

# Evaluating the Influence of the Vaping Epidemic on Lung Cancer Pathology and Younger Generations: A Scientific Review

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Despite claims that vaping, or electronic cigarette use, is a safer alternative to traditional tobacco smoking, the alarming rise in vaping among younger generations has triggered a global health issue known as the “vaping epidemic.” E-cigarettes are known to cause substantial damage to respiratory organs, causing health authorities to be alarmed about the rise of e-cigarette use among youth. This paper aims to explore the field of lung cancer related to the impact of e-cigarettes on lung cancer pathology. Through the synthesis of previously published papers and government websites, the objective of this scientific review is to explore and inform readers about the complex relationship between the recent introduction of vaping and an increased risk of developing lung cancer for younger generations. The paper explores (1) the background of lung cancer, (2) toxic chemicals and compounds in modern electronic cigarettes, (3) recent and future trends in the e-cigarette market, (4) prognosis and diagnosis of lung cancer across various regions, and (5) regulations and guidelines for preventing vaping among adolescents. Key findings suggest that e-cigarettes contain harmful chemicals, which are commonly associated with carcinogens. Unfortunately, recent trends show an increase in the diagnosis of lung cancer in adolescents, which is likely to be associated with vape use among teenagers. However, regulations, such as nicotine limits and flavor bans, attempt to prevent adolescents from developing nicotine dependence. Fortunately, progress in medical technology, such as improved CT scans and targeted mutation inhibitors, promises early diagnosis of lung cancer and more effective targeted treatment options. Regardless, ongoing research is key to fully comprehending and establishing stronger links to the latest vaping products and lung cancer disease, to protect younger generations, given that e-cigarettes are a newer health concern among the scientific community.

**Keywords:** e-cigarettes, health, lung cancer, nicotine addiction, vaping epidemic

## Introduction

According to the American Cancer Society, in 2024, an estimated 116,310 men and 118,270 women are predicted to be diagnosed with lung cancer, with an expected 125,070 lung cancer-related deaths within the U.S. The reason for this public health challenge is that lung cancer is one of the most challenging cancers to diagnose, resulting in delays in treatment. Lung cancer starts when cells located within the lung region undergo uncontrolled growth and spread and, in some instances, can result in death if not treated immediately. Scientists categorize lung cancer into two main groups: small-cell lung cancer (SCLC) and non-small cell lung cancer (NSCLC). Each type of lung cancer has different treatments and growth rates. Currently, both types of lung cancer incidence and mortality are closely linked to the tobacco epidemic, which accounts for more than 80% of lung cancer cases and deaths<sup>1</sup>.

As mentioned previously, the leading risk factor for lung cancer is predominantly tobacco smoking. The duration of the smoking habit and the number of cigarettes smoked daily also increase this risk<sup>2</sup>. Long-term scientific research has proven

that tobacco smoke contains various carcinogens, which can contribute to tumor formation and cell mutations. In recent years, however, the upsurge of vaping and e-cigarettes amongst younger generations has sparked a new global health concern, which many people call the “vaping epidemic.” Vaping, introduced as a safer alternative to traditional tobacco smoking and a means to assist smokers in quitting, gained popularity among youth. With strategic marketing and advertising, the introduction of appealing e-juice flavors, social influences, and nicotine addiction, many youths perceive vapes as a way of offering mental health benefits and relieving stress<sup>3</sup>. Similar to traditional smoking, however, vaping involves inhaling numerous aerosols and harmful chemicals such as nicotine and heavy metals. Emerging evidence suggests that vaping and the substances within it could possibly contribute to lung inflammation and cell damage.

Although modern tobacco devices are viewed as safer, they deliver numerous toxic chemicals, metals, and carcinogens directly into the lungs, thus causing severe harm to the sensitive tissue. According to the 2023 National Youth Tobacco Survey, e-cigarette products were the most common tobacco product

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in 2023 among middle and high school students (7.7%; 2.13 million)<sup>4</sup>. As a result of this rise in the usage of vaping products, many scientists speculate that these harmful devices may increase the risk of developing lung cancer<sup>5</sup>. Recently, respiratory risks related to vaping have rapidly emerged due to e-cigarette usage. Specifically, in February 2020, e-cigarette or vaping use-associated lung injuries (EVALI) resulted in 2807 hospitalizations, over half of which were teenagers and young adults (52%)<sup>6</sup>. Ultimately, this rising trend has led to numerous health, social, and regulatory challenges nationally and globally. For example, numerous states within the U.S. imposed further strict regulations, while in Australia, there are strict importation and sale restrictions on such devices<sup>7</sup>.

