

# THE EFFECTS OF VAPING ON ORAL AND DENTAL HEALTH

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## Introduction

“When it comes to your teeth and gums, vaping could be just as dangerous as cigarette smoking” said American Dental Association President Dr. Chad Gehani (2019). Electronic cigarettes, also known as vape pens, JUULS, and pods use an electric element to heat liquid-based flavorant into an aerosol for inhalation. As technology and science progress, the adverse health effects of nicotine, associated chemicals, and additives continue to be researched and discovered. With the rising popularity of e-cigarettes and vaping, dental and oral health effects have come into question. The 2020 National Youth Tobacco Survey found that 3.6 million youth are currently using e-cigarettes, with a concerning uptick in use of disposable products. Vaping affects the oral cavity by receding gingiva by blood vessel shrinkage, masks gum disease by reducing bleeding on probing due to blood flow loss, amplifies bad breath by compromising saliva production, increases bruxism by increased masticatory muscle stimulation, and increases the occurrence of tooth caries.

Electronic nicotine delivery systems (ENDS) gained popularity by excluding the harmful chemicals that are present in cigarettes. However, the regulation and long-term effects of e-cigarettes are still debated among many scientists and clinicians. To further understand the possible health complications associating with ENDS, many studies have been published investigating the ingredients, delivery systems, and synergistic effects of e-cigarettes. One of the major concerns for oral safety regarding e-cigarettes are the ingredients and chemicals used within the liquid that contains the flavorant and additive. The common chemicals and metals found in e-cigarettes include nicotine, propylene glycol, acrolein, diacetyl, tin, lead, diethylene glycol, additional carcinogens, chemicals, and ultrafine particles.

## **Social Attitude Towards Vaping**

To best understand the possible health effects of vaping, it is important to recognize the perceived consumers. Knowing the users and interested groups enable governing bodies to implement proper regulations, healthcare workers to be knowledgeable of possible patient-base, and accurate information availability. E-cigarettes are often promoted as a safe, or less harmful, alternative to traditional smoking and can be used as an aid for smoking cessation. In recent years, significant increases in marijuana vaping has been reported. Vaping replicates the behavioral and social aspects of smoking without burning tobacco, the main product responsible for producing numerous toxicants and carcinogens. E-cigarette usage is believed to have started for health reasons, primarily used as a transition from traditional smoking. However, there has been a rising concern of vaping appealing to nonsmokers and adolescents.

A study performed in the Netherlands worked to compare smokers, vapers, and dual users according to their characteristics and motivational factors (Schoren 2017). To study the social impact and importance of e-cigarettes, the study posed three important questions; duration, onset, and quantity? This study included 240 vapers, 104 smokers, and 73 dual users with noted demographics, smoking and vaping behavior, quit attempt, general attitudes towards e-cigarettes, social influences, and intention to quit.

To interpret the data listed previously, the Integrated Model for Change was used to assess relationships with perceived pros and cons of vaping, social modelling and norms towards vaping, and self-efficacy towards vaping. This model assumes awareness, motivation, and action as three phases in the behavioral change process. Personality, social factors, and

information availability were included to complete the assessment. Multinomial logistic regression analyses were performed to determine associations between the different variables. The study concluded that 23.7% of participants began vaping as a smoking cessation tool while 52.0% of participants began vaping because of the notion that it is healthier. Vapers used e-cigarettes more often (98.5%) on a daily basis compared to traditional and dual users (45.85). Nicotine containing cartridges were more popular among all users compared to nicotine-free cartridges.

A recent study at East Tennessee State University was conducted to analyze the prevalence of vaping and associated behavior of vaping among college students. A sample of 498 enrolled students completed a self-report health survey questionnaire. (Ogbebor 2020). The questions asked about behaviors and substance use including alcohol, tobacco products, electronic vapor products, marijuana, and prescription pain pills.

This study reported that (43.2%) college students frequently use e-cigarette and other vaporizing products. These findings were similar to a study done among university students in Central and Eastern Europe which found a similar prevalence (43.7%) (Brozek 2019). In this specific study, e-cigarette usage was not associated with the desire to quit traditional cigarette smoking (Ogbebor 2020). An additional study reported possible associations with the use of cannabis as well as the propensity for young persons who used other substances to vape as well (Oh 2019).

