A Comprehensive Review on Vaping: Health Risks, Pathophysiology, and Global Epidemiology

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***Abstract*— Electronic cigarettes (e-cigarettes), commonly referred to as vaping devices, have rapidly emerged as alternative nicotine delivery systems since their introduction in 2007. Although initially promoted as reduced-harm alternatives to combustible cigarettes and as smoking cessation aids, e-cigarettes have increasingly been adopted as recreational products, particularly among adolescents and young adults. Growing scientific evidence indicates that vaping is associated with significant respiratory, cardiovascular, neurological, immunological, and reproductive health risks. Moreover, the escalating prevalence of youth vaping represents a substantial global public health challenge. This review synthesizes current evidence on the composition of e-cigarettes, mechanisms of toxicity, pathophysiological effects, global epidemiological trends across multiple countries, and regulatory considerations. The findings underscore the urgent need for strengthened regulatory policies, improved public awareness, and evidence-based clinical guidance to mitigate the health burden associated with vaping.**

***Keywords*— E-cigarettes; Vaping; Nicotine dependence; Global epidemiology; Respiratory toxicity; Public health**

I. INTRODUCTION

Electronic nicotine delivery systems (ENDS), commonly known as e-cigarettes or vapes, are battery-operated devices designed to aerosolize a liquid solution for inhalation. These devices typically consist of a power source, a heating element, and a reservoir containing e-liquid composed of nicotine, propylene glycol, vegetable glycerin, and various flavoring agents. Since their commercialization in 2007, e-cigarettes have experienced rapid global adoption.

Initially, vaping products were marketed as harm-reduction tools for adult smokers and as potential aids for smoking cessation. However, over time, product design, aggressive marketing strategies, and the availability of appealing flavors have transformed e-cigarettes into popular recreational devices. This shift has been particularly evident among adolescents and young adults, many of whom have no prior history of combustible cigarette use.

The widespread belief that vaping is significantly safer than traditional cigarette smoking has been a key driver of its popularity. Nevertheless, emerging scientific evidence increasingly challenges this assumption. Studies have demonstrated that vaping exposes users to nicotine, ultrafine particulate matter, toxic aldehydes, heavy metals, and other harmful substances generated during aerosolization. These exposures have been linked to respiratory injury, cardiovascular dysfunction, immune suppression, and potential reproductive toxicity. Nicotine can alter neurodevelopmental pathways involved in attention, learning, and impulse control, thereby increasing vulnerability to long-term addiction and neuropsychiatric disorders.

Table 1: Evolution and Types of Electronic Nicotine Delivery Systems (ENDS)

Generation	Common Name	Examples	Key Characteristics	Typical Users
First-generation	Cig-a-likes	Blu, NJOY	Resemble conventional cigarettes; low battery power; disposable or cartridge-based	Early adopters, novice users

Second-generation	Vape pens / Tank systems	Ego, Aspire	Refillable tanks; adjustable airflow; higher aerosol production	Regular adult users
Third-generation	Mods	Box mods	High wattage; customizable voltage; increased toxicant generation	Experienced users
Fourth-generation	Pod-based systems	JUUL, Vuse	Nicotine salts; high nicotine delivery; discreet design	Adolescents and young adults
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II. GLOBAL EPIDEMIOLOGY OF VAPING

The prevalence of e-cigarette use has increased substantially worldwide over the past decade, although marked regional and national variations exist. These differences are influenced by regulatory frameworks, cultural perceptions, product availability, and public health policies.

2.1 United States

In the United States, e-cigarettes are the most commonly used nicotine product among adolescents. National surveys consistently report high rates of experimentation and current use among middle and high school students. Young adults aged 18–24 years exhibit the highest prevalence among adult populations. Although regulatory actions such as age restrictions and flavor bans have influenced usage patterns, youth vaping remains a significant concern.

2.2 Europe

Across Europe, vaping prevalence varies considerably between countries. The United Kingdom reports relatively high adult e-cigarette use, partly due to public health messaging that frames vaping as a smoking cessation aid. Other European countries, including France and Germany, report moderate experimentation rates with lower levels of daily use. Overall, youth uptake remains a growing concern across the region.

2.3 Asia

Vaping patterns in Asia are highly heterogeneous. China, despite being the world's largest producer of e-cigarettes, reports relatively low domestic prevalence due to regulatory restrictions. India has implemented a nationwide ban on e-cigarettes; however, informal and illicit markets persist, particularly in urban areas. Several Southeast Asian countries report increasing experimentation among adolescents despite partial bans or regulatory gaps.

2.4 Australia and New Zealand

Australia and New Zealand maintain strict regulatory controls on nicotine-containing e-cigarettes. These policies have resulted in moderate prevalence rates compared to Western countries, although youth experimentation continues to be reported.

