Electronic Cigarette Prevalence and Patterns of Use in Adults with a History of Cardiovascular Disease in the United States

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Background—Characterizing electronic cigarette (e-cigarette) use patterns is important for guiding tobacco regulatory policy and projecting the future burden of tobacco-related diseases. Few studies have examined patterns of e-cigarette use in individuals with cardiovascular disease (CVD).

Methods and Results—We examined e-cigarette use in adults aged 18 to 89 years with a history of CVD, using data from the 2014 National Health Interview Survey. We investigated associations between ever and current e-cigarette use and smoking with multivariable logistic regression. In a secondary analysis, we modeled the association between e-cigarette use and a quit attempt over the past year. Former smokers with CVD who quit smoking within the past year showed 1.85 (95% confidence interval, 1.03, 3.33) times the odds of having ever used e-cigarettes as compared with those who reported being "some days" current smokers. Current smokers who attempted to quit smoking within the past year showed significantly increased odds of ever having used e-cigarettes (odds ratio, 1.70; 95% confidence interval, 1.25, 2.30) and currently using e-cigarettes (odds ratio, 1.97; 95% confidence interval, 1.32, 2.95) as compared with smokers who had not attempted to quit over the past year.

Conclusions—Individuals with CVD who recently quit smoking or reported a recent quit attempt were significantly more likely to use e-cigarettes than current smokers and those who did not report a quit attempt. Our findings may indicate that this population is using e-cigarettes as an aid to smoking cessation. Characterizing emerging e-cigarette use behaviors in adults with CVD may help to inform outreach activities aimed at this high-risk population. (*J Am Heart Assoc*. 2018;7:e007602. DOI: 10.1161/JAHA.117.007602.)

Key Words: cardiovascular disease • e-cigarettes • epidemiology • smoking • smoking cessation

Despite impressive declines in cardiovascular disease (CVD) mortality over the past half century, CVD remains the leading cause of death in the United States.[1] In 2014, CVD was listed as the underlying cause of death for 807 775 deaths or approximately one third of all deaths that occurred in that year,[2] and recent data indicate that the rate of decline in CVD may be slowing.[3]

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Cigarette smoking is a leading modifiable risk factor for CVD, with cigarette smokers 2 to 4 times more likely to develop CVD than nonsmokers.[4,5] The Centers for Disease Control and Prevention estimates that 33% of all CVD deaths in 2008 among adults older than 35 years could be attributed to smoking.[5] Furthermore, risk of acute myocardial infarction increases with number of cigarettes smoked daily.[6]

Because of this, smoking cessation is a key component of both primary and secondary prevention of CVD.[7] Evidence suggests that quitting smoking is more effective in reducing the risk of mortality for patients with coronary heart disease (≥36% reduction) than other preventive measures, including use of statins (29% reduction), β-blockers (23% reduction), or angiotensin-converting enzyme inhibitors (23% reduction).[8] In addition, smoking cessation reduces the risk of cardiovascular events and deaths for smokers without prior coronary heart disease.[5] Importantly, the excess risk associated with smoking is rapidly reversible; quitting smoking after a myocardial infarction results in a 40% lower hazard of all-cause mortality over 2 years.[9]

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Clinical Perspective

What Is New?

- This study provides estimates of electronic cigarette use patterns in individuals with cardiovascular disease.
- Use of electronic cigarettes was significantly more likely among adults with cardiovascular disease who recently quit smoking or reported a recent quit attempt.

What Are the Clinical Implications?

- The present study suggests that individuals with cardiovascular disease may be using electronic cigarettes as an aid to smoking cessation, underscoring the need for research on the cardiovascular health effects of electronic cigarettes.

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Despite widespread awareness of the harms of cigarette use and the known positive impact of cessation on cardiovascular health, prior studies have reported that almost half of tobacco smokers continued to smoke after cardiovascular events,[10–12] indicating that smoking cessation efforts remain critical to improving health and survival of individuals living with CVD.

While the prevalence of tobacco smoking has declined significantly in the United States,[13] use of electronic cigarettes (e-cigarettes) has increased rapidly since they came on the market in 2007.[14–16] A common perception towards e-cigarettes is that they are potentially useful for assisting people to transition away from more harmful tobacco cigarettes.[14,17] A recent national survey of 5717 adults showed that 22.4% of regular e-cigarette users are former cigarette smokers.[18] However, evidence on their efficacy for smoking cessation remains limited and results so far are inconclusive.[19,20] Furthermore, although evidence to date suggests that e-cigarettes are less harmful than tobacco cigarettes, significant concerns remain regarding their health effects and to what extent they represent a viable harm-reduction strategy.[21]

Prior studies have characterized use of e-cigarettes in the general adult population.[22,23] However, there is currently no evidence on the prevalence or patterns of use of e-cigarettes among those with CVD, despite the fact that individuals with CVD represent a population highly vulnerable to the effects of tobacco use. The objectives of the present study therefore were to assess the prevalence of e-cigarette use in individuals with CVD using nationally representative data on adults in the United States and to characterize patterns of e-cigarette use by tobacco smoking status. We hypothesized that individuals with CVD who recently quit smoking and those who reported recent quit attempts would have higher prevalence of e-cigarette use than those who had not recently quit or reported a quit

attempt, suggestive of the use of e-cigarettes in this population for smoking cessation.

