Association between vaping and untreated caries

A cross-sectional study of National Health and Nutrition Examination Survey 2017-2018 data

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ABSTRACT

Background. With the rise in the prevalence of electronic cigarette (e-cigarette) and vaping products and the emergence of evidence indicating their cariogenic potential, it is essential to examine the association between vaping and untreated caries at a population level.

Methods. The authors obtained data from the 2017-2018 National Health and Nutrition Examination Survey and investigated the outcome variable—untreated caries—using oral health examination data. The authors applied multiple logistic regression analyses to assess the association between untreated caries and smoking (cigarette smoking, vaping, and both) while controlling for education, race or ethnicity, income, age, sex, and time since previous dental visit.

Results. A total of 4,618 participants were included in the analyses for this cross-sectional study. Participants who currently smoked e-cigarettes were more likely to have untreated caries (odds ratio, 1.69; 95% CI, 1.24 to 2.29) than those who had never smoked, when adjusted for demographic variables. Similarly, dual smokers (e-cigarette and conventional smokers) were more likely to have untreated caries compared with nondual smokers (odds ratio, 2.43; 95% CI, 1.36 to 4.36).

Conclusion. Both vaping and dual smoking are associated with an increased occurrence of untreated caries.

Practical Implications. Vaping status should be included as a part of health history questionnaires for patients. Dental professionals should be informed of the potential oral health implications of vaping and, in turn, impart this knowledge to patients.

Key Words. Untreated decay; caries; vaping; e-cigarette; dual smoker; NHANES.

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Since their introduction in 2006 through 2007, the use of electronic nicotine delivery systems or electronic cigarettes (e-cigarettes) has increased gradually, with a higher prevalence among the younger population.[1] Until 2016, there were no strict regulations on e-cigarettes.[1] From 2009 through 2012, the sale of e-cigarettes grew at a rate of 115%, with an estimated $3.5 billion in sales in the United States by the end of 2015.[2] During that period, the prevalence of vaping rose dramatically. From 2010 through 2013, the awareness and use of e-cigarettes doubled among US adults.[3] The prevalence of current e-cigarette users increased from 0.3% to 6.8%, and the proportion of those who have ever used e-cigarettes increased from 1.8% to 13%.[4] In 2014, Delnevo and colleagues[5] reported that never smokers and long-term former smokers were less likely to try e-cigarettes, whereas those who had quit smoking cigarettes recently might have used e-cigarettes to avoid going back to smoking. The authors also reported higher rates of e-cigarette experimentation among young adults than the older population,[6-13] whereas e-cigarette use remained stable or declined in the older population (aged 25-65 years).[7-9,14-17] Furthermore, US adolescents (aged 12-17 years) exhibited a decline in e-cigarette

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use for the first time in 2016 after a sharp rise. However, the prevalence rate increased substantially during 2017 and 2018.[18]

During the early days of e-cigarette use, there was a widespread belief that e-cigarettes were safe and an effective means to quit smoking.[19] Despite a lack of concrete evidence, these devices gained popularity as a successful harm-reduction modality.[20,21] However, evidence from 2020 has revealed that e-cigarettes have a detrimental effect on the lungs. According to a 2019-2020 report by the Centers for Disease Control and Prevention, 2,807 cases of lung injury and more than 52 deaths have been associated with the use of e-cigarettes or vaping products.[22] E-cigarettes contain traces of hazardous metals that are deleterious to systemic health.[23] Besides the respiratory system, other systems, including the gastrointestinal and cardiovascular systems, also are affected by vaping. Moreover, vaping is known to be associated with various mental health and drug use problems.[24]

Although the effects of e-cigarettes on general health are well understood, their effects on oral health are ambiguous. Although the effect of conventional smoking on periodontal health is well known, further research is needed regarding the effects of e-cigarettes on the periodontium. In vitro studies have found that aerosols in e-cigarettes contain aldehydes and free radicals that cause oxidative stress, various types of DNA damage, alterations in cellular antioxidant activity, and protein carbonylation.[25,26] These events are pathways to periodontal damage, bone loss, and, subsequently, periodontitis. Clinical studies have reported mixed findings on the effects of e-cigarettes on the periodontium.[27-29] Some studies have reported that e-cigarettes are less harmful than conventional cigarettes but still affect periodontal health.[25,30,31] Furthermore, researchers have reported instances of vaping-associated oral cancer, oral candidiasis, xerostomia, and burn injuries.[32,33]

