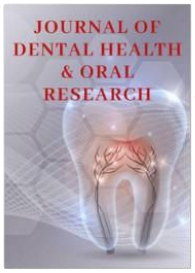

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Review Article

Relationship of E-cigarette Smoking (Vaping) with Dental Caries in Adolescents: A Systematic Review

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Abstract

Objective of study was to find association between e-cigarette use and dental caries among adolescents. Inclusion criteria were original articles (*in-vivo*/*in-vitro*), studying effects of e-liquids and aerosols on caries/ bacteria causing caries. Exclusion criteria were review articles and articles not showing caries as outcome. Review was registered in INPLASY, with registration number INPLASY202530057. Google Scholar and PubMed were searched till 16th March'25. AMSTAR-2 was used for risk of bias. Review was presented and organized in table form. Out of 15 original articles, four human studies found and three studies could not find significant differences between caries levels of control and e-cigarette groups. In four *in-vitro* studies, viscous and flavored e-cigarette aerosols were found to suppress growth of oral commensal streptococci and promote caries producing Streptococcus mutans growth. Aerosol form caused greater suppression of commensals compared to bacteria exposed to un-aerosolized e-liquid. In conclusion, e-cigarettes are cariogenic by shifting of oral microbiome in favor of caries, high levels of sugars and flavors in e-liquids and heating of e-liquids. All human studies included adolescent age within young adult groups. Hence, results of this study could not be inferred to adolescents alone. No funding was done for this review.

Keywords: Dental Caries; E-Cigarette; Adolescents; Vaping

Introduction

Electronic Nicotine Delivery System (ENDS), commonly called ECIGs (Electronic Cigarettes, E-Cigarettes) or 'vaping' devices, are battery-operated electronic devices [1]. They are designed to heat and aerosolize liquids, mainly diethylene glycol and glycerin, with nicotine and different flavoring agents [2]. These e-liquids are thought to produce dental caries either directly or by unbalancing the oral microbiome [3,4]. Adolescents are more likely to experiment with e-cigarettes due to variety of flavors used in them [3]. Although ECIGs smoking has been suggested to cause dental caries in literature, there is little evidence on the effects of e-cigarette on dental caries [5]. The objective of this study was to find the relationship between electronic cigarette (vape) use and dental caries in adolescents.

Methodology

This systematic review was registered on 13th March 2025, with registration number INPLASY202530057, under DOI number 10.37766/inplasy2025.3.0057. Google Scholar and PubMed (MeSH search) were used for the literature search. The search was carried out using the keywords "dental caries", "e-cigarette", "adolescents" and "vaping". Original work, in English language only, from any time since e-cigarettes were discussed in literature, was considered. The inclusion criteria were original researches, both *in-vivo* and *in-vitro*, that studied the effects of electronic cigarette liquids and aerosols on dental caries/bacterial agents causing caries. The exclusion criteria were review articles and articles not showing effects of e-liquids and aerosols on

dental caries/ bacterial agents causing caries. The time taken for the synthesis of the review was one month.

A total of 26 articles were extracted. One (01) article was removed as it was a duplicate. Eight (08) articles were excluded because they were review articles. Two (02) articles were excluded as they were not about dental caries. Hence, we included thirteen (15) articles in the review (Fig. 1). AMSTAR 2 was used to assess the quality of the systematic review. Results were tabulated and the study intervention, characteristics and comparison groups were mentioned in the Table 1.