Methods

The data used in this study are available for public use through the Integrated Public Use Microdata Series.[24] We estimated e-cigarette use in adults who had a history of CVD with respect to smoking history status using 2014 data from the National Health Interview Survey (NHIS).[25] The NHIS is a large cross-sectional survey of US adults that has been fielded annually since 1976 and is nationally representative of the US adult population. In 2014, the NHIS adult sample had 36 697 participants. The survey asks extensive questions on demographic, social, and behavioral variables, including smoking status. The NHIS information allows for the establishment of individuals' smoking histories and time since quitting. Beginning in 2014, the NHIS also started asking questions about current and ever e-cigarette use, affording researchers the opportunity to examine behaviors surrounding e-cigarette use in relation to use of tobacco cigarettes and other products.[25]

The current analysis included adults ages 18 years and older who reported a prior diagnosis of CVD, including stroke, coronary heart disease, angina pectoris, or other heart disease, defined as any heart condition or disease excluding heart attack. From a potential 5060 adults with CVD, individuals with missing observations for race/ethnicity (n=7), education (n=28), smoking status (n=8), time since quitting smoking in former smokers (n=15), and e-cigarette use (n=36) were excluded, leaving a total sample size of 4966 respondents who met these criteria and were included in the analysis.

To establish e-cigarette use, the NHIS uses 2 questions: first, to establish ever use, the survey asks "Have you ever used an e-cigarette, even one time?" and second, to establish current use among those reporting ever use, "Do you now use e-cigarettes every day, some days, or not at all?" Those who responded "Yes" to the first question were categorized as ever e-cigarette users, and those that responded "every day" or "some days" to the second question were considered current e-cigarette users.

Individuals were grouped into tobacco smoking status categories dependent on reported smoking history, classified as never smokers, former smokers, current "some days" smokers, and current "every day" smokers. We also categorized former smokers according to time since quitting, grouping together those who quit less than 1 year ago, quit between 1 year and less than 2 years ago, those who had quit smoking between 2 and less than 4 years ago, and those who had quit smoking at least 4 years ago.

We used multivariable logistic regression to examine the association between e-cigarette use and smoking history in adults with CVD. In the primary model, we used ever e-cigarette use as the dependent variable, and in another model we used current e-cigarette use. In both cases, we adjusted for age (specified continuously), sex, race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, other), education (some high school, high school degree, some college, college degree), and region (Northeast, South, Midwest, West). Adjusted odds ratios were generated from the models using current "some days" smokers as the reference category. As our primary interest was in characterizing the association between e-cigarette use and recent cigarette cessation in relation to current cigarette smokers, we adopted the "some days" current smoker category as the reference.

In a secondary analysis, we limited the sample to current smokers (including "some days" and "every day" users) to examine e-cigarette use in individuals who reported an attempt to quit smoking within the past year. We used logistic regression to examine the association between e-cigarette use and quit attempt in adults who were current smokers with CVD. We first ran the model using ever e-cigarette use as the dependent variable, and then substituted current e-cigarette use in a second model. We adjusted for the same covariates used in the primary analysis.

In a final analysis, we examined associations between e-cigarette use and years since quitting among former smokers with CVD. Former smokers were disaggregated into categories of those who quit within the last 2 years, those who quit smoking between 2 and less than 4 years ago, and those who quit 4 or more years ago. For purposes of examining the pattern of e-cigarette use by time since quitting in more detail, the latter category was further disaggregated into those who quit 4 to less than 10 years ago, and those who quit 10 or more years ago. We then implemented a logistic regression model with ever e-cigarette use as the dependent variable and quitting categories as the independent variable, adjusting for sex, age, race/ethnicity, education, and region. The parameters of this model were used to predict probabilities of ever e-cigarette use and current e-cigarette use per category of quitting with 95% confidence intervals (CI).

All analyses were performed using STATA version 14.2 (StataCorp, TX). NHIS data were extracted using the Integrated Health Interview Series.[26] We considered a 2-sided *P* value of <0.05 statistically significant. Institutional review board approval was not required as the study was based on secondary analyses of publicly available, de-identified data.

Results

Table 1 shows descriptive statistics for the population with CVD stratified by e-cigarette use status. In total, 11.0% of individuals with CVD reported that they had ever used e-cigarettes (3.7% current users and 7.2% former users). Compared with never users of e-cigarettes, those who had ever used e-cigarettes were younger, more likely to be non-Hispanic whites, and report some college without completion. With respect to cigarette smoking status, ever e-cigarette users were more likely than never e-cigarette users to be current or recent former smokers and less likely to have been long-time former smokers or never smokers.

Table 2 presents data on exclusive and dual use of tobacco and electronic cigarettes. A majority of the CVD population had a history of either tobacco or e-cigarette use (54.2%). The percentage of individuals with CVD reporting current use of cigarettes (16.6%) and ever use of cigarettes (53.3%) exceeded the corresponding percentages for e-cigarettes of 3.7% and 11.0%. Of individuals with CVD, 2.6% reported current dual use of both tobacco and electronic cigarettes, whereas 1.8% of individuals were former users of both products. Current dual users accounted for 15.9% of current smokers with CVD. The prevalence of current e-cigarette use was higher in current and recent former tobacco smokers compared with those who had quit less recently or had never smoked cigarettes.

Figure shows the prevalence of e-cigarette use among former smokers by the number of years since quitting smoking. Notably, those who quit less than 2 years ago showed much greater percentages of having ever used e-cigarettes (51.3 ± 17.5) compared with those who had quit 2 to less than 4 years ago (20.9 ± 10.5), 4 to less than 10 years ago (11.6 ± 7.5), or more than 10 years ago (1.0 ± 0.6).

