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RESEARCH ARTICLE

Association of E-Cigarettes With Erectile Dysfunction: The Population Assessment of Tobacco and Health Study

Omar El-Shahawy, MD, MPH, PhD,[1,2,3] Tanmik Shah, MPH,[1,2] Olufunmilayo H. Obisesan, MD, MPH,[3] Meghan Durr, MPH,[1] Andrew C. Stokes, PhD,[4] Iftekhar Uddin, MBBS, MSPH,[3] Ria Pinjani, MPH,[5] Emelia J. Benjamin, MD,[6] Mohammadhassan Mirbolouk, MD,[3,7] Albert D. Osei, MD, MPH,[3,8] Tom Loney, PhD,[9] Scott E. Sherman, MD, MPH,[1,2,10] Michael J. Blaha, MD[3]

Introduction: Smoking is independently associated with erectile dysfunction and cardiovascular disease. Given existing similarities in the constituents of e-cigarettes or ENDS and cigarettes, this study examines the association between ENDS use and erectile dysfunction.

Methods: Data from Wave 4 (2016−2018) of the Population Assessment of Tobacco and Health study were analyzed in 2020. Male participants aged ≥20 years who responded to the erectile dysfunction question were included. Multivariable logistic regression models examined the association of ENDS use with erectile dysfunction within the full sample and in a restricted sample (adults aged 20−65 years with no previous cardiovascular disease diagnosis) while adjusting for multiple risk factors.

Results: The proportion of erectile dysfunction varied from 20.7% (full sample) to 10.2% (restricted sample). The prevalence of current ENDS use within the full and restricted samples was 4.8% and 5.6%, respectively, with 2.1% and 2.5%, respectively, reporting daily use. Current daily ENDS users were more likely to report erectile dysfunction than never users in both the full (AOR=2.24, 95% CI=1.50, 3.34) and restricted (AOR=2.41, 95% CI=1.55, 3.74) samples. In the full sample, cardiovascular disease history (versus not present) and age ≥65 years (versus age 20−24 years) were associated with erectile dysfunction (AOR=1.39, 95% CI=1.10, 1.77; AOR= 17.4, 95% CI=12.15, 24.91), whereas physical activity was associated with lower odds of erectile dysfunction in both samples (AOR range=0.44−0.58).

Conclusions: The use of ENDS seems to be associated with erectile dysfunction independent of age, cardiovascular disease, and other risk factors. While ENDS remain under evaluation for harm reduction and smoking-cessation potential, ENDS users should be informed about the possible association between ENDS use and erectile dysfunction.

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From the [1]Department of Population Health, New York University Grossman School of Medicine, New York, New York; [2]Global and Environmental Health Program, NYU School of Global Public Health, New York, New York; [3]The Ciccarone Center for the Prevention of Cardiovascular Disease, John Hopkins Medicine, Baltimore, Maryland; [4]Department of Global Health, Boston University School of Public Health, Boston, Massachusetts; [5]New York University Steinhardt School of Culture, Education, and Human Development, New York, New York; [6]Cardiovascular Medicine Section, Whitaker Cardiovascular Institute, Boston University School of Medicine, Boston, Massachusetts; [7]Department of Internal Medicine, Yale School of Medicine, Yale University, New Haven, Connecticut; [8]Department of Medicine, MedStar Union Memorial Hospital, Baltimore, Maryland; [9]College of Medicine, Mohammed Bin Rashid University of Medicine and Health Sciences, Dubai, United Arab Emirates; and [10]Department of Medicine, VA NY Harbor Healthcare System, New York, New York

Address correspondence to: Omar El Shahawy, MD, MPH, PhD, Section on Tobacco, Alcohol and Drug Use, Department of Population Health, New York University Grossman School of Medicine, 180 Madison Avenue, Office 17−50, New York NY 10016. E-mail: omar.elshahawy@nyulangone.org.

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INTRODUCTION

Erectile dysfunction (ED), a distressing condition that significantly compromises the quality of life of men worldwide, is defined as the inability to attain and maintain an erection sufficient for satisfactory sexual intercourse.[1,2] It is estimated that approximately 26 new cases of ED per 1,000 men occur annually worldwide,[3] and in the U.S., 1 in every 5 men (18.4%) aged ≥20 years reports some degree of ED.[4] Although ED is commonly seen in older adults (aged >65 years),[5] there are underlying pathological and psychological conditions associated with ED that are independent of age, including cardiovascular disease (CVD).[4−7] In addition, both ED and CVD share common underlying risk factors such as older age, higher body mass index (BMI) and cholesterol, diabetes, hypertension, poor mental health status, and lack of physical activity.[6−9]

Tobacco use is an independent risk factor for ED, and smoking has been associated with changes in penile vasculature that are directly associated with ED.[10−14] Electronic Nicotine Delivery Devices (ENDS) are perceived to be less harmful than cigarettes[15] and are widely advertised as smoking-cessation aids.[16] Moreover, several countries such as Belgium and the United Kingdom use ENDS in smoking-cessation treatment.[17,18] However, there is a paucity of data on the association of ENDS with ED.[19] Studies have shown that the nicotine present in combustible cigarettes is responsible for many physiologic changes that contribute to the development of ED.[10,13,14,20−22] Whereas the first generation of ENDS delivered low levels of nicotine, many of the newer ENDS devices, coupled with currently available high-nicotine e-liquid concentrations, can effectively deliver higher levels of nicotine than cigarettes.[23,24] Findings from previous studies among patients with diabetes or CVD who were also diagnosed with ED suggested a synergistic effect of nicotine present in ENDS as a major risk factor for both CVD and ED.[25,26] However, there are no published studies investigating the association of ENDS use with ED as noted in a recent review by Corona et al.,[19] highlighting a major gap in the literature.

This study uses cross-sectional data from the nationally representative Population Assessment of Tobacco or Health (PATH) study to examine the association between self-reported ENDS use and ED among male adults in the U.S. It is hypothesized that ENDS use is associated with ED after adjusting for sociodemographic characteristics and other risk factors associated with ED.

METHODS

Study Sample

The PATH study is a nationally representative study of 45,971 U.S. adults aged ≥18 years. PATH examines various tobacco use behaviors and health outcomes.[27] Further details about PATH are published elsewhere.[28] The PATH study was approved by the Westat IRB.[27] For this investigation, data were analyzed from Wave 4 (December 2016−January 2018) of the public-use data file in 2020. This study was restricted to male participants aged ≥20 years who responded to the question regarding ED (N=13,711). Male adults aged <20 years did not receive the ED question.