2.5 Low- and Middle-Income Countries

In low- and middle-income countries, surveillance data remain limited. However, emerging evidence suggests rising awareness and experimentation among adolescents, particularly in urban settings. The lack of comprehensive regulatory frameworks and monitoring systems in these regions poses a growing public health challenge.

Overall, global epidemiological trends indicate that vaping is no longer confined to adult smokers but has become increasingly prevalent among adolescents and never-smokers, raising concerns regarding long-term nicotine dependence and future transitions to combustible tobacco use.

Table 2. Prevalence of E-Cigarette Use Across Selected Countries

Country/Region	Age Group	Prevalence (%)	Year	Source
United States	High school students	14.1	2022	CDC
United Kingdom	Adults (18+)	8.3	2023	Public Health England
China	Adults	<1.0	2021	WHO
India	Adolescents	<2.0*	2022	GYTS
Australia	Adults	3.5	2022	Australian Institute of Health
Europe (EU avg.)	Adolescents	7–12	2021	ERS

Table 3. Regulatory Status of E-Cigarettes by Region

Country	Legal Status	Age Restriction	Flavor Regulation	Enforcement Challenges
USA	Legal	≥21 years	Partial bans	Online sales
UK	Legal	≥18 years	Permitted	Youth uptake
India	Banned	Not applicable	Total ban	Black market
China	Restricted	≥18 years	Limited	Domestic production
Australia	Prescription-only	≥18 years	Restricted	Cross-border access

III. COMPOSITION OF E-CIGARETTES AND AEROSOL

Electronic cigarettes are complex electronic devices designed to generate an inhalable aerosol through the heating of a liquid formulation. Although often perceived as simple nicotine delivery systems, e-cigarettes expose users to a heterogeneous mixture of chemical constituents whose composition varies widely depending on device type, e-liquid formulation, power settings, and user behavior.

3.1 Device Components

E-cigarettes generally consist of three primary components:

1. Power source (battery)
2. Heating element (coil or atomizer)
3. E-liquid reservoir (cartridge or tank)

The battery supplies electrical energy to the heating coil, which rapidly raises the temperature of the e-liquid. The coil is typically composed of metals such as nickel, chromium, stainless steel, or kanthal. Repeated heating cycles can lead to metal degradation, contributing to metal particle release into the aerosol.

Devices may be classified as first-generation (cig-a-likes), second-generation (tank systems), or third-generation (mods and pod-based systems). Advanced devices allow users to modify voltage and wattage, which significantly influences aerosol composition and toxicant formation.

3.2 E-Liquid Constituents

E-liquids are composed of a base solvent, nicotine, and flavoring agents. The primary constituents include:

Nicotine

Nicotine is the principal psychoactive substance in most e-cigarettes. Concentrations vary widely, ranging from low levels to highly concentrated nicotine salts used in pod-based devices. Nicotine salts enhance palatability and facilitate deeper inhalation, increasing nicotine absorption and addiction potential. Nicotine exposure is associated with cardiovascular stimulation, neurodevelopmental alterations in adolescents, and reinforcement of dependence.

Propylene Glycol and Vegetable Glycerin

Propylene glycol and vegetable glycerin serve as solvents and aerosol carriers. When heated, these compounds undergo thermal decomposition, generating toxic carbonyl compounds, including formaldehyde, acetaldehyde, and methylglyoxal. These aldehydes are known respiratory irritants and contribute to oxidative stress, inflammation, and cellular injury in lung tissue.

Flavoring Agents

Thousands of flavoring compounds are used in e-liquids, many of which are approved for oral consumption but not for inhalation. Common flavoring chemicals include diacetyl, cinnamaldehyde, and benzaldehyde. Inhalation of these substances has been associated with airway epithelial toxicity, impaired ciliary function, and

inflammatory responses. Flavored e-liquids significantly increase product appeal among adolescents, contributing to initiation and sustained use.

3.3 Aerosol Composition

The aerosol produced by e-cigarettes is not a harmless vapor but a complex suspension of fine and ultrafine particles. Key components include:

- Nicotine
- Ultrafine particulate matter
- Volatile organic compounds (VOCs)
- Toxic aldehydes
- Heavy metals

Particle sizes in e-cigarette aerosols are sufficiently small to penetrate deep into the respiratory tract, reaching the bronchioles and alveoli. This facilitates systemic absorption of toxic constituents and contributes to pulmonary inflammation.

3.4 Metal Contamination

Analyses of e-cigarette aerosols have detected metals such as nickel, chromium, lead, tin, and cadmium. These metals originate from the heating coil and solder joints. Chronic inhalation of metal particles is associated with oxidative lung injury, impaired immune responses, and potential carcinogenic effects.

