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REVIEW PAPER/*PRACA POGLĄDOWA*

Harmfulness of e-cigarettes

Szkodliwość e-papierosów

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ABSTRACT

The rapid proliferation of electronic cigarettes, often referred to as e-cigarettes, has sparked a global debate about their safety and the potential health risks they pose. Promoted as a safer alternative to traditional tobacco smoking, e-cigarettes have garnered a substantial following. However, mounting evidence suggests that they are not without harm. This comprehensive article delves into the harmfulness of e-cigarettes and the e-liquids they use.

KEY WORDS

e-cigarettes, e-liquids, tobacco, propylene glycol, nicotine.

STRESZCZENIE

Szybki rozwój papierosów elektronicznych, często nazywanych e-papierosami, wywołał ogólnoświatową debatę na temat ich bezpieczeństwa i potencjalnych zagrożeń dla zdrowia. E-papierosy, promowane jako bezpieczniejsza alternatywa dla tradycyjnego palenia tytoniu, zyskały znaczną rzeszę zwolenników. Jednak coraz więcej dowodów sugeruje, że nie są one pozbawione szkód. W tym obszernym artykule omówiono szkodliwość e-papierosów i używanych przez nie e-liquidy.

SŁOWA KLUCZOWE

e-papierosy, e-liquidy, tytoń, glikol propylenowy, nikotyna.

ADDRESS FOR CORRESPONDENCE

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INTRODUCTION

Electronic cigarettes, commonly known as e-cigarettes, have become a pervasive part of modern society. Marketed as a safer alternative to traditional tobacco cigarettes, they have gained popularity, particularly among young people. However, as the use of e-cigarettes has surged, concerns have also grown regarding their potential harm to health. This article will provide an in-depth exploration of the harmfulness of e-cigarettes and the e-liquids they utilize, while substantiating the claims with references to scientific studies and reputable sources. By the end of this article, readers should have a comprehensive understanding of the health risks associated with e-cigarette use.

E-CIGARETTES: A BRIEF OVERVIEW

Electronic cigarettes, or e-cigarettes, are battery-operated devices that vaporize a liquid solution, often referred to as e-liquid, to create an aerosol that is inhaled by the user. These devices were initially introduced as a smoking cessation aid, aiming to provide a less harmful alternative to traditional tobacco cigarettes. However, they have evolved into a booming industry with a wide range of products, including disposable e-cigarettes, refillable vaporizers, and various flavors of e-liquids.

E-CIGARETTES CONSTRUCTION

E-cigarettes are typically comprised of a battery, an atomizer, and a cartridge or tank for e-liquids. These devices work by heating the e-liquid, turning it into an aerosol that users inhale. Understanding the mechanics of e-cigarettes is essential for evaluating their potential harm [1] (Figure 1).

INGREDIENTS OF E-LIQUIDS

E-liquids typically contain nicotine, flavorings, propylene glycol (PG), and vegetable glycerin (VG). Each of these components plays a role in the composition and potential health risks of e-liquids [2].

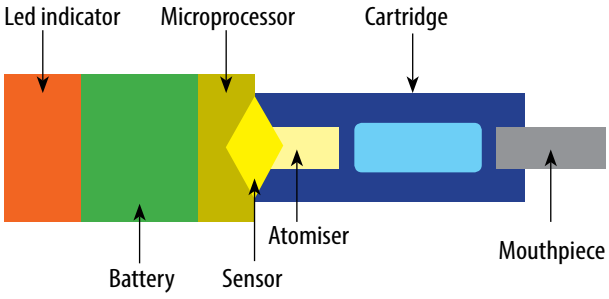

FIGURE 1. Construction of an e-cigarette

Nicotine, a highly addictive substance found in both traditional tobacco and e-cigarettes, is the primary component of e-liquids. Nicotine is a naturally occurring alkaloid found in the tobacco plant (Nicotiana tabacum) In e-cigarettes, nicotine is typically derived from tobacco leaves, although synthetic nicotine is also used [3, 4]. Nicotine addiction can lead to dependence and withdrawal symptoms, making it challenging for users to quit [5].

