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EFFECT OF AIR POLLUTION ON THE RESPIRATORY SYSTEM: A REVIEW

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Abstract: Air pollution, composed of particulate matter (PM) and gases such as ozone (O3) and nitrogen oxides, significantly impacts the respiratory system. High concentrations of oxidants and pro-oxidants in these pollutants cause the formation of free radicals, inducing oxidative stress in the airways. This triggers an inflammatory response that releases inflammatory cells and mediators (cytokines, chemokines, adhesion molecules) into the systemic circulation, resulting in subclinical inflammation with systemic effects. The effects of pollutants can be acute, manifesting within hours or days after exposure, or chronic, observed over years or decades. Groups more susceptible to the effects of pollution include children, the elderly, and people with pre-existing respiratory problems.
Keywords: Air pollution, Particulate matter (PM), Ozone (O3), Nitrogen oxides (NOx), Acute effects, Chronic effects.

INTRODUCTION

Air quality has a significant impact on public health, particularly with regard to the respiratory system. In the early 20th century, air pollution was not widely recognized as a public health problem, but industrial growth and increased vehicle traffic have brought the adverse effects of this pollution to light. The main air pollutants include particulate matter (PM), nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO) and sulfur dioxide (SO2). These pollutants are emitted by a variety of sources, such as industries, motor vehicles, thermoelectric plants, biomass and fossil fuel combustion, as well as natural sources such as volcanic eruptions and forest fires.

Air pollutants can be classified as primary, which are emitted directly into the atmosphere, and secondary, which are formed by chemical reactions between primary

pollutants. An example of a secondary pollutant is ozone (O3), which is formed from photochemical reactions between VOCs and NO2 in the presence of sunlight. Particulate matter, especially in the forms PM10, PM2.5 and PM0.1, is particularly harmful due to its ability to penetrate deep into the respiratory system, varying in chemical composition and size depending on the emission source and the place of production.

Several mechanisms explain how air pollutants affect the respiratory system. The main hypothesis is that high concentrations of oxidants and pro-oxidants in pollutants induce the formation of free radicals, causing oxidative stress in the airways. This triggers an inflammatory response, releasing inflammatory cells and mediators that can reach the systemic circulation and cause subclinical inflammation, affecting not only the respiratory system but also other systems in the body.

The health effects of pollutants can be acute, manifesting within a short period after exposure, or chronic, observed over years or decades. Epidemiological studies have shown that even pollutant levels below legal limits can cause adverse health effects. Susceptible population groups include children, the elderly and people with pre-existing respiratory problems, who are particularly vulnerable to increases in air pollution levels.

This introduction highlights the importance of understanding the effects of air pollution on the respiratory system, exploring the sources of pollution, the mechanisms of action of pollutants and the most vulnerable groups, underlining the continued relevance of research in this area for public health and the formulation of effective environmental policies.

METHODOLOGY

To conduct this review on the effects of air pollution on the respiratory system, strict search and selection criteria were established. The objective was to synthesize and evaluate the existing evidence on the impacts of air pollution on respiratory health, addressing both acute and chronic effects and the pathological mechanisms involved.

Searches were conducted in the electronic databases PubMed, Scopus, Web of Science and Google Scholar, using terms such as "air pollution", "respiratory effect", "respiratory diseases" and "pathological mechanisms". Studies published in English and Portuguese that addressed the relationship between air pollution and the respiratory system were included, including original articles and systematic reviews. Studies outside the scope were excluded, such as those that did not specifically focus on air pollution and its respiratory effects, and articles with limited access or insufficient data. Relevant data were extracted and organized, covering methodology, study population, types of pollution evaluated, respiratory effects and pathological mechanisms described. Data analysis was qualitative, identifying common patterns, discrepancies and gaps in the existing literature. The synthesis of evidence was presented in a narrative form, highlighting the main findings and their implications for public health.

