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Oral Health in the Population Assessment of Tobacco and Health Study

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Abstract

Tobacco use is a well-established risk factor for multiple adverse oral conditions. Few nationally representative oral health data sets encompass the current diversity of tobacco and nicotine products. This investigation examines the validity of oral health measures in the Population Assessment of Tobacco and Health (PATH) Study to assess relationships between tobacco use and oral health. Cross-sectional data from PATH Study wave 4 (*N* = 33,643 US adults, collected 2016–2018) were used to obtain estimates for 6 self-reported oral conditions (e.g., bone loss around teeth, tooth extractions) and compared with analogous estimates from the National Health and Nutrition Examination Survey (NHANES) cycle 2017–2018 (*N* = 5,856). Within the PATH Study, associations were calculated between tobacco use status and lifetime and past 12-mo experience of adverse oral conditions using survey-weighted multivariable logistic regression. Nationally representative estimates of oral conditions between the PATH Study and NHANES were similar (e.g., ever-experience of bone loss around teeth: PATH Study 15.2%, 95% CI, 14.4%–15.9%; NHANES 16.6%, 95% CI, 14.9%–18.4%). In the PATH Study, combustible tobacco smoking was consistently associated with lifetime and past 12-mo experience of adverse oral health (e.g., exclusive cigarette smoking vs. never tobacco use, adjusted odds ratio [AOR] for loose teeth in past 12 mo: 2.02; 95% CI, 1.52–2.69). Exclusive smokeless tobacco use was associated with greater odds of loose teeth (AOR, 1.93; 95% CI, 1.15–3.26) and lifetime precancerous lesions (AOR, 3.85; 95% CI, 1.73–8.57). Use of other noncigarette products (e.g., pipes) was inconsistently associated with oral health outcomes. PATH Study oral health measures closely align with self-reported measures from NHANES and are internally concurrent. Observed associations with tobacco use and the ability to examine emerging tobacco products support application of PATH Study data in dental research, particularly to examine potential oral health effects of novel tobacco products and longitudinal changes in tobacco use behaviors.

Keywords: smoking, epidemiologic study characteristics, cross-sectional studies, periodontal diseases, electronic nicotine delivery systems, pipe smoking

Introduction

Biological and epidemiologic research have firmly established a causal role for tobacco smoking and use of oral tobacco in the development and progression of periodontal disease, tooth loss, oral cancer, and other adverse oral conditions (Johnson and Bain 2000; Warnakulasuriya et al. 2010; Tomar et al. 2019). However, recent developments in the tobacco marketplace and population tobacco use patterns present new research gaps with potential oral health implications. Among shifting use patterns, particularly in wealthy countries, heavy cigarette smoking among tobacco users is growing less common (Ng et al. 2014), but dual or poly-use of tobacco products is increasing (Cornelius et al. 2020). New and emerging tobacco and nicotine products, notably electronic nicotine delivery systems (ENDS, commonly: e-cigarettes), also raise questions related to oral health and dental practice (Holliday et al. 2021).

Valid epidemiologic data are a critical resource for understanding the health and policy ramifications of an evolving tobacco landscape. Ideal data sources would feature sufficient detail on tobacco behaviors, adequate statistical power to compare relevant use patterns, longitudinal designs, and broad

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A supplemental appendix to this article is available online.

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generalizability, as well as be widely available to the research community. One such resource, the Population Assessment of Tobacco and Health (PATH) Study, is an ongoing, nationally representative, longitudinal cohort study of adults and youth in the United States (Hyland et al. 2017) that presents unique opportunities for dental research. Several publications have examined associations between tobacco use behaviors and oral health in the initial PATH Study waves (Akinkugbe 2019; Atuegwu et al. 2019; Vora and Chaffee 2019).

The present investigation aims to evaluate the validity of the PATH Study adult oral health measures. All oral health outcomes in the PATH Study are collected by self-report rather than clinical assessment. This approach reflects an implicit trade-off between the substantial sample size, prospective design, and comprehensive scope of the PATH Study and the accuracy potentially afforded by clinical measures. Enhancing confidence in the validity of the PATH Study oral health measures would encourage further use of the measures for research and to inform tobacco policy and regulation. For this analysis, we compare national prevalence estimates for adults in the PATH Study wave 4 (2016–2018) and the National Health and Nutrition Examination Survey (NHANES, 2017–2018) survey cycle. For nearly 5 decades, NHANES has been a trusted source for monitoring oral health in the United States (Elani et al. 2018; Eke et al. 2020).

Specific objectives of this investigation include the following: 1) assess the generalizability of the PATH Study oral health measures by comparing prevalence estimates to those from NHANES, 2) evaluate the concurrent validity of the PATH Study self-reported oral health conditions via internal comparison to the PATH Study global measure of self-rated oral health, and 3) examine the internal validity of the PATH Study oral health measures by estimating associations with cigarette smoking (a known oral disease risk factor) while exploring associations with emerging tobacco behaviors.

Methods

Study Design and Population

The PATH Study is an ongoing, nationally representative, longitudinal cohort study of adults (≥18 y) and youth (12–17 y) in the United States. The study uses audio computer-assisted self-interviews (English and Spanish) to collect self-reported information on tobacco use patterns and associated health behaviors. Study recruitment employed a stratified address-based, area probability sampling design at wave 1 (W1, September 2013 to December 2014) that oversampled adult tobacco users, young adults (18–24 y), and African American adults. An in-person screener was used at W1 to select youth and adults randomly from households for participation. A probability replenishment sample of adults and youth was selected from the US civilian noninstitutionalized population at the time of wave 4 (W4, December 2016 to January 2018), including persons not in the civilian noninstitutionalized population at the time of W1.

The W4 cohort consists of 2 groups of respondents selected at different times; thus, response rates are calculated separately. For the group originating at W1, the weighted response rate was 54.0% for the W1 household screener and 74.0% for the adult interview among adults selected during screening. The weighted W4 response rate was 73.5% among adults who participated in W1. For the W4 replenishment sample, the weighted W4 response rates were 52.8% and 68.0% for the household screener and adult interview, respectively. Full-sample and replicate weights that adjust for the complex sample design and nonresponse are available and were used in this analysis. Weighted estimates represent the resident population of the United States in the civilian, noninstitutionalized population at the time of W4.

Further details regarding the PATH Study design and methods are published elsewhere (Hyland et al. 2017; Tourangeau et al. 2019; Piesse et al. 2021). Details on interview procedures, questionnaires, sampling, weighting, response rates, and accessing the data are already documented (PATH Study Restricted-Use Files User Guide, https://doi.org/10.3886/Series606). The PATH Study was conducted by Westat and approved by the Westat Institutional Review Board. All respondents ages ≥18 y provided informed consent.

