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HEALTH CONSEQUENCES AND SOCIAL IMPLICATIONS OF E-CIGARETTE USE IN ADOLESCENTS

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ABSTRACT

Background: E-cigarette use among adolescents has emerged as a critical global public health challenge. Although electronic nicotine delivery systems (ENDS) were initially promoted as a less harmful alternative to conventional cigarettes for adults, they have become a primary source of nicotine exposure among youth. Adolescence represents a neurodevelopmentally vulnerable period characterized by ongoing maturation of the prefrontal cortex and heightened sensitivity of reward systems, which increases susceptibility to nicotine addiction and its potential long-term health consequences.
Methodology: A narrative review was conducted using literature identified through PubMed, Scopus, and Web of Science, encompassing recent original studies, systematic reviews, meta-analyses, and experimental models. The review synthesizes evidence from epidemiological, clinical, experimental, and neurobiological research to examine the biological, neurodevelopmental, cardiovascular, respiratory, and psychosocial effects of adolescent e-cigarette use. In addition, social determinants, marketing influences, regulatory frameworks, methodological limitations, and emerging research directions were considered to contextualize patterns of use and gaps in the current evidence base.
Results: Available evidence indicates that e-cigarette use during adolescence is associated with structural and functional alterations in brain development, including disrupted synaptic plasticity, impaired executive function, increased vulnerability to nicotine dependence, and heightened risk of subsequent substance use and mood disorders. Cardiovascular effects include sympathetic nervous system overactivation, elevated blood pressure, endothelial dysfunction, oxidative stress, and pro-inflammatory responses, potentially predisposing adolescents to long-term cardiovascular disease. Respiratory consequences involve airway irritation, impaired mucociliary clearance, inflammation, and early signs of functional decline, with risks amplified among dual users of e-cigarettes and conventional cigarettes. Initiation and sustained use are strongly influenced by social factors, including peer norms, social media marketing, flavor availability, and socioeconomic disparities, which reinforce normalization of nicotine use. Despite growing evidence of harm, substantial heterogeneity in study designs, exposure assessment, product types, and reliance on self-reported data, along with limited longitudinal evidence, continues to constrain causal inference.
Conclusions: Adolescent e-cigarette use poses significant neurodevelopmental, cardiovascular, respiratory, and psychosocial risks. Comprehensive public health strategies—including regulatory measures, preventive education, peer-based interventions, and equitable policies—are urgently needed to reduce nicotine initiation and dependence among vulnerable youth. Furthermore, large-scale longitudinal studies are essential to clarify long-term outcomes and guide evidence-based policies to protect adolescent health.

KEYWORDS

E-Cigarettes, Adolescents, Nicotine Addiction, Neurodevelopment, Cardiovascular Health, Respiratory Health

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Introduction

Over the past decade, electronic cigarettes have become one of the most commonly used nicotine-containing products in the world, especially among children, adolescents, and young adults, raising significant concerns regarding their short- and long-term health consequences (Arora et al., 2025; Banks et al., 2023).

E-cigarettes, also referred to as ENDS (Electronic Nicotine Delivery Systems), are battery-powered devices designed to deliver nicotine in the form of an aerosol created by heating a special liquid solution, which contains not only nicotine but also solvents such as propylene glycol and/or vegetable glycerin and a wide variety of flavoring agents (Breland et al., 2016). Technological innovation has led to increasingly efficient nicotine delivery, particularly through the use of protonated nicotine (nicotine salts), which enable faster and more effective absorption, increasing the addictive potential of these products (Arora et al., 2025). E-cigarettes encompass a diverse range of devices varying in design, size, and functionality, and represent a rapidly expanding segment of the global nicotine market, constituting a major challenge for contemporary public health (Breland et al., 2016).

The use of e-cigarettes has increased dramatically worldwide, especially in high-income countries in Europe, North America, and parts of Oceania. Epidemiological studies consistently demonstrate that adolescents and young adults represent the most rapidly growing user group. In many countries, more than 10% of adolescents report having experimented with e-cigarettes, while in some regions between 30% and 50% of teenagers report current or past use. Among young adults aged 18–24 years, prevalence rates are often even higher, with males more frequently reporting e-cigarette use, reflecting both experimentation and established patterns of regular use. Research indicates that in selected countries in Europe and the Pacific region, the percentage of e-cigarette users among young adults is among the highest in the world, highlighting the scale and urgency of the problem (Martins et al., 2022).

A key factor contributing to the widespread uptake of e-cigarettes among young people is the perception that these products are less harmful than conventional cigarettes as they were initially promoted as a safer alternative or as a smoking cessation tool. Nevertheless, accumulating scientific evidence indicates that their use is associated with significant health risks, especially in the adolescent population. This belief is reinforced by aggressive marketing strategies, such as influencer marketing and promotion via social media platforms that emphasize harm reduction, smoking cessation, and modern lifestyle appeal. The availability of thousands of appealing flavors, including fruit, candy, menthol, and beverage varieties, further enhances the attractiveness of e-cigarettes to adolescents. Sleek designs, discreet devices, and the absence of tobacco odor facilitate e-cigarette use in school and home environments, often without the knowledge of adults. In addition, online retail channels have facilitated easy access to these products, often bypassing age restrictions (Arora et al., 2025).

As a result, e-cigarettes have become the first contact with nicotine for many young people. From a public health perspective, the normalization of e-cigarette use among youth is especially concerning as it leads to the development of nicotine addiction in people who have not previously smoked conventional cigarettes (Martins et al., 2022). Research also suggests that early exposure to nicotine through e-cigarettes increases the risk of developing long-term nicotine dependence and may act as a "gateway" for subsequent smoking of tobacco products rather than as a harm reduction tool (Soneji et al., 2017). The phenomenon of so-called dual use, which involves the simultaneous use of e-cigarettes and conventional cigarettes, is common among adolescents and young adults, particularly during transitional periods of experimentation and habit formation, and is associated with higher health risks compared to smoking only conventional cigarettes (Arora et al., 2025).

Although the long-term health effects of e-cigarette use are still being elucidated, a growing number of studies indicate their association with cardiovascular dysfunction, respiratory symptoms, impaired immune responses, metabolic disturbances, and oral health problems (Arora et al., 2025). The aerosol generated by e-cigarettes is not harmless. It contains numerous potentially toxic and carcinogenic substances, including heavy metals, volatile organic compounds, aldehydes, and ultrafine particles.

