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E-cigarette Use to Aid Long-term Smoking Cessation in the US: Prospective Evidence from the PATH Cohort Study

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Conflict of interest: Dr. John P. Pierce reports grants from National Cancer Institute, during the conduct of the study; Ms. Martha M. White reports grants from National Institute of Health, during the conduct of the study; Dr. David R. Strong reports grants from NCI, RO1CA234539, during the conduct of the study.

Running head: E-cigarette Use for Smoking Cessation in the U.S.

ABSTRACT

E-cigarettes are the preferred smoking-cessation aid in the US, however there is little evidence regarding long-term effectiveness among those who use them. We used the Population Assessment of Tobacco and Health Study to compare long-term abstinence between matched US smokers who tried to quit with and without use of e-cigarettes as a cessation aid. We identified a nationally representative cohort of 2,535 adult US smokers in 2014-15 (baseline assessment), who in 2015-2016 (exposure assessment) reported a past-year quit attempt and the cessation aids used, and reported smoking status in 2016-17 (outcome assessment; self-reported 12+ months continuous abstinence). We used propensity-score methods to match each e-cigarette user with similar non-users. We found that, among US smokers who used e-cigarettes to help quit, 12.9% (95% CI: 9.1%,16.7%) successfully attained long-term abstinence. However, there was no difference compared to matched non-e-cigarette-users (cigarette abstinence difference: 2%; 95% CI: -3%, 7%). Furthermore, fewer e-cigarette users were long-term abstinent from nicotine products (nicotine abstinence difference: -4%; 95% CI: -7%, -1%); about two-thirds of e-cigarette users who successfully quit smoking continued to use e-cigarettes. These results suggest that e-cigarettes may not be an effective cessation aid for adult smokers, and instead may contribute to continuing nicotine dependence.

Keywords: E-cigarettes; long-term effectiveness; nationally representative cohort; propensity-score methods; matching; smoking cessation; nicotine abstinence.

Abbreviations

NRT Nicotine Replacement Therapy
PATH Population Assessment of Tobacco and Health

E-cigarette sales doubled in the US between 2015 and 2017.[1] In the UK and the US, e-cigarettes are now the most popular product type used to aid smoking cessation, ahead of FDA approved products including nicotine replacement therapy (NRT) such as a nicotine patch or nicotine gum, and prescription medications including buproprion and varenicline. While many herald e-cigarettes as a harm-reduction device,[2-4] experts have noted potential public health risks, including the potential for increased smoking initiation among minors, and for increased nicotine addiction among dual users of cigarettes and e-cigarettes.[5] In the US, e-cigarettes can deliver high doses of nicotine, and there is evidence of substantial uptake among nonsmoking minors.[6] Given these known risks, arguments for a net public health benefit rely on the effectiveness of e-cigarettes in helping adult smokers to quit cigarette smoking for the long-term.[7,8]

Several national reports have considered the evidence on whether e-cigarettes increase long-term smoking cessation. [5,9] The recent US Surgeon General's report [10] concluded that evidence remains inadequate to infer that e-cigarettes increase smoking cessation. Only four randomized trials, all conducted outside of USA, have directly tested whether e-cigarettes are efficacious for smoking cessation with a follow-up of at least 6 months. The most promising of these randomized attendees of UK National Health Service stop-smoking services (n=866) and reported that use of e-cigarettes as a cessation aid increased successful quitting one year later.[11] However, the importance of motivation was highlighted by a pragmatic trial conducted in wellness clinics at 54 US businesses, which reported that provision of free e-cigarettes in conjunction with a brief communication intervention did not increase cessation among 6004 randomized

smoking employees.