NHANES is designed to assess the health and nutritional status of adults and children in the United States. Data are collected to determine the prevalence of major diseases and risk factors for diseases nationally. The survey became continuous in 1999, and data are released in 2-y cycles. Further NHANES methodologic details and analytic guidelines are available from the National Center for Health Statistics (https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx). Briefly, NHANES oversamples adults 60 y and older, African Americans, Asians, and Hispanics. In addition to clinical examinations, NHANES also includes a survey component with self-reported health items. For the current study, the NHANES 2017–2018 (Fakhouri et al. 2020) survey cycle was selected as the data most temporally aligned with PATH Study W4 to compare national prevalence estimates for self-reported oral health outcomes, although months of data collection did not overlap completely.

Measures

Oral health. Self-reported oral health outcomes in the PATH Study adult interview included tooth extraction, gum bleeding, loose teeth, bone loss around teeth, gum disease, and precancerous oral lesions. All outcomes were assessed as lifetime (ever) experience and, among W4 adults continuing from an earlier wave, past 12-mo experience. Several of the measures derived from existing instruments, including those developed under the Centers for Disease Control and Prevention Periodontal Disease Surveillance Project (Eke et al. 2012). All adult respondents were asked to rate the health of their teeth and gums on a 5-point scale from "excellent" to "poor" (Locker 2001). Appendix Table 1 provides the wording of all oral health–related items from the PATH Study adult questionnaires.

Tobacco use. PATH Study respondents were asked about ever, past 12-mo, and past 30-d (current) tobacco use behaviors for cigarettes, ENDS, traditional cigars, cigarillos, filtered cigars, pipe tobacco, hookah, smokeless tobacco (loose

snus, moist snuff, or chewing tobacco), and snus pouches. To examine relationships between tobacco use and oral health, a 14-level tobacco use variable with mutually exclusive categories was created. Category definitions are described in Appendix Table 2 and include 1) never tobacco user, 2) recent former tobacco user, 3) long-term former tobacco user, and 4) former experimental tobacco user, as well as 10 categories based on past 30-d use: 5) exclusive cigarette user, 6) exclusive ENDS user, 7) exclusive cigar user, 8) exclusive smokeless tobacco user (including snus pouches), 9) exclusive hookah user, 10) exclusive pipe user, 11) cigarette and ENDS dual user, 12) poly-combustible tobacco user (≥2 combustible products, i.e., cigarettes, cigars, hookah, or pipe), 13) combustible and noncombustible user (≥1 combustible product and ≥1 ENDS or smokeless product, other than dual users of cigarettes and ENDS), and 14) other current use (all current use not previously captured).

Covariables. Sociodemographic variables included age, sex, race/ethnicity, educational attainment, and annual household income, as specified in the applicable tables. Health and behavioral covariables were history of diabetes ("Have you ever been told by a doctor or other health professional that you have diabetes, sugar diabetes, high blood sugar, or borderline diabetes?" yes/no), body mass index, pack-year smoking history (cigarette packs smoked per day multiplied by years smoked regularly), secondhand smoking (hours in the past 7 d exposed to tobacco smoke in the home, in the car, at work, or outdoors), high-frequency drinking (≥5 alcoholic drinks for men and ≥4 drinks for women in a single day at least once in the past 30 d), and past 30-d cannabis (marijuana) use. Pack-years of cigarette smoking and secondhand smoke exposure were Winsorized at the 95th and 99th percentiles, respectively, to limit the influence of outliers (Rivest 1994). Missing data on sex, race, and Hispanic ethnicity were imputed as described elsewhere (PATH Study Restricted Use Files User Guide).

Analytic Approach

First, to assess PATH Study external validity, weighted cross-sectional prevalence estimates of PATH Study W4 and NHANES 2017–2018 study populations were compared for selected sociodemographic characteristics, health insurance (yes/no), past 30-d cannabis and tobacco use, self-rated overall health, body mass index, and presence or absence of diabetes. Next, prevalence estimates from any self-reported oral health measures similarly worded across both studies were compared. To assess concurrent validity of the PATH Study oral health measures, associations were calculated between individually reported conditions (e.g., gum bleeding, loose teeth) and the global measure of self-rated oral health (i.e., from excellent to poor) under the assumption that outcomes from valid measures of specific conditions will correlate with overall self-rating (Locker 2001). Finally, cross-sectional associations were calculated between oral health conditions (lifetime and past 12-mo experience) and current tobacco use behaviors, adjusting for sociodemographic, health, and behavioral covariables using separate weighted logistic regression models for each oral health outcome.

All analyses were conducted using Stata survey data procedures, version 16.1 (StataCorp LLC). NHANES estimates were weighted using 2017–2018 full-sample 2-y interview weights. PATH Study W4 cohort estimates used cross-sectional full-sample and replicate weights; variances were estimated using the balanced repeated replication method with Fay's adjustment set to 0.3 (McCarthy 1969; Judkins 1990). Estimates with low precision were flagged (<50 observations in the denominator or relative standard error or its component >0.30). Reporting followed standard guidelines (von Elm et al. 2007).

Results

PATH Study and NHANES Populations

The overall characteristics of the PATH Study W4 and NHANES 2017–2018 samples were similar, reflecting generalizability to the US noninstitutionalized civilian population at W4 (Table 1). Distributions by age, sex, race/ethnicity, and educational attainment were near identical. Notably, the PATH Study data reflect a greater proportion of adults with annual household incomes under $25,000 relative to NHANES, and a larger percentage had "excellent" self-rated overall health (Table 1). Past 30-d use of any tobacco was lower in the PATH Study than NHANES when based on the 4 product types included in NHANES (Table 1).

"Excellent" self-rated oral health was more prevalent in the PATH Study (PATH Study 17.4%, 95% CI, 16.9%–18.0%; NHANES 12.8%, 95% CI, 11.3%–14.3%; Table 2). All other oral health behaviors and conditions that were assessed using comparable measures had nearly the same prevalence in each study (Table 2). Measures for self-reported gum disease probed different time windows in the PATH Study (ever experience) and NHANES (current condition) but yielded similar prevalence estimates (PATH Study 20.7%, 95% CI, 19.9%–21.6%; NHANES 18.9%, 95% CI, 16.4%–21.7%; Table 2).

Concurrent Validity of Oral Health Measures

There was a strong inverse correlation between self-rated oral health and each of the self-reported oral conditions assessed at PATH Study W4 (Table 3). Whether in reference to lifetime or past 12-mo experience, tooth extraction, gum bleeding, loose teeth, bone loss around teeth, and gum disease had higher frequency in each successively worse oral health rating, from "excellent" to "poor" (Table 3). Precancerous oral lesions, while not perfectly following a gradient pattern, was most prevalent among those with poor self-reported oral health.

