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E-Cigarettes: Biological Effects, Addiction Risk, and Public Health Challenges – A Narrative Review

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ABSTRACT

E-cigarettes have gained popularity as an alternative to traditional cigarettes; however, a growing body of research highlights potential health risks associated with their use. Chemical analyses have revealed the presence of toxic organic compounds and heavy metals, the inhalation of which is linked to an increased risk of respiratory diseases, including cancer. This risk may exceed acceptable safety thresholds, particularly with prolonged exposure. Although e-cigarettes exhibit a lower addictive potential compared to traditional cigarettes, their use—especially among adolescents – has been associated with worsening asthma symptoms and a higher frequency of wheezing episodes. Adverse effects on the cardiovascular system have also been demonstrated, along with potential negative outcomes during pregnancy and for fetal development. A clear link has been established between e-cigarette use and EVALI (E-cigarette or Vaping product use-Associated Lung Injury), a severe lung condition related to vaping. While some evidence suggests that nicotine-containing e-cigarettes may aid in smoking cessation, the safety of their use for this purpose remains uncertain.

Aim of study: The aim of the studies presented in the referenced sources is to evaluate the impact of e-cigarettes on health, encompassing various aspects such as addiction potential, toxicity, pregnancy outcomes, effectiveness in smoking cessation, EVALI, effects on the cardiovascular and respiratory systems (including asthma), cancer risk, and smoking initiation.

Keywords: e-cigarettes, EVALI, asthma, COPD, lung cancer, vaping

1. INTRODUCTION

Over the past two decades, the nicotine product market has undergone dynamic transformations, largely due to the emergence and widespread use of electronic cigarettes (e-cigarettes, ENDS – Electronic Nicotine Delivery Systems). These devices, advertised as less harmful alternatives to traditional cigarettes, have gained particular popularity among adolescents and young adults, becoming one of the major public health challenges of the 21st century [1–3]. In the United States, as of 2022, as many as 14.1% of high school students reported using e-cigarettes, and nearly 43.6% of them used these products daily [4].

Although e-cigarettes were introduced to the market as a tool to support smoking cessation, mounting evidence points to their own toxicity, addictive potential, and ability to induce adverse health effects regardless of prior tobacco dependence [5–7]. Studies have shown that the aerosol emitted by e-cigarettes contains numerous toxic compounds, including aldehydes, ultrafine particles, heavy metals, and nicotine—a highly addictive substance [8–11].

The mechanism of action of e-cigarettes involves heating a liquid that contains nicotine, glycerin, propylene glycol, and flavoring agents, leading to the formation of an aerosol inhaled by the user. The complex chemical composition of these liquids and the process of thermal degradation may result in the formation of compounds with carcinogenic, mutagenic, and irritant properties [12–14]. Importantly, many of these substances are not listed among the ingredients disclosed by manufacturers, and user exposure levels depend on device power, heating temperature, liquid composition, and user behavior [15–17].

In light of current data, there are serious concerns regarding the impact of e-cigarettes on the respiratory, cardiovascular, and neurological systems. Reports of EVALI (E-cigarette or Vaping Product Use-Associated Lung Injury) cases [18–19], observations of increased blood pressure and heart rate following aerosol exposure [20], and the potential risk of developmental disorders in adolescents—particularly in the domain of cognitive function [21–23]—raise significant doubts about the safety of these devices, especially when promoted as “less harmful.”

Chemical analyses have confirmed the presence of formaldehyde, acetaldehyde, acrolein, and heavy metals (such as lead, nickel, cadmium, and chromium) in e-cigarette aerosol, often in concentrations similar to or exceeding those found in cigarette smoke [24–27]. Moreover, evidence from in vitro studies and animal models indicates cytotoxic, genotoxic, and pro-inflammatory effects of aerosol components [28–30].

Simultaneously, there is a disturbing trend of new generations—primarily adolescents—becoming addicted to nicotine, despite having previously shown no inclination to use traditional

cigarettes [31–33]. The high bioavailability of nicotine in e-cigarettes, often comparable to or exceeding that of conventional cigarettes [34], contributes to the rapid development of dependence and increases the risk of subsequent use of other forms of tobacco [35–36].

This study aims to provide a comprehensive analysis of the available scientific evidence on the harmfulness of e-cigarettes. It examines data from epidemiological, clinical, and experimental studies regarding toxicity, public health impact, long-term consequences, and the potential role of e-cigarettes as a harm reduction tool. The objective is to present an objective review of recent literature to better understand the health risks associated with the use of these products.