E-liquids come in a wide range of flavors, making them attractive to users. A study by Khlystov and Samburova found that the heating of e-liquids can produce harmful chemicals from flavorings, potentially affecting the respiratory system [6]. Diacetyl, a buttery flavoring, is known to be associated with a severe lung condition called "popcorn lung" [7].

PG and VG are commonly used as carrier liquids in e-liquids. PG is a colorless, odorless, and nearly tasteless liquid that is commonly used in e-cigarette and vape products. It serves several crucial functions: PG is known for its ability to carry and disperse flavorings effectively in e-liquids. It plays a key role in delivering the desired taste to the user [8].

PG contributes to the "throat hit", which is a sensation resembling the feeling of smoking traditional cigarettes. This is an important aspect for some users, as it mimics the experience of smoking combustible tobacco [9].

Studies by Schober *et al.* have shown that these substances, when heated, can release volatile organic compounds, some of which may pose health risks when inhaled [10]. All liquids consist of up to > 90% of the humectants 1,2-propanediol (mean ± SD, 559.2 ±51.5 g/l) and glycerin (480.3 ±41.0 g/l). Nicotine levels (22 ±0.8 mg/ml) were on average 22% above the manufacturers' declaration of 18 mg/ml, but liquids labeled as nicotine-free had no nicotine present [10].

PG has a relatively thin consistency compared to VG, the other common base used in e-liquids. The thinner consistency makes it easier for PG-based e-liquids to be absorbed by the wicking material in the atomizer and vaporized when heated [11, 12].

VG is another primary component used in e-cigarettes and e-liquids, serving as a base and contributing to vapor production. VG is a thicker, sweeter, and less viscous liquid compared to PG, which is the other common base in e-liquids [13]. VG is primarily responsible for producing dense vapor clouds when e-liquids are heated. This characteristic is appealing to many vapers who enjoy creating thick vapor [14]. It provides a smoother and less harsh throat hit compared to PG. This can be a desirable attribute for users who prefer a milder sensation [15].

VG can carry flavors, although not as efficiently as PG. It is often used in combination with PG to balance vapor production and flavor intensity [15].

While they are generally recognized as safe for ingestion, their safety when inhaled is a matter of debate. Research has shown that when heated, these substances can produce harmful compounds, including formaldehyde and acrolein, which can be detrimental to lung health [16].

THE GLOBAL RISE IN E-CIGARETTE USE

E-cigarette use has seen a significant surge, especially among young people. A study published in *JAMA Pediatrics* in 2019 reported that e-cigarette use among high school students in the United States increased by 78% (from 11.7% to 20.8%, $p < 0.001$) from 2017 to 2018, raising concerns about the long-term health impacts, particularly among youth [17].

Research by Marynak *et al.* has demonstrated that youth exposure to e-cigarette advertising is associated with an increased likelihood of e-cigarette use, raising concerns about the industry's role in promoting these products to young consumers [18].

The World Health Organization (WHO) reported that there were over 41 million e-cigarette users globally in 2018. Vaping has increased from around 7 million users in 2011 to 41 million in 2018. However, these numbers are likely to have increased over the years, given the trend in rising e-cigarette use [19].

E-CIGARETTE USE IN THE EUROPEAN UNION

Usage of e-cigarettes among adults was 6% in 2022 according to the Healthy Ireland Survey, with 3% vaping daily and 3% occasionally. Among children, the 2018 Health Behaviour in School Aged Children survey showed that 9% had used an e-cigarette within the last 30 days and 22% had ever tried one. The European Schools Project on Alcohol and other Drugs 2019 Survey shows that 15.5% of 15–16-year-olds reported using an e-cigarette in the last 30 days [20].