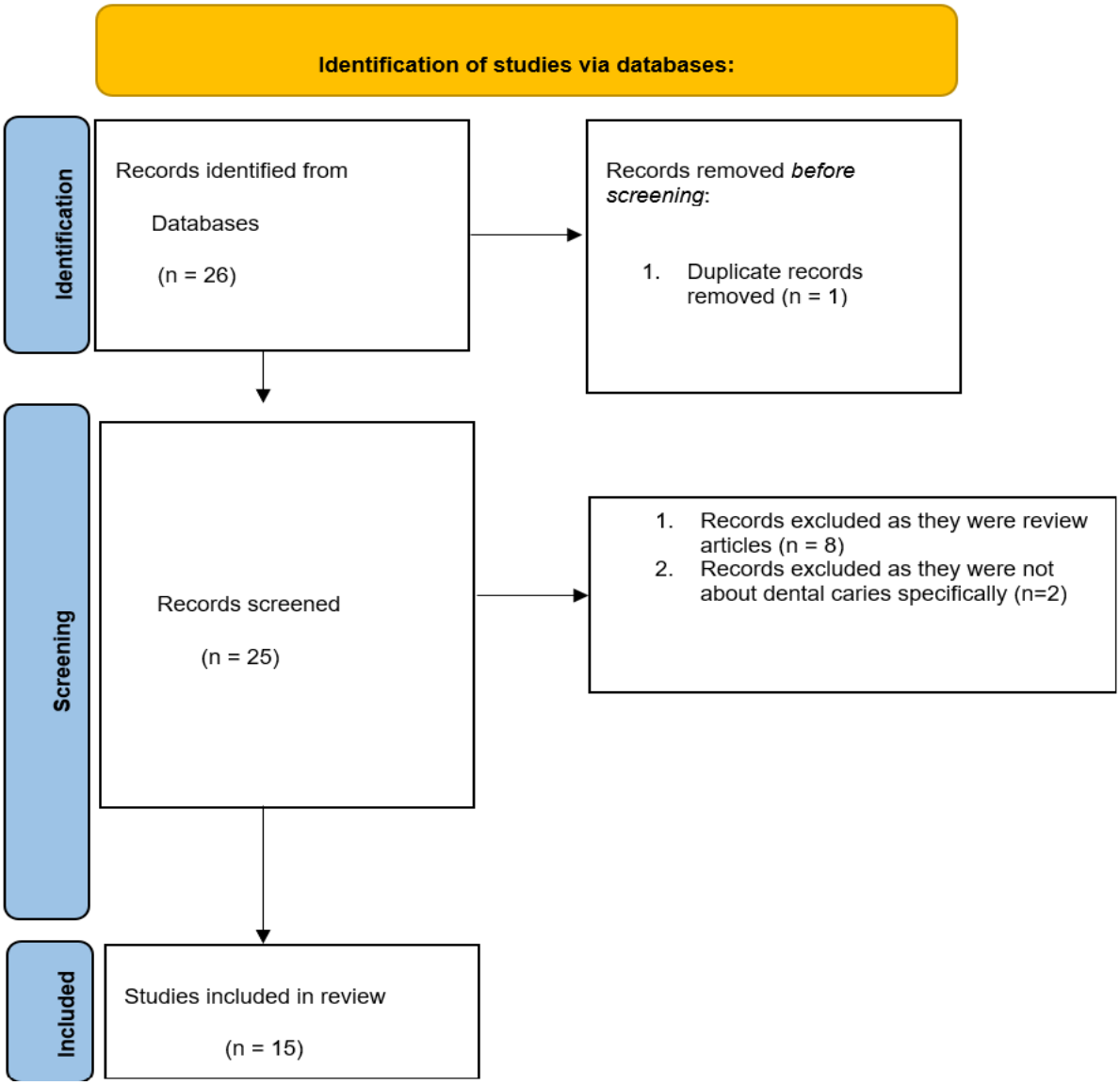

Figure 1: Flow diagram showing selection of articles for review article.

Study	Country	Type of Study	Methodology	Findings
Ghazali, 2018[14]	Malaysia	*In-vivo* (human) study Case-control study	40 participants in control, 40 participants in cigarette-smoker, and 40 participants in e-cigarette smoker groups Caries assessed by DMFT index.	- No differences were found between the DMFT index of control, cigarette and e-cigarette groups

