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Association between Electronic Cigarettes Use and Asthma in the United States: Data from the National Health Interview Survey 2016–2019

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Purpose: This article aimed to investigate 1) whether electronic cigarette (EC) users are more likely to experience asthma attacks or emergency room (ER) visits due to asthma than non-users and 2) how age and smoking behaviors moderate the effect size of the association.

Materials and Methods: We used National Health Interview Survey data from 2016–2019. Multiple logistic regression analysis was performed to identify the association between current EC use and having an asthma attack and ER visitation due to asthma. Interaction terms were included to explore the moderation effects of age and cigarette smoking status. Subgroup analysis was conducted according to age group.

Results: Of the 218911 participants, 2.0% of them experienced an asthma attack, and 0.5% visited the ER due to asthma. Current EC use was associated with higher odds of having an asthma attack. In interaction analysis, age and smoking status were identified as a moderator in the relationship between EC use and asthma attacks. Participants in their 20s or 30s showed the highest interaction effect.

Conclusion: Our analysis indicates the potential impact of EC use on public health and the moderating effects of smoking behavior.

Key Words: E-cigarette vapor, electronic nicotine delivery systems, asthma, cigarette smoking, public health

INTRODUCTION

Asthma is a chronic inflammatory airway disease affecting 1%–18% of the population in various regions.[1] Asthma affects around 25 million people in the US, which equivalates to almost 1 in every 13 Americans, including 8% of adults and 7% of children.[2] According to the Centers for Disease Control (CDC),[2] on average, asthma affects around 20 million adults over 18 years in the US, and 10 Americans die from asthma each day. Asthma is characterized by variable symptoms of wheeze, shortness of breath, chest tightness, cough, and by variable expiratory airflow limitation and life-threatening episodic flare-ups (exacerbations). These symptoms are often triggered by various factors, such as exercise, allergens, weather change, or viral respiratory infections. Adults are five times more likely than children to die from asthma. With adequate treatment and care, many asthma-related fatalities may be avoided.[1]

Recently, electronic cigarette (EC) use has been emphasized as a serious public health concern worldwide, especially among adolescents and young adults. According to the World Health Organization, in 2011, there were 7 million EC users, and by 2018, this increased by about 5.9 times (41 million). According to Euromonitor, by 2021, the numbers will increase to 55 million.[3] The US is one of the largest EC markets worldwide. Since 2007, when EC devices were introduced to the US market, the percentage of EC usage increased rapidly, especially among teenagers and young adults. However, in September 2019, a

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sweeping outbreak of lung injuries [i.e., e-cigarette and vaping use-associated lung injury (EVALI)], among EC users in the US brought forth national attention to the potential dangers of vaping and prompted the federal government and some states to enact policy measures.

ECs have grown in popularity since their introduction in 2003 as a smoking cessation aid and as an alternative to conventional cigarettes. Among studies reporting associations between EC use and clinical outcomes, respiratory conditions (e.g., asthma and asthma attacks) were crucial.[4] Several studies have investigated the influence of ECs on asthma development in terms of physiological mechanisms and reported that it generates a variety of carcinogens and irritants depending on the type of EC liquid. In vitro and in vivo cells exposed to these vapors can develop inflammation and oxidative damage. Organ systems, particularly cardiovascular and respiratory function, may be affected by EC aerosol.[5]

Even though some studies have demonstrated the impact of sociodemographic factors [e.g., age, race, or socioeconomic status (SES)] or smoking status among EC users on the likelihood of developing asthma,[6-8] there have been no studies to determine the likelihood of EC users having asthma attacks or emergency room (ER) visits, compared to non-users. Furthermore, no studies have investigated other moderating factors involved in the association between EC use and asthma attacks. Thus, the objective of this study was to investigate 1) whether EC users are more likely to have asthma attacks or ER visits due to asthma, 2) what moderating effects age and smoking status have on this trend, and 3) differences in the effect sizes of observed associations according to smoking status.

MATERIALS AND METHODS

Source of data

This study used data from the Integrated Public Use Microdata Series-National Health Interview Survey (IMPUS-NHIS) from years 2016–2019.[9] The IPUMS NHIS is a harmonized set of data covering over 50 years (1963-present) of the National Health Interview Survey (NHIS). The NHIS is a nationally representative annual cross-sectional household interview survey of the US civilian noninstitutionalized population conducted and sponsored by the National Center for Health Statistics (NCHS). Patients or the public were not involved in the design, or conduct, reporting, or dissemination plans of our research. The NHIS includes sociodemographic characteristics, health status and conditions, health-related behaviors, functioning and disability, pain and pain management, mental health, and health care service access/utilization. Although some survey questionnaires differ between certain amounts of time, NHIS data consists of three modules: Family or Household module, Sample Adult, and Sample Child. Data are given some weight to allow researchers to estimate the national population according to the NCHS variance estimation guide provided by NCHS.[10] Detailed information on the design or methodology used for the NHIS is provided by NCHS.[11] This study was exempt from Institutional Review Board inspection due to the deidentification of the applied data available for public use. The authors confirm that the research presented in this article met the ethical guidelines, including adherence to the legal requirements, of the USA. This study was determined by the National Institutes of Health Office of Human Subject Research Protection as non-human subject research (analysis of publicly available public health data and web content) and was, therefore, exempted from review by the Institutional Review Board.

A total of 117184 adults (33028 in 2016; 26742 in 2017; 25417 in 2018; 31997 in 2019) have completed the survey. Among respondents, the following were excluded: adults aged over 80 years and those who either refused to respond or were uncertain about having experienced an asthma attack or ER visit due to asthma. Thus, 10925 adults were excluded. A total of 106259 eligible participants (30371 in 2016; 24593 in 2017; 23392 in 2018; 27903 in 2019) were included for analysis.

