



The Effects of Air Pollution on the Cornea

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ABSTRACT :

The consequences of air pollution, a widespread worldwide problem, on cardiovascular and ocular health—particularly the cornea—have been well-documented. The highly innervated cornea is exposed to environmental contaminants such as gases like CO and NO₂, particle matter (PM), and volatile organic compounds (VOCs). These toxins can cause inflammation and oxidative stress, which can result in diseases including corneal damage and dry eye syndrome. Due to prolonged exposure to sources such as the cooking process, construction materials, and tobacco, pollution in the indoor environment poses considerable risks and is frequently more concentrated than outdoor pollution. The initial line of defense in the eye, the precorneal tear film, is especially vulnerable to pollution-induced tear film instability, hyperosmolarity, and corneal surface damage.

Key Words: Particle matter (PM), Volatile organic compounds (VOCs), Nitrogen dioxide (NO₂), carbon monoxide (CO), carbon dioxide (CO₂), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), Deoxyribonucleic acid (DNA), Chronic obstructive pulmonary disease (COPD), sick building syndrome (SBS),

Introduction to Air Pollution and Corneal Health :

Air pollution a growing global issue, with outdoor pollution being a major concern indoor pollution in high-income countries and in low-income ones¹ Many research has traditionally focused on the association between cardiopulmonary diseases air pollution and, but new studies suggest it also impacts the reproductive, neurological systems, and the eyes^{2,3}. Air pollution consists of and harmful gases and particulate matter (PM) with different sizes affecting specific organs. For example, PM₂ can reach the circulatory system, impacting both the pulmonary and cardiovascular systems, while PM₁₀ is mostly restricted to the lungs. The composition of PM can be organic (bioaerosols) or inorganic (dust, metals), and gases like CO, NO₂, also contribute to pollution^{4,5}. Both indoor and outdoor environments are interconnected, with pollutants moving between them. The ocular surface is constantly exposed towards environment, is particularly vulnerable to air pollution, leading to dry eye symptoms. Understanding the specific effects of different pollutants is crucial for developing targeted interventions, especially for indoor air quality, which is often modifiable. A dangerous mixture of particles and gaseous contaminants that are thrown into the atmosphere by both human activity and natural processes is known as air pollution. The combustion of fuel and activities in industries are the common sources of common atmospheric pollutants, like sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon dioxide (CO₂), nitrogen monoxide (NO), carbon monoxide (CO), and particulate matter (PM) with diameters of 2.5 μm (PM_{2.5}) and 10 μm (PM₁₀). In addition to emissions from industry and transportation, routine activities like cooking, remodeling, and smoking can produce volatile organic compounds (VOCs), carbon oxides (COx), and nitrogen oxides (NOx). For example, formaldehyde, a volatile organic compound (VOC), has been demonstrated to harm DNA in animal cells, and over the past thirty years, several studies have well-documented its carcinogenic potential⁶.

A hazardous mix of gaseous pollutants, particles through both natural processes and human activities are released into the atmosphere. Primarily resulting from fuel combustion and industrial activities. Besides emissions from transportation and industry, everyday activities such as smoking, home renovations, and cooking also generate carbon oxides (COx), nitrogen oxides (NOx), and volatile organic compounds (VOCs). For instance, formaldehyde, a VOC, has been a cause DNA damage in animal cells, and its carcinogenic potential is well-documented in numerous studies over the past thirty years. The main goal of this review is to explore how air pollution and weather affect dry eye symptoms and to determine how the severity of these effects varies with different pollutants.

Anatomy and Function of the Cornea

Cornea is a transparent, avascular tissue that is an important component of the ocular refractive system. It is one of the most densely innervated tissues in the body. It consists of five layers: epithelium, stroma, and endothelium and two interface layers consisting of Bowman's membrane and Descemet's membrane. Corneal stroma is composed of cellular (keratocytes) and extracellular components. Cornea is an immune-privileged tissue due to the absence of blood and lymphatic vessels. Although normal cornea is an avascular, many conditions can cause neovascularization, scarring, and corneal blindness⁷ The diameter of the human cornea is 10.5 mm in the vertical direction and 11.5 mm in the horizontal direction.

Sources and Types of Air Pollutants

Indoor air quality is a critical issue, with humans spending nearly 90% of their time indoors, primarily in their homes. Indoor air is influenced by various factors, including human activities like cooking and cleaning, emissions from building materials, and chemicals in personal care products. It can be up to 10 times worse than outdoor pollution, poses significant health risks. Common pollutants include SVOCs, VOCs, pesticides, and particulates from biomass fuel combustion, especially in developing countries like India. Poor quality of indoor air is linked to serious health conditions such as pneumonia, stroke, heart disease, COPD, and lung cancer, contributing to millions of premature deaths annually, particularly among women and children⁸.