Measures

Respondents' self-reported ED was categorized using the question: *Many men experience problems with sexual intercourse. How would you describe your ability to get and keep an erection adequate for satisfactory intercourse? Would you say that you are...* coupled with 4 response categories. Those responding *always or almost always* or *usually able to get and keep an erection* were defined as having no ED. Those who responded *sometimes* or *never* were defined as having moderate-to-severe ED.[29]

Respondents were classified as never, former, and current users. Current users were further classified as current someday (i.e., not every day or occasional) or daily users. Adults who responded *yes* to using ENDS *every day* and *some days* to the question *Do you now use ENDS?* were classified as daily users and current someday users, respectively, or were collectively classified as current users. Former users were those reporting ever use of ENDS and who responded *no* to the question: *Do you now use ENDS?* Adults who responded *no* to ever use of ENDS were considered never users.

Never smokers were those reporting never smoking >100 cigarettes in their lifetime. Otherwise, they were classified as current smokers if currently smoking cigarettes every day or some days or as former smokers if currently not smoking every day or some days. Past 30−day (yes/no) use of cigars, cigarillos, pipes, smokeless tobacco, or hookah was also included.

Information on sociodemographic characteristics included age, race/ethnicity, sexual orientation, education, annual household income, and U.S. region. Other covariates included a previous diagnosis of diabetes, hypertension, high cholesterol, or CVD (congestive heart failure, stroke, myocardial infarction, or other heart condition); BMI (underweight [<18.5 kg/m^2], normal [18.5−24.9 kg/m^2], overweight [25−29.9 kg/m^2], and obese [≥ 30 kg/m^2]); physical activity (ascertained by the number of days of any physical activity of at least moderate intensity to no physical activity, 1−2 days per week, 3−4 days per week, and 5−7 days per week); and self-perceived mental health, which was categorized as good (excellent, very good, good) or poor (fair, poor).

Statistical Analysis

Two samples were analyzed: (1) full sample representing all the male participants aged ≥20 years in the PATH study (N=13,711) and (2) age-restricted CVD-free sample (i.e., aged 20−65 years

with no reported CVD; n=11,207). Participants aged >65 years and those reporting previous history of CVD were excluded given the high prevalence of ED among them,[6,7,30] which was similar to the approach taken in previous studies evaluating the association between ED and smoking.[31,32] Because PATH is a nationally representative survey that employs a stratified, multistage sampling design, statistical analyses were performed using the survey module of Stata SE, version 16.0, to account for the complex sample design and responses and to provide estimates that are representative of the U.S. population. As suggested by the PATH study guidelines,[28] Wave 4 cross-sectional weights were used to account for sampling factors (e.g., variable probabilities of selection, oversampling) and nonresponse factors to ensure that a representative sample was used for this study.

Distribution of ENDS use, sociodemographic characteristics, health status, and other tobacco use characteristics were examined for the overall sample and for the age-restricted CVD-free sample by ED status. Univariate analyses and bivariate analyses using Pearson chi-square test are presented in Table 1. All variables were reported as weighted percentages and CIs. In Table 2, the multivariate logistic regression models were presented to quantify the association between ENDS use and ED. Multivariate models were adjusted for age, sexual orientation, race/ethnicity, educational attainment, annual household income, U.S. region, cigarette smoking, other tobacco product use, BMI, physical activity frequency, diabetes, hypertension, high cholesterol, and mental health status. Models including participants with CVD diagnosis adjusted for CVD as a covariate. ENDS use was included as a 4-level variable (never, former, current someday, and current daily) in the main analyses. Regression estimates were reported as ORs and AORs with CIs. In addition, sensitivity analyses using multivariable logistic regression models are presented in Table 3 to account for the impact of CVD and older age (>65 years) on the association of ED with ENDS use as well as including a subgroup analysis among respondents with normal BMI. For all these analyses, ENDS use was additionally included as a 3-level variable (never, former, current). Finally, the association between ED was characterized with both cigarettes and ENDS current use patterns by CVD diagnosis and older age (>65 years) in Table 4. All statistical tests were 2-tailed with the level of significance set at p<0.05.

RESULTS

This study included 13,711 adult men aged ≥20 years. Considering the full sample, most respondents were heterosexual or straight (95%) and non-Hispanic White (66%); 37% were from the Southern region of the U.S. Almost half (53%) of the participants were former cigarette smokers, 21% were current cigarette smokers, and 14% used other tobacco products. Most participants had no previous diagnosis of diabetes (87.8%) or CVD (85.0%). Detailed information are presented in Table 1, including information on the age-restricted CVD-free sample. The proportion of adults who reported ED varied from 20.7% (full sample), reflecting an estimated national prevalence of ED in the U.S., to 10.2% for the age-restricted CVD-free sample. The prevalence of current ENDS use was 4.8%, with 2.1% reporting current daily ENDS use. The prevalence of current ENDS use was 5.6% among the restricted sample, with 2.5% reporting current daily use. There was no substantive variation in the distribution of other covariates between the 2 samples.

Current daily ENDS users were more likely to report having ED (AOR=2.24, 95% CI=1.50, 3.34) than never ENDS users. Similarly, within the restricted sample, current daily ENDS users were more likely to report having ED than never ENDS users (AOR=2.41, 95% CI=1.55, 3.74). In the full sample, CVD history and age >65 years were associated with ED (AOR=1.39, 95% CI=1.10, 1.77; AOR=17.4, 95% CI=12.15, 24.91). Table 2 details the AOR for ED associated with other covariates in both samples. Those who were physically active at any weekly frequency were less likely to report ED than those reporting no physical activity (AOR range=0.44−0.58). Further details are presented in Table 2.

Table 3 shows the sensitivity analyses evaluating the variability in the association of ED with ENDS use while accounting for variability in CVD, older age, and patterns of current ENDS use. ENDS current use (without accounting for daily use) was associated with ED in both samples (AOR=1.69, 95% CI=1.20, 2.36; AOR=1.87, 95% CI=1.31, 2.67). Table 4 shows the association between ED and the patterns of ENDS use and cigarette smoking. Compared with that among never ENDS users and never cigarette smokers, everyday current use among former cigarette smokers was consistently associated with reporting ED (AOR range=2.31−2.57) in both samples, with and without CVD diagnosis. Similarly, ENDS current use (as a binary variable) among current cigarette smokers was associated with reporting ED in the full and restricted age samples without CVD diagnosis (AOR=1.66, 95% CI=1.07, 2.58; AOR=1.68, 95% CI=1.05, 2.69).