Therefore, adolescents may be particularly vulnerable, as nicotine exposure during critical periods of brain development can negatively affect cognitive function, emotional regulation, and susceptibility to other substance use disorders (U.S. Department of Health and Human Services, 2016). Major international health organizations, such as the International Pediatric Association and the Forum of International Respiratory Societies, warn against the uncontrolled increase in e-cigarettes use among youth and emphasize that e-cigarettes may renormalize smoking behaviors, weaken existing tobacco control policies, and create a new generation of nicotine-dependent individuals (Arora et al., 2025; Ferkol et al., 2018). In this context, e-cigarettes should be seen not only as a new consumer product, but as a significant public health problem with global reach and long-term consequences. The rapid expansion of e-cigarette use poses a serious challenge to health systems and health policy, requiring comprehensive actions including legal regulations, health education and effective prevention strategies aimed at children and young people. Regulatory approaches vary widely across countries, ranging from strict bans to minimal oversight, leading to inconsistent protections for vulnerable populations. Effective public health responses require comprehensive strategies that integrate regulatory measures, taxation, advertising restrictions, flavor bans, age verification enforcement, and evidence-based education campaigns. Without coordinated global action, e-cigarettes threaten to reverse longstanding achievements in tobacco control over the past decades (Cheng et al., 2025).

Methodology

This review was based on articles retrieved from the PubMed, Scopus, and Web of Science databases, with particular emphasis on recent original studies, systematic reviews, and meta-analyses examining e-cigarette use among adolescents and its health-related effects. The selection focused on studies addressing neurodevelopmental, cardiovascular, respiratory, addiction-related, and psychosocial outcomes associated with electronic nicotine delivery systems (ENDS). Both human studies and relevant experimental models were included to provide biological and mechanistic insights into the effects of nicotine and e-cigarette aerosol exposure during adolescence.

The literature search was conducted using combinations of the following keywords: electronic cigarettes, e-cigarettes, ENDS, vaping, adolescents, youth, neurodevelopment, brain development, addiction, nicotine dependence, cardiovascular health, respiratory health, social influence and public health policy. Articles were selected based on their relevance to adolescent vulnerability, patterns of e-cigarette use, and evidence linking exposure to short- and long-term health outcomes.

Studies were included if they involved adolescent populations aged 10–19 years, in accordance with the World Health Organization definition of adolescence, and evaluated e-cigarette use either alone or in combination with conventional tobacco products. Eligible publications included systematic reviews, cohort studies, cross-sectional studies, experimental human studies, and animal studies providing mechanistic or translational insight. Studies focusing exclusively on adult populations, case reports, non-English publications, and articles lacking sufficient methodological detail or relevant outcome data were excluded.

Overall, the selected studies were analyzed to synthesize current knowledge on the biological, clinical, and social implications of e-cigarette use during adolescence. This approach allowed for an integrated overview of existing evidence and helped identify key public health concerns and research gaps related to the growing use of e-cigarettes among young populations.

Adolescence as a Critical Developmental Period

Adolescence, defined by the World Health Organization (WHO) as the period of life between the ages of 10 and 19, represents one of the most important and sensitive stages of human development (WHO). It is a time of transition from childhood to adulthood, marked by profound biological, neurobiological, hormonal, psychological, and social changes that have long-term consequences for health and functioning in adulthood (Sawyer et al., 2012).

One of the key aspects of adolescence is the intensive development of the brain. During this period, the brain undergoes dynamic structural and functional reorganization, which has been confirmed both in human neuroimaging studies and in animal models (Yuan et al., 2015). Of particular significance is the development of the prefrontal cortex, responsible for executive functions such as planning, impulse control, predicting consequences, and decision-making. The prefrontal cortex matures at the latest, and this process can continue into the third decade of life (Konrad et al., 2013).

At the same time, subcortical structures, including the limbic system and the reward system, mature earlier. This developmental imbalance between highly reactive emotional–motivational systems and still-

developing cognitive control mechanisms is a characteristic feature of adolescence (Casey et al., 2008). This neurobiological profile promotes characteristic adolescent behaviors such as increased novelty seeking, risk-taking, impulsivity, and strong sensitivity to rewards, especially social rewards. These behaviors serve adaptive functions, supporting the development of autonomy, identity formation, and the transition toward independence, but at the same time they also increase vulnerability to problem behaviors, including substance use (Yuan et al., 2015; Walker et al., 2017).

Adolescence is also characterized by exceptionally high brain neuroplasticity, defined as the brain's ability to reorganize neuronal structures and functions under the influence of environmental experiences. This period of time has been described as a neurobiological "critical period" for the maturation of higher cognitive functions, especially those related to executive control and decision-making (Larsen & Luna, 2018). While heightened plasticity supports learning and adaptation, it simultaneously increases susceptibility to adverse environmental influences. A major concern is that adolescence is a critical period for the formation of long-lasting health-related behaviors: habits related to diet, physical activities, sleep, stress management, and psychoactive substances. Research indicates that exposure to alcohol, nicotine, cannabinoids, or opioids during this time may lead to lasting alterations in the functioning of neurotransmitter systems and the reward system, increasing the risk of substance addiction later in life (Banati et al., 2025).

In conclusion, adolescence constitutes a critical stage of development in which intense neurobiological and psychosocial processes make the individual particularly susceptible to environmental influences, both beneficial and harmful. Understanding the role of neuroplasticity, prefrontal cortex development, and reward system functioning is crucial for designing effective preventive, educational, and health interventions targeted at adolescents.

Composition of e-cigarettes and biological mechanisms of action

E-cigarettes deliver nicotine in the form of an aerosol generated by heating a liquid containing nicotine, propylene glycol (PG), vegetable glycerin (VG), and various flavorings (Banks et al., 2023). The primary component of e-cigarettes responsible for addiction is nicotine, which acts by activating nicotinic acetylcholine receptors (nAChRs) in the brain (Yuan et al., 2015). In the most common neuronal subtypes, such as α4β2*, nicotine induces the release of dopamine in the mesolimbic system, which is associated with reward mechanisms and behavioral reinforcement (Arora et al., 2025).

Nicotine concentrations in e-liquids are highly variable – modern products may contain from 0 to 50 mg/ml, and actual concentrations often exceed declared values. The introduction of nicotine salts in modern pod-mod devices allows higher nicotine concentrations at lower pH, reducing the irritating effect of inhalation and increasing the rate of absorption (Martins et al., 2022). Nicotine salt formulations can deliver 63–94% more nicotine to the bloodstream compared to free-base nicotine, reaching levels similar to conventional cigarettes smoking (Arora et al., 2025).