Outdoors

Traffic-related pollution is becoming more prevalent in cities. This pollution includes carbon monoxide (CO), nitrogen dioxide (NO₂), and particulate matter (PM).⁹

Mechanisms of Air Pollutant Entry into the Eye

Indoor air pollution stems from various sources, such as tobacco smoking, emissions from building materials, high-heat cooking, and burning coal or biomass for heating. These activities release volatile organic compounds (VOCs), including formaldehyde and acrolein, which can impact indoor air quality and contribute to health issues. VOCs, especially aldehydes, often have low odor thresholds, affecting perceived air quality and potentially leading to sensory symptoms, which can be influenced by personal factors like anxiety and health concerns.

High concentrations of indoor pollutants, such as carbon monoxide, can cause acute health effects like exacerbation of allergic symptoms or even death in extreme cases. Chronic exposure to these pollutants is linked to long-term health issues, including cancer, respiratory diseases, cardiovascular problems, and sick building syndrome (SBS) like conditions.

Indoor air pollutants also pose risks to eye health. Tobacco smoke can damage the ocular surface, leading to symptoms like itching, redness, and irritation. It can alter the tear film, reduce tear production, and cause inflammatory responses, contributing to disorders like dry eye syndrome and allergic conjunctivitis. Studies have shown that both tobacco smoke and other indoor pollutants, such as those from cook stoves, can cause significant eye irritation and damage. Research on indoor air pollution has revealed connections between these pollutants and various ocular diseases, demonstrating the harmful effects of exposure on eye health. The tear film, cornea, and conjunctiva form the ocular surface mucosa, which serves as the first defense against external hazards such as polluted air. Immunologically, the ocular surface is among the rare tissues with immune privilege, deprived of immune reactivity to the frequent exposure of foreign antigens, allergens, and pathogens, thereby maintaining immunological equilibrium and corneal transparency.¹⁰

Tear Film Barrier

For good vision, the precorneal tear film—the first surface to refract light entering the eye—is essential. It must create a smooth layer on top of the irregular corneal epithelium. According to studies and laser interferometry measurements, this tear film is a hydrated mucus gel that may be up to 40 μm thick. Although the precise origin of the mucin in this gel is unknown, it is most likely generated by the lacrimal gland, conjunctival goblet cells, and corneal epithelium, with MUC4 being the primary mucin component.

Patients with aqueous tear insufficiency frequently have an uneven corneal surface, leading to increased astigmatism and asymmetry. This irregularity is probably caused by variations in the tear film's thickness and smoothness, especially in cases like keratoconjunctivitis sicca, when the body produces less mucus than usual, resulting in a thinner, uneven mucus gel. Reduced visual contrast sensitivity, increased fluorescein dye permeability, and impaired barrier function can result from this^{11 12 13}.

Effects of Air Pollution on the Cornea

Because of its dense innervation on the ocular surface and its extreme sensitivity to external stimuli, the cornea is the most sensitive component of the human body. The thin precorneal tear film that covers the eyes shields them from dangerous chemicals outside of the body, leaving them open to the damaging effects of air pollution. The primary adverse effects of air pollutants such as CO, NO_x, PM, and O₃ on the eyes include inflammation and irritation; conjunctivitis is a frequent ailment. The impact of environmental pollutants on the surface of the eyes has been the subject of several research. Researchers Saxena and colleagues found substantial subclinical alterations in those exposed to extremely polluted places where particulate matter levels were five times higher than the WHO's yearly average guideline of 60 μg/m³. Versura et al. discovered that a confluence of air contaminants resulted in cytological changes and inflammation on the surface of the eyes, causing pain in the eyes. Because the ocular mucosa is continually in contact with the outside world, it may be used as a bioindicator of exposure to air pollution. People who are exposed to larger quantities of traffic-related air pollution have a higher risk of ocular irritation and tear film instability.¹⁴

Oxidative Stress and Inflammation

In individuals with more severe dry eye symptoms, there is an increase in inflammatory markers in their tears, along with evidence of oxidative damage to the ocular surface, indicated by significantly higher lipid peroxide levels in the tear film. In the study, lipid peroxide levels were measured using the thiobarbituric acid method and compared with other methods. While the correlation between the methods was strong, the stoichiometries were not identical¹⁵. As a result, it's critical to compare the values with those acquired using alternative techniques or to employ established controls.^{16 17} For the

