A Scoping Review of Electronic Cigarettes' Impact on Dental Caries

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Abstract

Background: Dental caries is a prevalent condition affecting children and adolescents, influenced by multiple factors. The increasing use of electronic cigarettes (ECs) among younger populations raises concerns about their potential impact on oral health.

Objective: To evaluate the association between EC use and the development of dental caries by analyzing relevant studies.

Methods: An electronic search was conducted in Medline (PubMed), Scopus, and Embase databases to identify studies examining the relationship between ECs and dental caries. Studies were selected based on relevance, focusing on EC liquid composition and aerosol effects on dental health.

Results: A total of 12 studies were reviewed. Findings suggest that certain components of e-liquids, including cariogenic carbohydrates (fructose, glucose, sucrose) and aldehydes, contribute to dental caries. Flavoring agents such as strawberry, cinnamon, and menthol also play a role in enamel demineralization. Additionally, EC aerosol exposure has been linked to an increase in caries development.

Conclusion: EC use may contribute to an increased risk of dental caries due to the presence of cariogenic substances in e-liquids and their impact on oral health. However, further clinical trials are required to establish a definitive causal relationship.

Keywords: *Electronic cigarettes, dental caries, e-liquids, cariogenic carbohydrates, vaping, oral health.*

INTRODUCTION

Worldwide, approximately 3.5 billion people are affected by oral diseases, with 520 million children suffering from caries of the primary teeth and approximately 2 billion suffering from caries of the permanent teeth [1]. The overall rise in dental caries is attributed to increased urbanization and altered daily environments. The growing popularity of foods and beverages high in sugar, nicotine, and alcohol among adolescents has led to unfortunate oral health issues like dental caries [1]. Electronic cigarettes (ECs) were first familiar with the European and North American business areas in 2006, ensuing to being authorized in China in 2003 [2]. They were exhibited as a humble, safer choice as opposed to standard cigarettes (CCs) and to quit smoking [3]. More energetic adults than additional carefully prepared people are investigating various roads concerning ECs these days. In the last 30 days, approximately 20% of students in secondary school and 5% of students in center school used them [3]. According to Reality Drive, 32.7% of secondary school students between the ages of 14 and 18 vape, which raises the likelihood of a tobacco pandemic [3]. Sadly, vaping, which was initially promoted as a means of quitting smoking, exposed younger generations to various drugs like nicotine. Fluids are warmed in ECs to create a thick spray that the client inhales [3]. The bits of them are a mouthpiece, a battery, an e-liquid stock, and a warming part. There are many shapes, sizes, shades, and tastes for them. The shower either interfaces itself to the tissues of the mouth pit or is acclimatized into the blood [4]. How much nicotine is given to a person is influenced by use, device-related restrictions, and fluid arrangement. Over 400 brands and 7000 distinct flavors of e-fluids are available for financial purchase [5, 6]. They appear to be to blame for the negative effects on oral and fundamental health due to their aldehydes and free extreme substances, which can cause oxidative pressure, DNA damage, decreased cell reinforcement action, and protein carbonylation [7-9]. The 2019-2020 Spots for Irresistible Counteraction and Expectation study [7, 10] states that the ECs achieved 2,807 lung wounds and more than 52 passings. Propylene glycol and glycerin, two sweet fixings in the e-fluid base, separate into acidic, lactic, and propionaldehyde, accelerating the veneer's demineralization [3, 7]. Additionally, nicotine and EC splash overhaul xerostomia and augmentation S. mutans attach to the facade surface [4, 7]. Specific e-fluids have been found to have higher concentrations of carcinogenic starches like sucrose and fructose [4, 6, 11]. The headway of dental caries, particularly pit and cleft caries, is worked with by these elements [7]. In light of this, the survey aims to shed light on the carcinogenic potential of ECs.

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Received: August 23, 2024; Revised: December 06, 2024; Accepted: April 25, 2025
DOI: https://doi.org/10.37184/lnjpc.2707-3521.7.59

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Table 1: Eelectronic cigarettes' contribution to tooth caries.