DISCUSSION

This is the first population-based study reporting the association between ENDS use and ED. Approximately 1 in 6 adult men in the U.S. reported suffering from moderate-to-severe ED, which is consistent with the findings of previous studies.[4] Current ENDS use was associated with higher odds of ED among U.S. adults, adjusting for age, other risk factors, and CVD history overall and also when evaluating the association among adult men aged 20−65 years with no history of CVD. In addition, daily ENDS use was significantly associated with higher odds for ED in all adjusted models in this study, whereas current ENDS users who are also former smokers seemed to consistently experience a higher risk of ED.

Table 1. Participant Characteristics: PATH Wave 4 (2016–2018)

Sample characteristics	Total sample (N=13,711)		ED among total sample[a] (*n*=2,128)		Age-restricted CVD-free sample (*n*=11,207)		ED among age-restricted CVD-free sample[b] (*n*=1,032)	
	n	Weighted %[c] (95% CI)	Weighted %[d] (95% CI)	*p*-value	*n*	Weighted %[c] (95% CI)	Weighted %[d] (95% CI)	*p*-value
Age, years				**<0.001*****				**<0.001*****
20–24	3,172	7.5 (7.1, 7.9)	6.5 (5.4, 7.7)		3,030	9.7 (9.2, 10.2)	6.0 (4.9, 7.3)	
25–34	3,305	19.2 (18.3, 20.1)	4.9 (4.0, 6.2)		3,134	24.8 (23.7, 26.1)	4.7 (3.6, 5.9)	
35–44	2,075	16.6 (15.6, 17.6)	5.4 (4.4, 6.6)		1,937	21.4 (20.1, 22.7)	4.8 (3.8, 6.0)	
45–54	1,893	18.5 (17.4, 19.6)	11.6 (9.7, 13.9)		1,681	22.9 (21.5, 24.3)	10.8 (8.9, 13.1)	
55–65	1,840	18.7 (17.8, 19.7)	26.5 (23.9, 29.4)		1,425	21.2 (20.0, 22.4)	23.4 (20.6, 26.5)	
≥65	1,426	19.5 (18.7, 20.5)	57.6 (53.8, 61.3)		NA	NA	NA	
Sexual orientation				0.48				0.43
Heterosexual/straight	12,842	95.3 (94.7, 95.8)	20.8 (19.6, 22.0)		10,481	94.9 (94.2, 95.5)	10.2 (9.2, 11.2)	
LGB+	774	4.7 (4.2, 5.3)	18.9 (14.2, 24.5)		662	5.1 (4.5, 5.8)	11.6 (8.4, 15.7)	
Race/ethnicity				**<0.001*****				**0.001*****
Non-Hispanic White	8,044	65.9 (64.9, 67.0)	23.1 (21.6, 24.7)		6,326	62.2 (61.0, 63.4)	10.1 (8.9, 11.4)	
Non-Hispanic Black	1,989	12.1 (11.4, 12.8)	19.8 (17.2, 22.6)		1,612	12.4 (11.7, 13.2)	14.6 (12.2, 17.3)	
Hispanic	2,543	14.5 (13.8, 15.1)	11.9 (9.8, 14.4)		2,293	16.6 (15.8, 17.5)	7.3 (5.7, 9.2)	
Non-Hispanic Other	1,104	7.5 (6.8, 8.3)	18.3 (14.1, 23.4)		958	8.7 (7.9, 9.7)	10.6 (7.4, 15.0)	
Education attainment				**0.02***				0.18
Less than high-school diploma	1,614	10.6 (9.9, 11.3)	24.6 (21.3, 28.3)		1,194	9.5 (8.7, 10.3)	11.6 (8.6, 15.4)	
High-school graduate	4,012	26.8 (25.8, 27.9)	22.1 (19.8, 24.5)		3,285	26.0 (25.0, 27.0)	11.5 (9.8, 13.5)	
Some college or associate degree	4,724	30.3 (29.4, 31.3)	20.4 (18.6, 22.2)		4,006	31.4 (30.2, 32.7)	10.1 (8.5, 11.9)	
Bachelor's degree or higher	3,315	32.3 (31.2, 33.3)	18.5 (16.3, 20.9)		2,688	33.1 (31.8, 34.5)	8.8 (7.2, 10.8)	
Annual household income, $				**<0.001*****				**<0.001*****
<25,000	4,273	24.9 (23.8, 26.2)	25.7 (23.6, 27.9)		3,359	22.7 (21.6, 24.0)	13.9 (12.1, 16.0)	
25,000–49,999	3,157	23.3 (22.1, 24.5)	22.1 (19.3, 25.1)		2,581	22.4 (21.2, 23.7)	10.0 (7.9, 12.5)	
50,000–99,999	3,313	28.0 (26.8, 29.3)	18.7 (16.8, 20.8)		2,763	28.9 (27.5, 30.5)	9.1 (7.5, 11.1)	
≥100,000	2,374	23.8 (22.3, 25.3)	20.4 (19.2, 21.6)		2,043	25.9 (24.3, 27.5)	8.8 (7.3, 10.5)	
U.S. region				**0.004****				0.11
Northeast	1,988	17.0 (16.3, 17.7)	17.7 (15.1, 20.6)		1,618	17.1 (16.2, 17.9)	8.1 (6.2, 10.6)	
Midwest	3,273	22.0 (21.1, 22.9)	24.3 (21.7, 27.1)		2,603	21.2 (20.4, 22.1)	11.0 (9.3, 13.0)	
South	5,218	37.0 (36.0, 38.1)	21.1 (19.3, 23.0)		4,250	36.5 (35.2, 37.8)	11.2 (9.4, 13.1)	
West	3,232	24.0 (22.9, 25.1)	19.0 (16.6, 21.7)		2,736	25.2 (23.9, 26.6)	9.6 (8.3, 11.0)	
ENDS use				**<0.001*****				**0.002****
Never user	6,531	70.7 (69.4, 71.9)	23.8 (22.3, 25.4)		4,954	66.1 (64.5, 67.6)	10.8 (9.5, 12.3)	
Former user	5,515	24.5 (23.4, 25.7)	13.3 (12.1, 14.5)		4,802	28.3 (26.9, 29.7)	8.5 (7.5, 9.6)	

