Healthcare utilisation and expenditures attributable to current e-cigarette use among US adults

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ABSTRACT

Aims This study estimated annual healthcare expenditures attributable to current e-cigarette use among US adults, including current exclusive and dual/poly e-cigarette use.

Methods Analysing the 2015–2018 National Health Interview Survey data, we estimated the impacts of e-cigarette use on healthcare utilisation among adults aged 18+ years. Healthcare utilisation outcomes were hospital nights, emergency room (ER) visits, doctor visits and home visits. Current e-cigarette use was categorised as exclusive and dual/poly e-cigarette use. The econometric model included two equations: health status as a function of e-cigarette use and other independent variables, and healthcare utilisation as a function of health status, e-cigarette use, and other independent variables. Using an 'excess utilisation' approach, we multiplied the e-cigarette-attributable fraction derived from the model by annual health expenditures to calculate healthcare expenditures attributable to current exclusive and dual/poly e-cigarette use, the sum of which were expenditures attributable to all current e-cigarette use.

Results Current exclusive and dual/poly e-cigarette use, with 0.2% and 3.5% prevalence in 2015–2018, were associated with higher odds of reporting poor health status than never tobacco users. Poor health status was associated with higher odds of using the four healthcare services and a greater number of ER and doctor visits. Annual healthcare expenditures attributable to all current e-cigarette use was $15.1 billion ($2024 per user) in 2018, including $1.3 billion attributable to exclusive e-cigarette use ($1796 per user) and $13.8 billion attributable to dual/poly e-cigarette use ($2050 per user).

Conclusion Adult current e-cigarette use was associated with substantial excess healthcare utilisation and expenditures.

INTRODUCTION

Electronic cigarettes have become increasingly popular since introduced in the US market, especially among youth and young adults. In addition to being very popular among middle school and high school students, young adults aged 18–24 years are also using e-cigarettes at increasing rates. Current e-cigarette use among young adults increased from 2.4% to 7.6% in 2012–2018.[1] E-cigarette prevalence among all adults remained stable and was 3.2% in 2018.[2]

The 2016 US Surgeon General's report comprehensively reviewed the public health risks of e-cigarette use among youth and young adults, and concluded that e-cigarettes can expose users to many chemicals known to have adverse health effects (eg, nicotine, carbonyl compounds and volatile organic compounds).[3] Since then, there has been a growing literature examining the negative health impacts of e-cigarette use, including health risks for respiratory health,[4–12] cardiovascular health,[13–15] oral health[16 17] and cancer.[18] In addition to adverse health effects, e-cigarette use can also result in unintended injuries and burns.[19] Intentional or accidental exposure to e-liquids can result in seizures, anoxic brain injury, vomiting and lactic acidosis; and drinking or injecting e-liquids can be fatal.[19] One of the consequences of these health risks and injuries associated with e-cigarette use is increased healthcare utilisation and expenditures.

Although we have a good understanding of the impacts of cigarettes and other tobacco products on healthcare expenditures,[20–22] no studies have examined the effects of e-cigarette use on healthcare utilisation and expenditures. The objective of this study is to estimate healthcare utilisation and expenditures attributable to current e-cigarette use for US adults aged 18+ years. Given that many adult current e-cigarette users have also used other tobacco products,[2 23] we will provide separate estimates for annual healthcare expenditures attributable to current exclusive e-cigarette use, dual/poly e-cigarette use and all e-cigarette use.

METHODS

We developed an econometric model to quantify the impacts of e-cigarette use on healthcare utilisation. An e-cigarette use-attributable fraction (EAF) was calculated based on the estimated model using an 'excess utilisation' approach. This EAF was then multiplied by the annual total health expenditures for US adults aged 18+ years to derive e-cigarette-attributable expenditures.

Data sources

The National Health Interview Survey

The National Health Interview Survey (NHIS) is a cross-sectional household interview survey of the civilian, non-institutionalised population in the USA.[24] It includes detailed questions about sociodemographic characteristics, tobacco product use, health status, health insurance coverage, healthcare access and use, and other health-related behaviours. We pooled the 2015–2018 NHIS data and included five tobacco products in this study: e-cigarettes, cigarettes, cigars, pipes and smokeless tobacco.

Medical Expenditure Panel Survey

The Medical Expenditure Panel Survey (MEPS) provides nationally representative estimates of healthcare utilisation, expenditures, sources of payment, health insurance coverage and health conditions for the US civilian, non-institutionalised population.[25] We used the 2018 MEPS to calculate total annual expenditures by type of healthcare service for all adults aged 18+ years.

