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E-Cigarettes and Gingival Pigmentation: A Public Health Concern Among Adolescents

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A B S T R A C T

Electronic cigarette (e-cigarette) use has rapidly increased among adolescents, raising concerns about its impact on oral health. This study investigated the association between e-cigarette and gingival pigmentation among adolescents in a community setting. A cross-sectional study was conducted in November 2024 among members of the Vapers City of Medan community. Data were collected through a Google Form questionnaire and photographic documentation of participants' gingiva. The questionnaire assessed e-cigarette use patterns, including frequency and duration, and any concurrent use of conventional cigarettes. Gingival pigmentation was assessed through photographs, noting the presence and extent of pigmentation. Data were analyzed using SPSS, employing Chi-Square, correlation, and multivariable tests to determine the association between e-cigarettes and gingival pigmentation. E-cigarette use was significantly associated with gingival pigmentation (p=0.026). Adolescents who used e-cigarettes had a higher prevalence of gingival pigmentation compared to those who did not. Correlation analysis revealed a moderate positive correlation between e-cigarette use and gingival pigmentation severity (r=0.54, p=0.01). Duration and frequency of e-cigarette use were also weakly positively correlated with gingival pigmentation severity. Multivariable analysis confirmed that e-cigarette use (OR=4.5, 95% CI=1.2-16.8, p=0.024), duration of use (OR=2.1, 95% CI=1.1-4.0, p=0.028), and frequency of use (OR=1.8, 95% CI=1.0-3.2, p=0.046) were independently associated with gingival pigmentation. In conclusion, e-cigarette use is significantly associated with gingival pigmentation in adolescents. This finding underscores the potential adverse effects of e-cigarettes on oral health, highlighting a growing public health concern.

1. Introduction

Electronic cigarettes (e-cigarettes) have surged in popularity globally, particularly among adolescents and young adults. Often marketed as a safer alternative to conventional cigarettes, e-cigarettes have attracted a new generation of users, raising concerns about their potential health effects. Unlike traditional cigarettes, e-cigarettes do not involve the combustion of tobacco, but rather heat a liquid solution (e-liquid) to generate an aerosol that is inhaled by the user. This e-liquid typically contains nicotine, flavorings, and other chemicals, some of which have been identified as potentially harmful. While the long-term health consequences of e-cigarette use are still being investigated, there is growing evidence of their adverse effects on various systems in the body, including the oral cavity. The oral cavity, as the entry point for e-cigarette aerosol, is directly exposed to high concentrations of nicotine, particulate matter, and other potentially harmful chemicals. These substances can trigger inflammation, oxidative stress, and cellular damage in the oral tissues, leading to a range of oral health problems. One notable oral health effect associated with e-cigarette use is gingival

pigmentation, a condition characterized by a darkening of the gums due to melanin deposition. Melanin is a natural pigment produced by melanocytes, specialized cells found in the basal layer of the gingival epithelium. While melanin plays a protective role against ultraviolet radiation, excessive melanin production can lead to visible changes in gum color, ranging from light brown to black. Gingival pigmentation can be caused by various factors, including genetic predisposition, systemic diseases, certain medications, and tobacco use. Both conventional cigarettes and e-cigarettes contain nicotine, which has been identified as a contributing factor to gingival pigmentation. Nicotine stimulates melanocytes, leading to increased melanin production and deposition in the gingiva. Previous studies have established a clear link between conventional cigarette smoking and gingival pigmentation. However, research on the oral health effects of e-cigarettes, including their impact on gingival pigmentation, is still emerging.[1-4]

The increasing prevalence of e-cigarette use among adolescents is a significant public health concern. Adolescence is a critical period for growth and development, and early exposure to nicotine and other harmful chemicals in e-cigarettes can have long-lasting consequences. Nicotine is highly addictive and can affect brain development, leading to cognitive impairment, mood disorders, and an increased risk of addiction to other substances later in life. Several factors contribute to the popularity of e-cigarettes among adolescents. The availability of various flavors, sleek designs, and the perception that e-cigarettes are less harmful than conventional cigarettes have made them appealing to young people. Furthermore, aggressive marketing tactics by e-cigarette companies have targeted adolescents and young adults, often through social media and online platforms.[5-7]

The oral health implications of e-cigarette use are becoming increasingly evident. In addition to gingival pigmentation, e-cigarette use has been linked to other oral health problems, such as xerostomia (dry mouth), dental erosion, and an increased risk of periodontal disease. Xerostomia can lead to discomfort, difficulty swallowing, and an increased risk of dental caries. Dental erosion is the irreversible loss of tooth structure due to acid exposure, and e-cigarette aerosol has been shown to contain acidic components that can contribute to this process. Periodontal disease is a chronic inflammatory condition that affects the tissues supporting the teeth, and e-cigarette use has been associated with increased inflammation and impaired healing in the gums. Given the growing prevalence of e-cigarette use among adolescents and the potential adverse effects on oral health, it is crucial to investigate the association between e-cigarette use and gingival pigmentation in this population. Understanding the extent to which e-cigarette use contributes to gingival pigmentation in adolescents can inform public health interventions and policies aimed at reducing e-cigarette use and promoting oral health.[8-10] This study aimed to investigate the association between e-cigarette use and gingival pigmentation among adolescents in a community setting.