Ghazali, 2019[15]	Malaysia	*In-vivo* (human) study Case-control study	45 participants in control, 45 participants in cigarette-smoker, and 45 participants in e-cigarette groups Caries assessed by DMFT index	- No differences were found between the DMFT index of control, cigarette and e-cigarette groups
Ismail, 2019[9]	Malaysia	*In-vivo* (human) study Prospective cohort study	45 participants use e-cigarettes for 6 months Caries assessed by DMFT index	- E-cigarette increased caries prevalence
Vemulapalli, 2021[10]	USA	*In-vivo* (human) study Cross-sectional study	4,618 participants Untreated caries assessed by coronal caries	- Untreated caries was found more in those who smoked only electronic cigarettes or who smoked both types of cigarettes.
Nigar, 2021[13]	Pakistan	*In-vivo* (human) study Cross-sectional study	150 active e-smokers 210 non-smokers Caries index was measured by adding decayed teeth.	- 69.51% e-cigarette smokers and 66.66% non-smokers had carious lesion in ≥1 teeth
Amaral, 2023[11]	USA	*In-vivo* (human) study Cross-sectional study	13,080 e-cigarette non-users, and 136 e-cigarette users. Caries assessed by CAMBRA.	- E-cigarette users exhibited a high level of caries risk.
Irusa, 2024[16]	USA	*In-vivo* (human) study Cross-sectional study	130 e-cigarette smokers, 1094 conventional smokers, and 27 using both. Caries assessed by CAMBRA.	- No statistically significant difference between caries risk among three groups
Alyaseen, 2024[8]	Iraq	*In-vivo* (human) study Case-control study	45 electronic-cigarette smokers, and 45 non-electronic-cigarette smokers. Caries assessed by DMFS index	- E-cigarettes may affect saliva components and dental caries.

Khattak, 2024[12]	Pakistan	*In-vivo* (human) study Cross-sectional study	142 users of e-cigarettes Caries assessed by DMFS index	- DMFT index had significant association with vaping frequency/day and time since started e-cigarette smoking
Kim, 2018[17]	USA	*In-vitro* study	Human (extracted) teeth and S. mutans **Exposed to:** Flavorless or flavored aerosols	1. Viscous aerosols caused four times increase in adhesion of microbes to tooth. 2. Exposure to flavored aerosols caused two-fold increase in biofilm formation 3. Exposure to flavored aerosols caused 27% decrease in enamel hardness by causing enamel demineralization compared to unflavored controls.
Nelson, 2019[18]	USA	*In-vitro* study	S. gordonii, S. mitis, and S. oralis **Exposed to:** nicotine alone, electronic cigarette liquid with nicotine, e-cigarette-generated aerosol nicotine, or cigarette smoke	- Smoke limits the growth of commensal streptococci.
Fischman, 2020[19]	USA	*In-vitro* study	S. gordonii, S. intermedius, S. mitis, and S. oralis **Exposed to:** flavorless vs. flavored (tobacco, menthol, cinnamon, strawberry and blueberry) e-cigarette generated aerosols	1. Aerosol exposure slowers growth of bacteria during the exponential phase compared to those exposed to un-aerosolized electronic cigarette liquid. 2. Electronic cigarette liquids with flavors are more injurious to oral commensal growth compared to unflavored ones.
Rouabhia, 2021[2]	Canada	*In-vitro* study	Human teeth and S. mutans **Exposed to:** Electronic cigarettes with and/or without nicotine, or to cigarette smoke	1. An increase in S. mutans growth with electronic cigarette 2. S. mutans cells attaches better to teeth exposed to electronic cigarette.
Catala-Valentin,	USA	*In-vitro* study	S. sanguinis, S. gordonii, and	1. Electronic cigarette aerosols inhibit growth of Streptococcus sanguinis

2022[20]			S. mutans **Exposed to**: e-cig aerosols with and without nicotine or flavoring	and Streptococcus gordonii but not of Streptococcus mutans, with or without nicotine. 2. Heating and aerosolization of e-liquid caused greater reduction in growth for both S. sanguinis and S. gordonii.
Xu, 2022[1]	USA	*In-vitro* study	S. gordonii, S. intermedius, S. mitis, and S. oralis **Exposed to**: E-liquids with and without flavors	- Flavored e-liquid, especially in higher concentration, has an inhibitory effect on the growth of oral commensal streptococci.

Table 1: Summary of studies included in the review.

