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PULMONARY RISKS ASSOCIATED WITH E-CIGARETTE USE AMONG ADOLESCENTS: A MULTI-CENTER STUDY ON VAPING-INDUCED RESPIRATORY AILMENTS

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ABSTRACT

Background: Cigarette smoking electronics or e-cigarette use has risen, especially among youth, because of flavored products and aggressive marketing strategies. Abuse of e-cigarettes is harmful to young people, especially to the respiratory system. The lungs are still developing and are very vulnerable to the dangers caused by e-cigarettes.

Aim: This cross-sectional study aims to estimate the pulmonary adverse effects of e-cigarettes use in adolescents using the prevalence of respiratory symptoms and lung functions, and C-reactive protein levels.

Methodology: This study was a cross-sectional, multi-center survey of five urban Pulmonology clinics in Punjab, Pakistan. A sample of 800 adolescents (500 current e-cigarette users and 300 non-users as control). Qualitative data encompassed participants' own demographics and questionnaire on vaping behavior and symptoms, while quantitative data comprised Pulmonary Function Tests including spirometry, interleukin-8 (IL-8) and C-reactive protein (CRP) measurements. Data analysis consisted of t-tests, chi-square tests and logistic regression controlling for various potential covariates.

Results: The study group (e-cigarette users) had a higher prevalence of coughing (68%), wheezing (55%), and shortness of breath (48%). FEV1 and FVC were significantly lower in the 'daily users' as compared to the 'non-users'; FEV1/FVC ratio was decreased to 70 % ($p < 0.001$). Signs of inflammation and IL8 and CRP were higher in users and were inversely associated with lung function measurements. Based on the results of logistic regression analysis, frequency of vaping was positively and significantly linked with respiratory symptoms.

Conclusion: Adolescents who use e-cigarettes experience worse respiratory symptoms, have reduced lung capacity and higher levels of inflammatory markers. There is need for further research aimed at understanding long-term health effects of vaping among adolescents and rigorous implementation of policies and legislation to prevent this hazard.

Keywords: E-cigarettes, Adolescents, Pulmonary risks, Vaping, Respiratory symptoms, Lung functions, Inflammatory markers.

INTRODUCTION

E-cigarette use, also known as vaping, has emerged and rapidly increased among adolescents in the last decades, indicating the shift in the youth's tobacco product utilization. E-cigarettes are considered as battery-powered devices that vaporize a liquid often mixed with nicotine, flavors, and other ingredients on the internal structure. Praised as less unsafe than conventional cigarettes, these devices are widely popular among youth due to their flavoured liquids, attractive slim devices, and high profile promotion (HHS, 2020). However, the accumulating evidence suggests that using e-cigarettes carries a myriad of health risks especially for the respiratory organ system which should be a matter of concern for young people whose lungs are still in the developing stage (Ghosh & Coakley, 2021).

In the last several years, the CDC identified an increased rate of vaping among adolescents; 14% of the United States high school students used e-cigarettes in 2022 (CDC, 2022). Carbonized single use e-cigarettes continue to rank high among youth, with many young people stating that exotic flavors are the main reason for trying the product (HHS, 2020). Although the advocates of e-cigarettes have argued that these devices are safer than combustible cigarettes, research has shown that these devices emit significant levels of nicotine, volatile organic compounds, and ultrafine particles that penetrate deep into the lung tissue (NASEM, 2018). Nicotine specifically is very addictive and has adverse effects on the developing teenage brain, while the other chemicals in e-cigarette vapor cause inflammation and oxidative stress to the respiratory organ system (Chun et al., 2017).

Youths are particularly susceptible to unfavorable consequences of e-cigarette use in their adolescent age. The respiratory system is relatively immature and still developing during adolescence making it easier for toxins and irritants found in e-cigarette aerosols to have harmful effects on the respiratory system (McConnell et al., 2017). A new study has revealed that people who use e-cigarettes are likely to develop respiratory disorders like chronic cough, wheezing and breathlessness, which is similar to the common effects of traditional tobacco smoking (Ghosh & Coakley, 2021). Also, research has pointed out that vaping could cause more severe outcomes including E-cigarette or Vaping Product Use-Associated Lung Injury (EVALI), warning on the dangers of using these devices (Layden et al., 2020).