2. Methods

This research employed a cross-sectional study design to investigate the association between e-cigarette use and gingival pigmentation among adolescents in a community setting. The study was conducted in November 2024 within the Vapers City of Medan community. This community was chosen due to its high concentration of e-cigarette users, providing a suitable sample for investigating the research question. Before commencing the study, ethical clearance was obtained from the relevant authorities, ensuring adherence to ethical guidelines and protecting the rights and well-being of the participants. Informed consent was obtained from all participants or their legal guardians if they were under 18 years of age. Participants were informed about the

study's purpose, procedures, potential risks and benefits, and their right to withdraw from the study at any time without penalty. Confidentiality and anonymity were maintained throughout the study by assigning unique identifiers to participants and de-identifying data before analysis.

Participants were recruited through convenience sampling, a non-probability sampling method. Convenience sampling was chosen for its feasibility and efficiency in recruiting participants from the Vapers City of Medan community. While convenience sampling may not be representative of the general population, it is appropriate for this study as the focus is on exploring the association between e-cigarette use and gingival pigmentation within a specific community of e-cigarette users. The following inclusion criteria were applied to ensure the selection of participants who were relevant to the research question; Age 16-45 years: This age range encompasses adolescence and young adulthood, the period when e-cigarette use is most prevalent and when the oral health effects of e-cigarette use are of particular concern; Self-reported heavy e-cigarette user: This criterion ensured that participants had sufficient exposure to e-cigarette aerosol to potentially experience oral health effects. Heavy e-cigarette use was defined as frequent use with high nicotine concentration; No history of conventional cigarette smoking or systemic diseases that could affect gingival pigmentation: These exclusion criteria aimed to minimize confounding factors that could influence the association between e-cigarette use and gingival pigmentation. Conventional cigarette smoking is a known cause of gingival pigmentation, and systemic diseases can also affect gingival health.

Data were collected through a combination of methods, including a Google Form questionnaire and photographic documentation of participants' gingiva. This multi-modal approach allowed for the collection of comprehensive data on both e-cigarette use patterns and gingival pigmentation. A structured questionnaire was developed using Google Forms, an online survey platform that allows for efficient data collection and management. The questionnaire was designed to assess various aspects of e-cigarette use, including; Frequency of e-cigarette use: Participants were asked how often they used e-cigarettes, with options ranging from "less than once a day" to "more than 20 times a day"; Duration of e-cigarette use: Participants were asked how long they had been using e-cigarettes, with options ranging from "less than 6 months" to "more than 5 years"; Nicotine concentration: Participants were asked about the nicotine concentration of the e-liquid they used, with options ranging from "0 mg/mL" to "more than 20 mg/mL"; Flavor preferences: Participants were asked about their preferred e-liquid flavors, with options including tobacco, menthol, fruit, and dessert flavors; Concurrent use of conventional cigarettes: Participants were asked whether they currently smoked conventional cigarettes or had a history of smoking. The questionnaire also collected demographic information, such as age, gender, and education level. This information was used to describe the characteristics of the study sample and to explore potential confounding factors. Photographic documentation was used to assess gingival pigmentation. Participants' gingiva was photographed using a digital camera under standardized lighting conditions. Standardized lighting was essential to ensure consistency in image quality and to minimize variations in color perception. Photographs were taken of both the maxillary and mandibular gingiva, capturing the full extent of the gums. The photographs were evaluated by a trained dentist who was blinded to the participants' e-cigarette use status. Blinding was implemented to prevent bias in the assessment of gingival pigmentation. The dentist used a standardized evaluation protocol to assess the presence and extent of gingival pigmentation. Pigmentation was defined as any visible darkening of the gums compared to the normal pink color. The severity of pigmentation was graded on a scale of 0 to 3, with 0 indicating no pigmentation and 3 indicating severe pigmentation.