In practice, this means that even a first use of an e-cigarette can trigger nicotine craving and accelerate the development of a persistent habit (Yuan et al., 2015). Propylene glycol (PG) and vegetable glycerin (VG) act as solvents, creating an inhalable mist. PG is responsible for the throat hit and consistency of the aerosol, while VG gives the vapor a thicker texture and a sweet taste. Although both substances are considered safe for oral consumption by the FDA (U.S. Food and Drug Administration; Arora et al., 2025), evidence regarding the long-term safety of inhalation remains limited. Studies indicate that inhalation of PG/VG may cause respiratory tract irritation, dry cough, wheezing, and increased mucus secretion. During the heating of PG and VG, thermal degradation occurs, leading to formation of toxic aldehydes such as formaldehyde, acetaldehyde, and acrolein, which are strong irritants and potential carcinogens (U.S. Department of Health and Human Services, 2016). Glycerin is the main source of acrolein and formaldehyde, while PG contributes less to aldehyde formation. E-cigarette aerosol may also contain heavy metals from the heating element, including nickel, chromium, and lead, contributing to cardiopulmonary toxicity (Rose et al., 2023). Additionally, glycol, propylene oxide, and diacetyl have also been detected – compounds with irritant and potentially carcinogenic properties (Banks et al., 2023).

The composition of e-liquids and their heating products have multi-level effects on the body. Nicotine mainly affects the central nervous system, causing changes in the reward system, impaired impulse control, and emotional regulation. PG and VG, together with the resulting aldehydes, irritate the respiratory system, induce inflammation, disrupt mucus hydration, and increase susceptibility to infections. Heavy metals and aldehydes have toxic effects on the cardiovascular system, contributing to elevated blood pressure, heart rhythm changes, and chronic cardiovascular disease risk. Long-term exposure may also disrupt immune function, increase the risk of metabolic disorders, and lead to damage mucous membranes of the mouth and lungs (U.S. Department of Health and Human Services, 2016; Rose et al., 2023).

Impact of E-Cigarette Use on the Developing Brain

Adolescence represents a critical "window of vulnerability" in human brain development, characterized by intense structural, functional, and molecular changes. During this period, extensive remodeling of neural networks occurs through synaptogenesis, selective elimination of synapses (synaptic pruning), and progressive myelination of white matter connections. These processes enhance neural efficiency and cognitive capacity but simultaneously increase the brain's susceptibility to neurotoxic exposures. Of particular importance is the maturation of the prefrontal cortex (PFC), a brain region responsible for executive functions, planning, impulse control, and emotional regulation. PFC development continues into early adulthood, rendering it especially sensitive to psychoactive substances such as nicotine (Yuan et al., 2015; Becker et al., 2021).

In parallel, the reward system, such as ventral tegmental area (VTA), nucleus accumbens (NAc), and dopaminergic projections to the PFC, undergoes significant maturation changes. During adolescence, this system shows excessive reactivity to rewarding stimuli, while inhibitory control from the prefrontal cortex remains immature. This neurobiological imbalance increases risk-taking behavior and predisposes adolescents not only to initial substance use but also to subsequent experimentation with other psychoactive substances, such as alcohol, cannabis, and opioids, illustrating the 'gateway effect.'

Moreover, it allows nicotine to rapidly reinforce habitual behaviors and promote tolerance even after brief use, further increasing the likelihood of engaging in dual use and other risky behaviors (Reynolds et al., 2025; Kandel & Kandel, 2014). Nicotine, the primary addictive component of e-cigarettes, affects the brain mainly through activation of nicotinic acetylcholine receptors (nAChRs). Particularly high receptor densities are observed in the prefrontal cortex, hippocampus, amygdala, and mesolimbic reward structures, regions that are still undergoing maturation during adolescence. During adolescence, the expression and functional regulation of nAChRs are dynamically changing, making adolescent neural networks particularly susceptible to exogenous nicotine stimulation (Castro et al., 2023).

Activation of nAChRs by nicotine leads to excessive dopamine release in the nucleus accumbens, disrupting physiological reward signaling and reinforcement-based learning mechanisms. Nicotine also modulates glutamatergic and GABAergic neurotransmission, affecting the excitatory–inhibitory balance within the prefrontal cortex. Preclinical studies indicate that adolescent exposure to nicotine causes the long-lasting alterations in synaptic neuroplasticity, including disruptions in long-term potentiation (LTP), a fundamental process underlying learning and memory (Yuan et al., 2015). Compared to adults, the imbalance between underdeveloped inhibitory GABAergic systems and overactive excitatory glutamatergic signaling in adolescents leads to amplification of reward responses and reduction of withdrawal symptoms, promoting rapid nicotine dependence (Jenssen et al., 2023). Beyond neurotransmission, nicotine exposure during adolescence also induces persistent molecular alterations in the expression of genes associated with neurodevelopment, oxidative stress responses, and regulation of the hypothalamic–pituitary–adrenal axis.

Epigenetic modifications initiated during this sensitive period may persist into adulthood, leading to permanent dysregulation of dopaminergic and cholinergic systems (Reynolds et al., 2025). The neurobiological disruptions caused by nicotine exposure during adolescence translate directly into cognitive and behavioral consequences. Animal models consistently indicate that nicotine administration during this developmental stage results in persistent deficits in attention, working memory, learning, and increased impulsivity, even after exposure has ceased. These cognitive impairments are closely associated with abnormal maturation of the prefrontal cortex and hippocampus, two regions critical for executive control and memory consolidation (Becker et al., 2021).

In addition, animal studies reveal increased vulnerability to stress, anxiety-like behaviors, and depressive-like phenotypes due to adolescent nicotine exposure, suggesting disrupted development of neural circuits responsible for emotional regulation and stress response (Yuan et al., 2015). Evidence from human studies strongly supports these preclinical findings. Epidemiological and clinical data consistently demonstrates associations between adolescent e-cigarette use and impairments in attention, learning difficulties, and increased impulsivity. Moreover, large-scale reviews indicate a higher prevalence of depression, anxiety disorders, and suicidal ideation among adolescents who use e-cigarettes (Kaur et al., 2025). Neuroimaging studies provide further insight into the neural correlates of these behavioral outcomes, revealing structural and functional brain differences in adolescents, who use e-cigarettes, such as alterations in prefrontal cortical thickness, disrupted functional connectivity within executive control networks, and atypical patterns of brain activation during tasks requiring attention and inhibitory control (Arora at al., 2025). Authoritative statements from professional organizations further reinforce these conclusions. The American Academy of Pediatrics, emphasizes that nicotine exposure, regardless of delivery method, is neurotoxic to the developing

brain and contributes to long-term impairments in cognition, impulse control, and mental health, while increasing vulnerability to substance use disorders (Jenssen et al., 2023). The long-term consequences of adolescent e-cigarette use may extend far beyond adolescence itself. The scientific consensus highlights adolescence as a uniquely sensitive developmental stage during which nicotine exposure can irreversibly alter brain maturation trajectories. Persistent alterations in dopaminergic and cholinergic neurotransmission increase susceptibility to substance use disorders, mood disorders, and anxiety disorders later in life (Castro et al., 2023).