### **Cariogenic Potential of Sweet Flavors**

A 2018 study by Shin Ae Kim of the American Dental Association investigated potential cariogenic tooth decay of sweet flavors in e-cigarette liquids. Sweet flavors include saccharides,

esters, acids, or aldehydes. A previous study has shown that e-liquids made from glycerin have high viscosity properties, adhering to exposed areas when generated into an aerosol. These surfaces can vary from the soft tissue in the oral cavity, lungs, clothing, and skin. The relationship between viscous aerosol and the oral cavity is of particular interest due to possible changes in tissue surface from high sucrose intake and aerosol interaction. Many e-liquids share similar chemical and physical properties to sugary and gelatinous foods that are proven dental caries, leading researchers and scientists to question additional caries in e-cigarettes and vaping.

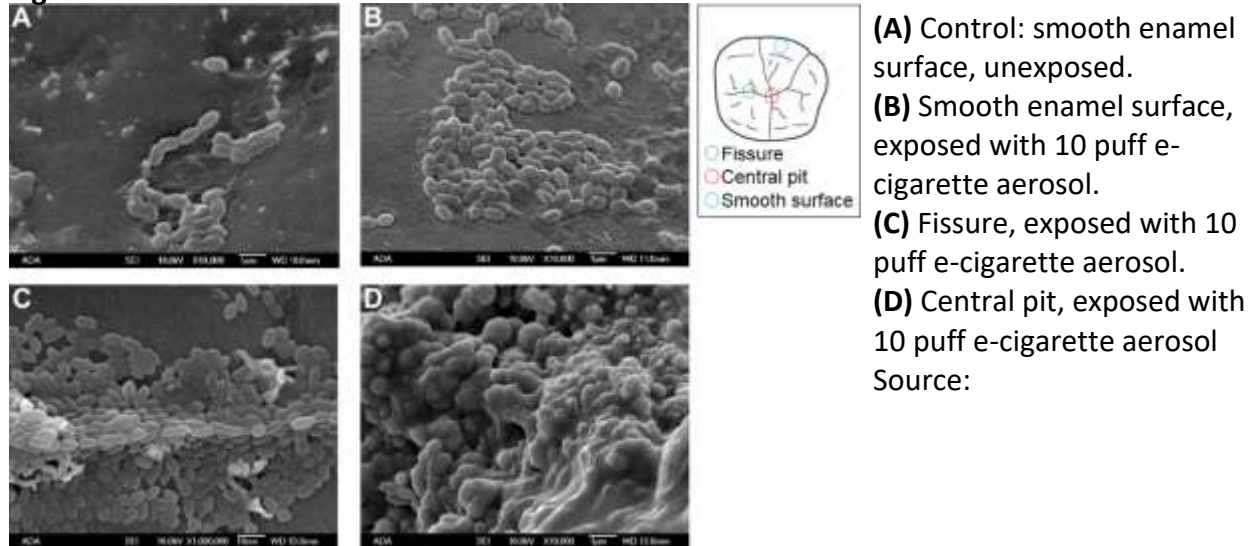
Dental caries were discovered more than 50 years ago, but continue to be the most prevalent infectious disease in humans, affecting 97% of the world population throughout their lifetimes (Berg 2006). Dental caries progress by pathogenic oral bacteria metabolizing fermentable carbohydrates such as glucose, fructose, and sucrose to produce lactic acid. At low or moderate carbohydrate concentrations, components within saliva are able to neutralize the low pH of the oral environment. However, higher concentrations from excess sucrose intake creates an imbalance between pathogens and protective components creating a prolonged low pH condition. Aciduric and acidogenic bacteria such as *Streptococcus mutans* have evolved to survive and thrive in such conditions. *S. mutans* can also produce glucosyltransferases (GTFs) that catalyze the production of Intracellular Polysaccharides (IPS) and Extracellular Polymeric Substances (EPS), which significantly contribute to the formation and stability of oral biofilm, also known as dental plaque. The accumulation of cariogenic biofilm leads to the breakdown of enamel and dentin.