Additionally, there have been several papers from nationally-representative longitudinal studies in which smokers self-selected to use e-cigarettes to help quit smoking. Use of e-cigarettes for quitting in the Adult Tobacco Cohort was associated with short-term but not long-term cigarette abstinence [12]. There have been five reports using data from the US Population Assessment of Tobacco and Health (PATH) Study [13]. Two analyses [14,15] had biased results as they included smokers who did not make a quit attempt only in the comparison group.[16] One reported that use of e-cigarettes to quit was associated with increased short-term abstinence, measured at the same time that e-cigarette use was assessed. [17] Another[18] reported that substitution of e-cigarettes for cigarettes at Wave 2 was not associated with sustained abstinence at Wave 3, confirming an earlier report[19] that use of e-cigarettes after quitting was associated with increased relapse to smoking one year later. These latter two studies suggest that nicotine abstinence after quitting cigarettes may be an important moderator of long-term abstinence from cigarette smoking.

In this paper we use more recent PATH data to address whether use of e-cigarettes to aid quitting contributed to increased successful smoking cessation in the US population (self-reported 12+ months continuous abstinece[20]). As many smokers use multiple cessation aids,[21] we focus on any e-cigarette use for quitting compared to no use. Further, we include as a second comparison group those who used an approved

pharmaceutical aid to quit but not an e-cigarette. The population of smokers who use e-cigarettes to quit is appreciably different from those who do not[22]. Thus, we identified *a priori* 24 potential confounders and used propensity score methods to match each e-cigarette user with up to two closely matched control respondents. We compared population-weighted abstinence rates in the matched samples. This approach estimates the causal effect of e-cigarette use explicitly among those who choose to use them as a cessation aid, and is less dependent on modelling assumptions than regression-based approaches which estimate average effects projected to the entire population[23]. However, we report regression-based approaches as sensitivity analyses.

METHODS

Data source and sample

Data are from the restricted public use file of the PATH Study.[24] The surveys are conducted at approximately annual intervals (Waves) with stratified oversampling for 18- to 24-year-olds, adult tobacco users, and African-American adults. Response rates were: initial household screener survey, 54%; in-depth adult interview at Wave 1, 74.0%; annual follow-up, 83.1%, 78.4% and 73.5% for Wave 2, Wave 3, and Wave 4 respectively. Surveys included informed consent and the study is overseen by the Westat Institutional Review Board. Our sample was identified from 10,722 cigarette smokers at Wave 2 (2014-15, baseline assessment) of whom 2852 reported a past-year quit attempt at Wave 3 (2015-16, exposure assessment), with 2,535 completing the

Wave 4 outcome assessment in 2017-18. The data collection schema is provided in Web Figure 1.

Measures

Tobacco and nicotine use. During each interview, after viewing an image of each tobacco product, participants were asked whether they had ever used that product, and whether they currently used it every day or some days. Non-current users were asked "In the past 30 days, have you smoked/used [product], even one or two puffs" and "In the past 12 months, have you smoked/used [product], even one or two puffs" respectively. Ever-smokers were asked whether they had used the following NRT products in the past 12 months: a nicotine patch, gum, inhaler, nasal spray, lozenge, or pill. Our two outcome variables (12+ months abstinence from (1) cigarettes and (2) all nicotine products) are identified from these questions on the Wave 4 survey. Nicotine use includes any use of cigarettes, e-cigarettes, NRT, cigars (traditional, cigarillo & filtered), pipes, hookah, snus, or other smokeless products.

Use of e-cigarettes and pharmaceutical aids to quit. Each survey asked smokers whether they had made a quit attempt within the past 12 months and which of the following products was used for their most recent quit attempt: e-cigarettes; NRT; varenicline (Chantix: Pfizer, Groton, Connecticut); buproprion (Wellbutrin or Zyban: GlaxoSmithKline, London, UK). The primary exposure is Wave 3 reported use of e-cigarettes to quit (e-cigarette group, n=427); comparison groups are those who did not

(no-e-cigarette group, n=2108), as well as those who reported use of a pharmaceutical cessation aid at Wave 3 (varenicline, buproprion, or NRT) but not e-cigarettes (n=465).