Determinants of Ever and Current Use of E-Cigarettes

In the logistic regression examining ever e-cigarette use, former smokers who quit within 1 year had 1.85 (95% CI, 1.03, 3.33) times the odds of ever having tried e-cigarettes, with current "some days" cigarette smokers as the reference (Table 3). Compared with current "some days" smokers, we also observed nonsignificant increased odds of ever e-cigarette use among current daily smokers and former smokers who quit between 1 and 2 years ago. In this model, sex, age, race/ethnicity, and education were significantly associated with having ever used e-cigarettes (Table 3). Females were more likely to have ever used e-cigarettes when compared with males, as were those who were younger. We also found that individuals who reported some college education were more likely to have ever used e-cigarettes when compared with those who reported some high school. Finally, non-Hispanic whites were more likely to have used e-cigarettes than non-Hispanic blacks or Hispanics.

In the additional multivariable logistic regression, age, race/ethnicity, and education were significantly associated with

Table 1. e-Cigarette Use in Adults With CVD, NHIS 2014 (n=4966)

	e-Cigarette Use			
	Never	Former	Current	Ever
All n (%)	4420 (89.0%)	360 (7.2%)	186 (3.7%)	546 (11.0%)
Sex, n (%)				
Men	2078 (47.0%)	163 (45.3%)	85 (47.5%)	248 (45.4%)
Women	2342 (53.0%)	197 (54.7%)	101 (54.3%)	298 (54.6%)
Age, mean±SD	64.8±15.8	49.4±16.3	52.0±15.4	50.3±16.0
Race/ethnicity, n (%)				
Non-Hispanic white	3110 (70.4%)	262 (72.8%)	160 (86.0%)	422 (77.3%)
Non-Hispanic black	625 (14.1%)	33 (9.2%)	11 (5.9%)	44 (8.1%)
Hispanic	431 (9.8%)	29 (8.1%)	11 (5.9%)	40 (7.3%)
Other	254 (5.8%)	36 (10.0%)	4 (2.2%)	40 (7.3%)
Education, n (%)				
Some high school	1039 (23.5%)	91 (25.3%)	49 (26.3%)	140 (25.6%)
High school degree	1095 (24.8%)	84 (23.3%)	39 (21.0%)	123 (22.5%)
Some college	1225 (27.7%)	133 (36.9%)	75 (40.3%)	208 (38.1%)
College degree	1061 (24.0%)	52 (14.4%)	23 (12.4%)	75 (13.7%)
Region, n (%)				
West	1033 (23.4%)	96 (26.7%)	43 (23.1%)	139 (25.5%)
Northeast	769 (17.4%)	49 (13.6%)	23 (12.4%)	72 (13.2%)
South	1651 (37.4%)	115 (31.9%)	68 (36.6%)	183 (33.5%)
Midwest	967 (21.9%)	100 (27.8%)	52 (28.0%)	152 (27.8%)
Cigarette smoking status, n (%)				
Current-daily	373 (8.4%)	192 (53.3%)	111 (59.7%)	303 (55.5%)
Current-some d	90 (2.0%)	38 (10.6%)	20 (10.8%)	58 (10.6%)
Former—quit within 1 y	42 (1.0%)	30 (8.9%)	19 (10.2%)	49 (9.0%)
Former—quit 1 to <2 y	31 (0.7%)	16 (4.4%)	12 (6.5%)	28 (5.1%)
Former—quit 2 to <4 y	87 (2.0%)	13 (3.6%)	10 (5.4%)	23 (4.2%)
Former—quit 4+ y	1523 (34.5%)	32 (8.9%)	6 (3.2%)	38 (7.0%)
Never	2274 (51.5%)	39 (10.8%)	8 (4.3%)	47 (8.6%)
Quit attempt in past y, n (%)*				
Yes	196 (42.3%)	125 (54.35%)	84 (64.1%)	209 (57.9%)
No	267 (57.7%)	105 (45.65%)	47 (35.9%)	152 (42.1%)

CVD indicates cardiovascular disease; e-cigarette, Electronic Cigarette; NHIS, National Health Interview Survey.
*Limited to current cigarette smokers.

current e-cigarette use (Table 3). Unlike for ever use, sex showed no relation to current e-cigarette use. Former smokers who quit within 1 year (odds ratio, 1.56, 95% CI, 0.76, 3.20), and those who quit between 1 and 2 years ago (odds ratio, 1.55, 95% CI, 0.68, 3.54), had higher odds of current e-cigarette use as compared with current "some days" smokers; however, these associations were not statistically significant.

E-Cigarette Use in Current Smokers With a Reported Quit Attempt

In a final analysis using multivariable logistic regression, limiting the analysis to current smokers, we observed increased odds of ever and current e-cigarette use among those who attempted to quit smoking in the past year. Current smokers who had attempted to quit smoking in the

Table 2. Prevalence of e-Cigarette Use and Smoking History in Adults With CVD, NHIS 2014

Smoking History	e-Cigarette Use			
	Never	Former	Current	
Never n (%)	2274 (45.8%)	39 (0.8%)	8 (0.2%)	2321 (46.7%)
Former—quit 4+ y n (%)	1523 (30.7%)	32 (0.6%)	6 (0.1%)	1561 (31.4%)
Former—quit <4 y n (%)	160 (3.2%)	59 (1.2%)	41 (0.8%)	260 (5.2%)
Current n (%)	463 (9.3%)	230 (4.6%)	131 (2.6%)	824 (16.6%)
	4420 (89.0%)	360 (7.2%)	186 (3.7%)	4966

CVD indicates cardiovascular disease; e-cigarette, electronic cigarette; NHIS, National Health Interview Survey.

past year showed 1.70 (95% CI, 1.25, 2.30) times the odds of ever having used e-cigarettes as compared with current smokers who had not attempted to quit smoking in the past year, adjusting for sex, age, race/ethnicity, education, and region (Table 4). We also observed increased odds of current e-cigarette use in those who had attempted to quit within the past year (odds ratio, 1.97; 95% CI, 1.32, 2.95).