Author Name	Type of Study	Salient Features of the Study	Factor Evaluated	Results and Conclusion
Kubica *et al.* 2014 [13]	*In vitro*	Developed a method for quickly confirming sucrose and other sugars in e-liquids; assessed sugar content.	Sugars	(i) Sucrose is present in branded e-liquids.
Fagan *et al.* 2018 [6]	*In vitro*	Evaluated sugar levels and aldehydes in marked e-liquids, flavors, and nicotine concentrations	Sugars Flavors Nicotine	(i) Increased aldehydes like formaldehyde, acetaldehyde, and acrolein, with acetaldehyde being the most significant. (ii) Sugars and aldehydes in unheated e-liquids may promote experimentation among adolescents.
Huilgol *et al.* 2018 [15]	*In vivo*	Investigated the link between e-cigarette use and oral health.	Frequency of EC Use	(i) Daily use of e-cigarettes was independently related to poor oral health.
Ghazali *et al.* 2019 [16]	*In vivo* observational (case-control)	Compared caries incidence among non-cigarette, non-e-cigarette users, cigarette users, and e-cigarette users.	EC Use	(i) No significant difference in mean DMFT values between all groups at baseline and six months.
Kim *et al.* 2020 [4]	*In vitro*	Evaluated the carcinogenic potential of e-cigarette aerosols from sweet-flavored e-liquids.	EC Aerosol Flavor	(i) E-cigarette use enhanced microbial adhesion to enamel, particularly *S. mutans*, due to increased biofilm growth. (ii) Esters in e-liquids promoted enamel demineralization. (iii) Sugar alcohols inhibited S. mutans growth and adhesion.
Fischman *et al.* 2020 [18]	*In vitro*	Tested the influence of popular e-liquid flavors on oral health.	E-Liquid Flavor	(i) Results pending (details not provided).
Rouabhia and Semlali 2021 [19]	*In vitro*	Evaluated effects of e-cigarettes on *S. mutans* growth, biofilm formation, and virulence gene expression.	EC Aerosol	(i) *S. mutans* growth was enhanced during early culture periods. (ii) E-cigarettes boosted the growth and virulence of S. mutans. (iii) The biofilm and adhesion of *S. mutans* increased.
Vemulapalli *et al.* 2021 [7]	*In vivo* observational (cross-sectional)	Analyzed the population-level relationship between vaping and untreated caries.	vaping and caries	(i) Higher levels of untreated caries were found in e-cigarette smokers and dual users (e-cigarettes + conventional cigarettes).

METHODS

Following the PRISMA-ScR (Preferred Revealing Things for Specific Surveys and Meta-Examinations Augmentation for Checking Audits) guidelines [12], the current audit was carried out. How do ECs add to the improvement of dental caries was the assessment issue. Databases like Medline (PubMed), Scopus, and Embase were used to find expounding on the cariogenic effects of ECs through July 13, 2022. After a keyword combination of "Dental Caries" AND "Electronic Cigarettes" OR "e-cigarette" OR "Electronic nicotine conveyance framework" OR "Electronic nicotine conveyance device" OR "e-fluid" OR "Vaping" was confirmed in the titles, modified works, or catchphrases, 146 articles were found (**Fig. 1**). We read 60 articles' titles and processes. Recalled were simply first-made English-language papers for the cariogenic effects of ECs. Master comments, meeting procedures, audits, specialized reports, creature exploration, suggestions, and non-original works were excluded from the investigation. The review type, goals, objectives, e-fluid structure, their capacity to cause dental caries, results, and conclusions [3, 4, 6, 7, 13-20] were among the information recovered from the previous 12 distinct examinations (**Table 1**).