As preparation for the study, human teeth were collected and prepped as enamel disks with uniform orientation and free of cracks, deformations, scratches, steps, or slopes. The quality of polishing was checked with a light metallurgical microscope at 40x magnification. A micro-indentation hardness test was ran on all tooth samples using Knoop hardness number following American Society for Testing and Materials (ASTM). The enamel disks were placed under the Knoop indenter and subjected to a load of 50 grams for 10 seconds. Five sites along the dentino-enamel junction were tested for hardness. After e-cigarette exposure, another set of measurements were taken on parallel tracks, approximately 100 um apart. To form biofilm, an overnight culture was inoculated in Biofilm Formation media and *S. mutans* were allowed to attach to the surface and collected for 4 hours. The solution was then died with crystal violet, dried, and 75 uL was transferred to a flat-bottomed plate. Absorbance was measured at 550nm. Aerosol droplet quantification were compared at 0, 10, and 150 puffs on an exposed surface that was captured with a stereoptical light microscope and quantified from random locations on the enamel disk. Optical emission spectrometry analysis was performed to measure the presence of 12 metals.

The quantity of sucrose intake, delivery method, how often it is delivered, and delivery duration can further increase the risk of initiation, progress, and severity of dental caries. The direct correlation between diet and dental caries incidence have been extensively researched over the years with many supportive studies. Ethyl butyrate, triacetin and hexyl acetate and their respective chemical by-products increase cariogenic potential were proven to increase cariogenic potential. From this study, the data proposes that esters in e-liquid flavors provide an additional food course for *S. mutans* to flourish in oral biofilm environment. Mechanical

testing, hardness and adhesion force, were also tested on the biofilm assays with SEM images showing complex surface changes and biological responses after e-cigarette exposure as shown below in Figure 1. As the exposure to vape ingredients increases, the prevalence of *S. mutans* also increases along the surface of the tooth.

**Figure 1**

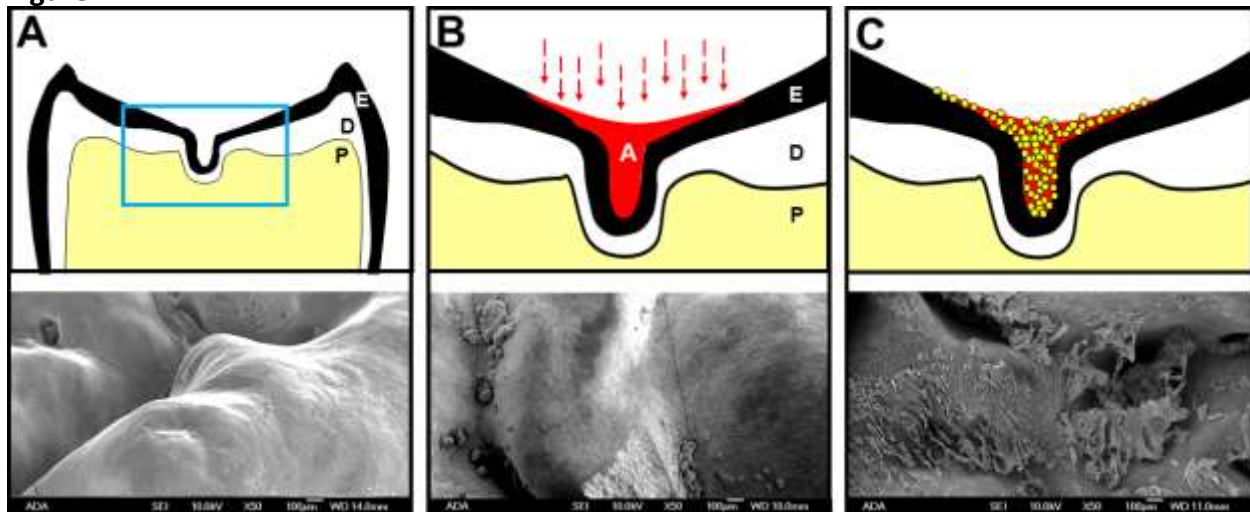


Kim, S., Smith, S., Beauchamp, C., Song, Y., Chiang, M., Giuseppetti, A., . . . Kim, J. (2018). Cariogenic potential of sweet flavors in electronic-cigarette liquids. Retrieved December 07, 2020, from <https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0203717>

Surface characteristics such as roughness, charge, tackiness, and energy have a large impact on how bacterial cells adhere and form biofilm. This study confirms that *S. mutans*-to-surface interactions can be altered by e-cigarette aerosols. EPS allow *S. mutans* to encapsulate itself on the surface, start multiplying in number and eventually forming biofilm to rapidly metabolize carbohydrates into lactic acid, creating locally a low pH, leading to demineralization of enamel surface. As seen in figure 2, *S. mutans* is able to occupy the deep pits and fissures of a tooth's surface and create a complex biofilm by secreting EPS. Demineralization of enamel is of great importance to oral health because the demineralization is the first step of dental caries development. The data from this study also suggests that the measured metal levels are well

tolerated by *S. mutans* as this bacteria is known to have a nutritional requirement for magnesium, while calcium, iron, and copper ions are known modulators in biofilm formation.