RESULTS AND DISCUSSIONS

ANATOMY

The human respiratory system is responsible for the exchange of oxygen and carbon dioxide between the body and the external environment. It is composed of a series of organs and structures that allow for proper breathing: The Upper Airway, composed of the Nose and Nasal Cavities, which filter, moisten and warm the inhaled air; and the Pharynx: Connects the upper airway to the lower airway and the esophagus. The Lower Airway: composed of the Larynx: Contains the vocal cords and is responsible for producing sound during speech; the Trachea: Cartilaginous tube that carries air from the larynx to the lungs; the Bronchi: Branches of the trachea that divide into the lungs; the Bronchioles: Smaller branches of the bronchi that carry air to the alveoli; and the Lungs: which have the Alveoli: Small air sacs in the lungs where gas exchange occurs (oxygen enters, carbon dioxide leaves); and the Pleura: Membrane that surrounds the lungs and helps with lubrication and movement during breathing. In addition, the Diaphragm and Respiratory Muscles participate: Diaphragm: Dome-shaped muscle below the lungs that contracts during inspiration and relaxes during expiration. And the Intercostal Muscles: Located between the ribs, they help to expand and contract the rib cage during breathing.

This system is essential not only for breathing, but also plays important roles in regulating blood pH and protecting against infectious agents and particles present in the inhaled air (MARIEB, 2018).

CONTEXTUALIZATION

At the beginning of the 20th century, the quality of the air needed for breathing was not an obvious concern (Russo, 2010). However, with the increasing number of vehicles in circulation and the increase in industrial activities, air pollution became a significant problem (Cesar et al., 2013). This pollution can also originate from natural sources, such as the accidental burning of biomass (material derived from plants or animals) and volcanic eruptions (Cançado et al., 2006; Gonçalves et al., 2010).

New sources of pollutants gained strength with the Industrial Revolution, including the burning of fossil fuels by engines, combustion, and the expansion of the steel industry, all without adequate monitoring of the possible damage that these pollutants could cause to human health (Coelho, 2007; Mario, 2012). These events prompted studies in the field of Epidemiology, with the aim of analyzing the effects of air pollutants on health (Martins et al., 2001; Cançado et al., 2006). Thus, systematic and scientific investigation of air pollution began only in the 20th century, motivated by a series of environmental accidents that resulted in a significant increase in mortality rates (GOMES et al., 2020).

Studies on air pollution and its effects on the health of the population show that, even when pollutants are below the levels determined by legislation, they are still capable of causing negative effects on people's health (Martins et al., 2002).

In addition to the impacts on health, air pollution also generates negative effects from an economic and social perspective. Examples include the decline in agricultural productivity, the increase in health system costs and the greater vulnerability of poor populations (Institute of Energy and Environment, 2014).

Pollutants can affect not only communities near emission sources, but also travel thousands of kilometers through the atmosphere, reaching distant locations (Leite et al., 2011).

Air quality in urban areas, such as São Paulo, is monitored by the Environmental Company of the State of São Paulo (Cetesb), focusing on pollutants such as particulate matter, sulfur dioxide, carbon monoxide, ozone, volatile organic compounds, and nitrogen oxides, due to their adverse health impacts (DAPPER et al., 2019). These pollutants are directly associated with the increase in respiratory diseases, such as asthma and chronic lung diseases, especially in children and the elderly (DAPPER et al., 2019).

Ozone, formed by photochemical reactions in the atmosphere, represents a significant control challenge due to its seasonal peaks during periods of heat and high solar radiation (DAPPER et al., 2019). Chronic exposure to these pollutants can lead to more frequent hospital admissions and serious adverse effects on the cardiovascular and nervous systems. (DAPPER et al., 2019).

SUSCEPTIBLE GROUPS

Among the age groups most affected by the effects of air pollution are children and the elderly. People who already suffer from respiratory problems also become more susceptible to suffering from the increase in air pollutant levels (Martins et al., 2001;).

1 Children: They are highly susceptible due to greater ventilation and physical activity, in addition to their still developing immune system, increasing the risk of respiratory infections and airway obstructions (GONÇALVES et al., 2021).

2 Elderly people: They have a less efficient immune system and decline in lung function, which can lead to respiratory problems and physical limitations (GONÇALVES et al., 2021).

3 People with chronic diseases: These include individuals with pre-existing respiratory and cardiovascular conditions, such as asthma and chronic obstructive pulmonary disease (COPD), who are particularly vulnerable to the exacerbated effects of air pollution (GONÇALVES et al., 2021).

