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Hypertension and Cardiovascular Diseases among Electronic and Combustible Cigarette Users

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ABSTRACT

Introduction. Combustible cigarette use is associated with an increased risk of several cardiovascular diseases; however, less is known about associations between these cardiovascular conditions and electronic cigarette use.

Methods. This study investigated relationships between electronic and/or combustible cigarette use and diagnoses of cardiovascular diseases using the National Health Interview Survey from 2014, 2016, 2017, and 2018.

Results. Compared to non-users, dual users of electronic and combustible cigarettes had increased likelihood of having prior diagnoses of hypertension (OR 1.660, 95% CI = 1.519-1.814), stroke (OR 2.396, 95% CI = 2.011-2.855), diabetes mellitus (OR 1.219, 95% CI = 1.108-1.341), coronary artery disease (OR 2.211, 95% CI = 1.837-2.660), and myocardial infarction (OR 3.839, 95% CI = 3.232-4.560). Exclusive use of electronic cigarettes was associated with an increased likelihood of having hypertension compared to non-users (OR 1.244, 95% CI = 1.048-1.477).

Conclusions. There were no differences in diagnoses of stroke, diabetes mellitus, coronary artery disease, or myocardial infarction among exclusive electronic cigarette users compared to non-users; however, these associations could change as young electronic cigarette users with hypertension age, indicating the need for continued research.

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INTRODUCTION

Cardiovascular diseases (CVDs), including myocardial infarction (MI) and stroke, accounted for more than 600,000 deaths among U.S. adults in 2017.[1] Many factors contribute to one's risk for developing CVDs, including tobacco use, hypertension, hyperlipidemia, diabetes mellitus (DM), and body mass index (BMI).[2-7] Controlling these modifiable risk factors decreases the development of CVDs and subsequent mortality. Although it has long been established that combustible cigarette use increases the risk of CVDs and some cardiovascular risk factors, such as hypertension,[2-4] the advent of electronic cigarettes (e-cigarettes) has brought new concerns to preventing and managing CVDs.

E-cigarettes, first introduced in 2006,[5] had an estimated 8.1 million U.S. adult users in 2018.[6] E-cigarettes offer an alternative to traditional combustible tobacco for nicotine delivery.[7] However, preliminary data indicated that e-cigarettes increased one's risk for the development of CVDs. For example, when compared to non-users, dual users of combustible and e-cigarettes have been associated with higher odds of MI, stroke, and coronary artery disease (CAD) than combustible cigarette users.[8,9] However, much is still unknown about e-cigarette use and cardiovascular risk, especially as the age of e-cigarette users has changed. Therefore, the purpose of this study was to investigate relationships between e-cigarette use, combustible cigarette use, and dual use of combustible and e-cigarettes and diagnoses of hypertension, stroke, CAD, DM, or MI.

METHODS

Study Population. Participants 18 years or older were included in this study if they completed the National Health Interview Survey (NHIS) tobacco use questionnaire in 2014, 2016, 2017, or 2018. Participants were categorized by their combustible and/or e-cigarette use based on their responses to the NHIS questions. Participants who did not complete all questions in a relevant section of the survey were excluded.

Measures. This study was conducted using the NHIS data from the years 2014, 2016, 2017, and 2018. These years were chosen due to similar coding of the e-cigarette use in the NHIS data. Administered in all 50 states by the U.S. Centers for Disease Control and Prevention as a household interview survey, the goal of the NHIS is to monitor a variety of diseases and health related concerns in the U.S., including tobacco use.[10] Because the NHIS is a de-identified database, IRB approval was not needed.

Participants were stratified into one of six groups based on their self-reported current or former use of combustible and e-cigarettes. The groups included: 1) current e-cigarette users, 2) current combustible cigarette users, 3) former combustible cigarette users currently using e-cigarettes, 4) former combustible cigarette users not currently using e-cigarettes, 5) current users of both combustible and e-cigarettes (referred to as dual users), and 6) never users of combustible or e-cigarettes (referred to as non-users). Those who reported using e-cigarettes every day or some days were identified as current e-cigarette users. Those who reported they had never used an e-cigarette, even one time, were considered non-users of e-cigarettes. Those who reported they had smoked at least 100 cigarettes in their entire lives were identified as combustible cigarette users; those who reported they had not smoked at least 100 cigarettes in their entire lives were considered non-users of combustible cigarettes.