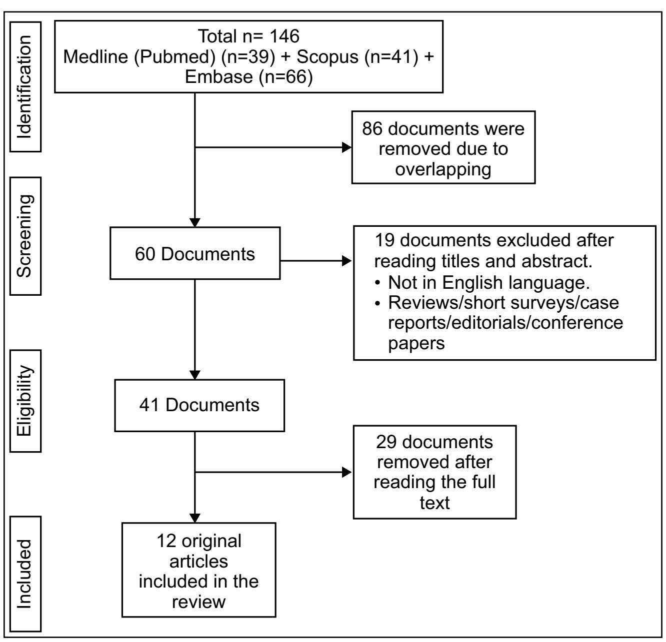

Fig. (1): Evidence linking electronic cigarettes to tooth cavities (dental caries).

RESULTS AND DISCUSSION

Types of Studies

Case-control [14, 16], cross-sectional [7, 15], and *in vitro* examinations [3, 4, 6, 13, 17-20] were among the papers that were thought of. A couple of examinations [14-16] assessed clinical oral well-being boundaries between CC, NSs (Nonsmokers), and EC clients.

*Research Citing ECs as Associated with Dental Caries

Youngsters between the ages of 18 and 24 were the interest group for vaping [7, 14, 16], with a remarkably higher extent of male clients [16]. Around 2.75 times however many individuals as there were in the review populace (4,618 members all out; 247 of them were EC clients) [7, 14, 15]. Between the ages of 25 and 64, non-Hispanic Dark smokers who utilized the two ECs and CCs, had less training than a secondary school confirmation, a poor financial position, scarcely any dental visits (more prominent than a half year), and were more defenseless against untreated caries [7, 16, 17].

Types of Liquid

E-fluids were either made in the lab [3, 4, 18] or bought monetarily [6, 17, 19, 20] for use in the *in vitro* assessments. Regardless of whether nicotine and flavorings were available, they were available in the example e-fluids at the proportions of 50:50 [3, 17, 18, 20] or 70:30 [19] or 20:80 [4].

**In vitro* Simulation of EC Aerosol Generation

Using a fourth-age EC (G-Priv Youngster pack) and one 10-second puff, which is indistinguishable from a 5-minute receptiveness, experts had the choice to splash e-liquids and copy vaping *in vitro* assessments [20]. In another report, 10 and 150 puffs were used to recurrent a single vaping meeting and a lone day of use, independently, using an overall electronic cigarette testing machine [4].

*Factors Responsible for Cariogenic Effects of ECs

The preferences and sugars in e-fluids increased the frequency of dental caries in light of the included investigation. The e-liquid splash that was conveyed when it warmed was taken in by the clients, which through different cycles upheld dental caries.

According to Fig. **(2)**, these variables linked to ECs' cariogenic effects are described.

Sugars in E-Liquids

Additional sugars significantly influence the sensory characteristics of tobacco products. They enhance the aroma of tobacco smoke, make nicotine less harsh, and impart a sweet taste. Monosaccharides (such as glucose and fructose) and disaccharides (like sucrose) naturally occur or form during the processing and curing stages of tobacco plants. Approximately 40 to 50 percent of tobacco products contain added natural or synthetic sugars that can contribute to pyrolysis. While these sugars can alter the effects of nicotine and tobacco alkaloids, they also exhibit cariogenic properties. Similar to how cocaine and morphine stimulate the brain, these sugars can enhance dopamine release, leading to potential addiction. In a study of 37 popular e-liquids, sucrose was present, but no correlation was found between sucrose levels and flavor, which varied among manufacturers. The lowest sucrose levels identified were 1.11 μg/g for Dim, 0.68 to 1.211 μg/g for Camel, 0.784 μg/g for L and M, 0.62 μg/g for Cherry, 0.76 μg/g for coffee, and 1.80 μg/g for fruit mix flavors. Consequently, commercially available e-liquids in this study demonstrated significantly higher concentrations of cariogenic sugars, particularly sucrose. However, further research is needed to confirm the carcinogenic effects of sugars inhaled through electronic cigarettes [21-26].