Research on the cariogenic potential of e-cigarettes is ongoing. In vitro studies have revealed that e-cigarettes generate fine, viscous aerosols that promote adhesion of *Streptococcus mutans* on the enamel surface, particularly at pits and fissures. These aerosols contain acetic acid, lactic acid, and propionaldehyde, which increase enamel demineralization.[34,35] In addition, a 2018 study[36] described high quantities of highly cariogenic sugars such as fructose and sucrose in e-cigarettes, especially those with sweet flavors. Moreover, xerostomia, which is commonly observed in e-cigarette smokers, creates an environment conducive to caries development.[37]

A prospective study reported a high rate of long-term caries (decayed, missing, and filled teeth) among e-cigarette users compared with nonsmokers.[38] From 2013 through 2016, 16.9% of US children aged 5 through 19 years had untreated caries, whereas 31.6% of adults aged 20 through 44 years had untreated caries.[39] These numbers may reflect an upward trend as the prevalence rate of vaping among young adults gradually rises. Although there is no concrete evidence supporting an association between vaping and caries, it is important to investigate this association and understand the influencing parameters on a population level to help drive major public health efforts. Therefore, the main purpose of our study was to examine the association between e-cigarette use and untreated caries among the US population and to determine the factors influencing this association.

METHODS

Data collection and study population

The National Health and Nutrition Examination Survey (NHANES) is a series of ongoing cross-sectional studies conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention. We used 2017-2018 NHANES data for this study.[40] Every 2 years, a complex stratifying study design is used by NHANES to collect data and conduct interviews and examinations for 5,000 noninstitutionalized people. The study design involves multistage probability sampling and the use of differing weights to allow for generalization. Interviews consist of socioeconomic, demographic, dietary, and health-related questions. The examination component includes dental, medical, and laboratory tests performed by trained medical personnel.

For the 2017 through 2018 period, 16,211 participants were chosen from 30 survey locations. A total of 8,704 people were examined in a mobile examination center to collect examination and laboratory data. A total of 9,254 people completed a questionnaire through at-home interviews. The data for our study were derived from both mobile examination center and questionnaire data files. As shown in Figure 1, the sample size for our study is 4,618 (N = 9,254). We excluded participants for whom data were missing on the oral health questionnaire and from the examination

ABBREVIATION KEY

CT: Carious tooth.
E-cigarettes: Electronic cigarettes.
FPG: Federal poverty guidelines.
NHANES: National Health and Nutrition Examination Survey.
OHX##CTC: Oral health examination ## coronal caries tooth count.