Study covariates. Web Appendix 1 presents survey questions for 24 potential confounders, which we identified a priori. These include sociodemographic variables, cigarette smoking history, duration of previous quit attempt reported prior to baseline, timing of most recent quit attempt from survey (assessed at Wave 3); self-efficacy about quitting; interest in quitting cigarettes; exposure to smoking; perceived harm of cigarettes and e-cigarettes; daily e-cigarette use reported at current or prior surveys ("ever" daily use); nicotine dependence level (average agreement with a series of 15 statements on emotional and physical response to nicotine products, scaled from 0 to 100) [25], and health related covariates. All were assessed at Wave 2, with the exception of timing of most recent quit attempt from the Wave 3 survey, used to control potential recall bias associated with type of aid used [26]. Univariate distributions by cessation aid category are shown in Web Table 1.

Statistical analyses

Estimates were weighted using the Wave 1-Wave 4 longitudinal survey weights, which adjust for the sampling design, survey-nonresponse, and longitudinal drop out [27]. Weighted percentages and Wilson Confidence Limits (CIs) for proportions were calculated. Confidence intervals and p-values used the replicate survey weights with balanced repeated replication with Fay adjustment (ρ=0.3)[28] in R, version 3.5.3 (R Foundation for Statistical Computing), except for the propensity score matched analyses where bootstrap percentile confidence intervals were used.

For propensity score matching, within each bootstrap sample for each participant we calculated a propensity score by estimating the probability of membership in the e-cigarette-use group using logistic regression. To obtain complete data for the 24 covariates, we used simple imputation (R package 'Mice'). To identify the optimal set of covariates among the 24 variables, for each logistic regression model we used a 10-fold cross-validated LASSO[29] procedure with tuning parameter selected from among the sequence 0 to 0.1 with step of 0.005 (R package 'glmnet'), conducted without survey weights. We repeated this propensity score estimate for each bootstrap-resampled dataset. Using the propensity score, we matched up to two controls for each case (nearest neighbor matches using R package 'Matchit'), within the a priori caliper distance of 0.1 (if possible) or 0.2 (maximum allowed).[30] We chose the caliper that provided the lowest standardized difference averaged across all covariates after matching. Cases that did not have a match were omitted from the sample.

For each matched bootstrap sample, we used logistic regression with survey weights (r package: survey) to estimate the average risk difference between the two matched groups, for each outcome. The model included an indicator of the matched pair (or triple), the overall propensity score, and, to adjust for any remaining covariate imbalance, any covariate with median standardized difference between the two study groups larger than 0.10.[31,32] We report the bootstrap mean estimate of risk difference, and calculate adjusted 95% bootstrap quantile confidence intervals, with Bonferroni adjustment[33] to account for the two abstinence outcomes studied. To identify a sufficient bootstrap sample size, we required a jackknife quality estimate[34] to be <0.1, resulting in 1500

bootstrap samples for the comparison of e-cigarette use vs no e-cigarette use.

Sensitivity analyses

Sensitivity analyses included incorporating matching as random instead of fixed effects, and 1:1 rather than 1:2 propensity score matching without further covariate adjustment. We also used weighted multivariable logistic regression on the full sample; covariates included were age, sex, ethnicity, race, education, income, nicotine dependence, relative perceived harm of e-cigarettes, previous daily e-cigarettes use, with simple imputation. Finally, we tested whether the results were robust to omission of adjustment for multiple comparisons.

As a post-hoc exploratory sensitivity analyses, we used logistic regression to test whether the association of e-cigarette use with long-term cigarette abstinence and nicotine abstinence differed by baseline smoking status, nicotine dependence, age, sex, education level and race / ethnicity. Statistical inference was based on 95% confidence intervals for interaction terms (uncorrected for multiple comparisons), and a stratified analysis was conducted when the boundary of the confidence interval was close to one.

RESULTS

Population rates of cigarette and nicotine abstinence at Wave 4 follow up

Among this representative sample of US smokers who reported a past-year quit attempt in 2015-2016 (Wave 3), 17.4% used e-cigarettes to help quit smoking. Those who used e-cigarettes were younger, more nicotine dependent, more likely to be non-Hispanic white, and had higher income and education (Table 1).

