Assessment of Exclusive, Dual, and Polytobacco E-Cigarette Use and COVID-19 Outcomes Among College Students

Ashley L. Merianos, PhD[1] , **Alex M. Russell, PhD[2]** ,
E. Melinda Mahabee-Gittens, MD, MS[3] , **Adam E. Barry, PhD[4], Meng Yang, MPH[5] and Hsien-Chang Lin, PhD[6]**

Abstract

Purpose: This study examined current (past 30-day) dual- and polytobacco use patterns and COVID-19 symptomatology, testing, and diagnosis status among college student electronic cigarette (e-cigarette) users.

Design: Cross-sectional online questionnaire administered during October–December 2020.

Setting: Four large, U.S. public universities in geographically diverse locations.

Sample: College students (N=756) ages 18–24 who reported current e-cigarette use.

Measures: Current use of e-cigarettes, combustible cigarettes, and cigars, and self-reported COVID-19 symptomatology, testing, and diagnosis status were measured.

Analysis: Multivariable logistic regression models accounting for students' demographics, university site, fraternity/sorority membership, and current residence.

Results: Over half (53.6%) of students were exclusive e-cigarette users, 20.4% were dual e-cigarette and combustible cigarette users, 4.6% were dual e-cigarette and cigar users, and 21.4% were poly users of e-cigarettes, combustible cigarettes, and cigars. Compared to exclusive e-cigarette users, dual users of e-cigarettes and combustible cigarettes (AOR=2.12, 95%CI=1.05–4.27) and poly users of e-cigarettes, combustible cigarettes, and cigars (AOR=3.70, 95%CI=1.78–7.70) had increased odds of COVID-19 symptomatology, even when accounting for covariates. While current tobacco use groups did not differ based on COVID-19 testing, polytobacco users had significantly increased odds (AOR=2.16, 95%CI=1.11–4.20) of having received a positive COVID-19 diagnosis.

Conclusion: Given use of two or more tobacco products increased COVID-19-related risks, results underscore the need to prevent dual- and polytobacco use behaviors in college student e-cigarette users.

"In Brief"

The study objective was to examine the associations between current (past 30-day) dual- and polytobacco use patterns and COVID-19 symptomatology, testing, and diagnosis status among college student electronic cigarette (e-cigarette) users. Dual e-cigarette and combustible cigarette users and poly users of e-cigarettes, combustible cigarettes, and cigars were at increased odds of having current COVID-19 symptomatology, compared to exclusive e-cigarette users. While no differences were found between tobacco use groups based on COVID-19 testing, when compared with exclusive e-cigarette users,

[1]School of Human Services, University of Cincinnati, Cincinnati, OH, USA
[2]Department of Health, Human Performance, and Recreation, University of Arkansas Fayetteville, Fayetteville, AR, USA
[3]Division of Emergency Medicine, Cincinnati Children's Hospital Medical Center, College of Medicine, University of Cincinnati, Cincinnati, OH, USA
[4]Department of Health and Kinesiology, Texas A&M University, College Station, TX, USA
[5]Department of Applied Health Science, Indiana University School of Public Health - Bloomington, Bloomington, IN, USA
[6]Department of Applied Health Science, Indiana University School of Public Health - Bloomington, Bloomington, IN, USA

Corresponding Author:
Ashley L. Merianos, School of Human Services, University of Cincinnati, PO Box 210068, Cincinnati, OH 45221, USA,
Email: ashley.merianos@uc.edu

polytobacco users were at increased odds of having a positive COVID-19 diagnosis. The current study provides information on COVID-19-related risks associated with dual- and poly-tobacco use of e-cigarettes with combustible tobacco products among young adults. Prevention efforts are urgently needed to prevent and reduce dual- and polytobacco use behaviors in college student e-cigarette users, especially during the current COVID-19 pandemic.

Purpose

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus causing coronavirus disease 2019 (COVID-19), has caused a pandemic resulting in nearly 200 million cases and over four million deaths.[1] Tobacco users are at increased risk for respiratory viruses, and tobacco smoking and potentially electronic cigarette (e-cigarette) use can up-regulate the known SARS-CoV-2 receptor.[2] Recently pub-lished meta-analyses suggest a direct association between combustible cigarette smoking and COVID-19 disease pro-gression,[3] severity, and death.[4] Specifically, COVID-19 pa-tients who were current smokers were at nearly two-fold odds of COVID-19 disease progression,[3] and about 1.5-fold odds of COVID-19 severity and risk of death compared to patients who were never smokers.[4]

While past 30-day (current) combustible cigarette smoking continues to decline significantly among U.S. college stu-dents, with a 2019 prevalence of about 8%, vaping nicotine has increased to 22% among this population.[5] Associations between current dual use of combustible cigarettes and e-cigarettes and COVID-19 symptomatology, testing, and diagnosis have been reported among youth and young adults.[6] When compared to never users, current dual-users of e-cigarettes and combustible cigarettes were at nearly five-fold odds of reporting COVID-19-related symptoms, nine-fold odds of reporting COVID-19 testing, and nearly seven-fold odds of reporting a positive COVID-19 diagnosis. However, a research gap re-mains on polytobacco use and COVID-19 outcomes among the college student population. Given concerns about the potential endemic nature of COVID-19,[7] and high e-cigarette use among college students,[5] there is a need to gain a better understanding of the link between polytobacco use and COVID-19-related outcomes among this high-risk population. Consequently, the current study examined dual- and poly-tobacco use patterns and COVID-19 symptomatology, testing, and diagnosis status among a sample of college student e-cigarette users in the U.S.