Table 4. Metals Detected in E-Cigarette Aerosols

Metal	Source	Target Organ	Health Risk
Nickel	Heating coil	Lung	Carcinogenic
Chromium	Coil alloy	Lung	DNA damage
Lead	Solder joints	CNS	Neurotoxicity
Tin	Coil degradation	Lung	Inflammation
Cadmium	Battery	Kidney	Renal toxicity

3.5 Formation of Toxic By-Products

The thermal degradation of e-liquid components is highly dependent on device voltage, temperature, and puff duration. Higher power settings increase the formation of toxic by-products, including carbonyl compounds and reactive oxygen species. “Dry puff” conditions, in which insufficient e-liquid contacts the heating coil, can result in particularly high concentrations of harmful chemicals.

3.6 Variability and Lack of Standardization

One of the major public health concerns associated with e-cigarettes is the lack of standardization in device design and e-liquid composition. Product labeling is often inconsistent, and actual nicotine concentrations may differ from reported values. This variability complicates risk assessment and regulatory oversight.

3.7 Clinical Implications

The complex and variable composition of e-cigarette aerosols challenges the perception that vaping is a safer alternative to smoking. Although e-cigarettes may contain fewer combustion-derived toxicants than traditional cigarettes, they expose users to a distinct profile of harmful substances with documented cytotoxic, inflammatory, and pro-oxidative effects.

Understanding the chemical composition of e-cigarettes is essential for evaluating their health risks and informing regulatory policy.

IV. PATHOPHYSIOLOGY AND HEALTH EFFECTS

4.1 Respiratory System Effects

The respiratory system is the primary site of exposure to e-cigarette aerosols. Ultrafine particles and toxic aldehydes penetrate deep into the airways, reaching the bronchioles and alveoli. Experimental studies have demonstrated that vaping induces epithelial cell injury, increased permeability of the airway lining, and impaired mucociliary clearance.

Thermal degradation products such as methylglyoxal and acetaldehyde generate oxidative stress within lung tissue, leading to mitochondrial dysfunction and disruption of the actin cytoskeleton. These alterations compromise cellular integrity and reduce the capacity of epithelial cells to respond to injury. Inflammatory signaling pathways are activated, resulting in the release of pro-inflammatory cytokines and recruitment of immune cells.

Clinically, vaping has been associated with chronic cough, wheezing, bronchitis, dyspnea, and reduced lung function. Former smokers who transition to

vaping may experience additive or synergistic lung injury due to pre-existing airway damage.

4.2 Vaping-Associated Lung Injury (EVALI)
E-cigarette or Vaping-Associated Lung Injury (EVALI) represents an acute and severe manifestation of vaping-related toxicity. Patients typically present with respiratory symptoms such as shortness of breath, chest pain, and hypoxemia, often accompanied by gastrointestinal and systemic symptoms including nausea, fever, and fatigue.
Pathophysiological mechanisms underlying EVALI include chemical pneumonitis, alveolar inflammation, and disruption of surfactant function. Vitamin E acetate, particularly in tetrahydrocannabinol-containing products, has been implicated in many cases; however, the condition highlights the broader pulmonary risks associated with inhalation of unregulated vaping aerosols.

4.3 Cardiovascular Effects
Nicotine is a potent stimulant of the sympathetic nervous system and plays a central role in the cardiovascular effects of vaping. Acute nicotine exposure increases heart rate, blood pressure, and myocardial oxygen demand. Repeated exposure contributes to endothelial dysfunction, a key early event in atherosclerosis.

E-cigarette aerosols also promote oxidative stress and systemic inflammation, which further impair vascular function. Studies suggest increased platelet activation and aggregation among e-cigarette users, raising concerns regarding thrombogenic risk.

These mechanisms may increase the likelihood of adverse cardiovascular events, particularly in individuals with underlying cardiovascular disease.

4.4 Immunological Effects
Vaping adversely affects both innate and adaptive immune responses. Exposure to e-cigarette aerosols impairs the function of alveolar macrophages and neutrophils, reducing their ability to phagocytose pathogens. This immune suppression increases susceptibility to respiratory infections.

Alterations in cytokine expression have been observed, characterized by a dysregulated inflammatory response that may contribute to chronic airway inflammation. Long-term immune impairment may predispose users to recurrent infections and exacerbate existing pulmonary conditions.

4.5 Neurological and Neurodevelopmental Effects
Nicotine readily crosses the blood–brain barrier and exerts profound effects on the central nervous system. In adolescents, nicotine exposure disrupts normal brain development by altering neural circuitry involved in attention, learning, and impulse control. Vaping has been associated with increased anxiety, mood disturbances, and impaired cognitive performance. Nicotine dependence established during adolescence increases the risk of continued substance use and addiction later in life.

4.6 Reproductive and Developmental Effects
Emerging evidence suggests that vaping may adversely affect reproductive health. Experimental studies indicate potential impairment of ovarian function, altered uterine receptivity, and reduced fertility. Nicotine exposure during pregnancy has been linked to adverse fetal outcomes, raising concerns about vaping among women of reproductive age.