Among US smokers who used e-cigarettes to quit, 12.9% (95% CI: 9.1%,16.7%) achieved 12+ months abstinence from cigarettes at Wave 4, compared to 11.3% (95% CI: 9.6,13.0) among US smokers who did not use e-cigarettes to quit. (Table 2) Among US smokers who used e-cigarettes to quit, the population weighted estimate of 12+ months nicotine abstinence at Wave 4 was 2.8% (95% CI: 0.9%,4.8%), compared to 8.1% (95% CI: 6.5%,9.7%) among those who did not use e-cigarettes to quit. Table 2 presents population abstinence rates among these smokers by baseline consumption level (daily or non-daily).

Propensity-score matched samples

We assessed appropriateness of the propensity score match by comparing kernel density estimates of the propensity score (i.e. the estimated probability of using e-cigarettes to quit on the index quit attempt). Comparing smokers who used e-cigarettes to quit and smokers who did not, prior to matching the two density estimates were very different (Web Figure 2A). In particular, there were few respondents with propensities above 0.6 in the no-e-cigarette population, indicating that some population subgroups are very unlikely to use e-cigarettes. Matching resulted in good overlap of the density estimates (Web Figure 2B), although restricted to respondents with propensity score less than 0.8. Matching used all of the 427 available e-cigarette users, with median sample size 386 for the matched sample. For each matching variable, we also plotted the standardized absolute mean difference between study groups across the 1500 bootstrap re-samples, for the full sample and the matched samples (Web Figure 3). The matched samples had a small between-group difference across all covariates with the

exception of prior daily e-cigarette use (Web Table 2). This variable was controlled for in the logistic regression comparing abstinence rates between the matched samples.

Figures assessing the quality of the match between the e-cigarette group and the matched FDA- approved pharmaceutical aid group are presented in Web Figure 4. The propensity scores were always positive, indicating that some respondents in each group were at least somewhat likely to belong to the other group. However, the smaller size of the available respondents in the comparison group resulted in fewer successful matches: all 427 e-cigarette users were included in at least one matched sample but the median matched sample size was 244. We again used 1500 bootstrap samples and the matching achieved a major improvement in the between-group balance for all covariates. However, a residual difference remained for age, prior daily e-cigarette use, relative perceived harm of e-cigarettes, and smoking-related diseases, which we controlled for in the logistic regression.

Comparisons of abstinence rates between matched samples

There was no evidence for a difference in the proportion who achieved long-term abstinence from cigarettes between those who used e-cigarettes to help quit smoking and the matched sample of those who did not use e-cigarettes as a cessation aid (Figure 1A). (Risk Difference (RD): 0.02, 95% CI: -0.03, 0.07). However, e-cigarettes users were less likely to be long-term nicotine abstinent at follow up (RD: -0.04, 95% CI: -0.07, -0.01).

Comparing e-cigarette users to the matched sample of those who used pharmaceutical aids (but not e-cigarettes) to quit (Figure 1B), there was no difference in the proportion who achieved either abstinence outcome (cigarette abstinence: RD=0.02, 95% C.I. -0.03, 0.08; nicotine abstinence: RD=-0.03, 95% C.I: -0.07, 0.01).

Sensitivity analyses were very consistent with these results (Web Figure 5, Web Appendices 2, 3, Web Table 3). Exploratory analyses of interaction terms between e-cigarette use and baseline smoking status, nicotine dependence, age, sex, education level and race / ethnicity revealed that all confidence intervals included one, unadjusted for multiple comparisons (Web Appendix 4, Web Table 4). However, the interaction terms for the association of e-cigarettes with daily or non-daily smoking status, and with educational level appeared to be worth future exploration, and stratified analyses for these variables are presented in Web Appendix 4, Web Table 4.