Methods

Design

College students reporting past 30-day e-cigarette use from four large, geographically diverse U.S. universities were re-cruited to participate in an online survey between October 2020 and December 2020. Located in Arkansas, Indiana, Ohio, and Texas, each of the four participating universities are public, 4-year doctoral institutions with very high research activity and have a student population ranging from 28,000–68,000.[8] Data collection at each university was planned to begin in the middle of fall semester of 2020 due to the overall study's objective of measuring past 30-day tobacco product use behavior among students on campus during the academic year. Due to the COVID-19 pandemic, all four universities offered similar course format options to students for them to complete their coursework in an online format, in-person format, or hybrid format. Despite the COVID-19 pandemic, each campus remained open to students and allowed students to live in on-campus housing during data collection in the fall semester. COVID-19 testing programs were similar among the four campuses, which required selected students to participate in random testing.

Institutional review boards at each institution vetted and approved study procedures by November 2020. Upon re-ceiving IRB approval, data collection began at each respective school, occurring between October 2020 and December 2020. Potential participants were recruited at each respective univer-sity by disseminating email invitations widely using under-graduate and graduate course listservs as well as campus-wide listservs. The email invitation described the study's purpose, which also included a link to a research information sheet and Qualtrics survey.[9] Students who clicked the website link had to first acknowledge reading the research information sheet and then proceed to the initial survey questions that confirmed they were eligible for participation. Students who met these eligibility criteria were then asked the main survey questions, which took approximately 10 min to complete. Three universities provided $10 incentives to students for survey completion. The university in Ohio was unable to offer monetary incentives to students for participation at the time of survey completion due to a student financial aid policy.

Sample

College students eligible for participation in the overall study were between the ages of 18–26 years, used an e-cigarette or vaping device in the past 30 days, and were currently on campus. For the purpose of the current study, we excluded student e-cigarette users who were ages 25–26 years due to differing age trends of tobacco product use among older age groups.[5,10] A total of 756 student current (past 30-day) e-cigarette users who were ages 18–24 years were included in the current study. Participants provided written informed consent by acknowledging the research information sheet before proceeding to the survey. Due to the nature of sending participation invitations via campus listservs, response rates could not be calculated. We calculated the needed sample size with a 95% confidence interval based on a 100,000-population size and a conservative 50–50 split where the population is assumed to be relatively varied.[11] Based on this calculation,

we estimated we needed a minimum of 383 completed surveys for the current study's final sample size in order to have sufficient power for the statistical analysis.

Measures

Current tobacco use. Participants were asked the following question to confirm current e-cigarette use: "During the past 30 days, on how many days did you use an electronic vapor product?" Response options ranged from 0–30 days. Electronic vapor products were defined as e-cigarettes, vapes, vape pens, e-cigars, e-hookahs, hookah pens, and mods, and brand examples were provided (eg, JUUL). All participants reported current use on ≥1 day in the past 30 days. To determine current dual- and polytobacco use, current e-cigarette users were asked two questions about their past 30-day combustible tobacco product use. Specifically, respondents were asked the following: 1) "During the past 30 days, on how many days did you smoke cigarettes? " and 2) "During the past 30 days, on how many days did you smoke cigars, cigarillos, or little cigars?" Response options for the two questions ranged from 0–30 days. Due to the highly skewed nature of the frequency of use variables, respondents were categorized into four mutually exclusive use groups: 1) exclusive e-cigarette users (ie, did not smoke combustible cigarettes or cigars in the past 30 days); 2) dual e-cigarette and cigarette users (ie, smoked combustible cigarettes, but not cigars in the past 30 days); 3) dual e-cigarette and cigar users (ie, smoked cigars, but not combustible cigarettes in the past 30 days); and 4) poly users of e-cigarettes, cigarettes, and cigars (ie, smoked combustible cigarettes and cigars in the past 30 days).

