

Article

Cross Sectional Observational Study of Current E-Cigarette Use and Oral Health Needs among Adolescents, Population Assessment of Tobacco and Health Study, Wave 5

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Abstract: Adolescents are vulnerable to marketing and normalization of electronic nicotine delivery systems (ENDS) and electronic non-nicotine delivery systems (ENNDS). ENDS/ENNDS have lung and neurological impacts and a potential for oral health consequences. The aim of this study is to compare adolescents who use ENDS/ENNDS with adolescents who do not use ENDS/ENNDS in oral healthcare needs. A cross-sectional design was used with U.S. Population Assessment of Tobacco and Health wave 5 (PATH5; 2018–2019) data, (n = 12,098 adolescents, ages 12–18 years). The Wave 5 response, weighted to be nationally representative was 83.5%. This study included 9538 adolescent/parent dyads. The outcome variable was parent/guardian report of their child's oral health need(s). The independent variable was self-reported current use/non-use of ENDS/ENNDS. Chi square and logistic regression analyses for oral health need were conducted. The Adjusted Odds Ratio for oral health needs comparing ENDS/ENNDS use vs. no use was 1.26 (95% CI: 1.01, 1.58; $p = 0.0451$) controlling for sex/gender, age, race, highest education in the household, physical activity of 60 min daily, self-perceived health, and language spoken at home. ENDS/ENNDS use continues to be a public health concern for U.S. youth. In this study, adolescents who used ENDS/ENNDS were more likely to have oral healthcare need than adolescents who did not use ENDS/ENNDS.

Keywords: ENDS; ENNDS; electronic cigarette; e-cigarette; oral health; needs assessment



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1. Introduction

Adolescent use of electronic nicotine delivery systems (ENDS) and electronic non-nicotine delivery systems (ENNDS) are global public health issues. Adolescent ever-use of ENDS/ENNDS is 17.2% [1]. Current adolescent use is 7.8% [1]. Adolescents prefer ENDS/ENNDS to combustible tobacco for many reasons, including the ease of discrete use. Some ENDS/ENNDS are disguised as pens, USB drives, and similar small common items [2]. The ENDS/ENNDS themselves and the e-liquid that is vaporized have potential health impacts on adolescents from neurological changes such as impacts on neuronal connections, learning, mood, and impulses [2]; to lung injury [3]; arterial stiffness, vascular endothelial changes, cardiorenal fibrosis, atherosclerotic plaque [4]; in addition to potential oral health issues such as periodontal disease, dental caries [5]; and, potentially oral carcinoma [6]. E-liquid (the liquid to be vaporized) usually has chemicals that have the potential to affect oral tissues. The chemicals of particular concern are nicotine and flavorings which are dissolved in propylene glycol and vegetable glycerin. Nicotine has known pathophysiological oral effects (oxidative stress, DNA damage, innate host response, inflammation, senescence at the cellular level, and dysregulation of tissue repair) [7].

The levels of nicotine in e-liquids differ widely among brands. Some have an additional 20% of nicotine in their declared, advertised amount [8], while others that declare having no nicotine actually do contain nicotine [9]. A typical disposable cartridge contains the same amount of nicotine as a pack of cigarettes [2]. An average use is one cartridge daily (15 vaping sessions with 10 puffs per session) [5]. In addition to nicotine exposure,

similar to combustible tobacco use, there are heavy metals (nickel, tin, and lead) [10], volatile organic compounds, ultrafine particles, and carcinogenic compounds present in ENDS/ENNDS vapor [2]. Use of ENDS/ENNDS often leads to the use of combustible tobacco with health consequences of cancer (including oral cancer), chronic obstructive pulmonary disease, heart disease and injury to most body organs.