Combustible cigarette users were stratified into current and former users; those who reported using combustible cigarettes every day or some days were considered current users of combustible cigarettes, and those who reported not at all were considered former users of combustible cigarettes. Former combustible cigarette users were stratified further into current and non-e-cigarette users based on their answers to the e-cigarette user questions. Participants who were non-users of combustible and e-cigarettes served as the comparison group for analyses.

Participants were evaluated for the presence or absence of a variety of CVDs based on their survey responses. Participants were considered

to have been diagnosed with hypertension, stroke, DM, CAD, or MI if they reported they had ever been told by a doctor or other health professional that they had hypertension (also called high blood pressure), stroke, diabetes or sugar diabetes (other than during pregnancy), CAD, or MI, respectively. Potential confounding variables included: sex, BMI, and age[11-14] and these were controlled for in each analysis.

Statistical Analysis. Data were analyzed using SAS version 9.4 (SAS Inst. Inc. Cary, NC). Since NHIS data are obtained through a complex, multistage sample design that involves stratification, clustering, and oversampling of specific population subgroups, survey procedures in SAS were used to handle problems such as oversampling, weighting, stratification, or clustering for the data from population-based representative surveys. Rao-Scott chi-square goodness-of-fit tests with Taylor series method to calculate the variance was used for the design-adjusted tests of independence, or no association, between the nominal and/or categorical variables. Generalized multiple linear logistic models applied to test the association between the outcome variables and smoking status (e-cigarette use and combustible cigarette use) after adjusting for confounding variables such as sex, BMI, and age. The maximum likelihood parameter estimates implemented for the multiple logistic regression with SURVEYLOGISTIC in SAS to incorporate complex survey sample designs, including designs with stratification, clustering, and unequal weighting. This procedure utilizes Taylor series linearization methods for NHIS variance estimation to avoid increasing the Type I error. Data were reported as frequencies, means, standard deviations, and other summary statistics. All statistical tests at $p \leq 0.05$ were considered significant.

RESULTS

A total of 121,884 people completed the NHIS survey in 2014, 2016, 2017, and 2018. Of the 84,553 respondents meeting the inclusion and exclusion criteria for this study, 3.1% (n = 2,619) were current e-cigarette users, 7.6% (n = 6,459) were current combustible cigarette users, 3.7% (n = 3,169) were former combustible cigarette users currently using e-cigarettes, 21.0% (n = 17,788) were former combustible cigarette users not currently using e-cigarettes, 7.8% (n = 6,581) were dual users, and 56.7% (n = 47,937) were non-users.

Dual users were 1.660 times more likely (95% CI = 1.519-1.814) than non-users to have been diagnosed with hypertension. Compared to non-users, combustible cigarette users were 1.384 (95% CI = 1.277-1.499) times more likely, and e-cigarette users were 1.244 (95% CI = 1.048-1.477) times more likely to have been diagnosed with hypertension. Former combustible cigarette users currently using e-cigarettes were 1.308 (95% CI = 1.162-1.472) times more likely, and former combustible cigarette users not using e-cigarettes were 1.139 (95% CI = 1.082-1.198) times more likely to have been diagnosed with hypertension compared to non-users. Males were 1.252 (95% CI = 1.196-1.309) times more likely to have been diagnosed with hypertension than females. Increasing BMI by one kilogram/meter squared (kg/m^2) was associated with 1.103 (95% CI = 1.098-1.107) times the odds and increasing age by one year was associated with 1.070 (95% CI = 1.068-1.072) times increased odds of hypertension diagnosis (Table 1).

Dual users were 2.396 (95% CI = 2.011-2.855) times more likely to have had a stroke compared to non-users. Current combustible cigarette users were 2.114 (95% CI = 1.815-2.463) times more likely to have had a stroke than non-users. There was no difference in stroke occurrence among e-cigarette users compared to non-users; however, former combustible cigarette users currently using e-cigarettes were 1.652 (95% CI = 1.245-2.191) times more likely to have had a stroke compared to non-users. Males were 1.114 (95% CI = 1.014-1.224) times more likely to have had a stroke than females. Increasing BMI by one kg/m^2 was associated with 1.032 (95% CI = 1.024-1.040) times increased likelihood, and increased age by one year was associated with 1.067 (95%; CI = 1.063-1.070) times increased likelihood of a prior stroke (Table 1).