Data were analyzed using SPSS version 28, a statistical software package commonly used in health research. Descriptive statistics were used to summarize participant characteristics and e-cigarette use patterns. The Chi-Square test was used to determine the association between e-cigarette use and gingival pigmentation. Correlation analysis was used to assess the relationship between e-cigarette use patterns (frequency, duration, and nicotine concentration) and the severity of gingival pigmentation. Multivariable logistic regression analysis was used to identify factors independently associated with gingival pigmentation, controlling for potential confounding factors. A p-value of less than 0.05 was considered statistically significant.

The sample size was calculated based on the estimated prevalence of gingival pigmentation among e-cigarette users. A previous study reported a prevalence of 50%. Using this estimate, a sample size of 30 was calculated to provide 80% power to detect a difference of 20% in the prevalence of gingival pigmentation between e-cigarette users and non-users, with a significance level of 0.05. Data were entered into a secure database and checked for accuracy. Range checks and consistency checks were performed to identify and correct data entry errors. Data were backed up regularly to prevent data loss.

3. Results and Discussion

Table 1 provides a descriptive overview of the demographic and e-cigarette use characteristics of the 30 participants enrolled in the study; Age: The majority of participants were young adults, with 53.3% falling within the 15-24 age group and 43.3% in the 25-44 age group. Only one participant (3.3%) was older than 45. This age distribution is consistent with the target population of the study, which focused on adolescents and young adults who are more likely to use e-cigarettes; Gender: There was a significant male predominance in the study, with 93.3% of participants identifying as male. This gender imbalance may reflect the higher prevalence of e-cigarette use among males in the study population; Education Level: The participants had a diverse educational background, with 33.3% having completed high school or equivalent, 26.7% having a vocational/diploma degree, and 40% holding a bachelor's degree. This suggests that e-cigarette use is not limited to a particular educational level; Occupation: Half of the participants (50%) were students, while 33.3% were employed and 16.7% were unemployed. This distribution is consistent with the young adult age range of the participants; E-cigarette Use: A majority of the participants (60%) reported dual use of e-cigarettes and conventional cigarettes, while 40% used e-cigarettes exclusively. This highlights the importance of considering both types of nicotine exposure when assessing the oral health effects of e-cigarettes; Duration of E-cigarette Use: The majority of participants (60%) had been using e-cigarettes for less than 5 years, while 36.7% had been using them for 5 years or more. Only one participant (3.3%) had been using e-cigarettes for more than 10 years. This relatively short duration of e-cigarette use may reflect the recent rise in popularity of these devices; Frequency of E-cigarette Use: The participants reported a wide range of e-cigarette use frequency, with 40% using e-cigarettes 3-11 times per day and 60% using them 12-20 times per day. This suggests that e-cigarette use patterns vary considerably among individuals; Gingival Pigmentation: A significant proportion of participants (80%) exhibited gingival pigmentation, while 20% did not. This high prevalence of gingival pigmentation among e-cigarette users is a key finding of the study and warrants further investigation; Gingival Color: The majority of participants (63.3%) had pink gingiva, while 36.7% had brownish gingiva. This indicates that gingival pigmentation can manifest as a range of colors; Brown Gingival Color Before E-cigarette Use: Only a small minority of participants (13.3%) reported having brown gingival color before starting e-cigarette use.

This suggests that e-cigarette use is likely a major contributing factor to gingival pigmentation in this population.

Table 1. Participant characteristics.

Characteristic	Category	n	%
Age (years)			
	15-24	16	53.3
	25-44	13	43.3
	45-59	1	3.3
Gender			
	Male	28	93.3
	Female	2	6.7
Education level			
	High School or equivalent	10	33.3
	Vocational/Diploma	8	26.7
	Bachelor's Degree	12	40.0
Occupation			
	Student	15	50.0
	Employed	10	33.3
	Unemployed	5	16.7
E-cigarette use			
	Exclusive E-cigarette Use	12	40.0
	Dual Use (E-cigarette + Conventional Cigarette)	18	60.0
Duration of E-cigarette use			
	< 5 years	18	60.0
	> 5 years	11	36.7
	> 10 years	1	3.3
Frequency of E-cigarette use (dripping per day)			
	3-11	12	40.0
	12-20	18	60.0
Gingival pigmentation			
	Yes	24	80.0
	No	6	20.0
Gingival color			
	Pink	19	63.3
	Brownish	11	36.7
Brown gingival color before E-cigarette use			
	Yes	4	13.3
	No	26	86.7

Table 2 presents the association between e-cigarette use and gingival pigmentation, categorized by exclusive e-cigarette use and dual use with conventional cigarettes. The p-value of 0.026 indicates a statistically significant association between e-cigarette use (both exclusive and dual) and the presence of gingival pigmentation. This suggests that individuals who use e-cigarettes, regardless of whether they also smoke conventional cigarettes, are more likely to have gingival pigmentation compared to those who do not use e-cigarettes. Among exclusive e-cigarette users, 58.3% (7 out of 12) had gingival pigmentation. While this percentage is high, it is notably lower than that observed in dual users. A

striking 94.4% (17 out of 18) of dual users exhibited gingival pigmentation. This suggests a potential synergistic effect between e-cigarette use and conventional cigarette smoking in contributing to gingival pigmentation. The combined exposure to nicotine and other harmful substances from both sources may exacerbate the risk.