US abstinence rates by product among those who successfully quit cigarettes

Table 3 presents population abstinence rates from various nicotine containing products among all those who were long-term abstinent from cigarettes at Wave 4. Among those who successfully used e-cigarettes to quit cigarette smoking, only about a third were also long-term abstinent from e-cigarettes follow-up. Among those who successfully used approved pharmacotherapy to quit smoking, about 70% were abstinent from NRT.

Among the larger group who successfully quit smoking without use of e-cigarettes (who may have used no aid, or approved pharmacotherapy), over 90% were long-term abstinent from each of NRT and e-cigarettes at follow-up. Importantly, in each

comparison group of cigarette-abstinent smokers, 7-17% were still using some form of combusted tobacco at follow up. Overall, among US smokers in 2014-2015 who reported using e-cigarettes to quit in the following year, 8.4% (95% CI: 5.4%,11.4%) had quit smoking and appeared to have substituted e-cigarettes for their cigarettes by 2016-17.

DISCUSSION

We used the PATH survey to prospectively compare long-term cessation outcomes between a nationally representative sample of US smokers who tried to quit smoking with the help of e-cigarettes in 2016-2017, and a matched sample of US smokers who also tried to quit, but without using e-cigarettes. We found that e-cigarette users did not have higher rates of long-term abstinence from cigarette smoking, but did have lower rates of abstinence from nicotine than their matched peers. This difference appeared to be largely due to high rates of continuing use of e-cigarettes among those who quit smoking cigarettes. Two-thirds of those who successfully used e-cigarettes to attain long-term abstinence from cigarettes were still using e-cigarettes during the follow-up year. It would be important to assess eventual relapse rates among these groups. [35]

We also compared abstinence rates among those who used e-cigarettes to quit and a matched sample of those who used FDA-approved pharmaceutical cessation aids. Estimated effects were very similar, but confidence intervals were wider, likely due to the smaller matched sample sizes.

The low rates of nicotine abstinence found in our study are worth noting. We included in this measure e-cigarettes, other tobacco products, and NRT products. Long-term nicotine abstinence was well under 5% for US smokers who used e-cigarettes to quit,

and under 10% for those who did not. Our matched analysis attributes 4 percentage points of this difference to the use of e-cigarettes. Of particular concern is the high rate of continued smoking of other forms of tobacco among those who successfully quit cigarettes, ranging from 17% of those who successfully used e-cigarettes to quit, to 7% among successful pharmaceutical aid users.

Smokers who used e-cigarettes to try to quit smoking were younger, more educated and affluent, had higher nicotine dependence levels, and were more likely to report mental health symptoms than smokers who tried to quit without e-cigarettes. We used propensity-score methods to match each e-cigarette user with up to two similar smokers who did not use e-cigarettes, and compared the difference in abstinence rates for the matched samples. This procedure estimates the average causal effect of e-cigarettes among the population of those who use them [36]. Alternatively, regression-based modeling can estimate average causal effects over the whole population, however at the risk of extrapolation to smokers who are unlikely to ever use e-cigarettes. Indeed, there were few non-e-cigarette users with a propensity score over 50%, whereas about 20% of e-cigarette users had a propensity score over 50%, indicating that such model-based extrapolation is needed to estimate a population-averaged effect. However, we used such model-based methods in our sensitivity analyses and obtained qualitatively similar results.

At the population level, we estimated that about 13% of US smokers who made a quit attempt using e-cigarettes achieved long-term smoking cessation success, as did about 11% of US smokers who tried to quit without use of e-cigarettes, similar to the propensity-score matched estimate of a difference of 2 percentage points in cessation rates. The 95% confidence interval for the matched difference in cessation rates was from -3 percentage points to 7 percentage points. These cessation rates observed in PATH are similar to those seen in other population studies. For example, the 2008 clinical practice guidelines for smoking cessation estimated that about 13% of US smokers who tried to quit smoking attained 6-12 months abstinence.