E-liquid sugary flavorings are problematic in adolescent initiation of ENDS/ENNDS [11] and in oral health consequences. Sweet flavorings act as lures to increase pleasant, pleasurable first exposures [12] and continued use. Adolescents prefer fruit, candy, and other sweet flavors [11]. The flavors, in a dose-dependent fashion, are bactericidal to oral commensal biofilms needed for homeostasis [13]. Additionally, flavored e-liquids' aerosols were shown to decrease enamel hardness by up to 27% in comparison with unflavored controls [14]. Therefore, flavored e-liquids have an increased cariogenic potential [14]. In February 2020, the US placed restrictions on flavorings in e-cigarette cartridges to dissuade adolescent initiation or use. Nevertheless, six months after implementation, 78.7% of people who vaped reported that they were able to find and use flavor prohibited cartridges or pods, or regulation-exempt disposable e-cigarettes with flavored e-liquid [15]. The result was no change in flavored e-liquid use [15]. Long-term effects of ENDS/ENNDS are not known, as they were first introduced commercially in the US in 2007 [16].

In addition to nicotine and flavorings, e-liquids may contain environmental toxins such as reactive aldehydes, carbonyls, and heavy metals that can alter the microbiome and host cells' responses, leading to poor oral health [17]. E-cigarettes and their oral health consequences are beginning to receive attention in research [5,18,19]. In a scoping review of e-cigarettes and dental caries, the reviewers suggested e-liquids and e-cigarette aerosols contributed to dental caries [20]. In another literature review, most of the studies did not have oral health effects as their primary outcome, and the researchers rated the quality of the evidence as weak [18]. In another review, researchers reported that the effects of e-cigarette vapors on oral health are unknown due to the lack of long-term information [21]. Similar equivocal conclusions were reported in another systematic review and meta-analysis [22].

ENDS/ENNDS have sequelae that are just being discovered. Sugary flavorings entice children/adolescents. The American Dental Association advocates for ENDS/ENNDS research and banning ENDS/ENNDS sales (exempting those with U.S. Food and Drug Administration [FDA] approval for tobacco cessation by prescription) [23]. Tobacco companies have been criticized as attempting to normalize youth vaping [24]. Efforts are needed and underway in dissuading ENDS/ENNDS use. For example, it became illegal to sell ENDS/ENNDS to U.S. children in 2016 [25]; and prevention campaigns as the FDA's "Real Cost" program are helping [25]. Similar efforts are needed to curb youth ENDS/ENNDS use.

The rationale for conducting this research is that there is a lack of scientific information about ENDS/ENNDS and oral health-related consequences as the result of nicotine and sugary flavored vapors upon adolescent oral tissues. Therefore, the aim of this study is to compare adolescents who use ENDS/ENNDS with adolescents who do not use ENDS/ENNDS in oral healthcare needs. The null hypothesis is that adolescents who use ENDS/ENNDS are more likely to have oral health needs than adolescents who do not use ENDS/ENNDS.

2. Materials and Methods

2.1. Study Design

This research had a cross-sectional, retrospective observational study design. Existing nationally representative data of the U.S. adolescent population was used.

2.2. Ethical Statement

This research received West Virginia University Institutional Review Board acknowledgement as non-human subject research (Protocol number 2303752366). The data for this retrospective study were from a publicly available, fully anonymized data set provided by

the US National Institute of Health Population Assessment of Tobacco and Health wave 5 (PATH5), file DS55002 (December 2018–November 2019). The de-identified data source itself was approved by the Westat Institutional Review Board, and participants provided consent [26].

2.3. Data Source for the Retrospective Study

PATH5 included 34,309 consenting adults and 12,098 consenting youth participants [26,27]. PATH is a national, longitudinal study of US non-institutionalized residents. It is a representative study in which participants provide self-reports of tobacco use/non-use and other measures of health. The data collection was conducted through computer-assisted personal interviews and audio computer-assisted self-interviewing [28]. There was an oversampling of participants who used tobacco, young adults, and African Americans [26]. Sample weights were provided and used [26]. Additional details about the PATH study's design, recruitment, and methods are provided elsewhere [26]. Sample size calculations were based on having a relative standard error (RSE, standard error divided by row percent) below 30% and available degrees of freedom > 12.

2.4. Measures

2.4.1. Inclusion and Exclusion Criteria

Participants were included in this study if they had complete data on the following measures for this secondary data analysis of PATH5. The outcome measure was need for oral healthcare (yes/no). This variable was derived from parent/guardian responses. They were asked, if, in the past 12 months, the youth had been told by a doctor, dentist, or other healthcare professional that he/she had a dental issue.