Figure 2



(A) Top: a cross section of a human tooth, Bottom: control, unexposed enamel fissure.  
(B) Top: a tooth after e-cigarette aerosol exposure, Bottom: aerosol exposed enamel fissure.  
(C) Top: a tooth after e-cigarette aerosol exposure and subsequent *S. mutans* attachment  
Kim, S., Smith, S., Beauchamp, C., Song, Y., Chiang, M., Giuseppetti, A., . . . Kim, J. (2018).  
*Cariogenic potential of sweet flavors in electronic-cigarette liquids*. Retrieved December 07, 2020, from  
<https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0203717>

This study by Kim and associated researches provides insight into the negative consequences of vaping on oral health, specifically teeth. Enamel is the hardest mineralized tissue in the body but has no way of regenerating itself once damaged. Certain e-liquid ingredients interact with the hard tissues of the oral cavity in a similar way to high-sucrose candies and acidic drinks. Viscous e-liquids made from propylene glycol and glycerin, along with sweet flavors facilitate attachment and provide additional food source which pathogenic oral bacteria such as *S. mutans* prefer.

## Oral Health and ENDS



Another study in 2019 studied the effects of e-cigarettes on periodontal health including several pathophysiological events including oxidative stress, DNA damage, inflammation, and periodontal diseases (Isik). Multifunctional infections arise from the interaction between bacteria found in dental plaque and the immune response in the surrounding structures. An inflammatory response causes swollen and bleeding gums which can result in gingivitis and eventually the loosening of teeth. Increased bleeding on probing (BOP) and local inflammatory cytokines act as markers for the progression of periodontitis and can be found in gingival crevicular fluid (GCF), saliva, and serum. Dry mouth, a common side effect experienced by e-cigarette users, is a condition in which the salivary glands in the mouth do not produce enough saliva to keep the mouth wet. Saliva helps prevent tooth decay by neutralizing acids produced by bacteria, limiting bacterial growth, and washing away food particles (Mayo Clinic 2018). Additional symptoms of dry mouth include increased plaque, tooth decay, and gum disease, mouth sores, oral yeast infections, and cracked lips.

Protein carbonylation, a nonreversible modification of amino acids, occurs during oxidative stress causing chronic inflammation and DNA damage. Pre-mature senescence, or growth arrest, is induced in gingival epithelium contributing to the pathogenesis of oral diseases from flavorants added to e-cigarette liquid (Sundar 2016). Increased oxidative stress, pro-inflammatory, and pro-senescence responses result in dysregulated repair mechanisms in periodontal cells. Periodontal ligament and gingival fibroblasts are the most abundant structural cells in periodontal tissue. Upon stress, these cells are able to induce an immune response resulting in inflammation.

Increased antibody production from protein carbonylation was shown to cause bone loss and matrix destruction due to the aldehydes and carbonyls present in e-cigarette liquid, playing a role in oral toxicity. Two e-cigarette flavors, classic tobacco and menthol, showed significant increase of RAGE and COX-2, inflammatory markers, and additional markers for DNA damage. The human 3D model of epithelial and gingival tissue showed high levels of pro-inflammatory cytokines, IL-8 and PGE2 after exposure to e-cigarette vapor. Nornicotine, a metabolite of nicotine, upregulates RAGE expression in e-cigarette users stimulating the secretion of cytokines, initiating a prolonged immune response (Katz 2005). Cytokine and ROS are heavily involved in the destruction of periodontal tissue within the oral cavity. The data collected during this study indicates the pathogenic role of e-cigarette aerosol to cells and tissues of the oral cavity, ultimately leading to compromised periodontal health. Both RAGE and HDAC2 are implicated in the regulation of inflammation and cellular senescence.