4 Genetic susceptibility: Polymorphisms in genes that encode antioxidant enzymes in lung tissue, such as GSTM1 and GSTP1, may increase susceptibility to the inflammatory and oxidative effects of air pollutants (GONÇALVES et al., 2021).

5 Pregnant women: Exposure to air pollution during pregnancy is associated with complications such as fetal growth retardation, prematurity, and low birth weight, potentially due to the impact on the mother's respiratory and cardiovascular systems, affecting the transport of oxygen and nutrients to the fetus (GONÇALVES et al., 2021).

AIR POLLUTION: SOURCES, SITE OF ACTION AND PATHOPHYSIOLOGY

SOURCES/POLLUTANTS

Particulate Matter

Particulate matter (PM) is a mixture of liquid and solid particles suspended in the air, with composition and size varying according to the emission sources (BRAGA et al., 1999). Particles can be divided into two main groups:

Large Particles: With a diameter between 2.5 and 30 μm, originating from uncontrolled combustion and dispersion of materials from the Earth's crust, containing elements such as silicon, titanium and aluminum, as well as pollen and spores (BRAGA et al., 1999).

Small Particles: With a diameter smaller than 2.5 μm, derived from the combustion of vehicles and industries, presenting greater

acidity and being able to reach the lower parts of the respiratory tract. Their main components include carbon, lead and oxides of sulfur and nitrogen (BRAGA et al., 1999).

The EPA (US Environmental Protection Agency) has determined the control of inhalable particles smaller than or equal to 10 μm (PM_{10}) due to the ability of these particles to reach the lower respiratory tract. They also transport adsorbed gases to distal regions of the respiratory tract, where gas exchange occurs (BRAGA et al., 1999). The effects of pollutants on the respiratory system are widely documented in epidemiological studies, which show a higher incidence of respiratory symptoms due to exposure to gaseous pollutants and particulate matter (PM). In the upper airways, this exposure is associated with symptoms such as rhinorrhea, nasal obstruction, cough, laryngospasm, and vocal cord dysfunction. In the lower airways, there is an increase in symptoms such as cough, dyspnea, and wheezing, especially in children (GONÇALVES et al., 2021). In adults, exposure to pollutants increases the occurrence of coughing and wheezing, both in individuals with chronic lung diseases and in healthy individuals (GONÇALVES et al., 2021).

In addition, lung function, which is an important marker of the effects of air pollution, predicts cardiorespiratory morbidity and mortality objectively and early. Epidemiological and toxicological studies also demonstrate a strong association between air pollution and bronchial asthma, with pollutants related to increased visits to emergency services, hospitalizations for acute asthma attacks, expiratory wheezing, respiratory symptoms, and use of rescue medication (GONÇALVES et al., 2021).

The main substances identified and measured by the local environmental agency (CETESB - Environmental Sanitation Technology Company) include sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide and carbon dioxide (CO and CO_2), ozone (O_3), lead (Pb) and total suspended particles (TSP), the particles being inhalable ≤ 10 μm (PM_{10}) the most worrying (GOMES et al., 2020). Measuring and recording pollutant concentrations are extremely important components of environmental epidemiological research, but discontinuous measurements due to equipment malfunction are the most frequent problem affecting the quality of the database (GOMES et al., 2020).

Ozone (O_3)

Ozone in the troposphere is formed by reactions catalyzed by sunlight (ultraviolet rays) involving nitrogen oxides (NO_x) and hydrocarbons, derived from mobile combustion sources (such as automotive vehicles) and stationary sources (such as thermal power plants), as well as natural sources (such as trees). Ozone levels increase significantly between late spring and early fall in peripheral regions of large urban centers, peaking in the afternoon and decreasing at night. In indoor environments, air purifiers and photocopying machines can be sources of ozone. Ozone is a potent and cytotoxic oxidant, capable of causing damage to the most distal parts of the respiratory tract (BRAGA et al., 1999).