While most existing research focuses on the short-term effects of e-cigarettes as they are relatively new, the limited understanding of the long-term factors prevents scientists from knowing the possible cognitive and psychological effects associated with e-cigarette use in teenagers. As a result, further research is crucial to explore the long-term risks of e-cigarettes associated with lung cancer and to help establish stricter regulatory guidelines given the increasing prevalence of vaping among teenage populations. Understanding the biological, environmental, and socioeconomic factors related to vaping among young people is critical for developing effective public health strategies to help prevent the adverse effects of the vaping epidemic on future generations. With that in mind, this scientific review seeks to evaluate the long-term effects of e-cigarettes and vaping on lung cancer prognosis and diagnosis, specifically for younger generations. This review offers a comprehensive understanding of the various types of lung cancer, the structure and composition of e-cigarettes, current market trends, societal impacts, and current regulations. This review aims to evaluate the effects of the vaping epidemic on young generations by synthesizing information and argumentation from previously established online sources. Given the increase in the use of e-cigarettes amongst youth and the health consequences related to electronic nicotine delivery devices, the topic of vaping and the association between e-cigarettes is critically important and timely. Unfortunately, since e-cigarettes are new to the scientific community, many of the long-term health effects regarding lung cancer are not yet apparent. Thus, this limits the ability to make definitive claims regarding the risks of vaping and the risk of developing lung cancer. Despite this, with the health implications of vaping slowly surfacing, it is important to start protecting younger generations from harmful devices through regulatory measures.

## Methodology

A comprehensive literature search was conducted using databases such as Google Scholar and PubMed. Additionally, information from various government organizations and other reputable sources was studied. These included the U.S. Food and

Drug Administration, the American Cancer Society, the Centers for Disease Control and Prevention (CDC), and government health department websites from foreign countries like Australia and Canada. For example, when exploring these databases and websites, common search phrases included “lung cancer diagnosis and prognosis,” “harmful chemicals in e-cigarettes,” “current e-cigarette trends,” “relationship between vapes and lung cancer,” “vaping regulations,” “e-cigarette impact on society,” and “influence of vaping on young adults.” The selection of articles was based on whether the paper was written in English, whether it was published between 2000-2025, whether it had been peer-reviewed, and whether the information was from a reliable source.

Additionally, data and information were extracted from numerous sources, as the information contained in the published sources matched or enhanced the topic of this review. Likewise, charts, tables, and graphs from online sources were analyzed and used in this review to help clarify the ideas. Also, extracted information from online sources included the types and stages of lung cancer, the toxins in e-cigarettes, societal impacts, market trends, and government regulations. Moreover, with numerous papers for each search result, a common theme or idea was established among the various sources that retain qualitative information, conveying this in this review. Similarly, quantitative data from various sources were summarized in this article and used to establish stronger connections between two or more ideas.

## Results

Lung cancer is the second most prevalent form of cancer, and smoking is the primary risk factor associated with it. E-cigarettes have emerged as a substitute for cigarettes and are increasingly popular among many young adults. These modern devices may contain toxic chemicals that could contribute to cancer risk; however, the long-term evidence is still emerging. While scientists suggest that e-cigarettes may contain harmful substances, the direct link between vaping and lung cancer is still under investigation. Since vaping is still relatively new to society, many of the long-term effects are yet to be known. Additionally, the rise of vaping and current e-cigarette market trends sparks concerns among many individuals regarding the health risks linked to e-cigarette use. Gaining insights into the causes and types of lung cancer and the impact of e-cigarettes can help establish regulations that can mitigate the emerging concerns about the long-term impact of e-cigarette use on lung health.

## Understanding Lung Cancer: Types and Stages Explained

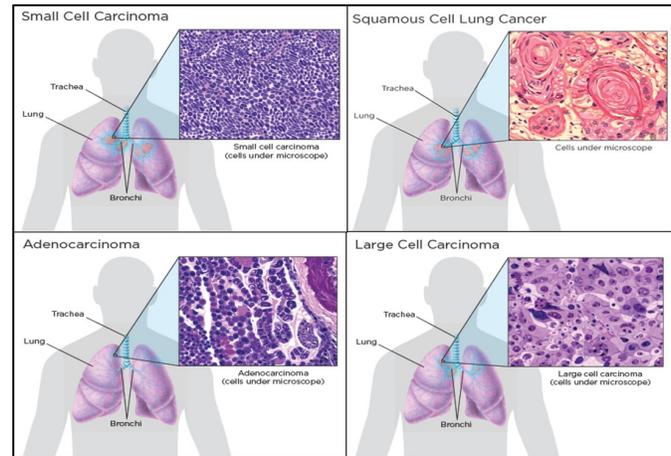
As vaping becomes prevalent, especially among young people, understanding how lung cancer develops is critical to understand-

ing the effects on lung health. More importantly, knowing the types and stages related to lung cancer can prevent individuals with long-term exposure to e-cigarettes from developing severe cases of lung cancer. The human lungs have a roughly cone-shaped appearance. When one breathes in, air travels through the trachea, or windpipe, into the lungs. Next, the air in the lungs travels into the bronchial tubes and the alveoli, or air sacs. Due to this reason, lung cancer begins when an uncontrolled mass of cells grows in the bronchi, bronchioles, or alveoli.

As mentioned previously, lung cancer is primarily classified into two main groups: small-cell lung cancer (SCLC) and non-small cell lung cancer (NSCLC). SCLC consists of round and oval cells with little cytoplasm within them. The mitotic count for these types of cells is high. As a result, SCLC is known for its aggressive lung tumors compared to NSCLC. Typically, SCLC spreads to different organs and tissues, such as the liver, brain, and bone. Typical symptoms include chest pain, cough, wheezing, and weight loss<sup>8</sup>. Patients suffering from SCLC tend to experience severe medical crises in which the disease is likely to spread to other parts of the body, thus making treatment challenging. For patients who undergo chemotherapy, there are a limited number who successfully reach long-term disease control. Typically, SCLC occurs in patients who have extended exposure to tobacco carcinogens, causing DNA damage. 95% of SCLC cases involve patients who have a smoking history<sup>9</sup>.