In our study, as in other population studies, daily smokers were less likely to quit successfully than non-daily smokers. Interestingly, the unadjusted observed association of e-cigarette use for cessation differed in direction between daily and non-daily smokers. In exploratory post-hoc analyses we used adjusted multivariable logistic regression to investigate interactions between the association of e-cigarette use and daily vs non-daily smoking, as well as with age, education, gender, and race ethnicity. All confidence intervals for these interaction terms included one; however estimated interactions for education and daily vs non-daily smoking appeared to be worth future investigation and are reported in Web Appendix 4, Web Table 4.

Our finding that e-cigarette use to quit smoking did not increase 12+ month cigarette abstinence is similar to results from the Adult Tobacco Use Cohort [12], which found a cessation benefit for e-cigarettes at 6 months but not at 12 or 18 months. Using an

earlier PATH Study cohort,[22] we reported that using an e-cigarette to quit was associated with short-term abstinence (30+ days); here abstinence was reported contemporaneously with the report of use of e-cigarettes to quit. Thus, it is possible that e-cigarettes help short-term quitting but not sustained abstinence rates. These results are also consistent with a recent study using the PATH Wave 1-3 database [18], which reported that e-cigarette use among older smokers was associated with abstinence at Wave 2 but relapse by Wave 3.

Our results on substitution of e-cigarettes for cigarettes are qualitatively similar to the randomized trial of attendees to UK National Health Service stop-smoking services, in which 80% of successful quitters in the e-cigarette arm continued to use e-cigarettes at 1 year, compared to persistent use of NRT by only 9% of successful quitters in the NRT arm.[11] However, we did not replicate this trial's findings of a sustained cessation benefit from use of an e-cigarette to quit. The difference in our results may be related to the intensiveness of the UK intervention, or to the lower level of nicotine in UK e-cigarettes. The motivation level of participants might also account for these differences: only 43% of those screened for the UK trial were randomized to the study, whereas the PATH study estimates are representative of the US population. Similar differences in conclusions between randomized trials and observational studies have been reported regarding use of NRT to quit.[22,37] Our findings are, however, consistent with the lack of efficacy of e-cigarettes in the recent pragmatic randomized trial of provision of e-cigarettes to help cessation among smoking employees at US workplaces [38]. It is possible that participants in the pragmatic trial more closely match the general population of US smokers who

want to quit.

Strengths of this study include that it is drawn from a large representative sample of the US population who report tobacco use on an annual basis, that it uses a prospectively assessed measure of 12-month abstinence, and that aims to assess the causal effect of e-cigarettes for cessation as they are used in the US population. Results were robust to a variety of sensitivity analyses, and our propensity score approach is relatively robust to modeling assumptions [23]. However, a limitation of all observational studies is the possibility of unmeasured confounding, such as differences in motivation level to quit smoking, in quitting history, or in self-efficacy to successfully quit smoking. The survey measures used are self-reported, and as such may have measurement error. While the PATH Study collects biomarkers of tobacco use, these were not available to validate the outcome at the time of writing. However, in an analysis of earlier PATH data self-reported tobacco use was strongly associated with biomarker data. [39] In this study, the e-cigarette devices used were those that were generally available in 2015-16 and the results may not generalize to the modifications in available products since that time.

In conclusion, we compared long-term abstinence rates between a nationally representative cohort of US smokers who tried to quit smoking using e-cigarettes as a cessation aid, and a matched sample of smokers who tried to quit without using e-cigarettes. We found no evidence that e-cigarettes helped these smokers to successfully quit smoking. We estimated that about 8% of all adult US smokers who used an e-cigarette to quit cigarettes in 2015-2016 were able to successfully substitute

e-cigarettes for cigarette smoking. However, our propensity-score matched results suggest that these smokers would have been equally successful in quitting smoking without the use of e-cigarettes. Furthermore, our results suggest, these respondents were more likely to remain dependent on nicotine, largely due to continuing use of e-cigarettes.

