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CHEMICAL FACTORS CAUSING DENTAL ENAMEL DAMAGE IN INDUSTRIAL AREAS

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Abstract
This article analyzes harmful chemical substances commonly encountered in industrial areas and their effects on human health, with particular emphasis on dental enamel. The anatomical and physiological structure of dental enamel is described, and its sensitivity to chemical agents is substantiated based on scientific sources. Data are presented on how substances released into the atmosphere from industrial enterprises—such as fluoride compounds, acids, heavy metals, sulfate and nitrate oxides—can lead to enamel demineralization, pigmentation, and structural damage. In addition, recommendations for preventive measures aimed at reducing dental problems among populations living in industrial zones are provided.

Keywords: Industrial area, dental enamel, chemical substances, fluoride compounds, heavy metals, demineralization, acid aerosols, environmental factors.

Introduction

The rapid development of industry, while creating essential products and conveniences for human life, simultaneously contributes to environmental pollution. Chemical substances released into the air, water, and soil from industrial enterprises have a direct impact on public health. Among these factors, dental health—particularly the condition of dental enamel—requires special attention. Although dental enamel is the hardest tissue in the human body, it is easily damaged under the influence of aggressive chemical agents and may lose its mineral composition.

Residents of industrial areas more frequently experience early enamel erosion, discoloration, increased sensitivity, and structural damage of enamel, which represent dental manifestations of environmental exposure. Fluoride compounds, heavy metal ions, acid aerosols, and other toxic substances released into the atmosphere as a result of industrial activity may enter the body through inhalation or indirectly, reducing the chemical stability of dental tissues.

This article examines the structure of dental enamel, the main harmful chemical agents prevalent in industrial areas, and the mechanisms by which they contribute to enamel damage, based on scientific literature. Preventive measures and recommendations for maintaining dental health among populations living in such areas are also discussed.

Structural Features of Dental Enamel. The unique structure of enamel serves as the primary protective barrier against external environmental factors, including aggressive chemical substances commonly found in industrial zones.

Mineral Components. Approximately 95–97% of dental enamel consists of inorganic minerals, primarily hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$). The highly ordered and densely packed crystalline lattice of hydroxyapatite provides enamel with exceptional strength and a low solubility coefficient.
The mineral composition includes the following ions: calcium (Ca^{2+}), the main structural element of the crystal lattice; phosphate (PO_4^{3-}), forming the structural basis of the mineral complex; fluoride (F^-), which promotes the conversion of hydroxyapatite into fluorapatite and increases resistance to acids; carbonate (CO_3^{2-}), which substitutes within the crystal lattice and moderately increases enamel solubility; and trace elements such as magnesium, sodium, chlorine, and strontium, which participate in enamel ion dynamics.
The high degree of mineralization makes enamel a hard but chemically sensitive tissue. In particular, a higher carbonate content increases enamel susceptibility to acidic environments.
Organic Components. Organic substances constitute approximately 1–2% of enamel and mainly include amelogenins, amelins, enamelins, structural proteins, and glycoproteins. These proteins play an important role during amelogenesis in the formation of prism structures, although their quantity in mature enamel is minimal. The limited organic matrix contributes to enamel strength but also creates surface sites that facilitate ion exchange with chemical agents.
Water Fraction. Dental enamel contains approximately 2–3% water, located within intercrystalline spaces and the interprismatic phase. Water molecules enhance ion migration, hydroxyapatite solubility reactions, and acid–base balance shifts. Consequently, acids or toxic substances present in industrial environments may penetrate deeper enamel layers through the aqueous phase.
Morphological Structure. The micromorphology of enamel is characterized by a complex structure composed of prisms (rods) and interprismatic substance. Enamel prisms, approximately 4–5 µm in diameter, form a highly oriented crystalline system.
This structure provides high mechanical resistance, resistance to compression and pressure, relative stability against chemical penetration, and controlled susceptibility to microcrack formation. However, because ion exchange and solubility are higher in the interprismatic phase than within prisms, scientific evidence indicates that chemical damage typically begins in these regions.

Chemical Sensitivity of Dental Enamel. Although the high mineral content of dental enamel ensures macroscopic hardness and apparent stability, at the microstructural level it remains sensitive to acids, heavy metal ions, excessive fluoride concentrations, and abrasive aerosols. This sensitivity increases the susceptibility of enamel to demineralization and erosion when exposed to chemical agents characteristic of industrial environments.
Harmful Chemical Substances Emitted from Industrial Areas.Industrial production processes release a wide range of chemical substances into the atmosphere, water, and soil. These compounds accumulate within ecological systems and may exert both direct and indirect harmful effects on biological organisms, including the tissues of the human oral cavity.
As the first mineral tissue to come into contact with the external environment, dental enamel is particularly vulnerable to such chemical contaminants.
Fluoride and Its Compounds.In industrial areas—especially those associated with aluminum production, phosphate fertilizer manufacturing, glass production, and metallurgy—significant

amounts of fluoride gases (hydrogen fluoride, HF) and fluoride-containing aerosols are released into the atmosphere.

Fluoride ions may enter the body via inhalation, leading to systemic fluorosis (fluoride intoxication), while locally they can cause enamel pigmentation and areas of hypermineralization. High concentrations of fluoride compounds accelerate the degradation of organic components within the enamel matrix.

Heavy Metals.A substantial portion of industrial waste consists of heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), and chromium (Cr). These elements enter the human body through atmospheric dust, water sources, and the food chain.Heavy metal ions bind to hydroxyapatite crystals in enamel, disrupting calcium–phosphate balance and destabilizing the crystalline structure, which ultimately compromises enamel integrity.