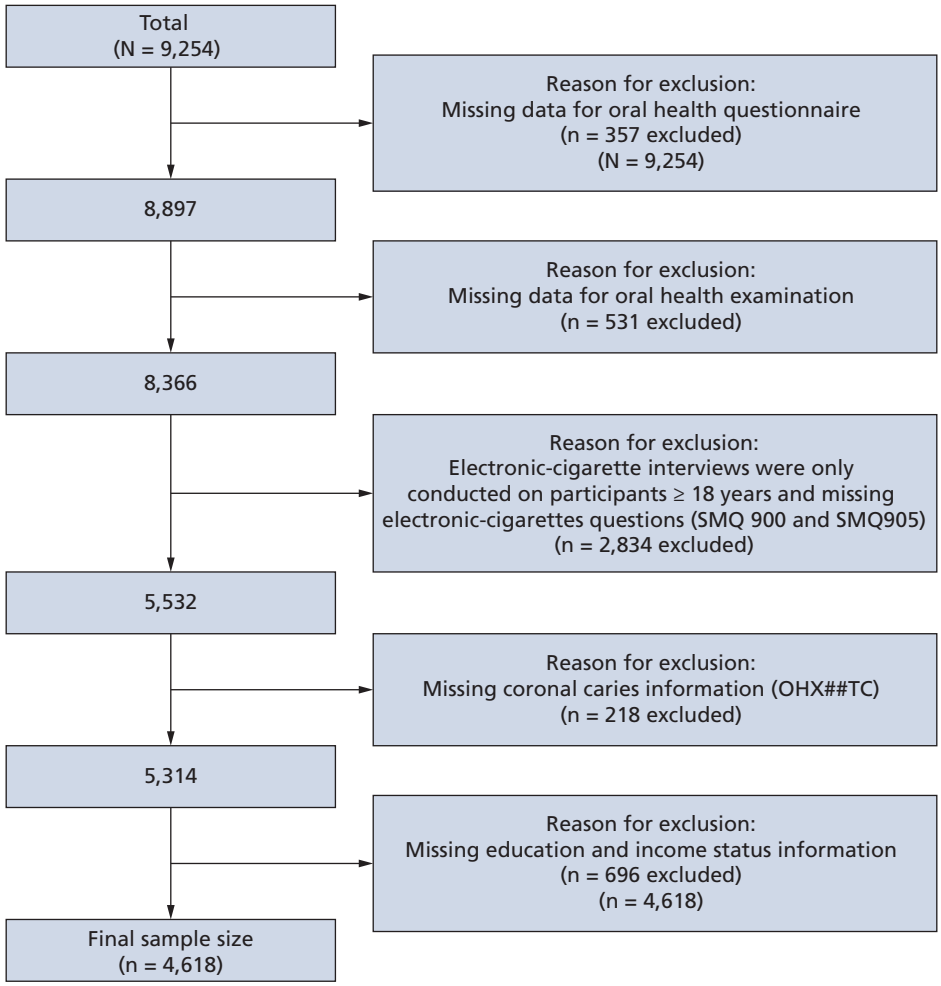

Figure 1. Study sample distribution. OHX##CTC: Oral health examination ## coronal caries tooth count.

(n = 357 and n = 531, respectively), who were younger than 18 years because only participants 18 years or older answered questions regarding e-cigarette use (n = 2,834), and for whom coronal caries information was missing (n = 218).

Outcome variable

We determined the outcome variable—untreated caries status—by means of considering only coronal caries from oral health examination data. We did not include root caries and third molars in the calculation. Variables OHX##CTC (oral health examination ## coronal caries tooth count) were used to identify coronal caries for 28 tooth spaces. The fourth and fifth digits in the variable names identify the tooth according to the Universal Numbering System. We determined the total number of untreated caries for each person, resulting in a carious tooth (CT) score ranging from 0 through 28. For the purpose of analysis, we created a new dichotomous variable, which indicated whether a person did (CT score $\geq$ 1) or did not (CT score = 0) have untreated caries.

Predictor variables

The predictor variables were smoking (vaping and dual), education, race or ethnicity, income, age, sex, and time since previous dental visit.

In NHANES, information about e-cigarette use is obtained via interviewing participants using a computer-assisted interview system. For this study, we used questions SMQ900 (ever used an e-cigarette?) and SMQ905 (how many days used an e-cigarette?) from the smoking-cigarette use section of NHANES. Each participant was grouped into 1 of 3 categories: current vaper, former vaper, and nonvaper. Participants who answered "yes" for having ever used an e-cigarette and who had smoked an e-cigarette in the past 30 days were categorized as a current vaper. Those who

answered "yes" for having ever used an e-cigarette and who had not smoked an e-cigarette in the past 30 days were categorized as a former vaper. Participants who answered "no" for having ever used an e-cigarette were categorized as a nonvaper.[41]

We calculated smoking status using questions SMQ020 (smoked at least 100 cigarettes in life?) and SMQ040 (do you now smoke cigarettes?). People who had smoked at least 100 cigarettes in their life and also smoked cigarettes every day or some days were defined as current smokers. Those who had smoked at least 100 cigarettes in their life but who answered "not at all" to the question about current cigarette smoking were defined as former smokers. We defined participants who had not smoked at least 100 cigarettes in their life as nonsmokers.

We also created a new variable that combined e-cigarette and cigarette use to aid in the analysis. We defined this variable as follows:

- current dual: current vapers and current smokers
- former dual: current or former vaper and former smoker; current or former smoker and former vaper
- never dual: any smoker status and never vaper status or any vaper status and never smoker status.

We included the following demographic variables in this study: sex, age, race or ethnicity, educational level, and income status. We included only participants 18 years or older, who were then categorized into 1 of 3 groups: 18 through 24 years, 25 through 64 years, and 65 years and older. We identified the ethnicity of the participants as Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, and other. We defined educational level using DMDEDUC3 (education level, children and youth 6-19 years) and categorized it as high school or less and more than high school. We defined income status using INDFMPIR (ratio of family income to poverty). In addition, we categorized each participant as at below 200% federal poverty guidelines (FPG) or 200% FPG or higher. We also included information regarding the participants' previous dental visit in our analysis, which was defined according to OHQ0300 (when did you last visit a dentist?). We categorized participants into 1 of 2 groups based on the duration since their last dental visit: 6 months or less and more than 6 months.