It is important to assess dualtobacco use of e-cigarettes and cigars separately from dualtobacco use of e-cigarettes and combustible cigarettes due to differences in the sizes, fillers, flavors, constituents (eg, nicotine and carcinogens), and topography patterns of combustible cigars compared to combustible cigarettes.[12-14] However, the sample size of the dual e-cigarette and cigar use group in the current study was relatively small (n=35), which was anticipated due to the relatively lower cigar smoking prevalence of about 4% compared to the combustible cigarette smoking prevalence of about 8% among U.S. 18–24-year-olds.[10] In order to test if statistical results were sensitive to the grouping of participants, a sensitivity analysis was performed combining the dualtobacco use groups into one group, resulting in three mutually exclusive use groups: 1) exclusive e-cigarette users (ie, did not smoke combustible cigarettes or cigars in the past 30 days); 2) dual e-cigarette and combustible cigarette or cigar users (ie, smoked either combustible cigarettes or cigars, but did not smoke both combustible cigarettes and cigars in the past 30 days); and 3) poly users of e-cigarettes, combustible cigarettes, and cigars (ie, smoked combustible cigarettes and cigars in the past 30 days).

COVID-19 outcomes. Respondents reported whether they were currently experiencing COVID-19 symptoms (eg, cough,

fever or chills, difficulty breathing, fatigue, muscle ache, headache, new loss of taste or smell, nasal congestion, sore throat, nausea or vomiting, and diarrhea). Symptoms were those outlined specifically by the Centers for Disease Control and Prevention.[15] Students endorsing ≥1 symptom were categorized as having COVID-19 symptomatology. Students also reported whether they had been tested for COVID-19. Those tested were subsequently asked whether they had positive or negative diagnoses. Student demographics and other information—including age, sex, race/ethnicity (non-Hispanic White, Black, Other/Multiracial, and Hispanic), sexual orientation (heterosexual, lesbian, gay, bisexual, transgender, and questioning (LGBTQ)), university site, current fraternity/sorority membership status, and current residence (off-campus housing, campus residence hall, other university housing, and parent's home)—were also assessed.

Analysis

Multivariable logistic regression models compared differences in the likelihood of reporting COVID-19 symptomatology, testing, and prior positive diagnosis by the four mutually exclusive polytobacco use groups. All models controlled for student age, sex, race/ethnicity, sexual orientation, university site, fraternity/sorority membership status, and residence. We tested the sensitivity of our main models' results by combining the two dualtobacco product use groups to assess three mutually exclusive groups (ie, exclusive e-cigarette use, dualtobacco use, and polytobacco use) and the covariates as the independent variables in three refitted multivariable logistic regression models for each of the three outcome variables of COVID-19 symptomatology, testing, and diagnosis. We report model fit statistics (ie, Hosmer and Lemeshow goodness-of-fit tests) and adjusted odds ratios (AORs) and 95% confidence intervals (CIs). Participants with missing data on COVID-19 symptoms (n=41, 5.1%), past 30-day tobacco use (n=5, 0.7%), and student covariates (n=5, 0.7%) were removed prior to analysis. Statistical analyses conducted using Stata SE version 16,[16] indicated no significance differences between those providing complete and missing data.

Results

Among the 756 current e-cigarette users, the mean student age was 20.3 (SD=1.5) years; 49.6% (n=375) were female; 20.0% (n=151) were LGBTQ; and 61.6% (n=466) were non-Hispanic White, 15.5% (n=117) were Hispanic, 14.8% (n=112) were non-Hispanic Other/Multiracial, and 8.1% (n=61) were non-Hispanic Black (Table 1). Approximately 25% (n=187) of students were current fraternity/sorority members, and the majority (57.9%; n=438) lived in off-campus housing.

Concerning current dual- and polytobacco use patterns among the four exclusive groups, 53.6% (n=405) were exclusive e-cigarette users, 20.4% (n=154) were dual e-cigarette

Table 1. Current Tobacco Use Patterns based on COVID-19 Outcomes Among College Student E-Cigarette Users.