Compared to non-users, dual users were 1.219 (95% CI = 1.108-1.341) times more likely, and combustible tobacco users were 1.141 (95% CI = 1.023-1.274) times more likely to have been diagnosed with DM. There was no difference between non-users and e-cigarette users or former combustible cigarette users using e-cigarettes regarding likelihood of having been diagnosed with DM. Former combustible cigarette users not using e-cigarettes were 1.083 (95% CI = 1.010-1.162) times more likely to have been diagnosed with DM compared to non-users. Males were 1.124 times more likely to have been diagnosed with DM than females (95% CI = 1.067-1.183). Increased BMI and increased age also increased the likelihood of DM diagnosis (Table 1).

Compared to non-users, dual users were 2.211 (95% CI = 1.837-2.660) times more likely, and combustible cigarette users were 1.962 (95% CI = 1.611-2.151) times more likely to have been diagnosed with CAD. There was no difference in CAD occurrence between e-cigarette users and non-users. Compared to non-users, former combustible cigarette users currently using e-cigarettes were 2.278 (95% CI = 1.791-2.898) times more likely, and former combustible cigarette users not using e-cigarettes were 1.531 (95% CI = 1.402-1.672) times more likely to have been diagnosed with CAD. Males were 1.973 (95% CI = 1.817-2.143) times more likely to have been diagnosed with CAD than females. Increasing BMI by one kg/m2 was associated with 1.047 (95% CI = 1.040-1.054) times increased likelihood and increasing age by one year was associated with 1.086 (95% CI = 1.082-1.090) times increased likelihood of CAD diagnosis (Table 1).

Dual users were 3.839 (95% CI = 3.232-4.560) times more likely to have had a MI compared to non-users. Combustible cigarette users were 2.836 (95% CI = 2.442-3.294) times more likely to have had a MI compared to non-users. There was no difference in likelihood of MI occurrence between non-users and e-cigarette users. Compared to non-users, former combustible cigarette users currently using e-cigarettes were 2.448 (95% CI = 1.880-3.189) times more likely, and former combustible cigarette users not currently using e-cigarettes were 1.752 (95% CI = 1.576-1.947) times more likely to have had a MI. Males were 2.142 (95% CI = 1.946-2.359) times more likely to have had a MI compared to females. Increasing BMI by one kg/m^2 was associated with 1.041 (95% CI = 1.034-1.048) times increased likelihood and increasing age by one year was associated with 1.077 (95% CI = 1.073-1.081) times increased likelihood of a prior MI (Table 1).

Table 1. Condition among e-cigarette and/or combustible cigarette users compared to non-users.

Group	Hypertension Odds Ratio (95% CI)	Stroke Odds Ratio (95% CI)	Diabetes Mellitus Odds Ratio (95% CI)	Coronary Artery Disease Odds Ratio (95% CI)	Myocardial Infarction Odds Ratio (95% CI)
E-Cigarette Only Users	1.244 (1.048-1.477)*	1.058 (0.586-1.911)	1.108 (0.972-1.263)	0.856 (0.519-1.412)	0.984 (0.555-1.747)
Combustible Cigarette Only Users	1.384 (1.277-1.499)*	2.114 (1.815-2.463)*	1.141 (1.023-1.274)*	1.862 (1.611-2.151)*	2.836 (2.442-3.294)*
Former Combustible Cigarette Users Currently Using E-Cigarettes	1.308 (1.162-1.472)*	1.652 (1.245-2.191)*	0.952 (0.831-1.091)	2.278 (1.791-2.898)*	2.448 (1.880-3.189)*
Former Combustible Cigarette Users Not Currently Using E-Cigarettes	1.139 (1.082-1.198)*	1.287 (1.151-1.436)*	1.083 (1.010-1.162)*	1.531 (1.402-1.672)*	1.752 (1.576-1.947)*
Dual Users of E-Cigarettes and Combustible Cigarettes	1.660 (1.519-1.814)*	2.396 (2.011-2.855)*	1.219 (1.108-1.341)*	2.211 (1.837-2.660)*	3.839 (3.232-4.560)*
Sex (males compared to females)	1.252 (1.196-1.309)*	1.114 (1.014-1.224)*	1.124 (1.067-1.183)*	1.973 (1.817-2.143)*	2.142 (1.946-2.359)*
Body Mass Index	1.103 (1.098-1.107)*	1.032 (1.024-1.040)*	1.056 (1.055-1.183)*	1.047 (1.040-1.054)*	1.041 (1.034-1.048)*
Age	1.070 (1.068-1.072)*	1.067 (1.063-1.070)*	1.030 (1.029-1.032)*	1.086 (1.082-1.090)*	1.077 (1.073-1.081)*

