Original Article

Lung cancer screening use and implications of varying eligibility criteria by race and ethnicity: 2019 Behavioral Risk Factor Surveillance System data

Randi M. Williams, PhD, MPH [1]; Tengfei Li, MS [2]; George Luta, PhD [2]; Min Qi Wang, PhD[3]; Lucile Adams-Campbell, PhD [1]; Rafael Meza, PhD [4]; Martin C. Tammemägi, DVM, MSc, PhD [5]; and Kathryn L. Taylor, PhD [1]

BACKGROUND: In 2021, the US Preventive Services Task Force (USPSTF) expanded the eligibility criteria for low-dose computed tomographic lung cancer screening (LCS) to reduce racial disparities that resulted from the 2013 USPSTF criteria. The annual LCS rate has risen slowly since the 2013 USPSTF screening recommendations. Using the 2019 Behavioral Risk Factor Surveillance System (BRFSS), this study 1) describes LCS use in 2019, 2) compares the percent eligible for LCS using the 2013 versus 2021 USPSTF criteria, and 3) determines the percent eligible using the more detailed $PLCOm2012_{Race3L}$ risk-prediction model. **METHODS:** The analysis included 41,544 individuals with a smoking history from states participating in the BRFSS LCS module who were ≥50 years old. **RESULTS:** Using the 2013 USPSTF criteria, 20.7% (95% confidence interval [CI], 19.0-22.4) of eligible individuals underwent LCS in 2019. The 2013 USPSTF criteria was compared to the 2021 USPSTF criteria, and the overall proportion eligible increased from 21.0% (95% CI, 20.2-21.8) to 34.7% (95 CI, 33.8-35.6). Applying the 2021 criteria, the proportion eligible by race was 35.8% (95% CI, 34.8-36.7) among Whites, 28.5% (95% CI, 25.2-31.9) among Blacks, and 18.0% (95% CI, 12.4-23.7) among Hispanics. Using the 1.0% 6-year threshold that is comparable to the 2021 USPSTF criteria, the $PLCOm2012_{Race3L}$ model selected more individuals overall and by race. **CONCLUSIONS:** Using data from 20 states and using multiple imputation, higher LCS rates have been reported compared to prior BRFSS data. The 2021 expanded criteria will result in a greater number of screen-eligible individuals. However, risk-based screening that uses additional risk factors may be more inclusive overall and across subgroups. ***Cancer* 2022;128:1812-1819**. © *2022 American Cancer Society*.

LAY SUMMARY:

- In 2013, lung cancer screening (lung screening) was recommended for high risk individuals.
- The annual rate of lung screening has risen slowly, particularly among Black individuals.
- In part, this racial disparity resulted in expanded 2021 criteria.
- Survey data was used to: 1) describe the number of people screened in 2019, 2) compare the percent eligible for lung screening using the 2013 versus 2021 guidelines, and 3) determine the percent eligible using more detailed criteria.
- Lung screening rates increased in 2019, and the 2021 criteria will result in more individuals eligible for screening.
- Using additional criteria may identify more individuals eligible for lung screening.

KEYWORDS: Behavioral Risk Factor Surveillance System, low dose computed tomography, lung cancer screening, PLCOm2012 risk prediction model, race disparities, US Preventive Services Task Force.

INTRODUCTION

Lung cancer is a major public health problem in the United States (US) with disparities in the burden of disease as well as in the use of low-dose computed tomographic lung cancer screening (LCS).[1-3] The National Lung Screening Trial (NLST), which found that annual LCS resulted in a 20% lung cancer-specific mortality reduction compared to chest x-ray, informed the 2013 United States Preventive Services Task Force (USPSTF) screening recommendations.[4,5] These guidelines recommended annual LCS for adults 55 to 80 years old with a 30+ pack-year smoking history, who currently smoked or who had quit within the past 15 years. Since the release of the guidelines, several studies have examined the use of LCS in the United States. Initial reports indicated as low as 3.9% uptake of screening using National Health Interview Survey 2010 and 2015 data.[3] More recently, 12% to 19% of eligible individuals have reported LCS in the past year according to data from the Behavioral Risk Factor Surveillance System (BRFSS).[2,6-9]

Corresponding Author: Randi M. Williams, PhD, MPH, Assistant Professor, Cancer Prevention & Control Program, Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, 2115 Wisconsin Avenue, NW Ste 300, Washington, DC 20007 (rmw27@georgetown.edu).

[1]Cancer Prevention & Control Program, Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, Washington, DC; [2]Department of Biostatistics, Bioinformatics and Biomathematics, Georgetown University, Washington, DC; [3]School of Public Health, University of Maryland, College Park, Maryland; [4]Department of Epidemiology, University of Michigan, Ann Arbor, Michigan; [5]Department of Health Sciences, Brock University, St Catharines, Ontario, Canada

Additional supporting information may be found in the online version of this article.

DOI: 10.1002/cncr.34098, **Received:** July 26, 2021; **Revised:** November 12, 2021; **Accepted:** December 20, 2021, **Published online** February 24, 2022 in Wiley Online Library (wileyonlinelibrary.com)

In addition to reviewing uptake of screening in the US population, studies began evaluating the appropriateness of the 2013 screening criteria for diverse populations, given the lack of diversity among participants in the NLST trial,[10-13] as well as the known differences in smoking patterns by race.[14] These studies suggested the 2013 USPSTF criteria might exacerbate lung cancer disparities because certain subgroups, including African American/Black individuals, were less likely to meet the screening eligibility criteria due to lower levels of cigarette smoking, despite being more susceptible to lung cancer.[10,15,16] These studies highlighted the importance of considering race-specific pack-year eligibility, as well as risk-based screening to make LCS guidelines more equitable.