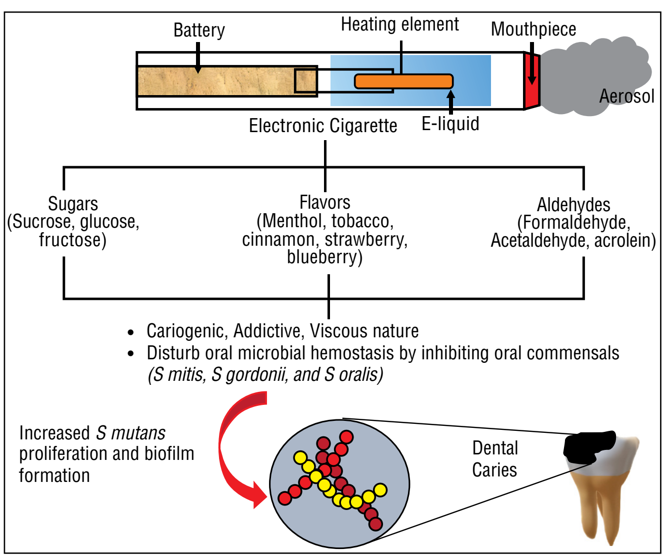

Fig. (2): Parts of an electronic cigarette and its role in dental caries.

Aldehydes in E-Liquids

When propylene glycol and glycerin in e-liquids are heated, they can produce harmful aldehydes such as formaldehyde, acetaldehyde, and acrolein. The type of sugar, tobacco, temperature, and other ingredients can influence the levels of these aldehydes. Aldehydes and organic acids can form at temperatures as low as 200°C; since electronic cigarettes typically operate at around 250°C and propylene glycol has a boiling point of 188°C, this poses a risk. Preliminary investigations revealed variations in aldehyde levels across different brands, flavors, and nicotine concentrations. Formaldehyde, acrolein, and vanillin may have adverse health effects for electronic cigarette users, while acetaldehyde's addictive properties might encourage nicotine dependence. Additionally, some electronic cigarettes allow users to adjust battery voltage, which can lead to increased aldehyde production and heightened exposure to harmful components [27-30].

Flavors in E-Liquids

Flavors such as menthol, tobacco, cinnamon, strawberry, and blueberry—particularly appealing to younger users—are among the most frequently tested. Concentrations of these flavorings range from 0 to 25%. Investigations have focused on artificial sweeteners, including ethyl butyrate (11.1 mg/mL), ethyl maltol (27.2 mg/mL), hexyl acetic acid (2.5 mg/mL), sucralose (2.0 mg/mL), and triacetin (11.6 mg/mL). An examination of sixteen e-liquid flavors from eight different brands sold commercially was also conducted [31-33].

The Effect of Flavors on Oral Commensals and *S. mutans* Growth

All tested Streptococcus species were inhibited by 5% concentrations of menthol and cinnamon, while

3% cinnamon yielded the lowest biofilm mass of *S. intermedius*. At 1% concentration, these flavors showed varied effects on biofilm mass similar to that of the positive control. Notably, menthol and cinnamon inhibited the growth and production of biofilms in both single and multispecies contexts. Tobacco flavor reduced colony counts, while menthol, cinnamon, blueberry, and strawberry flavors significantly inhibited microbial growth. Tobacco flavor specifically affected microbial community structure, while the single-species biofilms produced in strawberry-flavored and flavorless e-liquids were comparable. However, the biomass of multispecies biofilms significantly decreased, indicating that microbial communities were more sensitive to strawberry flavor. Notably, *S. oralis* was one of the less affected microorganisms, showing that flavorings disrupted oral microbiome homeostasis, thus promoting dental caries.