Data analysis

We used SAS Version 9.4 (SAS Institute) and RStudio to carry out the analyses. We categorized counts and weighted percentages of baseline characteristics by untreated caries status (yes or no), and we made comparisons using the Rao-Scott χ^2 test. We fit a logistic regression model to determine the associations between untreated caries and e-cigarette smoking and untreated caries and dual smoking.

First, each primary predictor was regressed against the outcome variable—untreated caries—using a univariable model to evaluate the independent effect of each predictor on the outcome. Next, we included all predictor variables in multivariate analyses to evaluate the adjusted effect of the predictor variables. We used a correlation matrix to evaluate collinearity between predictor variables.

RESULTS

Descriptive statistics for the study sample are presented in Table 1. A total of 4,618 participants were included in the study. Of the 4,618 participants, 48.11% were males, 11.85% were 18 through 24 years old, 68.46% were 25 through 64 years old, and 19.68% were 65 years and older. Moreover, 64.35% of the study participants were non-Hispanic White, 61.04% had more than a high school education, and 66.34% had an annual income of more than 200% FPG. For 55.10% of the participants, their previous dental visit had occurred more than 6 months prior. Among the 4,618 participants, 928 (17.29%) had untreated caries. Overall, 247 participants (6.32%) reported current use of e-cigarettes, with varying frequencies: daily use (1.40%), intermediate use (1.06%), and infrequent use (3.85%). Moreover, of the 4,618 participants, 16.73% reported current use of cigarettes, and 3.15% reported current use of both cigarettes and e-cigarettes.

The distribution of vaping prevalence by sociodemographic characteristics is shown in Figure 2. The prevalence of vaping in 18- through 24-year-old people (17.29%) is 2.75 times the overall prevalence of the study population.

Bivariate analysis results for untreated caries and the predictor variables are presented in Table 2. Significant associations were found for age, sex, race or ethnicity, education, income level, time since previous dental visit, vaping, conventional smoking, and dual smoking.

Table 1. Demographic characteristics of study participants (weighted percentages).

CHARACTERISTIC	NO. (WEIGHTED %)
Untreated Caries	928 (17.29)
E-cigarette Use	
Current	247 (6.32)
Daily use	48 (1.41)
Intermediate use	47 (1.06)
Infrequent use	152 (3.85)
Former	700 (17.35)
Never	3,671 (76.33)
Age, y	
18-24	522(11.86)
25-64	2,956 (68.46)
≥ 65	1,140 (19.68)
Sex	
Male	2,234 (48.11)
Female	2,384 (51.89)
Race or Ethnicity	
Asian	651 (5.50)
Hispanic	983 (14.50)
Non- Hispanic Black	1,035 (10.78)
Non-Hispanic White	1,703 (64.36)
Others	246 (4.86)
Education	
≥ High school	2,036 (38.95)
< High school	2,582 (61.05)
Income	
≥ 200% federal poverty guidelines	2,434 (66.34)
< 200% federal poverty guidelines	2,184 (33.66)
Last Dental Visit	
≤ 6 mo	1,788 (44.89)
> 6 mo	2,830 (55.11)
Conventional Smoking Use	
Current smoker	803 (16.73)
Former smoker	1,089 (24.66)
Nonsmoker	2,726 (58.61)
Dual (Conventional and E-cigarette) Use	
Current dual	120 (3.15)
Former dual	561 (14.42)
Never dual	3,937 (82.43)

Results of logistic regression analyses between untreated caries and significant variables from the bivariate analysis are shown in Tables 3 and 4. In the unadjusted model (model 1), the odds ratio (OR) for participants who currently smoked e-cigarettes compared with those who had never smoked e-cigarettes was 2.04 (95% CI, 1.46 to 2.86). In the adjusted model (model 2), the OR for participants who currently smoked e-cigarettes compared with those who had never smoked was 1.69 (95% CI, 1.24 to 2.29). In the adjusted model, participants aged 25