On the other hand, NSCLC is the most common type of cancer, accounting for 80% of all lung cancer cases, while SCLC accounts for 15-20% of all cases. NSCLC is separated into different sub-categories, each with a different kind of cancer cell: squamous cell carcinoma, adenocarcinoma, and large cell carcinoma. Before the 1960s, squamous cell carcinoma was the prevalent subtype. Squamous cell carcinoma is much more aggressive than adenocarcinoma and begins in cells that line the lung airways. With the introduction of filtered cigarettes, however, the incidence of developing adenocarcinoma increased as tobacco users experienced higher exposure to toxic smoke particles<sup>10</sup>. Often, the term “filtered cigarettes” makes people perceive that the filter protects them from breathing in carcinogens; however, this cigarette type leads users to inhale much smaller, highly toxic particles and chemicals. Specifically, the filter ventilation alters tobacco combustion, which increases smoke toxicants, and the new design lets smokers take in more smoke while getting the same amount of nicotine. This altered puffing and inhaling allows more dangerous smoke to enter lung cells, thereby making them prone to adenocarcinoma<sup>11</sup>. In a case-control study performed between 1977-1995 with 2,292 lung carcinoma patients and 1,343 hospital controls who were current smokers, scientists concluded that those who used filtered cigarettes during their lives may slightly reduce the risk of squamous cell carcinoma; however, it may increase the risk of adenocarcinoma<sup>12</sup>. Filtered cigarettes do not make smoking safe, instead, they shift the kind of damage your body might

experience. Adenocarcinoma begins in the glands that secrete mucus. Since this form of cancer is in the lung periphery, targeted treatment can manage the mutations. Meanwhile, large-cell carcinoma begins in various types of large cells located in the lungs. For a better understanding of the different types of lung cancer, Figure 1 illustrates how the various types of lung cancerous cells may be observed under the microscope.



**Fig. 1** Microscopic Level of SCLC (Small Cell Carcinoma) versus NSCLC (squamous cell carcinoma, adenocarcinoma, and large cell carcinoma) (LUNgevity Foundation. (n.d.). Types of Lung Cancer. LUNgevity Foundation. <https://www.lungevity.org/lung-cancer-basics/types-of-lung-cancer>)

*Note.* This figure shows the significant differences observed between SCLC and the three types of NSCLC. Each image consists of both a lung showing the tumor location and the cellular structure of the tumor under a microscope.

Although there are significant differences in both types of lung cancer, they are equally difficult to diagnose. An individual diagnosed with lung cancer does not show symptoms until the cancer is in its later stages. The median diagnostic interval (the time from first presentation to diagnosis) is 112 days, making lung cancer one of the most prolonged diagnostic intervals compared to other types of cancers<sup>13</sup>. For instance, breast cancer, the most diagnosed cancer among women, has a median diagnostic interval of 36 days, which is relatively short compared to that of lung cancer<sup>14</sup>.

Typically, after the doctor has imaging information and results from the biopsy, the cancer can be staged. Lung cancer is staged from 0 to IV, with Stage 0 indicating an early precancerous state, while Stage IV represents a cancerous tumor spread to other distant organs. Essentially, the stages of lung cancer are categorized based on size and spread. Most people with lung cancer are diagnosed at a later stage (III or IV). Patients found to be in Stages I-III may be able to have surgery to remove the tumor. In contrast, patients diagnosed with Stage IV

lung cancer typically do not undergo surgery, as medicinal treatment is generally no longer feasible at that stage. The five-year survival rates for SCLC compared to NSCLC are much lower, as demonstrated in Table 1 below. According to the National Cancer Institute (NCI), their Surveillance, Epidemiology, and End Results (SEER) database provides numerous survival statistics for various types of cancers. The SEER database classifies cancer stages into different groups based on the extent of the spread. Three of these groups include localized, regional, and distant stages. The localized group signifies no sign that cancer has spread outside the lung. The regional group indicates cancer has spread outside the lung to nearby structures or lymph nodes. Lastly, the distant group means cancer has spread to distant parts of the body, such as the brain, bones, liver, or the other lung.

**Table 1** Five-year relative survival rates for SCLC and NSCLC based on lung cancer patients between 2012–2018

SEER Stage	SCLC	NSCLC
Localized	30%	65%
Regional	18%	37%
Distant	3%	9%
All SEER Stages Combined	7%	28%

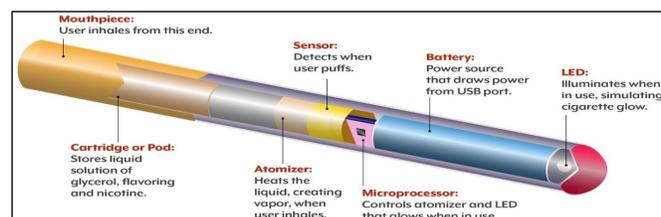
Source: American Cancer Society. (n.d.). Lung Cancer Survival Rates. <https://www.cancer.org/cancer/types/lung-cancer/detection-diagnosis-staging/survival-rates.html>

Understanding the various types and stages of lung cancer is critical for diagnosis, treatment, and improving the overall prognosis for patients, considering the current rise in e-cigarette use. Specifically, with high-risk individuals, such as dual users who use tobacco cigarettes and e-cigarettes, monitoring signs of lung cancer is essential for prevention, as decades of research show that smoking increases lung cancer risk<sup>15</sup>. Additionally, public health strategists should emphasize the risks of e-cigarette and vaping usage to younger generations to help contribute to lung cancer prevention in the future. For example, the American Cancer Society urges people who use tobacco products, including e-cigarettes, to stop to help mitigate the increasing health problems and the growing nicotine addiction<sup>15</sup>.