Student characteristic	Overall n (%)[a]	COVID-19 symptomatology				COVID-19 testing				COVID-19 diagnosis			
		n (%)[b]	AOR	95% CI	p	n (%)[b]	AOR	95% CI	p	n (%)[b]	AOR	95% CI	p
Current tobacco use													
Exclusive e-cigarette use	405 (53.6)	21 (5.2)	Ref	Ref	Ref	338 (83.5)	Ref	Ref	Ref	48 (14.2)	Ref	Ref	Ref
Dual e-cigarette and combustible cigarette use	154 (20.4)	17 (11.0)	2.12	1.05–4.27	0.035	130 (84.4)	0.87	0.50–1.50	0.615	27 (20.8)	1.40	0.80–2.44	0.234
Dual e-cigarette and cigar use	35 (4.6)	4 (11.4)	2.50	0.77–8.07	0.125	29 (82.9)	1.24	0.47–3.28	0.660	8 (27.6)	2.08	0.83–5.20	0.116
Polytobacco use	162 (21.4)	53 (32.7)	3.70	1.78–7.70	<0.001	149 (92.0)	1.43	0.67–3.04	0.354	25 (16.8)	2.16	1.11–4.20	0.023
Age, M (SD)	20.3 (1.5)	21.2 (1.8)	1.31	1.11–1.54	0.001	20.2 (1.5)	0.90	0.76–1.07	0.224	20.0 (1.5)	0.97	0.82–1.16	0.765
Sex													
Male	381 (50.4)	49 (12.9)	Ref	Ref	Ref	329 (86.4)	Ref	Ref	Ref	65 (19.8)	Ref	Ref	Ref
Female	375 (49.6)	46 (12.3)	1.85	1.09–3.15	0.022	317 (84.5)	1.16	0.74–1.83	0.514	43 (13.6)	0.55	0.34–0.87	0.010
Race/Ethnicity													
Non-Hispanic White	466 (61.6)	52 (11.2)	Ref	Ref	Ref	400 (85.8)	Ref	Ref	Ref	79 (19.8)	Ref	Ref	Ref
Non-Hispanic Black	61 (8.1)	19 (31.2)	1.35	0.62–2.94	0.444	57 (93.4)	1.22	0.38–3.96	0.735	4 (7.0)	0.47	0.15–1.46	0.192
Non-Hispanic Other/Multiracial[c]	112 (14.8)	14 (12.5)	1.23	0.60–2.54	0.567	91 (81.3)	0.82	0.45–1.47	0.499	10 (11.0)	0.40	0.19–0.83	0.014
Hispanic	117 (15.5)	10 (8.6)	0.90	0.40–2.01	0.798	98 (83.8)	1.24	0.68–2.26	0.489	15 (15.3)	0.78	0.40–1.50	0.451
Sexual orientation													
Heterosexual	605 (80.0)	59 (9.8)	Ref	Ref	Ref	518 (85.6)	Ref	Ref	Ref	89 (17.2)	Ref	Ref	Ref
LGBTQ[d]	151 (20.0)	36 (23.8)	1.62	0.91–2.86	0.098	128 (84.8)	0.71	0.41–1.23	0.223	19 (14.8)	1.02	0.58–1.82	0.937
University site													
University in Texas	328 (43.4)	18 (5.5)	Ref	Ref	Ref	250 (76.2)	Ref	Ref	Ref	41 (16.4)	Ref	Ref	Ref
University in Arkansas	177 (23.4)	53 (29.9)	2.66	1.07–6.60	0.035	169 (95.5)	6.50	2.35–18.01	<0.001	15 (8.9)	0.22	0.09–0.56	0.002
University in Indiana	194 (25.7)	15 (7.7)	1.47	0.69–3.12	0.314	184 (94.9)	5.84	2.87–11.87	<0.001	39 (21.2)	1.22	0.71–2.09	0.471
University in Ohio	57 (7.5)	9 (15.8)	2.69	1.06–6.83	0.037	43 (75.4)	1.00	0.49–2.03	0.995	13 (30.2)	1.61	0.72–3.58	0.243
Fraternity/Sorority membership													
No	569 (75.3)	55 (9.7)	Ref	Ref	Ref	479 (84.2)	Ref	Ref	Ref	72 (15.0)	Ref	Ref	Ref
Yes	187 (24.7)	40 (21.4)	1.09	0.62–1.91	0.769	167 (89.3)	1.07	0.61–1.89	0.814	36 (21.6)	1.90	1.15–3.14	0.012
Current residence													
Off-campus housing	438 (57.9)	33 (7.5)	Ref	Ref	Ref	361 (82.4)	Ref	Ref	Ref	63 (17.5)	Ref	Ref	Ref
Campus residence hall	198 (26.2)	13 (15.7)	1.29	0.62–2.70	0.501	184 (92.9)	1.16	0.56–2.38	0.692	27 (14.7)	1.33	0.71–2.51	0.377
Other on-campus housing	65 (8.6)	19 (29.2)	2.29	1.05–5.03	0.038	59 (90.8)	1.46	0.58–3.73	0.424	12 (20.3)	1.08	0.50–2.32	0.840
Parent home	55 (7.3)	12 (21.8)	1.38	0.57–3.34	0.480	42 (76.4)	0.42	0.20–0.92	0.030	6 (14.3)	1.30	0.48–3.54	0.609

Abbreviations; e-cigarette, electronic cigarette; COVID-19, coronavirus disease 2019; AOR, adjusted odds ratio; CI, confidence interval; Ref, reference category; LGBTQ, lesbian, gay, bisexual, transgender, and questioning.

All multivariable logistic regression models control for student age, sex, race/ethnicity, sexual orientation, university site, fraternity/sorority membership, and current residence.

[a]Percent refers to column percent, unless otherwise noted.

[b]Percent refers to row percent, unless otherwise noted.

[c]Non-Hispanic Other/Multiracial category includes Asian or Pacific Islander, American Indian, Alaska Native, or Native Hawaiian, Biracial, and Multiracial.