Impact of E-Cigarette Use on Cardiovascular Health in Adolescents

The widespread popularity of e-cigarettes among adolescents and young adults has raised significant public health concern. While often marked as a safer alternative to conventional cigarettes, accumulating evidence indicates that e-cigarette use affects cardiovascular health even in young individuals by disturbing hemodynamic function, vascular integrity, and inflammatory pathways (Rose et al., 2023).

Nicotine, as a primary active component in e-cigarettes, stimulates the sympathetic nervous system, leading to acute increases in heart rate and blood pressure. Nicotine stimulation of nicotinic receptors within autonomic ganglia and central nervous system pathways enhances sympathetic tone, elevated peripheral vascular resistance, and accelerated heart rate. This process occurs through dose-dependent catecholamine release, primarily adrenaline and noradrenaline, which subsequently elevates cardiac output and vascular tone. These changes elevate cardiac workload and may predispose young users to arrhythmias and abnormal cardiac conduction, particularly with repeated or chronic exposure. Experimental studies indicate that the combination of nicotine with aldehydes and metal elements can disrupt cardiac electrophysiology, alter autonomic balance, and increase susceptibility to rhythm disturbance (Mears et al., 2023; Rose et al., 2023; Garcia et al., 2020).

Short-term exposure to nicotine-containing aerosols can produce acute cardiovascular stress similar to those observed after conventional cigarette smoking, although generally with slightly lower magnitude. Repeated exposure to acute cardiovascular stressors may lead to maladaptive changes in cardiac and vascular function, particularly among adolescents, whose cardiovascular and autonomic systems are still maturing (Cheraghi et al., 2024; Garcia et al., 2020).

Beyond acute hemodynamic consequences, e-cigarette use negatively contributes to endothelial dysfunction and overall vascular health. Nicotine and other components of e-cigarette aerosols, including propylene glycol, glycerol, and aldehydes, increase the production of reactive oxygen species and reduce nitric oxide bioavailability, leading to endothelial dysfunction. Nitric oxide is fundamental for maintaining vascular tone, regulating platelet activity, and preventing pathological vascular remodeling, and its reduction may trigger early vascular impairment. The nicotine-free cigarettes are also capable of inducing inflammatory responses. Carbonyl compounds such as acrolein, generated during e-liquid heating, independently induce oxidative stress and endothelial injury, leading to significant hemodynamic and vascular dysfunction, while the presence of nicotine amplifies these effects through additional sympathetic activation (Stokes et al., 2021).

These mechanisms impair endothelium-dependent vasodilation and promote a pro-inflammatory and pro-atherogenic environment within the vasculature (Zong et al., 2024). Oxidative stress induced by e-cigarette aerosols is accompanied by systemic inflammation. The e-cigarettes young users exhibit elevated levels of inflammatory markers, including C-reactive protein, pro-inflammatory cytokines, and adhesion molecules. These molecules facilitate leukocyte recruitment, endothelial activation, and early atherogenic changes (Rose et al., 2023).

The persistent low-grade inflammation in adolescence can establish a foundation for the development of atherosclerosis and other cardiovascular diseases later in life (Jones et al., 2023). In addition to endothelial dysfunction and inflammatory activation, the inhalation of e-cigarette aerosols may affect platelet function and hemostatic balance. The exposure to aerosol constituents increases platelet activation and aggregation, creating a pro-thrombotic state that may further impair cardiovascular vulnerability and elevate the risk of acute cardiovascular events, particularly in the context of repeated sympathetic stimulation and endothelial injury.

Collectively, these findings underscore that e-cigarettes, while potentially less harmful than combustible cigarettes, are not risk-free and have substantial implications for cardiovascular health in adolescents and young adults. These hemostatic alterations represent an additional mechanism through which e-cigarette use may contribute to cardiovascular risk in adolescents and young adults, complementing the observed effects on endothelial function, inflammation, and autonomic regulation. Consistent with these mechanisms, evidence from animal models demonstrates that repeated exposure to e-cigarette aerosols results in increased arterial

stiffness, early remodeling of vascular walls, and the expression of biomarkers associated with atherosclerosis (Rose et al., 2023).

Long-term biomarkers in adolescents e-cigarettes users indicate a potential progression toward chronic cardiovascular disease, which are predictive of future hypertension and cardiovascular morbidity (Rose et al., 2023). Exclusive e-cigarette use is also associated with subclinical cardiovascular changes, while dual use with conventional cigarettes may amplify these risks (Kundu et al., 2025).

Respiratory Effects of E-Cigarette Use in Adolescents

E-cigarette use is also associated with respiratory consequences, particularly among adolescents and young adults whose respiratory systems continue to develop into early adulthood. Exposure to e-cigarette aerosols adversely affects respiratory health through airway irritation, inflammation, impaired host defense mechanisms, and mucociliary clearance (de Miranda Schmitz et al., 2025). These effects are especially concerning given the vulnerability of the developing lung and the potential for long-term respiratory morbidity.

E-cigarette aerosols contain a complex mixture of potentially harmful substances, including volatile aldehydes, metals, flavoring chemicals, propylene glycol, and glycerol. Inhalation of these compounds has been shown to induce airway epithelial irritation, oxidative stress, and inflammatory responses, while also impairing mucociliary clearance, a critical defense mechanism of the respiratory tract (de Miranda Schmitz et al., 2025).

Clinically, these pathological processes manifest as cough, wheeze, dyspnea, shortness of breath, chest tightness, bronchitic symptoms, even among otherwise healthy adolescents with no prior history of lung disease. Experimental studies demonstrate that e-cigarette aerosols can directly disrupt airway epithelial integrity, increasing epithelial permeability and provoking inflammatory infiltration into lung tissue. Oxidative stress induced by aldehydes and metals triggers the release of pro-inflammatory cytokines. This results in increased production of cytokines such as interleukins and tumor necrosis factor, which induce airway inflammation and may initiate airway structural remodeling, increasing the long-term risk of chronic respiratory disease during adulthood (Rose et al., 2023).