Based on the accumulating evidence,[10,17] the USPSTF released new guidelines in March 2021 that lowered the initial age to start screening from 55 to 50 years and the smoking history from 30 to 20 pack-years (2021 USPSTF). These expanded criteria increase the estimated number of US adults who are eligible for LCS from 8 million to 14.5 million.[18] Additionally, these revised criteria will increase the number of minorities who are eligible to be screened.[18,19]

However, it remains uncertain if the revised guidelines will eliminate screening eligibility disparities, because the criteria rely on age and pack-year smoking history alone. The current guidelines do not take into account other risk factors that contribute to higher lung cancer incidence and diagnosis at younger ages seen in Black individuals compared with Whites.[20,21] The validated PLCOm2012 risk prediction model was developed using data from the control arm of the Prostate, Lung, Colorectal, and Ovarian Cancer Screening Randomized Controlled Trial. It includes 11 risk factors (including education, race and/or ethnicity, and personal history of cancer), has been validated in the United States and other countries, and has shown improved sensitivity for Black individuals.[22-26] Additionally, the PLCOm2012 model has been implemented in public health lung cancer screening programs in Ontario, Canada and the United Kingdom.[27,28]

Using the BRFSS 2019 survey data, the goals of this analysis were to: 1) describe LCS use in the past year, 2) examine the impact of varying the pack-years and age criteria by race and ethnicity on the proportion of individuals eligible, and 3) apply a risk-prediction model to determine the percent eligible for LCS among individuals with a smoking history, stratified by race.

MATERIALS AND METHODS

Study Population

The Centers for Disease Control and Prevention BRFSS is a health-related telephone survey that collects data from more than 400,000 adults (≥18 years old) annually in 50 states, the District of Columbia, and 3 US territories. The survey is conducted using random digit dialing techniques on landline and cellular phones and is administered using in-house interviewers, telephone call centers, or academic institutions. Data are weighted using an iterative proportional fitting (or raking) methodology to account for age, gender, ethnicity, geographic regions within states, marital status, education level, home ownership, and type of phone ownership (landline/cellular telephone).

For the present study, we used the publicly available data from the core components and optional lung cancer screening module from the 2019 survey. We limited the data set to include individuals 50+ years old who currently smoked or formerly smoked cigarettes. The BRFSS data are publicly available, are de-identified, and are exempt from institutional review board approval.

Measures

We included items from the BRFSS core component that all participating states must ask, including demographic characteristics, health status, and behaviors (eg, cancer screening, tobacco use, and physical activity). The 4-item lung cancer screening module was an optional component of the 2019 survey and was administered by 20 states (Arizona, Idaho, Kansas, Kentucky, Maine, Maryland, Minnesota, Missouri, Montana, Nebraska, North Carolina, North Dakota, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Utah, Vermont, West Virginia, and Wisconsin).

Demographic characteristics

We used race and ethnicity, age, gender, marital status, health insurance status, and education to characterize the sample. The BRFSS data set collapsed respondents 81+ years old with respondents 80 years old, thus the present analysis includes individuals 50+ years old.

Cigarette smoking

Ever versus never smoking status was determined by the question, "Have you smoked at least 100 cigarettes in your entire life?" The item, "Do you now smoke cigarettes every day, some days, or not at all?" gauged whether an individual currently or formerly smoked cigarettes. Current smoking was defined as those who responded "every day" or "some days." Former smoking

included those who responded "not at all." To calculate pack-years, we used the age that respondents indicated they last smoked cigarettes regularly minus the age when they first started to smoke regularly, as well as the reported average number of cigarettes smoked each day ("On average, how many cigarettes do you smoke each day?"). The reported average number of cigarettes smoked each day was divided by 20 and then multiplied by the total number of years smoked to obtain pack-years.

Other risk factors

To assess lung cancer risk, we used the $PLCOm2012_{Race3L}$ risk prediction model, which includes sociodemographic variables: 1) age; 2) highest level of education ("What is the highest grade or year of school you completed?"); 3) race collapsed into 4 levels: White/non-Hispanic, Black/non-Hispanic, Hispanic, and Other that included Asian, American Indian/Alaska Native, and those who identified as having "other." Predictors related to medical history and smoking exposure included self-reported: 4) a diagnosis of chronic obstructive pulmonary disease, emphysema, or chronic bronchitis; 5) personal history of cancer as measured by the single item, "(Ever told) you had any other types of cancer?" without consideration of skin cancer; 6) body mass index (BMI) in which we used weight in kilograms and height in centimeters (the formula used to calculate BMI is a person's weight in kilograms/their height in meters squared); 7) smoking status (current or former); 8) average number of cigarettes smoked per day; 9) duration smoked in years; and 10) number of years since quitting smoking among those who formerly smoked. Because the BRFSS survey did not assess family history of lung cancer, this 1 variable was excluded from the model.