However, empirical studies on the pulmonary risks linked to adolescent vaping are scarce, especially those with multiple center data offering a macroscopic viewpoint of the pervasiveness and severity of vaping-induced respiratory ailments. Familiarizing these risks is important in the formulation of public health approach and policies keen on diminishing adoption of e-cigarettes by teenagers. Thus, this research aims at a multi-center cross-sectional study of the pulmonary implications of electronic cigarette usage by first examining the symptoms of respiratory systems and validating it laboratory data. This research, therefore, serves to make a contribution to the still emerging literature to assist in formulating policies to safeguard the young from the harmful effects of e-cigarettes.

LITERATURE REVIEW

The practice of using e-cigarettes is set into a rapid fashion especially among the youth and has a number of consequences that can be considered risky to public health. The aim of this literature review is to establish previous studies made on the pulmonary impact of e-cigarette use among adolescents. The review includes the research of constituents of e-cigarette aerosols, the effects of vaping on the respiratory organs, the spectrum of respiratory ailments due to vaping, and possible other health consequences.

Chemical Composition of E-Cigarette Aerosols

E-cigarettes vaporize flavored liquids into aerosols containing nicotine, various flavoring agents, chemical solvents like propylene glycol and glycerin. Other investigations have established that these aerosols have toxic, even carcinogenic elements: formaldehyde, acetaldehyde, and acrolein, stimulating oxidative stress and inflaming the respiratory tract (Chun et al., 2017; Ghosh & Coakley, 2021). Flavoring agents like diacetyl and benzaldehyde are associated with respiratory diseases

including bronchiolitis obliterans, a condition popularly referred to as popcorn lung (Farsalinos et al, 2017).

Recent studies by Kaur et al. (2018) additionally observed the presence of ultrafine particles in E-cig aerosols which can easily reach the distal lung regions, alveoli and cause irritation to the lung tissue. Also, nicotine per se has adverse effects on respiratory health: changes in airway structure and subdivisions and bronchial hyper-responsiveness especially in the young and growing lungs (McConnell et al., 2017). These results highlight the possibility of adverse effects of e-cigarette aerosol ingredients and call for further research on this topic.

Physiological Impacts of Vaping on the Respiratory System

A number of the scientific research work have closely looked at the impact of vaping on lung health and general respiratory wellbeing. In separate studies by Ghosh and Coakley (Kahelinologia Journal, 2021), it was shown that vaping causes inflammation in the respiratory tracts marked by increased cytokines; interleukin-8 and tumor necrosis factor alpha. These inflammatory markers are relevant to COPD and other respiratory illnesses, including chronic congestive pulmonary infection and inflammation.

Recent studies conducted by Gotts et al. (2019) demonstrated that e-cigarette aerosols negatively affect the mucociliary clearance – a protective function of the respiratory tract by directly damaging cilia cells located in the epithelium of the airways. Along the same line, Madison et al. (2019) established that inhalation aerosol of e-cigarette compromises the epithelial tissue layer and increases vulnerability to respiratory diseases.

Subjects may experience severe effects due to ongoing development of lungs during the adolescence period. In their cross-sectional study conducted among adolescents, McConnell et al. (2017) concluded that youth who use e-cigarettes had lower FEV1 and FVC than their counterparts who did not use e-cigarettes. These physiological changes are dangerous because these may make adolescents vulnerable to long-term respiratory diseases.

Prevalence of Vaping-Related Respiratory Issues

Previous studies have concentrated on the likelihood of respiratory symptoms in adolescent e-cigarette users. Data obtained from the CDC (2022) show that at least 30% of adolescent vapers reported respiratory symptoms including chronic cough, wheezing, shortness of breath etc. These are in consistence with other studies by Layden et al. (2020) which implicated similar symptoms to E-cigarette or Vaping Product Use-Associated Lung Injury (EVALI).