Acids and Acid Aerosols.Chemical and oil–gas industries, as well as metal-processing plants, emit sulfur dioxide (SO_2), nitrogen oxides (NO_x), hydrochloric acid (HCl), and other acidic aerosols into the air.

These acidic particles enter the oral cavity via the respiratory tract and sharply reduce the pH of the enamel surface. This process activates demineralization and increases the solubility of hydroxyapatite.

In humid conditions, SO_2 is converted into sulfuric acid, leading to superficial enamel erosion.

Organic Solvents and Volatile Industrial Compounds. Industries involved in paint, varnish, polymer production, and petroleum processing release volatile organic compounds (VOCs) such as benzene, toluene, formaldehyde, and acetates. Although these substances do not act directly on enamel, they enhance oxidative stress in the oral mucosa and alter the oral environment. Their indirect effects may contribute to the formation of microcracks on the enamel surface and structural disruption of enamel prisms.Silicate, cement, and metal dust emitted from cement production, metallurgy, and construction industries exert a microabrasive effect on the enamel surface. Mechanical damage caused by these particles creates small erosion sites on enamel prisms, facilitating deeper penetration of chemical substances.

Combined Impact of Industrial Chemical Agents. Chemical substances emitted from industrial areas exert a complex pathogenic influence on dental enamel through biochemical, physicochemical, and mechanical pathways. High concentrations of fluoride compounds, heavy metals, acids, and organic solvents disrupt enamel mineral balance and significantly increase the risk of dental diseases.

Chemical Agents Responsible for Enamel Damage in Industrial Areas. Chemical pollutants prevalent in industrial regions directly affect the physicochemical stability of dental enamel, rendering it more susceptible to demineralization, erosion, and pigmentation. These processes are typically associated with long-term exposure to low-concentration but continuous chemical loads and develop through gradual pathobiochemical changes within the enamel microstructure.

Excessive Effects of Fluoride Compounds. Hydrofluoric acid (HF) and fluoride aerosols present in industrial atmospheres damage enamel tissues through two primary mechanisms:

1. Systemic effects — high-dose exposure during amelogenesis disrupts mineralization, leading to areas of hyper- or hypomineralization.
2. Local effects — fluoride ions interact with the calcium component of hydroxyapatite, altering the crystal lattice; excessive fluoride results in structural defects within fluorapatite.

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Clinically, these changes manifest as enamel discoloration, increased brittleness, and microcrack formation.

Erosive Effects of Acids and Acidic Oxides. Sulfur dioxide (SO_2), nitrogen oxides (NO_x), hydrochloric acid (HCl), and other acids lower the pH of the enamel surface, intensifying the following pathological processes: increased solubility of hydroxyapatite crystals, disruption of ion exchange on the enamel surface, and gradual degradation of the organic matrix. Acid aerosols deposited from the atmosphere can transform into strong acids in humid conditions, producing shallow but widespread enamel erosion. This phenomenon is particularly common among populations residing near chemical and metallurgical industries.

Toxic Effects of Heavy Metals on Dental Enamel. Heavy metal ions such as lead (Pb), cadmium (Cd), and mercury (Hg) penetrate the calcium–phosphate layer of dental enamel, disrupting ion exchange within the crystalline structure. This results in mineral deficiency, lattice instability, increased enamel brittleness, and the formation of microstructural cracks.

Cadmium ions compete with calcium ions during the process of amelogenesis, leading to a reduction in the quality of mineralization. Lead, in turn, enhances oxidative stress and promotes the degradation of the organic components of dental enamel.

Effects of Organic Solvents and Volatile Chemical Compounds. Volatile organic compounds (VOCs) such as benzene, toluene, and formaldehyde are commonly present in industrial air. Although they do not exert a direct effect on dental enamel, they induce oxidative stress, inflammation, and pH alterations in the oral mucosa and oral microbiome. These changes accelerate erosive processes in enamel and weaken the microstructure of enamel prisms.

Hard and abrasive aerosols, including silicate dust, cement dust, and metal particles, cause micro-abrasive erosion on the enamel surface. This harmful mechanical impact facilitates deeper penetration of chemical agents into enamel tissues. Thus, mechanical and chemical factors act synergistically, producing a combined pathogenic effect.

Conclusion

The environmental burden observed in industrial areas exerts continuous and direct pressure on the stability of dental enamel. Although enamel is inherently the hardest tissue in the human body, chemical exposure shows little mercy: persistent, low-dose, but chronic exposure ultimately leads to clinically significant damage. Analysis of the available scientific evidence allows the following conclusions to be drawn.

1. Fluoride compounds, heavy metal ions, acid aerosols, and volatile organic compounds present in industrial emissions represent the main chemical determinants disrupting the mineral balance of dental enamel. These agents reduce the stability of hydroxyapatite crystals, resulting in demineralization, pigmentation, and microstructural damage.

2. The highly mineralized yet water- and interprismatic-phase-rich microarchitecture of enamel makes it particularly sensitive to aggressive chemical environments characteristic of industrial zones. Acids and heavy metal ions accelerate ion-exchange processes, increasing enamel brittleness and erosive damage. The combined effects of mechanical (abrasive dust) and chemical factors further intensify pathological changes.

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webofjournals.com/index.php/5

3. The high prevalence of enamel-related disorders among populations residing in industrial areas indicates that dental health should not be regarded solely as an issue of individual hygiene, but rather as an environmental and socio-hygienic problem. Preventive strategies—including strict control of fluoride levels in drinking water, use of remineralizing agents, regular dental screening, and environmental monitoring—are effective only when implemented within a comprehensive, integrated approach.

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