Variables

In this study, participants with the following two dependent variables were defined: 1) those who experienced asthma attacks and 2) those who visited the ER due to asthma. To better focus on the direct association between an asthma attack and EC use, study participants over the age of 18 years who answered "Yes" to the question, "During the past 12 months, have you had an episode of asthma or an asthma attack?" were categorized into the event group, and participants who answered "No" were categorized into the controlled group. The others were excluded from the study (referred variable name as asthma attack). Similarly, study participants over the age of 18 years who answered "Yes" to the question, "During the past 12 months, have you had to visit an ER or urgent care center because of asthma?" were categorized into the event group, and those who answered "No" were categorized into the controlled group. The others were excluded from the study (referred variable name as ER visits).

The primary variable of interest (i.e., current EC use) was identified for adults over the age of 18 years responding to a question regarding whether they now use ECs or other electronic vaping products "every day" or "some days." In further analyses, the interaction terms of the participants' current EC vaping status and smoking status were added to assess whether the effect size of the participants' current EC vaping status on an asthma attack or ER visit due to asthma differ depends on the participants' current smoking status (i.e., current smoker, former smoker, and non-smoker).

Other covariates were considered, including the study participants' socio-demographic status (sex, age, ethnicity, race, insurance type, education, working status, marital status, and region) and other related factors that can affect asthma symp-

Table 1. General Characteristics of the Study Population

	Experience of asthma episode/attack			Total	ER visit due to asthma		
	Yes	No	*p* value		Yes	No	*p* value
Total	4323 (2.0)	214588 (98.0)	<0.0001	218911 (100.0)	1167 (0.5)	217744 (99.5)	<0.0001
Current e-cigarette use			<0.0001				<0.0001
Yes	194 (5.3)	3471 (94.7)		3668 (1.7)	53 (1.4)	3615 (98.6)	
No	4129 (1.9)	211114 (98.1)		215243 (98.3)	1114 (0.5)	214129 (99.5)	
Smoking status			<0.0001				<0.0001
Current smoker	880 (5.1)	16349 (94.9)		17229 (7.9)	281 (1.6)	16948 (98.4)	
Former smoker	1137 (3.9)	27746 (96.1)		28883 (13.2)	284 (1.0)	28599 (99.0)	
Non-smoker	2306 (1.3)	170493 (98.7)		172799 (78.9)	602 (0.4)	172197 (99.7)	
Sex			<0.0001				<0.0001
Male	1222 (1.2)	102512 (98.8)		103734 (47.4)	297 (0.3)	103437 (99.7)	
Female	3101 (2.7)	112076 (97.3)		115177 (52.6)	870 (0.8)	114307 (99.2)	
Age			<0.0001				0.0579
18–29	624 (1.6)	38348 (98.4)		38972 (17.8)	178 (0.5)	38794 (99.5)	
30–39	617 (1.7)	35403 (98.3)		36020 (16.5)	180 (0.5)	35840 (99.5)	
40–49	751 (2.2)	34133 (97.9)		34884 (15.9)	192 (0.6)	34692 (99.5)	
50–59	913 (2.4)	37800 (97.6)		38713 (17.7)	234 (0.6)	38479 (99.4)	
60s and over	1418 (2.0)	68904 (98.0)		70322 (32.1)	383 (0.5)	69939 (99.5)	
Ethnicity			<0.0001				0.0955
Hispanic	471 (1.5)	30339 (98.5)		30810 (14.1)	184 (0.6)	30626 (99.4)	
Non-hispanic	3852 (2.1)	184249 (98.0)		188101 (85.9)	983 (0.5)	187118 (99.5)	
Race			<0.0001				<0.0001
White only	3376 (2.0)	169694 (98.1)		173070 (79.1)	787 (0.5)	172283 (99.6)	
Black/African American only	548 (2.3)	23209 (97.7)		23757 (10.9)	261 (1.1)	23496 (98.9)	
AIAN/Asian only	188 (1.2)	15325 (98.8)		15513 (7.1)	47 (0.3)	15466 (99.7)	
Other	211 (3.2)	6360 (96.8)		6571 (3.0)	72 (1.1)	6499 (98.9)	
Insurance type			<0.0001				<0.0001
No insurance	393 (1.7)	22336 (98.3)		22729 (10.4)	130 (0.6)	22599 (99.4)	
Private	2014 (1.5)	129388 (98.5)		131402 (60.0)	406 (0.3)	130996 (99.3)	
Public (Medicare, Medicaid, Double eligible, etc.)	1681 (3.2)	51000 (96.8)		52681 (24.1)	577 (1.1)	52104 (98.9)	
Other	235 (1.9)	11864 (98.1)		12099 (5.5)	54 (0.5)	12045 (99.6)	
Marital status			<0.0001				<0.0001
Married or living with partner	1685 (1.4)	117383 (98.6)		54208 (24.8)	365 (0.3)	118703 (99.7)	
Divorced, separated, widowed	1510 (3.3)	44125 (96.7)		45635 (20.9)	439 (1.0)	45196 (99.0)	
Single never married	1128 (2.1)	53080 (97.9)		119068 (54.4)	363 (0.7)	53845 (99.3)	
Currently taking prescribed hypertension medications			<0.0001				<0.0001
Yes	2762 (4.7)	31655 (95.3)		33216 (15.2)	464 (1.4)	32752 (98.6)	
No	1561 (1.5)	182933 (98.5)		185695 (84.8)	703 (0.4)	184992 (99.6)	
Taking low-dose aspirin medication			<0.0001				<0.0001
Yes	136 (5.8)	2213 (94.2)		2349 (1.1)	37 (1.6)	2312 (98.4)	
No	4187 (1.9)	212375 (98.1)		216562 (98.9)	1130 (0.5)	215432 (99.5)	
Diabetes medication status			<0.0001				<0.0001
Currently taking	628 (5.6)	10549 (94.4)		11177 (5.1)	219 (2.0)	10958 (98.0)	
DM but not taking meds	241 (6.6)	3422 (93.4)		3663 (1.7)	62 (1.7)	3604 (98.3)	
Never had DM nor taking meds	3454 (1.7)	200617 (98.3)		204071 (93.2)	886 (0.4)	203185 (99.6)	
COPD history			<0.0001				<0.0001
Yes	918 (17.0)	4470 (83.0)		5388 (2.5)	346 (6.4)	5042 (93.6)	
No	3405 (1.6)	210118 (98.4)		213523 (97.5)	821 (0.4)	212702 (99.6)	
Body mass index			<0.0001				<0.0001
Unknown	145 (0.1)	106695 (99.9)		106840 (48.8)	34 (0.0)	106806 (100.0)	