Discussion

Several prior studies have characterized e-cigarette prevalence and use patterns in the US adult population.[22,23,27] The current study extends this literature by providing estimates for individuals with a history of CVD, a subpopulation that is highly vulnerable to the effects of tobacco use and one that stands to benefit significantly from smoking cessation efforts. We found the odds of having ever used e-cigarettes was 85% higher in former smokers with CVD who quit smoking within the past year compared with those who reported being "some days" current smokers. The odds of e-cigarette use were also higher among those who attempted to quit smoking within the past year; current smokers who attempted to quit smoking within the past year showed 70% higher odds of ever having used e-cigarettes and 97% higher odds of currently using e-cigarettes as compared with smokers who had not attempted to quit over the past year.

The prevalence of current e-cigarette use in the CVD population (3.7%) was similar to rates in currently working adults aged ≥18 years based on data from the NHIS in 2014
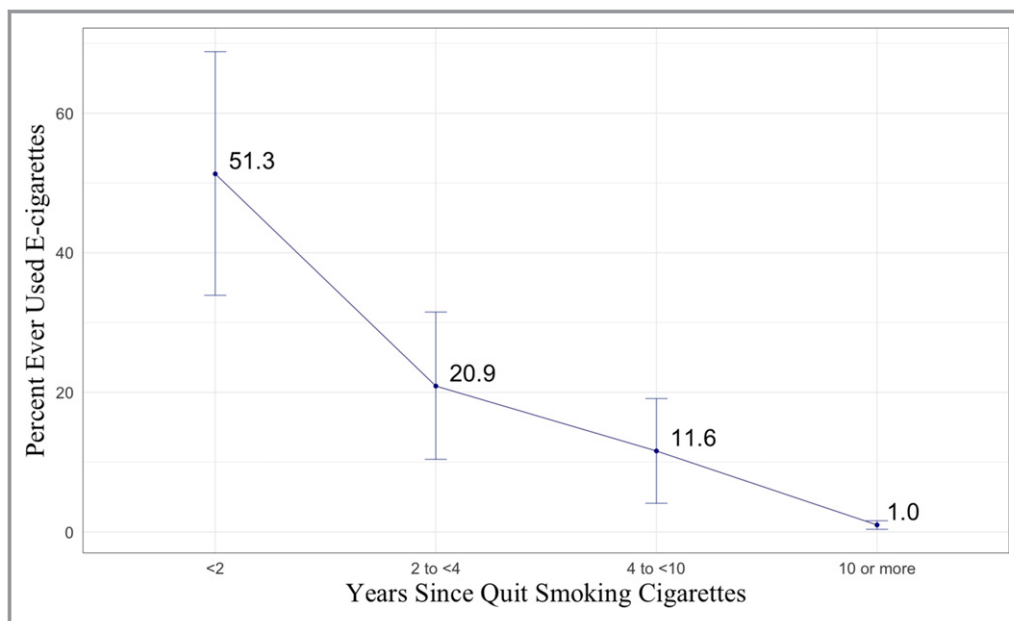

Figure. Percentage of electronic cigarette use among former smokers with CVD, NHIS 2014. CVD indicates cardiovascular disease; NHIS, National Health Interview Survey.

Table 3. Multivariable-Adjusted OR for Ever and Current e-Cigarette Use by Smoking Behavior in Adults With CVD, NHIS 2014

	Ever: e-Cigarette Use			Current: e-Cigarette Use		
	OR	95% CI	*P* Value*	OR	95% CI	*P* Value*
Cigarette smoking status						
Current—some d	1.00	…	<0.001	1.00	…	<0.001
Current—daily	1.31	(0.88, 1.97)		1.17	(0.68, 2.00)	
Former—quit within 1 y	1.85	(1.03, 3.33)		1.56	(0.76, 3.20)	
Former—quit 1 to <2 y	1.54	(0.79, 3.02)		1.55	(0.68, 3.54)	
Former—quit 2 to <4 y	0.43	(0.23, 0.80)		0.63	(0.27, 1.43)	
Former—Quit 4+ y	0.06	(0.03, 0.08)		0.03	(0.01, 0.07)	
Never	0.03	(0.03, 0.04)		0.02	(0.009, 0.05)	
Sex						
Men	1.00	…	0.021	1.00	…	0.309
Women	1.31	(1.04, 1.65)		1.18	(0.856, 1.64)	
Age	0.95	(0.94, 0.96)	<0.001	0.98	(0.97, 0.99)	<0.001
Race/ethnicity						
Non-Hispanic white	1.00	…	<0.001	1.00	…	<0.001
Non-Hispanic black	0.35	(0.24, 0.51)		0.27	(0.17, 0.56)	
Hispanic	0.53	(0.34, 0.82)		0.50	(0.27, 1.00)	
Other	0.80	(0.51, 1.26)		0.19	(0.07, 0.52)	
Education						
Some high school	1.00	…	0.003	1.00	…	0.038
High school degree	1.04	(0.75, 1.44)		0.92	(0.58, 1.45)	
Some college	1.67	(1.23, 2.27)		1.62	(1.07, 2.44)	
College degree	1.27	(0.86, 1.86)		1.12	(0.64, 1.96)	
Region						
West	1.00	…	0.113	1.00	…	0.888
Northeast	0.73	(0.50, 1.07)		0.82	(0.47, 1.45)	
South	0.74	(0.54, 1.02)		0.99	(0.64, 1.54)	
Midwest	0.97	(0.70, 1.35)		1.01	(0.64, 1.60)	

CI indicates confidence interval; CVD, cardiovascular disease; e-cigarette, electronic cigarette; NHIS, National Health Interview Survey; OR, odds ratio.
*Overall *P* value: Wald test.