Lung cancer screening history

The single item from the lung cancer screening module assessed use: "In the last 12 months, did you have a CT or CAT scan?" Response options: "Yes, to check for lung cancer," "No (did not have a CT scan)," and "Had a CT scan, but for some other reason."

Statistical Methods

We used sample weights to account for the complex survey sampling design. The analyses followed the BRFSS guidelines (https://www.cdc.gov/brfss/index.html). Weighted frequency distributions are presented for all variables of interest. We describe the findings based on the absolute proportions without hypothesis testing. We present the sociodemographics, smoking history variables, and screening utilization stratified by race and ethnicity (Table 1). In Table 2 we show the proportion of individuals eligible using the 2013 and 2021 USPSTF screening criteria and the application of the $PLCOm2012_{Race3L}$ model stratified by race.

In the analyses in which we applied the $PLCOm2012_{Race3L}$ model to determine the percent eligible for LCS (Table 2), we stratified across 3 groups (see Supplemental Table 3a): non-Hispanic White, non-Hispanic Black, and Other (that includes Hispanic, Asian, American Indian or Alaska Native [AI/AN], and Other race) as well as by 4 groups: non-Hispanic White, non-Hispanic Black, Hispanics, and Other (that includes Asian, AI/AN, and Other race). Based on community-level evidence,[29] the lung cancer risk effect estimated by the original PLCOm2012 underestimates the independent risk associated with being Hispanic. Because of this underestimation, Hispanics have been pooled with Whites and Other races in the updated version of the $PLCOm2012_{Race3L}$. This version of the $PLCOm2012_{Race3L}$ model has been well validated and has led to less under-selection of Hispanics for LCS than occurs applying the original PLCOm2012.[29] To an extent, pooling helps overcome the deficiency and allows for comparison between the data (Table 2 and Supplemental Table 3a). We used a re-parameterized $PLCOm2012_{Race3L}$ that excluded family history of lung cancer based on the equations provided by the developer of the model (MT). Family history of lung cancer was the only variable excluded from the risk prediction model, and this re-parameterized model has been used previously.[24] Eligibility according to the PLCOm2012 lung cancer incidence risk prediction model with a 1.0% and 1.5% threshold is also presented by race and ethnicity. The 1.5% risk threshold was used for the analysis due to the LCS mortality reduction benefit versus chest x-ray.[30] The 1.0% cutpoint was used because it has been shown to be comparable to 2021 USPSTF guidelines.[29-31]

Multiple imputation

Missing variables were imputed for all patients 50 years of age or older. After the imputation process, we selected patients meeting the 2013 USPSTF or 2021 USPSTF criteria. We used a 2-stage multiple imputation procedure to address the missing values of variables of interest, including: screened in the past year (34% missing), pack-years (20% missing), total years of smoking (17% missing), years since quitting smoking (16% missing),

TABLE 1. Sociodemographic and Smoking History Among Individuals 50 Years Old or Older by Race/Ethnicity