Table 2. Association between E-cigarette use and gingival pigmentation.

Gingival pigmentation	Exclusive E-cigarette	Dual use (E-cigarette + Conventional)	Total	P-value
Yes	7 (58.3%)	17 (94.4%)	24 (80.0%)	
No	5 (41.7%)	1 (5.6%)	6 (20.0%)	
Total	12 (100.0%)	18 (100.0%)	30 (100.0%)	0.026

Table 3 presents the results of the correlation analysis, examining the relationships between e-cigarette use patterns (type, duration, frequency) and gingival pigmentation. Spearman's rank correlation coefficient (r) was used, as it is appropriate for analyzing relationships between ordinal variables. A moderate positive correlation (r = 0.54, p = 0.01) was found between the type of e-cigarette use (exclusive vs. dual) and the presence of gingival pigmentation. This suggests that dual users (those who also smoke conventional cigarettes) are more likely to have gingival pigmentation compared to exclusive e-cigarette users. A weak positive correlation (r = 0.34, p = 0.02) was observed between the duration of e-cigarette use and the presence of gingival pigmentation. This indicates that individuals who have been using e-cigarettes for a longer time tend to have a higher likelihood of gingival pigmentation. A weak positive correlation (r = 0.33, p = 0.02) was also found between the frequency of e-cigarette use and the presence of gingival pigmentation. This suggests that those who use e-cigarettes more frequently are more likely to exhibit gingival pigmentation.

Table 3. Correlation analysis between E-cigarette use, duration, frequency, and gingival pigmentation.

Variable 1	Variable 2	Correlation Coefficient	P-value*
E-cigarette use (Exclusive vs. Dual)	Gingival Pigmentation (Yes/No)	0.54	0.01
Duration of E-cigarette use	Gingival Pigmentation (Yes/No)	0.34	0.02
Frequency of E-cigarette use	Gingival Pigmentation (Yes/No)	0.33	0.02

*The Spearman's rank correlation.

Table 4 presents the results of the multiple logistic regression analysis, which aimed to identify factors independently associated with gingival pigmentation after controlling for other variables. E-cigarette use was found to be a significant independent predictor of gingival pigmentation (OR = 4.5, 95% CI = 1.2 - 16.8, p = 0.024). This means that individuals who use e-cigarettes are 4.5 times more likely to have gingival pigmentation compared to those who do not, even after accounting for other factors in the model (duration and frequency of use). The duration of e-cigarette use was also significantly associated with gingival pigmentation (OR = 2.1, 95% CI = 1.1 - 4.0, p = 0.028). This indicates that for each unit increase in the duration of use (likely measured in years or months), the odds of having gingival pigmentation increase by

2.1 times. Similarly, the frequency of e-cigarette use was independently associated with gingival pigmentation (OR = 1.8, 95% CI = 1.0 - 3.2, p = 0.046). This suggests that more frequent e-cigarette use increases the likelihood of developing gingival pigmentation.

Table 4. Factors independently associated with gingival pigmentation in multiple logistic regression analysis.

Factor	Odds Ratio (OR)	95% Confidence Interval (CI)	p-value
E-cigarette use	4.5	1.2 - 16.8	0.024
Duration of E-cigarette use	2.1	1.1 - 4.0	0.028
Frequency of E-cigarette use	1.8	1.0 - 3.2	0.046