The Effect of Synthetic Flavors on Oral Commensals and *S. mutans* Growth

S. mutans thrives in e-liquids containing certain synthetic flavors such as ethyl butyrate, triacetin, and hexyl acetic acid. Ethyl butyrate, reminiscent of pineapple, is produced by oral bacteria such as *Lactococcus lactis* and *Streptococcus salivarius*. In oral biofilms, various microorganisms convert carbohydrates to acetate, creating favorable conditions for *S. mutans*. Triacetin, as an ester, is broken down by *S. mutans*, which has esterase activity that degrades monomers found in dental materials. Propylene glycol in e-liquids, despite its bactericidal properties, does not effectively inhibit *S. mutans*, which can lead to enamel demineralization.

The Effect of Nicotine in E-Liquids on Cariogenic Bacteria

E-liquids contain various nicotine concentrations: 3 mg/mL, 10 mg/mL, 18 mg/mL, and 20 mg/mL. Other studies have examined concentrations ranging from 0 to 24 mg/mL. E-liquids with higher nicotine levels significantly increased *S. mutans* biofilm mass after six exposures. It has been suggested that nicotine enhances the colonization and biofilm formation of *S. mutans*. At concentrations of 1 to 4 mg/mL, nicotine upregulates harmful receptor proteins, extracellular polysaccharide synthesis, and glycolytic pathway intermediates.

Effects of EC Aerosol

Influence on Oral Commensals and S. mutans Biofilm

Electronic cigarette (EC) vapor exposure dysregulates oral bacterial homeostasis, suppressing the growth of oral commensals while promoting the formation of *Streptococcus mutans* biofilm. Factors contributing to the dominance of *S. mutans* over other species include environmental conditions such as viscosity, nutrient availability, and pH, which favor dental adhesion and biofilm formation. Unlike *S. sanguinis* and *S. gordonii*, *S. mutans* colonization increases with EC exposure due to its insensitivity to nicotine and menthol flavorings. Studies show that two daily sessions of 15 minutes each, or 10 to 150 puffs, can enhance the adhesion between S. mutans and the enamel surface. After a 24-hour incubation period, *S. mutans* concentrations rise in pits, crevices, and smooth surfaces exposed to vapor. The EC vapor alters the surface interactions of *S. mutans*, as the viscous vapor coats the enamel surface. This process facilitates biofilm formation by adhering to exposed surfaces, disrupting the balance of e-liquid bases, and secreting extracellular polymeric substances that promote aggregation and growth. *S. mutans* rapidly converts sugars to lactic acid, leading to enamel demineralization and the development of dental caries, resulting in a locally low pH. The number of puffs influences the adhesion strength between *S. mutans* and the enamel surface, with ten puffs resulting in a consistently distributed vapor. As puff frequency increases, droplets begin to accumulate. Furthermore, the aerosolization process significantly affects microbial growth and alters the chemical composition of e-liquids, producing compounds such as urea, carbonyls, alcohols, carboxylic acids, formaldehyde, and acetaldehyde from propylene glycol and glycerol.

Influence on Bacterial Genes

EC exposure enhances the expression of bacterial genes encoding virulence factors, biofilm formation, stress response, and quorum sensing in *S. mutans*. Specifically, exposure increases the expression of genes related to biofilm formation, including com C, D, and E; glucosyltransferases (gtf B, C, and D); and glucan-binding proteins (gbp B and C). These genes are crucial for bacterial viability and adaptation in challenging environments. When exposed to EC vapor, *S. mutans* upregulates specific com genes to promote biofilm formation. Elevated mRNA levels of gtfBCD and gbpBC correlate with increased virulence factor expression. It is proposed that e-liquid components, such as nicotine, flavorings, and viscosity, influence the expression of these virulence and regulatory genes. After exposure to nicotine-rich ECs and conventional cigarette smoke, *S. mutans* upregulates the expression of gtf, gbp, com D, and com C genes on tooth surfaces, while com E expression remains unchanged.