(3.8%),[27] though the CVD population in our study was considerably older than the general population. We found that 43.8% of current smokers in the CVD population had ever used an e-cigarette. Prior estimates of the general adult population from the NHIS 2014 suggested 47.6% of current smokers had ever used an e-cigarette and that 15.9% currently used e-cigarettes.[28] We observed that 15.9% of current smokers with CVD were dual users (Table 2). Levels of observed dual use could indicate attempts at smoking cessation, reduction, or supplemental use. Moreover, when exploring e-cigarette use among former smokers, our analysis demonstrated that e-cigarettes are not being adopted by established quitters (Figure). By supplanting cigarette use and

not appealing to long-term former smokers, e-cigarettes could provide a viable path to cigarette smoking reduction, or even cessation.

Our analysis found that former smokers who quit within 1 year had 1.85 times the odds of currently using e-cigarettes when compared with current "some days" smokers. This pattern is similar to findings reported in the adult population from the 2014 NHIS,[22] although the difference in the present study is more pronounced. The greater elevation in odds of currently using e-cigarettes among recent quitters could suggest that the population with CVD might be more reliant on e-cigarettes as a smoking cessation tool than the general population. We also observed differences in e-cigarette use

Table 4. Multivariable-Adjusted OR for e-Cigarette Use by Quit Attempt Over the Past Year in Adult Cigarette Smokers With CVD, NHIS 2014

	Ever: e-Cigarette Use			Current: e-Cigarette Use		
	OR	95% CI	P Value*	OR	95% CI	P Value*
Quit attempt in past year						
No	1.00	…	0.001	1.00	…	0.001
Yes	1.70	(1.25, 2.30)		1.97	(1.32, 2.95)	
Sex						
Men	1.00	…	0.076	1.00	…	0.446
Women	1.32	(0.97, 1.78)		1.16	(0.79, 1.72)	
Age	0.96	(0.95, 0.97)	<0.001	0.98	(0.97, 0.99)	0.022
Race/ethnicity						
Non-Hispanic white	1.00	…	<0.001	1.00	…	0.001
Non-Hispanic black	0.33	(0.21, 0.53)		0.36	(0.18, 0.72)	
Hispanic	0.34	(0.18, 0.64)		0.59	(0.26, 1.31)	
Other	0.60	(0.33, 1.10)		0.20	(0.06, 0.67)	
Education						
Some high school	1.00	…	0.013	1.00	…	0.175
High school degree	0.89	(0.60, 1.32)		0.90	(0.52, 1.54)	
Some college	1.66	(1.14, 2.43)		1.47	(0.92, 2.37)	
College degree	1.23	(0.72, 2.11)		1.50	(0.76, 2.94)	
Region						
West	1.00	…	0.074	1.00	…	0.845
Northeast	0.70	(0.41, 1.19)		0.72	(0.35, 1.48)	
South	0.62	(0.41, 0.95)		0.93	(0.54, 1.57)	
Midwest	0.92	(0.59, 1.43)		0.94	(0.54, 1.63)	

CI indicates confidence interval; CVD, cardiovascular disease; e-cigarette, electronic cigarette; NHIS, National Health Interview Survey; OR, odds ratio.
*Overall P value: Wald test.

across education, with those who have some college showing the greatest use, which agrees with findings in prior studies characterizing e-cigarette use.[29]

Furthermore, we found that current smokers in the CVD population who attempted to quit smoking within the past year had 1.70 times the odds of ever having used e-cigarettes and 1.97 times the odds of currently using e-cigarettes as compared with smokers who did not attempt to quit over the past year. The increased likelihood of e-cigarette use among smokers attempting to quit complements a recent analysis of the US Current Population Survey-Tobacco Use Supplement, which demonstrated that e-cigarette users were more likely to attempt to quit smoking (65.1% of e-cigarette users versus 40.1% of nonusers).[30] However, an earlier consumer-based survey found that cigarette smokers who tried e-cigarettes did not differ significantly in their attempts to quit smoking within the past year from those who had never used e-cigarettes,[15] which may indicate that e-cigarettes have become more popular for smoking cessation over time.

Although the evidence on efficacy of e-cigarettes for smoking cessation remains limited and, thus, inconclusive,[19,20] recent data from the Current Population Survey-Tobacco Use Supplement suggest that e-cigarette users in 2014 to 2015 were more likely to attempt to quit smoking tobacco cigarettes and to succeed in quitting than nonusers.[30] Furthermore, population-level trends in cessation rates reveal that the overall rate of smoking cessation in the United States has significantly increased from 2010 to 2011 to 2014 to 2015 alongside a similar rise in e-cigarette use.[30] The higher overall cessation rate found in the 2014 to 2015 Current Population Survey–Tobacco Use Supplement survey reflects a significantly higher cessation rate among those who reported e-cigarette use within the past year than those who did not (8.2% versus 4.8%), suggesting that e-cigarettes may have played a role in increasing smoking cessation in the US population.[30] However, other tobacco control measures including increases in federal and local tobacco taxes and regulations, and national smoking cessation campaigns also may have contributed to improving

the population-level cessation rates; e-cigarettes are unlikely to be the sole explanation for the higher overall cigarette cessation rates in 2014 to 2015.[30]