The primary independent variable was the adolescent's response to having current ENDS/ENNDS use (past 30-day use, yes/no). This variable was only specific to past 30-day use of ENDS/ENNDS and respondents who reported no past 30-day use did not indicate if they had never used ENDS/ENNDS or combustible tobacco.

Other included variables were the adolescent's responses to: self-perception of overall health (\geq good, fair/poor); race (black, other, white); 60 min of daily physical activity daily (yes, no); alcohol use within the previous 12 months (yes, no); and body mass index (less than 25, 25 to less than 30, 30 or greater). Age was a derived variable (12 to less than 15 years, 15 to less than 18 years). This was the participants' age in wave 5 of PATH.

Considered in the research were also the factors influenced by the adolescent's parents/guardians. The parents/guardians provided responses to questions about language spoken at home (English, other), and highest level of education in the household (dichotomized to \leq high school, and >high school).

2.4.2. Statistical Analysis

Data analysis was completed with SAS[®] Analytics Software v9.4 (SAS Institute, Cary, NC, USA). Included in the analyses were Chi Square test (Rao Scott) and bivariate and multivariable logistic regression analyses. Replicate weights provided by PATH were used in the analyses with the Balanced Repeated Replication-Fay method [29]. A priori, a *p*-value of <0.05 was determined as the significance level.

3. Results

Table 1 provides the sample characteristics. The sample included 9538 adolescent-parent/guardian dyads. There were 78.8% of the possible pairs that were available for the research. Of the adolescents, half were female (50.7%). There were 41.9% who were ages 12 to less than 15 years old. Most of the participants were white (69.5%). Nearly three-fourths of the adolescents had a body mass index < 25 (73.5%). There were 94.5% who reported a good or excellent overall health perception. The sample included 10.2% of participants who had current (30-day) use of an ENDS/ENNDS and 18.6% who had an oral health need.

Table 1. Sample Characteristics of the Adolescents, PATH Survey, Wave 5, n = 9538.

Category	Number	Weighted %
Sex/gender		
Female	4922	50.7%
Male	4616	49.3%
Age categories (years)		
12 to less than 15	3490	41.9%
15 to less than 18	6048	58.1%
Race		
White	6477	69.5%
Black	1465	14.4%
Other	1596	16.0%
Body mass index		
Less than 25	6838	73.5%
25 to less than 30	1619	16.3%
30 or greater	1081	10.3%
60 Min of daily physical activity		
Yes	1859	20.0%
No	7679	80.0%
Self-perceived health		
Good or excellent	9006	94.6%
Fair or poor	532	5.4%
Alcohol use within the previous 12 months		
Yes	2794	29.8%
No	5744	70.2%
Current electronic nicotine product usage		
Yes	995	10.2%
No	8643	89.8%
Language spoken at home		
English	2459	23.3%
Other	7079	76.7%
Highest education level of any household member		
High school graduate or less than high school education	2609	24.2%
More than a high school education	6929	75.8%
Oral health need		
Yes	1788	18.6%
No	7750	81.4%

The associations of oral health needs with variables of interest are presented in Table 2 with their associated weighted percentages and *p*-values for comparisons among the categories. These categories failed to reach a significant difference in oral health needs: sex, age, body mass index, 60 min of daily physical activity, self-perceived health, alcohol use, and language spoken at home. There were two significant associations with oral health need. The first concerned household members' education. Adolescents living in a

household where the highest education of any household member was having a high school education or less had greater oral health need than adolescents living in a household in which the highest education of any household member was above high school graduation (20.2% versus 18.0%; $p = 0.0459$). The second significant association with oral health need was among adolescents who currently used ENDS/ENNDS. They had a greater oral health need than adolescents who did not currently use ENDS/ENNDSs (22.0% versus 18.2%; $p = 0.0278$).

Table 2. Current Oral Health Need of Adolescents, PATH Survey, Wave 5, n = 9538.