Dependent variables

The dependent variables in our model included four healthcare utilisation outcomes (all measured in the past 12 months) and a health status variable.

Hospital nights were the number of nights spent in a hospital receiving inpatient care. Emergency room (ER) visits were the number of visits to the ER for the respondents' own health. Doctor visits were the number of visits to a physician or other healthcare professional for the respondents' own health. Home visits were the total number of home care visits received from a nurse or other healthcare.

Health status was constructed as an ordinal variable based on the question: 'Would you say your health, in general, is excellent, very good, good, fair, or poor', with '1' indicating 'excellent' and '5' indicating 'poor'.

Independent variables

The key independent variable was e-cigarette use, which was classified into four categories: current exclusive e-cigarette use, current dual/poly e-cigarette use, other tobacco use and never tobacco use. Current e-cigarette users were those who ever used e-cigarettes and reported now using e-cigarettes every day or some days or having used e-cigarettes at least 1 day in the past 30 days. We further classified all current e-cigarette users into (1) Current exclusive e-cigarette users if they never smoked ≥100 cigarettes in their lifetime and never used cigars, pipes or smokeless tobacco even once, and (2) Current dual/poly e-cigarette users if they have ever smoked ≥100 cigarettes, or ever used cigars, pipes or smokeless tobacco even once in their lifetime. Never tobacco users were those who have never smoked ≥100 cigarettes and never used e-cigarettes, cigars, pipes or smokeless tobacco in their lifetime. Other tobacco users comprised the remaining respondents.

Other independent variables were selected based on previous studies that examined healthcare expenditures attributable to cigarette smoking, cigar smoking and smokeless tobacco use.[20–22]

Sociodemographic characteristics included sex (male and female), age (18–34 years, 35–64 years and ≥65 years), race/ethnicity (Hispanic, non-Hispanic white, non- Hispanic black, non-Hispanic Asian and non-Hispanic other), education (<high school; high school graduate including general educational development; some college; college degree; and postgraduate), income level (poor (<100% of the federal poverty level (FPL)), low-income (100%–199% FPL), middle-income (200%–399% FPL), high-income (≥400% FPL) and unknown), marital status (married, separated/divorced/widowed, never married and living with a partner) and region of residence (North-East, Midwest, South and West). Income was defined as the ratio of family income to the FPL after adjusting for household size. We included the 5.8% of adults whose incomes were unknown as a separate category ('unknown') because we were concerned that data on income might not be missing at random.

CPD was the number of cigarettes smoked per day for daily current cigarette smokers (ever smoked ≥100 cigarettes in their lifetime and now smoke cigarettes every day). For non-daily current cigarette smokers (ever smoked ≥100 cigarettes in their lifetime and now smoke cigarettes some days), we calculated CPD by multiplying the average number of cigarettes smoked on smoking days by the number of days smoked in the past 30 days and then dividing by 30. If the respondent was not a current smoker, CPD was coded as zero. Years since quitting cigarette smoking was determined for former smokers (ever smoked ≥100 cigarettes in their lifetime and do not smoke cigarettes now) according to the question: 'How long has it been since you quit smoking cigarettes'. If the respondent was not a former smoker, it was coded as zero. Heavy drinkers were those who answered one or more days to the question: 'In the past year, on how many days did you have ≥5 drinks (for men) or ≥4 drinks (for women) of any alcoholic beverage?'. We categorised body mass index (BMI) as underweight (BMI <18.5 kg/m^2), normal (BMI 18.5–24.9 kg/m^2), overweight (BMI 25.0–29.9 kg/m^2) and obese (BMI ≥30.0 kg/m^2). Health insurance coverage was classified based on the proportion of months without any health insurance coverage in the past 12 months as full coverage (covered all 12 months), partial coverage and no coverage (no insurance).

Study sample

The pooled 2015–2018 NHIS data contained 118 859 adults aged 18+ years. After excluding those with missing values for dependent and independent variables, the final study sample was 109 133.

Econometric model of the impact of e-cigarette use on healthcare utilisation

We developed a structural econometric model to estimate the impacts of e-cigarette use on healthcare utilisation. The conceptual framework of the model is shown in the top row of figure 1. Similar to previous econometric studies that estimated the impact of cigarette smoking on healthcare expenditures,[26–29] our model assumed that e-cigarette use has impacts on healthcare utilisation through health effects, that is, e-cigarette use causes poorer health, which in turn causes more healthcare utilisation (the solid pathway in figure 1).