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Table 1. Participant Characteristics: PATH Wave 4 (2016–2018) (*continued*)

Sample characteristics	Total sample (N=13,711)		ED among total sample[a] (*n*=2,128)		Age-restricted CVD-free sample (*n*=11,207)		ED among age-restricted CVD-free sample[b] (*n*=1,032)	
	n	Weighted %[c] (95% CI)	Weighted %[d] (95% CI)	*p*-value	*n*	Weighted %[c] (95% CI)	Weighted %[d] (95% CI)	*p*-value
Current user	1,270	4.8 (4.4, 5.2)	15.3 (12.7, 18.4)		1,131	5.6 (5.2, 6.1)	12.1 (9.7, 15.0)	
Current someday user	765	2.7 (2.4, 3.0)	12.8 (9.8, 16.7)		683	3.1 (2.8, 3.5)	9.6 (7.0, 13.0)	
Current daily user	505	2.1 (1.9, 2.4)	18.5 (13.8, 24.4)		448	2.5 (2.2, 2.9)	15.2 (11.0, 20.7)	
Cigarette smoking				**<0.001*****				0.18
Never smoker	2,442	25.1 (23.4, 27.0)	17.1 (15.7, 18.7)		2,148	23.4 (25.3, 29.5)	11.8 (10.5, 13.1)	
Former smoker	6,166	53.4 (51.8, 55.0)	23.8 (22.0, 25.7)		4,868	49.2 (47.3, 51.1)	9.7 (8.4, 11.2)	
Current smoker	4,984	21.5 (20.6, 27.0)	17.2 (14.7, 20.0)		4,093	27.4 (25.3, 29.5)	9.7 (7.8, 12.0)	
Other tobacco product use[h]				**<0.001*****				0.10
Yes	3,600	14.5 (13.7, 15.3)	15.5 (13.7, 17.4)		3,039	16.0 (15.1, 16.9)	9.0 (7.7, 10.4)	
No	10,087	85.5 (84.7, 86.3)	21.6 (20.3, 22.9)		8,154	84.0 (83.0, 84.9)	10.4 (9.4, 11.5)	
BMI (kg/m^2)				**<0.001*****				**<0.001*****
Underweight (<18.5)	195	0.8 (0.6, 1.0)	14.2 (8.5, 22.8)		156	0.8 (0.6, 1.1)	8.4 (4.4, 15.7)	
Normal (18.5–24.9)	4,290	26.3 (24.9, 27.7)	19.2 (17.3, 21.4)		3,593	26.4 (25.0, 27.9)	7.8 (6.4, 9.5)	
Overweight (25–29.9)	4,922	39.3 (37.8, 40.8)	18.5 (16.6, 20.5)		4,004	39.5 (37.9, 41.1)	9.1 (7.8, 10.6)	
Obese (≥30)	4,108	33.6 (32.2, 35.1)	24.4 (22.4, 26.6)		3,304	33.3 (31.7, 34.9)	13.1 (11.3, 15.1)	
Physical activity frequency				**<0.001*****				**<0.001*****
No physical activity	2,359	17.5 (16.4, 18.8)	32.8 (29.7, 36.1)		1,723	15.7 (14.6, 16.8)	17.6 (14.9, 20.6)	
1–2 days per week	3,220	25.0 (23.8, 26.3)	19.0 (16.9, 21.3)		2,672	25.7 (24.4, 27.1)	10.3 (8.5, 12.3)	
3–4 days per week	3,597	26.2 (25.0, 27.3)	18.4 (16.4, 20.6)		3,013	26.9 (25.6, 28.3)	8.8 (7.3, 10.5)	
5–7 days per week	4,502	31.3 (30.0, 32.6)	17.2 (15.3, 19.2)		3,771	31.7 (30.3, 33.1)	7.8 (6.5, 9.3)	
History of diabetes				**<0.001*****				**<0.001*****
Yes	1,265	12.2 (11.2, 13.3)	17.2 (16.1, 18.3)		667	7.6 (6.7, 8.6)	24.3 (19.6, 29.6)	
No	12,433	87.8 (86.7, 88.8)	45.8 (41.6, 50.1)		10,532	92.4 (91.4, 93.3)	9.1 (8.3, 9.9)	
History of hypertension				**<0.001*****				**<0.001*****
Yes	4,081	38.6 (37.3, 39.8)	34.8 (32.7, 37.0)		2,555	28.8 (27.5, 30.1)	17.8 (15.7, 20.1)	
No	9,630	61.4 (60.2, 62.7)	11.9 (10.8, 13.0)		8,652	71.2 (69.9, 72.4)	7.1 (6.4, 7.8)	
History of high cholesterol				**<0.001*****				**<0.001*****
Normal	3,143	33.0 (31.6, 34.4)	36.7 (34.3, 39.1)		1,856	23.8 (22.6, 26.2)	18.6 (16.1, 21.5)	
High	10,568	67.0 (65.6, 68.4)	12.9 (11.7, 14.1)		9,351	76.2 (74.8, 77.4)	7.6 (6.8, 8.4)	
Self-reported mental health				**<0.001*****				**<0.001*****
Good mental health status	11,799	89.1 (88.2, 89.9)	19.3 (18.0, 20.6)		9,738	90.0 (89.1, 90.9)	9.1 (8.3, 10.1)	
Poor mental health status	1,887	10.9 (10.1, 11.8)	31.9 (28.7, 35.3)		1,448	10.0 (9.1, 10.9)	19.3 (16.1, 22.9)	

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Table 1. Participant Characteristics: PATH Wave 4 (2016−2018) (*continued*)

Sample characteristics	Total sample (N=13,711)		ED among total sample[a] (*n*=2,128)		Age-restricted CVD-free sample (*n*=11,207)		ED among age-restricted CVD-free sample[b] (*n*=1,032)	
	n	Weighted %[c] (95% CI)	Weighted %[d] (95% CI)	*p*-value	*n*	Weighted %[c] (95% CI)	Weighted %[d] (95% CI)	*p*-value
History of CVD				**<0.001*** **				—
Yes	1,614	15.0 (14.2, 16.0)	46.9 (43.0, 50.8)		—	—	—	
No	12,097	85.0 (84.1, 85.8)	16.1 (15.0, 17.2)		—	—	—	