### **Gingival Fibroblasts Apoptosis and Cytotoxicity**

Several studies have presented the correlation between the use of tobacco products and the increased severity of periodontal diseases. Cigarette smoking cytotoxicity is due to various components and the physiological functions of different cell types in the oral cavity have been studied regarding their responsive healing process. Nicotine is also responsible for migration inhibition, cytoskeleton alteration, and extracellular matrix remodeling in human gingival fibroblasts (HGFs), one of the cell types mostly exposed to smoking and vaping (Fang 2005).

Human gingival fibroblasts (HGF's) were obtained, prepared, and treated with two different solutions that contained nicotine, propylene glycol, glycerin, and artificial flavorings

for up to 72 hours (Sancilio 2005). After exposure to 5 and 2 mg/mL solutions, the metabolic activity within the cells was reduced up to 20% compared to the control group for both nicotine-containing (NC) and nicotine-free (Nf) fluids. After 72 hours of exposure from the vaped 1mg/mL concentration, the study suggests a decrease in metabolic activity to less than 50%. The NC experimental condition appeared to be more toxic than the Nf condition having a higher level of measured toxicity which is determined by the number of detached cell walls.

The pro-oxidative action of nicotine is well known; however, this study has also shown that nicotine-free fluids induced and increase ROS production, indicating a role for the fluid itself in triggering the oxidative stress in HGF's. The results of the 2005 Sancilio study showed that the nicotine-treated sample showed higher early and late apoptotic cell percentages with lower viability. Results of a lesser severity were shown in nicotine-free samplings following research claiming a greater danger in nicotine products. Both samples reported an upregulation in Bax gene expression, the primary cause of P53-mediated apoptosis.

A previous study showed that e-cigarette exposure in vitro produced inflammatory responses in human periodontal ligament fibroblasts and gingival epithelium progenitor cells. Markers, such as PGE2 and IL-1 $\beta$ , play an important role in inflammatory pathways leading to compromising conditions in the lungs and oral cavity (Mokeem 2018). These results suggest that vaping may be associated with the development of chronic systemic and oral disease, although less so than the effects brought on by smoking traditional cigarettes. Smoking-induced endothelial dysfunction may lead to activation of inflammatory markers within vascular tissue from nicotine (Conklin 2010).

## Dental Implants

E-cigarettes deliver nicotine at varying concentrations. Nicotine and nornicotine have been associated with low leukocyte activity and healing by inhibiting neovascularization and osteoblastic differentiation. Without a proper immune response, an increased risk of implant failure, impaired healing, poor papilla regeneration and increased bone loss can occur. Many studies have been conducted to study the clinical, radiographic, and immunological peri-implant parameters among nicotine users.

A specific study by a research group at The College of Dentistry in Riyadh, Saudi Arabia looked to compare implant and levels of metalloproteinase (MMP)-9 and interleukin (IL)-1 $\beta$  levels among traditional cigarette smokers, e-cigarette smokers, and nonsmokers. (MMP)-9 and (IL)-1 $\beta$  have proinflammatory effects that play a central role in peri-implant tissue destruction (Zani 2016). Reactive oxygen species generated by the triggered macrophages can go on to activate (MMP)-9 and (IL)-1 $\beta$ . Participants received an initial oral exam and detailed questionnaire to determine demographics, duration of dental implants, duration and daily frequency of cigarette and e-cigarette usage, and oral hygiene care. Peri-implant plaque index, bleeding on probing, probing depth, and marginal bone loss were examined. Each measurement was recorded at six sites on each implant then recorded as mean percentages per individual. Peri-implant marginal bone loss was measured as the vertical distance from the crest of alveolar bone to the platform of the dental implant.

The findings of this study concluded that the plaque index and probing depth measurements were significantly higher for traditional cigarette and e-cigarette users, groups 1 and 2, compared to nonsmokers, group 3, as seen on Figure 3. Although bleeding on probing

was lower for groups 1 and 2, this occurrence is due to the effect of nicotine exerting vasoconstriction on gingival blood vessels (Wagener 2015). Figure 3 also shows that sites of higher plaque index among the cigarette and e-cigarette users were shown to have higher levels of marginal bone loss.