[d]LGBTQ includes asexual, bisexual, gay, lesbian, pansexual, queer, questioning, and same gender loving.

Table 2. Sensitivity to Combining Current Dualtobacco Use Groups: Current Tobacco Use Patterns Based on COVID-19 Outcomes Among College Student E-Cigarette Users.

Student current tobacco use	Overall	COVID-19 symptomatology				COVID-19 testing				COVID-19 diagnosis			
	n (%)[a]	n (%)[b]	AOR	95% CI	p	n (%)[b]	AOR	95% CI	p	n (%)[b]	AOR	95% CI	p
Exclusive e-cigarette use	405 (53.6)	21 (5.2)	Ref	Ref	Ref	338 (83.5)	Ref	Ref	Ref	48 (14.2)	Ref	Ref	Ref
Dualtobacco use[c]	189 (25.0)	21 (11.1)	2.19	1.13–4.23	0.020	159 (84.1)	0.94	0.56–1.56	0.807	35 (22.0)	1.52	0.91–2.53	0.110
Polytobacco use	162 (21.4)	53 (32.7)	3.71	1.78–7.71	<0.001	149 (92.0)	1.43	0.67–3.04	0.353	25 (16.8)	2.16	1.11–4.19	0.023

e-cigarette, electronic cigarette; COVID-19, coronavirus disease 2019; AOR, adjusted odds ratio; CI, confidence interval; Ref, reference category.
All multivariable logistic regression models control for student age, sex, race/ethnicity, sexual orientation, university site, fraternity/sorority membership, and current residence.
[a]Percent refers to column percent.
[b]Percent refers to row percent.
[c]Dual use of e-cigarettes and combustible cigarettes or dual use of e-cigarettes and cigars.

and combustible cigarette users, 4.6% (n=35) were dual e-cigarette and cigar users, and 21.4% (n=162) were poly users of e-cigarettes, combustible cigarettes, and cigars (see Table 1). Concerning the current dual- and polytobacco use patterns among the three exclusive groups for the sensitivity analysis, 53.6% (n=405) were exclusive e-cigarette users, 25.0% (n=189) were dual e-cigarette and combustible cigarette or cigar users, and 21.4% (n=162) were poly users of e-cigarettes, combustible cigarettes, and cigars (Table 2).

Current Dual- and Polytobacco Use Patterns and COVID-19 Outcomes

Overall, 12.6% (n=95) of students reported currently experiencing COVID-19 symptomatology, with the top three symptoms being nasal congestion (34.7%, n=33), cough (30.5% n=29), and sore throat (29.5%, n=28). Respondents with current symptomatology reported an average of 2.3 (SD=1.5) symptoms. Most students (85.5%, n=646) reported COVID-19 testing, and of those, 16.7% (n=108) reported a positive COVID-19 diagnosis.

The main multivariable logistic regression model results are presented in Table 1. The Hosmer and Lemeshow goodness-of-fit tests for the main models with COVID-19 symptomatology (P=0.359), testing (P=0.818), and diagnosis (P=0.549) as the outcomes were not significant, indicating good fit for all three models. Additionally, for all models, variance inflation factors (VIFs) ranged from 1.06–2.81 with mean VIFs of 1.34–1.37, indicating no multicollinearity in the models. The sensitivity multivariable logistic regression model results are presented in Table 2. The Hosmer and Lemeshow goodness-of-fit tests for the sensitivity models

with COVID-19 symptomatology (P=0.410), testing (P=0.781), and diagnosis (P=0.737) as the outcomes were also not significant, indicating good fit for all three models. Additionally, for all sensitivity models, variance inflation factors (VIFs) ranged from 1.09–2.81 with mean VIFs of 1.36–1.39, indicating no multicollinearity in the models.

For the main model findings, dual e-cigarette and combustible cigarette users (AOR=2.12, 95%CI=1.05–4.27) and poly users of e-cigarettes, combustible cigarettes, and cigars (AOR=3.70, 95%CI=1.78–7.70) were more likely to have current COVID-19 symptomatology, compared to exclusive e-cigarette users (see Table 1). Older students, female students, those attending the university in Arkansas and Ohio, and who lived in on-campus housing other than a campus residence hall were significantly more likely to have COVID-19 symptomatology than younger students, male students, those attending the university in Texas, and who lived in off-campus housing, respectively. For the sensitivity model findings, dualtobacco users of e-cigarettes and combustible cigarettes or cigars were 2.19 times more likely (95%CI =1.13–4.23) to report current COVID-19 symptomatology compared to exclusive e-cigarette users after covariate adjustment (see Table 2). Polytobacco users of e-cigarettes, combustible cigarettes, and cigars were 3.71 times more likely (95%CI =1.78–7.71) to report COVID-19 symptomatology than exclusive e-cigarette users. Similar to the main model covariate findings, older students (AOR=1.31, 95%CI=1.11–1.53, P=0.001), female students (AOR=1.85, 95%CI=1.09–3.13, P=0.023), those attending the universities in Arkansas (AOR=2.64, 95%CI=1.06–6.55, P=0.036) and Ohio (AOR=2.71, 95%CI=1.07–6.86, P=0.036), and who lived in on-campus housing other than a campus residence hall (AOR=2.29,

95%CI=1.05–5.03, P=0.038) were significantly more likely to have COVID-19 symptomatology than younger students, male students, those attending the university in Texas, and who lived in off-campus housing, respectively.