2. MATERIALS AND METHODS

A search of the PubMed database was conducted using relevant keywords to find available studies published up to April 15, 2025. Only articles written in English were included. A preliminary selection of titles and abstracts was made, followed by a full-text review of the relevant publications.

3. RESULTS

3.1 E-cigarettes and The Cardiovascular System

The impact of e-cigarettes on the cardiovascular system is the subject of intensive research, especially in the context of the growing number of users. Although initially promoted as a “less harmful” alternative to tobacco smoking, an increasing body of evidence indicates that e-cigarettes may induce a range of adverse cardiovascular effects, particularly among young individuals and patients with comorbidities.

Studies have shown that even short-term use of e-cigarettes can lead to increased heart rate, elevated blood pressure, and arterial stiffness – all classic risk factors for cardiovascular disease [20, 37, 38]. Exposure to nicotine-containing aerosol and other e-cigarette components, such as aldehydes and heavy metals, may contribute to endothelial dysfunction, arrhythmias, and the development of atherosclerosis [30, 39, 40].

A study by Moheimani et al. demonstrated that even a single use of a nicotine-containing e-cigarette can result in reduced heart rate variability (HRV) and increased oxidative stress [20]. These changes are strongly associated with an elevated risk of cardiovascular mortality. Other studies suggest that e-cigarette aerosol may increase sympathetic activity and reduce parasympathetic tone, which promotes the development of hypertension and heart failure [41, 42].

In animal models, exposure to e-cigarette aerosol has been shown to cause myocardial necrosis, cardiac fibrosis, and vascular dysfunction [30, 43]. In vitro studies, in turn, have demonstrated

that e-cigarette aerosol condensates are cytotoxic to endothelial cells and induce inflammatory responses and oxidative stress, which are recognized as early mechanisms in the pathogenesis of atherosclerosis [44, 45].

In a prospective analysis involving over 100,000 individuals, e-cigarette users had a significantly higher risk of myocardial infarction and angina, even after adjusting for traditional cardiovascular risk factors [46]. Moreover, the common practice of dual use—simultaneous use of e-cigarettes and conventional tobacco products—may lead to synergistic cardiovascular damage [47].

Emerging studies also suggest that even nicotine-free products can negatively affect blood vessels due to flavoring agents and other chemical additives. Some flavors (e.g., cinnamon, menthol) have been shown to be toxic to cardiac and endothelial cells [48, 49].

The cardiovascular effects of e-cigarettes are particularly concerning in the context of young users who previously exhibited no signs of systemic disease. Although the long-term cardiovascular risks remain not fully understood, the accumulated evidence highlights the need for strict regulatory measures and further research in this area [2, 7].

3.2 E-cigarettes and Asthma

The results of numerous studies indicate a significant association between e-cigarette use and the occurrence of asthma symptoms, both in pediatric and adult populations. In a cross-sectional analysis of data from the American Youth Risk Behavior Surveillance System, it was found that high school students using e-cigarettes more frequently reported symptoms of wheezing, shortness of breath, and nighttime coughing compared to those not using these products [50]. Similarly, a study based on data from the National Youth Tobacco Survey showed that current e-cigarette use was associated with a significantly higher risk of self-reported asthma, as well as worsening of asthma symptoms in US adolescents [51].

Cohort analyses suggest that e-cigarettes may also increase the risk of developing asthma in previously healthy individuals. A study involving more than 21,000 adult e-cigarette users in South Korea revealed a significantly higher incidence of asthma diagnosis and hospitalizations due to asthma exacerbations among current and former e-cigarette users compared to individuals who had never used ENDS [52]. Similar results were obtained in analyses from Canada and the United States, where e-cigarette use correlated with worsening lower respiratory symptoms and an increased risk of asthma diagnosis, even after adjusting for tobacco smoking as a confounding factor [53].

From a biological mechanism perspective, e-cigarette aerosol contains numerous irritants and pro-inflammatory substances such as aldehydes, heavy metals, and ultrafine particles, which can lead to damage to the respiratory epithelium, increased production of pro-inflammatory cytokines (including IL-6, IL-8, TNF-α), and oxidative stress [5, 58]. In vitro studies confirm that e-cigarette condensates can enhance the inflammatory response and impair the epithelial barrier in the airways, promoting the development of chronic inflammatory conditions characteristic of asthma [6].