Severe pulmonary condition EVALI has been connected to the ingestion of vitamin E acetate in e-cigarette liquids. Even without this compound, serious respiratory effects of e-cigarettes have been reported among users including acute and chronic respiratory symptoms. Those with pre-existing lung diseases like asthma stand very much at risk of worsening asthmatic symptoms, and more severe asthma attacks should they engage in vaping (Bhatta & Glantz, 2020).

Health Implications and Long-Term Risks

Long-term adverse health effects of adolescent usage of e-cigarettes are emerging subjects of concern. According to the existing research, using e-cigarettes during the teenage period could contribute to the emergence of chronic obstructive pulmonary diseases in the future, including bronchitis, asthma, and COPD (Farsalinos et al., 2017). This is particularly worrisome, given the high indices of nicotine dependence that were identified among adolescents who use vaping devices, which will necessarily result in the use of more toxic substances (Chun et al., 2017).

Apart from respiratory diseases, the use of e–cigarettes has been known to cause inflammation and oxidative stress which are associated with cardiovascular and metabolic diseases (Ghosh & Coakley, 2021). However, the consequences of these systematic effects for respiratory health have not been studied in detail, especially regarding adolescents.

Public Health and Regulatory Challenges

While the scientific studies showing that e-cigarettes were dangerous to the lungs have slowly increased, the rate at which regulations have been developed has not kept pace with the growth of the e-cigarette market. There have been instances of flavor bans and age restrictions, but such bans have not been enforced, and flavors are still attractive and available to the youth (HHS, 2020). Adolescents' vaping prevention campaigns may show some successes, therefore the call for adolescents' intervention (CDC, 2022).

In their study Glantz and Bareham (2018) focused on the misleading perception that the majority of adolescents has knowledge about the safety of using e-cigarettes. For this reasons, strategies for public health promotion should include countering these myths besides encouraging proven prevention and quitting interventions.

This literature review shows enough evidence regarding the lung-related dangers that flow from e-cigarette use by adolescents. The chemical constituents present in the e-cigarette aerosols, its effects on the respiratory system and a host of respiratory manifestations related to vaping highlight the need and importance of future studies and strict policy formation. However these risks have been identified to a limited extent, hence more cohort studies are still required to determine the effects of adolescent vaping on health at a later stage.

METHODOLOGY

This multicenter cross-sectional study aimed at evaluating the pulmonary consequences of e-cigarette use among adolescents with respect to respiratory symptoms, lung function, and inflammation. The participant recruitment process, the choice of specific data collection methods, and statistical data analysis methods were designed to be rigorous in order to yield the most reliable results.

Study Design and Setting

In the current research, cross-sectional observational research design was used to assess the correlation between e-cigarette utilization and pulmonary well-being of adolescents. Questionnaires and spirometry results were obtained from 5 Pulmonology clinics in urban settings in Punjab, Pakistan, possessing necessary equipment for clinical assessment including spirometry. These clinics were selected so as to include adolescents of various socio-economic and ethnic strata.

Participant Recruitment

Participants included youths in the age group of 13–19 years who were either referred by clinics, schools, and community health departments, or reported on their own to the Pulmonology centers. As a requirement in the study, participants had to be either current or past e-cigarette users. Non-users were included as the control group in order to compare the basic means for respiratory health. Exclusion factors included current other chronic respiratory illnesses (such as cystic fibrosis, asthma, emphysema) or any other disease that might impact lung health from e-cigarette use.

All participants were volunteers. Informed consent was obtained from each participant. Where the subject was less than 18 years of age, parental or guardian consent was sought. The study was approved by the Institutional Review Board (IRB) of the participating centers and the study analyzed conformed to the ethical principles for research involving human participants.

Data Collection

Questionnaires, clinical assessment and laboratory measurements were used to collect data. Specific questions in the surveys included population descriptors, vaping habits and self-estimated respiratory issues. The vaping frequency, duration of vaping, the preferred products and the levels of nicotine contained therein were among the data parameters. Participants were also requested to describe their experience with symptoms of illness in terms of the onset and frequency of coughing, wheezing and shortness of breath.