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Table 1. General Characteristics of the Study Population (continued)

	Experience of asthma episode/attack			Total	ER visit due to asthma		
	Yes	No	*p* value		Yes	No	*p* value
Underweight	70 (3.7)	1809 (96.3)		1879 (0.9)	20 (1.1)	1859 (98.9)	
Healthy weight	977 (2.7)	35580 (97.3)		36557 (16.7)	232 (0.6)	36325 (99.4)	
Overweight	1165 (3.0)	37550 (97.0)		38715 (17.7)	288 (0.7)	38427 (99.3)	
Obese	1966 (5.6)	32954 (94.4)		34920 (16.0)	593 (1.7)	34327 (98.3)	
Have a doctor for medical advice			<0.0001				<0.0001
Clinic or health center	824 (4.0)	19872 (96.0)		20696 (9.5)	238 (1.2)	20458 (98.9)	
Doctor's office of HMO	2991 (3.9)	73918 (96.1)		76909 (35.1)	777 (1.0)	76132 (99.0)	
Hospital emergency room	83 (6.9)	1125 (93.1)		1208 (0.6)	43 (3.6)	1165 (96.4)	
Hospital outpatient department	61 (3.8)	1532 (96.2)		1593 (0.7)	21 (1.3)	1572 (98.7)	
Others	52 (3.1)	1648 (96.9)		1700 (0.8)	15 (0.9)	1685 (99.1)	
None	312 (0.3)	116493 (99.7)		116805 (53.4)	73 (0.1)	116732 (99.9)	

ER, emergency room; AIAN, American Indian/Alaska Native; DM, diabetes mellitus; COPD, chronic obstructive pulmonary disease; HMO, Health Maintenance Organization.
Data are presented as n (%).

toms or ER visits, such as monthly smoking amounts, medication status,[12,13] other underlying conditions [chronic obstructive pulmonary disease (COPD)],[14-16] body mass index,[17,18] and whether the participants consult with a doctor for medical advice.[12]

Statistical analyses

Descriptive analyses were used to examine the distribution of general characteristics according to asthma attack and ER visit. Each categorical variable was examined by the frequencies and row percentages and by χ^2 tests to identify significant correlations between the variables. Multiple logistic regression analysis was performed to identify associations between the variables, especially current EC use, and an asthma attack and ER visit. In addition, to explore the moderation effects of cigarette smoking status and age, individual interaction terms were included in the model separately. Lastly, to evaluate differences between smoking status groups, subgroup analyses were conducted. The method used in 2018 NHIS and prior years was no longer the basis for the generation of sampling weights, and there was a significant redesign of the NHIS questionnaire and data collection approach. AS such, we did not use the "survey" procedure and did not apply sampling weights. All *p*-values<0.05 were considered to indicate statistical significance. All statistical analyses were conducted in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Characteristics of the study population

Among all selected participants (n=218911), 2.0% had experienced an asthma attack (n=4323), and the participants who visited the ER accounted for 0.5% of all study participants (n=1167). Current EC users comprised 1.7% of the study participants (equivalent to 3668). Of these, 194 had experienced an asthma attack, and 53 had visited the ER. With respect to cigarette smoking habits, the participants who experienced an asthma attack or visited ER tended to smoke more frequently and more cigarettes, compared to the average or control group. Among other variables, the following showed a higher percentage of asthma attacks and visits to the ER: females, African Americans, public insurance holders, those who were unemployed the week prior to the survey, those who are currently taking or have taken prescribed medication, patients with COPD history, obese people, or those who went to the hospital ER for medical advice (Table 1).

Multiple logistic regression analysis

The adjusted model of the data showed that the odds of having an asthma attack was 1.22 for current EC users, compared to non-EC users. Although the odds of having an ER visit experience was 1.14 among current EC users, compared with non-current users, statistical significance was not shown. Also, participants in younger age groups (i.e., age group of 20s and 30s) showed a higher odds of having an asthma attack and having an asthma-related ER visit experience. Depending on the participants' insurance type, those with public insurance were more likely to have an asthma attack and ER visit, compared to those with private insurance. The participants with COPD history or going to the ER for medical advice showed statistically significant odds of having an asthma attack, and the odds of having an asthma related ER visit was 8.39 and 5.29, respectively. Considering smoking status, there was no statistical significance in relation to the odds of an ER visit, although current smokers or former smokers showed statistically significant higher odds of experiencing an asthma attack (Table 2).