**Figure 3**

Peri-implant parameters	Cigarette smokers (Group 1)n = 32	Vaping individuals (Group 2)n = 31	Non-smokers (Group 3)n = 32
Plaque index (%)	56.4 ± 12.3 <sup>ab</sup>	43.5 ± 8.1 <sup>a</sup>	29.7 ± 5.2
Bleeding on	18.4 ± 4.8 <sup>a</sup>	14.7 ± 5.3 <sup>a</sup>	39.8 ± 18.1
Probing depth	23.8 ± 2.7 <sup>a</sup>	15.9 ± 1.4 <sup>a</sup>	4.5 ± 0.7
Marginal bone loss (mm)			
Mesial	2.1 ± 1.1 <sup>ab</sup>	1.2 ± 0.7 <sup>a</sup>	0.8 ± 0.2
Distal	2.4 ± 1.6 <sup>ab</sup>	1.6 ± 1.0 <sup>a</sup>	1.1 ± 0.5
Total	2.3 ± 1.2 <sup>ab</sup>	1.4 ± 0.9 <sup>a</sup>	0.9 ± 0.3

Source: Al-Aali, K., Alrabiah, M., & ArRejaie, A. (2018, March). Peri-implant parameters, tumor necrosis factor- $\alpha$ , and interleukin-1 beta levels in vaping individuals. Retrieved December 11, 2020, from <https://onlinelibrary-wiley-com.libproxy.uwo.edu/doi/full/10.1111/cid.12597>

The levels on (MMP)-9 and (IL)-1 $\beta$  were significantly higher among cigarette and e-cigarette users than nonsmokers. It has been suggested that cigarette smoking and vaping e-cigs have the potential to induce oxidative stress and increases expression of advanced glycation end products (AGEs) and their receptors in cells, including gingival/periodontal

tissues. Interaction between AGEs and their receptors (RAGEs) have been associated with ROS that induce an oxidative burst within gingival tissues, reduced chemotactic, and phagocytic function of polymorphonuclear cells (Sundar 2016, Katz 2005). Decreased production of antibodies occurs leading to an increase of bacterial adhesion, and systemic and local inflammatory through increased expression of cytokines in the serum and crevicular fluid. The mechanisms occurring under the conditions associated with e-cigarettes have been related with oral connective tissue inflammation and alveolar bone destruction around natural teeth.

**Figure 3**

	<b>Cigarette smokers (Group 1)</b>	<b>Vaping individuals (Group 2)</b>	<b>Non-smokers (Group 3)</b>
<b>Parameters</b>	<b>n = 32</b>	<b>n = 31</b>	<b>n = 32</b>
Volume of PISF collected	3.31 ± 0.4 <sup>c</sup>	3.16 ± 0.6 <sup>c</sup>	1.52 ± 0.5
MMP-9 (ng/mL)	113.59 ± 29.6 <sup>ab</sup>	88.34 ± 32.4 <sup>c</sup>	27.72 ± 18.3
IL-1 $\beta$ (pg/mL)	246.53 ± 115.2 <sup>ab</sup>	196.23 ± 90.8 <sup>b</sup>	36.91 ± 22.3

Source: Al-Aali, K., Alrabiah, M., & ArRejaie, A. (2018, March). Peri-implant parameters, tumor necrosis factor-alpha, and interleukin-1 beta levels in vaping individuals. Retrieved December 11, 2020, from <https://onlinelibrary-wiley-com.libproxy.uwyo.edu/doi/full/10.1111/cid.12597>

This study was performed to determine inflammatory parameters and cytokine, (MMP)-9 and (IL)-1 $\beta$ , levels among various cigarette, e-cigarette, and none users. From the recorded results, peri-implant health was compromised among cigarette and e-cigarette users. Increased levels of proinflammatory cytokines, (MMP)-9 and (IL)-1 $\beta$ , suggests greater

peri-implant inflammatory response.

## **Results**

Numerous studies have been conducted to begin understanding the potential oral health consequences of e-cigarettes, commonly known as vaping. Vaping has continued to gain popularity to new users and as an alternative to traditional cigarettes for established smokers. Research has shown e-cigarettes confer great susceptibility to oral and dental complications. Additional research should be conducted to follow the long-term effects on oral and general health. Public awareness, product regulation, and further research should be promoted regarding e-cigarettes to ensure the existence of an educated community and consumer base.

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