### The Structure and Toxic Chemicals in Electronic Cigarettes

Understanding how chemicals and particulates in vapor affect lung tissue and contribute to cancer growth is essential as e-cigarette usage is quickly growing. In other words, comprehensive knowledge of the different vape products allows scientists to know common substances within them that contribute to this alarming rise in lung cancer cases associated with vaping. The term electronic nicotine delivery system (ENDS) includes tobacco products such as electronic cigarettes (e-cigarettes or e-cigs), vapes, e-pipes, hookah pens, and e-cigars. According

to the Food and Drug Administration (FDA), e-cigarettes are devices that allow users to inhale an aerosol containing nicotine or other substances. Standard e-cigarettes consist of a cartridge or tank that holds the e-liquid, an atomizer that heats the e-liquid and turns it into an aerosol of tiny particles, a sensor that detects when the user inhales the e-cigarette enabling it to turn on, and a rechargeable battery that heats the atomizer<sup>16</sup>. The main element of e-cigarettes is the e-liquid stored in the cartridges or pod. The e-liquid consists of nicotine, extracted from tobacco, and mixed with a base (commonly propylene glycol) as well as flavors, colorings, and chemicals such as formaldehyde and acrolein known to cause irreversible lung damage<sup>17</sup>.



**Fig. 2** Structure of the Electronic Cigarette (Jalyn Ingalls. (March 10, 2023). Vapor Trail. Colorado Health Institute. <https://www.coloradohealthinstitute.org/research/vapor-trail/>)

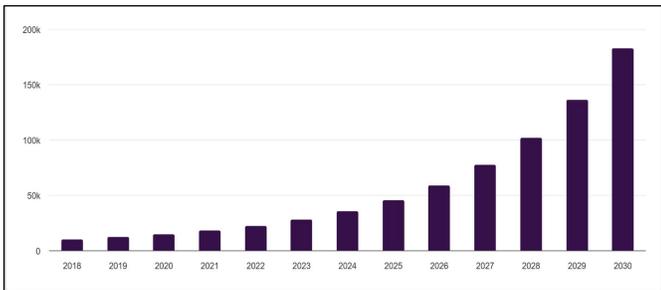
In the 2016 *E-Cigarette Use Among Youth and Young Adults* report by former U.S. Surgeon General Vivek Hallelgere Murthy, he concluded that aerosol produced from e-cigarettes contains up to 31 compounds, including nicotine, nicotyrine, formaldehyde, acetaldehyde, glycidol, acrolein, acetol, and diacetyl<sup>18</sup>. In simpler terms, ultrafine chemical particles produced from vapes cause severe lung damage, such as diacetyl and acrolein, a powerful irritant. Not only that, but another volatile organic compound, benzene, commonly found in car exhaust, is part of e-cigarette emissions. In 2017, scientists Lim and Shin tested flavored e-liquids, nicotine liquids, and disposable cartridges and concluded that the concentration of benzene ranged from 0.008 to 2.28 mg/L<sup>19</sup>. Any amount of benzene exposure is considered a serious health hazard as it is a carcinogen and, over time, can lead to blood disorders (decrease in red blood cells) and cancer<sup>20</sup>. Even though the FDA has reviewed and regulated some e-cigarette products for their potential role in smoking cessation, the FDA has not seen any e-cigarette to be effective or safe in assisting smokers to quit. As of May 2024, the FDA's current stance on e-cigarettes is that they have not approved any e-cigarette products for quitting smoking. The FDA, however, has approved seven medications (five medicines known as nicotine replacement therapies (NRTs) and two pills (varenicline and bupropion), which do not have nicotine. Overall, these medications attempt to help stop and quit smoking for users<sup>21</sup>.

The connection between e-cigarette usage and lung damage is concerning for young adults. In particular, young adult or-

gans are known to grow constantly; therefore, teenagers are more susceptible to the toxic effects caused by e-cigarettes. In other terms, early age exposure to harmful elements increases the chances of developing long-term respiratory damage such as lung cancer, a hard-to-diagnose, potentially deadly disease. Overall, nicotine addiction and the complexity of toxic chemicals and carcinogens in e-cigarettes make the vapor hazardous. In the long term, it can lead to severe respiratory injury and the development of lung cancer<sup>22</sup>. Therefore, with the rapidly increasing use of e-cigarettes among young people, it is becoming increasingly important to address and understand the risks associated with e-cigarettes.

### Recent Electronic Cigarette Market Trends and Their Societal Impacts

With traditional tobacco cigarette alternatives such as e-cigarettes and vapes gaining popularity, the U.S. and global e-cigarette market continues to see an increasing growth in these potentially harmful products. Specifically, the use of electronic nicotine delivery systems (ENDS) has multiplied in the U.S. market and around the globe over the past decade. The global e-cigarette and vape market will reach an estimated revenue of \$182,843.0 million by 2030, with a compound annual growth rate of 30.6% from 2023 to 2030, as proposed in Figure 3.