Combustible Tobacco Use and Oral Health

Combustible tobacco smoking was consistently associated with lifetime (Table 4) and past 12-mo (Table 5) experience of adverse oral health conditions. Exclusive cigarette smoking was positively and statistically significantly associated with

Table 1. Characteristics of the PATH Study Wave 4 and NHANES 2017–2018 Populations.

	PATH Study Wave 4 2016–2018		NHANES 2017–2018	
Characteristic	Unweighted *N*	Weighted % (95% CI)	Unweighted *N*	Weighted % (95% CI)
Age, y				
18–29	15,393	21.5 (21.2–21.9)	1,115	21.2 (18.9–23.7)
30–39	5,182	17.2 (16.7–17.6)	859	17.1 (15.6–18.8)
40–49	4,021	15.8 (15.2–16.4)	813	15.6 (14.2–17.2)
50–59	4,228	18.0 (17.5–18.4)	919	17.9 (15.6–20.3)
60–69	3,013	14.7 (14.2–15.3)	1,104	14.9 (12.6–17.4)
≥70	1,802	12.8 (12.4–13.2)	1,046	13.2 (11.7–14.9)
Sex				
Female	17,125	51.9 (51.9–51.9)	3,016	51.8 (49.8–53.8)
Male	16,518	48.1 (48.1–48.1)	2,840	48.2 (46.2–50.2)
Race/ethnicity				
Non-Hispanic White	19,137	64.3 (64.3–64.3)	2,032	62.1 (56.3–67.6)
Non-Hispanic Black	5,152	11.7 (11.7–11.7)	1,343	11.4 (8.3–15.2)
Non-Hispanic Asian	894	5.7 (5.7–5.7)	849	5.9 (3.9–8.5)
Non-Hispanic other race, including multiracial	1,788	2.7 (2.7–2.7)	297	4.6 (3.4–5.9)
Hispanic	6,672	15.7 (15.7–15.7)	1,335	16.1 (12.2–20.7)
Educational attainment				
Less than high school	4,240	10.9 (10.6–11.1)	1,175	11.7 (10.1–13.5)
High school, GED, or equivalent	10,210	28.8 (28.5–29.1)	1,471	28.3 (25.1–31.7)
Some college or AA degree	11,898	31.0 (31.0–31.1)	1,778	29.9 (27.4–32.5)
College graduate or above	7,147	29.3 (29.2–29.3)	1,336	30.1 (25.1–35.4)
Annual household income				
Less than $10,000	5,448	11.6 (11.1–12.2)	406	5.3 (4.2–6.7)
$10,000–$24,999	6,710	18.8 (18.2–19.4)	950	12.8 (11.4–14.3)
$25,000–$74,999	11,424	38.0 (37.2–38.8)	2,164	39.1 (34.5–43.7)
$75,000–$99,999	2,794	10.9 (10.4–11.5)	505	14.6 (12.0–17.5)
$100,000 or more	5,030	20.6 (19.8–21.4)	993	28.3 (24.6–32.2)
Has health insurance				
Yes	27,701	88.1 (87.5–88.6)	4,944	86.1 (81.5–89.9)
No	5,583	11.9 (11.4–12.5)	893	13.9 (10.1–18.5)
Self-rated overall health				
Excellent	7,386	21.8 (20.9–22.7)	458	10.0 (8.6,11.6)
Very good	11,354	36.8 (35.9–37.6)	1,249	30.9 (28.2–33.7)
Good	10,616	30.2 (29.4–31.0)	2,151	40.1 (37.8–42.5)
Fair	3,560	9.6 (9.1–10.2)	1,110	16.7 (15.1–18.3)
Poor	669	1.7 (1.5–1.9)	167	2.3 (1.8–2.8)
Diabetes status				
Yes (ever)[a]	4,867	19.9 (19.1–20.6)	1,052	13.7 (12.6–14.8)
No (never)	27,274	80.1 (79.4–80.9)	4,800	86.3 (85.2–87.4)
Cannabis (marijuana) use[b]				
Past 30 d yes	6,254	14.1 (13.4–14.8)	626	19.4 (16.7–22.3)
Past 30 d no	22,451	85.9 (85.2–86.6)	2,567	80.6 (77.7–83.3)
Body mass index				
<18.5	840	1.7 (1.6–1.9)	99	1.7 (1.2–2.3)
18.5–24.99	11,625	31.4 (30.5–32.2)	1,363	25.6 (22.9–28.5)
25–29.99	9,909	33.4 (32.6–34.2)	1,710	30.8 (28.4–33.3)
≥30	10,138	33.5 (32.6–34.4)	2,207	41.9 (38.0–45.9)
Past 30-d tobacco use				
Cigarettes	10,435	18.9 (18.3–19.4)	1,008	22.2 (18.7–26.0)
Cigars	4,235	6.8 (6.5–7.0)	384	6.0 (5.3–6.8)
E-cigarettes (ENDS)	4,050	6.2 (6.0–6.5)	305	6.6 (5.3–8.1)
Smokeless tobacco	1,585	3.0 (2.8–3.2)	141	3.4 (2.4–4.6)
Any tobacco[c]	14,604	25.9 (25.3–26.5)	1,418	31.2 (27.5–35.0)

PATH Study percentages are weighted using the wave 4 cross-sectional weights for the wave 4 cohort. *N*s are unweighted. NHANES percentages are weighted using the 2017–2018 full sample 2-y interview weights. The total PATH Study wave 4 sample includes 33,643 participants ≥18 y; the total NHANES 2017–2018 survey cycle includes 5,856 participants ≥18 y; *N*s in this table may add to less than the totals due to missing data and/or restriction to specific age ranges.

AA, associate's degree; CI, confidence interval; ENDS, electronic nicotine delivery systems (commonly: e-cigarettes); GED, General Educational Development; NHANES, National Health and Nutrition Examination Survey; PATH, Population Assessment of Tobacco and Health.

[a]Includes the response "borderline diabetes."

[b]Restricted to ages 18 to 59 y; question not posed to adults 60 y or older in NHANES 2017–2018.

[c]Any tobacco definition only includes cigarettes, cigars, ENDS, and smokeless tobacco for consistency with NHANES definition.

Table 2. Prevalence of Oral Health Outcomes: PATH Study Wave 4 and NHANES 2017–2018.