Influence on Bacterial Hydrophobicity

The cariogenic bacterium *S. mutans* exhibits a hydrophobic cell surface characterized by hydrophobic amino acid residues, outer membrane proteins, lipids, and lipoteichoic acid. Exposure to EC vapor alters the membrane properties, often reducing the hydrophobicity of *S. sanguinis* and *S. gordonii*, which are more hydrophilic. *S. mutans* demonstrates higher hydrophobicity compared to commensals, resulting in increased coaggregation and adhesion to oral epithelial cells. This alteration also promotes the secretion of IL-8 and antimicrobial substances, which may prevent epithelial recognition of *S. mutans* as pathogenic, thereby evading the immune response.

Influence of Flavors in EC Aerosol on Host Immune Response

Flavors such as strawberry, cinnamon, and tobacco in ECs alter the host immune response, impacting microbial growth. For instance, cinnamaldehyde, a primary component of cinnamon flavor, reduces the survival of human monocytes and decreases the expression of pro-inflammatory cytokine IL-8. These flavors can deplete glutathione levels, disrupting redox balance. While compounds like cinnamaldehyde and menthol possess antibacterial properties, they also serve as low-level carbon sources, stimulating microbial metabolism. At high concentrations, their effects on oral commensal growth resemble those of antibiotics. Remarkably, they promote the formation of *S. mutans* biofilms even in the absence of nicotine in EC vapor [32, 33].

LIMITATIONS

1. **Lack of Human Data:** The majority of the findings are based on *in vitro* studies, which may not accurately reflect the complexities of human oral environments. The absence of clinical data limits the applicability of these results to real-world scenarios.

2. **Small Sample Size in Studies:** Many studies included in the review had small sample sizes, which may affect the generalizability of the findings. Larger, more diverse populations are needed to draw more robust conclusions.

3. **Variability in E-Liquid Composition:** The chemical composition of e-liquids varies widely across brands and flavors, making it challenging to standardize results. This variability can influence the outcomes related to microbial behavior and oral health.

4. **Short Duration of Exposure in Studies:** Many studies examined short-term exposure effects, which may not capture the long-term implications of EC use on oral health and the progression of dental caries.

5. **Methodological Differences:** The methodologies employed in the included studies varied significantly, from experimental setups to measurement techniques. This inconsistency can complicate comparisons and syntheses of findings.

6. **Lack of Control over Confounding Variables:** Some studies did not adequately control for confounding variables, such as participants' dietary habits, oral hygiene practices, and use of other tobacco products, which could influence the results.

7. **Limited Exploration of Biological Mechanisms:** While some studies identified associations between EC exposure and microbial changes, the underlying biological mechanisms were not always thoroughly investigated, leaving gaps in understanding.

8. **Potential for Publication Bias:** The reviewed studies may be subject to publication bias, where studies with significant findings are more likely to be published than those with null results, skewing the overall understanding of the impact of ECs on dental health.

CONCLUSION

The findings from the included studies indicate that electronic cigarettes (ECs) may pose risks to oral health, primarily due to the diverse range of flavors and sweeteners in e-liquids. Aldehydes, released when e-liquids are heated, are among the potentially harmful byproducts that can disrupt the homeostasis of the oral microbiome, leading to bacterial dysbiosis and increased risk of dental diseases, including dental caries. Additionally, the appealing nature of aldehydes and sugars in these products may contribute to higher usage rates among youth.

Given these concerns, long-term *in vivo* studies are essential to accurately assess the impact of ECs on the development of dental caries in human populations.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We would like to thank Dr. Nida Talpur who assisted in the study, for her valuable support and contributions. We also appreciate the helpful comments and suggestions from the anonymous reviewers that greatly improved this manuscript.

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