**Fig. 3** U.S. E-cigarette and Vape Market from 2018-2030 in U.S. dollars in millions (Horizon Grand Review Research. (n.d.). Global E-cigarette and Vape Market Size & Outlook. Horizon Grand Review Research. <https://www.grandviewresearch.com/horizon/outlook/e-cigarette-and-vape-market-size/global>.)

As e-cigarettes have become popular among teenagers and young adults, there have been negative societal impacts on numerous people and age groups. Specifically, the rise of social media among youth has led to a growth in the promotion of vaping products on countless social media platforms. Social media actively advertises and promotes e-cigarettes, with many influencers targeting young age groups. According to the 2023 National Youth Tobacco Survey (NYTS) released by both the Food and Drug Administration (FDA) and Centers for Disease Control and Prevention (CDC), e-cigarettes remain the most

commonly used tobacco product among middle and high schoolers. Specifically, among younger generations who currently use e-cigarette products, 25.2% used e-cigarettes daily, and 89.4% used flavored e-cigarettes<sup>23</sup>. As a result of this, tobacco product usage at a young age is likely to increase the risk of developing a nicotine addiction and severe health consequences. The National Academies of Science, Engineering, and Medicine (NASEM) concluded that there is significant evidence that using e-cigarette products increases a young adult’s inclination to engage in smoking in the future. E-cigarette usage at a young age is associated with 3.6 times the likelihood of using traditional tobacco cigarettes in adulthood<sup>24</sup>. In other terms, the rising trend raises concerns about nicotine dependency and the possibilities for e-cigarettes to act as a gateway to typical tobacco products. Ultimately, this has increased the persistent demand for stronger regulation of marketing techniques to protect young people.

Even though e-cigarettes are marketed as a safe alternative to traditional tobacco products, there are serious health consequences associated with them. As mentioned before, e-cigarettes contain harmful substances such as nicotine, heavy metals, and volatile organic compounds. The long-term effects on an individual are not yet fully understood, but it is clear that e-cigarettes cause lung damage and cardiovascular issues. Research indicates that vape solutions contain chemicals (such as diacetyl and formaldehyde) and toxic materials (including lead, tin, and nickel). When such chemicals are inhaled, they can damage the lung sacs, leading to a condition called “popcorn lung”, which requires hospitalization and, in some cases, leads to death. Additionally, nicotine acts as a strong vasoconstrictor, and its concentration in vape solutions is often unregulated among many brands<sup>25</sup>. As a result, as e-cigarettes deliver high levels of nicotine, this can lead to addiction at a young age. In adolescents, nicotine dependence can harm brain development, meaning it could have adverse effects on learning, memory, attention, behavior, and lead to future addiction. It can also lead to poor mental health, worsen anxiety, cause severe mood swings, and in some cases lead to depression<sup>26</sup>. Such addiction at a young age can result in long-term nicotine addiction and increase the likelihood of using tobacco cigarettes in the future. The idea of using other tobacco and nicotine products in the future is particularly concerning for adolescents as their organs continue to develop. Among younger adults, e-cigarette use increased in all groups of smokers, with notable increases between 2014 and 2018 among never-smokers (1.3%–3.3%) and near-term quitters (9.1%–19.2%)<sup>27</sup>.

### Current Prognosis and Diagnosis of Lung Cancer Across Various Age Groups and Populations

#### Lung Cancer Statistics and Prognosis

Lung cancer is a complex disease. Genetics, environmental exposure, lifestyle, and additional factors can lead to different

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prognoses and diagnoses across various age groups and populations. Based on data from 2017-2021, the rate of new cases of lung cancer was 49.0 per 100,000 men and women per year, while the death rate was 32.4 per 100,000 men and women per year<sup>28</sup>. Additionally, based on prior years' data, approximately 6.1% of men and women will be diagnosed with lung and bronchus cancer at some point during their lifetime. In fact, in 2021 alone, a shocking estimated number of 610,816 Americans were living with lung and bronchus cancer<sup>28</sup>.

Lung cancer has an overall poor prognosis, with only 10-20% of patients surviving five years or longer<sup>29</sup>. The most important prognostic factor is the phase in which lung cancer is present. In other terms, the earlier stages (0 and I) tend to have a better prognosis due to a contained tumor within the lungs, while later stages (II, III, IV) have a poor prognosis. Furthermore, patients diagnosed with non-small cell lung cancer (NSCLC), which is known to be less aggressive, tend to have a better prognosis compared to patients with small-cell lung cancer (SCLC), who face a severe type of lung cancer disease. Overall, healthier people can increase their survival chances by undergoing surgery as they can tolerate intense chemotherapy and radiation. Patients who face lung and heart problems, on the other hand, might have a less promising prognosis if diagnosed with lung cancer<sup>30</sup>. Currently, the median age of lung cancer diagnosis is around 71, with most people diagnosed between the ages of 65-74<sup>28</sup>. For people habituated to smoking and vaping daily, the risk of developing lung cancer increases. With vaping being relatively new to the scientific community, however, it is too early to conclude how vaping will affect the median age of lung cancer diagnosis.