Animal studies have shown that exposure to e-cigarette aerosol induces histopathological changes in the bronchi, increased inflammatory infiltration, and airway hyperreactivity—typical features of an asthmatic pattern [54]. Notably, a synergistic effect of nicotine and flavoring substances in e-liquids was also observed, suggesting potentially greater toxicity of certain flavored products [29].

Overall, the results of existing studies suggest that e-cigarette use may both increase the risk of developing asthma in previously healthy individuals and exacerbate the disease course in already diagnosed patients. Although many analyses are based on observational rather than prospective data, the growing body of epidemiological, experimental, and molecular evidence supports the harmful impact of these products on the function of the lower respiratory tract.

3.3 E-cigarettes and COPD

Chronic obstructive pulmonary disease (COPD) is a progressive, irreversible respiratory condition characterized by airflow limitation and chronic inflammation. Traditionally, the main risk factor for COPD was tobacco smoking; however, in recent years, there has been growing interest in the potential role of e-cigarettes in the pathogenesis and progression of this disease.

Studies have shown that e-cigarette aerosol contains a range of irritating and toxic substances that may contribute to the development of COPD. These products induce oxidative stress and inflammation in the airways, as observed both in vitro and in animal models [6,29]. Exposure to e-cigarettes resulted in increased expression of pro-inflammatory cytokines (e.g., IL-6, IL-8) and damage to the bronchial epithelium, which may lead to the chronic inflammation characteristic of COPD [28].

An epidemiological analysis of population-based data from the United States revealed that e-cigarette users have a significantly higher risk of being diagnosed with COPD compared to non-users of any nicotine products, even after adjusting for a history of conventional cigarette smoking [62]. Additionally, e-cigarette users who had previously been smokers do not show

full improvement in lung function after switching to vaping, suggesting continued damage to the airways [63].

Cross-sectional and prospective studies have shown that e-cigarette users are more likely to report symptoms of chronic cough, wheezing, and shortness of breath compared to those who do not use any tobacco products, with these symptoms correlating with the frequency of use [64,1]. At the same time, exposure to e-cigarettes disrupts mucociliary clearance mechanisms and promotes airway remodeling—processes that are crucial in the pathogenesis of COPD [65]. Although some studies suggest that e-cigarettes may be a "less harmful" alternative for tobacco smokers, the data indicate that their long-term use can still lead to lung damage typical of COPD. Thus, they cannot be considered safe in terms of respiratory health, especially for individuals with existing risk factors.

3.4 EVALI

In 2019, the United States witnessed a sharp increase in cases of severe lung damage associated with the use of e-cigarettes or vaping products, which led to the definition of a new clinical syndrome – EVALI (E-cigarette or Vaping product use-Associated Lung Injury). By January 2020, over 2,800 hospitalized cases and 68 deaths related to this condition were identified [18]. The clinical presentation of EVALI is nonspecific, but most commonly includes respiratory symptoms (cough, shortness of breath, chest pain), systemic symptoms (fever, chills, fatigue), and gastrointestinal symptoms (nausea, vomiting, diarrhea). Radiologically, bilateral ground-glass opacities on computed tomography dominate, suggesting damage to the pulmonary alveoli [59].

Autopsy and histopathological studies have described the presence of alveolar damage with foam macrophages and lipid material in the alveoli, initially leading to the hypothesis of a "lipid inflammatory lung disease." However, later studies indicated that a more likely etiological factor is vitamin E acetate (VEA), used as a thickening agent in illegal THC-containing products [19, 28].

Analysis of bronchoalveolar lavage (BAL) fluid samples from patients with EVALI revealed the presence of VEA in 94% of cases, confirming its role in the pathogenesis of the condition [60]. At the same time, infectious agents were excluded as the predominant cause, and corticosteroid treatment was effective in most cases, suggesting an inflammatory mechanism [61].

Epidemiologically, EVALI primarily affected young adults (average age 24) and teenagers, with a predominance of males. As many as 82% of patients reported using products containing

THC, and 57% used nicotine e-cigarettes, often sourced from illegal outlets [18]. After preventive measures were implemented, including informational campaigns and the removal of products containing VEA, the number of new EVALI cases significantly decreased.

EVALI serves as an example of acute, severe lung injury induced by vaping products and highlights the need for strict regulation of the e-cigarette market, particularly products containing THC and chemical additives.