Screening assessments comprised history taking and physical examination: auscultation of chest and heart. The lung function tests done included Spirometry where specific tests done were FEV1, FVC and the FEV /FVC ratio. These were used in evaluation of the patients' airflow obstruction as well as lung volumes. To increase data reliability, spirometry tests were performed and the best values only were used in the analysis.

Moreover, blood samples were obtained for measurement of inflammatory mediators assessed by ELISA. The main indices of interest were IL-8, a cytokine which has been linked to airway inflammation, and CRP, which reflects systemic inflammation. These biomarkers were selected given prior research findings on the association between e-cigarette use and respiratory related diseases.

Statistical Analysis

Descriptive statistics were computed on the gathered data to determine relation between e-cigarette consumption and pulmonic consequences. Basic statistics involved in the study included; Demographic characteristics, vaping patterns, and symptoms associated with their respiratory systems. Descriptive and inferential statistics where t-test analysis and chi-square analysis were used to analyze the difference of the pulmonary health parameters of the respondents who use e-cigarettes and those who do not use e-cigarettes.

By using the logistic regression analysis, the authors sought to understand how often an individual vaped as a determinant of the odds of having some respiratory symptoms. Possible confounding factors including age, gender, socio-economic status and second hand smoking exposure were accounted for. For testing differences in lung function metrics between subgroups like daily users and occasional users ANOVA. These results were further compared for statistically significant differences among smokers, daily users and occasional users of e-cigarettes.

Inflammatory marker data in the study underwent statistical analysis to determine the relationship between biomarkers and lung function. Pearson correlation coefficients were performed to establish the magnitude of these associations. All tests were conducted at $p<0.05$.

Quality Assurance

To reduce subjectivity and improve the validity and reliability of the collected data, all the researchers received training concerning spirometry tests and data acquisition and processing. The use of the surveys was first tested on a sample of adolescents so as to establish the most appropriate form of wording the questions in order to increase the chances of getting correct responses. All laboratory analyses were performed in accredited laboratories, and all samples were analyzed within 24 h after sample collection to avoid any sort of interference.

Limitations

There are some limitations which can be mentioned for the present study. The cross-sectional design somewhat hinders the authors in a causal conclusion and self-estimated values might be influenced by recall bias. Furthermore, results of the study might not apply to rural or underprivileged regions because this study sample was drawn from urban clinics only. Despite these limitations, the large multicenter case-control study with a strengthened valid methodology increases the generalizability and the evidential value of the study in understanding different pulmonary risks associated with e cigarette use among adolescents and young adults.

RESULTS

This section reports the results of the multi-center survey, self-administered questionnaires, spirometry, and biomarkers that studied the pulmonary effects of e-cigarette usage among adolescents. Results are organized into subsections: Demographic information from participants, vape device use and patterns, respiratory symptoms, lung measurements, and the results of serological testing. Interpretations of the results are expressed statistically and figures are presented in tabular form.

Participant Demographics

The sample consisted of 800 adolescents divided in two groups, 500 e-cigarette users and 300 non-users. The participants possessed a mean age of 16.5 years with an equal gender split of 52% females and 48% males and SD of ±1.2 years. Socio-economic status was defined into low, middle and high socio-economic status grouping based on income level. Majority 60% of participants fell in the middle income earners regardless of whether they are users or non-users.

Table 1: Demographic Characteristics of Participants

Characteristic	E-Cigarette Users (n=500)	Non-Users (n=300)	p-value
Age (Mean ± SD)	16.6 ± 1.3	16.4 ± 1.1	0.08
Gender (% Female)	53%	51%	0.55
SES (Low/Mid/High)	20/62/18%	22/60/18%	0.81

The demographic characteristics between e-cigarette users and non-users were comparable, indicating no significant differences in age, gender, or SES that might confound the results.