Sulfur Dioxide (SO_2)

The SO_2 and acidic aerosols result from the combustion of fossil fuels such as coal and oil. After being released into the atmosphere, SO_2 is oxidized to form sulfuric acid (H_2SO_4). Its transformation depends on several factors, such as time spent in the air and atmospheric conditions. The SO_2 is highly soluble in water and most of the SO_2 inhaled is absorbed in the upper airways. During physical activity, absorption may occur in the more distal

regions of the lungs. Common acidic aerosols include sulfate (SO_4^{2-}) e bissulfato (HSO_4^-), sulfuric acid being one of the most irritating acidic aerosols for the respiratory tract (BRAGA et al., 1999).

Carbon monoxide (CO)

CO is emitted mainly by automobiles and can impact those who spend several hours in traffic, as well as indoor environments such as homes and offices. CO has an affinity for hemoglobin 240 times greater than oxygen, reducing the blood's ability to transport oxygen and causing a shift in the hemoglobin dissociation curve to the left, decreasing the release of oxygen into the tissues (BRAGA et al., 1999).

Nitrogen Oxides (NO_x)

The main emitters of NO_x, including nitric oxide (NO) and nitrogen dioxide (NO_2), are car engines and thermal power plants. During combustion, oxygen reacts with nitrogen to form: NO and NO_2. O NO_2 reacts with hydrocarbons and oxygen under sunlight to form ozone (O_3). The concentrations of NO_2 in indoor environments are strongly related to external concentrations and can have several internal sources, such as gas stoves and cigarettes (BRAGA et al., 1999).

Furthermore, polluted air is a mixture of particles (particulate matter - PM) and gases, emitted mainly by industries, automotive vehicles, thermoelectric plants, biomass burning and fossil fuels. Pollutants can be classified as primary and secondary. Primary pollutants are emitted directly into the atmosphere, while secondary pollutants result from chemical reactions between primary pollutants (GONÇALVES et al., 2021).

The main primary pollutants monitored in Brazil and by environmental agencies around the world include nitrogen oxides (NO_2 or NO_x), volatile organic compounds (VOCs), carbon monoxide (CO) and sulfur dioxide (SO_2). An example of a secondary pollutant is ozone. (O_3), formed by the chemical reaction induced by the photochemical oxidation of VOCs and NO_2 in the presence of ultraviolet rays from sunlight (GONÇALVES et al., 2021).

The PM is the most studied pollutant, and can have primary or secondary origin. PM varies in number, size, shape, surface area and chemical composition, depending on the location of its production and the emission source. The deleterious effects of PM on human health depend on its chemical composition and size. PM is composed of multiple chemical constituents, including an elemental or organic carbon nucleus, inorganic compounds (sulfates and nitrates), transition metals (oxides), soluble salts, organic compounds (polycyclic aromatic hydrocarbons) and biological material (pollen, bacteria, spores and animal remains). PM is classified according to its size into total suspended particles (up to 30 μm in diameter), inhalable particles (diameter less than 10 μm - MP_{10}), fine particles (diameter less than 2,5 μm - $MP_{2,5}$) and ultrafine particles (diameter less than 10 nm - $MP_{0,1}$) (GONÇALVES et al., 2021).

SITE OF ACTION AND PATHOPHYSIOLOGY

Air pollution is a serious global public health problem, affecting not only vulnerable individuals, such as children and the elderly, but also the general population. Epidemiological studies show that acute and chronic exposure to air pollutants is directly related to a higher incidence of acute respiratory diseases, such as bronchitis and pneumonia. This is especially true in urban environments, where the concentration of fine particles ($MP_{2,5}$) and bigger (MP_{10}) from sources such as fossil fuel and industrial combustion is high, the adverse health effects are alarming (GONÇALVES et al., 2021).

In addition to respiratory diseases, air pollution is also a significant factor in the development of lung cancer. Studies show that prolonged exposure to pollutants increases the risk of this disease, both in smokers and non-smokers. This is due to the presence of carcinogenic substances in pollutants, which can cause DNA damage and promote the formation of tumors over time.

The chronic inflammation induced by constant exposure to these pollutants also plays a crucial role in this process (GONÇALVES et al., 2021).