	Oral Health Need (n)	Weighted %	No Oral Health Need (n)	Weighted %	p-Value	RSE
Overall sample	1788	18.6%	7750	81.4%		2.50%
Sex/gender					0.8553	
Male	902	18.5%	4020	81.5%		3.7%
Female	886	18.6%	3730	81.4%		3.2%
Age categories (years)					0.5430	
12 to less than 15	638	18.25	2852	81.7%		3.9%
15 to less than 18	1150	18.8%	4898	81.2%		3.1%
Race					0.5829	
White	1.222	18.9%	5255	81.1%		2.8%
Black	268	17.9%	1197	82.1%		6.4%
Other	298	17.9%	1298	82.1%		6.4%
Body mass index					0.1021	
Less than 25	1249	18.3%	5589	81.7%		3.2%
25 to less than 30	306	18.0%	1313	82.0%		5.5%
30 or greater	233	21.7%	848	78.7%		6.3%
60 min of daily physical activity					0.8231	
Yes	336	18.4%	1523	81.6%		5.3%
No	1452	18.6%	6227	81.4%		2.7%
Self-perceived health					0.0597	
Good or excellent	1665	18.4%	7341	81.6%		2.6%
Fair or poor	123	22.1%	409	77.9%		8.9%
Alcohol use within the previous 12 months					0.4995	
Yes	548	19.0%	2246	81.0%		4.1%
No	1240	18.4%	5504	81.6%		3.3%
Language spoken at home					0.2620	
English	1343	18.8%	5736	81.2%		2.6%
Other	445	17.8%	2014	82.2%		4.7%
Highest education level of any household member					0.0459	
High school graduate or less than high school education	513	20.2%	2096	79.8%		4.8%
More than a high school education	1275	18.0%	5654	82.0%		2.9%
Current electronic nicotine product usage					0.0278	
Yes	215	22.0%	780	78.0%		8.0%
No	1573	18.2%	6970	81.8%		2.6%

Note: The abbreviation, RSE, relative standard error, is the standard error divided by the row percent.

In logistic regression of current electronic nicotine product use on oral health need with an unadjusted analysis, adolescents who currently used ENDS/ENNDS were more

likely to have an oral health need compared with adolescents who did not currently use ENDS/ENNDS (unadjusted odds ratio (UOR): 1.27; 95% confidence level [CI]: 1.02, 1.55; $p = 0.0237$). In adjusted analysis on oral health need, controlling for sex/gender, age, race, highest education in the household, physical activity of 60 min daily, self-perceived health, alcohol use within the previous 12 months, and language spoken at home, the adjusted odds ratio (AOR) for adolescents who currently used ENDS/ENNDS versus adolescents who did not was 1.26 (95% CI: 1.01, 1.58; $p = 0.0451$) (Table 3).

Table 3. Logistic Regression of Current Electronic Nicotine Product Use on Oral Health Need of Adolescents.

	UOR	95% CI	<i>p</i> -Value	AOR	95% CI	<i>p</i> -Value
Current electronic nicotine product usage			0.0237			0.0451
Yes	1.27	1.03, 1.55		1.26	1.01, 1.58	
No	Ref			Ref		

Note: The abbreviations are UOR: unadjusted odds ratio; CI: confidence interval; AOR: adjusted odds ratio; and Ref: reference group. The adjusted model controlled for sex/gender (male, female); age (12 to less than 15 years, 15 to less than 18 years); race (black, white, other); highest education level of any household member (high school graduate or less than high school education, more than high school education); body mass index (less than 25, 25 to less than 30, 30 or greater); physical activity of 60 min daily (yes, no); self-perceived health (good or excellent, fair or poor); alcohol use within the previous 12 months; and language spoken at home. The models used 100 degrees of freedom in computing the confidence limits.

4. Discussion

In this study, overall, 18.6% of adolescents had oral health needs. Among adolescents who currently used ENDS/ENNDS, there were 27% greater odds of having oral health needs vs. adolescents who did not use ENDS/ENNDS. These results support other current research of adolescent oral health and ENDS/ENNDS. In a similar study of an earlier wave of PATH (2013–2014) data, the prevalence OR for provider-diagnosed dental problems among adolescents, ages 12–17, who used ENDS/ENNDS 1.11 (95% CI: 0.79, 1.55) [30]. In a study of 65,528 students who used ENDS/ENNDS, the AOR for a fractured tooth within the previous year were 1.54 (95% CI: 1.19, 2.27) and the AOR for oral pain (tongue and/or buccal mucosa) were 1.54 (95% CI: 1.05, 2.26) [31]. In a multi-country study in which 32.4% of survey participants were ages ≤ 20 years, those who used ENDS/ENNDS were more likely to report oral symptoms (dry mouth, and black tongue) [32].