*Indicates significant difference.

DISCUSSION

The current study suggested that e-cigarette use, whether alone or combined with concurrent combustible cigarette use, increased the likelihood of a person being diagnosed with hypertension. Several small studies have evaluated the short-term effects of e-cigarette use on blood pressure with mixed findings;[15] however, this was the first large-scale study to analyze the prevalence of hypertension among e-cigarette users compared to non-users, while also analyzing hypertension among current and former combustible cigarette users. Due to the variability of ingredients in e-cigarettes,[16,17] it is difficult to pinpoint a common underlying component in both combustible and e-cigarettes that could be contributing to the increased occurrence of hypertension among combustible and e-cigarette users in the current study. However, because most e-cigarettes contain nicotine,[17] a sympathetic nervous system stimulant[7] and a component of combustible cigarettes,[18] the results of the current study could suggest that the consumption of nicotine in any form, including e-cigarettes, increases the chance of a person developing hypertension. Regardless of exactly which ingredient(s) of combustible and e-cigarettes contribute to the increased occurrence of hypertension observed among users in the current analysis, these results indicated a need for public health action, as hypertension is a major risk factor for stroke,[19] CAD,[19] and MI.[20,21]

Compared to non-users, dual users had more than twice the likelihood of previously having a stroke. Combustible cigarette users, both current and former, also had increased likelihood of having a stroke compared to non-users. However, e-cigarette users did not demonstrate an increased likelihood of stroke compared to non-users, which supported previous findings.[9,22] Prior research identified an increased likelihood of CVDs (stroke, CAD, and MI) among dual users compared to non-users, but no difference between e-cigarette users and non-users.[9,22] However, one previous study did not evaluate each CVD individually,[9] as did the current analysis. Another previous study identified the control group as individuals who previously had tried e-cigarettes but were not current e-cigarette users,[22] rather than the current study's control group who had never used combustible or e-cigarettes. The lack of an association between e-cigarette use and stroke occurrence in the current analysis could be due to differences in age between combustible and e-cigarette users. E-cigarette users tended to be younger; more than 85% of e-cigarette users who have never smoked combustible cigarettes were younger than 35 years.[23] Most combustible cigarette users, on the other hand, were 45 to 64 years.[24] Because stroke risk was greater among older individuals,[25] it was possible that the younger age of e-cigarette users in the current analysis was protective against stroke. Additionally, older individuals were more likely to have been diagnosed with conditions that are predisposed to stroke, like hypertension,[26] and an increased duration of uncontrolled hypertension increases one's risk for having a stroke.[27] Therefore, the currently young population of e-cigarette users, who were more likely to have hypertension than non-users based on the current analysis, could go on to experience a greater frequency of strokes than non-users. Continued monitoring of stroke occurrence among e-cigarette users is needed to observe if the findings of the current study change as e-cigarette users age.

In addition to hypertension, DM was another stroke risk factor.[28,29] The current analysis was the first large study to analyze associations between e-cigarette use and diagnoses of DM while adding analyses of DM among current and former combustible cigarette users. Compared to non-users in the current analysis, dual users, combustible cigarette users, and former combustible cigarette users not currently using

e-cigarettes were more likely to have been diagnosed with DM. However, when compared to non-users, there was no difference in association between having a prior diagnosis of DM and e-cigarette use, nor former combustible cigarette use with current e-cigarette use. The lack of association between former combustible cigarette users currently using e-cigarettes and DM diagnosis was unique from the trends observed for the other CVDs analyzed in the current study, where a lack of association generally occurred among e-cigarette users when compared to non-users. This could be due to potential differences in weight gain after cessation of combustible cigarettes, as individuals who stop using combustible cigarettes were most likely to experience weight gain and be diagnosed with DM within seven years of cessation.[30] If, in fact, the cessation of nicotine, generally present in both combustible and e-cigarettes, was associated with weight gain and increased risk of DM development, then use of e-cigarettes among former combustible cigarette users potentially could explain these study findings. More research is needed to understand the associations between DM occurrence, combustible cigarette cessation, and e-cigarette use.