In a previous study, EC use was associated with higher odds of cigarette smoking and may have encouraged conventional cigarette use among adolescents.[15] Thus, to understand the

Table 2. Factors Associated with Asthma Attacks and ER Visits

	Asthma episode/ attack	ER visit due to asthma
	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)
Current e-cigarette use		
Yes	1.22 (1.04–1.43)	1.14 (0.85–1.54)
No	1.00	1.00
Smoking status		
Current smokier	1.15 (1.05–1.26)	1.13 (0.96–1.34)
Former smoker	1.09 (1.00–1.18)	1.00 (0.86–1.18)
Non-smoker	1.00	1.00
Sex		
Male	1.00	1.00
Female	2.21 (2.06–2.37)	2.27 (1.98–2.61)
Age		
18–29	2.44 (2.14–2.79)	2.69 (2.09–3.45)
30–39	2.10 (1.86–2.37)	2.53 (2.02–3.17)
40–49	2.50 (2.24–2.79)	2.56 (2.09–3.15)
50–59	2.05 (1.86–2.26)	1.88 (1.57–2.25)
60s and over	1.00	1.00
Ethnicity		
Hispanic	0.83 (0.75–0.93)	1.31 (1.10–1.57)
Non-hispanic	1.00	1.00
Race		
White only	1.00	1.00
Black/African American only	0.94 (0.85–1.04)	1.76 (1.50–2.06)
AIAN/Asian only	0.76 (0.65–0.88)	0.91 (0.67–1.23)
Other	1.30 (1.12–1.52)	1.47 (1.13–1.91)
Insurance type		
No insurance	1.32 (1.17–1.49)	1.54 (1.24–1.91)
Private	1.00	1.00
Public (Medicare, Medicaid, Double eligible, etc.)	1.52 (1.40–1.65)	1.86 (1.59–2.17)
Other	1.12 (0.96–1.30)	1.11 (0.82–1.51)
Education attainment		
No diploma, High School Graduate	1.00	1.00
Associate degree only	1.28 (1.19–1.39)	1.05 (0.91–1.20)
Bachelor's degree, Graduate Degree, Professional School Degree	1.35 (1.24–1.47)	0.90 (0.76–1.07)
Have been working last week		
Yes	0.83 (0.76–0.89)	0.80 (0.69–0.93)
No	1.00	1.00
Marital status		
Married or living with partner	0.89 (0.81–0.97)	0.76 (0.64–0.90)
Divorced, separated, widowed	0.99 (0.89–1.09)	0.92 (0.77–1.09)
Single, never married	1.00	1.00
Region		
Northeast	0.95 (0.86–1.04)	1.05 (0.87–1.27)
Midwest	0.81 (0.73–0.88)	0.78 (0.65–0.94)
South	0.78 (0.72–0.85)	0.88 (0.75–1.04)
West	1.00	1.00
Currently taking prescribed hypertension medications		
Yes	1.18 (1.09–1.28)	1.15 (0.99–1.34)
No	1.00	1.00
Low-dose aspirin medication status		
Yes	1.33 (1.10–1.61)	1.23 (0.87–1.74)
No	1.00	1.00
Diabetes medication status		
Currently taking	1.26 (1.14–1.39)	1.40 (1.18–1.66)
DM but not taking meds	1.46 (1.26–1.69)	1.24 (0.94–1.63)
Never had DM nor taking meds	1.00	1.00
COPD history		
Yes	6.29 (5.73–6.91)	8.39 (7.16–9.84)
No	1.00	1.00
Body mass index		
Unknown	0.14 (0.11–0.17)	0.16 (0.10–0.25)
Underweight	1.03 (0.80–1.32)	1.10 (0.69–1.75)
Healthy weight	1.00	1.00
Overweight	1.28 (1.17–1.40)	1.26 (1.06–1.51)
Obese	1.96 (1.80–2.13)	2.03 (1.72–2.39)
Have a doctor for medical advice		
Clinic or health center	2.34 (1.98–2.75)	2.79 (2.02–3.87)
Doctor's office of HMO	2.47 (2.11–2.88)	2.75 (2.01–3.75)
Hospital emergency room	3.57 (2.71–4.72)	5.29 (3.42–8.19)
Hospital outpatient department	2.62 (1.93–3.57)	3.66 (2.12–6.30)
Others	2.06 (1.50–2.82)	2.54 (1.40–4.59)
None	1.00	1.00
Survey year		
2016	1.24 (1.13–1.35)	1.01 (0.85–1.19)
2017	1.16 (1.05–1.27)	1.03 (0.87–1.22)
2018	1.13 (1.03–1.24)	1.02 (0.85–1.21)
2019	1.00	1.00

ER, emergency room; OR, odds ratio; CI, confidence interval; AIAN, American Indian/Alaska Native; DM, diabetes mellitus; COPD, chronic obstructive pulmonary disease; HMO, Health Maintenance Organization.
*All variables in the table were simultaneously adjusted in the logistic regression model.

moderating effect of smoking status and age on the relationship between EC us and an experience of asthma attack and an asthma-related ER visit, each of the interaction terms was included (Table 3, Supplementary Tables 1 and 2, only online). In interaction analyses, the relation between EC use and an asthma attack depended on the participants' smoking status. Specifically, compared to non-smokers, both current and former smokers showed ORs less than 1, indicating that the associations were weaker than expected when considering only

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Table 3. Interaction Effects of Cigarette Smoking Status and Age