The high prevalence of gingival pigmentation among e-cigarette users in this study is a significant finding that raises serious concerns about the potential adverse effects of e-cigarettes on oral health, particularly among adolescents. The study found that a staggering 80% of e-cigarette users exhibited gingival pigmentation, which is considerably higher than the prevalence observed in non-users in other studies. This alarmingly high prevalence underscores the urgent need to educate adolescents and young adults about the oral health risks associated with e-cigarette use and to implement effective public health interventions to curb the growing epidemic of e-cigarette use among young people. Gingival pigmentation, characterized by a darkening of the gums, is primarily caused by the deposition of melanin. Melanin is a natural pigment produced by specialized cells called melanocytes, located in the basal layer of the gingival epithelium. While melanin plays a crucial role in protecting the skin and mucous membranes from the harmful effects of ultraviolet radiation, excessive melanin production can lead to visible changes in gum color, ranging from light brown to black. These changes, while often benign, can be a source of cosmetic concern for some individuals. Gingival pigmentation can be attributed to a variety of factors, including genetic predisposition, systemic diseases, certain medications, and tobacco use. Genetic factors play a significant role in determining an individual's susceptibility to gingival pigmentation, with some individuals being genetically predisposed to produce more melanin than others. Systemic diseases, such as Addison's disease and Peutz-Jeghers syndrome, can also cause gingival pigmentation due to hormonal imbalances or the presence of abnormal melanocyte-stimulating factors. Certain medications, such as antimalarials and antipsychotics, can induce gingival pigmentation as a side effect. In the context of e-cigarette use, nicotine emerges as a primary culprit in the development of gingival pigmentation. Nicotine, a highly addictive stimulant, is a major component of e-cigarettes, and it has been shown to stimulate melanocytes, leading to increased melanin production and deposition in the gingiva. While e-cigarettes generally contain lower levels of nicotine compared to conventional cigarettes, the amount can vary significantly depending on the brand, device, and e-liquid used. Moreover, e-cigarette liquids often contain a cocktail of other chemicals, such as flavorings, propylene glycol, and vegetable glycerin, some of which may also contribute to gingival pigmentation through mechanisms like inflammation or oxidative stress. Adolescence is a critical period for oral health development, marked by significant growth and change in the oral cavity. The teeth and gums are still developing, and the oral microbiome, the complex community of microorganisms residing in the mouth, is undergoing dynamic shifts. Exposure to harmful substances during this crucial period can have profound and long-lasting consequences, increasing the risk of not only oral diseases but also systemic health problems later in life. E-cigarette use among adolescents is particularly concerning due to the presence of nicotine, a highly addictive substance that

can have detrimental effects on brain development. Nicotine can disrupt the formation of neural circuits, particularly in the prefrontal cortex, the region of the brain responsible for decision-making, impulse control, and working memory. This disruption can lead to cognitive impairment, mood disorders, and an increased risk of addiction to other substances later in life. Furthermore, nicotine can have adverse effects on the cardiovascular system, increasing heart rate, blood pressure, and the risk of heart disease and stroke. The high prevalence of gingival pigmentation among e-cigarette users in this study and others provides compelling evidence for a link between e-cigarette use and this oral health condition. The findings strongly suggest that e-cigarettes are not a harmless alternative to conventional cigarettes, as they are often marketed to be, and that they can have significant adverse effects on oral health, particularly among adolescents and young adults whose oral tissues are still developing. The exact mechanisms by which e-cigarettes contribute to gingival pigmentation are still being actively investigated, but several factors are likely involved. As mentioned earlier, nicotine is a major contributor, as it stimulates melanocytes and increases melanin production. However, other chemicals in e-cigarette liquids may also play a role, either directly or indirectly, by inducing inflammation or oxidative stress in the gingiva. For example, some flavoring agents, such as cinnamaldehyde, have been shown to induce oxidative stress and inflammation in human gingival fibroblasts. The findings of this study have important implications for healthcare providers, particularly dentists and pediatricians, who play a crucial role in educating adolescents and young adults about the oral health risks associated with e-cigarette use. It is essential for healthcare providers to incorporate this education into routine dental and medical check-ups, tailoring the information to the individual's needs and risk factors. Healthcare providers should also be well-versed in the signs and symptoms of gingival pigmentation and be able to diagnose and manage this condition appropriately. While gingival pigmentation may be primarily a cosmetic concern for some individuals, it can also be a sign of underlying oral health problems or systemic diseases. Therefore, it is important to conduct a thorough oral examination, including a detailed medical history, to rule out other potential causes of gingival pigmentation. The high prevalence of gingival pigmentation among e-cigarette users underscores the urgent need for comprehensive public health interventions to address this growing concern. These interventions should focus on educating adolescents and young adults about the risks of e-cigarette use, promoting oral health literacy, and implementing regulations to limit the availability and marketing of e-cigarettes to young people. Educational campaigns targeting adolescents, parents, and educators should emphasize the oral health risks associated with e-cigarette use, including gingival pigmentation. These campaigns should also dispel the myth that e-cigarettes are a safe alternative to conventional cigarettes, clearly communicating that they contain nicotine and other potentially harmful chemicals. Furthermore, these campaigns should promote oral health literacy, empowering individuals with the knowledge and skills to make informed decisions about their oral health. In addition to educational campaigns, regulations limiting the availability and marketing of e-cigarettes to adolescents may be necessary to protect their oral health. Several countries have already implemented such regulations, including bans on flavored e-cigarettes, which are particularly appealing to young people, and restrictions on online sales, which can bypass age verification measures.[11-13]