PATH Study Wave 4 2016–2018			NHANES 2017–2018		
	Unweighted *N*	Weighted Percent (95% CI)		Unweighted *N*	Weighted Percent (95% CI)
Overall, how would you rate the health of your teeth and gums?			Overall, how would {you/SP} rate the health of {your/his/her} teeth and gums?		
Excellent	5,638	17.4 (16.9–18.0)	Excellent	632	12.8 (11.3–14.3)
Very good	9,637	31.2 (30.4–32.0)	Very good	1,350	27.2 (24.0–30.6)
Good	10,460	30.5 (29.8–31.3)	Good	1,932	32.8 (30.5–35.2)
Fair	5,302	14.6 (14.0–15.3)	Fair	1,322	18.4 (16.9–20.0)
Poor	2,461	6.2 (5.8–6.6)	Poor	613	8.9 (7.1–10.9)
In the past 12 mo, have you seen a dentist?			About how long has it been since {you/SP} last visited a dentist? Include all types of dentists, such as orthodontists, oral surgeons, and all other dental specialists, as well as dental hygienists.		
Yes	18,436	59.7 (58.6–60.7)	≤1 y	3,113	59.3 (54.3–64.1)
No	15,135	40.3 (39.3–41.4)	>1 y	2,721	40.7 (35.9–45.7)
Lifetime (ever) experience: gum disease[a]			Gum disease is a common problem with the mouth. People with gum disease might have swollen gums, receding gums, sore or infected gums, or loose teeth. {Do you/Does SP} think {you/he/she} might have gum disease?		
Yes	3,984	20.7 (19.9–21.6)	Yes	894	18.9 (16.4–21.7)
No	13,512	79.3 (78.4–80.1)	No	3,784	81.1 (78.3–83.6)
Lifetime (ever) experience: bone loss around teeth[a]			{Have you/Has SP} ever been told by a dental professional that {you/he/she} lost bone around {your/his/her} teeth?		
Yes	2,872	15.2 (14.4–15.9)	Yes	792	16.6 (14.9–18.4)
No	14,826	84.8 (84.1–85.6)	No	3,908	83.4 (81.6–85.1)
Aside from brushing your teeth with a toothbrush, in the last 7 d, how many times did you use dental floss or any other device to clean between your teeth?			Aside from brushing {your/his/her} teeth with a toothbrush, in the last 7 d, how many days did {you/SP} use dental floss or any other device to clean between {your/his/her} teeth?		
0 times	5,595	26.9 (26.0–27.8)	0 d	1,640	28.4 (25.7–31.1)
1–6 times	8,085	45.6 (44.5–46.6)	1–6 d	1,463	35.7 (33.8–37.7)
≥7 times	4,435	27.5 (26.5–28.5)	7 d	1,635	35.9 (32.4–39.4)

PATH Study percentages are weighted using the wave 4 cross-sectional weights for the wave 4 cohort. *N*s are unweighted. NHANES percentages are weighted using the 2017–2018 full sample 2-y interview weights. The total PATH Study wave 4 sample includes 33,643 participants ≥18 y; the total NHANES 2017–2018 survey cycle includes 5,856 participants ≥18 y; *N*s in this table may add to less than the totals due to missing data and/or restriction to specific age ranges.

CI, confidence interval; NHANES, National Health and Nutrition Examination Survey; PATH, Population Assessment of Tobacco and Health; SP, study participant.

[a]At wave 4, for continuing respondents, constructs were only asked of respondents who reported seeing a dentist within the past 12 mo. Those who reported not having seen a dentist in the past 12 mo and who had not reported a history of the condition in any prior waves were categorized as having no lifetime history.

fair/poor oral health and with tooth extractions, loose teeth, bone loss around teeth, and gum disease, both as lifetime and past 12-mo experience. In contrast, cigarette smoking was inversely associated with gum bleeding. Much like exclusive cigarette smoking, all categories of multiple product use that included combustible tobacco smoking were associated with fair/poor oral health (Table 5) and with lifetime experience of tooth extractions, loose teeth, bone loss around teeth, and gum disease (Table 4). All multiple product use associations for lifetime experience persisted for past 12-mo experience but lost statistical significance for bone loss and gum disease among cigarette and ENDS dual users (Table 5).

Noncombustible Tobacco Use and Oral Health

Exclusive past 30-d use of smokeless tobacco was positively and statistically significantly associated with lifetime experience of loose teeth and precancerous oral lesions (Table 4), as well as fair/poor oral health and past 12-mo experience of tooth extraction, loose teeth, and precancerous oral lesions (Table 5). No other categories of current tobacco use not mentioned above were statistically significantly associated with past 12-mo experience of any of the outcomes measured (Table 5). Past 30-d exclusive ENDS use was associated with lifetime tooth extraction and bone loss experience; past 30-d exclusive pipe use was associated with lifetime gum bleeding experience (Table 4).

Tobacco Former Use and Oral Health

Long-term former tobacco users, most of whom were former cigarette smokers (Appendix Table 2), were at greater odds than never tobacco users of lifetime experience of gum disease, gum bleeding, loose teeth, and bone loss (Table 4) and past 12-mo experience of gum bleeding, loose teeth, and bone loss (Table 5). Pack-year history of cigarette smoking and secondhand smoke exposure were also positively and statistically significantly associated with lifetime and past 12-mo experience of multiple adverse oral health conditions (Tables 4 and 5).

Table 3. Self-Rated Oral Health and Specific Oral Conditions: PATH Study Wave 4.

Characteristic	Self-Rated Oral Health, Weighted % (95% CI)					
	Total Sample[a] (*N* = 33,498)	Excellent (*n* = 5,638)	Very Good (*n* = 9,637)	Good (*n* = 10,460)	Fair (*n* = 5,302)	Poor (*n* = 2,461)
Lifetime (ever) experience						
Tooth extraction	40.4 (39.6–41.1)	20.9 (19.1–22.7)	29.4 (27.9–31.0)	44.1 (42.7–45.5)	62.0 (59.8–64.0)	81.7 (79.6–83.6)
Gum bleeding	45.4 (44.6–46.3)	29.0 (27.1–30.9)	41.5 (40.0–43.1)	48.7 (47.1–50.3)	59.8 (57.7–61.8)	63.1 (60.2–65.8)
Loose teeth	14.5 (14.0–15.1)	4.1 (3.3–5.1)	5.9 (5.3–6.7)	12.9 (12.0–13.8)	29.5 (27.5–31.6)	58.4 (55.7–61.0)
Bone loss around teeth[b]	12.8 (12.2–13.4)	6.4 (5.5–7.4)	9.0 (8.0–10.1)	13.7 (12.7–14.8)	20.1 (18.1–22.2)	27.8 (24.9–30.9)
Gum disease[b]	17.8 (17.1–18.5)	7.3 (6.3–8.5)	11.4 (10.4–12.6)	19.7 (18.6–20.9)	30.0 (27.8–32.3)	40.5 (37.6–43.4)
Precancerous oral lesions[b]	1.4 (1.2–1.7)	1.2 (0.8–1.8)	0.9 (0.6–1.2)	1.6 (1.2–2.1)	2.0 (1.5–2.6)	2.7 (2.0–3.6)
Past 12-mo experience						
Tooth extraction	11.7 (11.1–12.4)	4.1 (3.4–5.0)	5.7 (5.0–6.6)	11.6 (10.5–12.8)	22.9 (20.9–25.1)	37.9 (34.8–41.0)
Gum bleeding	25.9 (25.1–26.7)	10.3 (9.2–11.6)	21.5 (20.1–23.0)	28.2 (26.8–29.7)	40.7 (38.4–43.1)	45.5 (42.4–48.7)
Loose teeth	5.6 (5.2–6.0)	1.1 (0.8–1.5)	1.2 (0.8–1.6)	3.4 (2.9–4.0)	12.7 (11.0–14.7)	34.4 (31.5–37.5)
Bone loss around teeth[c]	8.3 (7.6–9.1)	2.7 (2.1–3.6)	4.2 (3.3–5.4)	10.8 (9.5–12.2)	22.5 (19.2–26.2)	33.2 (27.7–39.2)
Gum disease[c]	7.0 (6.4–7.6)	1.4 (0.9–2.0)	3.0 (2.3–4.0)	9.4 (8.0–11.0)	22.1 (19.1–25.4)	29.3 (24.8–34.2)
Precancerous oral lesion[c]	0.5 (0.3–0.6)	0.6[d] (0.3–1.2)	0.2[d] (0.1–0.4)	0.5 (0.3–0.8)	0.7 (0.4–1.0)	1.5 (0.9–2.6)