Our econometric model consisted of two equations. Equation 1 was to quantify the relationship between e-cigarette use and health status and Equation 2 was to quantify the relationship between health status and healthcare utilisation. In Equation 1, the dependent variable was health status, and the independent variables included e-cigarette use and all the other independent variables. Equation 1 was estimated by an ordered logistic regression. In Equation 2, the dependent variable was healthcare utilisation, and the independent variables included predicted health status derived from Equation 1, e-cigarette use status, and all the other independent variables. The predicted health status derived from Equation 1 incorporated the effects of e-cigarette use on health status. Therefore, the coefficient of the predicted health status indicated the impact of e-cigarette use on healthcare utilisation through health effects. We also included e-cigarette use in Equation 2 to reflect differences in risk preference and other factors between e-cigarette users and never tobacco users that are associated with healthcare utilisation (the top dashed line in figure 1). For example, e-cigarette users might use fewer healthcare services (eg, preventive healthcare services) than never tobacco users due to their risk-taking attitudes or lower preference for seeking medical care. For each healthcare utilisation variable, Equation 2 was estimated as a two-part model.[20 27] The first part of the two-part model was estimated by a probit regression on the probability of having positive healthcare utilisation

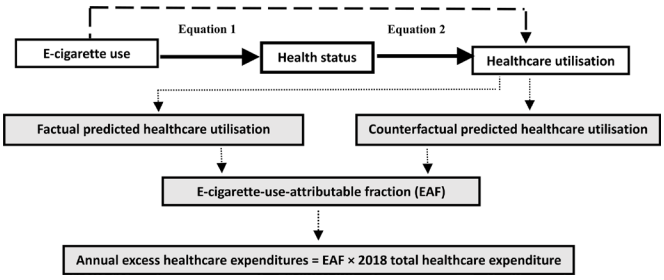

Figure 1 Model of healthcare expenditures attributable to e-cigarette use. The white boxes depict how e-cigarette use affects health status and healthcare utilisation. E-cigarette use was classified as current exclusive e-cigarette use, current dual/poly e-cigarette use, other tobacco use and never tobacco use in the model. To calculate excess healthcare expenditures attributable to e-cigarette use, only the pathway from e-cigarette use through health status to healthcare utilisation (solid arrow lines) was considered. We also include e-cigarette use status as an independent variable in the model of healthcare utilisation to reflect the differences in risk preference and other factors between e-cigarette users and never tobacco users that are associated with healthcare utilisation (the top dashed line). From the estimated model, we estimated the factual and counterfactual predicted values of healthcare utilisation to derive the relative risks. Then we derived the EAFs using the relative risks and the 2018 tobacco use prevalence. Last, we multiplied the EAF by 2018 total healthcare expenditure to derive annual excess healthcare expenditures attributable to current exclusive e-cigarette use and current dual/poly e-cigarette use. The sum of these two attributable expenditures was annual excess healthcare expenditures attributable to all current e-cigarette use.

among all adults. The second part of the two-part model was estimated by an ordinary least squares regression on the logarithmically transformed number of services used among those who had positive healthcare utilisation (visits or nights).

Estimation of healthcare expenditures attributable to e-cigarette use

We used an 'excess utilisation' approach to estimate healthcare utilisation attributable to current exclusive (or dual/poly) e-cigarette use.[21 22 30 31] In the calculation, we only counted the excess utilisation through the health effects pathway (the solid pathway in figure 1).

First, based on the estimated coefficients from Equation 1 and Equation 2, we calculated two sets of predicted healthcare utilisation under two scenarios (figure 1). Under the factual scenario, we calculated the predicted value of health status from Equation 1 using the actual values of e-cigarette use status and all the other independent variables, and the predicted value of healthcare utilisation from Equation 2 based on the predicted health status, the sample mean of e-cigarette use status and the actual values of all the other independent variables for all adults. Under the counterfactual scenario, we derived the predicted values of the dependent variables for hypothetical 'never tobacco-using' current exclusive (or dual/poly) e-cigarette users who had the same characteristics as current (or dual/poly) e-cigarette users except that they were assumed to be never tobacco users. We calculated the counterfactual predicted value of health status from Equation 1 assuming that current exclusive (or dual/poly) e-cigarette users were never tobacco users while still using the actual values of all the other independent variables, and the counterfactual predicted value of healthcare utilisation from Equation 2 based on the counterfactual predicted health status, the sample mean of e-cigarette use status and the actual values of all the other independent variables.