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Table 1. Sample Characteristics of PATH Study Smokers[a] in 2014-2015 Reporting a Past Year Quit Attempt in 2015-2016, According to Use, or No Use, of E-cigarettes to Aid Quitting

Sociodemographic Factors	Used e-cigarettes on Quit Attempt[b] (n=427)			Did not use e-cigarettes on Quit Attempt[b] (n=2108)			
	N	Wtd %	95% C.L.	N	Wtd %	95% C.L.	P-value
Age (years)							<0.001
18-34	218	46.8	41.1, 52.5	922	38.3	35.6, 41.0	
35-50	127	32.0	26.7, 37.3	546	28.5	26.0, 31.0	
50+	82	21.2	16.9, 25.5	640	33.2	30.5, 35.9	
Sex							0.500
Male	202	50.7	44.8, 56.6	1012	53.0	50.5, 55.5	
Female	225	49.3	43.4, 55.2	1095	47.0	44.5, 49.5	
Education							0.006
Less than high school	89	19.4	14.9, 23.9	593	26.8	24.6, 29.0	
High school graduate	90	23.1	17.2, 29.0	502	27.5	25.0, 30.0	
Some college or higher	230	55.2	48.9, 61.5	944	43.7	41.2, 46.2	
Ethnicity							<0.001
Hispanic	37	6.9	4.7, 9.1	334	15.1	13.1, 17.1	
Non-Hispanic	390	93.1	90.9, 95.3	1732	82.9	80.7, 85.1	
Race							<0.001
White	354	85.8	82.5, 89.1	1400	69.1	66.6, 71.6	
Black	26	5.5	3.3, 7.7	433	19.5	17.5, 21.5	
Other	43	8.0	5.1, 10.9	223	9.0	7.6, 10.4	
Income (monthly, US$)							<0.001
< 35000	220	47.5	42.2, 52.8	1341	59.8	56.9, 62.7	
>= 35000	190	48.0	42.7, 53.3	633	34.0	31.3, 36.7	
Smoking-related diseases							0.178
Marked	201	47.0	41.7, 52.3	1069	51.1	48.4, 53.8	
Not Marked	226	53.0	47.7, 58.3	1039	48.9	46.2, 51.6	
Nicotine dependence scale							0.009
0-33.3	89	22.4	17.1, 27.7	571	28.5	25.6, 31.4	
33.4-66.7	172	38.6	33.9, 43.3	839	39.4	36.9, 41.9	
66.8-100	165	38.7	33.4, 44.0	648	29.6	27.4, 31.8	
Relative perceived harm of e-cigarettes							<0.001
Less harmful	262	61.3	56.4, 66.2	726	34.7	32.3, 37.1	
More harmful	158	36.9	31.8, 42.0	1306	61.4	58.9, 63.9	
E-cigarette use prior to W2							0.001
Never	44	10.9	7.4, 14.4	949	48.1	45.9, 50.3	
Ever	383	89.1	85.6, 92.6	1154	51.7	49.5, 53.9	
E-cigarette use prior to W2							<0.001
Daily use at W1 or W2	106	24.5	20.0, 29.0	96	4.3	3.3, 5.3	
Not daily use at W1 or W2	321	75.5	71.0, 80.0	2012	95.7	94.7, 96.7	

Abbreviations: Wtd, Weighted; W1, PATH Study Wave 1; W2, PATH Study Wave 2.

[a] Weighted US population estimates.

[b] E-cigarette use status for most recent quit attempt, among all smokers reporting a quit attempt at Wave 3.