Note: Boldface indicates statistical significance (*$p<0.05$; **$p<0.01$; ***$p<0.001$).
Weighted estimates represent the U.S. population.
[a]Total participant sample, including those with a history of CVD and all age groups.
[b]Age-restricted (20−65 years) CVD-free sample that includes participants not reporting a history of CVD (heart attack, stroke, congestive heart failure, and other heart conditions).
[c]Column percentage (i.e., adds up to 100%).
[d]Row percentage.
[h]Other tobacco products include past 30−day use of cigar, cigarillos, pipe, hookah, snus, and smokeless tobacco products.
CVD, cardiovascular disease; ED, erectile dysfunction; ENDS, Electronic Nicotine Delivery Devices; LGB+, lesbian, gay, bisexual, or other nonstraight sexual orientation; NA, not applicable; PATH, Population Assessment of Tobacco and Health.

Abundant evidence suggests that nicotine prevents vasodilatation of blood vessels and reduces blood flow, which impairs normal erectile function and negatively affects male sexual performance.[10,13,14,20−22] Another plausible mechanism for ENDS association with ED is that exposure to ENDS refill liquids with or without nicotine reduces circulating testosterone levels (by 50% and 30%, respectively) owing to a decrease in the messenger RNA expression of 2 key steroidogenesis enzymes, cytochrome P450scc and 17β-hydroxysteroid dehydrogenases, at least in rodent models. A reduction in circulating testosterone levels might also impair normal erectile function.[33] Moreover, human studies have shown a dose−response association between the nicotine concentration in cigarettes and ED, with high-nicotine cigarettes being associated with higher rates of ED than low-nicotine cigarettes.[34] In addition, a meta-analysis reported that the OR for ED was significantly higher among those who smoked 10 cigarettes per day than among those smoking less than that, including an increased risk of ED when considering smoking duration.[35] Considering the high levels of nicotine present in many e-liquids,[26,27] along with the availability of ENDS devices that are very efficient in delivering nicotine,[23,24] the findings suggest that daily ENDS users may be at a higher risk of reporting ED than those who do not use ENDS on daily basis.

The widespread perception that ENDS is less harmful than cigarettes might have contributed to its increased uptake, particularly among youth[36,37] and among smokers and nonsmokers alike.[38−42] Furthermore, some smokers consider ENDS to be safer than nicotine-replacement therapy (NRT).[41] Although a few studies have compared the efficacy of ENDS and NRT for smoking cessation, they are not currently Food and Drug Administration approved for this purpose.[43] A recent large-scale clinical trial by Hajek and colleagues[44] found that ENDS doubled continuous smoking abstinence compared with NRT (18.0% vs 9.9%) at 1-year follow-up among highly motivated adults (*n*=889). However, among participants reporting abstinence, 80% of those in the ENDS group were still using an ENDS product at follow-up. Although ENDS may have been more effective in achieving prolonged combustible smoking abstinence, most of the participants using ENDS were not abstinent from using nicotine, which may have its own set of implications from continued use, such as ED, which would not be the case with using NRTs in achieving abstinence from all nicotine products. ENDS use among former smokers was associated with ED in full and age-adjusted models. Clinicians and researchers should evaluate the full range of implications of using Food and Drug Administration−approved cessation medications in contrast to ENDS given that current

Table 2. Multivariate Model of the Association Between ED and ENDS Use

	ED among total sample[a]				ED among age-restricted CVD-free sample[b]			
Characteristics	**OR (95% CI)**	***p*-Value**	**AOR[c] (95% CI)**	***p*-Value**	**OR (95% CI)**	***p*-value**	**AOR[c] (95% CI)**	***p*-Value**
ENDS use								
Never user	ref		ref		ref		ref	
Former user	0.48 (0.43, 0.56)	**<0.001*** **	1.11 (0.89, 1.37)	0.34	0.46 (0.39, 0.55)	**<0.001*** **	1.12 (0.87, 1.45)	0.38
Current someday user	0.47 (0.35,0.64)	**<0.001*** **	1.28 (0.80, 2.04)	0.30	0.50 (0.35, 0.72)	**<0.001*** **	1.43 (0.88, 2.31)	0.14
Current daily user	0.72 (0.50, 1.04)	0.08	2.24 (1.50, 3.34)	**<0.001*** **	0.92 (0.62, 1.39)	0.70	2.41 (1.55, 3.74)	**<0.001*** **
Age, years								
20–24	ref		ref		ref		ref	
25–34	0.75 (0.55, 1.03)	0.08	0.83 (0.58, 1.20)	0.33	0.76 (0.54, 1.07)	0.12	0.82 (0.54, 1.22)	0.32
35–44	0.83 (0.62, 1.11)	0.21	0.84 (0.59, 1.21)	0.35	0.79 (0.57, 1.09)	0.15	0.84 (0.56, 1.26)	0.40
45–54	1.91 (1.44, 2.52)	**<0.001*** **	1.90 (1.32, 2.72)	**0.001****	1.89 (1.41, 2.54)	**<0.001**	2.07 (1.42, 3.02)	**<0.001*** **
55–65	5.23 (4.06, 6.75)	**<0.001*** **	4.89 (3.41, 7.02)	**<0.001*** **	4.77 (3.59, 6.32)	**<0.001**	5.21 (3.60, 7.55)	**<0.001*** **
≥65	19.68 (15.36, 25.23)	**<0.001*** **	17.40 (12.15, 24.91)	**<0.001*** **	—		—	
Sexual orientation								
Heterosexual/straight	ref		ref		ref		ref	
LGB+	0.89 (0.62, 1.26)	0.50	1.05 (0.69, 1.60)	0.81	1.05 (0.68, 1.63)	0.23	1.01 (0.66, 1.55)	0.96
Race/ethnicity								
White, non-Hispanic	ref		ref		ref		ref	
Black, non-Hispanic	0.82 (0.68, 0.99)	0.04	0.96 (0.72, 1.29)	0.80	0.93 (0.73, 1.18)	0.52	1.51 (1.09, 2.09)	**0.01***
Hispanic	0.45 (0.35, 0.58)	**<0.001*** **	0.74 (0.55, 0.99)	0.05	0.47 (0.34, 0.63)	**<0.001**	0.85 (0.59, 1.22)	0.38
Other, non-Hispanic	0.74 (0.54, 1.03)	0.08	1.51 (1.05, 2.18)	**0.03***	0.90 (0.62, 1.32)	0.59	1.36 (0.87, 2.15)	0.18
Education attainment								
Less than high-school diploma	ref		ref		ref		ref	
High-school graduate	0.87 (0.68, 1.10)	0.24	1.17 (0.85, 1.60)	0.34	1.02 (0.75, 1.37)	0.92	1.26 (0.79, 1.99)	0.33
Some college or associate degree	0.78 (0.63, 0.97)	**0.03***	1.33 (0.99, 1.78)	0.09	0.91 (0.66, 1.25)	0.56	1.26 (0.79, 2.03)	0.33
Bachelor's degree or higher	0.70 (0.54, 0.90)	**0.01***	1.25 (0.87, 1.81)	0.23	0.89 (0.65, 1.21)	0.44	1.40 (0.81, 2.41)	0.23
Annual household income, $								
<25,000	ref		ref		ref		ref	
25,000–49,999	0.82 (0.67, 1.01)	0.06	0.84 (0.64, 1.09)	0.18	0.78 (0.61, 1.00)	0.05	0.76 (0.54, 1.08)	0.12
50,000–99,999	0.67 (0.56, 0.79)	**<0.001*** **	0.72 (0.54, 0.96)	**0.025***	0.76 (0.62, 0.94)	**0.01***	0.65 (0.47, 0.89)	**0.01****
≥100,000	0.52 (0.43, 0.63)	**<0.001*** **	0.63 (0.45, 0.88)	**0.008****	0.55 (0.44, 0.70)	**<0.001*** **	0.61 (0.43, 0.88)	**0.008****