3.5 E-cigarettes and Respiratory Infections

Many researchers have attempted to understand the impact of e-cigarettes on the respiratory system, especially in terms of susceptibility to respiratory infections. E-cigarettes contain an aerosol composed of various chemicals, such as nicotine, vegetable glycerin, propylene glycol, and a range of other flavor additives, which can affect the functioning of the respiratory immune system, consequently increasing the risk of infections.

In vitro studies have shown that exposure to e-cigarettes causes changes in the function of airway epithelial cells, including a reduction in their ability to respond immunologically to pathogens. Decreased activity of epithelial cells may contribute to an increased risk of infections, including viral and bacterial infections [6,29]. Studies also suggest a negative impact of e-cigarettes on the respiratory microbiome, which can lead to disturbances in the microflora balance and promote the development of infections [28].

Additionally, animal studies have shown that exposure to e-cigarette aerosol reduces the body's ability to fight viral infections, such as influenza [66]. These studies suggest that inhaling substances found in e-cigarettes weakens the immune response, making the body more susceptible to viral infections [64]. In clinical studies involving humans, e-cigarette users reported more frequent upper respiratory tract infections compared to non-users [63].

Furthermore, other studies suggest that e-cigarettes may alter the immune response to bacteria, including *Streptococcus pneumoniae* and *Haemophilus influenzae*, two major pathogens responsible for pneumonia and other lower respiratory tract infections. E-cigarette users are at a higher risk of developing such infections than individuals who have never smoked tobacco [62,21]. Similar to viral infections, in the case of bacterial infections, e-cigarettes may impair the protective abilities of the airways, making it easier for pathogens to spread within the respiratory system [8].

In conclusion, e-cigarettes may weaken the immune response to respiratory infections, increasing the risk of both viral and bacterial infections. Further research is necessary to better

understand the mechanisms underlying these changes and to accurately determine the extent to which e-cigarettes contribute to the increased risk of infections.

3.6 E-cigarettes and Oral Health

Based on research studies, it can be stated that e-cigarettes have a significant and potentially harmful effect on oral health, although the extent and mechanisms of these interactions are still under investigation. The aerosol produced by e-cigarettes contains numerous chemical compounds, including nicotine, aldehydes (e.g., formaldehyde, acrolein), heavy metals, and other toxic molecules that may have both direct and indirect effects on oral tissues [71-76].

One of the main mechanisms by which e-cigarettes affect oral health is the alteration of the microbiome. Studies have shown that e-cigarette users have an imbalanced oral microbiota, with a predominance of opportunistic and pro-inflammatory bacteria such as *Porphyromonas gingivalis* and *Fusobacterium nucleatum*. This disruption of homeostasis can lead to the development of periodontal tissue inflammation and contribute to the progression of periodontitis [71, 72]. Moreover, the aerosol from e-cigarettes can increase the expression of pro-inflammatory cytokines such as IL-1β, IL-6, and TNF-α, which activates a local inflammatory response [72, 73].

E-cigarettes also affect the integrity of the oral epithelium. Epithelial cells exposed to aerosol show increased apoptosis and reduced regenerative capacity, weakening the mucosal barrier and increasing susceptibility to infections and mechanical injuries [73, 74]. There has also been an observed increase in free radical levels and oxidative stress in the mucosal cells, which further worsens their condition [72, 73].

The use of e-cigarettes may also disrupt the quantity and composition of saliva. Reduced saliva secretion and changes in its enzymatic composition can lead to dry mouth (xerostomia), which is a risk factor for tooth decay, fungal infections, and mucosal damage [73, 74]. Additionally, e-liquid components, especially sweetened flavors, may lower the pH in the mouth, promoting enamel demineralization and the development of cavities [75].

A systematic review and meta-analysis indicate that e-cigarette users have higher rates of gum bleeding, greater pocket depth, and increased loss of epithelial attachment compared to non-smokers, although these indicators are generally lower than those of traditional cigarette smokers [76]. Nevertheless, these data suggest that e-cigarettes are not neutral for the periodontium, and their long-term use may lead to chronic diseases of the supporting tissues of the teeth.

E-cigarettes negatively affect many aspects of oral health—ranging from microbiological changes, induction of inflammatory processes, to structural and functional damage to the mucosa. While often perceived as a less harmful alternative to traditional cigarettes, their impact on the oral cavity may lead to significant clinical consequences. Further research, particularly long-term cohort studies and mechanistic investigations, is essential to fully understand their effects.