Next, we derived the relative risk (RR) of healthcare utilisation separately for current exclusive e-cigarette users, dual/poly e-cigarette users, hypothetical 'never tobacco-using' exclusive e-cigarette users, and hypothetical 'never tobacco-using' dual/poly e-cigarette users as the ratio of mean predicted utilisation for corresponding e-cigarette users to mean predicted utilisation for never tobacco users.[32] Assuming that these RRs remained unchanged during 2015–2018,[32] we calculated the 2018 EAF for current exclusive (or dual/poly) e-cigarette users by applying the RRs and the 2018 prevalence of e-cigarette use from the 2018 NHIS data to the EAF formula (see Equations A2 and A3 in online supplemental appendix 1).

Finally, we derived the 2018 total healthcare expenditures attributable to current exclusive (or dual/poly) e-cigarette use by multiplying the 2018 EAF for current exclusive (or dual/poly) e-cigarette use by the 2018 total adult healthcare expenditures for each type of healthcare services from the 2018 MEPS data. The sum of the total attributable expenditures for both current exclusive and dual/poly e-cigarette users is the 2018 total healthcare expenditures attributable to all current e-cigarette use. Dividing 2018 total attributable expenditures by the number of e-cigarette users in 2018 provides per-user attributable expenditures.

Statistical analysis

We used survey data analysis procedures due to the complex multistage sample design of the NHIS. Descriptive analyses were conducted using SAS V.9.4 with PROC SURVEYFREQ and PROC SURVEYMEANS for statistical calculation. We estimated the models using STATA V.14.0. We considered a two-tailed $p<0.05$ to be statistically significant.

RESULTS

Among the study sample, 3.7% were current e-cigarette users, including 0.2% exclusive users and 3.5% dual/poly e-cigarette users (table 1). Also, 47.3% were male, 50.8% were aged 35–64, 24.4% were heavy drinkers, 86.9% had full-coverage health insurance, and 13.2% reported fair or poor health. In 2015–2018, the prevalence of past 12-month healthcare utilisation was 9.1% for hospitalisations, 19.6% for ER visits, 84.1% for doctor visits and 3.0% for home visits.

The estimated results from Equation 1 of our econometric model indicate that compared with never tobacco users, current exclusive e-cigarette users were 1.62 times more likely, and current dual/poly e-cigarette users were 1.75 times more likely to report poor health status (table 2). The results from Equation 2 indicate that predicted poor health status was significantly associated with an increased likelihood of using healthcare utilisation for all four healthcare services, and an increased number of ER visits (coefficient=0.28, $p=0.002$) and doctor visits (coefficient=0.72, $p<0.001$) in the past 12 months.

The EAFs shown in table 3 ranged from 0.1% for hospital nights, ER visits and doctor visits to 0.3% for home visits for current exclusive e-cigarette use, and ranged from 1.2% for hospital nights and doctor visits to 2.6% for home visits for current dual/poly e-cigarette use. The annual e-cigarette use-attributable healthcare expenditures in 2018 dollars were $1.3 billion for current exclusive e-cigarette use, $13.8 billion for current dual/poly e-cigarette use and $15.1 billion for all current e-cigarette use. The per-user attributable healthcare

Table 1 Distribution of the study sample of US adults aged 18+ years by e-cigarette use, various characteristics and healthcare utilisation, National Health Interview Survey, 2015–2018