	Asthma episode/ attack	ER visit due to asthma
	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)
Current e-cigarette use		
Yes	1.94 (1.33–2.83)	1.55 (0.75–3.20)
No	1.00	1.00
Smoking status		
Current smoker	1.17 (1.06–1.28)	1.12 (0.94–1.33)
Former smoker	1.10 (1.01–1.19)	1.03 (0.88–1.21)
Non-smoker	1.00	1.00
Smoking status×e-cigarette use		
Current smoker	0.57 (0.37–0.89)	0.84 (0.37–1.91)
Former smoker	0.58 (0.37–0.93)	0.46 (0.18–1.22)
Non-smoker	1.00	1.00
Current e-cigarette use		
Yes	0.88 (0.57–1.34)	0.12 (0.02–0.83)
No	1.00	1.00
Age		
18–29	2.38 (2.08–2.72)	2.50 (1.94–3.23)
30–39	2.07 (1.84–2.34)	2.39 (1.90–3.01)
40–49	2.48 (2.22–2.77)	2.55 (2.07–3.14)
50–59	2.07 (1.88–2.29)	1.88 (1.57–2.25)
60s and over	1.00	1.00
Current e-cigarette use×Age		
18–29	1.96 (1.16–3.28)	19.36 (2.54–147.63)
30–39	1.61 (0.93–2.78)	17.39 (2.25–134.10)
40–49	1.46 (0.84–2.52)	7.43 (0.91–61.00)
50–59	0.99 (0.57–1.72)	6.16 (0.76–49.76)
60s and over	1.00	1.00

ER, emergency room; OR, odds ratio; CI, confidence interval.
*All variables in the table were simultaneously adjusted in the logistic regression model.

the main effects. A similar trend was shown in the association between EC use and asthma-related ER visits, although it was not statistically significant. The highest odds of having an asthma attack and ER visit were for the interaction between the 20s age group and current EC use, compared to the age group of 60 and over (Supplementary Table 3, only online).

Among non-smokers, EC users had higher odds of having asthma attacks and asthma-related ER visits (Tables 4 and 5). Additionally, participants who obtained their medical advice from hospital ERs showed statistically higher odds of having an asthma attack and asthma-related ER visits. Among current and former smokers, EC use did not significantly affect the odds of having asthma attack and asthma related ER visits. On the other hand, much higher odds of having asthma attack and ER visits were shown in individuals aged in their 20s to 40s showed higher odds (Tables 4 and 5).

DISCUSSION

The purpose of the study was to identify associations between current EC use and having asthma attacks and ER visits. An experience of an asthma attack or ER visits related to asthma can be clinical "red flags" of uncontrolled asthma and act as clinical markers for poor asthma outcomes.[6,7,19-22] Asthma-related ER visits can be avoided with the right management and control, according to studies that have shown improvements in medical care over the past two decades.[23-25] Thus, to describe the influence of EC vaping on asthma, we considered an experience of asthma attack or asthma-related ER visit as a dependent variable. The multiple regression results showed that participants currently using ECs are more likely to have an asthma attack and ER visit. From additional analyses, among smokers, daily smoking amount showed the greatest moderation effect on the association.

First, we found the general characteristics of a population potentially vulnerable to asthma attacks or ER visits due to asthma. In regards to EC use, several similar analyses have shown an association of current EC use with a higher likelihood of suffering from asthma in a variety of study participants.[26,27] The odds of having asthma in other studies were about 1.22 to 1.39, which is similar with this study's result. Supporting physiological mechanisms have been described in other studies.[4,28] However, we were not able to find significantly higher odds of visiting the ER due to asthma in EC users, compared to non-EC users. More complex relationships were observed between EC use and the participants' smoking behaviors and age.

With the rapid increase of EC or electronic vaping product use and an outbreak of vaping product use-associated lung injury (e.g., EVALI), some states in the US started to regulate or prohibit EC use or ban EC sales to minors. According to study figures, cigarette smoking rates were lowered or about the same between 2016 to 2019. The rate of EC use increased significantly in the age groups of 20s and 30s (Supplementary Fig. 1, only online). Additionally, in this study, participants who did not seek medical advice at a hospital ER or with no health insurance were most likely to use ECs, compared to other groups (Supplementary Figs. 2 and 3, only online). These participants share a common characteristic of being a vulnerable population in the healthcare system or society.

Asthma has significant national economic and public health effects across the world. The CDC regularly releases reports on asthma surveillance among minority subgroups using NHIS data, and there is a persistent need to clarify factors linked to unfavorable asthma outcomes, such as hospital readmission or utilization of the ER.[29] One of the main goals of the Healthy People 2020 campaign is to decrease ER visits because of asthma.[30] Adults currently suffering from asthma are more likely to reside in homes with an annual income of less than $15000 dollars (13.3 percent). In 2007, the entire cost of asthma to society was projected to be $56 billion (2009 dollars), comprising medi-

Table 4. Subgroup Analyses of E-Cigarette Use Associated with asthma Attack according to Smoking Status