3.7 E-cigarettes and Pregnancy

The growing interest in the potential impact of e-cigarettes on the health of pregnant women and fetal development has led to the emergence of numerous studies assessing the toxicity of e-cigarette aerosol in the prenatal context. Although e-cigarettes are often perceived as a "safer alternative" to traditional tobacco products, their use during pregnancy raises serious concerns due to the presence of nicotine and other harmful substances.

It has been shown that nicotine crosses the placenta, and fetal exposure to its effects can lead to impaired neurological development, increased risk of miscarriage, preterm birth, and low birth weight. In vivo studies have demonstrated that exposure of pregnant mice to e-cigarette aerosol results in disturbances in lung and brain development in offspring, suggesting potentially negative effects in humans as well [55].

Epidemiological studies indicate that pregnant women who use e-cigarettes often perceive them as less harmful than traditional cigarettes, despite the lack of conclusive evidence on their safety. In an analysis of data from U.S. population studies, it was estimated that about 5-7% of pregnant women reported using e-cigarettes during pregnancy, with the highest percentage of users being younger women, white, and with lower education levels [56, 57].

It has also been shown that fetal exposure to e-cigarettes can modulate the immune response and increase the risk of respiratory diseases after birth. Crotty Alexander et al. observed in animal models that offspring of exposed mothers exhibited increased inflammatory responsiveness in the airways and impaired local immunity, which may result in increased susceptibility to infections in newborns [58].

Additionally, some studies suggest that flavoring agents used in e-cigarettes, although seemingly harmless, may have teratogenic or embryotoxic effects. Sassano et al. demonstrated that flavoring ingredients in many popular e-cigarette liquids cause cytotoxicity to human cells in vitro, which in the context of pregnancy may pose a potential threat to the developing fetus [29].

Despite the growing body of preclinical and epidemiological evidence, there is still a lack of randomized clinical trials regarding the safety of e-cigarettes during pregnancy, making it difficult to formulate clear guidelines. However, based on the current state of knowledge, public health organizations such as the CDC and ACOG unanimously advise against the use of e-cigarettes by pregnant women, emphasizing the risks associated with exposure to nicotine and other toxic components of the aerosol.

3.8 E-cigarettes and Smoking Cessation

E-cigarettes have been widely promoted as an alternative to traditional cigarettes, particularly in the context of aiding smoking cessation. There are numerous studies suggesting that their use may help smokers reduce the number of cigarettes smoked or even quit traditional smoking entirely. However, the effectiveness of e-cigarettes in smoking cessation and their potential health effects remain controversial.

Some studies indicate that e-cigarettes may be an effective alternative to nicotine replacement therapy (NRT), particularly in cases where smokers have not succeeded with other methods. In a study by Romberg et al. (2022), it was found that nicotine-containing e-cigarettes could aid in achieving short-term smoking cessation, especially when used in conjunction with appropriate behavioral therapy [3]. Similar results were found in the study by Goniewicz et al. (2013), who suggested that e-cigarettes could effectively reduce the number of cigarettes smoked, and in some cases even lead to quitting smoking, at least in the short term [24].

However, it is important to note that the long-term effectiveness of e-cigarettes in helping people quit smoking remains unclear. In some cases, e-cigarette users may return to traditional cigarettes. This phenomenon may be related to the continued addiction to nicotine. Studies indicate that younger individuals who begin using e-cigarettes may struggle to quit smoking entirely, which could lead to the development of nicotine addiction [7].

Additionally, some studies suggest that e-cigarettes may act as a trap for those trying to quit, as they can lead to "dual use," meaning the simultaneous use of both e-cigarettes and traditional cigarettes. In this case, the effectiveness of e-cigarettes in helping people quit smoking may be significantly reduced [9]. Furthermore, there are concerns that e-cigarettes may contribute to further nicotine addiction, even if the smoker does not return to traditional cigarettes [10].

On the other hand, other studies suggest the possibility of using e-cigarettes to satisfy nicotine cravings without the need to smoke traditional cigarettes, which may help in transitioning from tobacco addiction to reduced nicotine consumption [31]. There is also a hypothesis that e-cigarettes could serve as a less harmful alternative to smoking traditional cigarettes, at least in

terms of the risk of exposure to chemicals such as tar and carbon monoxide, which are present in cigarette smoke [26].