		N	W%
All		109 133	100.0
E-cigarette use	Current exclusive e-cigarette users	186	0.2
	Current dual/poly e-cigarette users	3845	3.5
	Other tobacco users	54 536	48.2
	Never tobacco users	50 566	48.3
Sex	Male	49 986	47.3
	Female	59 147	52.7
Age, years	18–34	26 807	26.0
	35–64	52 944	50.8
	65+	29 382	23.2
Race/ethnicity	Hispanic	14 342	14.6
	NH White	74 760	67.2
	NH Black	12 664	11.0
	NH Asian	5874	6.1
	NH Other	1493	1.1
Education	<HS	12 992	11.7
	HS	26 605	24.3
	Some college	34 097	30.5
	College	22 068	20.9
	Postgraduate	13 371	12.6
Income	Poor	14 488	10.3
	Low-income	19 507	16.2
	Middle-income	29 465	26.9
	High-income	39 824	40.8
	Unknown	5849	5.8
Marital status	Married	48 993	54.8
	S/D/W	29 197	18.1
	Never married	24 446	20.0
	Living with partner	6497	7.1
Region	North-East	17 891	17.9
	Midwest	24 669	22.3
	South	38 566	36.1
	West	28 007	23.7
BMI	Underweight	1873	1.8
	Normal	35 935	33.0
	Overweight	37 580	34.5
	Obese	33 745	30.8
Heavy drinking	No	82 226	75.6
	Yes	26 907	24.4
Health insurance coverage in the past 12 months	Full coverage	94 769	86.9
	Partial coverage	4093	3.6
	No coverage	10 271	9.5
Health status	Excellent	27 896	27.1
	Very good	36 163	33.0
	Good	29 663	26.8
	Fair	11 872	10.2
	Poor	3539	3.0
Hospital nights in the past 12 months	No	98 430	90.9
	Yes	10 703	9.1
ER visits in the past 12 months	No	86 727	80.4
	Yes	22 406	19.6
Doctor visits in the past 12 months	No	16 933	15.9
	Yes	92 200	84.1
Home visits in the past 12 months	No	105 347	97.0
	Yes	3786	3.0
CPD	*Mean (SD)	1.60 (0.02)	
The number of years of quitting	*Mean (SD)	4.59 (0.04)	

*Mean value among all 109 133 respondents.
BMI, body mass index; CPD, cigarettes smoked per day; ER, emergency room visits; HS, high school; NH, non-Hispanic; S/D/W, separated/divorced/widow.

expenditures were $1796 per current exclusive e-cigarette user, $2050 per current dual/poly e-cigarette user and $2024 per all current e-cigarette user.

DISCUSSION

This is the first study to estimate healthcare expenditures attributable to e-cigarette use among adults in the USA. Our finding that current e-cigarette use resulted in $15.1 billion in excess healthcare expenditures in 2018 indicates that even with a relatively low prevalence of current e-cigarette use among adults, the economic burden associated with e-cigarette use is substantial.

Our estimates of the per-user healthcare expenditures for current e-cigarette users ($2024) are lower than a recent estimate of per-smoker healthcare expenditures calculated from Xu and colleagues' estimate.[20] Xu and colleagues used data from the 2006–2010 MEPS linked to the 2004–2009 NHIS and estimated that annual healthcare expenditures attributable to adult cigarette smoking (current and former smoking) amounted to

Table 2 Estimated results of the econometric model among adults aged 18+ years, National Health Interview Survey 2015–2018, n=1 09 133

Equation 1*: ordered logistic regression on health status, the adjusted ORs of e-cigarette use status			
	AOR	**P value**	**95% CI**
Current exclusive e-cigarette users	1.62	0.003	1.18 to 2.23
Current dual/poly e-cigarette users	1.75	<0.001	1.62 to 1.90
Other tobacco users	1.35	<0.001	1.31 to 1.41
Never tobacco users	Reference		
Equation 2†: two-part model on healthcare utilisation, the coefficient of the predicted health status			
	Home visits		
	Coefficient	**P value**	**95% CI**
First part	1.71	<0.001	1.19 to 2.23
Second part	0.29	0.676	–1.08 to 1.66
	Hospital nights		
First part	0.68	<0.001	0.43 to 0.93
Second part	0.23	0.349	–0.25 to 0.72
	ER visits		
First part	0.71	<0.001	0.51 to 0.90
Second part	0.28	0.002	0.10 to 0.45
	Doctor visits		
First part	1.74	<0.001	1.54 to 1.94
Second part	0.72	<0.001	0.58 to 0.85

*Controlled for all the other independent variables.
†Controlled for e-cigarette use and all the other independent variables.
AOR, adjusted OR; ER, emergency room.