Results

Out of total 15 studies extracted for the review, nine (09) studies were *in-vivo* human studies and six (06) studies were *in-vitro* studies (Table 1). Four (04) studies used DMFT index for assessment of caries level. It is the sum of the number of Decayed, Missing due to caries and Filled Teeth in the permanent teeth [6]. One study used DMFS index to assess caries level. It gives the sum of an individual's decayed, missing and filled permanent teeth surfaces.6 Two studies used CAMBRA (Caries Management By Risk Assessment) CRA (caries risk assessment) tool for assessment of caries. This tool was published in the Journal of the California Dental Association in 2007.7 One study used caries index that was measured by adding decayed teeth.

None of the *in-vivo* human studies were done specifically for adolescents. All studies included adolescent age within the bracket of late adolescents and young adults. One *in-vivo* case-control human study, one prospective cohort and three (03) cross-sectional studies showed high levels of caries in e-cigarette smokers [8-12]. In one cross-sectional study, although caries in ECIG-smokers was higher than in non-smokers, but the significance of the difference was not measured in the study [13]. However, three (03) *in-vivo* human studies could not find any significant differences between the caries levels of control, cigarette and e-cigarette groups. Of these studies, two studies were case-control studies and one study was cross-sectional one [14-16].

In two *in-vitro* studies, extracted human teeth were used [2,17]. The activity of *S. mutans* on human teeth enamel was studied under effect of various flavors of e-cigarette aerosols. It was found that viscous aerosols generated by e-cigarette promoted *S. mutans* growth and attachment. Out of five (5) ECIG liquid flavors chosen, due to their ability of producing caries i.e., pH or sweetness, four (04) flavors i.e., sucralose, triacetin, ethyl butyrate and hexyl acetate enhanced formation of biofilm, however, ethyl maltol decreased biofilm formation as compared to the control [17]. The percentage of the loss of hardness was highest with triacetin and decreased in following order; hexyl acetate > ethyl butyrate > sucralose > ethyl maltol > control.

In one *in-vitro* study, effect of nicotine only, e-liquid with or without nicotine, air, aerosol with nicotine and smoke bound in growth media containing oral commensals *Streptococcus gordonii*, *Streptococcus mitis* and S*treptococcus oralis* was studied [18]. Only smoke-treated growth media inhibited the growth of oral commensal streptococci. Two other studies showed greater inhibition of oral commensal bacteria (S*. gordonii, S. intermedius, S. mitis and S. oralis*) growth by flavored (tobacco, cinnamon, menthol, blueberry and strawberry) e-liquids, especially at higher concentrations, as compared to flavorless ones [1,19]. One of these studies also showed that the aerosol form of e-liquid caused slower growth of bacteria during the exponential phase compared to bacteria exposed to un-aerosolized electronic cigarette liquid [19].

Another *in-vitro* study showed that electronic cigarette aerosols inhibited growth of *Streptococcus sanguinis* and *Streptococcus gordonii* but did not affect growth of *Streptococcus mutans* [20]. It also showed that when e-liquid was added without heating and

aerosolization, it caused only a minor reduction in growth of both *S. sanguinis* and *S. gordonii*, showing that heating resulted in the emission of harmful and toxic by-products.

Discussion

Liquids that are used in e-cigarettes are available with or without nicotine. In e-cigarettes, nicotine is transferred from the device to the airway of user in the form of aerosol. The Vegetable Glycerin (VG) and Propylene Glycol (PG), are hygroscopic (water-absorbing) substances, that are used as solvents for nicotine and flavoring agents present in the liquid. They form an aerosol when heated and then inhaled. Glycol is less viscous, produces throat stimulation and mimics the feel of smoking, whereas glycerin has a natural sweet flavor, making it pleasing to exhale. There are thousands of flavors incorporated into e-cigarette liquids, including tobacco, menthol and sweet flavors [2]. The cartridge can be prefilled or refillable [2,21].

In the US, the majority of e-cigarette users are between the ages of 18 and 44 years [3]. It is, however, more common among teens and young adults [22,23]. It actually became popular in cigarette smokers as a tool to stop smoking. Pregnant ladies and youth also considered it to be a safer and acceptable alternative to regular cigarettes.