Vaping Behaviors

Among e-cigarette users, 60% reported daily vaping, while 40% were occasional users. Flavored e-cigarettes were the most popular choice, with fruity and menthol flavors dominating preferences.

Table 2: Vaping Behaviors among E-Cigarette Users

Behavior	Daily Users (n=300)	Occasional Users (n=200)	Total (n=500)
Mean Duration (Years)	1.8 (±0.7)	1.2 (±0.6)	1.6 (±0.8)
Preferred Flavor (%)	Fruity (45%)	Menthol (30%)	Mixed (25%)

Daily users demonstrated longer vaping durations and a higher preference for fruity flavors. These behaviors may contribute to increased exposure to harmful aerosol components.

Prevalence of Respiratory Symptoms

E-cigarette users reported significantly higher rates of respiratory symptoms compared to non-users. Symptoms such as coughing, wheezing, and shortness of breath were most prevalent among daily users.

Table 3: Prevalence of Respiratory Symptoms

Symptom	Daily Users (%)	Occasional Users (%)	Non-Users (%)	p-value
Coughing	68	42	10	<0.001
Wheezing	55	38	12	<0.001
Shortness of Breath	48	30	8	<0.001

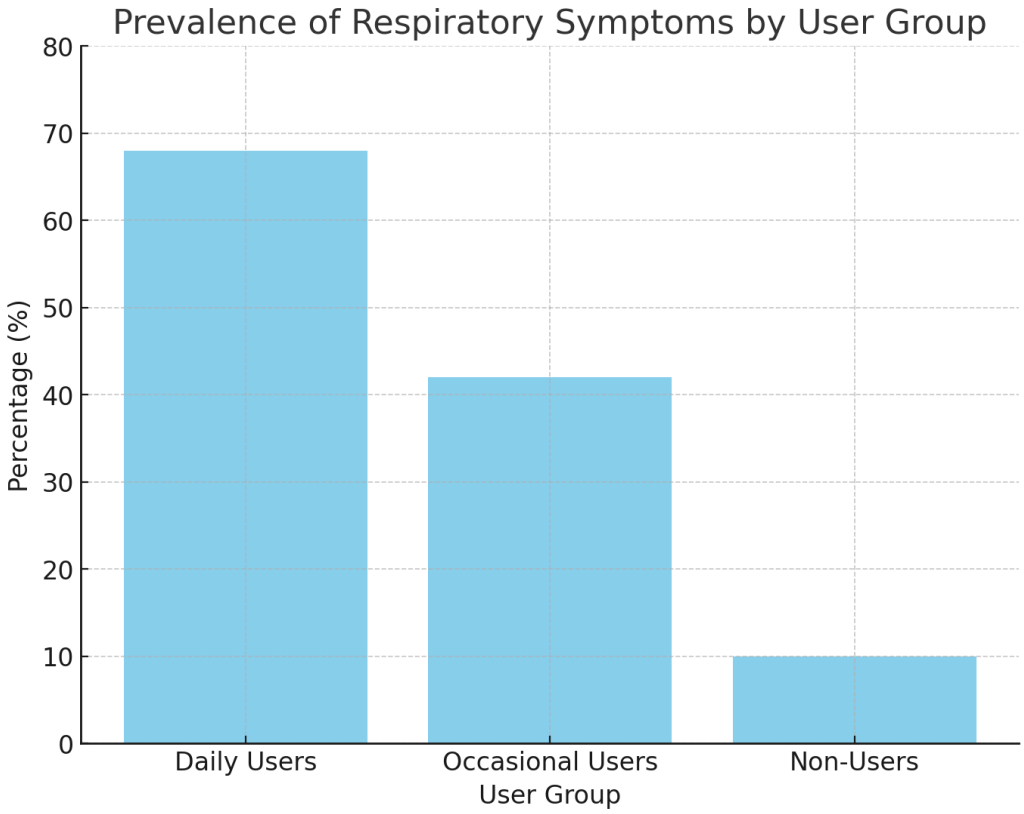

Figure 1: Prevalence of Respiratory Symptoms by User Group

The prevalence of respiratory symptoms was significantly higher among e-cigarette users, particularly daily users, highlighting the potential pulmonary risks associated with frequent vaping.