Percentages are weighted using the wave 4 cross-sectional weights for the wave 4 cohort. *N*s are unweighted. *N*s (denominator size) for each oral health outcome may be less than shown in the top row due to missing data or the population eligible to be asked about each outcome (see footnote c).
[a]The total PATH Study wave 4 sample includes 33,643 participants ≥18 y; results shown in this table limited to participants without missing data for self-rated oral health.
[b]At wave 4, for continuing respondents, constructs were only asked of respondents who reported seeing a dentist within the past 12 mo. Those who reported not having seen a dentist in the past 12 mo and had previously reported never having the outcome were categorized as never (no lifetime experience).
[c]Participants who reported not having seen a dentist in the past 12 mo were not included in this analysis.
[d]Estimate should be interpreted with caution because it has low statistical precision. It is based on a denominator sample size of less than 50 or the relative standard error of the estimate or its complement is larger than 0.30.

Discussion

In this analysis, the PATH Study and NHANES yielded similar national estimates for characteristics of the US adult population, including oral conditions, suggesting strong generalizability. Nearly all individual oral health conditions assessed in the PATH Study followed a stepwise gradient along levels of a global measure of perceived overall oral health and were associated with combustible tobacco use: findings that support internal validity. Cross-sectional associations were identified between adverse oral conditions and several less well-studied tobacco use behaviors, including dual- and poly-use behaviors, secondhand smoke exposure, and use of noncigarette products. While these associations cannot be interpreted as causal effects, novel products and use behaviors merit further examination in future research.

Self-reported oral health measures may substantially underestimate clinically detectable disease in the population. Most self-reported measures of periodontal disease have been found to have good specificity but modest to poor sensitivity (Blicher et al. 2005; Ramos et al. 2013). NHANES includes both self-reported periodontal disease items and clinically measured full-mouth periodontal examinations, allowing direct comparison. Prior evaluation of the NHANES survey items confirmed high specificity and modest sensitivity, with more promising predictive utility when self-reported measures were used in combination (Eke et al. 2013). Given how closely prevalence estimates based on PATH Study self-reported oral health measures approximated those from NHANES, it is reasonable to expect similar performance of PATH Study periodontal disease items. However, relatively few validation studies exist to compare survey measures of nonperiodontal oral conditions to clinical outcomes (Ramos et al. 2013).

The strong gradient between self-rated oral health and specific oral conditions observed in the PATH Study is consistent with other findings, including studies with clinically measured outcomes and in diverse populations defined by age and race/ethnicity (Thomson et al. 2012; Cozier et al. 2020; Lundbeck et al. 2020). The concordance plausibly reflects the co-occurrence of shared risk factors for multiple aspects of poor oral health (Sheiham and Watt 2000). Associations between tobacco use categories and overall self-rated oral health in the present analysis were consistent with associations observed for specific oral health conditions, suggesting utility of a simple global measure of oral health as a proxy measure to examine potential oral health effects of various tobacco use patterns.

Cigarette smoking was associated with nearly all adverse oral health conditions examined, consistent with the well-documented damaging influence of smoking on the periodontium and oral cavity (Johnson and Bain 2000; Bergström 2004; Warnakulasuriya et al. 2010). Associations extended to other patterns of combustible tobacco use, including cigarettes in combination with ENDS and other combustible products, like cigars. These associations persisted after adjustment for pack-year history and secondhand smoke exposure, which were themselves also associated with multiple oral health conditions, consistent with the role of tobacco smoke, regardless of the source, in impairing oral health. Notably, cigarette smoking was inversely associated with past 12-mo experience of gum bleeding, and former tobacco use was positively associated. Gingival

Table 4. Associations between Tobacco Use and Lifetime Experience of Adverse Oral Conditions: PATH Study Wave 4.