### ***Demographic Variations and Risk Factors***

Based on data on lung cancer survival rates provided by the American Cancer Society, Black men are about 12% more likely to develop lung cancer compared to white men. Black men, however, are less likely to develop SCLC compared to White men. In contrast, Black and White women appear to have lower rates than men, but with the rise of vaping, the gap is narrowing. Currently, the rate of developing lung cancer is about 16% lower in Black women than in White women<sup>31</sup>. Not only that, but globally, Asia accounts for about two-thirds of lung cancer cases, partly due to air pollution and germline mutations<sup>32</sup>. Specifically, modern-day Indians have a higher chance of getting a mutated epidermal growth factor receptor (EGFR) gene, and such mutated genes are commonly found in cancers such as NSCLC. A mutation in the EGFR gene causes cells to multiply rapidly, leading to cancer growth<sup>33</sup>. To determine the prevalence of the EGFR mutation in patients of lung cancer in Indian populations, a study was conducted, which concluded EGFR mutations to be much higher in Indian populations (35.5%) compared to Caucasians (13%)<sup>34</sup>. Similarly, patients of Western

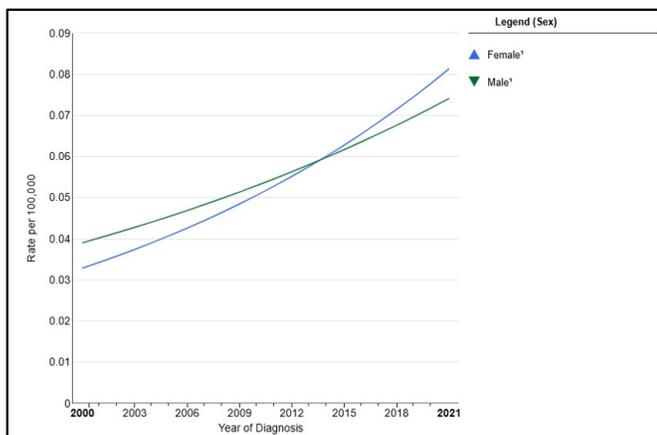
European descent and current or former smokers are at a higher risk of Kirsten RAt Sarcoma virus (KRAS) gene mutations<sup>35</sup>. Normal cells strictly regulate KRAS signaling; however, in tumorous cells, the KRAS signaling pathway is hyperactivated due to genetic mutations. This leads to oncogenesis and increased cell lifetime. Over time, rapid cell proliferation can lead to cancer, and unfortunately, the spread of these tumorous cells throughout the body<sup>36</sup>. In simpler terms, the mutation in the KRAS gene sends numerous signals to the cell to initiate cell growth, leading to cells growing uncontrollably and ultimately contributing to cancer<sup>35</sup>.

Considering treatment options for the gene mutations mentioned above (EGFR and KRAS), patients with lung cancer who test positive for the EGFR mutation have several treatment options. Particularly, EGFR inhibitors can block the activity caused by gene mutations, which can inhibit the cancer for months or years; however, they do not serve as a permanent cure, as the cancer can develop resistance towards them. In some cases, doctors may recommend a combination of therapies (e.g., chemotherapy) along with the use of EGFR inhibitors to block the mutated proteins on cancerous cells<sup>33</sup>. In the same way, patients with a KRAS mutation and diagnosed with lung cancer may initially receive surgery, radiation, chemotherapy, or a combination of both, depending on the situation. Patients may receive targeted therapy pills, such as KRAS inhibitors, if the cancer stops responding to chemotherapy; alternatively, a combination of both treatments may be used<sup>35</sup>.

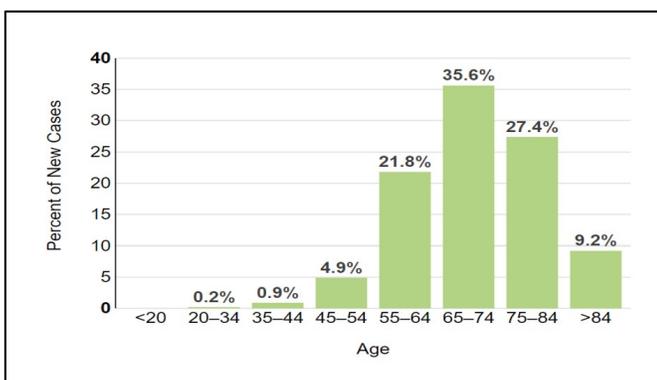
Though the demographic reports of vaping use are constantly evolving, the growing vaping epidemic amongst the younger generations is particularly concerning. Many scientists and medical professionals are conducting ongoing research to evaluate the risks linked with prolonged vaping. With current data trends from tobacco and vaping cigarette usage, however, there is an increasing rate of new lung cancer cases for adolescents less than 15 years old, as suggested by Figure 4. In other words, with the recent incursion of the vaping epidemic, teenagers who vape early are developing lung cancer at a premature age. As shown in Figure 5, the highest percentage of new cases occurs between the ages of 65 and 74; however, the current trends may suggest that young people who often vape are more likely to develop lung cancer earlier, shifting the percentage of new cases to a younger age. It is evident how toxic compounds from vaping products accumulate in the respiratory system and soon lead to the symptoms of lung cancer at an early age.