E-CIGARETTE USE IN POLAND

Poland had a relatively high prevalence of e-cigarette use among EU member states. The Polish Public Opinion Research Center (CBOS) reported that in 2020, 18% of Poles aged 15 and older had used e-cigarettes. This made Poland one of the countries with a higher prevalence of e-cigarette use in the EU [21, 22]. The prevalence of daily e-cigarette use was 4.8% (4.0% among females and 5.6% among males; $p = 0.2$). The prevalence of e-cigarette use among adults in Poland, $n = 1090$ [23].

In September 2019, the prevalence of smoking among Poles aged 15 and over was 22.3% (19.1% of females (18% daily smokers and 1.1% occasional smokers) and 25.9% (24.4% daily smokers and 1.5% occasional smokers) of males; $p = 0.01$) (Table 1) [24–31].

HEALTH IMPLICATIONS OF E-CIGARETTE USE

RESPIRATORY COMPLICATIONS

E-cigarette use has been associated with various respiratory issues. A study by Polosa *et al.* suggested that e-cigarette aerosol can irritate the airways and potentially lead to chronic obstructive pulmonary disease (COPD) and asthma [32]. Several studies, such as the one by Gotts *et al.* have highlighted that inhaling e-cigarette aerosol can lead to lung inflammation, acute lung injury, and COPD. This indicates a potential risk for e-cigarette users, particularly those with pre-existing respiratory conditions [33].

E-cigarette aerosols can contain harmful substances, including propylene glycol and vegetable glycerin. When these substances are heated and inhaled, they can lead to inflammation in the lungs. This inflammation is linked to various respiratory issues [34].

E-cigarette use has been associated with a decrease in lung function, as measured by reduced forced expiratory volume in 1 s (FEV1) and forced vital capacity (FVC). This decline in lung function can affect the ability to breathe effectively [35].

E-cigarette use can impair the immune system in the respiratory tract, making individuals more susceptible to respiratory infections. Vaping has been associated with a higher risk of pneumonia, bronchitis, and other respiratory illnesses [36].

Individuals with preexisting respiratory conditions, such as asthma or COPD, are particularly vulnerable to the harmful effects of e-cigarettes. Vaping can exacerbate these conditions, leading to worsened symptoms and increased healthcare utilization [33].

E-cigarette aerosols often contain harmful chemicals, such as formaldehyde, acetaldehyde, and acrolein, which are known respiratory irritants and can damage lung tissue [37].

It is important to note that while e-cigarettes may be considered less harmful than traditional tobacco smoking, they are not without risks, especially to the respiratory system. Long-term health effects are still being studied, but the evidence suggests that e-cigarette use should not be considered a safe alternative, particularly for young people and non-smokers [38].

CARDIOVASCULAR RISKS

E-cigarettes are not only harmful to the respiratory system but also to the cardiovascular system. Several studies have linked e-cigarette use to an increased risk of heart