In-vivo Studies

Out of 15 studies selected in our review, five (05) human studies showed an association between e-liquids and e-cigarette aerosols and dental caries. Four (04) human studies, however, could not show an effect of the e-cigarettes on dental caries.

The strength of one of the human cross-sectional studies that showed a significant relationship of e-cigarette smoking with dental caries, was that this study included a nationwide representative sample [10]. The second cross-sectional study also had a large sample size, collected over three years from dental clinic [11]. In two human studies that could not show significant difference between dual smokers, e-cigarette/ vape only users and cigarette smokers only, still had more than 65% participants at high risk of caries [13,16]. All human studies included adolescent age within the bracket of late adolescents and young adults. Hence, the results of the study could not be inferred to adolescents alone.

In-vitro Studies

Out of the studies selected in our review, five (05) *in-vitro* studies showed an association between e-liquids and e-cigarette aerosols and dental caries. However, one (01) *in-vitro* study also failed to show effect of e-liquid or e-cigarette aerosol on dental caries. In one vitro study, which could only show tobacco smoke inhibiting biofilm growth of oral commensals, only flavorless e-cigarette aerosol was used for comparison [18]. Hence, it can be assumed that if flavored ECIG liquid and its aerosol had been used in the study, it might not have been completely harmless. Tobacco smoke has also been found to promote growth of pathogenic biofilms, including Porphyromonas gingivalis and Streptococcus mutans, in literature [18].

In two *in-vitro* studies, extracted human teeth were utilized to study the activity of *S. mutans* on human teeth enamel in presence of various flavors of e-cigarette aerosols [2,17]. Viscous aerosols promoted *S. mutans* growth and their attachment to the enamel. Although four (04) flavors enhanced formation of biofilm, ethyl maltol lowered formation of biofilm as opposed to the control [17]. The loss of hardness of teeth was highest with triacetin and least with sucralose [17].

Two other *in-vitro* studies showed greater reduction in oral commensals (*Streptococcus gordonii, Streptococcus intermedius, Streptococcus mitis and Streptococcus oralis*) due to flavored e-liquids, as compared to flavorless ones [1,19]. One of these studies also showed greater reduction at higher concentrations of these e-liquids [19]. This study also showed greater effect of the aerosol form of e-liquid as compared to un-aerosolized e-liquid [19].

Factors Responsible for Developing Caries in ECIG-Smokers

Various factors in e-cigarettes might act alone or in combination to cause dental caries (Fig. 2)

1. *Alteration of Oral Microbiome*

There are various factors responsible for development of dental caries [24]. Alteration in oral microbiome favors dental caries. This shift occurs when either the oral commensals, like *S. gordonii, S. intermedius, S. mitis and S. oralis*, are suppressed or when there is overgrowth of pathogenic bacteria like *S. mutans* [17]. *S. mutans* is the main causative agent of caries [25]. The vegetable glycerin (VG), Propylene Glycol (PG) and nicotine mixture in e-cigarette aerosol alone is enough to inhibit growth of oral

commensals, hence promoting overriding of pathogens [1]. The most abundant bacteria in oral microbiome are *Streptococcus sanguinis* and *Streptococcus gordonii. S. mutans* is an opportunistic bacterium that disturbs oral homeostasis due to environmental changes. *S. mutans* is connected with dental caries. E-cigarette aerosols were found to limit *Streptococcus gordonii* and *Streptococcus sanguinis* growth, but not of *Streptococcus mutans*, hence increasing the formation of biofilm by *Streptococcus mutans* but not of *S. gordonii* and *S. sanguinis* [24]. Some components of e-cigarette aerosols are sweet and might act as a substrate for cariogenic bacteria [16]. Glycerin has a natural sweet flavor and thousands of flavors, incorporated into e-cigarette liquids, include sweet flavors [2]

2. *Dental Plaque:*

Development of dental plaque predisposes to dental caries. This plaque is actually a biofilm that is present on natural teeth and it plays an important role in dental caries whenever there is a shift in oral microbiome balance [17]. Research also observed that amount of calcium in saliva of e-cigarette smokers was elevated than in that of those who did not smoke. A higher amount of calcium in saliva can cause greater mineralization of plaque, which is a risk factor for caries [24]