The potential benefits of e-cigarettes in assisting individuals to transition away from tobacco cigarettes must be balanced with the potential health risks associated with e-cigarette use.[31] Evidence from the few randomized controlled trials conducted to date suggests that e-cigarettes do not appear to have major short-term health effects.[32] However, a recent systematic review of the health effects of e-cigarettes, drawing on evidence from 76 cohort and experimental studies, concluded that e-cigarettes cannot be regarded as harmless.[33] A number of existing studies have significant methodological problems and conflicts of interest,[33] and there have been no studies published on the long-term health effects associated with e-cigarette use, so the true health impact remains unknown.

The impact of e-cigarette use, on cardiovascular health in particular, is of significant interest to individuals with CVD, who stand to benefit immensely from smoking cessation. Several small, short-term studies of the impact of e-cigarette use on cardiovascular health support the harm-reduction strategy of switching from tobacco cigarettes to e-cigarettes.[34,35] While acute cigarette smoking caused a delay in myocardial relaxation among 36 healthy tobacco cigarette smokers, the same effect was not observed after product use in a small sample of 40 e-cigarette users.[34] Another small study (n=23) demonstrated that heart rate, systolic blood pressure, and diastolic blood pressure were significantly elevated after cigarette use but less so after e-cigarette use. The same study found that e-cigarette use was not associated with exhaled carbon monoxide levels, whereas cigarette use resulted in exhaled carbon monoxide more than 8 times above the baseline.[35]

On the contrary, a study of 16 healthy volunteers found that e-cigarette use caused an increase in endothelial progenitor cells of the same magnitude as smoking a traditional cigarette, suggesting possible acute vascular changes after e-cigarette inhalation.[36] Using an e-cigarette has also been shown to decrease flow-mediated dilation, another measure of vascular function, to the same extent as smoking a traditional cigarette.[37] Furthermore, results from a new experimental study using mice presented at a recent cardiovascular conference indicated acute e-cigarette use may reduce vasodilation, and long-term exposure may result in aortic stiffness, which can be an indicator of CVD.[38] E-cigarette use also may increase oxidative stress and reduce heart rate variability, both of which are associated with increased cardiovascular risk.[39] Additional evidence suggests e-cigarette use may result in higher exposure to metals such as copper compared with traditional cigarette smoking.[40] Other components of e-cigarette vapor, including nicotine, acrolein, and other chemicals, could potentially result in cardiovascular harm.[41] Adverse health effects may be exacerbated in dual users who supplement their tobacco use with e-cigarettes. The potential for harm may be of particular concern among dual users within susceptible populations, such as those with CVD. Furthermore, the lack of standardization across brands and product types contributes to uncertainty surrounding chemical exposures. In light of the conflicting evidence, the implications of e-cigarette use on cardiovascular health remain debated.[42,43]

The safety of e-cigarettes and the merits of harm-reduction approaches are contested, but there is general consensus in the scientific community that e-cigarettes are less harmful than traditional tobacco cigarettes.[21,44] However, additional longitudinal research on both the impact of e-cigarette use on cigarette use and safety of e-cigarettes is needed before e-cigarettes can be recommended with confidence for smoking cessation specifically for smokers with CVD or for the general population.

The primary strength of our analysis is that we provide evidence on the previously undescribed patterns of e-cigarette use among individuals with CVD. Additionally, data used in the analysis come from a large, nationally representative survey of the adult population in the United States. However, our study had several limitations. First, our conclusions surrounding e-cigarette use and cigarette cessation in the CVD population are limited by the cross-sectional, observational nature of the study. Longitudinal studies will be necessary to examine the changes in e-cigarette use over time and infer temporality of associations between e-cigarette use and cigarette cessation among those with CVD. Additionally, we cannot exclude the potential for residual confounding by unmeasured confounders, such as motivations for using e-cigarettes, the use of smoking cessation aids, number of quit attempts, intensity of e-cigarette use, recency of CVD diagnosis, and e-cigarette features or brand. Finally, we did not have adequate sample size of individuals with CVD to perform stratified analyses by race/ethnicity or other characteristics.

Taken together, our findings suggest that individuals with CVD may be using e-cigarettes as an aid to smoking cessation. Future outreach activities aimed at this high-risk population would benefit from a better understanding of the beliefs underlying use of e-cigarettes, including perceived harm of e-cigarette use compared with smoking, and the motivations for e-cigarette use, including as an aid to smoking cessation efforts or as a potential reduced-risk tobacco product. Future research should continue to focus on the critical determinations of the relative safety and health effects of e-cigarettes, given that at least a subset of the population is using them to quit smoking cigarettes. In pursuing this research, it is important to consider the net impact that e-cigarettes may have on smoking behavior within susceptible populations, such as those with CVD.

ORIGINAL RESEARCH

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Disclosures

None.

References

1. US Burden of Disease Collaborators. The state of US health, 1990 to 2010: burden of diseases, injuries and risk factors. *JAMA*. 2013;310:591–608.