TABLE 1. Epidemiology of e-cigarette use

Variable	Worldwide	European Union	Poland
Prevalence	E-cigarette use has been on the rise worldwide, particularly among young people. The prevalence varies from country to country, with some nations experiencing a rapid increase in usage [21]. The results of studies showed that the lifetime and current prevalence of e-cigarette vaping were 23% (with a confidence interval (CI) of 95%: 21–25%) and 11% (95% CI: 10–11%). The lifetime and current prevalence of e-cigarette vaping among women were 16% (95% CI: 15–18%) and 8% (95% CI: 0.07–0.08%), respectively (Figure 3). Also, the lifetime and current prevalence of e-cigarette vaping among men were 22% (95% CI: 20–25%) and 12% (95% CI: 11–13%), respectively. The lifetime prevalence of e-cigarette vaping among adolescents and school students, adults, college students, and patients was 25% (95% CI: 21–30%), 19% (95% CI: 17–21%), 26% (95% CI: 15–37%), and 29% (95% CI: 16–43%), respectively. Also, the current prevalence of e-cigarette vaping among adolescents and school students, adults, college students, and patients was 11% (95% CI: 10–12%), 11% (95% CI: 10–12%), 14% (95% CI: 7–22%), and 10% (95% CI: 8–11%), respectively. The lifetime prevalence of e-cigarette vaping in the continents of America, Europe, Asia, and Oceania was 24% (95% CI: 21–27%), 26% (95% CI: 21–31%), 16% (95% CI: 11–20%), and 25% (95% CI: 18–33%), respectively. The current prevalence of e-cigarette vaping in the continents of America, Europe, Asia, and Oceania was 10% (95% CI: 9–10%), 14% (95% CI: 10–17%), 11% (95% CI: 10–11%), and 6% (95% CI: 4–8%), respectively. According to the type of study, the lifetime prevalence of e-cigarette vaping in cohort studies and cross-sectional studies was 28% (95% CI: 11–45%) and 23% (95% CI: 21–25%), respectively (Figure 5). Also, based on the type of study, the current prevalence of e-cigarette vaping in cohort studies and cross-sectional studies was 13% (95% CI: 11–16%) and 11% (95% CI: 10–11%). respectively [24].	E-cigarette use in the EU has been increasing, but prevalence rates varied between member states. Some countries have had higher usage rates than others [22]. The prevalence of ever use of e-cigarettes increased from 7.2% in 2012 to 11.6% in 2014 (adjusted OR (aOR) = 1.91) [21]. Several EU member states, such as Malta (aOR = 5.46; 95% CI: 2.82–10.58), showed considerable increase in the odds of ever e-cigarette use, whereas in some countries, the odds of ever e-cigarette use did not change significantly between 2012 and 2014. Also, within the 2014 Eurobarometer survey, approximately one in seven respondents who had ever tried an e-cigarette defined themselves as current e-cigarette users – indicating a transition from experimentation to current use (15.3%; 95% CI: 12.9–17.7%), with between-EU member state variation ranging from 1.7% in Slovenia to 28.9% in Portugal [21].	E-cigarette use in Poland has been on the rise, particularly among young people. The prevalence is higher among youth and young adults compared to older age groups [23, 29]. The overall prevalence of daily e-cigarette use is 4.8% (4.0% of females and 5.6% of males; $p = 0.2$). In September 2019, the prevalence of smoking among Poles aged 15 and over was 22.3% (19.1% of females (18% daily smokers and 1.1% occasional smokers) and 25.9% (24.4% daily smokers and 1.5% occasional smokers) of males; $p = 0.01$) [23]. Daily tobacco smoking was declared by 28.8% of respondents (27.1% of females and 30.8% of males; $p = 0.2$) and 4.2% were occasional smokers (4.2% of females and 4.3% of males; $p = 0.8$). Most of the current smokers (62.1%) smoked regular cigarettes and 25.2% smoked hand-rolled cigarettes. The prevalence of daily e-cigarette use was 4.8% (4.0% among females and 5.6% among males; $p = 0.2$). Daily heated tobacco use is declared by 4.0% of respondents (5.1% of females and 2.9% of males; $p = 0.07$). The prevalence of smoking is 28.8% (27.1% of females and 30.8% of males; $p = 0.2$). Current daily smoking was declared by 22.9% of females and 26.5% of males ($p = 0.2$). Moreover, 4.2% of females and 4.3% of males declare that they smoke cigarettes occasionally ($p = 0.8$). Among the females, there were no significant differences in the prevalence of smoking by socioeconomic factors [23].

TABLE 1. Cont.

Variable	Worldwide	European Union	Poland
Regulation	The regulation of e-cigarettes varies globally. Some countries have strict regulations, while others have more lenient approaches, which can impact usage patterns [25].	The EU had introduced the Tobacco Products Directive (TPD) to regulate e-cigarettes. This directive imposed restrictions on e-cigarette marketing, packaging, and nicotine content. Each member state could also have additional regulations [27].	Poland had specific regulations governing e-cigarettes, which included restrictions on sales to minors and advertising. However, the regulations were not as strict as in some other EU countries [30].
Health concerns	Health concerns regarding the safety and long-term health effects of e-cigarettes continue to emerge. These concerns have influenced both user behavior and regulatory actions [26].	EU countries are concerned about the safety of e-cigarettes and their potential impact on public health. This led to varying attitudes towards e-cigarettes, ranging from strict regulation to more permissive stances [28].	Concerns about the health risks associated with e-cigarette use are present in Poland as in other countries. These concerns are a part of public health discussions and policy debates [31].

disease. The inhalation of e-cigarette aerosols can introduce harmful chemicals and fine particulate matter into the bloodstream, which may contribute to the development of cardiovascular diseases including myocardial infarction [39].