Despite the potential benefits of reducing risks compared to traditional cigarettes, e-cigarettes carry other health risks. It is important to note that many e-cigarettes contain chemicals whose long-term effects on health are still unknown. E-cigarette users are exposed to inhaling substances that may cause harmful effects in the body, and some of these substances may have carcinogenic or toxic properties [28].

In conclusion, while e-cigarettes may be an effective method for aiding smoking cessation, their long-term effectiveness and safety require further, detailed research. E-cigarettes may serve as a transitional step in the smoking cessation process, but their full potential and health risks remain subjects of ongoing analysis.

3.9 Gateway Effect

The so-called "gateway effect" refers to the theory that the use of one substance (e.g., e-cigarettes) could lead to the use of other substances, including traditional cigarettes. In the context of e-cigarettes, the gateway effect suggests that their use might be the first step toward smoking traditional cigarettes, particularly among younger users who were not previously smokers. There is controversy in the scientific literature regarding this phenomenon, and studies on the impact of e-cigarettes on smoking initiation show mixed results.

Many researchers point to a potential link between e-cigarette use and an increased likelihood of starting to smoke traditional cigarettes, especially among adolescents and young adults. A study by Soneji et al. (2017) found that individuals who used e-cigarettes were more likely to transition to traditional cigarettes compared to those who had no exposure to e-cigarettes [22]. Similarly, research by Choi and Kim (2016) suggested that youth who used e-cigarettes were more prone to taking up regular smoking of traditional cigarettes in the future [67].

Other studies have shown that e-cigarettes may serve as a bridge between smoking tobacco and alternative nicotine products, potentially leading to further exposure to harmful substances and, consequently, nicotine addiction. However, not all studies confirm these observations. A study by Goniewicz et al. (2014) did not find a clear link between e-cigarette use and an increased risk of smoking traditional cigarettes. The researchers suggested that while e-cigarettes might serve as a precursor to smoking, they could also act as an alternative for those who already smoke, helping them reduce the harms associated with smoking [16].

In 2020, a study by Fairchild et al. focused on evaluating the role of e-cigarettes in smoking initiation among teenagers. The authors stated that although e-cigarettes may pose a risk in

terms of smoking initiation, their role in this process is not as clear-cut as it is often presented in the public debate. E-cigarettes may attract young users but do not always lead to later smoking of traditional cigarettes [68].

Despite this controversial issue, there is also a hypothesis that e-cigarettes could serve as a less harmful alternative to smoking traditional cigarettes, at least in terms of the risk of exposure to chemicals like tar and carbon monoxide, which are present in cigarette smoke [31].

3.10 E-liquids Containing THC

The use of e-cigarettes to inhale substances other than nicotine liquids, such as THC (tetrahydrocannabinol), is becoming increasingly common. This practice presents a new public health challenge because e-cigarettes were originally designed for nicotine delivery, not for other psychoactive substances. Although research on the impact of smoking THC using e-cigarettes is still in its early stages, there are several concerns related to safety and potential health risks.

First, some studies suggest that using e-cigarettes to vape THC may involve the inhalation of toxic chemicals. During the global e-cigarette crisis in 2019, known as EVALI (electronic-cigarette or vaping-associated lung injury), some cases involved individuals using e-cigarettes to smoke THC liquids. Many of these liquids contained additives such as vitamin E acetate, which was recognized as a potentially toxic substance causing severe lung damage [19]. Furthermore, THC itself can have negative effects on lung health, especially when subjected to heating, which leads to the formation of chemicals that may irritate the airways and cause inflammation [28].

Another risk associated with using e-cigarettes to vape THC is the potential increase in addiction risk. THC, like nicotine, is a psychoactive substance that can lead to addiction, particularly with regular use. Using e-cigarettes for vaping THC may contribute to faster addiction, especially among youth and those who have not previously used marijuana [69]. Additionally, e-cigarettes may make THC more accessible and discreet, leading to more frequent consumption.

Long-term use of THC, regardless of the form, can also affect the mental health of users. There is substantial evidence that regular use of THC may lead to memory and concentration problems and increase the risk of developing mental health disorders, such as depression and anxiety [70]. Using THC in the form of e-cigarettes could amplify these risks because it allows for faster absorption of the substance into the body, intensifying its psychoactive effects.

Another issue is the lack of appropriate regulations regarding e-cigarettes used to vape substances other than nicotine, including THC. In many countries, e-cigarettes are not designed for this type of use, which can lead to the sale of unsafe products that have not been tested for safety. As a result, individuals using e-cigarettes to vape THC may be exposed to chemicals that are not officially approved for use in inhalation devices [26].