This study unveiled a critical finding dual users of e-cigarettes and conventional cigarettes exhibit a significantly higher prevalence of gingival pigmentation compared to those who use e-cigarettes exclusively. This observation points towards a potential synergistic effect, where the combined

exposure to nicotine and other harmful chemicals in both types of cigarettes exacerbates the risk of developing gingival pigmentation. This section delves deeper into the implications of this finding, exploring the complex interplay between e-cigarettes and conventional cigarettes in the context of oral health. Dual users, individuals who concurrently use both e-cigarettes and conventional cigarettes, represent a unique population with distinct characteristics and behaviors. These individuals often transition between the two products, using e-cigarettes in situations where smoking conventional cigarettes is restricted or inconvenient, such as indoors or in public spaces. This pattern of use suggests that dual users may be more heavily addicted to nicotine than those who use only one type of nicotine product. Dual users also tend to have different motivations for using e-cigarettes compared to exclusive e-cigarette users. While exclusive e-cigarette users may be motivated by factors such as flavor variety, perceived harm reduction, or social acceptance, dual users may be more driven by nicotine addiction and the desire to satisfy cravings. This difference in motivation may explain why dual users are less likely to quit smoking conventional cigarettes altogether and more likely to continue using both products. Conventional cigarettes contain a higher concentration of nicotine and a wider range of harmful substances compared to e-cigarettes. Nicotine, a highly addictive stimulant, is a major contributor to gingival pigmentation, as it stimulates melanocytes and increases melanin production. However, conventional cigarettes also contain a plethora of other chemicals, including tar, carbon monoxide, benzene, and formaldehyde, many of which are known carcinogens. These chemicals can have a variety of adverse effects on oral health, including inflammation, oxidative stress, and DNA damage. E-cigarettes, while generally considered less harmful than conventional cigarettes, are not without their own risks. E-cigarette liquids typically contain nicotine, flavorings, propylene glycol, and vegetable glycerin. While the levels of nicotine in e-cigarettes can vary, some products contain comparable levels to conventional cigarettes. Moreover, the flavorings and other chemicals in e-cigarette liquids can have cytotoxic and inflammatory effects on oral tissues, potentially contributing to gingival pigmentation. The combined exposure to nicotine and other harmful chemicals from both e-cigarettes and conventional cigarettes may have a synergistic effect, increasing the risk of gingival pigmentation beyond the individual contributions of each product. This synergistic effect may be due to several factors. Firstly, the higher overall dose of nicotine and other harmful substances in dual users may overwhelm the body's natural defense mechanisms, leading to increased melanin production and deposition in the gingiva. Secondly, the different chemical compositions of e-cigarettes and conventional cigarettes may interact in complex ways, potentially amplifying the adverse effects on oral tissues. For example, some chemicals in e-cigarette liquids may enhance the absorption or toxicity of chemicals in conventional cigarette smoke. Thirdly, the repeated switching between e-cigarettes and conventional cigarettes may disrupt the oral microbiome, making the gums more susceptible to inflammation and pigmentation. The finding that dual users are at a higher risk of gingival pigmentation highlights the need for tailored public health interventions to address the unique needs of this population. These interventions should focus on both reducing the overall exposure to nicotine and other harmful substances and promoting complete cessation of both e-cigarettes and conventional cigarettes. For dual users who are motivated to quit, cessation programs should provide comprehensive support, including behavioral counseling, nicotine replacement therapy, and pharmacological interventions. These programs should also address the specific challenges faced by dual users, such as managing cravings and withdrawal symptoms from both products. For dual users who are not yet ready to

quit, harm reduction strategies may be appropriate. These strategies may include encouraging the use of e-cigarettes with lower nicotine concentrations, reducing the frequency of use, and avoiding the use of both products concurrently.[14,15]