Variables	White–Non-Hispanic (n = 36,787)	Black–Non-Hispanic (n = 2066)	Hispanic (n = 786)	Other–Non-Hispanic[a] (n = 1,905)	Total (n = 41,544)
Age, mean (SE), y	65.1 (0.1)	63.6 (0.3)	61.1 (0.5)	62.6 (0.4)	64.7 (0.1)
Gender, %					
Male	51.9 (51.0, 52.8)	50.7 (47.4, 54.1)	55.6 (49.2, 62.0)	59.8 (55.5, 64.1)	52.2 (51.3, 53.1)
Female	48.1 (47.2, 49.0)	49.3 (45.9, 52.6)	44.4 (38.0, 50.8)	40.2 (35.9, 44.7)	47.8 (46.9, 48.7)
Marital status, %					
Married	58.0 (57.1, 58.9)	34.8 (31.6, 38.1)	55.9 (49.5, 62.3)	50.4 (45.8, 55.1)	55.5 (54.6, 56.4)
Not married	42.0 (41.1, 42.9)	65.2 (61.9, 68.4)	44.1 (37.7, 50.5)	49.6 (44.9, 54.2)	44.5 (43.6, 45.4)
Missing, No.	231	11	4	11	257
Health insurance, %					
Yes	94.3 (93.9, 94.8)	91.3 (89.0, 93.5)	82.6 (77.0, 88.2)	92.5 (90.0, 94.9)	93.6 (93.1, 94.1)
No	5.7 (5.2, 6.1)	8.7 (6.5, 11.0)	17.4 (11.8, 23.0)	7.5 (5.1, 10.0)	6.4 (5.9, 6.9)
Missing, No.	89	10	4	4	107
Education, %					
Less than high school graduate	12.6 (11.9, 13.4)	19.9 (17.0, 22.8)	43.6 (37.1, 50.0)	18.8 (14.6, 23.0)	14.5 (13.8, 15.3)
High school graduate	34.8 (33.9, 35.7)	35.3 (32.0, 38.5)	21.3 (16.3, 26.4)	30.0 (25.3, 33.8)	34.2 (33.3, 35.0)
Some college	32.6 (31.7, 33.4)	31.0 (27.9, 34.0)	23.0 (18.0, 27.9)	32.3 (28.1, 36.6)	32.1 (31.3, 32.9)
College graduate	20.0 (19.4, 20.7)	13.9 (12.0, 15.8)	12.1 (8.6, 15.6)	19.3 (15.7, 22.9)	19.2 (18.6, 19.8)
Missing, No.	108	6	3	4	121
History of lung diseases, COPD, %					
Yes	19.4 (18.7, 20.2)	16.8 (14.2, 19.4)	8.7 (5.6, 11.9)	24.9 (20.5, 29.2)	19.1 (18.4, 19.8)
No	80.6 (79.8, 81.3)	83.2 (80.6, 85.8)	91.3 (88.1, 94.4)	75.1 (70.8, 79.5)	80.9 (80.2, 81.6)
Missing, No.	283	15	4	27	329
Cancer history, %					
Yes	15.2 (14.6, 15.9)	12.8 (10.6, 15.1)	9.8 (6.0, 13.6)	13.8 (11.0, 16.6)	14.8 (14.2, 15.4)
No	84.8 (84.1, 85.4)	87.2 (84.9, 89.4)	90.2 (86.4, 94.0)	86.2 (83.4, 89.0)	85.2 (84.6, 85.8)
Missing, No.	108	4	5	15	132
BMI, mean (SE)	28.6 (0.1)	29.8 (0.2)	29.1 (0.4)	28.3 (0.3)	28.7 (0.1)
Missing, No.	1778	97	50	86	2011
Smoking status, %					
Current smoker	28.3 (27.4, 29.2)	38.6 (35.3, 41.9)	33.2 (26.9, 39.6)	40.7 (36.0, 45.4)	29.9 (29.0, 30.7)
Former smoker	71.7 (70.8, 72.6)	61.4 (58.1, 64.7)	66.8 (60.4, 73.1)	59.3 (54.6, 64.0)	70.1 (69.3, 71.0)
Cigarettes per day, mean (SE)	18.5 (0.1)	12.3 (0.3)	12.3 (0.6)	17.1 (0.6)	17.6 (0.1)
Missing, No.	5666	478	160	342	6646
Pack-years, mean (SE)	27.4 (0.3)	19.5 (0.6)	15.2 (1.2)	27.3 (1.3)	26.3 (0.2)
Missing, No.	7069	591	209	440	8309
Total duration of smoking, mean (SE), y	29.1 (0.2)	31.3 (0.5)	24.3 (1.1)	30.4 (0.8)	29.2 (0.1)
Missing, No.	6114	516	184	363	7177
Screened in past year, %[b]	13.1 (12.4, 13.8)	14.6 (12.0, 17.2)	9.5 (4.3, 14.7)	14.9 (10.8, 18.9)	13.2 (12.6, 13.8)
Missing, No.	7827	495	157	471	8950
Eligible individuals screened in past year, %[c]	20.8 (19.0, 22.5)	20.2 (10.8, 29.6)	23.8 (4.4, 43.3)	19.1 (12.0, 26.2)	20.7 (19.0, 22.4)
Missing, No.	1800	78	24	100	2002

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; USPSTF, US Preventive Services Task Force.
Note: Percentages are weighted. The values in parenthesis following percentages are the corresponding 95% confidence intervals of the estimate.
[a]Other–non-Hispanic includes Asian (n = 101), American Indian/Alaska Native (n = 845), other race (n = 959).
[b]Among 33,235 individuals 50-80 years old with any pack-years.
[c]Among 7273 individuals eligible according to the USPSTF2013 screening criteria 55-80 years old and with 30+ pack-years.

and number of cigarettes smoked per day (16% missing). The 2-stage imputation procedure was required due to skip patterns. For stage 1, we imputed all variables except the number of cigarettes smoked per day and the age that respondents indicated when they last smoked cigarettes regularly. For stage 2, we imputed the number of cigarettes smoked per day and the age that respondents indicated when they last smoked cigarettes regularly only for the subsets of records of current or former smokers generated from stage 1. We created 10 multiple imputed data sets and analyzed them by taking into account the complex survey sampling design. We combined the results of the analyses of the 10 multiple imputed data sets using the rule of Rubin and provided estimated means with standard errors for the continuous variables and estimated percentages with 95% CIs

TABLE 2. Percent Eligible for Screening by Race/Ethnicity Using Multiple Imputation

	% Eligible			
	USPSTF 2013[a]	USPSTF 2021[b]	PLCOm2012$_{Race3L}$ at 1.5% Threshold[c]	PLCOm2012$_{Race3L}$ at 1.0% Threshold[c]
White–non-Hispanic	21.9 (21.1, 22.7)	35.8 (34.8, 36.7)	36.2 (35.2, 37.1)	46.3 (45.3, 47.2)
Black–non-Hispanic	16.0 (13.2, 18.8)	28.5 (25.2, 31.9)	31.1 (27.7, 34.5)	39.3 (35.8, 42.7)
Hispanic	9.8 (5.3, 14.3)	18.0 (12.4, 23.7)	15.0 (9.7, 20.2)	20.3 (13.7, 26.9)
Other–non-Hispanic[d]	22.1 (18.2, 26.0)	39.3 (34.5, 44.0)	43.4 (38.7, 48.1)	51.4 (46.6, 56.3)
Total	21.0 (20.2, 21.8)	34.7 (33.8, 35.6)	35.3 (34.4, 36.2)	45.0 (44.1, 45.9)