(*continued on next page*)

Table 2. Multivariate Model of the Association Between ED and ENDS Use (*continued*)

	ED among total sample[a]				ED among age-restricted CVD-free sample[b]			
Characteristics	**OR (95% CI)**	***p*-Value**	**AOR[c] (95% CI)**	***p*-Value**	**OR (95% CI)**	***p*-value**	**AOR[c] (95% CI)**	***p*-Value**
U.S. region								
Northeast	ref		ref		ref		ref	
Midwest	1.49 (1.18, 1.89)	**<0.001*** **	1.49 (1.09, 2.05)	**0.013***	1.37 (1.02, 1.85)	**0.04***	1.52 (0.99, 2.33)	0.06
South	1.24 (0.99, 1.55)	0.05	1.18 (0.90, 1.56)	0.23	1.20 (0.91, 1.59)	0.20	1.25 (0.99, 2.33)	0.28
West	1.09 (0.86, 1.39)	0.47	1.26 (0.90, 1.76)	0.17	1.14 (0.86, 1.51)	0.36	1.33 (0.99, 2.33)	0.18
Cigarette smoking								
Never smoker	ref		ref		ref		ref	
Former smoker	1.51 (1.21, 1.86)	**<0.001*** **	0.89 (0.66, 1.18)	0.41	1.48 (1.17, 1.89)	**0.01***	0.84 (0.60, 1.19)	0.33
Current smoker	0.99 (0.81, 1.23)	0.98	1.00 (0.74, 1.35)	0.99	1.02 (0.81, 1.31)	0.81	1.05 (0.72, 1.53)	0.81
Other tobacco product use[d]								
No	ref		ref		ref		ref	
Yes	0.67 (0.56, 0.79)	**<0.001*** **	0.99 (0.84, 1.19)	0.98	1.56 (1.30, 1.88)	**<0.001*** **	0.92 (0.73, 1.16)	0.48
BMI (kg/m^2)								
Underweight (<18.5)	ref		ref		ref		ref	
Normal (18.5–24.9)	1.44 (0.78, 2.66)	0.25	1.55 (0.78, 3.07)	0.21	1.41 (0.56, 3.57)	0.46	1.84 (0.74, 4.57)	0.19
Overweight (25–29.9)	1.37 (0.74, 2.52)	0.31	1.23 (0.61, 2.50)	0.56	1.55 (0.61, 3.89)	0.35	1.63 (0.64, 4.17)	0.30
Obese (>30)	1.95 (1.07, 3.55)	**0.03***	1.68 (0.82, 3.47)	0.16	1.95 (0.78, 4.87)	0.15	2.25 (0.88, 5.74)	0.09
Physical activity frequency								
No physical activity	ref		ref		ref		ref	
1–2 days per week	0.48 (0.39, 0.60)	**<0.001*** **	0.58 (0.44, 0.76)	**<0.001*** **	0.51 (0.40, 0.65)	**<0.001*** **	0.57 (0.41, 0.79)	**0.001****
3–4 days per week	0.46 (0.38,0.56)	**<0.001*** **	0.57 (0.44, 0.75)	**<0.001*** **	0.51 (0.40, 0.64)	**<0.001*** **	0.52 (0.38, 0.73)	**<0.001*** **
5–7 days per week	0.43 (0.34,0.52)	**<0.001*** **	0.50 (0.40, 0.64)	**<0.001*** **	0.51 (0.40, 0.64)	**<0.001*** **	0.44 (0.32, 0.61)	**<0.001*** **
History of diabetes								
No	ref		ref		ref		ref	
Yes	4.07 (3.36,4.94)	**<0.001*** **	1.76 (1.37, 2.27)	**<0.001*** **	3.94 (3.13, 4.95)	**<0.001*** **	1.47 (1.03, 2.09)	**0.035***
History of hypertension								
No	ref		ref		ref		ref	
Yes	3.97 (3.46,4.56)	**<0.001*** **	1.28 (1.05, 1.58)	**0.016***	3.46 (2.96, 4.04)	**<0.001*** **	1.40 (1.12, 1.76)	**0.004****
History of high cholesterol								
No	ref		ref		ref		ref	
Yes	3.92 (3.37, 4.57)	**<0.001*** **	1.70 (1.40, 2.07)	**<0.001*** **	3.51 (2.93, 4.21)	**<0.001*** **	1.62 (1.27, 2.06)	**<0.001*** **
Self-reported mental health								
Good mental health status	ref		ref		ref		ref	
Poor mental health status	1.96 (1.62, 2.37)	**<0.001*** **	1.89 (1.42, 2.51)	**<0.001*** **	1.67 (1.34, 2.07)	**<0.001*** **	2.17 (1.60, 2.94)	**<0.001*** **