While no differences were found between the four tobacco use groups based on COVID-19 testing in the main model, significant covariates included university site and residence location; students attending the universities in Arkansas and Indiana were at increased odds of being tested for COVID-19 than students attending the university in Texas, whereas those who lived with their parents were at reduced odds of being tested than students who lived in off-campus housing (see Table 1). No differences were found between the three tobacco use groups based on COVID-19 testing in the sensitivity model (see Table 2). Similar to the main model findings, participants attending the universities in Arkansas (AOR=6.40, 95%CI=2.31–17.74, P<0.001) and Indiana (AOR=5.71, 95%CI=2.82–11.57, P<0.001) were at increased odds of being tested for COVID-19, and participants who lived with their parents (AOR=0.43, 95%CI=0.20–0.93, P=0.031) were at reduced odds of being tested than students attending the university in Texas and who lived in off-campus housing, respectively.

When compared with exclusive e-cigarette users, poly-tobacco users were 2.16 times more likely (95%CI=1.11–4.20) to have a positive COVID-19 diagnosis. Concerning significant covariates, students who were female, non-Hispanic Other/Multiracial, and attending the university in Arkansas were at reduced odds of having a prior positive COVID-19 diagnosis than students who were male, non-Hispanic White, and attending the university in Texas (see Table 1). Additionally, fraternity/sorority members were at increased odds of having a prior positive COVID-19 diagnosis than students who were not fraternity/sorority members. Similarly, in the sensitivity model, polytobacco users were significantly more likely (AOR=2.16, 95%CI=1.11–4.19) to have a prior positive COVID-19 diagnosis than exclusive e-cigarette users (see Table 2). Similar to the main model findings, students who were female (AOR=0.54, 95%CI=0.34–0.86, P=0.010), non-Hispanic Other/Multiracial (AOR=0.40, 95%CI=0.19–0.84, P=0.015), and attending the university in Arkansas (AOR=0.22, 95%CI=0.09–0.56, P=0.002) were at reduced odds of having a COVID-19 diagnosis compared to students who were male, non-Hispanic White, and attending the university in Texas. Fraternity/sorority members (AOR=1.90, 95%CI=1.15–3.14, P=0.012) were at increased odds of having a COVID-19 diagnosis compared to students who were not fraternity/sorority members (see Table 1).

Discussion

Summary

Overall, findings from this investigation assert that compared to college student exclusive e-cigarette users, college student e-cigarette users who concurrently engage in polytobacco use

with combustible cigarettes and cigars were at increased risk of having COVID-19 symptomatology and having received a prior positive diagnosis. No differences were found between current tobacco use groups and COVID-19 testing, which was expected due to similar random COVID-19 testing programs at all four universities during the fall academic semester. Further, dual e-cigarette and combustible cigarette users exhibited more than two times the odds of reporting current COVID-19 symptomatology compared to exclusive e-cigarette users. Our findings align with prior research among a U.S. sample of adults documenting current exclusive e-cigarette users had reduced odds of reporting respiratory symptoms compared to dual users.[17] It is noteworthy that dual e-cigarette and cigar users were also at over two-fold increased odds of having COVID-19 symptomatology and diagnosis, although not statistically significant likely due to the small group size. Thus, sensitivity results combining dualtobacco use groups revealed that dualtobacco users of e-cigarettes and combustible cigarettes or cigars were at significantly two-fold odds of reporting COVID-19 symptomatology. A prior review reports tobacco use may increase COVID-19 infection risk via alteration of the immune and oxidative stress responses and adverse respiratory and cardiovascular effects.[18] Additionally, e-cigarette use and combustible tobacco use impair endothelial function, which is an early marker of cardiovascular disease and may contribute to increased COVID-19 symptomatology and severe health consequences.[19] Thus, tobacco use can lead to increased cardiopulmonary risk due to increased risk of both infection and more severe COVID-19 outcomes.[20]