### ***Diagnostic and Prognostic Challenges***

The rising increase in vaping among young generations is becoming a substantial concern in the scientific community. Although lung cancer is known to be more common during late adulthood, the early indications in younger adults could be misdiagnosed or even overlooked due to less suspicion of children



**Fig. 4** Lung and Bronchus Cancer: Recent Trends in SEER Age-Adjusted Incidence Rates, 2000—2021 By Sex, Observed SEER Incidence Rate, All Races / Ethnicities, Ages <15, All Stages (National Cancer Institute Surveillance, Epidemiology, and End Results Program. Cancer statistics explorer network: SEER Explorer. National Cancer Institute Surveillance, Epidemiology, and End Results Program. <https://seer.cancer.gov/statistics-network/explorer/application.html>.)



**Fig. 5** Percent of New Cases by Age Group for Both Sexes: Lung and Bronchus Cancer (2017-2021) (National Cancer Institute Surveillance, Epidemiology, and End Results Program. Cancer stat facts: lung and bronchus cancer. National Cancer Institute Surveillance, Epidemiology, and End Results Program. <https://seer.cancer.gov/statfacts/html/lungb.html>.)

developing this disease at a young age. According to the U.S. Preventive Services Task Force, adults aged 50-80 years old who have smoked 20 packs and did not quit within the past 15 years should have a low-dose computed tomography (LDCT) scan annually for lung cancer<sup>37</sup>. Since LDCT screening is less common for youths, this could potentially lead to severe later-stage diagnosing for youth who vape frequently. On the contrary, older adults who smoke have frequent LDCT screenings, thus

resulting in a better prognosis for such individuals. Furthermore, patients who experience early stages of NSCLC and can undergo surgery are recommended to have a thoracotomy test for tissue diagnosis and staging. Meanwhile, patients with SCLC can be diagnosed using a convenient and minimally invasive method<sup>38</sup>.

Given that each human body presents symptoms differently and, in some cases, may be asymptomatic in patients, this can pose a diagnostic challenge, leading to delayed treatment. A longer delay in diagnosis results in a more significant negative impact on treatment and survival rates. As mentioned earlier, SCLC is an aggressive form of lung cancer and can progress rapidly. Delays in diagnosis can lead to rapid tumor growth and, ultimately, increase mortality. According to a meta-analysis, every four-week delay in cancer treatment was associated with a 6-8% increase in mortality of cancer patients<sup>39</sup>. Essentially, delayed diagnosis can restrict treatment options, such as chemotherapy or surgery, as the patient becomes weaker over time.

### ***Advances in Diagnostic Technologies and Implications for Public Health***

Although lung cancer continues to have a poor prognosis rate, recent advances in diagnostic technologies related to lung cancer could change the course of this fatal disease. Specifically, new 3D CT imaging systems could help diagnose lung cancer much earlier by pointing out potential cancerous growths, thus leading to precise lung cancer biopsies<sup>40</sup>. Additionally, recent advanced imaging at UC Davis Health could be the key to tracking lung cancer treatment. In other words, once a patient receives treatment, the doctor must determine if the treatment is effective or if another form of treatment should be administered. As a result, the new imaging technology could enable doctors to monitor how their patients are responding to the treatment and see if there are any improvements<sup>40</sup>. Not only that, but lung cancer biomarker testing helps identify mutations, additions, deletions, or possible rearrangements in DNA. It can also track protein levels or the amount of tumor DNA in the blood, allowing for a better diagnosis<sup>41</sup>. Collectively, this information can aid in patient treatment and the type of care. Moreover, low-dose CT scans can help reduce mortality for those at high risk (current or former smokers over the age of 50). This special X-ray takes multiple images while the patient lies down and composites them to create a detailed image of the lungs<sup>42</sup>. Overall, recent advancements in medical technology offer hope for early detection and diagnosis of lung cancer.

Various age groups and populations have different diagnoses and prognoses for lung cancer. For young adults specifically, lung damage caused by vaping may not present the same symptoms caused by traditional tobacco cigarettes, thus leading to delays in diagnosis. Particularly, vaping carries the risk of lung injury while traditional smoking damages every organ in the

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body and increases the chance of getting heart disease and stroke. In terms of death, by early 2020, the CDC reported 2,800 cases of e-cigarette or vaping use-associated lung injuries (EVALI), with 68 of those resulting in death. In contrast, more than 480,000 deaths occur in the U.S. due to smoking<sup>43</sup>. With recent advancements in medical technologies, however, there remains hope for early detection of lung cancer, hence improving the outcomes for the numerous age groups and populations. Despite this, ongoing research, along with public health efforts, are critical to help mitigate the impact of threats linked with vaping, as many scientists and doctors do not fully understand the effects of vaping on lung health. Key areas might include focusing on the long-term effects and conducting studies, if possible, on inhaling ultrafine harmful chemicals found in e-cigarettes and how that influences cancer development. Particularly, scientists should focus on the genetic and cellular changes that nicotine can cause in adolescents. Possible public health interventions can include conducting school programs and educating youth about the health risks linked with vaping, and increasing social media counter-marketing campaigns.