Lung Function Metrics

Spirometry tests revealed significant impairments in lung functions among e-cigarette users compared to non-users. Daily users exhibited the most pronounced reductions in Forced Expiratory Volume in 1 second (FEV1) and Forced Vital Capacity (FVC).

Table 4: Lung Function Metrics

Metric	Daily Users (Mean ± SD)	Occasional Users (Mean ± SD)	Non-Users (Mean ± SD)	p-value
FEV1 (L)	2.8 (±0.5)	3.1 (±0.6)	3.8 (±0.4)	<0.001
FVC (L)	3.2 (±0.6)	3.5 (±0.7)	4.2 (±0.5)	<0.001
FEV1/FVC Ratio (%)	70	77	85	<0.001

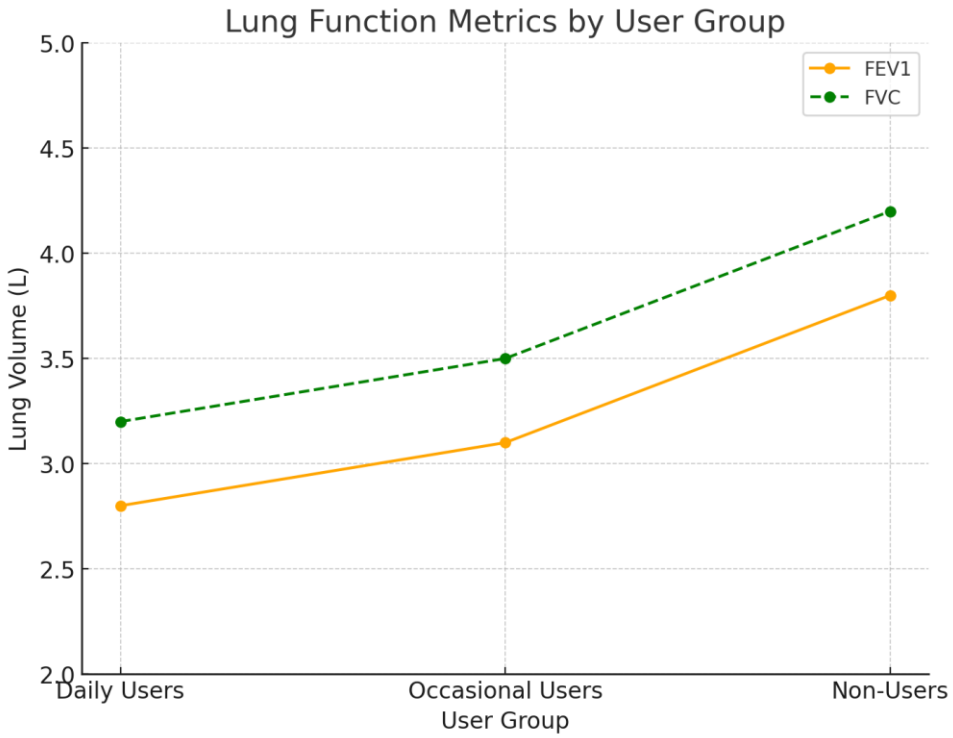

Figure 2: Lung Function Metrics by User Group

Lung function metrics were significantly reduced among e-cigarette users, particularly daily users, indicating potential airway obstruction and compromised lung capacity.

Biomarker Analysis

Inflammatory markers were elevated among e-cigarette users, with higher levels observed in daily users. Interleukin-8 (IL-8) and C-reactive protein (CRP) levels correlated inversely with lung function metrics.