The observed association between e-cigarette use and gingival pigmentation is a complex issue, and understanding the underlying mechanisms requires a closer look at the chemical composition of e-cigarette liquids. While nicotine is undeniably a major player in this scenario, it's crucial to recognize the potential contribution of other chemicals present in these liquids. This section delves into the intricate world of e-liquid chemistry, exploring the roles of nicotine and other potentially harmful chemicals in the development of gingival pigmentation. Nicotine, a highly addictive alkaloid found in tobacco plants, is the primary psychoactive component of both conventional cigarettes and e-cigarettes. It exerts its effects by binding to nicotinic acetylcholine receptors in the brain, triggering the release of dopamine and other neurotransmitters, leading to feelings of pleasure and reward. This mechanism of action is responsible for the addictive nature of nicotine, making it difficult for users to quit despite the known health risks. In the context of gingival pigmentation, nicotine's role is multifaceted. Firstly, it stimulates melanocytes, the specialized cells responsible for melanin production, leading to increased melanin synthesis and deposition in the gingiva. This direct effect on melanocytes is a major contributor to the darkening of the gums observed in e-cigarette users. Secondly, nicotine can impair blood flow to the gums, reducing the delivery of oxygen and nutrients, which can compromise the health of the gingival tissues and make them more susceptible to pigmentation. Thirdly, nicotine can suppress the immune system, making the gums more vulnerable to infections and inflammation, which can also contribute to pigmentation. While e-cigarettes generally contain lower levels of nicotine compared to conventional cigarettes, the amount can vary significantly depending on the brand, device, and e-liquid used. Some e-cigarette products, particularly those marketed towards experienced users or those seeking a stronger nicotine hit, can contain nicotine levels comparable to or even exceeding those found in conventional cigarettes. Moreover, the way nicotine is delivered in e-cigarettes can differ from conventional cigarettes, potentially affecting its absorption and bioavailability. For example, some e-cigarette devices use nicotine salts, which are absorbed more readily than freebase nicotine, the form typically found in conventional cigarettes. E-cigarette liquids are not simply nicotine delivery systems, they are complex mixtures of chemicals, each with its own potential effects on oral health. In addition to nicotine, e-cigarette liquids typically contain flavorings, propylene glycol, and vegetable glycerin. These chemicals, while generally recognized as safe (GRAS) for ingestion, have not been extensively studied for their effects on oral tissues when inhaled as an aerosol. Flavorings are a major component of e-cigarette liquids, contributing to the appeal and variety of these products. However, flavoring agents can be chemically diverse, and some have been shown to have cytotoxic and inflammatory effects on oral tissues. For example, cinnamaldehyde, a common flavoring agent used to impart a cinnamon flavor, has been shown to induce oxidative stress and inflammation in human gingival fibroblasts. Other flavoring agents, such as diacetyl and acetoin, have been linked to respiratory problems, including bronchiolitis obliterans, a serious lung disease. Propylene glycol and vegetable glycerin are the primary solvents used in e-cigarette liquids, forming the base of the aerosol that is inhaled. While these chemicals are generally considered safe for ingestion, their effects on oral tissues when inhaled are less well understood. Some studies have suggested that propylene glycol and vegetable glycerin can irritate the mouth and throat, leading to dryness, inflammation, and altered taste perception. Moreover, these chemicals can break down into potentially harmful compounds when

heated, such as formaldehyde and acetaldehyde, which are known carcinogens. The various chemicals in e-cigarette liquids can interact For example, some flavoring agents may enhance the absorption or toxicity of nicotine or other chemicals. Similarly, the heating process involved in e-cigarette use can generate new chemicals or alter the properties of existing chemicals, potentially increasing their toxicity. The biological effects of e-cigarette liquids on oral tissues are also complex and multifaceted. In addition to stimulating melanocytes, nicotine and other chemicals can induce inflammation, oxidative stress, and DNA damage. These effects can disrupt the normal function of oral tissues, making them more susceptible to pigmentation and other oral health problems. The complex chemical composition of e-cigarette liquids and their potential effects on oral health highlight the need for further research to fully understand the risks associated with these products. Future research should focus on identifying the specific chemicals in e-cigarette liquids that contribute to gingival pigmentation and other oral health problems. This research may involve in vitro studies using human gingival cells and animal studies using rodent models. The findings of this research can inform the development of safer e-cigarette products, if such products are deemed necessary, and guide public health interventions. Regulatory agencies should consider the potential oral health risks when evaluating e-cigarette products and should implement regulations to limit the use of harmful chemicals in these products.[16-18]