2. Kochanek KD, Murphy SL, Xu J. Deaths: final data for 2011. *Natl Vital Stat Rep*. 2015;63;1–120.

3. Benjamin E, Blaha M, Chiuve S, Cushman M, Das S, Deo R, de Ferranti S, Floyd J, Fornage M, Gillespie C, Isasi C, Jimenez M, Jordan L, Judd S, Lackland D, Lichtman J, Lisabeth L, Liu S, Longenecker C, Mackey R, Matsushita K, Mozaffarian D, Mussolino M, Nasir K, Neumar R, Palaniappan L, Pandey D, Thiagarajan R, Reeves M, Ritchey M, Rodriguez C, Roth G, Rosamond W, Sasson C, Towfighi A, Tsao C, Turner M, Virani S, Voeks J, Willey J, Wilkins J, Wu J, Alger H, Wong S, Muntner P. Heart disease and stroke statistics–2013 update: a report from the American Heart Association. *Circulation*. 2013;127:e6–e245.

4. United States Department of Health and Human Services. The health consequences of smoking—50 years of progress a report of the surgeon general. *A Rep Surg Gen*. 2014. Available at: https://globalhealth.usc.edu/2014/01/17/the-health-consequences-of-smoking-50-years-of-progress-a-report-of-the-surgeon-general/. Accessed March 14, 2018.

5. U.S. Department of Health and Human Services. How tobacco smoke causes disease: the biology and behavioral basis for smoking-attributable disease. 2010. Available at: https://www.ncbi.nlm.nih.gov/books/NBK53017/. Accessed March 14, 2018.

6. Teo KK, Ounpuu S, Hawken S, Pandey M, Valentin V, Hunt D, Diaz R, Rashed W, Freeman R, Jiang L, Zhang X, Yusuf S. Tobacco use and risk of myocardial infarction in 52 countries in the INTERHEART study: a case-control study. *Lancet*. 2006;368:647–658.

7. Smith SC, Benjamin EJ, Bonow RO, Braun LT, Creager MA, Franklin BA, Gibbons RJ, Grundy SM, Hiratzka LF, Jones DW, Lloyd-Jones DM, Minissian M, Mosca L, Peterson ED, Sacco RL, Spertus J, Stein JH, Taubert KA. AHA/ACCF secondary prevention and risk reduction therapy for patients with coronary and other atherosclerotic vascular disease: 2011 update: a guideline from the American Heart Association and American College of Cardiology Foundation. *Circulation*. 2011;124:2458–2473.

8. Critchley JA, Capewell S. Mortality risk reduction associated with smoking cessation in patients with coronary heart disease: a systematic review. *JAMA*. 2003;290:86–97.

9. Shah AM, Pfeffer MA, Hartley LH, Moye LA, Gersh BJ, Rutherford JD, Lamas GA, Rouleau JL, Braunwald E, Solomon SD. Risk of all-cause mortality, recurrent myocardial infarction, and heart failure hospitalization associated with smoking status following myocardial infarction with left ventricular dysfunction. *Am J Cardiol*. 2010;106:911–916.

10. Gerber Y, Rosen LJ, Goldbourt U, Benyamini Y, Drory Y. Smoking status and long-term survival after first acute myocardial infarction: a population-based cohort study. *J Am Coll Cardiol*. 2009;54:2382–2387.

11. Rea TD, Heckbert SR, Kaplan RC, Smith NL, Lemaitre RN, Psaty BM. Smoking status and risk for recurrent coronary events after myocardial infarction. *Ann Intern Med*. 2002;137:494–500.

12. Quiñones AR, Nagel CL, Newsom JT, Huguet N, Sheridan P, Thielke SM. Racial and ethnic differences in smoking changes after chronic disease diagnosis among middle-aged and older adults in the United States. *BMC Geriatr*. 2017. Available at: https://bmcgeriatr.biomedcentral.com/articles/10.1186/s12877-017-0438-z. Accessed March 14, 2018.

13. Centers for Disease Control and Prevention. Trends in Current Cigarette Smoking Among High School Students and Adults, United States, 1965-2014. Smoking & Tobacco Use.

14. Glasser AM, Collins L, Pearson JL, Abudayyeh H, Niaura RS, Abrams DB, Villanti AC. Overview of electronic nicotine delivery systems: a systematic review. *Am J Prev Med*. 2017;52:e33–e66.

15. Regan AK, Promoff G, Dube SR, Arrazola R. Electronic nicotine delivery systems: adult use and awareness of the "e-cigarette" in the USA. *Tob Control*. 2013;22:19–23.

16. McMillen RC, Gottlieb MA, Whitmore Shaefer RM, Winickoff JP, Klein JD. Trends in electronic cigarette use among U.S. adults: use is increasing in both smokers and nonsmokers. *Nicotine Tob Res*. 2015;17:1195–1202.

17. Bullen C, Howe C, Laugesen M, McRobbie H, Parag V, Williman J, Walker N. Electronic cigarettes for smoking cessation: a randomised controlled trial. *Lancet*. 2013;382:1629–1637.

18. Weaver SR, Majeed BA, Pechacek TF, Nyman AL, Gregory KR, Eriksen MP. Use of electronic nicotine delivery systems and other tobacco products among USA adults, 2014: results from a national survey. *Int J Public Health*. 2016;61:177–188.

19. Orellana-Barrios MA, Payne D, Medrano-Juarez RM, Yang S, Nugent K. Electronic cigarettes for smoking cessation. *Am J Med Sci*. 2016;352:420–426.

20. Hajek P. Electronic cigarettes for smoking cessation. *Lancet*. 2013;382:1614–1616.

21. Cahn Z, Siegel M. Electronic cigarettes as a harm reduction strategy for tobacco control: a step forward or a repeat of past mistakes? *J Public Health Policy*. 2011;32:16–31.