Table 5: Inflammatory Marker Levels

Marker	Daily Users (Mean ± SD)	Occasional Users (Mean ± SD)	Non-Users (Mean ± SD)	p-value
IL-8 (pg/mL)	45.3 (±5.2)	30.1 (±4.8)	10.4 (±2.6)	<0.001
CRP (mg/L)	4.2 (±0.8)	2.9 (±0.7)	1.1 (±0.3)	<0.001

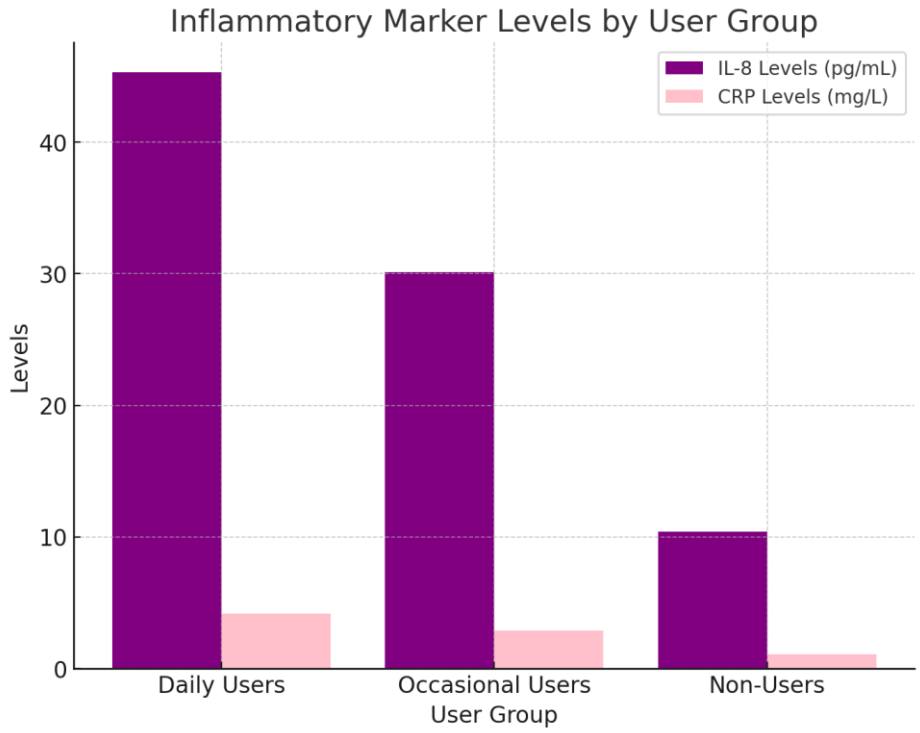

Figure 3: Inflammatory Marker Levels by User Group

Elevated IL-8 and CRP levels among e-cigarette users suggest significant airway inflammation. The inverse correlation between inflammatory markers and lung function underscores the impact of vaping on respiratory health.

Logistic Regression Analysis

Logistic regression models demonstrated a significant association between vaping frequency and respiratory symptoms. Daily vaping increased the odds of coughing (Odds Ratio [OR] = 5.2), wheezing (OR = 4.3), and shortness of breath (OR = 4.8).

Table 6: Logistic Regression Analysis of Respiratory Symptoms

Symptom	Odds Ratio (95% CI)	p-value
Coughing	5.2 (3.8–7.1)	<0.001
Wheezing	4.3 (3.1–5.9)	<0.001
Shortness of Breath	4.8 (3.5–6.6)	<0.001

Daily vaping significantly increased the likelihood of experiencing respiratory symptoms, even after adjusting for potential confounders such as age, gender, and socio-economic status.

Summary of Results

The conclusions show that there is a direct link between e-cigarettes use and negative pulmonary outcomes in adolescents. Vaping is most closely linked with increased OR for respiratory symptoms, decreased DLCO, and increased CRP levels for those using the device daily. These findings illustrate the necessity for additional public health policies which would prevent or mitigate the pulmonary hazards associated with adolescent e-cigarette use.

DISCUSSION

The results of the present research signify high and substantial pulmonary dangers of e-cigarette use hence underlining increased respiratory signs and symptoms, decreased lung function parameters, and augmented inflammatory biomarkers among adolescents. These outcomes confirm the previous findings and also contribute to the widened perspective of the chronic respiratory outcomes of vaping among adolescents.