3. *Dental Hardness*

A decrease in dental hardness favors development of caries. Certain e-liquid flavors were also found to cause demineralization of the tooth enamel and hence decrease tooth hardness [17]

4. *Aerosol Form of E-liquid:*

A study also showed greater effect of the aerosol form of e-liquid as compared to un-aerosolized e-liquid [19]. This fact showed that heating of e-liquids through e-cigarettes caused greater damage to dental enamel as compared to plain e-liquids

5. *Viscosity of E-liquid:*

Caries may also develop due to viscosity of e-cigarette aerosol. This viscosity is due to Propylene Glycol (PG) and glycerol (VG), which seemed to promote bacterial attachment by occupying pits and fissures of human teeth [17]

6. *Xerostomia:*

Dry mouth (xerostomia) caused by propylene glycol and glycerol in the e-cigarettes might increase the risk of dental caries by causing water absorption [4]. Yet another reason in adolescents might be exposure to caries because of sugar intake and bad dental hygiene [17]

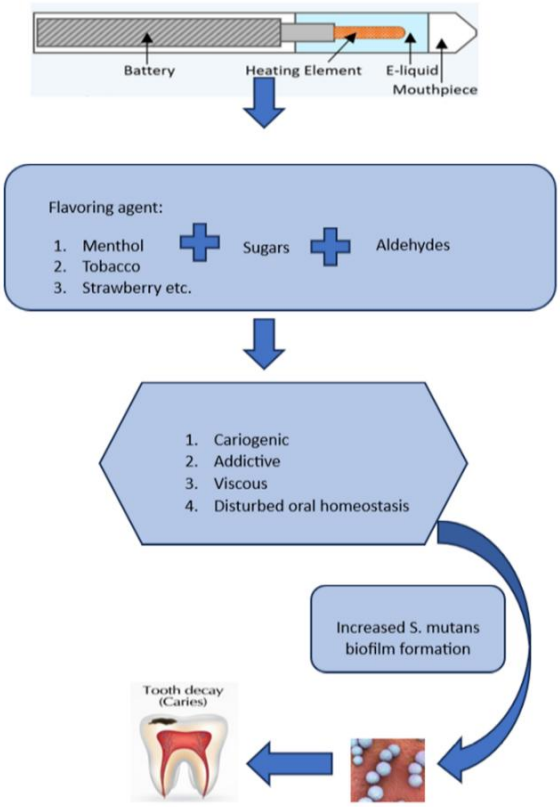

Figure 2: Diagram showing possible effects of e-cigarette on dental caries.

Strengths, Limitations and Future Prospects

The strength of this study was that it included all *in-vivo* (human) and *in-vitro* studies since the time e-cigarettes were introduced. All studies were found through MeSH PubMed search. The limitations of this review were the lack of quantitative studies that assess effects of e-liquid aerosols on dental caries, a lack of homogeneity among the studies and smaller number of human studies included in review. Future research should include longitudinal *in-vivo* human studies, which must include valid tools to study the doses of e-liquid aerosols and to evaluate dental caries, while controlling for confounders and using validation with biomarkers.

Conclusion

Our review suggests that e-cigarettes are cariogenic due to shifting of the oral microbiome in favor of dental caries, high levels of sugars and flavors in the e-liquids and heating of the e-liquids and shift the oral microbiome in favor of dental caries. Although sugars are addictive especially for adolescents and e-cigarettes can affect adolescents more than the older age groups, but all studies in our review included adolescent age within the bracket of late adolescents and young adults. Hence, the results of the study could not be extrapolated to adolescents alone.

Conflict of Interest Statement

All authors declare that there are no conflicts of interest.

Informed Consent Statement

Not applicable.

Authors' Contributions

1. MON was major contributor to writing manuscript.
2. AKS was major contributor to literature search.
3. YA was major contributor to screen literature.
4. RT was major contributor to proofread the manuscript.
5. SK was major contributor to draft manuscript and correspondence.

Financial Disclosure

The authors received no external financial support for this study.

Ethical Statement

Not applicable.

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