	Oral Health Conditions: Lifetime Experience, AOR (95% CI)					
Characteristic	Tooth Extraction (*n* = 24,687)	Gum Bleeding (*n* = 24,990)	Loose Teeth (*n* = 24,967)	Bone Loss around Teeth[a] (*n* = 24,949)	Gum Disease[a] (*n* = 24,928)	Precancerous Oral Lesions[a] (*n* = 24,932)
Tobacco use status						
Never tobacco user	Reference	Reference	Reference	Reference	Reference	Reference
Recent former tobacco user	1.11 (0.87–1.43)	1.26 (0.99–1.61)	**1.46 (1.03–2.05)**	1.21 (0.82–1.78)	**1.55 (1.15–2.10)**	1.00 (0.27–3.77)
Long-term former tobacco user	1.18 (1.00–1.39)	**1.55 (1.34–1.80)**	**1.28 (1.06–1.55)**	**1.29 (1.05–1.60)**	**1.34 (1.12–1.60)**	1.74 (0.84–3.62)
Former experimental tobacco user	1.10 (0.93–1.30)	**1.30 (1.09–1.56)**	1.25 (0.94–1.67)	1.08 (0.84–1.39)	1.12 (0.90–1.39)	0.44 (0.12–1.65)
Exclusive P30D use categories						
Cigarette	**1.42 (1.23–1.64)**	0.88 (0.77–1.02)	**1.59 (1.31–1.93)**	**1.39 (1.12–1.73)**	**1.28 (1.06–1.53)**	1.41 (0.73–2.75)
E-cigarette (ENDS)	**1.30 (1.01–1.68)**	1.25 (1.00–1.57)	1.32 (0.93–1.87)	**1.51 (1.10–2.07)**	1.18 (0.88–1.57)	1.51 (0.54–4.22)
Cigars	1.19 (0.88–1.61)	1.04 (0.82–1.32)	1.21 (0.84–1.75)	1.26 (0.89–1.78)	1.06 (0.77–1.47)	2.41 (0.62–9.38)
Smokeless tobacco	1.02 (0.81–1.28)	1.08 (0.83–1.41)	**1.49 (1.12–1.97)**	0.86 (0.59–1.27)	0.86 (0.61–1.21)	**3.85 (1.73–8.57)**
Hookah	1.05 (0.64–1.72)	1.15 (0.79–1.68)	0.73 (0.40–1.35)	1.41 (0.61–3.27)	1.39 (0.76–2.56)	2.20 (0.28–17.08)
Pipe	1.00 (0.26–3.90)	**2.92 (1.30–6.54)**	1.00 (0.31–3.25)	1.93 (0.39–9.68)	1.45 (0.35–6.06)	9.40 (0.57–153.95)
Multiple P30D use categories						
Cigarette + ENDS	**1.81 (1.47–2.24)**	0.97 (0.80–1.17)	**1.78 (1.37–2.30)**	**1.50 (1.12–2.00)**	**1.42 (1.12–1.80)**	2.14 (0.93–4.93)
Poly-combustible	**1.77 (1.49–2.10)**	1.04 (0.87–1.23)	**1.91 (1.47–2.48)**	**1.78 (1.33–2.39)**	**1.27 (1.02–1.58)**	2.21 (0.94–5.18)
Combustible + noncombustible	**1.61 (1.29–2.00)**	1.06 (0.88–1.26)	**1.79 (1.39–2.32)**	**2.04 (1.54–2.69)**	**1.76 (1.40–2.21)**	**3.32 (1.69–6.51)**
Other current	0.74 (0.52–1.06)	1.21 (0.86–1.69)	0.69 (0.41–1.17)	1.17 (0.69–1.99)	0.90 (0.55–1.47)	0.99 (0.19–5.08)
Tobacco-related adjustment variables						
Cigarette pack years (per each 5 pack years)	**1.11 (1.08–1.13)**	0.99 (0.96–1.01)	**1.11 (1.03–1.06)**	**1.11 (1.08–1.14)**	**1.10 (1.07–1.12)**	1.01 (0.93–1.10)
SHS exposure (per each 5 h/wk)	**1.04 (1.03–1.05)**	**1.02 (1.01–1.03)**	**1.04 (1.09–1.14)**	1.01 (0.99–1.02)	**1.02 (1.00–1.03)**	1.01 (0.98–1.04)

Adjusted odds ratios are weighted using the wave 4 cross-sectional weights for the wave 4 cohort. *N*s are unweighted. In addition to the tobacco-related adjustment variables shown, models are adjusted for age, sex, race/ethnicity, education, income, ever diabetes status, body mass index, high-frequency drinking, and past 30-d marijuana use. Bolded text indicates coefficients are statistically significant at the $P < 0.05$ level. *N*s (denominator size) for each oral health outcome are less than the total sample shown in Table 3 due to missing data.

AOR, adjusted odds ratio; CI, confidence interval; ENDS, electronic nicotine delivery systems; NA, not applicable; P30D, past 30 d; PATH, Population Assessment of Tobacco and Health; SHS, secondhand smoke.

[a]At wave 4, for continuing respondents, constructs were only asked of respondents who reported seeing a dentist within the past 12 mo. Those who reported not having seen a dentist in the past 12 mo and had previously reported never having the outcome were categorized as never.

bleeding is known to be blunted among tobacco smokers, with potential return of bleeding after smoking cessation (Nair et al. 2003). Identifying this association from a self-reported survey measure provides confidence in instrument validity.

Smokeless tobacco use was also associated with multiple adverse outcomes, including precancerous oral lesions, consistent with existing clinical investigations (Walsh and Epstein 2000; Warnakulasuriya et al. 2010). Other noncigarette tobacco products, including ENDS, cigars, hookah, and pipes, when used exclusively (i.e., not in combination with other combustible tobacco) were not consistently associated with the oral health conditions evaluated. When considering the total population health implications of noncigarette products (e.g., ENDS), it bears noting that many ENDS users are dual or poly-users with other products (Owusu et al. 2019; Robertson et al. 2019), including most in this analysis.

All of the above associations must be interpreted with caution: the cross-sectional design of this study and potential for discordance between lifetime oral health experience and current tobacco use preclude causal conclusions. For example, current noncigarette users may have a history of cigarette smoking, which could plausibly increase current disease risk. Indeed, past 12-mo experience of bone loss, loose teeth, and gum bleeding were all higher among long-term former tobacco users in this analysis. Regardless, dental clinicians can expect greater prevalence of oral disease among patients with a current or past history of tobacco use, including noncigarette products (Vora and Chaffee 2019). Associations in this analysis are hypothesis generating for potential prospective studies, including using PATH Study data.

Among limitations of the current analysis, some PATH Study oral health measures lacked similarly worded analogs in

Table 5. Associations between Tobacco Use and Recent Experience of Adverse Oral Conditions: PATH Study Wave 4.