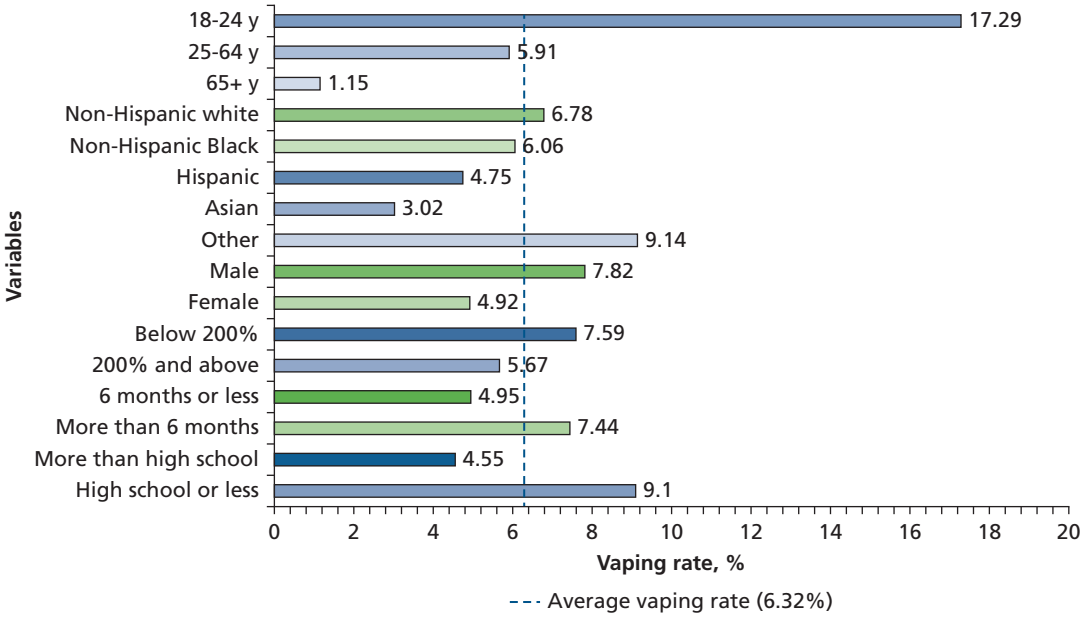

Figure 2. Prevalence rates of vaping.

through 64 years (OR, 1.70; 95% CI, 1.24 to 2.34), non-Hispanic Blacks (OR, 1.64; 95% CI, 1.16 to 2.32), participants whose income was less than 200% FPG (OR, 1.91; 95% CI, 1.48 to 2.46), those with less than a high school education (OR, 1.74; 95% CI, 1.54 to 1.96), and those whose previous dental visit was more than 6 months prior (OR, 2.36; 95% CI, 1.67 to 3.34) exhibited a statistically significant association with untreated caries, in contrast with the other participants in the study. When we introduced conventional smoking to the model to examine the interaction of smoking with e-cigarette smoking, multicollinearity occurred because of an insufficient sample size. Therefore, we combined vaping and conventional smoking as a new variable: dual smoking.

The association between dual smoking and untreated caries is shown in Table 4. In the unadjusted model (model 3), the OR for participants who currently smoked both e-cigarettes and conventional cigarettes (that is, dual) compared with those who had never smoked both e-cigarettes and conventional cigarettes was 3.16 (95% CI, 1.81 to 5.5). In the adjusted model (model 4), the OR for participants who currently smoked both e-cigarettes and conventional cigarettes compared with those who had never smoked both e-cigarettes and conventional cigarettes was 2.43 (95% CI, 1.36 to 4.36). In addition, non-Hispanic Blacks, participants with income less than 200% FPG, those with less than a high school education, and those whose previous dental visit was more than 6 months prior exhibited a significant association with untreated caries. Overall, the results in models 3 and 4 show trends similar to those in models 1 and 2.

DISCUSSION

The primary objective of this study was to assess the association between e-cigarette use and caries. We evaluated sociodemographic factors including sex, race or ethnicity, socioeconomic status, age, and time since previous dental visit for any confounding effects. The results of our study showed that untreated caries was more likely in current vapers as well as dual smokers after adjusting for sociodemographic factors and time since their previous dental visit. Because this study is cross-sectional, causality could not be established, but the results confirm that vaping may be a major risk factor for caries.

Current vapers who were 25 through 64 years old, non-Hispanic Blacks, not high school graduates, of low socioeconomic status ($\leq$ 200 FPG), and infrequent dental visitors were more likely to have untreated caries. This finding held true for current dual smokers as well. In both current vapers and dual smokers, sex did not influence the association with untreated caries. In addition, there was a significant association between untreated caries and sociodemographic factors, except for sex, independent of vaping or dual smoking status. However, people who were in the non-Hispanic

Table 2. Bivariate analysis of all variables in the study.