22. Delnevo CD, Giovenco DP, Steinberg MB, Villanti AC, Pearson JL, Niaura RS, Abrams DB. Patterns of electronic cigarette use among adults in the United States. *Nicotine Tob Res*. 2015;18:715–719.

23. Wilson FA, Wang Y. Recent findings on the prevalence of e-cigarette use among adults in the U.S. *Am J Prev Med*. 2017;52:385–390.

24. IPUMS-USA. IPUMS health surveys. Available at: https://nhis.ipums.org/nhis/. Accessed February 20, 2018.

25. Parsons VL, Moriarity C, Jonas K, Moore TF, Davis KE, Tompkins L. Design and estimation for the national health interview, 2006–2015. National Center for Health Statistics. *Vital Heal Stat 2*. 2014;2:1–53.

26. Blewett LA, Rivera Drew JA, Griffin R, King ML, Williams K. *IPUMS Health Surveys: National Health Interview Survey, Version 6.2*. Minneapolis: University of Minnesota; 2016.

27. Syamlal G, Jamal A, King BA, Mazurek JM. Electronic cigarette use among working adults—United States, 2014. *Morb Mortal Wkly Rep*. 2016;65:557–561.

28. Schoenborn C, Gindi R. Electronic cigarette use among adults: United States, 2014. *NCHS Data Brief*. 2015;217:1–7.

29. Coleman BN, Rostron B, Johnson SE, Ambrose BK, Pearson J, Stanton CA, Wang B, Delnevo C, Bansal-travers M, Kimmel HL, Goniewicz ML, Niaura R, Abrams D, Conway KP, Borek N, Compton WM, Hyland A. Electronic cigarette use among US adults in the Population Assessment of Tobacco and Health (PATH) Study, 2013–2014. *Tob Control*. 2017;26:e117–e126.

30. Zhu S-H, Zhuang Y-L, Wong S, Cummins SE, Tedeschi GJ. E-cigarette use and associated changes in population smoking cessation: evidence from US current population surveys. *BMJ*. 2017;358:1–8.

31. Qasim H, Karim ZA, Rivera JO, Khasawneh FT, Alshbool FZ. Impact of electronic cigarettes on the cardiovascular system. *J Am Heart Assoc*. 2017;6: e006353. DOI: 10.1161/JAHA.117.006353.

32. Hartmann-Boyce J, McRobbie H, Bullen C, Begh R, Stead L, Hajek P. Electronic cigarettes for smoking cessation (Review). *Cochrane Database Syst Rev*. 2016. doi:10.1002/14651858.CD010216.pub3.

33. Pisinger C, Dossing M. A systematic review of health effects of electronic cigarettes. *Prev Med*. 2014;69:248–260.

34. Farsalinos KE, Tsiapras D, Kyrzopoulos S, Savvopoulou M, Voudris V. Acute effects of using an electronic nicotine-delivery device (electronic cigarette) on myocardial function: comparison with the effects of regular cigarettes. *BMC Cardiovasc Disord*. 2014;14:78.

35. Yan XS, D'Ruiz C. Effects of using electronic cigarettes on nicotine delivery and cardiovascular function in comparison with regular cigarettes. *Regul Toxicol Pharmacol*. 2015;71:24–34.

36. Antoniewicz L, Bosson JA, Kuhl J, Abdel-Halim SM, Kiessling A, Mobarrez F, Lundbäck M. Electronic cigarettes increase endothelial progenitor cells in the blood of healthy volunteers. *Atherosclerosis*. 2016;255:179–185.

37. Carnevale R, Sciarretta S, Violi F, Nocella C, Loffredo L, Perri L, Peruzzi M, Marullo AGM, De Falco E, Chimenti I, Valenti V, Biondi-Zoccai G, Frati G. Acute impact of tobacco vs electronic cigarette smoking on oxidative stress and vascular function. *Chest*. 2016;150:606–612.

38. Olfert M. Acute and chronic effects of e-cigarette vapor exposure on vascular function: new friend or old foe? *Cardiovascular Aging: New Frontiers and Old*

Friends. 2017. Available at: http://www.the-aps.org/mm/Conferences/APS-Conferences/2017-Conferences/CV-Aging/Schedule/Program-of-Symposia.PDF. Accessed March 14, 2018.

39. Moheimani R, Bhetraratana M, Yin F, Peters K, Gorbein J, Araujo J, Middlekauff H. Increased cardiac sympathetic activity and oxidative stress in habitual electronic cigarette users: implications for cardiovascular risk. *JAMA Cardiol*. 2017;2:278–284.

40. Lerner CA, Sundar IK, Watson RM, Elder A, Jones R, Done D, Kurtzman R, Ossip DJ, Robinson R, McIntosh S, Rahman I. Environmental health hazards of e-cigarettes and their components: oxidants and copper in e-cigarette aerosols. *Environ Pollut*. 2015;198:100–107.

41. Bhatnagar A, Whitsel LP, Ribisl KM, Bullen C, Chaloupka F, Piano MR, Robertson RM, McAuley T, Goff D, Benowitz N. Electronic cigarettes: a policy statement from the American Heart Association. *Circulation*. 2014;130:1418–1436.

42. Bhatnagar A. Cardiovascular perspective of the promises and perils of e-cigarettes. *Circ Res*. 2016;118:1872–1875.

43. Benowitz NL, Fraiman JB. Cardiovascular effects of electronic cigarettes. *Nat Rev Cardiol*. 2017;14:447–456.

44. Gornall J. Why e-cigarettes are dividing the public health community. *Br Med J*. 2015;350:h3317.