	Non-smoker	Former smoker	Current smoker
	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)
Current e-cigarette use			
Yes	1.96 (1.34–2.87)	1.08 (0.82–1.43)	1.11 (0.89–1.39)
No	1.00	1.00	1.00
Sex			
Male	1.00	1.00	1.00
Female	2.06 (1.86–2.27)	2.50 (2.18–2.86)	2.16 (1.85–2.53)
Age			
18–29	2.04 (1.72–2.43)	2.73 (1.98–3.78)	3.81 (2.77–5.23)
30–39	1.60 (1.36–1.89)	2.52 (1.98–3.20)	3.41 (2.59–4.49)
40–49	2.04 (1.75–2.37)	2.41 (1.93–3.01)	4.13 (3.24–5.26)
50–59	1.74 (1.52–2.01)	2.43 (2.04–2.90)	2.38 (1.92–2.96)
60s and over	1.00	1.00	1.00
Ethnicity			
Hispanic	0.83 (0.72–0.95)	0.94 (0.74–1.20)	0.90 (0.68–1.19)
Non-hispanic	1.00	1.00	1.00
Race			
White only	1.00	1.00	1.00
Black/African American only	0.94 (0.82–1.07)	1.05 (0.83–1.32)	0.92 (0.74–1.16)
AIAN/Asian only	0.59 (0.48–0.73)	1.47 (1.08–2.00)	1.11 (0.77–1.60)
Other	1.42 (1.17–1.74)	1.25 (0.89–1.75)	1.09 (0.77–1.54)
Insurance type			
No insurance	1.26 (1.07–1.49)	1.41 (1.08–1.82)	1.16 (0.91–1.49)
Private	1.00	1.00	1.00
Public (Medicare, Medicaid, Double eligible, etc.)	1.44 (1.29–1.61)	1.54 (1.32–1.79)	1.67 (1.37–2.03)
Other	1.22 (0.99–1.49)	1.02 (0.78–1.33)	1.20 (0.83–1.74)
Education attainment			
No diploma, High School Graduate	1.00	1.00	1.00
Associate degree only	1.37 (1.23–1.53)	1.33 (1.15–1.54)	1.10 (0.94–1.29)
Bachelor's degree, Graduate Degree, Professional School Degree	1.51 (1.34–1.69)	1.33 (1.13–1.58)	1.02 (0.80–1.30)
Have been working last week			
Yes	0.88 (0.79–0.98)	0.85 (0.72–0.99)	0.66 (0.55–0.78)
No	1.00	1.00	1.00
Marital status			
Married or living with partner	0.83 (0.74–0.94)	1.05 (0.87–1.28)	0.99 (0.81–1.22)
Divorced, separated, widowed	1.01 (0.88–1.16)	0.99 (0.81–1.21)	1.02 (0.83–1.24)
Single, never married	1.00	1.00	1.00
Region			
Northeast	0.81 (0.71–0.93)	1.14 (0.95–1.38)	1.20 (0.94–1.52)
Midwest	0.74 (0.65–0.84)	0.92 (0.77–1.10)	0.87 (0.70–1.08)
South	0.72 (0.65–0.81)	0.84 (0.71–1.00)	0.90 (0.73–1.11)
West	1.00	1.00	1.00
Currently taking prescribed hypertension medications			
Yes	1.18 (1.05–1.32)	1.17 (1.01–1.36)	1.13 (0.95–1.35)
No	1.00	1.00	1.00
Low-dose aspirin medication status			
Yes	1.42 (1.09–1.85)	1.16 (0.84–1.61)	1.37 (0.85–2.19)
No	1.00	1.00	1.00
Diabetes medication status			
Currently taking	1.26 (1.09–1.45)	1.19 (1.00–1.43)	1.26 (1.00–1.58)
DM but not taking meds	1.33 (1.07–1.66)	1.22 (0.93–1.60)	2.01 (1.51–2.69)

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Table 4. Subgroup analyses of E-Cigarette Use Associated with asthma Attack according to Smoking Status (continued)

	Non-smoker	Former smoker	Current smoker
	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)
Never had DM nor taking meds	1.00	1.00	1.00
COPD history			
Yes	9.81 (8.34–11.55)	5.92 (5.07–6.92)	5.54 (4.61–6.65)
No	1.00	1.00	1.00
Body mass index			
Unknown	0.10 (0.07–0.14)	1.80 (1.27–2.56)	1.04 (0.65–1.66)
Underweight	0.97 (0.67–1.41)	1.26 (0.73–2.18)	1.01 (0.64–1.58)
Healthy weight	1.00	1.00	1.00
Overweight	1.28 (1.13–1.44)	1.32 (1.10–1.58)	1.20 (0.99–1.46)
Obese	2.08 (1.85–2.33)	1.93 (1.63–2.30)	1.67 (1.39–2.01)
Have a doctor for medical advice			
Clinic or health center	2.67 (2.11–3.39)	1.57 (1.15–2.15)	1.10 (0.84–1.44)
Doctor's office of HMO	2.92 (2.33–3.66)	1.49 (1.11–2.00)	1.18 (0.92–1.51)
Hospital emergency room	4.13 (2.68–6.38)	1.74 (0.95–3.21)	1.99 (1.30–3.04)
Hospital outpatient department	2.55 (1.58–4.13)	2.03 (1.17–3.51)	1.56 (0.87–2.78)
Others	2.78 (1.83–4.21)	0.78 (0.35–1.74)	1.02 (0.56–1.89)
None	1.00	1.00	1.00
Survey year			
2016	1.00	1.00	1.00
2017	1.37 (1.21–1.54)	1.32 (1.11–1.56)	0.95 (0.78–1.16)
2018	1.16 (1.02–1.31)	1.33 (1.11–1.59)	1.05 (0.85–1.29)
2019	1.18 (1.04–1.34)	1.32 (1.10–1.59)	0.89 (0.71–1.11)

OR, odds ratio; CI, confidence interval; AIAN, American Indian/Alaska Native; DM, diabetes mellitus; COPD, chronic obstructive pulmonary disease; HMO, Health Maintenance Organization.
*All variables in the table were simultaneously adjusted in the logistic regression model.

cal bills ($50.1 billion per year), lost productivity due to missed work and education ($3.8 billion per year), and premature mortality ($2.1 billion per year).[31] Considering the SES indicators of participants, our study showed that participants of low SES status or those who are vulnerable in the healthcare system (i.e., participants with public insurance or participants going to the hospital ER for medical advice) had a higher likelihood of having asthma or visiting the ER for asthma. In addition to these results, young adults had higher odds of having asthma attacks or visiting the ER for asthma. Thus, certain populations, especially EC users, those with higher odds of asthma attacks or ER visits due to asthma, including young adults and those with low SES with limited access to healthcare, may suffer the economic burden associated with asthma.