Importantly, even aerosols without nicotine can increase markers of airway inflammation and epithelial injury, although nicotine amplifies these adverse effects not only by enhancing oxidative stress, impairing immune responses but also by altering neural regulation of airway tone. Thus, nicotine represents only one component of respiratory harm, as the complex composition of e-cigarette aerosols confers toxic effects that extend beyond nicotine exposure alone.

Chronic exposure to e-cigarette aerosols may further impair pulmonary immune defenses through disruption of macrophage function, altered innate immune signaling, and an increased susceptibility to respiratory infections among e-cigarettes users. Persistent low-grade airway inflammation may lead to tissue injury and interfere with normal lung growth and maturation, potentially resulting in long-term reductions in respiratory reserve (Zong et al., 2024). Spirometry-based studies demonstrate subtle but measurable declines in lung function and increased airway resistance and reduced airflow, suggesting early functional impairment before overt respiratory disease clinically manifests (Rose et al., 2023).

Longitudinal analyses show that initiation of e-cigarette use during adolescence is associated with higher incidence of wheeze and persistent respiratory symptoms, such as chronic cough, shortness of breath, and symptoms consistent with asthma or bronchitis (Kundu et al., 2025).

Beyond chronic symptoms, acute and severe respiratory consequences have also been reported in adolescents and young adults using e-cigarettes. Cases of e-cigarette or vaping-associated lung injury (EVALI) have demonstrated that inhalation of vaping aerosols can lead to severe diffuse pulmonary inflammation, alveolar damage, and hypoxemia, often requiring hospitalization and intensive care. These cases show that e-cigarette aerosol inhalation is not benign and can indicate life-threatening pulmonary injury (de Miranda Schmitz et al., 2025).

In addition to localized pulmonary effects, respiratory inflammation associated with e-cigarette use may also have systemic implications. Chronic airway inflammation promotes oxidative stress and the release of circulating inflammatory mediators, which can interact with vascular endothelium and influence cardiovascular physiology (Rose et al., 2023). These interactions highlight that pulmonary injury induced by e-cigarette exposure extends beyond the respiratory system and represents a component of a broader systemic inflammatory response.

Taken together, e-cigarette use in adolescents and young adults negatively affects respiratory health through airway irritation, inflammatory activation, oxidative stress, impaired immune defense, and potential

structural changes. The developing lung is particularly susceptible to these insults, and regular exposure may establish a trajectory toward chronic respiratory disease, even in the absence of conventional cigarette smoking. Vulnerability of the developing lung to toxic exposures suggests that repeated e-cigarette use may promote long-term pulmonary pathology, even in the absence of conventional cigarette smoking (Rose et al., 2023).

Social Norms, Public Health Challenges, and Policy Responses to E-Cigarette Use Among Adolescents

E-cigarette use among adolescents represents a significant social issue, with implications that reach far beyond physical health to affect multiple aspects of psychosocial development. One of the most notable social consequences is the normalization of nicotine use among young people. As e-cigarettes use becomes more common within peer groups, adolescents increasingly view it as a typical, acceptable, or even desirable behavior. This process of normalization is driven by social dynamics, as adolescents tend to adopt behaviors that reflect the habits of their friends and the broader youth culture. Peer approval and the desire to socialize strongly influence attitudes toward e-cigarettes, leading many adolescents to experiment with smoking roles to gain acceptance or reinforce their social identity within a group. These social pressures often create a self-perpetuating cycle, integrating e-cigarette use into everyday adolescent life and strengthening both individual and group-level norms (Donaldson et al., 2022).

Peer influence remains one of the most significant factors in determining e-cigarette use among young people. Adolescents whose friends vape are more likely to experiment with and continue using e-cigarettes themselves, highlighting the critical role of social networks in shaping behavior. The e-cigarettes smoking can serve as a marker of social identity, signaling alignment with contemporary youth trends and group membership. In contrast, parental influence appears less impactful, indicating the need for interventions targeting family environments complemented with broader social and peer-focused strategies (Wang et al., 2022). Marketing and social media play a central role in promoting e-cigarette use among adolescents. Online platforms expose young people to constant streams of content from influencers, lifestyle brands, and peers that portray vaping as trendy or socially rewarding (Adekeye & Exten, 2025). Influencer marketing, sponsored posts, and peer-generated content can bypass traditional regulatory restrictions and subtly encourage experimentation among young audiences in persuasive ways. Flavorings, including menthol and fruit options, are especially attractive and are often highlighted in marketing campaigns toward adolescents. Such marketing not only stimulates curiosity and experimentation but also reinforces the perception that e-cigarette use is socially acceptable and desirable behavior (Arora et al., 2025).

E-cigarette use also affects educational outcomes and school functioning. Adolescents who smoke are more likely to experience lower academic performance, higher absenteeism, and disruptions in classroom engagement (Augenstein et al., 2024). These consequences may result from both the cognitive impact of nicotine on attention, memory, and executive function, as well as the behavioral factors associated with substance use. Social interactions at school can also be influenced, with smoking affecting peer dynamics, social hierarchies, and opportunities for inclusion or exclusion. Within families, e-cigarette use can create tension or disengagement, particularly when parents are unaware of the behavior or uncertain about how to respond. Although parental guidance remains important, the influence of peers and social norms often outweighs familial efforts, becoming a stronger factor inducing adolescents behavior (Augenstein et al., 2024; Wang et al., 2022; Arora et al., 2025).

Socioeconomic inequalities further influence patterns of e-cigarette use. Adolescents in lower-income neighborhoods or with less parental education are at higher risk of initiation and continued use, reflecting both increased exposure and susceptibility to targeted marketing. Environmental factors such as neighborhood norms, local availability of products, and social expectations create conditions that reinforce initiation and continued use, highlighting the need for equity-focused public health strategies (Simon et al., 2018).

Beyond these social and structural factors, chronic adolescent nicotine exposure can also have long-term psychosocial consequences. Research in both human and animal models indicates that early nicotine use may contribute to mood disorders, increased anxiety, emotional distress, and cognitive impairments, including working memory deficits and anhedonia-like behaviors (Yuan et al., 2015). These effects can influence social functioning, potentially reducing engagement in school and extracurricular activities, straining peer groups, and negatively impacting overall well-being. Adolescents who use e-cigarettes often report higher levels of unhappiness and social difficulties, suggesting that nicotine use both reflects and reinforces social pressures.