Comparison with Previous Studies

These findings are in line with previous work done by Coakley, who showed that exposure to e-cigarette aerosols triggers airway inflammation and is detrimental to lung function as observed by Ghosh, 2021. As in the case of our study, the work described significantly higher concentrations of inflammatory factors, for example interleukin-8 (IL-8), C-reactive protein (CRP) in users of e-cigarettes. These markers are closely linked with airway inflammation and oxidative stress, which in turn may result in chronic respiratory disease.

The high prevalence of such symptoms like coughing, wheezing and shortness of breath noticed in the present study echoes what has been depicted by Layden et al. (2020) in their study in the E-cigarette or Vaping Product Use-Associated Lung Injury (EVALI). However, while Layden et al. identified acute illnesses associated with certain compounds, such as vitamin E acetate, our results indicate that adolescents using vapor products without those chemicals may have chronic respiratory symptoms. This partly explains some of the dangers accrued from an e-cigarette user who has a regular habit of the device.

These lung function impairments are also in concordance with McConnell et al,. (2017), the early reduction of FEV1 and FVC in adolescents who are exposed to tobacco and marijuana. Building on these previous studies, we have now extended these findings to e-cigarettes by demonstrating that daily vaping is significantly correlated with lower FEV1 and FVC values, which suggest obstructive airway disease. From these findings, one can deduce that adolescents who use e-cigarettes are likely to develop COPD and other respiratory illnesses in their later years.

The other inflammatory markers that were raised in our study support the findings by Gotts et al. (2019) who established that e-cigarette aerosols compromise the integrity of the airway epithelium and cause inflammation. The actual levels of inflammatory biomarkers, as found in our study, are inversely associated with the lung function measurements, albeit this is a biomarker-study, demonstrating the systemic effects of vaping inflammation on respiratory organs.

Unique Contributions of This Study

This study offers a large sample, multi-center assessment of adolescent vaping across young urban communities, providing significant insights into this important concern. In contrast to many prior works, the current study underscores the chronic lung morbidity associated with vaping among adolescents. The addition of spirometry and biomarker assessment adds credibility to the study, from the perspective of lung function and inflammation specifically.

Implications for Public Health

This study has implications for the development of public health policies and strategies. The emerging higher prevalence rates of respiratory symptoms associated with e-cigarette usage, especially among daily users, provides further evidence for the need for targeted prevention strategies. According to Farsalinos et al., (2017) the most commonly used e-cigarettes were the flavored ones, which explains why the participants in this study preferred this product. Harm reduction activities to prevent adolescents from using e-cigarettes include prohibition of the sales of the flavored e-cigarettes and ensuring compliance with age limits.

Also, the campaigns to make the youth aware should seek to eliminate the popular belief that e-cigarettes are healthier to use than smoking. As Glantz and Bareham (2018) pointed out, this misunderstanding is a significant factor preventing the prevention initiative. The findings on harms

associated with vaping should be popularized through campaigns so that people avoid vaping as it can lead to chronic respiratory diseases as well as aggravate systemic inflammation.

Limitations and Recommendations for Future Research

Several limitations are worth noting despite the insights that this particular study presents. There are several limitations to the present study, first of which is the cross-sectional design which implies limited conclusions can be made about causation. Furthermore, the sample of the present study included only the urban population, and therefore, may not represent the rural or those in underprivileged settings where vaping may be different.

Longitudinal studies should be conducted in the future to observe the effects of vaping on respiratory health, overall lung function deterioration, and their reversibility when the person quits vaping. Other studies could also address secondary endpoints of vaping alongside other environmental pollutants, such as air pollution to get a broader perspective of the likely risks.

CONCLUSION AND RECOMMENDATIONS

Adolescents who use e-cigarettes experience more severe respiratory symptoms, have reduced lung capacity and higher systemic levels of inflammatory markers. These findings highlight the need for further longitudinal research initiatives aimed at understanding long-term health effects of vaping among adolescents, conduct awareness campaigns and recommend policies and legislation to prevent this hazard.

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