Abbreviation: USPSTF, US Preventive Services Task Force.
[a]Eligible according to USPSTF 2013 screening criteria (55-80 years old, ≥30 pack-years, current, or former who quit within 15 years).
[b]Eligible according to USPSTF 2021 screening criteria (50-80 years old, ≥20 pack-years, current, or former who quit within 15 years).
[c]Eligible using the PLCOm2012$_{Race3L}$ risk prediction model that predicts 6-year risk of lung cancer using multiple risk factors (age, education, body mass index, chronic obstructive pulmonary disease/emphysema/chronic bronchitis, personal history of cancer, race/ethnicity, smoking status, cigarettes per day, duration smoked, years quit). Participants with a probability of being diagnosed with lung cancer of 1.5% and 1.0% or greater using the PLCOm2012 criteria.
[d]Other-non-Hispanic includes Asian, American Indian, Alaska Native, and other race.

for the categorical variables.[32] All analyses were performed using SAS, version 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

Participants

Of the 41,544 individuals included in the present analysis, 88.5% (36,787) were non-Hispanic White, 5% (2066) were non-Hispanic Black/African American, 2% (786) were Hispanic, and 4.5% (1905) reported being of a non-Hispanic other race (Asian, American Indian/Alaska Native, Other) (Table 1). The mean age of respondents was 64.7 years (SE = 0.1) with White respondents being older on average (mean [M] = 65.1 years, SE = 0.1) compared to Blacks (M = 63.6 years, SE = 0.3), Hispanics (M = 61.1 years, SE = 0.5), and others (M = 62.6 years, SE = 0.4). White individuals were least likely to be currently smoking (28.3%; 95% CI, 27.4-29.2). Hispanic individuals had the fewest pack-years (M = 15.2 years, SE = 1.2) followed by Blacks (M = 19.5 years, SE = 0.6). Black individuals reported the longest duration of total years smoked (M = 31.3 years, SE = 0.5).

LCS Use

Among those eligible according to the 2013 USPSTF screening criteria (55 years+ and with 30+ pack-years), 20.7% (95% CI, 19.0-22.4) were screened in the past 12 months (Table 1). When stratified by race, the rates were comparable with 20.8% (95% CI, 19.0-22.5) of Whites and 20.2% (95% CI, 10.8-29.6) of Black individuals. The highest rates of screening were among Hispanics at 23.8% (95% CI, 4.4-43.3) and the lowest at 19.1% (95% CI, 12.0-26.2) of others having reported a computed tomography (CT) scan to check for lung cancer within the last year.

Comparing 2013 and 2021 USPSTF Screening Eligibility Criteria

Overall, the proportion of individuals who would be eligible for LCS increased from 21.0% (95% CI, 20.2-21.8) using the 2013 USPSTF criteria to 34.7% (95% CI, 33.8-35.6) using the 2021 USPSTF criteria (Table 2). There were increases in the proportion eligible for screening between the 2013 and 2021 criteria across racial subgroups (14% absolute increase for Whites, 13% increase for Blacks, 8% for Hispanics, and 17% increase for Others). Applying the 2021 USPSTF criteria, the proportion of individuals who would be eligible for LCS by race were: 35.8% (95% CI, 34.8-36.7) among Whites, 28.5% (95% CI, 25.2-31.9) among Blacks, 18.0% (95% CI, 12.4-23.7) among Hispanics, and 39.3% (95% CI, 34.5-44.0) among Others.

Using the PLCOm2012$_{Race3L}$ Model for Screening Eligibility Criteria

Using the 1.5% 6-year lung cancer risk threshold, 35.3% (95% CI, 34.4-36.2) of the sample would be eligible for lung screening (Table 2). To compare 2021 USPSTF criteria to the PLCOm2012$_{Race3L}$ model using the 1.0% 6-year risk threshold, the risk prediction model selected a larger proportion of individuals 45.0% (95% CI, 44.1-45.9) versus 34.7% (95% CI, 33.8-35.6) of the sample being eligible for LCS. The proportion of individuals eligible by race using the PLCOm2012$_{Race3L}$ model (1.0% cutpoint) was: 46.3% (95% CI, 45.3-47.2) among Whites, 39.3% (95% CI, 35.8-42.7) among Blacks, 20.3% (95% CI, 13.7-26.9) among Hispanics, and 51.4% (95% CI, 46.6-56.3) among Others.

We conducted a sensitivity analysis using the nonimputed data set to compare it to the imputed data set (see Supporting Tables). When using the nonimputed data, we found the percent eligible for screening was higher among Whites and those in the other race category, but lower among Blacks. The overall proportion eligible was higher using the raw data for the 2013 and 2021 USPSTF criteria.

DISCUSSION

Based on 2019 BRFSS survey data from 20 US states, 20.7% of those meeting the 2013 USPSTF LCS guidelines underwent a low-dose CT examination for lung cancer. This represents an increase from the prior BRFSS surveys conducted in 2017 to 2019 with screening rates ranging from 12% to 19%.[2,6-9] It should be noted the states included in 2017 to 2019 were not identical to the 20 states included in the present analysis. Possible reasons for differences in the rates presented from prior publications include: 1) different states administering the optional lung cancer screening module over the years, 2) the current analysis includes individuals 80 years and older, and 3) imputation of missing values rather than doing a complete case analysis. Based on the differences in the rates between the nonimputed and imputed data sets, we believe that the imputation resulted in more accurate estimates. Importantly, White (20.8%) and Black (20.2%) respondents had similar rates of LCS in 2019, which is a change to 2017, in which it was reported that 14.8% of Whites versus 12.6% of Blacks reported undergoing LCS in the past year.[2] Hispanics reported the highest rate of LCS at 23.8% that also represents an increase from the 2017 BRFSS report.[2] Compared to the other 3 groups, individuals in the other race group reported the lowest proportion of being screened for lung cancer in the last 12 months.