As adolescents are a vulnerable group, and ENDS/ENNDS use is prohibited, there are few peer-reviewed sources with which to compare adolescent oral health needs when considering ENDS/ENNDS. The existing research with adolescents and ENDS/ENNDS has often been limited to other medical conditions rather than specifically to the research of adolescent oral health. Some research is available on adult oral health and ENDS/ENNDS. In a study of adults (ages 19–80 years), periodontal disease was associated with ENDS/ENNDS [33]. A similar association was with gingival disease diagnosis (AOR = 2.9 [95% CI: 1.6, 4.5]) in a study of adults [34]. Other studies of adults have not shown an effect on tooth health or inflammation [35]. It is unknown if adult oral responses to e-liquid can be generalizable to adolescent responses.

This study is important because the sequela of ENDS/ENNDS use is yet to be determined and the possibility of progression from ENDS/ENNDS to combustible tobacco use could have serious current and future health consequences. Among the adolescents who do have current combustible tobacco use, many reported respiratory conditions [36]. Combustible tobacco use was found to affect respiratory functions in 13.8% of adolescents as symptoms of wheezing, and night-time coughing [37]. If adolescent ENDS/ENNDS use progresses to adolescent combustible tobacco use and also progresses to adult combustible tobacco use, then the consequences of additional serious smoking-related risks may occur. It is therefore important for healthcare professionals to discourage the initiation of ENDS/ENNDS and encourage ENDS/ENNDS cessation if the use has begun.

Although not a focus of the study, there was a relationship of having a household member with an education level above high school that was protective of the adolescent not having an oral health need. This factor requires additional exploration and research to best provide preventive oral health interventions to vulnerable adolescents. It is interesting that oral health need is perceived as being separate and distinct from self-perceived health by many participants. In this study, 18.4% of adolescents reporting \geq good self-perceived health actually had an oral health need. This discrepancy also requires further research consideration.

Strengths and Limitations

A strength of this study is that the researcher used a recent, nationally representative large data set (PATH5). The questions in the survey were vetted by an expert panel of researchers from the Geisel School of Medicine at Dartmouth, the Medical University of South Carolina, New York University, Roswell Park Comprehensive Cancer Center, Rutgers University, the University of California San Diego, the University of Minnesota, and the University of Waterloo [26]. A limitation of this study is that participants or their parent/guardian provided the responses, and there is a potential for recall bias or social desirability bias. The respondents may have had difficulty remembering if they had actually used ENDS/ENNDS within the previous month, or their parents/guardians may have had difficulty remembering if their child had a dental need that needed to be addressed. Similarly, the adolescent may have wanted to appear to be “doing the right thing” and may have answered that they did not use ENDS/ENNDS to conduct their lives in a socially acceptable manner. These inaccuracies could have influenced the study results. Additionally, the question posed to parents/guardians may have been misinterpreted. The study design precludes a causal determination. Additional socioeconomic variables, detailed oral health variables, frequency, and duration of e-cigarette use/cigarette use would have also strengthened the study.

5. Conclusions

In this study, adolescents who used ENDS/ENNDS were more likely to have oral healthcare need than adolescents who did not use ENDS/ENNDS.

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Institutional Review Board Statement: This study was approved by the West Virginia University Institutional Review Board (Protocol: 2303752366) as a Not Human Subjects Research protocol.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data files are available from PATH, Population Assessment of Tobacco and Health: A collaboration between the NIH and FDA. Available online: PATH (Population Assessment of Tobacco and Health) Study-Researchers ([nih.gov](https://www.nih.gov)) accessed on 10 October 2023 [27].

Conflicts of Interest: The author declares no conflict of interest.

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