In conclusion, the social implications of adolescent e-cigarette use are complex and excessive. Normalization of nicotine use, peer influence, exposure to social media and marketing strategies progressively

shape behaviors and perceptions, while educational disruptions, family dynamics, and socioeconomic disparities further amplify these social risks. Addressing adolescent e-cigarettes use requires comprehensive strategies that extend beyond physical health, including peer-based interventions, regulation of marketing and flavors, educational support, and targeted efforts to reduce social and economic inequalities. By understanding the broader social context of e-cigarette use, public health initiatives can more effectively mitigate its impact on adolescent development and well-being.

Limitations of Current Evidence

Despite the rapidly expanding body of research on e-cigarette use among adolescents, important limitations remain that must be considered when interpreting current findings. One of the most critical constraints is the lack of long-term, prospective studies. E-cigarettes are relatively recent products, and their widespread uptake among adolescents has occurred primarily over the past decade. As a result, most available studies focus on short-term or intermediate outcomes, such as acute cardiovascular responses, respiratory symptoms, or early neurocognitive and behavioral changes. Many of the most serious health consequences potentially associated with nicotine exposure, such as chronic cardiovascular disease, long-term respiratory impairment, and persistent neuropsychiatric disorders, develop over decades. Consequently, the current evidence base is likely to underestimate the true long-term burden of adolescent e-cigarette use. Longitudinal studies following individuals from adolescence into adulthood are essential to determine causality and fully characterize lifelong health risks.

Another major limitation is the substantial heterogeneity in study methodologies and exposure definitions. Existing research includes a wide range of study designs, including cross-sectional surveys, longitudinal cohorts, experimental studies, and animal models, each with distinct strengths and limitations. Definitions of e-cigarette use vary considerably across studies, encompassing measures such as ever use, current use, frequency, intensity, and device type. In addition, e-cigarette products themselves are highly diverse, differing in nicotine concentration, formulation, flavoring agents, and device power. Rapid technological innovation further complicates interpretation, as findings from earlier generations of e-cigarettes may not be directly applicable to modern high-nicotine pod-based systems commonly used by adolescents today. This heterogeneity limits comparability across studies and challenges efforts to synthesize results into unified conclusions.

A further limitation concerns the widespread reliance on self-reported data. Many epidemiological studies depend on adolescents' self-disclosure of e-cigarette use, nicotine exposure, and health symptoms, which introduces potential recall bias, reporting inaccuracies, and social desirability effects. Adolescents may underreport use due to stigma, parental supervision, or uncertainty regarding product characteristics. Similarly, self-reported health outcomes may lack clinical verification, leading to misclassification or underestimation of adverse effects. Although some studies incorporate objective biomarkers or physiological assessments, such approaches remain relatively uncommon.

Overall, while existing evidence consistently indicates that e-cigarette use poses significant risks to adolescent health, these methodological limitations underscore the need for more standardized, objective, and long-term research to strengthen causal inference and guide effective public health policy.

Future Research Directions

Future research on e-cigarette use among adolescents should focus on addressing current knowledge gaps while adapting to the rapidly evolving landscape of nicotine products and digital influences. A key priority is the implementation of long-term longitudinal studies that follow individuals from early adolescence into adulthood. Such studies are essential for establishing causal relationships between e-cigarette exposure and long-term health outcomes, including cardiovascular disease, respiratory morbidity, cognitive deficits, and mental health disorders. Longitudinal designs would also allow researchers to examine developmental timing effects, patterns of initiation and escalation, persistence of use, cessation, and transitions between exclusive e-cigarette use, dual use, and conventional cigarette smoking. Incorporating objective biomarkers of nicotine and toxicant exposure alongside self-reported data would significantly strengthen causal inference.

Neuroimaging research represents another critical direction. Advanced imaging techniques, including functional magnetic resonance imaging and diffusion-based methods, provide valuable tools for examining how e-cigarette use affects the developing adolescent brain. Future studies should aim to integrate neuroimaging with cognitive, emotional, and behavioral assessments to identify structural and functional changes in brain regions responsible for executive control, reward processing, and emotional regulation.

Longitudinal neuroimaging designs are particularly important to determine whether nicotine-related alterations in neural circuitry are transient or persist into adulthood, potentially predisposing individuals to long-term cognitive or psychiatric vulnerability.

Equally important is the development and evaluation of effective preventive interventions. Future research should prioritize evidence-based, developmentally appropriate prevention strategies targeting adolescents before and during the period of highest vulnerability. School-based programs, family-focused interventions, and peer-led approaches should be rigorously evaluated using controlled study designs. Digital prevention tools, including mobile applications and social media–based educational campaigns, also require systematic assessment to determine their effectiveness, reach, and sustainability.

Finally, the role of emerging technologies, particularly artificial intelligence–driven marketing, warrants urgent investigation. AI-based algorithms used on social media platforms personalize content and advertising, potentially increasing adolescents' exposure to pro-vaping messages. Research examining how such technologies influence attitudes, risk perception, and initiation of e-cigarette use is essential to inform modern regulatory and public health responses.

Conclusions

The widespread use of e-cigarettes among adolescents and young adults represents a significant and complex public health challenge with far-reaching consequences. While initially promoted as a safer alternative to conventional cigarettes or as a smoking cessation aid for adults, e-cigarettes have unintentionally become a primary source of nicotine exposure for youth. Attractive flavors, sleek and discreet device designs, and aggressive marketing on social media platforms have contributed to experimentation and early initiation, normalizing nicotine use among peer groups and reinforcing its social acceptability. These factors, combined with easy access and the perception of reduced harm, have accelerated the development of nicotine dependence in individuals who might never have otherwise used tobacco products.

Adolescence is a uniquely vulnerable period due to ongoing brain maturation, particularly within the prefrontal cortex, which serves executive functions such as decision-making, impulse control, and emotional regulation. Concurrently, the reward system is highly reactive, enhancing sensitivity to pleasurable stimuli and novelty. Nicotine exposure during this critical window disrupts neural development, alters synaptic plasticity, and dysregulates neurotransmitter systems, reinforcing habitual use and increasing susceptibility to other substance use. These neurobiological changes manifest as cognitive deficits, including impaired attention, memory, and learning, as well as increased impulsivity and emotional dysregulation. The potential long-term consequences extend into adulthood, raising the risk of substance use disorders and mood or anxiety disorders.

E-cigarette aerosols also contain multiple toxic components, heavy metals and solvents, which impact cardiovascular and respiratory health. Nicotine stimulates the sympathetic nervous system, elevating heart rate and blood pressure, while other compounds of e-cigarettes promote oxidative stress, endothelial dysfunction, and systemic inflammation. The developing lungs are particularly susceptible, with repeated exposure leading to airway irritation, impaired mucociliary clearance, inflammation, and structural changes, all of which may increase the risk of chronic respiratory disease. Dual use with conventional cigarettes further amplifies these risks, creating a synergistic burden on health.