This study also compared the percentage of individuals who would be eligible for LCS according to the 2013 and 2021 USPSTF criteria. Supporting prior research,[18] our findings suggest the 2021 USPSTF criteria will increase the proportion of individuals eligible for LCS across racial and ethnic groups compared to the 2013 guidelines. However, racial differences remained in the percent eligible according to the 2021 USPSTF criteria, such that Whites still have the highest percentage eligible when compared to Blacks and Hispanics according to the new guidelines. These findings align with data evaluating the 2021 guidelines among racial and/or ethnic populations using 2017 and 2018 BRFSS data. Reese et al[33] found Black and Hispanic individuals were less likely to be eligible for LCS compared with White respondents.[33]

To examine a risk-based model for determining screening eligibility, the $PLCOm2012_{Race3L}$ model using both the 1.0% and 1.5% 6-year risk threshold identified the largest proportion of individuals overall and within racial and ethnic subgroups. The 1.0% threshold that is comparable to the 2021 guidelines selected the largest proportion of individuals overall and within subgroups. This supports a previous finding that showed greater sensitivity of the PLCOm2012 in identifying more racially diverse groups at risk for lung cancer.[22] Consideration of other factors beyond age and pack-years may be important in further reducing screening eligibility disparities.

In this sample, Black and Hispanic individuals had fewer pack-years. These results support previous studies reporting different smoking patterns among Black individuals and younger ages of individuals who smoke among Hispanics.[14,20,34,35] The differences in smoking behavior between subgroups continue to have important implications for the revised screening criteria and lung cancer risk. Whether duration smoked or amount smoked is a larger contributor to lung cancer is an important question and may be related to other factors like greater exposure to carcinogens through inhalation and/or metabolism.[20,21,36] These differences should continue to be considered when determining the optimal way to screen eligible individuals to address disparities in lung cancer incidence and mortality rates.

Study limitations are similar to other studies conducted with BRFSS data.[2,7,33] These include the potential for limited generalizability, because only 20 states administered the optional lung cancer screening module. In the current sample, 5% were Black in comparison to 13.4% Black or African American in the total US population.[37] The US population is 18.5% Hispanic or Latino, whereas in the current sample only 2% were of Hispanic origin. The present study was unable to provide eligibility estimates for the other racial and/or ethnic groups separately due to data limitations, and future research should examine each of these subgroups. Because of self-report, responses may be subject to recall bias. To our knowledge, the current BRFSS lung cancer screening question has not been validated. Without medical record validation and with the reliance on self-report, it is possible that some participants might be unaware of the exact test they received or if their physician ordered

it for LCS. However, in comparing our estimates to past BRFSS data, we report an increase in screening use. The BRFSS survey collapses age for those 80 and older, and there was no way to tease apart these individuals in the present analysis, although we expect this number to be small. Finally, there was substantial missingness on several key variables and that is a limitation. Other related studies[2,7,8,33] have not used statistical methods to deal with missing data and have performed their statistical analyses only on complete data. Therefore, a substantial strength of this study is that we used a 2-stage multiple imputation procedure, which accounted for the uncertainty of the imputed values and therefore had potential to improve the validity of the estimations.

Collected before the COVID-19 pandemic, our study reports the highest rates of LCS using the 2013 USPSTF criteria compared to lung screening use reported using past BRFSS data.[2,6,7,9] Importantly, we observed that gains among Blacks and Hispanics even out the differences between racial and/or ethnic groups. It should be noted that estimates from other sources have suggested lower uptake of LCS.[38,39] It is possible the current BRFSS lung cancer screening question wording measures something different from low dose CT scans reported to the American College of Radiology Lung Cancer Screening Registry, because the BRFSS lung cancer screening rates appears higher than what is reported by radiology facilities to the American College of Radiology. A recent review article has suggested that it may be helpful to revise the wording of the BRFSS lung cancer screening question or add additional items to improve the accuracy of surveillance of lung cancer screening.[40] Future validation studies on the BRFSS lung screening module items as well as additional questions to improve the accuracy of surveillance of lung cancer screening are needed. With the recently expanded screening criteria, it will be imperative to ensure those newly eligible individuals are informed of their option to get screened, particularly once insurance coverage becomes available.[41] The lowering of both the age and pack-year criteria has substantially increased the number of people eligible, especially those groups, like Black and Hispanic individuals, with a long-term smoking history, who were excluded under the 2013 criteria, but yet are still at high risk for developing lung cancer. Inclusion of other risk factors may still be needed to close the gap between the proportions eligible by race.

FUNDING SUPPORT

This work was supported by the National Cancer Institute, Integrating Smoking Cessation Interventions with Lung Cancer Screening Programs: A Randomized Trial (R01 CA207228) as part of the NCI's Smoking Cessation at Lung Examination (SCALE) collaboration, the National Cancer Institute Research Diversity Supplement (R01CA207228-03S1), Administrative Supplement to Support Cancer Disparity Collaborative Research (R01CA207228-05S1), and the National Cancer Institute, A Multilevel Intervention to Address Disparities in Lung Cancer Screening (K99 CA256515).