Due to the increased risk of nicotine dependence, it is concerning that about 1-in-5 college student e-cigarette users in the current study were polytobacco users, though this is consistent with prior national estimates noting a 21% prevalence rate of polytobacco use.[21] Longitudinal evidence suggests the majority of e-cigarette users are also poly-tobacco users, and that polytobacco users are at decreased likelihood of quitting tobacco use 2–3 years later compared with exclusive e-cigarette users.[22] Moreover, polytobacco users may be at higher risk of having a prior positive COVID-19 diagnosis due to vaping/smoking behavior involving higher finger-to-lip contact and sharing devices, as these behaviors can increase the modes of transmission of SARS-CoV-2 (ie, contact or droplet, fomite).[23] Future research should consider measuring these behavioral aspects of tobacco product use that may place polytobacco users at increased susceptibility of COVID-19 diagnosis. Additionally, we found female students were more likely to report COVID-19 symptomatology, but less likely to report a prior positive COVID-19 diagnosis when compared to male students. This parallels documented sex-based disparities in which males have higher COVID-19 incidence and severity than females, likely due to varying genetics and sex hormones, as well as a higher prevalence of comorbidities and poor health behaviors including tobacco use among males.[24]

Specifically, polytobacco use risk is higher in male young adults than that of female young adults.[21]

Limitations

The findings of this investigation should be considered in unison with several limitations. First, although we included students at four geographically diverse U.S. locations, the data are not nationally generalizable. Second, while COVID-19 testing programs and course format offerings were similar at each of the four university campuses, we did not collect data on whether students were completing their courses in-person, online, or via a hybrid format during the fall semester. We did not have information available on COVID-19 testing rates at each campus. Specifically, university sites may have differed based on students' likelihood of being tested for COVID-19, irrespective of tobacco use, due to the number of tests randomly administered during the fall semester, which may have varied based on test availability and accessibility both on-campus and off-campus (eg, pharmacy). Third, we were unable to quantify tobacco product use behaviors (eg, number of hand-to-mouth instances) or other preventive health behaviors (eg, hand-washing) that may place college student e-cigarette users at greater risk for COVID-19 infection risk. Fourth, we were unable to assess biochemically measured tobacco use (eg, cotinine) or confirm COVID-19 outcomes via medical record review due to the anonymous survey nature. Fifth, since all participants currently used e-cigarettes, we did not have a nontobacco use comparison group. Finally, we administered the survey cross-sectionally and were unable to assess relationships over time.

Significance

Notwithstanding the limitations noted, this investigation suggests polytobacco use could increase the risk of COVID-19 symptomatology and diagnosis among college student e-cigarette users. Since the concurrent use of two or more tobacco products increased COVID-19-related risks, our results underscore the need to strengthen programming geared to prevent and combat college student e-cigarette and polytobacco use.

"SO WHAT?" Implications for Health Promotion Practitioners and Researchers

What is already known on this topic?

Tobacco use is a potential risk factor for COVID-19 symptoms and infection among youth and young adults. A research gap remains on dual- and polytobacco use and COVID-19 outcomes among college student electronic cigarette (e-cigarette) users.

What does this article add?

College student polytobacco users of e-cigarettes, combustible cigarettes, and cigars are at increased risk of COVID-19 symptomatology and diagnosis compared to college student exclusive e-cigarette users. College student dualtobacco users are also at increased risk of COVID-19 symptomatology compared to exclusive e-cigarette users.

What are the implications for health promotion practice or research?

Implementing university-based programming to reduce dual- and polytobacco use of e-cigarettes with combustible tobacco products may have the potential to reduce COVID-19 symptomatology and infection.

Authors' Contribution

Dr. Merianos conceptualized and designed the study, carried out the analysis and interpretation of the data, drafted the manuscript, and approved the final manuscript as submitted. Dr. Russell conceptualized and designed the study, revised the manuscript for important intellectual content, and approved the final manuscript as submitted. Dr. Mahabee-Gittens conceptualized and designed the study, drafted the manuscript, and approved the final manuscript as submitted. Dr. Barry conceptualized and designed the study, revised the manuscript for important intellectual content, and approved the final manuscript as submitted.

Meng Yang conceptualized and designed the study, revised the manuscript for important intellectual content, and approved the final manuscript as submitted. Dr. Lin conceptualized and designed the study, interpreted the data, revised the manuscript for important intellectual content, and approved the final manuscript as submitted.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Research Ethics and Patient Consent

The University of Cincinnati (IRB#: 2020-0717), University of Arkansas (IRB#: #2007273054), Texas A&M University (IRB#: 2020-0160), and Indiana University (IRB#: 2004149119) provided approval for all study procedures. Participants provided written informed consent by acknowledging the research information sheet before proceeding to the survey.

References

1. Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect Dis.* 2020;20(5):533-534. doi:10.1016/S1473-3099(20)30120-1

2. Brake SJ, Barnsley K, Lu W, McAlinden KD, Eapen MS Sohal SS. Smoking upregulates angiotensin-converting enzyme-2 receptor: a potential adhesion site for novel coronavirus SARS-CoV-2 (Covid-19). *J Clin Med* 2020;9(3):841. doi:10.3390/jcm9030841.