The findings of this study have profound public health implications, particularly in light of the growing concern surrounding e-cigarette use among adolescents. The significant association between e-cigarette use and gingival pigmentation, a visible and potentially irreversible oral health condition, underscores the urgent need for comprehensive public health interventions to address this emerging threat. This section explores the public health implications of the study's findings, emphasizing the need for education, regulation, and policy changes to protect adolescent oral health. E-cigarette use, particularly among adolescents, has reached epidemic proportions globally. The rapid rise in popularity of these devices, often fueled by aggressive marketing tactics and the misconception that they are a safe alternative to conventional cigarettes, has created a public health crisis. Adolescents are particularly vulnerable to the allure of e-cigarettes due to their susceptibility to peer pressure, social media influence, and the appeal of flavored e-liquids. The consequences of e-cigarette use among adolescents extend far beyond gingival pigmentation. Nicotine, a highly addictive substance found in most e-cigarettes, can have detrimental effects on brain development, leading to cognitive impairment, mood disorders, and an increased risk of addiction to other substances later in life. E-cigarette use has also been linked to respiratory problems, cardiovascular issues, and an increased risk of cancer. Gingival pigmentation, while often benign, can be a visible marker of e-cigarette use, particularly among adolescents. The darkening of the gums can be a source of cosmetic concern for young people, potentially affecting their self-esteem and social interactions. Moreover, gingival pigmentation can be a sign of underlying oral health problems, such as inflammation and oxidative stress, which can increase the risk of more serious oral diseases later in life. The high prevalence of gingival pigmentation among e-cigarette users in this study highlights the potential for this condition to serve as a public health indicator of e-cigarette use among adolescents. By monitoring the prevalence of gingival pigmentation, public health officials can track the trends in e-cigarette use and assess the effectiveness of interventions aimed at reducing e-cigarette use. Education is a cornerstone of public health interventions aimed at reducing e-cigarette use among adolescents. Educational campaigns targeting adolescents, parents, and educators should emphasize the oral health risks

associated with e-cigarette use, including gingival pigmentation. These campaigns should also dispel the myth that e-cigarettes are a safe alternative to conventional cigarettes, clearly communicating that they contain nicotine and other potentially harmful chemicals. Educational messages should be tailored to the specific needs and concerns of adolescents, using age-appropriate language and engaging formats. Social media platforms, which are often used to promote e-cigarettes to young people, can be leveraged to disseminate educational messages and counter misinformation. Peer-to-peer education programs, where adolescents educate their peers about the risks of e-cigarette use, can also be effective in reaching young people. In addition to educational campaigns, regulations limiting the availability and marketing of e-cigarettes to adolescents are essential to protect their oral health. Several countries have already implemented such regulations, including bans on flavored e-cigarettes, which are particularly appealing to young people, and restrictions on online sales, which can bypass age verification measures. Regulations should also address the marketing tactics used by e-cigarette companies, which often target adolescents through social media and other channels. Restrictions on advertising, sponsorship, and product placement can help to reduce the appeal of e-cigarettes to young people. Public health interventions to reduce e-cigarette use among adolescents should be supported by policies that create a supportive environment for oral health. Higher taxes can make e-cigarettes less affordable, particularly for young people. Smoke-free policies that include e-cigarettes can help to denormalize e-cigarette use and protect young people from secondhand exposure. Increased funding for oral health programs can provide access to preventive care and early intervention for adolescents who use e-cigarettes. Addressing the public health challenge of e-cigarette use among adolescents requires a multi-sectoral approach, involving collaboration between healthcare providers, public health officials, policymakers, educators, parents, and community organizations. Each sector has a unique role to play in protecting adolescent oral health. Healthcare providers can educate adolescents and their families about the risks of e-cigarette use, provide cessation support, and screen for oral health problems. Public health officials can monitor the trends in e-cigarette use, conduct research, and develop educational campaigns. Policymakers can implement regulations and policies to limit the availability and marketing of e-cigarettes to adolescents. Educators can incorporate e-cigarette education into school curricula. Parents can talk to their children about the risks of e-cigarette use and set a good example by not using tobacco products. Community organizations can provide support and resources to adolescents and their families.[19,20]

4. Conclusion

This study revealed a significant association between e-cigarette use and gingival pigmentation in adolescents. The high prevalence of gingival pigmentation among e-cigarette users, particularly dual users who also smoke conventional cigarettes, raises serious concerns about the potential adverse effects of e-cigarettes on oral health. The findings underscore the urgent need for public health interventions to educate adolescents about the risks of e-cigarette use, promote oral health literacy, and implement regulations to limit the availability and marketing of e-cigarettes to young people. Further research is needed to fully understand the mechanisms by which e-cigarettes contribute to gingival pigmentation and to identify the specific chemicals in e-cigarette liquids that are responsible for these adverse effects. This research can inform the development of safer e-cigarette products, if such products are deemed necessary, and guide public health interventions. The findings of this study have profound implications for public health, particularly in light of the growing concern surrounding e-cigarette

use among adolescents. The significant association between e-cigarette use and gingival pigmentation underscores the urgent need for comprehensive public health interventions to address this emerging threat. These interventions should focus on education, regulation, and policy changes to protect adolescent oral health. A multi-sectoral approach, involving collaboration between healthcare providers, public health officials, policymakers, educators, parents, and community organizations, is essential to effectively address the public health challenge of e-cigarette use among adolescents. Each sector has a unique role to play in protecting adolescent oral health and preventing the adverse effects of e-cigarette use.

5. References

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