Table 3 E-cigarette use-attributable fractions (EAFs) for current exclusive e-cigarette use and current dual/poly e-cigarette use, and annual total healthcare expenditures attributable to current exclusive e-cigarette use, current dual/poly e-cigarette and all current e-cigarette use among US adults aged 18+ years, National Health Interview Survey, 2015–2018

	Current exclusive e-cigarette use		Current dual/poly e-cigarette use		All current e-cigarette use
	EAF*(%)	Expenditure ($)†	EAF*(%)	Expenditure ($)†	Expenditure ($)†
Hospital nights	0.1	506M	1.2	4904M	5410M
ER visits	0.1	86M	1.4	844M	930M
Doctor visits	0.1	497M	1.2	5560 M	6057M
Home visits	0.3	247M	2.6	2466M	2714M
Total		1336M		13774M	15110M
Per-user cost‡		1796		2050	2024

*Derived based on the 2018 prevalence of tobacco use: 0.3% for current exclusive e-cigarette use, 3.1% for current dual/poly e-cigarette use, 48.2% for other use group; 48.4% for never tobacco use.
†In 2018 $; The total HC expenditure for adults aged 18+ years was derived from the 2018 Medical Expenditures Panel Survey data: $419269M for hospital night, $60500M for emergency department visit, $452209M for physician visit, and $94480M for home visits.
‡Derived by dividing annual attributable expenditures by the weighted frequency of current exclusive e-cigarette users (n=743770), current dual/poly e-cigarette users (n=6720045), and current e-cigarette users (n=7463815) from the 2018 National Health Interview Survey.
EAF, e-cigarette use-attributable fraction; ER, emergency room; M, million.

$167.5 billion in 2010 including $61.6 billion from current smokers. We divided their healthcare expenditures attributable to current smokers ($61.6 billion) by the average number of current smokers estimated from the 2004–2009 NHIS data to come up with an estimate of $4481 per-user healthcare expenditures attributable to current smoking in 2010. Using the Consumer Price Index for Medical Care for All Urban Consumers,[33] their per-smoker estimate would be $5602 in 2018. Our estimate of $2024 per-user healthcare expenditures for current e-cigarette users is approximately a third of their estimate for current smokers. This evidence indicates that despite the lack of understanding of the long-term health impact of e-cigarette use, the contribution of current e-cigarette use to rising healthcare spending is significant and should not be overlooked.

In two studies, Wang and colleagues estimated the annual excess healthcare expenditures attributable to smokeless tobacco use[21] and cigar smoking.[23] Using the Consumer Price Index for Medical Care for All Urban Consumers,[33] the annual attributable healthcare expenditures would be $3.8 billion for smokeless tobacco use and $2.0 billion for cigar smoking in 2018. Although the two studies included both current and former use in their estimation, their annual attributable healthcare expenditures are much lower than our estimates of the annual healthcare expenditures attributable to current e-cigarette use in 2018 ($15.1 billion). This suggests that the impact of e-cigarettes on healthcare expenditures is already greater than the impact of smokeless tobacco and cigar, an important finding given that e-cigarettes are relatively new tobacco whose impact is likely to increase over time.

Our results indicated that current exclusive e-cigarette users had higher odds of reporting poor health status than never tobacco users, and the per-user healthcare expenditures were $1796 for current exclusive e-cigarette users in 2018. These results suggest that using e-cigarettes exclusively has substantial impacts on healthcare utilisation and expenditures. In addition, e-cigarette products are continually evolving, and the use of new versions of the product might result in unexpected negative health effects and therefore excessive healthcare expenditures from time to time, such as happened in the 2019 outbreak of vaping-related lung injuries and the associated hospitalisations and ER visits.[34–36] If current youth e-cigarette users continue to use e-cigarettes when they become adults[37] the negative impacts of e-cigarette use on healthcare utilisation and spending are likely to increase over time. Therefore, continuing tobacco prevention and intervention efforts including regulations to deter youth use, are needed to reduce the need for the healthcare services associated with e-cigarette use and the e-cigarette attributable healthcare expenditures.

Our estimates are subject to several limitations. First, due to lack of data availability, we were not able to account for healthcare services such as nursing home care, medications or dental care. Therefore, the estimates of e-cigarette use-attributable healthcare expenditures are likely to be underestimated. Second, self-reported healthcare utilisation may be subject to recall bias and could be underreported. Third, we assumed that the RR of healthcare expenditures is the same as the RR of healthcare utilisation. If this assumption is not valid, our estimates could be biased. Fourth, this study focused on adults. We did not include youth in the analysis due to their low healthcare utilisation. Fifth, we did not include former e-cigarette use in our

What this paper adds

What is already known on this topic

⇒ No studies have examined the effects of e-cigarette use on healthcare utilisation and expenditures.
⇒ This is the first study to estimate healthcare expenditures attributable to e-cigarette use among US adults, with separate estimates determined for exclusive e-cigarette use and dual/poly e-cigarette use.