Addressing adolescent e-cigarette use requires comprehensive, multi-level strategies that integrate regulation, education, and community engagement. Policy measures such as age restrictions, flavor bans, and advertising limits must be coupled with evidence-based prevention programs, peer-led interventions, and equitable public health strategies that address socioeconomic disparities. By targeting both biological vulnerabilities and social determinants of use, such interventions can prevent the establishment of nicotine addiction, reduce long-term health risks, and safeguard the achievements of decades of tobacco control efforts. Without coordinated action, e-cigarettes threaten to create a new generation of nicotine-dependent individuals, undermining public health and adolescent development globally.

REFERENCES

1. Adekeye, O. T., & Exten, C. (2025). Exploring the impact of social media on e-cigarette usage among adolescents: A scoping review. *Journal of Child & Adolescent Substance Use, 30*(4), 141–156. https://doi.org/10.1080/29973368.2025.2488837
2. Arora, M., Kulkarni, M. M., Ghosal, S., Sathyan, A., Gupta, M., Verma, S., Farmer, M., Hadjipanayis, A., Klein, J. D., Winickoff, J., Thacker, N., & Glantz, S. A. (2025). E-cigarettes and the nicotine epidemic: Statement from the International Pediatric Association. *Pediatrics, 156*(5), Article e2025072337. https://doi.org/10.1542/peds.2025-072337
3. Augenstein, J. A., Smaldone, A. M., Usseglio, J., & Bruzzese, J.-M. (2024). Electronic cigarette use and academic performance among adolescents and young adults: A scoping review. *Academic Pediatrics, 24*(2), 228–242. https://doi.org/10.1016/j.acap.2023.09.012
4. Banati, P., Vedechkina, M., De Rubeis, V., Kalai, S., Massaquoi, L., Sadana, R., Baltag, V., & Baird, S. (2025). Adolescent experiences and exposures: A systematic review of life course outcomes. *EClinicalMedicine, 88*, Article 103453. https://doi.org/10.1016/j.eclinm.2025.103453
5. Banks, E., Yazidjoglou, A., Brown, S., Nguyen, M., Martin, M., Beckwith, K., Daluwatta, A., Campbell, S., & Joshy, G. (2023). Electronic cigarettes and health outcomes: Umbrella and systematic review of the global evidence. *The Medical Journal of Australia, 218*(6), 267–275. https://doi.org/10.5694/mja2.51890
6. Becker, T. D., Arnold, M. K., Ro, V., Martin, L., & Rice, T. R. (2021). Systematic review of electronic cigarette use (vaping) and mental health comorbidity among adolescents and young adults. *Nicotine & Tobacco Research, 23*(3), 415–425. https://doi.org/10.1093/ntr/ntaa171
7. Breland, A., Soule, E., Lopez, A., Ramôa, C., El-Hellani, A., & Eissenberg, T. (2017). Electronic cigarettes: What are they and what do they do? *Annals of the New York Academy of Sciences, 1394*(1), 5–30. https://doi.org/10.1111/nyas.12977
8. Casey, B. J., Jones, R. M., & Hare, T. A. (2008). The adolescent brain. *Annals of the New York Academy of Sciences, 1124*(1), 111–126. https://doi.org/10.1196/annals.1440.010
9. Castro, E. M., Lotfipour, S., & Leslie, F. M. (2023). Nicotine on the developing brain. *Pharmacological Research, 190*, Article 106716. https://doi.org/10.1016/j.phrs.2023.106716
10. Cheng, D., Lee, B., Jeffers, A. M., Stover, M., Kephart, L., Chadwick, G., Kruse, G. R., Evins, A. E., Rigotti, N. A., & Levy, D. E. (2025). State e-cigarette flavor restrictions and tobacco product use in youths and adults. *JAMA Network Open, 8*(7), Article e2524184. https://doi.org/10.1001/jamanetworkopen.2025.24184
11. Cheraghi, M., Amiri, M., Omidi, F., Shahidi Bonjar, A. H., Bakhshi, H., Vaezi, A., Nasiri, M. J., & Mirsaeidi, M. (2024). Acute cardiovascular effects of electronic cigarettes: A systematic review and meta-analysis. *European Heart Journal Open, 4*(6), Article oeae098. https://doi.org/10.1093/ehjopen/oeae098
12. de Miranda Schmitz, B., de Miranda Schmitz, F., Prazeres, G. B., & Marchioni, C. (2025). Major pulmonary clinical manifestations of e-cigarette use by adolescents: A scoping review. *Respiratory Medicine, 247*, Article 108281. https://doi.org/10.1016/j.rmed.2025.108281
13. Donaldson, S. I., Dormanesh, A., Perez, C., Majmundar, A., & Allem, J.-P. (2022). Association between exposure to tobacco content on social media and tobacco use: A systematic review and meta-analysis. *JAMA Pediatrics, 176*(9), 878–885. https://doi.org/10.1001/jamapediatrics.2022.2223
14. Ferkol, T. W., Farber, H. J., La Grutta, S., Leone, F. T., Marshall, H. M., Neptune, E., Pisinger, C., Vanker, A., Wisotzky, M., Zabert, G. E., & Schraufnagel, D. E. (2018). Electronic cigarette use in youths: A position statement of the Forum of International Respiratory Societies. *European Respiratory Journal, 51*(5), Article 1800278. https://doi.org/10.1183/13993003.00278-2018
15. Garcia, P. D., Gornbein, J. A., & Middlekauff, H. R. (2020). Cardiovascular autonomic effects of electronic cigarette use: A systematic review. *Clinical Autonomic Research, 30*(6), 507–519. https://doi.org/10.1007/s10286-020-00683-4
16. Jenssen, B. P., Walley, S. C., Boykan, R., Caldwell, A. L., & Camenga, D. (2023). Protecting children and adolescents from tobacco and nicotine. *Pediatrics, 151*(5), Article e2023061804. https://doi.org/10.1542/peds.2023-061804
17. Jones, C. A., Wallace, M. J., Bandaru, P., Woodbury, E. D., Mohler, P. J., & Wold, L. E. (2023). E-cigarettes and arrhythmogenesis: A comprehensive review of pre-clinical studies and their clinical implications. *Cardiovascular Research, 119*(12), 2157–2164. https://doi.org/10.1093/cvr/cvad113
18. Kandel, E. R., & Kandel, D. B. (2014). A molecular basis for nicotine as a gateway drug. *The New England Journal of Medicine, 371*(10), 932–943. https://doi.org/10.1056/NEJMsa1405092
19. Kaur, J., Goel, S., Shabil, M., Rana, R. K., Rinkoo, A. V., Chauhan, A., & Gupta, S. (2025). Health impacts of electronic nicotine delivery systems: An umbrella review of systematic reviews. *BMJ Open, 15*(10), Article e100168. https://doi.org/10.1136/bmjopen-2025-100168