Our study suggests that among people who smoke a lot, their smoking behavior moderated the odds of EC use, leading to asthma attacks and ER visits. Also, based on subgroup analysis by age groups, participants in their 30s had higher odds than other age groups, except in terms of ER visits, which had the highest odds in the age group of 60s and over. Although the FDA and the US Preventative Service Task Force have both disapproved EC as smoking cessation aids,[32] there are mixed results reporting that ECs can be used as an aid for smoking cessation. According to the National Academies of Sciences, Engineering, and Medicine analysis, using ECs more frequently may enhance a person's chances of quitting smoking.[33] ECs may help individuals stop smoking, according to research published in the New England Journal of Medicine in 2019: when compared to a group utilizing nicotine replacement products, those using ECs as a combustible tobacco substitute were more likely to remain abstinent after a year (18 percent vs. 9.9 percent).[34] Still, the 2020 US Surgeon General's report on smoking cessation suggested that while ECs may assist some adult users reduce their chances of smoking-related diseases if they avoid prolonged dual use, there is considerable evidence to suggest that their use in general would enhance smoking cessation, stating the variable elements of ECs, the various ways in which they are utilized, and a lack of evaluative studies.[35] Another study also reported that using EC as an aid of smoking cessation may instead contribute to continuing nicotine dependence.[36] Thus, whether EC is an aid for smoking cessation or not, it is our study's suggestion that ECs are a threat to public health, particularly among participants with heavy smoking behaviors.

Despite the ban on EC sale to minors, adults still can purchase EC or vaping products and use them, which can lead to secondhand smoke to minors. Secondhand smoking is worrisome, considering smoking age and interaction results. Secondhand inhalation to vapor or aerosol ejected by EC users has the poten-

Table 5. Subgroup Analyses of E-Cigarette Use Associated with Asthma-Related ER Visits according to Smoking Status

	Non-smoker	Former smoker	Current smoker
	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)
Current e-cigarette use			
Yes	1.73 (0.83–3.63)	0.63 (0.33–1.21)	1.24 (0.85–1.80)
No	1.00	1.00	1.00
Sex			
Male	1.00	1.00	1.00
Female	2.24 (1.83–2.75)	2.33 (1.78–3.06)	2.21 (1.68–2.92)
Age			
18–29	2.12 (1.52–2.95)	4.10 (2.24–7.50)	5.46 (3.11–9.60)
30–39	1.54 (1.12–2.13)	4.00 (2.55–6.28)	5.68 (3.50–9.22)
40–49	1.86 (1.39–2.50)	2.46 (1.55–3.89)	5.55 (3.63–8.50)
50–59	1.55 (1.19–2.02)	2.36 (1.68–3.31)	2.68 (1.82–3.96)
60s and over	1.00	1.00	1.00
Ethnicity			
Hispanic	1.36 (1.08–1.71)	1.46 (0.99–2.16)	1.25 (0.81–1.93)
Non-hispanic	1.00	1.00	1.00
Race			
White only	1.00	1.00	1.00
Black/African American only	1.83 (1.47–2.27)	1.65 (1.14–2.39)	1.84 (1.33–2.56)
AIAN/Asian only	0.95 (0.65–1.39)	0.76 (0.33–1.74)	1.22 (0.63–2.36)
Other	1.18 (0.80–1.75)	1.98 (1.20–3.27)	1.74 (1.06–2.86)
Insurance type			
No insurance	1.60 (1.18–2.15)	1.06 (0.61–1.85)	1.41 (0.92–2.16)
Private	1.00	1.00	1.00
Public (Medicare, Medicaid, Double eligible, etc.)	1.85 (1.50–2.28)	2.01 (1.48–2.73)	1.60 (1.12–2.30)
Other	0.92 (0.57–1.48)	1.30 (0.77–2.20)	1.36 (0.70–2.65)
Education attainment			
No diploma, High School Graduate	1.00	1.00	1.00
Associate degree only	1.09 (0.89–1.33)	1.05 (0.80–1.38)	0.97 (0.74–1.27)
Bachelor's degree, Graduate Degree, Professional School Degree	0.96 (0.77–1.21)	0.95 (0.67–1.34)	0.73 (0.45–1.17)
Have been working last week			
Yes	0.83 (0.68–1.02)	0.89 (0.65–1.23)	0.69 (0.50–0.93)
No	1.00	1.00	1.00
Marital status			
Married or living with partner	0.85 (0.67–1.07)	0.82 (0.56–1.19)	0.65 (0.46–0.93)
Divorced, separated, widowed	0.97 (0.76–1.25)	1.08 (0.74–1.57)	0.76 (0.55–1.04)
Single, never married	1.00	1.00	1.00
Region			
Northeast	0.94 (0.72–1.22)	1.12 (0.78–1.61)	1.31 (0.86–2.00)
Midwest	0.75 (0.58–0.98)	0.74 (0.51–1.07)	0.87 (0.59–1.30)
South	0.84 (0.67–1.05)	0.93 (0.67–1.29)	0.89 (0.62–1.29)
West	1.00	1.00	1.00
Currently taking prescribed hypertension medications			
Yes	1.18 (0.95–1.47)	0.93 (0.70–1.24)	1.31 (0.96–1.77)
No	1.00	1.00	1.00
Low-dose aspirin medication status			
Yes	1.24 (0.75–2.05)	1.46 (0.84–2.55)	0.71 (0.25–1.99)
No	1.00	1.00	1.00
Diabetes medication status			
Currently taking	1.22 (0.95–1.57)	1.69 (1.23–2.32)	1.36 (0.94–1.95)
DM but not taking meds	1.22 (0.82–1.82)	1.33 (0.79–2.25)	1.22 (0.70–2.11)