### Present Regulations and Guidelines for Vaping Usage

As vaping becomes increasingly popular among adolescents, regulating vaping and e-cigarette use has received significant concern around the globe. Specifically, there have been many recent regulations on e-cigarette and vaping products in response to the rise of vaping trends amongst youth. In August 2016, the U.S. Food and Drug Administration (FDA) began regulating electronic nicotine delivery systems (ENDS) and other tobacco products<sup>44</sup>. The free distribution of samples of e-cigarettes became an illegal practice, the sale of ENDS products is prohibited without the authorization of the FDA, and the use of vaping products under 21 years of age is strictly prohibited. According to an FDA report, they received a shocking number of 6.7 million tobacco product applications to which more than one million flavored ENDS products were denied for marketing<sup>44</sup>. While the FDA establishes federal regulatory laws, rules vary per state. In some cases, states could implement strict measures such as flavor bans, enforcing higher taxes, and establishing vaping restrictions.

Similarly, the European Union takes measures to regulate e-cigarette products by strictly setting a maximum nicotine concentration of 20 mg/mL in e-cigarette liquid, a maximum volume of 10 mL to hold e-liquids, and mandating e-cigarette devices to be child-resistant to minimize the risk of unintentional exposure<sup>45</sup>. Furthermore, members of the European Union have taken additional measures, such as banning e-cigarette flavors (Estonia) and establishing regulations on e-cigarette liquids, such as prohibiting certain additives and flavors (Finland)<sup>45</sup>. In the same way, Canada has a similar maximum nicotine concentration established by the European Union and restricts vaping

advertising, particularly to younger generations<sup>46</sup>. Also, the Australian government is taking further measures to prevent young people from nicotine dependence. Specifically, as of July 1, 2024, nicotine vapes in the country are used for therapeutic goods. Essentially, this means that vapes are prescribed to adults and are available only at pharmacies to help people quit smoking<sup>47</sup>. Moreover, in Asian countries such as Singapore, the purchase, possession, or use of e-cigarettes and vaping is prohibited due to the Tobacco Control of Advertisements and Sale Act (TCASA) passed in February 2018<sup>48</sup>. Essentially, with countries taking on strict regulatory approaches and mandates regarding e-cigarette use, this could help prevent youth from coming in contact with these harmful products. In other words, it is one method to help lower the vaping rates among younger generations; however, it could spark an uprising in unregulated black markets.

Overall, the various approaches led by different regions and countries appear effective. A study showed that flavor bans, sales licenses, and taxation were associated with a decreased rate of vaping amongst younger generations<sup>49</sup>. Also, warning labels were associated with a drop to start vaping. On the other hand, recommended age restrictions, restrictions on the location of use, and other regulations proved to be inadequate for stopping vaping among youth<sup>49</sup>. In addition, a survey study of 8,660 10th-12th graders concluded that the rising vaping trend from 2017—2019 halted in 2020<sup>50</sup>. This data indicates how increasing regulation on ENDS devices can help mitigate the vaping epidemic seen among the younger generation and have a positive effect in the long term, providing hope for a better future.

### Discussion

Although vaping continues to be perceived as a much safer alternative to traditional tobacco cigarettes, current research shows that vaping may still pose significant health risks, including potential links to lung cancer. Given this, the access to vapes in younger generations is sparking alarming attention globally. A critical review of existing literature highlights the urgent need for increased awareness of vaping and its association with lung cancer, especially given the significant rise in e-cigarette use among young adolescents. While the direct relationship between vaping and lung cancer remains underexplored due to how relatively new vaping products are, e-cigarettes contain harmful carcinogenic compounds (formaldehyde, benzene, diacetyl, and others) that are known to cause severe damage to the respiratory system, thus contributing to lung cancer risk. Even with the rise of filtered cigarettes, there is unfortunately a shift in the type of cancer rather than a reduced risk; the risk of adenocarcinoma has increased while squamous cell carcinoma cases decreased due to the introduction of filtered cigarettes. Furthermore, specific populations and regions are prone to genetic mutations, increas-

ing their risk of lung cancer. This can affect treatment outcomes, but a combination of mutation inhibitors and other therapies can help mitigate lung cancer risk, depending on the spread of tumor cells. Similarly, with vaping gaining popularity amongst the youth, this could push the average lung cancer diagnosis to a younger age. With current and emerging technologies (low-dose CT scans, biomarker testing, and 3D CT imaging systems), this holds promise for early detection and improved treatment. Existing regulations and guidelines also mitigate these potential risks; however, the effectiveness of similar laws varies per country and region.

Ultimately, the purpose of this scientific review is to increase current understanding of lung cancer and address possible associations with vaping, particularly among the youth. By focusing on the various types of lung cancer, their causes, diagnostic challenges, and recent technological progress, this paper provides a basis for future medical research and public policy. With vaping being a new form of smoking, the long-term effects remain indefinite to many scientists and researchers. As a result, continued research is necessary to fully understand and draw stronger connections relating the newly vaping product to lung cancer disease in light of protecting younger generations. To help mitigate the effects of vaping and the potential risks of developing lung cancer, public health campaigns should focus on the risks of vaping, particularly among adolescents. For further regulations, federal law should mandate a tax on e-cigarettes and potentially ban flavored e-cigarettes to prevent adolescents from purchasing them. In the end, cooperation amongst researchers and healthcare professionals is critical to fully understand the unknown and complex effects of the vaping epidemic on lung health among young vapers.

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