20. Konrad, K., Firk, C., & Uhlhaas, P. J. (2013). Brain development during adolescence: Neuroscientific insights into this developmental period. *Deutsches Ärzteblatt International, 110*(25), 425–431. https://doi.org/10.3238/arztebl.2013.0425
21. Kundu, A., Feore, A., Sanchez, S., Abu-Zarour, N., Sutton, M., Sachdeva, K., Seth, S., Schwartz, R., & Chaiton, M. (2025). Cardiovascular health effects of vaping e-cigarettes: A systematic review and meta-analysis. *Heart, 111*(13), 599–608. https://doi.org/10.1136/heartjnl-2024-325030
22. Larsen, B., & Luna, B. (2018). Adolescence as a neurobiological critical period for the development of higher-order cognition. *Neuroscience & Biobehavioral Reviews, 94*, 179–195. https://doi.org/10.1016/j.neubiorev.2018.08.009
23. Martins, B. N. F. L., Normando, A. G. C., Rodrigues-Fernandes, C. I., Wagner, V. P., Kowalski, L. P., Marques, S. S., Marta, G. N., Castro Júnior, G. de, Ruiz, B. I. I., Vargas, P. A., Lopes, M. A., & Santo-Silva, A. R. (2022). Global frequency and epidemiological profile of electronic cigarette users: A systematic review. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology, 134*(5), 548–561. https://doi.org/10.1016/j.oooo.2022.07.019
24. Mears, M. J., Hookfin, H. L., Bandaru, P., Vidal, P., Stanford, K. I., & Wold, L. E. (2023). Electronic nicotine delivery systems and cardiovascular/cardiometabolic health. *Circulation Research, 132*(9), 1168–1180. https://doi.org/10.1161/CIRCRESAHA.123.321565
25. Reynolds, L. M., Faure, P., & Barik, J. (2025). Adolescent nicotine exposure and persistent neurocircuitry changes: Unveiling lifelong psychiatric risks. *Molecular Psychiatry, 30*(11), 5534–5545. https://doi.org/10.1038/s41380-025-03110-0
26. Rose, J. J., Krishnan-Sarin, S., Exil, V. J., Hamburg, N. M., Fetterman, J. L., Ichinose, F., Perez-Pinzon, M. A., Rezk-Hanna, M., & Williamson, E. (2023). Cardiopulmonary impact of electronic cigarettes and vaping products: A scientific statement from the American Heart Association. *Circulation, 148*(8), 703–728. https://doi.org/10.1161/CIR.0000000000001160
27. Sawyer, S. M., Afifi, R. A., Bearinger, L. H., Blakemore, S.-J., Dick, B., Ezeh, A. C., & Patton, G. C. (2012). Adolescence: A foundation for future health. *The Lancet, 379*(9826), 1630–1640. https://doi.org/10.1016/S0140-6736(12)60072-5
28. Simon, P., Camenga, D., Morean, M., Kong, G., Bold, K. W., Cavallo, D. A., & Krishnan-Sarin, S. (2018). Socioeconomic status (SES) and adolescent e-cigarette use: The mediating role of e-cigarette advertisement exposure. *Preventive Medicine, 112*, 193–198. https://doi.org/10.1016/j.ypmed.2018.04.019
29. Soneji, S., Barrington-Trimis, J. L., Wills, T. A., Leventhal, A. M., Unger, J. B., Gibson, L. A., Yang, J., Primack, B. A., Andrews, J. A., Miech, R. A., Spindle, T. R., Dick, D. M., Eissenberg, T., Hornik, R. C., Dang, R., & Sargent, J. D. (2017). Association between initial use of e-cigarettes and subsequent cigarette smoking among adolescents and young adults: A systematic review and meta-analysis. *JAMA Pediatrics, 171*(8), 788–797. https://doi.org/10.1001/jamapediatrics.2017.1488
30. Stokes, A. C., Xie, W., Wilson, A. E., Yang, H., Orimoloye, O. A., Harlow, A. F., Fetterman, J. L., DeFilippis, A. P., Benjamin, E. J., Robertson, R. M., Bhatnagar, A., Hamburg, N. M., & Blaha, M. J. (2021). Association of cigarette and electronic cigarette use patterns with levels of inflammatory and oxidative stress biomarkers among US adults: Population Assessment of Tobacco and Health Study. *Circulation, 143*(8), 869–871. https://doi.org/10.1161/CIRCULATIONAHA.120.051551
31. U.S. Department of Health and Human Services. (2016). *E-cigarette use among youth and young adults: A report of the Surgeon General*. Centers for Disease Control and Prevention.
32. U.S. Food and Drug Administration. (n.d.). *Generally recognized as safe (GRAS)*. https://www.fda.gov/food/food-ingredients-packaging/generally-recognized-safe-gras
33. Walker, D. M., Bell, M. R., Flores, C., Gulley, J. M., Willing, J., & Paul, M. J. (2017). Adolescence and reward: Making sense of neural and behavioral changes amid the chaos. *Journal of Neuroscience, 37*(45), 10855–10866. https://doi.org/10.1523/JNEUROSCI.1834-17.2017
34. Wang, Y., Duan, Z., Weaver, S. R., Self-Brown, S. R., Ashley, D. L., Emery, S. L., & Huang, J. (2022). Association of e-cigarette advertising, parental influence, and peer influence with US adolescent e-cigarette use. *JAMA Network Open, 5*(9), Article e2233938. https://doi.org/10.1001/jamanetworkopen.2022.33938
35. Yuan, M., Cross, S. J., Loughlin, S. E., & Leslie, F. M. (2015). Nicotine and the adolescent brain. *The Journal of Physiology, 593*(16), 3397–3412. https://doi.org/10.1113/JP270492
36. Zong, H., Hu, Z., Li, W., Wang, M., Zhou, Q., Li, X., & Liu, H. (2024). Electronic cigarettes and cardiovascular disease: Epidemiological and biological links. *Pflügers Archiv: European Journal of Physiology, 476*(6), 875–888. https://doi.org/10.1007/s00424-024-02925-0