What this study adds

⇒ In 2018, $1.3 billion ($1796 per user) annual healthcare expenditures were attributable to current exclusive e-cigarette use, $13.8 billion ($2050 per user) were attributable to current dual/poly e-cigarette use and $15.1 billion ($2024 per user) were attributable to all current e-cigarette use.

How this study might affect research, practice and/or policy

⇒ This first estimate of healthcare utilisation and expenditures attributable to e-cigarette use will provide valuable information to Food and Drug Administration regulatory impact analyses of proposed regulations that affect e-cigarette use.

estimation because the NHIS does not allow us to differentiate experimental e-cigarette users (ever tried e-cigarettes one or two times in their lifetime) from former users who used to use e-cigarettes regularly. Therefore, including former e-cigarette use in the estimation might bias the estimates. Sixth, our estimates do not reflect healthcare expenditures attributable to the use of e-cigarette products in the USA after 2018 (eg, puff bars and newly approved e-cigarettes by the Food and Drug Administration). Future studies are needed that investigate the impact of newly available e-cigarette products on healthcare utilisation and expenditures.

In conclusion, healthcare utilisation and expenditures attributable to e-cigarette use are substantial and likely to increase over time. Due to the rapid evolution of e-cigarette products, the impacts of e-cigarette use on healthcare utilisation and expenditures may change and should be closely monitored. The challenges of e-cigarettes for public health are global and our findings regarding the economic burden of e-cigarette use in the USA have broader relevance in an international context.

Contributors WBM is Principal Investigator. YW, H-Y S, JL, and WBM designed the methodology. YW conducted literature review and the statistical analysis. YW wrote the original draft of the manuscript. YW, H-Y S, JL, TY, and WBM reviewed, edited, and revised the manuscript. YW and WBM are responsible for the overall content.