(*continued on next page*)

Table 2. Multivariate Model of the Association Between ED and ENDS Use (*continued*)

Characteristics	ED among total sample[a]				ED among age-restricted CVD-free sample[b]			
	OR (95% CI)	*p*-Value	AOR[c] (95% CI)	*p*-Value	OR (95% CI)	*p*-value	AOR[c] (95% CI)	*p*-Value
History of CVD								
No	ref		ref		—		—	
Yes	4.62 (3.85, 5.52)	**<0.001*****	1.39 (1.10, 1.77)	**0.006****	—		—	

Note: Boldface indicates statistical significance (**p*<0.05; ***p*<0.01; ****p*<0.001).
Weighted estimates represent the U.S. Census population.
[a]Total participant sample, including those with a history of CVD and all age groups.
[b]Age-restricted (20−65 years) CVD-free sample that includes participants not reporting a history of CVD (heart attack, stroke, congestive heart failure, and other heart conditions).
[c]Models were adjusted for age, sexual orientation, race/ethnicity, educational attainment, annual household income, U.S. region, cigarette smoking, other tobacco product use, BMI, physical activity frequency, diabetes, hypertension, high cholesterol, and mental health status.
[d]Other tobacco products include past 30-day use of cigar, cigarillos, pipe, hookah, snus, and smokeless tobacco products.
CVD, cardiovascular disease; ED, erectile dysfunction; ENDS, electronic nicotine delivery devices; LGB+, lesbian, gay, bisexual, or other nonstraight sexual orientation.

evidence supports that most combustible cigarette smokers maintain using ENDS when quitting smoking rather than being completely abstinent from all forms of nicotine.[44,45] Nevertheless, this study failed to detect an association between cigarette smoking and ED, also when accounting for current daily smoking versus for nondaily smoking (data not shown). A possible interpretation could be that some cigarette smokers who refused to respond to the ED question may have suffered from ED or that they were mostly light smokers overall.[46] Finally, it is worth noting that dual use of cigarettes and ENDS was also associated with ED among respondents with no CVD diagnosis in the full and age-restricted samples. Future research is needed to fully understand the risks associated with dual use of ENDS and cigarette smoking regarding the development and treatment of ED.

There is a need to continue evaluating the full range of ENDS as a tobacco harm reduction strategy. ENDS have been reported to be less harmful than cigarettes and have been considered as a potential harm reduction strategy among smokers.[43,47−49] However, there could be potential unexplored hazards for ENDS dual use among current smokers with no reported CVD. ENDS emit lower levels of toxicants, including volatile organic compounds, tobacco-specific nitrosamines, formaldehyde, and acetaldehyde.[50,51] However, known physiologic effects after acute exposure to ENDS vary from immediate airway obstruction and inflammation, increased heart rate, and respiratory irritation, to changes in white blood cell counts that might indicate inflammation,[51,52] strongly indicating that they are not harmless. Nevertheless, several studies have shown some benefits of switching from combustible cigarettes to ENDS among smokers with comorbid conditions such as chronic obstructive pulmonary disease.[48,49] Thus, the long-term health outcomes of ENDS use still need to be fully established in contrast to continued cigarette smoking, necessitating further longitudinal studies, with a particular focus on outcomes that are yet to be fully evaluated such as ED, in the general population and among patients with comorbid conditions.[48]

Limitations

There are several limitations of this study. Given its cross-sectional nature, inferences about the temporality of using or quitting ENDS and the development of ED and therefore causality cannot be made. In addition, the duration since quitting ENDS was not included, and potential ENDS-induced ED may be reversible with time. Future longitudinal studies can address this limitation. The possibility of residual confounding cannot be excluded. In addition, there was no information in the

Table 3. Sensitivity Analyses: Multivariate Models of Association of Self-Reported ED With ENDS Use

	Self-reported ED			
Adjusted multivariable models[a]	**Former ENDS user, AOR (95% CI)**	**Current ENDS user, AOR (95% CI)**	**Current someday ends user, AOR (95% CI)**	**Current ENDS daily user, AOR (95% CI)**
All age groups with CVD diagnosis/ ENDS binary[b]	1.12 (0.91, 1.38)	**1.69 (1.20, 2.36)****	—	—
All age groups with no CVD diagnosis/ENDS binary[b]	1.04 (0.81, 1.34)	**1.67 (1.18, 2.36)****	—	—
All age groups with no CVD diagnosis/ENDS 3 level[c]	1.03 (0.80, 1.33)	—	1.27 (0.80, 2.03)	**2.15 (1.39, 3.34)****
Age 20–65 years with CVD diagnosis/ENDS binary[b]	1.18 (0.96, 1.44)	**1.82 (1.30, 2.56)****	—	—
Age 20–65 years with CVD diagnosis/ENDS 3 level[c]	1.16 (0.85, 1.42)	—	1.36 (0.83, 2.23)	**2.47 (1.66, 3.68)*****
Normal BMI + age 20–65 years with CVD diagnosis/ENDS binary[d]	1.41 (0.91, 2.21)	**2.35 (1.13, 4.91)***	—	—
Normal BMI + age 20–65 years with CVD diagnosis/ENDS 3 level[e]	1.40 (0.91, 2.17)	—	1.64 (0.78, 3.43)	**3.32 (1.89, 9.27)***
Age 20–65 years with no CVD diagnosis/ENDS binary[b]	1.13 (0.88, 1.46)	**1.87 (1.31, 2.67)****	—	—
Normal BMI + age 20–65 years with no CVD diagnosis/ENDS binary[d]	1.30 (0.78, 2.16)	**2.35 (1.02, 5.42)***	—	—

Note: Boldface indicates statistical significance (*$p<0.05$; **$p<0.01$; ***$p<0.001$).
CVD includes heart attack, stroke, congestive heart failure, and other heart conditions.
[a]Models were adjusted for age, sexual orientation, race/ethnicity, educational attainment, annual household income, U.S. region, cigarette smoking, other tobacco product use, BMI, physical activity frequency, diabetes, hypertension, high cholesterol, and mental health status. Models including participants with CVD diagnosis adjusted for CVD as a covariate. Models restricted to normal BMI population excluded BMI in the covariates. Never ENDS users is the ref group. Models with significant association with the main outcome are presented (i.e., reporting having ED).
[b]Current ENDS use was conceptualized as a binary variable (yes/no).
[c]Current ENDS use was conceptualized as a 3-level variable (current someday/current everyday/no).
[d]Current ENDS use was conceptualized as a binary variable (yes/no) among the subpopulation with normal BMI.
[e]Current ENDS use was conceptualized as a 3-level variable (current someday/current everyday/no) among the subpopulation with normal BMI.
CVD, cardiovascular disease; ED, erectile dysfunction.