In conclusion, the use of e-cigarettes to inhale substances other than nicotine, including THC, carries several health risks that require further investigation. Increased risks of lung damage, addiction, and mental health effects are just a few of the potential consequences. Moreover, the lack of regulation and quality control for such products may lead to additional health problems. In light of these challenges, it is crucial to introduce appropriate regulations that will protect users from the potential dangers associated with these practices.

4. DISCUSSION AND CONCLUSIONS

In recent years, e-cigarettes have become one of the most commonly used nicotine products, particularly among adolescents and young adults. This trend is driven by their accessibility, variety of flavors, aggressive marketing campaigns, and the perception of being a "healthier" alternative to traditional tobacco smoking. Although they do not produce tobacco smoke and contain fewer tar substances than conventional cigarettes, numerous in vitro, in vivo, and observational studies provide growing evidence of their harmful effects on human health.

E-cigarette aerosol, in addition to nicotine, contains glycerin, propylene glycol, heavy metals (including nickel, lead, cadmium, and chromium), volatile organic compounds (such as formaldehyde, acetaldehyde, and acrolein), and flavoring agents that can degrade into toxic by-products under high temperatures. While their concentrations are generally lower than in tobacco smoke, long-term exposure – especially with intensive use – may lead to respiratory epithelial damage, inflammation, increased oxidative stress, and endothelial dysfunction.

Findings from clinical and experimental studies indicate that e-cigarettes are not harmless to the cardiovascular system – they may increase blood pressure, accelerate heart rate, and impair vascular function. In the respiratory system, increased cytotoxicity, epithelial irritation, ciliary dysfunction, and chronic inflammation have been observed, which may predispose users to asthma, COPD, and respiratory infections. Notably, some cases of acute respiratory failure, known as EVALI (e-cigarette or vaping product use-associated lung injury), pose a direct threat to life, especially in the context of inhaling THC-containing products and vitamin E acetate.

One of the most serious concerns is the impact of e-cigarettes on nicotine addiction, particularly in individuals who have not previously used tobacco products. New-generation products, such

as Juul, contain nicotine salts with high bioavailability and rapid absorption, resulting in a strong addictive potential comparable to traditional cigarettes [18–20]. Population studies have shown that adolescents using e-cigarettes are several times more likely to initiate conventional cigarette smoking in the future.

Additionally, an increasing body of evidence suggests that e-cigarettes may affect neurological, immunological, and metabolic functions. They have been shown to influence dopaminergic neurotransmission, which is significant in the context of addiction, and modulate immune responses by altering pro-inflammatory cytokine expression and immune cell function.

Environmental contamination is also a relevant issue—waste in the form of used cartridges and batteries may pose a threat to ecosystems, a concern rarely addressed in public discourse.

In light of the above findings, e-cigarettes should not be regarded as a harmless alternative to smoking. While they may serve as a harm-reduction tool for tobacco-dependent individuals, their use among non-smokers – especially youth – carries significant health risks.

This literature review demonstrates that although e-cigarettes contain fewer tar substances than traditional cigarettes, they are not free of toxicity and can negatively impact various organ systems, particularly the respiratory, cardiovascular, and nervous systems. The presence of irritants, potentially carcinogenic compounds, and highly addictive nicotine raises serious concerns about their safety, particularly with long-term use.

E-cigarettes have been found to impair endothelial function, induce oxidative stress, promote inflammation, and cause immunological dysfunctions. Moreover, their use among adolescents is strongly associated with an increased likelihood of initiating tobacco smoking, which may undermine progress in tobacco control and prevention.

Given the available evidence, it is crucial to implement effective legal regulations to limit youth access to these products, standardize their chemical composition, and conduct further long-term observational studies. Public health policy should clearly communicate the potential risks associated with e-cigarette use, counter youth-targeted marketing strategies, and support cessation interventions based on products with proven safety profiles.

In conclusion, e-cigarettes are not safe and should not be promoted as a completely harmless alternative to smoking. Their role in health policy must be carefully considered, taking into account not only potential benefits in harm reduction but also the real and significant health risks they pose.

5. Disclosure

Author's Contribution:

Conceptualization: KT, DK

Methodology: NS, KM

Formal analysis: DL, KT, MS

Investigation: VM, AM, VK

Writing-rough preparation: IK, DL, MS

Writing-review and editing: DK, KT

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