VARIABLE	UNTREATED CARIES (NO), NO. (WEIGHTED %)	UNTREATED CARIES (YES), NO. (WEIGHTED %)	*P* VALUE
E-cigarette Use			< .0001
Current	169 (4.65)	78 (1.67)	
Daily use	34	14	
Intermediate use	36	11	
Infrequent use	99	53	
Former	524 (13.16)	176 (4.19)	
Never	2,997 (64.89)	674 (11.43)	
Age, y			< .0001
18-24	436 (10.12)	86 (1.73)	
25-64	2,279 (55.04)	677 (13.43)	
≥ 65	975 (17.55)	165 (2.12)	
Sex			.0089
Male	1,745 (38.83)	489 (9.27)	
Female	1,945 (43.87)	439 (8.01)	
Race or Ethnicity			< .0001
Asian	563 (4.71)	88 (0.78)	
Hispanic	799 (11.92)	184 (2.58)	
Non- Hispanic Black	752 (7.78)	283 (3.00)	
Non-Hispanic White	1,391 (54.51)	312 (9.84)	
Other	185 (3.78)	61 (1.07)	
Education			.0000
High school or less	1,519 (29.43)	517 (9.51)	
More than high school	2,171 (53.26)	411 (7.78)	
Income			< .0001
≥ 200% federal poverty guidelines	2,098 (58.20)	336 (8.14)	
< 200% federal poverty guidelines	1,592 (24.50)	592 (9.15)	
Last Dental Visit			< .0001
≤ 6 mo	1,585 (40.75)	203 (4.13)	
> 6 mo	2,105 (41.94)	725 (13.15)	
Conventional Smoking Use			< .0001
Current smoker	516 (10.94)	287 (5.78)	
Former smoker	903 (21.29)	186 (3.36)	
Nonsmoker	2,271 (50.46)	455 (8.14)	
Dual (Conventional and E-cigarette) Use			< .0001
Current dual	72 (2.02)	48 (1.12)	
Former dual	405 (10.56)	156 (3.86)	
Never dual	3,213 (70.12)	724 (12.30)	

Black and low socioeconomic status groups were disproportionately affected by oral health disparities.[42] Thus, it is difficult to ascertain the true effect of vaping on caries without a well-controlled longitudinal study.

Despite the low prevalence of the use of e-cigarettes compared with the use of conventional cigarettes, the use of e-cigarettes is associated with multiple oral health[32,33] and general health[22-24] complications. According to previous studies,[25,26,34-36] the potential adverse effects of e-cigarettes

Table 3. Models 1 and 2: unadjusted and adjusted odds ratio between untreated caries and e-cigarette status.

VARIABLE	UNADJUSTED MODEL (MODEL 1)		ADJUSTED MODEL (MODEL 2)	
	Odds Ratio	95% CI	Odds Ratio	95% CI
Vaping				
Current vaper versus nonvaper	2.04*	1.46 to 2.86	1.69*	1.24 to 2.29
Former vaper versus nonvaper	1.80*	1.41 to 2.31	1.47*	1.162 to 1.87
Age, y				
18-24 versus ≥ 65	1.42	0.91 to 2.18	0.86	0.56 to 1.33
25-64 versus ≥ 65	2.01*	1.40 to 2.88	1.70*	1.24 to 2.34
Sex				
Male versus female	1.31*	1.05 to 1.64	1.23	0.96 to 1.57
Income				
< 200% federal poverty guidelines versus ≥ 200% federal poverty guidelines	2.67*	1.96 to 3.65	1.91*	1.48 to 2.46
Education				
Less than high school versus more than high school	2.21*	1.87 to 2.61	1.74*	1.54 to 1.96
Race or Ethnicity				
Asian versus non-Hispanic White	0.94	0.60 to 1.42	0.94	0.61 to 1.45
Hispanic versus non-Hispanic White	1.20*	0.83 to 1.74	0.84	0.59 to 1.21
Non-Hispanic Black versus non-Hispanic White	2.14*	1.48 to 3.09	1.64*	1.16 to 2.32
Others versus non-Hispanic White	1.58*	1.11 to 2.26	1.20	0.79 to 1.82
Dental Visit				
> 6 mo versus ≤ 6 mo	3.09*	2.26 4.24	2.36*	1.67 to 3.34

* Statistically significant estimate.

on oral health include damage to the periodontium and caries. The potential causal pathways for caries from e-cigarettes are as follows. E-cigarettes generate aerosols, increasing the adhesion of *Streptococcus mutans*, which is associated with pit and fissure caries, to tooth surfaces. In addition, these aerosols contain acetic acid, lactic acid, and propionaldehyde, which increase enamel demineralization.[34,35] Some e-cigarettes also contain high levels of fructose and sucrose, which are highly cariogenic. Studies[32,33] have also shown that vaping causes xerostomia, an environment highly conducive for caries incidence.

