctly used and maintained. Health care settings where nurses have potential exposure to cadmium include cleaning agents, equipment, and clinical settings such as pathology, cytology, histology, and autopsies. Research has found a correlation between health care workers´ exposure to cadmium and health effects. For this reason, it is important to raise awareness among nurses about this occupational hazard and provide guidance on safe handling. (Charkiewicz et al.2023)(Tarhonska et al.2022)(Satir, 2022)(Annar, 2022)(Cui et al.2021)(López-Lázaro, 2022)

4. Health Effects of Airborne Metal Exposure on Nurses

Airborne metal exposure refers to the inhalation or dermal contact with metals that are present in the air, usually in the form of fine particles that result from occupational processes. It can impact nurses' health both physically and psychologically, affecting them in several ways. Health effects are determined by the exposure levels, routes, and durations. Generally, the high exposed group tends to have worse health effects from airborne metals than the low exposed group (Johannes van den Heever, 1996). Respiratory effects from airborne metal exposures have been mostly studied in foundry and welding workers. Chronic cough, chronic bronchitis, and chronic obstructive pulmonary disease (COPD) were found to be associated with exposure to airborne metals. Manganese and chromium were found to increase the risk of respiratory symptoms and lower respiratory tract illness. While studies have mostly considered only one metal or a close group of metals, nurses are exposed to various metals through the air from different occupational processes. There are concerns about the health effects of exposure to several airborne metals commonly encountered in the nursing profession. Nursing is a profession that often involves taking care of patients undergoing invasive procedures such as angiography, stenting, fluoroscopy, or radiation therapy. These involve a range of processes that generate airborne metals, and the resultant exposure may lead to possible health effects (Palacios et al., 2014). Moreover, many nursing procedures encounter or generate airborne metals outside the hospital, such as in metal machining, welding, painting, or grinding. Many of these airborne metal encounters may be overlooked. Long-term exposure to airborne metals can bring about various health effects on nurses. Health effects of common airborne metals

found in the nursing environment are explored, focusing on health outcomes with empirical studies. Excessive exposure to airborne metals may result in respiratory effects, neurological effects, and various other health effects. Early detection and intervention of the exposure and health effects could prevent the possibilities of the adverse health outcomes. The most studied metals have been manganese, nickel, lead, and chromium among nurses' health effects from exposure to airborne metals. There are also disparities in health outcomes based on exposure levels, sex, age, and other factors. Even though health effects may be evident from one or a few studies on a metal, there may be many other possible health effects that are unobserved. Hence, the need for further research on that metal is warranted. There have been many studies on health effects from exposure to a particular airborne metal. However, studies addressing multiple metals are sparse, with most studies focusing on major health effects on one or few exposed groups. Nurses' health has been the least studied in this regard, though studies have indicated that they are exposed to several airborne metals. Therefore, a comprehensive summary of health effects from exposure to various airborne metals is presented, specifically concerning nurses and their occupation. It aims to indicate what is known and unknown regarding the health effects of exposure to airborne metals concerning nurses and highlight the need for monitoring nurses' health actively. (Cocârţă et al.2021)(Bonanni & Newman, 2024)(Baig et al.2024)(Danahy et al.2023)

4.1. Respiratory System Effects

Health complications as a result of airborne metal exposure typically target the respiratory system first. Metals can impact lung function through either direct or indirect exposure during inhalation. Applicable direct exposure scenarios for nurses include triage, resuscitation, and rendering care to patients with extensive burns involving metal exposure. Common symptoms associated with metal exposure to the respiratory system include shortness of breath, chest tightness, wheezing, dry cough, and the development of chronic bronchitis or asthma (Rahimimoghadam et al., 2022). Allergic responses from metal exposure may result in the development of hypersensitive reactions within the bronchial tubes of the respiratory tract and are associated with an atopic family or personal history, as well as high IgE reactivity to the metalloallergens. These chronic symptoms reduce lung capacity in the long term, even if exposure ceases. A review of the epidemiological data revealed a connection between occupational exposure to scenario metals and respiratory complications. The risk factors affecting the severity of health complications were the duration of exposure and concentration of the metal. Therefore, applying exposure monitoring alongside health surveillance programs is key to interpreting the spirometry results and better protecting nursing staff.