Daily e-cigarette use was independently associated with increased odds of having had a myocardial infarction (OR = 1.79, 95% CI: 1.20, 2.66, $p = 0.004$) as was daily conventional cigarette smoking (OR = 2.72, 95% CI: 2.29, 3.24, $p < 0.001$). Former and some day e-cigarette use were not significantly associated with having had a myocardial infarction ($p = 0.608$ and $p = 0.392$) whereas former (OR = 1.70, $p < 0.001$) and some day cigarette smoking (OR = 2.36, $p < 0.001$) were. Odds of a myocardial infarction were also increased with history of hypertension (OR = 2.32, $p < 0.001$), high cholesterol (OR = 2.36, $p < 0.001$) and diabetes (OR = 1.77, $p < 0.001$), and age (OR = 1.65 per 10 years, $p < 0.001$). Women (OR = 0.47, $p < 0.001$) had lower odds of myocardial infarction [39].

Nicotine is a common component of e-cigarette liquids, and it can lead to an increase in the heart rate and blood pressure, which are risk factors for cardiovascular events. These acute changes in cardiovascular parameters can be particularly concerning for individuals with preexisting heart conditions [40].

Studies have shown that e-cigarette use may increase the risk of blood clot formation, which can lead to conditions like deep vein thrombosis, pulmonary embolism, and stroke. The presence of nicotine and other potentially harmful substances in e-cigarette aerosols may contribute to this risk [41, 42]. A shortened whole blood clotting time resulting from increasing platelet aggregation in chronic smokers has also been reported [43, 44]. The correlation coefficient computed on the effect of duration smoked against whole blood clotting time, showed negative correlation in all the durations (2–6 years, $r = -0.20$, $p > 0.05$); (7–11 years, $r = -0.40$, $p < 0.05$); (12–16 years, $r = -0.58$, $p < 0.05$) and (17–21 years, $r = -0.67$, $p < 0.05$). A unit increase in duration of smoking causes a unit decrease in the whole blood clotting time in these chronic smokers. The strongest negative effect was also observed in 12–16-years' and 17–21-years' durations ($p < 0.05$) [42].

Smoking increases activation of platelets by 100 times, which can lead to a significant increase in blood clots. The total platelet counts revealed positive correlation coefficients with the duration of smoking in the chronic smokers in all the durations (2–6 years, $r = -0.44$, $p < 0.05$); (7–11 years, $r = -0.47$, $p < 0.05$); (12–16 years, $r = -0.52$, $p < 0.05$) and (17–21 years, $r = -0.69$, $p < 0.05$). Those who smoked for 12–17 years and 17–21 years showed a stronger positive correlation when compared to the others. The positive correlation implied that unit increase in duration of smoking increases the total platelet counts in these smokers [42].

Individuals with underlying cardiovascular conditions, such as hypertension or coronary artery disease, may experience worsening of their conditions due to e-cigarette use. The nicotine in the e-cigarette is significantly associated with several different cardiovascular outcomes, such as atherosclerosis, myocardial infarction and stroke [45].

It is important to note that while e-cigarettes are often marketed as a less harmful alternative to traditional cigarettes, their impact on the cardiovascular system is a cause for concern. The long-term health effects of e-cigarette use are still being studied, and evidence suggests that their use should not be considered entirely safe, par-

ticularly for those with cardiovascular risk factors or pre-existing conditions [46].

NICOTINE ADDICTION

One of the most significant concerns associated with e-cigarette use is nicotine addiction, particularly among adolescents. A study by Goniewicz *et al.* revealed that e-cigarettes can deliver nicotine more efficiently than traditional cigarettes, making them highly addictive [47]. Benowitz also emphasized how difficult it is to break the nicotine addiction, which makes e-cigarette users susceptible to addiction and withdrawal symptoms [5].