Several mechanisms explain the adverse effects of air pollutants. The most consistent explanation is that high concentrations of oxidants and pro-oxidants in environmental pollutants, such as PM of various sizes and compositions, as well as gases such as O_3 and nitrogen oxides, in contact with the respiratory epithelium, cause the formation of oxygen and nitrogen free radicals. This induces oxidative stress in the airways, initiating an inflammatory response with the release of inflammatory cells and mediators (cytokines, chemokines and adhesion molecules) that reach the systemic circulation, leading to subclinical inflammation with repercussions not only in the respiratory system, but also causing systemic effects (GONÇALVES et al., 2021).

Particles deposited in the respiratory tract are removed by mechanisms such as sneezing and coughing. When they reach the surface of the cells in the respiratory tract, the mucociliary apparatus removes the particles by pushing them towards the mouth. Particles that reach more distal regions are phagocytosed by alveolar macrophages and removed by the mucociliary apparatus or lymphatic system (BRAGA et al., 1999).

The effects of pollutants on health can be acute or chronic. Acute effects manifest themselves shortly after exposure (hours or days). Chronic effects are generally evaluated in longitudinal studies lasting years or decades (GONÇALVES et al., 2021). The most vulnerable populations include children, the elderly, and those with respiratory diseases. Inhalable particulate matter, with dimensions smaller than 10 μm and 2.5 μm, is often associated with health damage. Studies indicate that air quality standards are inadequate to protect the most susceptible population and that mortality from cardiovascular diseases is also related to air pollution (BRAGA et al., 1999).

Several studies in different countries have investigated the effects of acute and chronic exposure to air pollution. Regarding acute exposure, in Athens, Greece, a 10 μg/m^3 increase in MP_{10} and SO_2 levels led to a significant increase in asthma-related hospitalizations in children. In Denmark, increased concentrations of NOx, NO_2, MP_{10} and $MP_{2,5}$ resulted in more hospitalizations for asthma in children and adolescents. In Brazil, in Araraquara, the burning of sugarcane straw increased pollutant levels and hospital admissions for asthma. During the Atlanta and Beijing Olympic Games, measures to reduce pollution resulted in a significant drop in asthma-related hospitalizations (GONÇALVES et al., 2021). Regarding the effects associated with chronic exposure, a study in California, USA, followed 3,535 schoolchildren for five years and found a higher risk of developing asthma in communities with high ozone concentrations. In the Netherlands, high levels of $PM_{2,5}$ were associated with a significant increase in the incidence, prevalence, and symptoms of asthma in children. In Munich, Germany, children who lived near heavily trafficked roads had a higher incidence of asthma up to the age of four and six. In Switzerland, non-smoking adults who lived in more polluted areas had a higher risk of developing asthma

(GONÇALVES et al., 2021). Thus, studies carried out in different parts of the world clearly and consistently demonstrate that both acute and chronic exposure to air pollution has significant adverse effects on respiratory health, especially in children and vulnerable adults (GONÇALVES et al., 2021).

Air pollution is associated with significant increases in cardiopulmonary mortality. Robust studies indicate that even small increases in $PM_{2,5}$ concentrations are associated with increased mortality rates, especially among the elderly and children. These groups are particularly vulnerable due to their more sensitive physiology and greater susceptibility to cardiovascular and respiratory diseases (GONÇALVES et al., 2021).

Exercising in polluted environments also poses an additional health challenge. During physical activity, increased pulmonary ventilation exposes individuals to a greater amount of pollutants, which can compromise both immediate lung function and vascularization. This is especially concerning for people with pre-existing conditions, such as asthma and chronic obstructive pulmonary disease (COPD), who may experience worsening symptoms and a higher risk of complications related to exposure to these pollutants (GONÇALVES et al., 2021)

CONCLUSION

In conclusion, the effects of air pollution on the respiratory system are widely documented and cause concern, especially in urban environments where exposure to pollutants such as particulate matter, ozone, nitrogen dioxide, and others is frequent. Epidemiological studies have consistently demonstrated associations between these pollutants and increased incidence of respiratory diseases such as asthma, chronic bronchitis, and acute respiratory infections. In addition, vulnerable groups such as children, the elderly, and people with pre-existing conditions are particularly affected, resulting in higher morbidity and mortality related to respiratory problems. Therefore, urgent measures to reduce pollutant emissions and improve air quality are essential to protect public health and mitigate adverse impacts on the respiratory system of the population.

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