purpose of identifying peroxides, the authors suggested comparing values with other techniques or use verified controls. They came to the conclusion that their data did not allow them to distinguish between the causes and effects of oxidative damage and inflammatory activity on the surface of the eye, nor could they establish if oxidative damage had a direct role in the pathophysiology of dry eye.¹⁸ However, as will be addressed below, a number of theories that could contribute to the explanation of the observed rise in lipid peroxide and myeloperoxidase levels can be built upon the knowledge now available about oxidative reactions and alterations linked to dry eye disease. First of all, oxidative reactions—like those brought on by photodynamic processes—may harm the eye surface epithelium and possibly alter the DNA of conjunctival, corneal, and accessory lacrimal gland cells. Enzymatic alterations and cellular involution may follow from this.¹⁹ A part from air pollution, regular exposure to UV radiation has also been found to induce ocular epithelial cells to undergo apoptosis.^{20 21 22} When the corneal epithelium is exposed to UV-B radiation, it causes nuclear fragmentation, tissue loss, and other clinically relevant effects including as inflammation and cell death.²³ It has been determined that both passive and chronic cigarette smoking have a negative impact on the lipid layer of the tear film and are major causes of tear instability and dry eye illness.^{24 25}

Corneal Surface Damage :

The ocular surface is made up of the cornea, conjunctiva, lacrimal gland, auxiliary lacrimal glands, meibomian gland, glands of Zeiss and Moll, and the nasolacrimal duct. These structures are continuously exposed to air pollution, which can affect them and result in a range of clinical indications and symptoms. It is now well acknowledged that outdoor air pollution can have an effect on human health. The ability of ambient pollution's chemical components to irritate mucosal membranes, especially those in the respiratory system, is widely known. Though the ocular surface is more vulnerable to air pollution than the respiratory mucosa, less attention has been given to it because only a thin tear film shields the corneal and conjunctival epithelia from airborne pollutants.^{26 27 28} Ocular symptoms can be caused by dysfunction in any element of the ocular surface system through two interrelated mechanisms: lacrimal film instability and hyperosmolarity.²⁹ Lacrimal hyperosmolarity causes harm to the epithelium's surface by initiating a series of inflammatory reactions on the ocular surface and producing inflammatory mediators in the tear film; this injury results in goblet cell loss, apoptosis, and altered mucin expression, all of which lead to cell death and instability in the tear film, which then creates a vicious cycle when this instability exacerbates the hyperosmolarity on the surface of the eye.³⁰

Examining the adverse occurrences caused by air pollution. Patients seeking ocular examinations because of subjective symptoms such as burning, itching, photophobia, foreign body sensation, and tears have become more widespread in recent years. Clinical exams, however, often fail to reveal any associated eye abnormalities.³¹ There were no statistically significant changes in Schirmer's or lacrimal film rupture tests across groups in an examination of 100 people exposed to various degrees of environmental contamination. The outcomes of these tests did not significantly correlate with high pollution levels, in contrast to earlier research. Studies on the ocular surface using impression cytology have for the first time shown signs of inflammation and hinted that those with higher pollution exposure levels may have more severe cases. This important discovery implies that depending only on clinical indicators may not be adequate, particularly in cases with unclear etiology, and highlights the importance of cytological examination in situations where clinical observation alone is insufficient to make a diagnosis. Research indicates that when different irritants are directly applied to the ocular surface, the result is neurogenic conjunctival vasodilatation and instantaneous tearing.³²

Conclusion and Future Research :

Although the harmful consequences of air pollution on respiratory and cardiovascular health have long been known, its impacts on ocular health, particularly the cornea, are becoming more and more obvious. Due to its high level of innervations and environmental exposure, the cornea is susceptible to the damaging effects of gases including CO and NO₂, particulate matter (PM), and volatile organic compounds (VOCs). These contaminants have the potential to cause inflammation and oxidative stress, which can result in diseases like dry eye syndrome and other damage to the cornea. Maintaining the health of the eyes is greatly dependent on the complex structure of the cornea, which consists of many layers and a protective tear film. But excessive exposure to air pollution can upset this fragile balance, leading to more inflammation and oxidative damage. The eye's initial line of defense, the thin precorneal tear film, is especially vulnerable to pollutants, which can cause tear film instability, hyperosmolarity, and corneal surface injury as a result. Given how much time individuals spend indoors, indoor air pollution, which can be more concentrated than outdoor pollution, poses serious concerns. If left untreated, pollutants from sources such as cooking oil, building materials and cigarette smoke can have a serious negative effect on the surface of the eyes and result in chronic illnesses.

Accurately identifying and treating pollution-induced ocular disorders requires both clinical and cytological examinations, as research continues to reveal the precise processes by which air pollution affects the cornea and overall health of the eyes. In order to maintain corneal health and avoid long-term visual damage, it is imperative to protect interior air quality and reduce outside pollution exposure.

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