Nurses often encounter airborne metal exposure due to the nature of their profession, necessitating mitigation measures such as protective equipment and ensuring a safe care environment for patients. Nurses are also exposed to airborne metals through other emerging exposure scenarios like electronic waste disposal or metal-containing consumer products. These stressors, coupled with the persistent COVID-19 pandemic, have exacerbated nurses' mental health burdens. Investigating the health effects of airborne metal exposure would assist in drafting clinical intervention recommendations and action plans to manage nurses' health concerns. (Cocârţă et al.2021)(Vlahovich & Sood, 2021)(Japundžić et al.2023)(Srinivas & Sethy, 2023)

4.2. Neurological Effects

Airborne metals pose significant health risks for nurses as the middle-aged population composed most health care workers. Metal compounds are common in many occupations and widely affect the nervous system. Soluble metals, such as mercury and lead, are known to disrupt nervous system functioning, causing symptoms from cognitive decline to neuropathy. Several studies noted an array of neurodegenerative diseases occurring among individuals exposed to metals at occupational levels: high exposure to manganese links to parkinsonism; chronic welding fume exposure led to a Parkinson's disease-like syndrome; and lead-exposed

nurses presented with postmortem histopathological findings of Alzheimer's disease, demonstrating a complicated link between occupational hazard exposure and brain illnesses (A. Potter et al., 2021). Synthetic fumes containing manganese significantly linked Parkinson's symptoms in a dose-dependent manner and were exacerbated by age and prior risk factors. Similarly, a case series of five neurolithiasis patients inferred metallic dust exposure as a risk factor for this rare condition. However, confounding factors like age, gender, comorbidities, and genetic history complicate the determination of sole metal exposure as the cause of neurological disorders. Chronic emotional stress is also linked to Alzheimer's disease progression; thus, mental and emotional health issues from chronic exposure may impact general health.

Health care workers are routinely exposed to metals such as sodium, lithium, lead, and copper in their workplace. Exposure levels incurred for each metal differed by job title; nurses recorded the highest exposure to sodium, lithium, and copper. As dementia or cognitive decline-related risk factors are often overlooked in the younger population, educated nurses aged < 30 were significantly more affected than older nurses or those with fewer years of service. To provide a clear perspective of the research, occupational nephrotoxicity of globally used metals was briefly discussed, emphasizing the complexity behind defining exposure as the cause of a particular disorder. In addition, readily misunderstood concepts regarding the susceptibility of pre-existing conditions were defined as risk factors, providing a more detailed viewpoint into the studied population. As whole breath was collected for metal analysis, limitations in attributing exposure levels might arise. Nonetheless, emotional stress and other mental disabilities involved in chronic exposure are discussed, as they could holistically affect general health. Routine health assessments focusing on neurological health are imperative workplace safety, monitoring for early signs of impairment and ensuring nurses receive necessary support. To maintain nurses' mental well-being, the workplace should regularly provide education on the importance of monitoring emotional health and preventative measures. (Ahmed et al.2023)(Erdem, 2024)(Flores-Guadarrama et al.2023)(Pacheco et al.2024)(Bharatiya et al.2024)(Malamba-Lez et al.2021)(Chen et al.2021)

5. Preventive Measures and Interventions

To protect nurses from exposure to airborne metals in clinical settings, a variety of preventive measures and interventions can be promoted. Following on from the study's findings and suggestions on best practices for prevention, it is advised that workplace safety protocols be developed for each of the metal hazards discussed. At a minimum, this should include a comprehensive risk assessment, regular monitoring of airborne metals in the clinical environment, exposure frequency and length assessment for nurses, and raising awareness of these potential dangers among nurses. Continue to use snowball sampling to encourage nurses to fill out questionnaires, and personally consult with nursing directors after they have read the reports on air metal exposure risks in their departments . This study highlights the important role of institutional policies in ensuring that workplace safety regulations regarding metal exposure are enforced and actively promoting a culture of health awareness in organizations.