CONFLICT OF INTEREST DISCLOSURES

Martin Carl Tammemägi developed the PLCOm2012 and $PLCOm2012_{Race3L}$ lung cancer risk prediction models. These models are open access and is available free of charge to non-commercial users. For commercial users, licensing has been assigned to Brock University. To date, MCT has not received any money for use of the PLCOm2012 model, nor does he anticipate any payments in the future. The other authors made no disclosures.

AUTHOR CONTRIBUTIONS

Randi M. Williams: Conceptualization, methodology, data curation, writing–original draft, editing and review, project administration, formal analysis, investigation, and resources. **Tengfei Li:** Data curation, formal analysis, writing–original draft, editing and review, investigation, and project administration. **George Luta:** Methodology, software, validation, formal analysis, writing–review and editing, supervision. **Min Qi Wang:** Methodology, software, validation, formal analysis, writing–review and editing, and supervision. **Lucile Adams-Campbell:** Methodology, investigation, resources, writing–review and editing, and supervision. **Rafael Meza:** Methodology, investigation, writing–review and editing, and supervision. **Martin C. Tammemägi:** Methodology, software, validation, formal analysis, supervision, and writing–review and editing. **Kathryn L. Taylor:** Conceptualization, methodology, investigation, resources, writing–review and editing, project administration, supervision, and funding acquisition.

REFERENCES

1. American Cancer Society Cancer facts & figures for African Americans 2016-2018. Published online 2016. Accessed November 12, 2021. https://www.cancer.org/content/dam/cancer-org/research/cancer-facts-and-statistics/cancer-facts-and-figures-for-african-americans/cancer-facts-and-figures-for-african-americans-2016-2018.pdf
2. Zahnd WE, Eberth JM. Lung cancer screening utilization: a Behavioral Risk Factor Surveillance System analysis. *Am J Prev Med*. 2019;57:250-255. doi:10.1016/j.amepre.2019.03.015
3. Jemal A, Fedewa SA. Lung cancer screening with low-dose computed tomography in the United States—2010 to 2015. *JAMA Oncol*. 2017;3:1278-1281. doi:10.1001/jamaoncol.2016.6416
4. Aberle DR. Reduced lung-cancer mortality with low-dose computed tomographic screening. *N Engl J Med*. 2011;365:395-409. doi:10.1056/NEJMoa1102873
5. Moyer VA. Screening for lung cancer: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med*. 2014;160:330-338. doi:10.7326/M13-2771
6. Advani S, Zhang D, Tammemagi M, et al. Comorbidity profiles and lung cancer screening among older adults: U.S. Behavioral Risk Factor Surveillance System 2017 to 2019. *Ann Am Thorac Soc*. 2021;18:1886-1893. doi:10.1513/AnnalsATS.202010-1276OC
7. Kee D, Wisnivesky J, Kale MS. Lung cancer screening uptake: analysis of BRFSS 2018. *J Gen Intern Med*. 2021;36:2897-2899. doi:10.1007/s11606-020-06236-9
8. Narayan AK, Gupta Y, Little BP, Shepard JO, Flores EJ. Lung cancer screening eligibility and use with low-dose computed tomography: results from the 2018 Behavioral Risk Factor Surveillance System cross-sectional survey. *Cancer*. 2021;127:748-756. doi:10.1002/cncr.33322
9. Richards TB. Screening for lung cancer—10 states, 2017. *MMWR Morb Mortal Wkly Rep*. 2020;69:201-206. doi:10.15585/mmwr.mm6908a1
10. Aldrich MC, Mercaldo SF, Sandler KL, Blot WJ, Grogan EL, Blume JD. Evaluation of USPSTF lung cancer screening guidelines among African