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REFERENCES

1 Initiative T. *E-Cigarettes: facts, STATs and regulations*, 2020.
2 Villarroel MA, Cha AE, Vahratian A. Electronic cigarette use among U.S. adults, 2018. *NCHS Data Brief* 2020;365:1–8.
3 National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health. *E-Cigarette Use Among Youth and Young Adults: A Report of the Surgeon General [Internet]*. Atlanta (GA): Centers for Disease Control and Prevention (US), 2016.
4 Gotts JE, Jordt S-E, McConnell R, *et al*. What are the respiratory effects of e-cigarettes? *BMJ* 2019;366:l5275.
5 Miyashita L, Foley G. E-Cigarettes and respiratory health: the latest evidence. *J Physiol* 2020;598:5027–38.
6 Bhatta DN, Glantz SA. Association of e-cigarette use with respiratory disease among adults: a longitudinal analysis. *Am J Prev Med* 2020;58:182–90.
7 Entwistle MR, Valle K, Schweizer D, *et al*. Electronic cigarette (e-cigarette) use and frequency of asthma symptoms in adult asthmatics in California. *J Asthma* 2021;58:1–7.
8 Osei AD, Mirbolouk M, Orimoloye OA, *et al*. The association between e-cigarette use and asthma among never combustible cigarette smokers: behavioral risk factor surveillance system (BRFSS) 2016 & 2017. *BMC Pulm Med* 2019;19:180.
9 Xie Z, Ossip DJ, Rahman I, *et al*. Use of electronic cigarettes and self-reported chronic obstructive pulmonary disease diagnosis in adults. *Nicotine Tob Res* 2020;22:1155–61.
10 Perez MF, Atuegwu NC, Mead EL, *et al*. Adult e-cigarettes use associated with a self-reported diagnosis of COPD. *Int J Environ Res Public Health* 2019;16:3938.
11 Li D, Sundar IK, McIntosh S, *et al*. Association of smoking and electronic cigarette use with wheezing and related respiratory symptoms in adults: cross-sectional results from the population assessment of tobacco and health (path) study, wave 2. *Tob Control* 2020;29:140–7.
12 Wang JB, Olgin JE, Nah G, *et al*. Cigarette and e-cigarette dual use and risk of cardiopulmonary symptoms in the health eHeart study. *PLoS One* 2018;13:e0198681.
13 Buchanan ND, Grimmer JA, Tanwar V, *et al*. Cardiovascular risk of electronic cigarettes: a review of preclinical and clinical studies. *Cardiovasc Res* 2020;116:40–50.
14 Keith R, Bhatnagar A. Cardiorespiratory and immunologic effects of electronic cigarettes. *Curr Addict Rep* 2021;8:336–46.
15 Tarran R, Barr RG, Benowitz NL, *et al*. E-Cigarettes and cardiopulmonary health. *Function* 2021;2:zqab004.
16 Yang I, Sandeep S, Rodriguez J. The oral health impact of electronic cigarette use: a systematic review. *Crit Rev Toxicol* 2020;50:97–127.
17 Irusa KF, Vence B, Donovan T. Potential oral health effects of e-cigarettes and vaping: a review and case reports. *J Esthet Restor Dent* 2020;32:260–4.
18 Bjurlin MA, Matulewicz RS, Roberts TR, *et al*. Carcinogen biomarkers in the urine of electronic cigarette users and implications for the development of bladder cancer: a systematic review. *Eur Urol Oncol* 2021;4:766-783.
19 Eaton DL, Kwan LY, Stratton K, eds. *Public health consequences of e-cigarettes*. Washington, DC: National Academies Press (US), 2018.
20 Xu X, Bishop EE, Kennedy SM, *et al*. Annual healthcare spending attributable to cigarette smoking: an update. *Am J Prev Med* 2015;48:326–33.
21 Wang Y, Sung H-Y, Lightwood J, *et al*. Health care utilization and expenditures attributable to smokeless tobacco use among US adults. *Nicotine Tob Res* 2018;20:1359–68.
22 Wang Y, Sung H-Y, Yao T, *et al*. Health care utilization and expenditures attributable to cigar smoking among US adults, 2000-2015. *Public Health Rep* 2018;133:329–37.
23 Sung H-Y, Wang Y, Yao T, *et al*. Polytobacco use and nicotine dependence symptoms among US adults, 2012-2014. *Nicotine Tob Res* 2018;20:S88–98.
24 National Center for Health Statistics. National health interview survey, 2017. Public-use data file and documentation, 2018. Available: https://www.cdc.gov/nchs/nhis/data-questionnaires-documentation.htm
25 US Department of Health and Human Services, Agency for Healthcare Research & Quality. *Medical expenditure panel survey (MEPS)*, 2017.
26 Miller LS, Zhang X, Novotny T, *et al*. State estimates of Medicaid expenditures attributable to cigarette smoking, fiscal year 1993. *Public Health Rep* 1998;113:140–51.
27 Max W, Sung H-Y, Shi Y, *et al*. The cost of smoking in California. *Nicotine Tob Res* 2016;18:1222–9.
28 Max W, Rice DP, Sung H-Y, *et al*. The economic burden of smoking in California. *Tob Control* 2004;13:264–7.
29 Max W, Sung H-Y, Tucker L-Y, *et al*. The disproportionate cost of smoking for African Americans in California. *Am J Public Health* 2010;100:152–8.
30 Yao T, Sung H-Y, Wang Y, *et al*. Healthcare costs attributable to secondhand smoke exposure at home for U.S. adults. *Prev Med* 2018;108:41–6.
31 Yao T, Sung H-Y, Wang Y, *et al*. Healthcare costs of Secondhand smoke exposure at home for U.S. children. *Am J Prev Med* 2019;56:281–7.
32 Max W, Sung H-Y, Lightwood J. The impact of changes in tobacco control funding on healthcare expenditures in California, 2012-2016. *Tob Control* 2013;22:e10–15.
33 U.S. Bureau of Labor Statistics. The consumer price index. Available: https://www.bls.gov/cpi/data.htm
34 Layden JE, Ghinai I, Pray I, *et al*. Pulmonary Illness Related to E-Cigarette Use in Illinois and Wisconsin - Final Report. *N Engl J Med* 2020;382:903–16.
35 Krishnasamy VP, Hallowell BD, Ko JY, *et al*. Update: Characteristics of a Nationwide Outbreak of E-cigarette, or Vaping, Product Use-Associated Lung Injury - United States, August 2019-January 2020. *MMWR Morb Mortal Wkly Rep* 2020;69:90–4.
36 Cherian SV, Kumar A, Estrada-Y-Martin RM. E-Cigarette or Vaping Product-Associated lung injury: a review. *Am J Med* 2020;133:657–63.
37 Dunbar MS, Davis JP, Rodriguez A, *et al*. Disentangling within- and Between-Person effects of shared risk factors on e-cigarette and cigarette use trajectories from late adolescence to young adulthood. *Nicotine Tob Res* 2019;21:1414–22.