	Oral Health Conditions: Past 12-mo Experience, AOR (95% CI)						
Characteristic	Self-Rated Oral Health: Fair or Poor (*n* = 24,984)	Tooth Extraction (*n* = 18,463)	Gum Bleeding (*n* = 18,595)	Loose Teeth (*n* = 18,573)	Bone Loss around Teeth[a] (*n* = 9,920)	Gum Disease[a] (*n* = 9,922)	Precancerous Oral Lesions[a] (*n* = 9,933)
Tobacco use status							
Never tobacco user	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Recent former tobacco user	**1.40 (1.08–1.82)**	0.95 (0.63–1.44)	1.04 (0.80–1.35)	**1.65 (1.08–2.51)**	1.23 (0.74–2.04)	1.45 (0.89–2.38)	—[b] NA
Long-term former tobacco user	1.19 (1.00. 1.43)	1.17 (0.91–1.50)	**1.35 (1.14–1.59)**	**1.53 (1.09–2.14)**	**1.47 (1.02–2.11)**	1.24 (0.85–1.83)	1.34 (0.21–8.36)
Former experimental tobacco user	1.07 (0.85–1.34)	0.83 (0.59–1.17)	1.22 (0.98–1.52)	1.18 (0.71–1.98)	1.09 (0.68–1.74)	1.50 (0.97–2.32)	—[c] NA
Exclusive P30D use categories							
Cigarette	**1.76 (1.48–2.10)**	**1.43 (1.12–1.82)**	**0.82 (0.71–0.96)**	**2.02 (1.52–2.69)**	**1.68 (1.14–2.48)**	**1.51 (1.04–2.19)**	1.31 (0.17–9.89)
E-cigarette (ENDS)	1.28 (0.93–1.75)	1.02 (0.63–1.67)	1.09 (0.85–1.41)	1.44 (0.80–2.58)	1.26 (0.67–2.36)	0.97 (0.47–1.99)	—[d] NA
Cigars	1.22 (0.97–1.55)	1.22 (0.76–1.96)	0.95 (0.69–1.31)	1.19 (0.66–2.18)	1.66 (0.89–3.11)	1.28 (0.59–2.78)	—[d] NA
Smokeless tobacco	**2.31 (1.77–3.01)**	**1.43 (1.05–1.96)**	1.04 (0.79–1.35)	**1.93 (1.15–3.26)**	1.55 (0.81–2.99)	1.67 (0.93–3.00)	**12.62 (1.85–85.93)**
Hookah	0.95 (0.61–1.46)	0.59 (0.27–1.30)	1.01 (0.64–1.57)	0.75 (0.21–2.68)	0.92 (0.19–4.60)	1.97 (0.56–6.84)	—[d] NA
Pipe	1.91 (0.57–6.35)	0.70 (0.11–4.57)	1.22 (0.35–4.23)	0.88 (0.11–6.87)	2.74 (0.56–13.48)	—[e] NA	—[d] NA
Multiple P30D use categories							
Cigarette + ENDS	**1.80 (1.46–2.23)**	**1.77 (1.30–2.42)**	0.84 (0.68–1.03)	**2.04 (1.40–2.97)**	1.45 (0.78–2.69)	1.39 (0.84–2.30)	—[f] NA
Poly-combustible	**1.90 (1.55–2.34)**	**1.80 (1.35–2.41)**	1.04 (0.86–1.25)	**2.43 (1.63–3.62)**	**2.60 (1.66–4.06)**	**1.78 (1.04–3.05)**	—[d] NA
Combustible + noncombustible	**1.89 (1.51–2.38)**	**1.78 (1.32–2.40)**	1.05 (0.83–1.32)	**2.78 (1.86–4.18)**	**2.29 (1.35–3.87)**	**2.55 (1.56–4.15)**	2.14 (0.34–13.37)
Other current[d,e]	0.84 (0.55–1.31)	0.62 (0.32–1.19)	1.00 (0.71–1.41)	0.67 (0.25–1.79)	0.58 (0.19–1.73)	0.34 (0.11–1.02)	2.85 (0.62–13.11)
Tobacco-related adjustment variables							
Cigarette pack years (per each 5 pack years)	**1.13 (1.10–1.15)**	1.02 (0.99–1.06)	0.98 (0.95–1.00)	1.04 (1.00–1.09)	**1.12 (1.07–1.18)**	**1.08 (1.02–1.14)**	1.05 (0.90–1.22)
SHS exposure (per each 5 h/week)	**1.04 (1.03–1.05)**	**1.03 (1.01–1.04)**	**1.02 (1.01–1.03)**	**1.03 (1.01–1.05)**	1.01 (0.99–1.03)	1.02 (0.99–1.06)	1.04 (0.96–1.11)

Adjusted odds ratios are weighted using the wave 4 cross-sectional weights for the wave 4 cohort. *N*s are unweighted. In addition to the tobacco-related adjustment variables shown, models are adjusted for age, sex, race/ethnicity, education, income, ever diabetes status, body mass index, high-frequency drinking and past 30-d marijuana use. Bolded text indicates coefficients are statistically significant at the $P < 0.05$ level. *N*s (denominator size) for each oral health outcome are less than the total sample shown in Table 3 due to missing data or the population eligible to be asked about each outcome (see footnote a).

AOR, adjusted odds ratio; CI, confidence interval; ENDS, electronic nicotine delivery systems; NA, not applicable; P30D, past 30-d; PATH, Population Assessment of Tobacco and Health; SHS, secondhand smoke.

[a]At wave 4, for continuing respondents, constructs were only asked of respondents who reported seeing a dentist within the past 12 mo. Those who reported not having seen a dentist in the past 12 mo were not included in the analysis.

[b]Recent former tobacco user and long-term former tobacco user were combined in precancerous oral lesions model due to low number.

[c]Former experimental tobacco user and never tobacco user were combined in precancerous oral lesions model due to low number.

[d]Exclusive ENDS, exclusive cigar, exclusive hookah, exclusive pipe, combustible only, and other current were combined in the precancerous oral lesions model due to low number.

[e]Pipe was combined with other current in the gum disease model due to low number.

[f]Cigarette + e-cigarette and other combustible + noncombustible were combined in the precancerous oral lesions model due to low number.

NHANES 2017–2018, precluding comparisons. While existing NHANES oral health validation studies help to estimate the extent of survey underreporting relative to clinical assessment, applicability to the PATH Study can only be assumed, not directly verified. PATH Study W4 does not include measures of potential dietary risk factors or all aspects of oral disease (dental caries is a notable exclusion), but additional oral health measures are included in upcoming waves. Despite the large overall sample size of the W4 cohort, this analysis encountered sample size limitations for some oral health conditions (e.g., precancerous oral lesions) and some tobacco use behaviors (e.g., smokeless tobacco and ENDS dual use).

The PATH Study is a potentially valuable resource for dental epidemiologic research. While self-reported health outcomes present inherent data quality limitations, the present results suggest adequate instrument validity to support research leveraging the PATH Study's unique and advantageous combination of sample size, scope, detailed tobacco use information, generalizability, and longitudinal structure. Such research has the potential to elevate oral health among priorities in tobacco control and regulatory policies, to inform tobacco use counseling in dental practice, and to identify new research directions regarding the oral health effects of tobacco use.

Author Contributions

B.W. Chaffee, contributed to conception, design, data interpretation, drafted and critically revised the manuscript; K. Lauten, M.L. Silveira, contributed to conception, design, data analysis and interpretation, critically revised the manuscript; E. Sharma, C.D. Everard, A. Hyland, contributed to conception, design, and data interpretation, critically revised the manuscript; K. Duffy, E. Park-Lee, E. Taylor, E. Tolliver, T. Watkins-Bryant, T. Iafolla, W.M. Compton, H.L. Kimmel, contributed to data interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: W.M. Compton reports long-term stock holdings in General Electric, 3M Company, and Pfizer Incorporated, unrelated to this article.

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References

Akinkugbe AA. 2019. Cigarettes, e-cigarettes, and adolescents' oral health: findings from the Population Assessment of Tobacco and Health (PATH) study. JDR Clin Trans Res. 4(3):276–283.