To this end, the study recommends that actions be taken to publicize the results of this analysis of exposure risks to nurse supervisors and managers, as well as the relevant administrative officials in each healthcare facility. Consideration should be given to integrating preventive education about air metal exposure hazards into nursing training programs. Nurses should be equipped with a basic understanding of how to monitor, analyze, and mitigate potential exposure risks. In addition, healthcare facilities should consider adopting innovative technologies and regularly updating practices already in place that can help reduce healthcare-related metal exposure risks, such as the use of non-titanium or metal-free devices. Finally, to ensure that any intervention strategies are effective, it is crucial to promote collaboration among

healthcare professionals in the relevant departments to address the issues highlighted in their own healthcare facilities. (Lulli et al.2022)(Albaqawi et al.2021)(Tang et al., 2021)(Iruretagoyena et al.2021)(El-Sokkary et al.2021)(Llop-Gironés et al.2021)

5.1. Personal Protective Equipment (PPE)

Personal protective equipment (PPE) is one of the primary preventive strategies to mitigate the risk of airborne metal exposure among nurses working in environments with potential exposure to metals, such as dental clinics and hospitals. PPE includes gear designed to safeguard the wearer from hazardous substances or conditions that could compromise health and safety. Healthcare workers, including nurses, are advised to utilize PPE such as gloves, masks, and goggles to protect their skin and respiratory systems from metal exposure.

The importance of PPE in preventing airborne metal exposure has been demonstrated in various studies. Research shows that respiratory protective equipment is key to reducing occupational exposure to airborne metals. This is particularly relevant for nurses, who are at risk of exposure to metals when cleaning or sterilizing dental instruments following procedures performed on patients with metal-containing restorations. PPE also plays a crucial role in protecting healthcare personnel from exposure to cytotoxic drugs when handling contaminated materials.

However, while PPE is vital, its use in hospitals or clinics tends to be suboptimal. In dental clinics, adherence to PPE protocols was found to be low among supporting staff. Similarly, many nurses do not use PPE, such as masks and gloves, when handling contaminated materials, despite awareness of the need. Factors affecting PPE use include knowledge, attitudinal aspects, environmental and procedural factors, and the availability of PPE. Addressing these issues is crucial to ensuring the proper use of PPE, as it is a simple, low-cost method to significantly reduce airborne metal exposure. (Moura et al.2021)(Kang et al.2021)(Asefa et al.2021)(Lee et al.2021)(Curryer et al.2021)(Adesina et al.2022)(Pirot et al.2024)

6. Conclusion:

In conclusion, the exposure of nurses to airborne metals within healthcare settings is a significant yet often under-recognized occupational hazard. Despite the growing body of evidence linking airborne metal exposure to various health issues, especially respiratory and neurological disorders, there remains a notable gap in research that specifically addresses the risks to nurses. This comprehensive review has highlighted key sources of airborne metals, including medical devices and patient treatments, that contribute to these exposures. Additionally, the review emphasizes the need for better monitoring and preventive measures to protect nurses, the most vulnerable group in healthcare environments, from these harmful exposures. Effective preventive strategies, such as the implementation of personal protective equipment (PPE), regular air quality monitoring, and the adoption of safer medical technologies, are essential to safeguard nurse health and ensure the quality of care provided to patients.

7. Recommendations:

1. Enhanced Air Quality Monitoring: Healthcare institutions should implement regular air quality assessments to detect airborne metal concentrations and identify areas of high exposure. This data will be crucial in understanding exposure patterns and managing risks effectively.
2. Education and Training: Nurses should receive specialized training regarding the risks associated with airborne metal exposure and the use of personal protective equipment

(PPE). Awareness programs can empower healthcare workers to take proactive steps in protecting themselves from harmful exposure.

3. Adoption of Safer Technologies: Healthcare facilities should prioritize the use of medical equipment and materials that minimize the release of airborne metals. Innovation in metal-free or less hazardous technologies should be encouraged to reduce occupational exposure risks.
4. Policy Development and Implementation: Clear guidelines and safety protocols should be established to address airborne metal exposure in healthcare settings. Regulatory bodies should work with healthcare institutions to enforce safety standards and ensure consistent implementation of protective measures.
5. Further Research: There is an urgent need for more focused research on the specific impacts of airborne metal exposure on nurses, particularly with respect to long-term health outcomes. Studies should aim to identify thresholds of exposure and explore the cumulative effects of various metals in occupational environments.

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