3. Patanavanich R, Glantz SA. Smoking is associated with COVID-19 progression: a meta-analysis. *Nicotine Tob Res.* 2020;22(9):1653-1656. doi: 10.1093/ntr/ntaa082

4. Umnuaypornlert A, Kanchanasurakit S, Lucero-Prisno DEI and Saokaew S. Smoking and risk of negative outcomes among COVID-19 patients: a systematic review and meta-analysis. *Tob Induc Dis* 2021;19:09. doi:10.18332/tid/132411.

5. Schulenberg JE, Johnston LD and O'Malley PM. *Monitoring the Future national survey results on drug use, 1975-2019: volume II, college students & adults ages 19-60*. Ann Arbor, MI: Institute for Social Research, The University of Michigan; 2020.

6. Gaiha SM, Cheng J, Halpern-Felsher B. Association between youth smoking, electronic cigarette use, and coronavirus disease 2019. *J Adolesc Health.* 2020;67(4):519-523. doi:10.1016/j.jadohealth.2020.07.002

7. Phillips N. The coronavirus is here to stay - here's what that means. *Nature*. 2021;590(7846):382-384. doi: 10.1038/d41586-021-00396-2

8. Indiana University Center for Postsecondary Research. *The Carnegie Classification of Institutions of Higher Education*, 2018 edition. Bloomington, IN: Indiana University Center for Postsecondary Research; 2018. Available at: http://carnegieclassifications.iu.edu/. Accessed August 4, 2021.

9. Qualtrics. *Qualtrics* Available at: https://www.qualtrics.com/. Updated 2021. Accessed August 4, 2021.

10. Cornelius ME, Wang TW, Jamal A, Loretan CG, Neff LJ. Tobacco product use among adults - United States, 2019. *MMWR Morb Mortal Wkly Rep.* 2020;69(46):1736-1742. doi: 10.15585/mmwr.mm6946a4.

11. Salant P, Dillman DA. *How to conduct your own survey*. New York: Wiley; 1994.

12. Chang CM, Rostron BL, Chang JT, et al. Biomarkers of exposure among U.S. adult cigar smokers: Population Assessment of Tobacco and Health (PATH) Study Wave 1 (2013-2014). *Cancer Epidemiol Biomarkers Prev.* 2019;28(5):943-953. doi: 10.1158/1055-9965.EPI-18-0539

13. Kong G, Creamer MR, Simon P, et al. Systematic review of cigars, cigarillos, and little cigars among adolescents: setting research agenda to inform tobacco control policy. *Addict Behav* 2019;96:192-197. doi:10.1016/j.addbeh.2019.04.032.

14. Koszowski B, Thanner MH, Pickworth WB, Taylor KM, Hull LC, Schroeder MJ. Nicotine content and physical properties of large cigars and cigarillos in the United States. *Nicotine Tob Res*. 2018;20(3):393-398. doi: 10.1093/ntr/ntx054

15. Centers for Disease Control and Prevention. Symptoms of coronavirus. Available at: https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html. Updated 2021. Accessed August 4, 2021.

16. StataCorp. *Stata statistical software: release 16*. College Station, TX: StataCorp LLC; 2019.

17. 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(2):140-147. doi:10.1136/tobaccocontrol-2018-054694.

18. Haddad C, Bou Malhab S, Sacre H and Salameh P. Smoking and COVID-19: a scoping review. *Tob Use Insights* 2021;14:1179173X21994612. doi:10.1177/1179173X21994612.

19. Münzel T, Hahad O, Kuntic M, Keaney JF, Deanfield JE and Daiber A. Effects of tobacco cigarettes, e-cigarettes, and waterpipe smoking on endothelial function and clinical outcomes. *Eur Heart J* 2020;41(41):4057-4070. doi:10.1093/eurheartj/ehaa460.

20. Gupta AK, Nethan ST, Mehrotra R. Tobacco use as a well-recognized cause of severe COVID-19 manifestations. *Respir Med.* 2020;176:106233. doi: 10.1016/j.rmed.2020.106233

21. Soneji S, Sargent J and Tanski S. Multiple tobacco product use among US adolescents and young adults. *Tob Control* 2016;25(2):174-180. doi:10.1136/tobaccocontrol-2014-051638.

22. Stanton CA, Sharma E, Edwards KC, et al. Longitudinal transitions of exclusive and polytobacco electronic nicotine delivery systems (ENDS) use among youth, young adults and adults in the USA: findings from the PATH Study waves 1–3 (2013–2016). *Tob Control* 2020;29(Suppl 3):S147-S154. doi:10.1136/tobaccocontrol-2019-055574.

23. World Health Organization. Coronavirus disease (COVID-19): tobacco. Available at: https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-tobacco. Updated May 27, 2020. Accessed August 4, 2021.

24. Haitao T, Vermunt JV, Abeykoon J, et al. COVID-19 and sex differences: mechanisms and biomarkers. *Mayo Clin Proc* 2020;95(10):2189-2203. doi:10.1016/j.mayocp.2020.07.024.