E-cigarette use has seen a significant surge, especially among young people. A study published in *JAMA Pediatrics* in 2019 reported that e-cigarette use among high school students in the United States increased by 78% from 2017 to 2018, raising concerns about the long-term health impacts, particularly among youth [17].

A study by Primack *et al.* suggests that adolescents who use e-cigarettes may be at higher risk of transitioning to traditional tobacco products, thereby perpetuating nicotine addiction. Cigarette smoking was initiated by 47.7% of e-cigarette users and 10.2% of non-users (p = 0.001) [48].

IMPAIRMENT OF ENDOTHELIAL FUNCTION

Endothelial cells lining blood vessels play a crucial role in cardiovascular health. Research by Kloner *et al.* has suggested that exposure to e-cigarette aerosol can impair endothelial function, potentially contributing to the development of atherosclerosis and heart disease [49].

Studies have demonstrated also that e-cigarette aerosol contains harmful chemicals, including acrolein and fine particulate matter, which can induce oxidative stress and inflammation in the vascular endothelium, impairing its normal function [50].

Nicotine, a primary component of e-cigarettes, also contributes to endothelial dysfunction. Nicotine can lead to vasoconstriction and increased blood pressure, resulting in increased stress on the endothelial cells. This can further exacerbate the impairment of endothelial function [51].

E-cigarette use can lead to an elevation in blood pressure, which, in turn, can impair endothelial function. Elevated blood pressure increases the risk of endothelial damage, making the endothelium less capable of regulating blood flow and maintaining vascular health [52].

A study by Park *et al.* shows that patients with the highest SBP had a significantly higher incidence of major lesions in small arteries (p < 0.01 for trend) and left ventricular hypertrophy (LVH) (p < 0.05 for trend). Endothelial dysfunction was increased with BP elevation (p = 0.07 for trend). By multivariate analysis, media-to-lumen ratio [M/L]) correlated with ambulatory systolic blood pressure (SBP) (β = 0.40, p = 0.02), and left ventricular mass index (LVMI) correlated with ambulatory SBP (β = 0.41, p = 0.001) and body mass index (β = 0.30, p < 0.05). Female sex influenced endothelial function negatively (β = –0.63, p < 0.01) [43]. These findings tend to support the concept that the vascular remodeling of small arteries in response to high BP may be the first detectable stage of the progression from hypertension to endothelial dysfunction and target organ damage [53].

E-cigarette aerosol can trigger oxidative stress, causing damage to endothelial cells. Oxidative stress leads to the production of free radicals and inflammation, which are harmful to the endothelium and can interfere with its ability to function properly [54].

E-cigarette use has been associated with an increased inflammatory response in the vascular endothelium. Chronic inflammation can damage the endothelium, contributing to endothelial dysfunction [55].

The impact of e-cigarettes on endothelial function is a concerning aspect of their potential cardiovascular risks. E-cigarette aerosol, along with the effects of nicotine, oxidative stress, inflammation, and elevated blood pressure, can contribute to endothelial dysfunction, which is a crucial step in the development of cardiovascular disease. Understanding these effects is vital in recognizing the potential dangers of e-cigarette use, especially among individuals with existing cardiovascular risk factors [56] (Figure 2).

THE PERILS OF FLAVORED E-LIQUIDS: DIACETYL AND "POPCORN LUNG"

The use of flavorings in e-liquids has been a source of concern, particularly the presence of diacetyl. Diacetyl is a chemical used to create a buttery flavor but has been associated with bronchiolitis obliterans, colloquially known as "popcorn lung." A case study by Palamidas *et al.* documented a severe case of bronchiolitis obliterans in a young e-cigarette user exposed to diacetyl-containing e-liquids [57].