Table 4. Multivariate Models of Association of Self-Reported ED With ENDS and Cigarette Use

	Self-reported ED			
	Current ENDS user		Current daily ENDS user	
Adjusted multivariable models[a]	**Former smoker, AOR (95% CI)**	**Current smoker, AOR (95% CI)**	**Former smoker, AOR (95% CI)**	**Current smoker, AOR (95% CI)**
All age groups with CVD diagnosis/ENDS 3 level[b]	—	—	**2.31 (1.22, 4.37)****	NS
All age groups with no CVD diagnosis/ENDS binary[b]	**1.85 (1.06, 3.24)***	**1.66 (1.07, 2.58)***	—	—
All age groups with no CVD diagnosis/ENDS 3 level[c]	—	—	**2.32 (1.15, 4.68)***	NS
Age 20–65 years with CVD diagnosis/ENDS binary[b]	**1.91 (1.05, 3.47)***	NS	—	—
Age 20–65 years with CVD diagnosis/ENDS 3 level[c]	—	—	**2.57 (1.36, 4.87)****	NS
Age 20–65 years with no CVD diagnosis/ENDS binary[b]	NS	**1.68 (1.05, 2.69)***	—	—
Age 20–65 years with no CVD diagnosis/ENDS 3 level[c]	—	—	**2.44 (1.20, 4.95)***	NS

Note: Boldface indicates statistical significance (*$p<0.05$; **$p<0.01$; ***$p<0.001$).
CVD includes heart attack, stroke, congestive heart failure, and other heart conditions.
[a]Models were adjusted for age, sexual orientation, race/ethnicity, educational attainment, annual household income, U.S. region, other tobacco product use, BMI, physical activity frequency, diabetes, hypertension, high cholesterol, and mental health status. Models including participants with CVD diagnosis adjusted for CVD as a covariate. Never users for both ENDS and cigarette is the ref group. Models with significant association with the main outcome are presented (i.e., reporting having ED).
[b]Current ENDS use was conceptualized as a binary variable (yes/no).
[c]Current ENDS use was conceptualized as a 3-level variable (current someday/current everyday/no).
CVD, cardiovascular disease; ED, erectile dysfunction; ENDS, electronic nicotine delivery devices; NS, nonsignificant.

PATH data set on whether the respondents received any anti-ED medication, such as phosphodiesterase-5 inhibitors. There were no data on the use of medications that may be associated with ED as a side effect such as thiazide diuretics; beta-blockers; and antidepressants, including selective serotonin reuptake inhibitors and tricyclic antidepressants.[53−55] However, this is not likely to impact the findings because patients who reported having CVD were excluded from the alternative model in the main analysis.[44] Similarly, because most participants reported having good mental health, it is likely that the use of antidepressants in the study population would also be limited. Furthermore, the content of e-liquid used by the study participants is unknown; traces of drugs such as amino−tadalafil, which is used to treat ED, have been identified in the e-liquid of some ENDS products. However, although unlikely, this may have only attenuated the observed association and would not likely alter the findings.[56] In addition, there was a significant association between ENDS use and ED among respondents aged 20−65 years with normal BMI with and without CVD, suggesting an association of ED with ENDS use among a relatively healthy population. Moreover, the analyses were based on both self-reported covariate data, ENDS use status, and ED status, all of which are subject to misclassification, recall, and social desirability bias, although PATH included its survey questions that remain the gold standard in the field. In addition, a 1-item question for ED was used instead of, for example, a validated questionnaire that comprehensively evaluates ED; the study may have failed to capture patients with mild symptoms or identified people as having ED where they may not have a clinical ED diagnosis. Furthermore, other commonly used tobacco products were included but not marijuana. The relationship between marijuana (or cannabis) use and ED, independent of tobacco use, is unclear and was not a focus of this study. However, future work can further explore the association between marijuana use and ED. Finally, the study only included men and cannot extrapolate the current findings to sexual dysfunction among women using ENDS.

This study provides important information on the association between ENDS use and ED, with potential implications for the public, clinicians, public health officials, and tobacco product regulation and interventions. It is important for clinicians to collect information concerning ENDS use when assessing and counseling patients with ED. If validated by longitudinal studies, the current findings may further inform public health messages and tobacco regulation policies. For example, highlighting the association between ENDS use and ED may be particularly important for comprehensive anti-tobacco use and not only for antismoking health communication campaigns targeting youth initiation.[57,58]

CONCLUSIONS

The study findings indicate that ENDS use may be associated with ED, independent of age, risk factor profile, and the presence of CVD. While ENDS use is still being evaluated for its harm reduction and smoking-cessation potential, ENDS users need to be informed about the possible harms associated with ENDS use and particularly ENDS current daily use, including ED. This study highlights a novel finding that ENDS use could have serious implications on men's sexual health. Further longitudinal evaluation on the long-term health impacts of ENDS should be performed to clarify whether ENDS use is an independent risk factor for the development of ED.

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CREDIT AUTHOR STATEMENT

Omar El Shahawy: Conceptualization; Formal analysis; Methodology; Software; Writing - original draft; Writing - review & editing. Tanmik Shah: Formal analysis; Methodology; Project administration; Writing - review & editing. Olufunmilayo H. Obisesan: Writing - review & editing. Meghan Durr: Writing - review & editing. Andrew C. Stokes: Methodology; Writing - review & editing. Iftekhar Uddin: Writing - review & editing. Ria Pinjani: Writing - review & editing. Emelia J. Benjamin: Writing - review & editing. Mohammadhassan Mirbolouk: Writing - review & editing. Albert D. Osei: Writing - review & editing. Tom Loney: Project administration; Writing - review & editing. Scott E. Sherman: Funding acquisition; Supervision; Writing - review & editing. Michael J. Blaha: Supervision; Writing - review & editing.

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