Table 2. Long-term Abstinence at Follow-up [a,b] among US Smokers who made a Quit Attempt in 2015-2016, according to Use, or No Use, of E-cigarettes to Aid Quitting

Cigarette smoking status (W2) and e-cigarettes used to aid quit attempt?[c]	Cigarette abstinence (W4)			Nicotine[d] abstinence (W4)		
	n	*Wtd % Abstinent*	*95% C.L.*	*n*	*Wtd % Abstinent*	*95% C.L.*
All current cigarette smokers						
Yes	427	12.9	9.1, 16.7	427	2.8	0.9, 4.8
No	2108	11.3	9.6, 13.0	2108	8.1	6.5, 9.7
Daily cigarette smokers						
Yes	290	13.7	8.8, 18.7	290	3.4	0.8, 6.1
No	1455	9.5	7.7, 11.3	1455	7.3	5.7, 9.0
Non-daily cigarette smokers						
Yes	137	11.1	5.7, 16.5	137	1.5	-0.6, 3.7
No	653	15.1	11.7, 18.4	653	9.6	6.6, 12.6

Abbreviations: Wtd, Weighted; C.L., Confidence Limit; W2, PATH Study Wave 2; W4, PATH Study Wave 4.

[a] Abstinence of 12+ months, reported at Wave 4.

[b] Weighted US population estimates.

[c] E-cigarette use status for most recent quit attempt, among all smokers reporting a quit attempt at Wave 3.

[d] Nicotine use includes any of cigarettes, e-cigarettes, nicotine replacement therapy.

Table 3. Long-term Abstinence [a,b] (12+ months) from E-cigarettes, NRT, Other Tobacco Products [c] , among US Smokers who were 12+ Months Cigarette Abstinent at Follow-up in 2016-2017 according to Use of E-cigarettes, No Use of E-cigarettes, or Use of Pharmacotherapy to Aid Quitting

12+ month abstinence at W4 from:	E-cigarettes used to quit [d] (n=49)		E-cigarettes not used to quit [d] (n=227)		Pharmaceutical aid[e] used to quit [d] (n=45)	
	Wtd % Abstinent	95% C.L.	Wtd % Abstinent	95% C.L.	Wtd % Abstinent	95% C.L.
E-cigarettes	31.7	16.4, 47.0	93.0	89.0, 96.9	96.1	89.7, 102.4
NRT	94.5	85.3, 103.8	91.9	87.4, 96.3	71.0	55.7, 86.4
Other tobacco products	82.2	70.0, 94.5	82.9	77.3, 88.5	93.1	85.2, 101.1
Combustible [f]	83.0	70.7, 95.2	86.1	80.5, 91.6	93.1	85.2, 101.1
Smokeless [g]	93.3	84.0, 102.6	95.6	92.6, 98.6	97.2	91.5, 102.9

Abbreviations: Wtd, Weighted; C.L., Confidence Limit; W4, PATH Study Wave 4, NRT, Nicotine Replacement Therapy.
[a] Abstinence of 12+ months, reported at Wave 4.
[b] Weighted U.S. population estimates.
[c] Other tobacco products include cigars (traditional, cigarillo & filtered), pipes, hookah, snus, or other smokeless products.
[d] E-cigarette use and pharmaceutical aid status for most recent quit attempt, among all smokers reporting a quit attempt at Wave 3.
[e] Pharmaceutical aids include varenicline (Chantix); buproprion (Wellbutrin, Zyban).
[f] Combustible products include cigars, pipes, hookah.
[g] Smokeless products include snus, moist snuff, dip, spit and chewing tobacco.

Figure 1. Differences in long-term abstinence rates from smoking cigarettes, and from use of any nicotine containing product, comparing the type of aid used for smoking cessation: A) e-cigarettes used for cessation vs no e-cigarettes used for cessation; B) e-cigarettes used for cessation vs pharmacotherapy but no e-cigarettes used for cessation. Weighted differences in rates of 12+ months abstinence between e-cigarette users and a matched sample of non-e-cigarette users, matched on 26 smoking-related characteristics and further adjusted by logistic regression. Bars represent Bonferroni adjusted 95% bootstrap confidence intervals. Samples drawn from 2852 adult respondents to the Population Assessment of Tobacco and Health Study who reported smoking at Wave 2 (2014-15), reported a quit attempt and cessation aids used at Wave 3 (2015-16) and reported abstinence outcomes at Wave 4 (2017-18). RD: Risk difference. CI: Confidence Interval.