DM is a risk factor for CAD,[31] and the current analysis investigated associations between diagnoses of CAD and combustible and e-cigarette use. Compared to non-users, dual users and former combustible cigarette users currently using e-cigarettes were twice as likely to have been diagnosed with CAD. Although there were increased odds of CAD among current combustible cigarette users and former combustible cigarette users not using e-cigarettes compared to non-users, there was no difference in the likelihood of CAD among e-cigarette users compared to non-users. These findings supported previous research.[9,22] However, the current study was unique from previous research in its separate evaluation of CAD[9] and its control group that included respondents who never used combustible or e-cigarettes.[22] Similar to stroke, the lack of association between CAD and e-cigarette use in the current analysis could be related to age differences between combustible and e-cigarette users. CAD was most prevalent among older adults, affecting 19.8% of adults older than 65 years compared to 1.2% of adults 18 to 44 years;[32] however, most e-cigarette users were younger than 35 years.[23] Thus, as e-cigarette users age and as hypertension, a risk factor for CAD,[33] progresses in this group, it is possible that the occurrence of CAD among e-cigarette users will change. Because CAD was a risk factor for MI,[19] continued monitoring for the development of CAD among e-cigarette users is warranted.

MI occurrence has been analyzed previously among e-cigarette users,[8,9,22] and the current analysis built upon these findings from 2014 and 2016.[8] In the current analysis, compared to non-users, dual users were 3.839 times more likely to have had a MI, which was slightly lower than the 4.62 times increased odds of MI calculated among dual users in prior research.[8] Additionally, the current analysis suggested that, when compared to non-users, former combustible cigarette users currently using e-cigarettes were 2.448 times more likely to have had a MI, while former combustible cigarette users not currently using e-cigarettes were 1.752 times more likely to have experienced a MI. This was consistent with previous estimates that, when compared to non-users, the odds of MI were greater among former combustible cigarette users currently using e-cigarettes than among former combustible cigarette users not using e-cigarettes.[8] Unlike previous research,[8] the current analysis did not identify an association between exclusive e-cigarette consumption and likelihood of experiencing a MI compared to non-users. This could be due to differences in how analyses were conducted, as the previous study stratified e-cigarette users by daily and non-daily consumption in an adjusted model.[8] Alternatively, these findings could be due to changes in e-cigarette consumption trends in the U.S. in 2017 and 2018. E-cigarette use increased 2.4% among adults 18 to 24 years in the U.S. from 2017 to 2018, while e-cigarette use among adults 45 or older decreased.[34] Thus, because e-cigarette users tend to over-represent younger generations, who are less likely to experience a MI based on age alone, it was possible that the differences observed between the current analysis and the former study[8] could reflect these changing trends in e-cigarette use. More research is needed to understand the effects of exclusive e-cigarette use on cardiovascular health better, including MI.

Limitations. The results of this study relied on survey responses, which were affected by recall and non-response biases.[35] Additionally, e-cigarettes have been available commercially in the U.S. for 15 years,[5] limiting the time for long-term observation on the association of e-cigarette use and chronic health conditions. However, the limited knowledge of the long-term effects of e-cigarettes on CVDs validated the need for the current and future analyses.

CONCLUSIONS

The analyses of each cardiovascular condition in the current study suggested that, compared to non-users, dual users of combustible and e-cigarettes had the greatest likelihood of reporting having been diagnosed with hypertension, stroke, DM, CAD, and MI. The current analysis extended previous research findings regarding associations between e-cigarette use and these CVDs. The increased occurrence of hypertension observed among all forms of e-cigarette use was concerning for future development of CVDs among the generally young population of e-cigarette users. The findings of this study indicated that e-cigarettes were not a cardiovascular risk-free alternative to combustible cigarettes.

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