Practical implications

The findings of this study support the hypothesis that people who smoke e-cigarettes are at a higher risk of having untreated caries. Therefore, dentists should ask patients whether they smoke e-cigarettes and inform them of the harmful effects of e-cigarettes on oral and systemic health. When educating patients about the cessation of smoking and other harmful social habits, dentists should advise patients to avoid e-cigarettes to minimize the risk of developing caries. In addition, disparities among ethnic minority groups can be mitigated through public health efforts aimed at raising awareness through education.

Strengths

The greatest strengths of this study include our use of a national standardized data sample representing different sections of the country, information about several variables pertinent to oral health, and information about caries recorded by licensed dentists.

Limitations

- The information regarding e-cigarette use in this study was self-reported and, thus, is subject to recall bias. We classified e-cigarette users as current vapers, former vapers, and never vapers,

Table 4. Models 3 and 4: unadjusted and adjusted odds ratio between untreated caries and dual smokers.

VARIABLE	UNADJUSTED MODEL (MODEL 3)		ADJUSTED MODEL (MODEL 4)	
	Odds Ratio	95% CI	Odds Ratio	95% CI
Vaping				
Current dual versus never dual	3.16	1.81 to 5.5	2.43*	1.36 to 4.36
Former dual versus never dual	2.09	1.52 to 2.85	1.57*	1.14 to 2.15
Age, y				
18-24 versus ≥ 65	1.42	0.91 to 2.18	0.95	0.60 to 1.49
25-64 versus ≥ 65	2.01*	1.40 to 2.88	1.69*	1.21 to 2.34
Sex				
Male versus female	1.31*	1.05 to 1.64	1.23	0.96 to 1.57
Income				
< 200% federal poverty guidelines versus ≥ 200% federal poverty guidelines	2.67*	1.96 to 3.65	1.90*	1.48 to 2.44
Education				
Less than high school versus more than high school	2.21*	1.87 to 2.61	1.71*	1.52 to 1.92
Race or Ethnicity				
Asian versus non-Hispanic White	0.94	0.60 to 1.42	0.97	0.63 to 1.49
Hispanic versus non-Hispanic White	1.20*	0.83 to 1.74	0.87	0.60 to 1.25
Non-Hispanic Black versus non-Hispanic White	2.14*	1.48 to 3.09	1.69*	1.19 to 2.41
Other versus non-Hispanic White	1.58*	1.11 to 2.26	1.21	0.81 to 1.81
Dental Visit				
> 6 mo versus ≤ 6 mo	3.09*	2.26 to 4.24	2.34*	1.66 to 3.29

* Statistically significant estimate; unadjusted point estimates for age, sex, income, education, race or ethnicity, and dental visits are the same for model 1 and model 3.

similar to categories used for conventional cigarette smoking. However, there is no standardized method for classifying e-cigarette use. More information about different brands of e-cigarettes, flavors, and frequency and duration of use could provide greater insight into the association between e-cigarette use and caries.

- Dietary factors are known to play a role in caries, but because of data unavailability, we did not include these factors in our analysis.
- More detailed information about the type of services rendered at previous dental visits could provide a better picture of the baseline caries status of the study participants.
- Adolescents (aged 12-17 years) were not included in this study because they were not represented in the data.
- The low prevalence of vaping in our study masks any kind of association between vaping and caries. A larger trial with a higher number of participants using only e-cigarettes is needed to further investigate this association.

CONCLUSIONS

The findings of our cross-sectional study have shown that the presence of untreated caries was higher in participants who smoked only e-cigarettes as well as in those who smoked both e-cigarettes and conventional cigarettes. Prospective studies would be helpful in establishing an independent correlation between vaping and caries. Inquiries regarding vaping history at dental visits could provide dentists with insight to eliminate a potential caries-contributing factor. ■

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