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Table 5. Subgroup Analyses of E-Cigarette Use Associated with Asthma-Related ER Visits according to Smoking Status (continued)

	Non-smoker	Former smoker	Current smoker
	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)	Adjusted OR* (95% CI)
Never had DM nor taking meds	1.00	1.00	1.00
COPD history			
Yes	12.82 (10.04–16.38)	7.13 (5.36–9.48)	8.82 (6.48–12.01)
No	1.00	1.00	1.00
Body mass index			
Unknown	0.12 (0.06–0.23)	1.61 (0.80–3.24)	1.05 (0.47–2.36)
Underweight	1.21 (0.61–2.42)	1.51 (0.59–3.85)	0.84 (0.35–1.98)
Healthy weight	1.00	1.00	1.00
Overweight	1.31 (1.02–1.69)	1.12 (0.78–1.61)	1.25 (0.89–1.76)
Obese	2.55 (2.02–3.22)	1.63 (1.16–2.28)	1.4 (1.07–2.04)
Have a doctor for medical advice			
Clinic or health center	3.52 (2.16–5.73)	1.53 (0.81–2.89)	1.43 (0.87–2.34)
Doctor's office of HMO	3.46 (2.16–5.56)	1.55 (0.86–2.81)	1.36 (0.86–2.15)
Hospital emergency room	6.79 (3.44–13.39)	2.61 (1.02–6.68)	2.70 (1.41–5.17)
Hospital outpatient department	4.14 (1.77–9.67)	2.38 (0.88–6.43)	1.80 (0.68–4.79)
Others	3.70 (1.65–8.29)	0.49 (0.06–3.77)	1.46 (0.54–3.91)
None	1.00	1.00	1.00
Survey year			
2016	1.21 (0.96–1.53)	1.02 (0.73–1.41)	0.74 (0.53–1.03)
2017	1.23 (0.96–1.56)	0.83 (0.58–1.19)	0.95 (0.67–1.33)
2018	1.20 (0.94–1.54)	1.06 (0.75–1.49)	0.74 (0.51–1.08)
2019	1.00	1.00	1.00

ER, emergency room; OR, odds ratio; CI, confidence interval; AIAN, American Indian/Alaska Native; DM, diabetes mellitus; COPD, chronic obstructive pulmonary disease; HMO, Health Maintenance Organization.
*All variables in the table were simultaneously adjusted in the logistic regression model.

tial to be harmful. Inhaling the aerosol or coming in touch with vapor-contaminated surfaces are two ways to get secondhand exposure. Each of the above negative implications of EC availability might result in more diseases and early deaths.[4] Between 2013 and 2017, over 5000 children under the age of 5 years required ER treatment due to e-liquid nicotine exposure.[37]

Several limitations need to be acknowledged. First, self-reports of EC use, asthma attacks, ER visits due to asthma, and amounts of cigarette smoking and smoking days may have resulted in underestimation of the prevalence. Additionally, other clinical-related risk factors for asthma were based on self-reports rather than clinically validated data. Second, since this study was a cross-sectional study, no inferences can be made regarding whether having an experience of asthma attack or visiting the ER due to asthma happened before or after the participant's EC use. Despite these limitations, the study has several important strengths. This study examined the association between EC use and experiencing an asthma attack or ER visit in a large population representative of the US non-institutionalized population. Another strength is that other previous studies have not examined the interaction effect of conventional cigarettes to the association between current EC use and asthma attacks. This study examined the interaction terms of cigarette smoking habits and current EC use.

In conclusion, there are several public concerns to be raised regarding EC use and asthma attacks or ER visits. Although EC use is directly related to EVALI, it can also have an indirect negative impact on other respiratory conditions, such as asthma. A population of young adults, those with heavy smoking behaviors, and those with limited access to healthcare exhibited a higher likelihood of having asthma attacks and ER visits because of asthma upon exposure to ECs. Even though there are certain policies regarding EC use, they are not federal policies, rather state policies that differ state by state. Policies concerning EC use target the general population rather than vulnerable populations. This study calls for more investigation on the reason why EC use is still high among young adults or people with limited healthcare access, as well as ways to lower EC use to prevent its negative impact on others via second-hand smoking.

DATA AVAILABILITY STATEMENT

Data are available in public at NHIS webpage.

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AUTHOR CONTRIBUTIONS

Conceptualization: Seo Yoon Lee and Jaeyong Shin. Data curation: Seo Yoon Lee. Formal analysis: Seo Yoon Lee. Investigation: Seo Yoon Lee and Jaeyong Shin. Methodology: Seo Yoon Lee and Jaeyong Shin. Project administration: Jaeyong Shin. Resources: Seo Yoon Lee. Software: Seo Yoon Lee. Supervision: Jaeyong Shin. Validation: Seo Yoon Lee and Jaeyong Shin. Visualization: Seo Yoon Lee. Writing—original draft: Seo Yoon Lee. Writing—review & editing: Seo Yoon Lee and Jaeyong Shin. Approval of final manuscript: all authors.

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