Additionally, prenatal and early-life exposure to e-cigarette aerosols may have long-term developmental consequences, although further research is needed to fully characterize these effects.

4.7 Dual Use and Cumulative Toxicity
A substantial proportion of e-cigarette users engage in dual use of vaping products and combustible cigarettes. This pattern results in cumulative exposure to toxicants from both sources, potentially increasing disease risk beyond that associated with smoking alone. Dual use has been linked to heightened oxidative stress, inflammation, and respiratory symptoms.

4.8 Systemic and Long-Term Health Implications
Although e-cigarettes may reduce exposure to certain combustion-related toxicants, they introduce a distinct profile of chemical exposures with poorly understood long-term consequences. The chronic activation of inflammatory and oxidative pathways suggests a potential role in the development of chronic respiratory disease, cardiovascular pathology, and systemic health effects.

Table 5. System-Wise Health Effects of Vaping

Organ System	Pathophysiology	Clinical Manifestations	Evidence Strength
Respiratory	Oxidative stress, inflammation	Cough, bronchitis	Strong
Cardiovascular	Endothelial dysfunction	Hypertension	Moderate
Neurological	Neurodevelopmental disruption	Addiction, anxiety	Strong
Immune	Macrophage dysfunction	Infections	Moderate
Reproductive	Hormonal alteration	Reduced fertility	Emerging

V. DISCUSSION

This review highlights growing evidence that electronic cigarettes are not harmless alternatives to combustible tobacco products. Although vaping has been promoted as a harm-reduction strategy for adult smokers, its increasing use among adolescents and non-smokers represents a significant public health concern. The perception of reduced harm, combined with flavored products and aggressive marketing, has contributed substantially to widespread uptake.

E-cigarette aerosols contain a complex mixture of toxic aldehydes, ultrafine particles, and metals generated through thermal degradation of e-liquid components. These substances induce oxidative stress, inflammation, and cellular injury, particularly within the respiratory tract. Clinical and experimental studies consistently associate vaping with airway irritation, impaired pulmonary defense mechanisms, and increased susceptibility to respiratory infections. Acute conditions such as vaping-associated lung injury further underscore the potential severity of vaping-related toxicity.

Beyond respiratory effects, vaping has been linked to cardiovascular dysfunction through nicotine-mediated sympathetic activation, endothelial injury, and platelet activation. Emerging evidence also indicates immune dysregulation and potential neurological and reproductive effects, suggesting that the health impact of vaping is systemic rather than localized.

The disproportionate impact of vaping on adolescents is especially concerning. Nicotine exposure during neurodevelopment increases the risk of addiction and may impair cognitive and behavioral outcomes. Additionally, epidemiological data suggest that vaping among tobacco-naïve youth may increase the likelihood of future cigarette smoking.

VI. CONCLUSION

Electronic cigarettes have rapidly transitioned from niche smoking cessation devices to widely used recreational products, particularly among adolescents and young adults. Although initially promoted as safer alternatives to combustible tobacco, growing scientific evidence demonstrates that vaping is associated with significant adverse health effects. Exposure to e-cigarette aerosols results in inhalation of nicotine, toxic aldehydes, ultrafine particles, and heavy metals, which collectively contribute to respiratory injury, cardiovascular dysfunction, immune dysregulation, and potential neurological and reproductive harm.

The pathophysiological mechanisms underlying vaping-related toxicity are multifactorial and include oxidative stress, mitochondrial dysfunction, inflammatory activation, and nicotine-mediated sympathetic stimulation. Clinical manifestations range from chronic respiratory symptoms and impaired lung function to acute conditions such as vaping-associated lung injury. Of particular concern is the rising prevalence of vaping among adolescents, for whom nicotine exposure poses long-term risks to brain development and increases the likelihood of sustained addiction and future tobacco use.

Epidemiological trends across diverse regions indicate that vaping is a global public health issue rather than a localized phenomenon. Variability in regulatory frameworks has resulted in inconsistent control of product availability, marketing, and youth access. While some countries have implemented stringent restrictions or bans, others continue to face increasing rates of experimentation and regular use, especially among young populations.

In conclusion, although e-cigarettes may reduce exposure to certain combustion-derived toxicants compared with traditional cigarettes, they are not risk-free and should not be considered harmless. Comprehensive regulatory policies, public education initiatives, and ongoing surveillance are essential to mitigate the health and environmental impacts of vaping. Healthcare professionals play a critical role in screening for e-cigarette use, correcting

misconceptions regarding safety, and promoting evidence-based smoking cessation strategies. Further longitudinal research is required to clarify the long-term health consequences of vaping and to guide effective public health interventions.

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