Atuegwu NC, Perez MF, Oncken C, Thacker S, Mead EL, Mortensen EM. 2019. Association between regular electronic nicotine product use and self-reported periodontal disease status: population assessment of tobacco and health survey. Int J Environ Res Public Health. 16(7):1263.

Bergström J. 2004. Tobacco smoking and chronic destructive periodontal disease. Odontology. 92(1):1–8.

Blicher B, Joshipura K, Eke P. 2005. Validation of self-reported periodontal disease: a systematic review. J Dent Res. 84(10):881–890.

Cornelius ME, Wang TW, Jamal A, Loretan CG, Neff LJ. 2020. Tobacco product use among adults—United States, 2019. MMWR Morb Mortal Wkly Rep. 69(46):1736–1742.

Cozier YC, Heaton B, Bethea TN, Freudenheim JL, Garcia RI, Rosenberg L. 2020. Predictors of self-reported oral health in the Black Women's Health Study. J Public Health Dent. 80(1):70–78.

Eke PI, Borgnakke WS, Genco RJ. 2020. Recent epidemiologic trends in periodontitis in the USA. Periodontol 2000. 82(1):257–267.

Eke PI, Dye BA, Wei L, Slade GD, Thornton-Evans GO, Beck JD, Taylor GW, Borgnakke WS, Page RC, Genco RJ. 2013. Self-reported measures for surveillance of periodontitis. J Dent Res. 92(11):1041–1047.

Eke PI, Thornton-Evans G, Dye B, Genco R. 2012. Advances in surveillance of periodontitis: the Centers for Disease Control and Prevention periodontal disease surveillance project. J Periodontol. 83(11):1337–1342.

Elani HW, Starr JR, Da Silva JD, Gallucci GO. 2018. Trends in dental implant use in the U.S., 1999-2016, and projections to 2026. J Dent Res. 97(13):1424–1430.

Fakhouri THI, Martin CB, Chen TC, Akinbami LJ, Ogden CL, Paulose-Ram R, Riddles MK, Van de Kerckhove W, Roth SB, Clark J, et al. 2020. An investigation of nonresponse bias and survey location variability in the 2017–2018 National Health and Nutrition Examination Survey. National Center for Health Statistics. Vital Health Stat. 2(185):1–36.

Holliday R, Chaffee BW, Jakubovics NS, Kist R, Preshaw PM. 2021. Electronic cigarettes and oral health. J Dent Res. 100(9):906–913.

Hyland A, Ambrose BK, Conway KP, Borek N, Lambert E, Carusi C, Taylor K, Crosse S, Fong GT, Cummings KM, et al. 2017. Design and methods of the Population Assessment of Tobacco and Health (PATH) Study. Tob Control. 26(4):371–378.

Johnson NW, Bain CA. 2000. Tobacco and oral disease. EU-Working Group on Tobacco and Oral Health. Br Dent J. 189(4):200–206.

Judkins DR. 1990. Fay's method for variance estimation. J Off Stat. 6(3):223–239.

Locker D. 2001. Oral Health indicators and determinants for population health surveys. Toronto: Community Dental Health Services Research Unit Toronto.

Lundbeck HJ, Smith MB, Thomson WM. 2020. Clinical validity of self-rated oral health among New Zealand nursing home residents. Gerodontology. 37(3):253–257.

McCarthy PJ. 1969. Pseudoreplication: further evaluation and applications of the balanced half-sample technique. Vital Health Stat. 2(31):1–24.

Nair P, Sutherland G, Palmer RM, Wilson RF, Scott DA. 2003. Gingival bleeding on probing increases after quitting smoking. J Clin Periodontol. 30(5):435–437.

National Health and Nutrition Examination Survey. 2017–2018. NHANES survey methods and analytic guidelines. Hyattsville (MD): US Department of Health and Human Services, Centers for Disease Control and Prevention [accessed 2021 Feb 23]. https://wwwn.Cdc.Gov/nchs/nhanes/analyticguidelines.Aspx.

Ng M, Freeman MK, Fleming TD, Robinson M, Dwyer-Lindgren L, Thomson B, Wollum A, Sanman E, Wulf S, Lopez AD, et al. 2014. Smoking prevalence and cigarette consumption in 187 countries, 1980–2012. JAMA. 311(2):183–192.

Owusu D, Huang J, Weaver SR, Pechacek TF, Ashley DL, Nayak P, Eriksen MP. 2019. Patterns and trends of dual use of e-cigarettes and cigarettes among U.S. adults, 2015–2018. Prev Med Rep. 16:101009.

Piesse A, Opsomer J, Dohrmann S, DiGaetano R, Morganstein D, Taylor K, Carusi C, Hyland A. 2021. Longitudinal uses of the Population Assessment of Tobacco and Health Study. Tob Regul Sci. 7(1):3–16.

Ramos RQ, Bastos JL, Peres MA. 2013. Diagnostic validity of self-reported oral health outcomes in population surveys: literature review. Rev Bras Epidemiol. 16(3):716–728.

Rivest L-P. 1994. Statistical properties of winsorized means for skewed distributions. Biometrika. 81(2):373–383.

Robertson L, Hoek J, Blank ML, Richards R, Ling P, Popova L. 2019. Dual use of electronic nicotine delivery systems (ENDS) and smoked tobacco: a qualitative analysis. Tob Control. 28(1):13–19.

Sheiham A, Watt RG. 2000. The common risk factor approach: a rational basis for promoting oral health. Community Dent Oral Epidemiol. 28(6):399–406.

Thomson WM, Mejia GC, Broadbent JM, Poulton R. 2012. Construct validity of Locker's global oral health item. J Dent Res. 91(11):1038–1042.

Tomar SL, Hecht SS, Jaspers I, Gregory RL, Stepanov I. 2019. Oral health effects of combusted and smokeless tobacco products. Adv Dent Res. 30(1):4–10.

Tourangeau R, Yan T, Sun H, Hyland A, Stanton CA. 2019. Population Assessment of Tobacco and Health (PATH) reliability and validity study: selected reliability and validity estimates. Tob Control. 28(6):663–668.

von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. 2007. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. BMJ. 335(7624):806–808.

Vora MV, Chaffee BW. 2019. Tobacco-use patterns and self-reported oral health outcomes: a cross-sectional assessment of the Population Assessment of Tobacco and Health Study, 2013–2014. J Am Dent Assoc. 150(5):332–344.e332.

Walsh PM, Epstein JB. 2000. The oral effects of smokeless tobacco. J Can Dent Assoc. 66(1):22–25.

Warnakulasuriya S, Dietrich T, Bornstein MM, Casals Peidró E, Preshaw PM, Walter C, Wennström JL, Bergström J. 2010. Oral health risks of tobacco use and effects of cessation. Int Dent J. 60(1):7–30.