TOXIC ALDEHYDES

The heating of e-liquids can lead to the production of toxic aldehydes, including formaldehyde, acetaldehyde, and acrolein. These substances are known to cause respiratory irritation and damage. Jensen *et al.* demonstrated that significant levels of formaldehyde and acetaldehyde can be generated at high vaping temperatures [58].

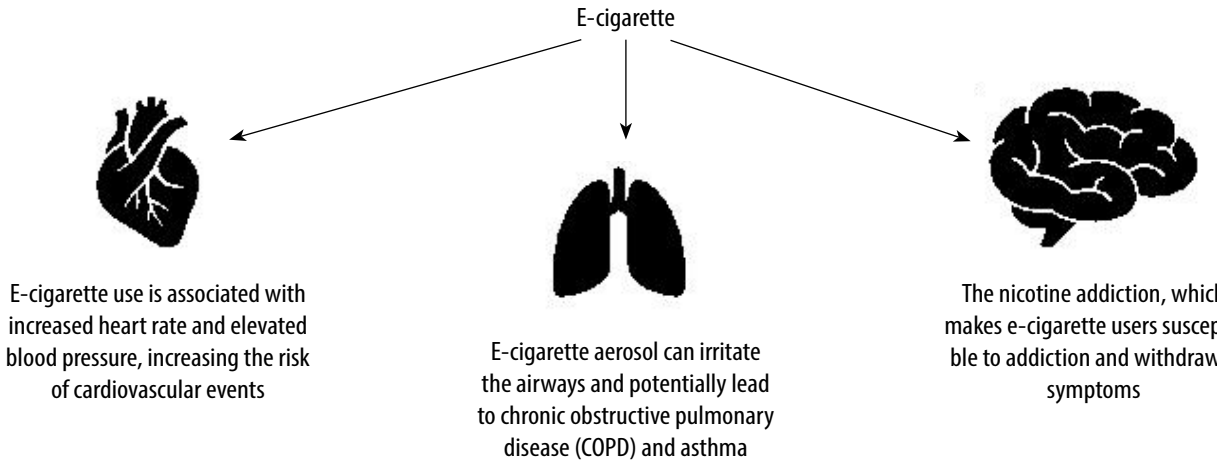

FIGURE 2. The effect of e-cigarettes on the body

ADOLESCENTS AND TOBACCO INITIATION

One of the most concerning aspects of using e-cigarette is that they can be used as a gateway to traditional tobacco smoking. Several studies, including one by Leventhal *et al.* have found a strong association between e-cigarette use and an increased likelihood of transitioning to smoking traditional cigarettes [59]. This trend raises alarm about the potential resurgence of tobacco addiction, especially among young people.

FORMATION OF HARMFUL COMPOUNDS

Heating e-liquids can lead to the formation of harmful compounds, including aldehydes. Research by Sleiman *et al.* found that the thermal decomposition of e-liquids produces formaldehyde and acetaldehyde, both of which can irritate the respiratory system and potentially lead to long-term health issues [60].

CONTAMINANTS

Studies have found contaminants in e-cigarette liquids, including harmful chemicals not listed on product labels. This lack of quality control raises concerns about the safety of these products. Many e-liquids are not accurately labeled, and consumers may not be aware of what they are inhaling. This makes it difficult for users to make informed decisions about their e-cigarette choices.

CONCLUSIONS

The rapid proliferation of electronic cigarettes has sparked a global debate about their safety and the potential health risks they pose. While e-cigarettes were initially introduced as a less harmful alternative to traditional tobacco smoking, there is mounting evidence that they are not without harm. Unfortunately, the long-term effects of using e-cigarettes and liquids are not yet fully understood because these products are relatively new to the market. The harmfulness of e-cigarettes and their liquids extends beyond nicotine addiction, encompassing respiratory and cardiovascular risks, exposure to harmful chemicals, and the troubling potential to serve as a gateway to traditional tobacco use. To address these issues and safeguard public health, regulatory efforts and public awareness campaigns are essential [46]. E-cigarettes face significant regulatory challenges worldwide. While some countries have implemented strict regulations on e-cigarettes and e-liquids, many lack consistent and comprehensive guidelines [61].

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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