American adult smokers. *JAMA Oncol*. 2019;5:1318. doi:10.1001/jamaoncol.2019.1402
11. Pinsky PF, Kramer BS. Lung cancer risk and demographic characteristics of current 20-29 pack-year smokers: implications for screening. *J Natl Cancer Inst*. 2015;107:djv226. doi:10.1093/jnci/djv226
12. Pasquinelli MM, Kovitz KL, Koshy M, et al. Outcomes from a minority-based lung cancer screening program vs the National Lung Screening Trial. *JAMA Oncol*. 2018;4:1291. doi:10.1001/jamaoncol.2018.2823
13. Annangi S, Nutalapati S, Foreman MG, Pillai R, Flenaugh EL. Potential racial disparities using current lung cancer screening guidelines. *J Racial Ethn Health Disparities*. 2019;6:22-26. doi:10.1007/s40615-018-0492-z
14. CDCTobaccoFree. Burden of tobacco use in the U.S. Centers for Disease Control and Prevention. Published April 23, 2018. Accessed May 14, 2018. https://www.cdc.gov/tobacco/campaign/tips/resources/data/cigarette-smoking-in-united-states.html
15. Han SS, Chow E, ten Haaf K, et al. Disparities of national lung cancer screening guidelines in the U.S. population. *J Natl Cancer Inst*. 2020;112:1136-1142. doi:10.1093/jnci/djaa013
16. Centers for Disease Control and Prevention. Racial/ethnic disparities and geographic differences in lung cancer incidence—38 states and the District of Columbia, 1998-2006. *MMWR Morb Mortal Wkly Rep*. 2010;59:1434-1438.
17. de Koning HJ, van der Aalst CM, de Jong PA, et al. Reduced lung-cancer mortality with volume CT screening in a randomized trial. *N Engl J Med*. 2020;382:503-513. doi:10.1056/NEJMoa1911793
18. Landy R, Young CD, Skarzynski M, et al. Using prediction-models to reduce persistent racial/ethnic disparities in draft 2020 USPSTF lung-cancer screening guidelines. *J Natl Cancer Inst*. 2021;113:1590-1594. doi:10.1093/jnci/djaa211
19. Henderson LM, Rivera MP, Basch E. Broadened eligibility for lung cancer screening: challenges and uncertainty for implementation and equity. *JAMA*. 2021;325:939-941. doi:10.1001/jama.2020.26422
20. Ryan BM. Lung cancer health disparities. *Carcinogenesis*. 2018;39:741-751. doi:10.1093/carcin/bgy047
21. Haiman CA, Stram DO, Wilkens LR, et al. Ethnic and racial differences in the smoking-related risk of lung cancer. *N Engl J Med*. 2006;354:333-342. doi:10.1056/NEJMoa033250
22. Pasquinelli MM, Tammemagi MC, Kovitz KL, et al. Risk prediction model versus United States Preventive Services Task Force lung cancer screening eligibility criteria: reducing race disparities. *J Thorac Oncol*. 2020;15:1738-1747. doi:10.1016/j.jtho.2020.08.006
23. Tammemägi MC, Katki HA, Hocking WG, et al. Selection criteria for lung-cancer screening. *N Engl J Med*. 2013;368:728-736. doi:10.1056/NEJMoa1211776
24. Fiscella K, Winters P, Farah S, Sanders M, Mohile SG. Do lung cancer eligibility criteria align with risk among Blacks and Hispanics? *PLoS One*. 2015;10:e0143789. doi:10.1371/journal.pone.0143789
25. ten Haaf K, Jeon J, Tammemägi MC, et al. Risk prediction models for selection of lung cancer screening candidates: a retrospective validation study. *PLoS Med*. 2017;14:e1002277. doi:10.1371/journal.pmed.1002277
26. Katki HA, Kovalchik SA, Petito LC, et al. Implications of nine risk prediction models for selecting ever-smokers for computed tomography lung cancer screening. *Ann Intern Med*. 2018;169:10. doi:10.7326/M17-2701
27. National Health Service England. Targeted screening for lung cancer with low radiation dose computed tomography. Accessed September 20, 2021. https://www.england.nhs.uk/publication/targeted-screening-for-lung-cancer/
28. Darling GE, Tammemägi MC, Schmidt H, et al. Organized lung cancer screening pilot: informing a province-wide program in Ontario, Canada. *Ann Thorac Surg*. 2021;111:1805-1811. doi:10.1016/j.athoracsur.2020.07.051
29. Pasquinelli MM, Tammemägi MC, Kovitz KL, et al. Addressing sex disparities in lung cancer screening eligibility: USPSTF vs PLCOm2012 criteria. *Chest*. 2021;Jul 9:S0012-3692(21)01316-70(0). doi:10.1016/j.chest.2021.06.066
30. Tammemägi MC, Church TR, Hocking WG, et al. Evaluation of the lung cancer risks at which to screen ever- and never-smokers: screening rules applied to the PLCO and NLST cohorts. *PLoS Med*. 2014;11:e1001764. doi:10.1371/journal.pmed.1001764
31. Meza R, Jeon J, Toumazis I, et al. Evaluation of the benefits and harms of lung cancer screening with low-dose computed tomography: modeling study for the US Preventive Services Task Force. *JAMA*. 2021;325:988. doi:10.1001/jama.2021.1077
32. Rubin DB, Schenker N. Multiple imputation in health-care databases: an overview and some applications. *Stat Med*. 1991;10:585-598. doi:10.1002/sim.4780100410
33. Reese TJ, Schlechter CR, Potter LN, et al. Evaluation of revised US Preventive Services Task Force lung cancer screening guideline among women and racial/ethnic minority populations. *JAMA Netw Open*. 2021;4:e2033769. doi:10.1001/jamanetworkopen.2020.33769
34. Holford TR, Levy DT, Meza R. Comparison of smoking history patterns among African American and White cohorts in the United States born 1890 to 1990. *Nicotine Tob Res*. 2016;18(suppl 1):S16-S29. doi:10.1093/ntr/ntv274
35. Centers for Disease Control and Prevention. Hispanics/Latinos and tobacco use. Published December 17, 2018. Accessed September 20, 2021. https://www.cdc.gov/tobacco/disparities/hispanics-latinos/index.htm
36. Benowitz NL. Cotinine as a biomarker of environmental tobacco smoke exposure. *Epidemiol Rev*. 1996;18:188-204. doi:10.1093/oxfordjournals.epirev.a017925
37. US Census Bureau QuickFacts: United States. Accessed September 20, 2021. https://www.census.gov/quickfacts/fact/table/US/PST045219
38. Fedewa SA, Kazerooni EA, Studts JL, et al. State variation in low-dose computed tomography scanning for lung cancer screening in the United States. *J Natl Cancer Inst*. 2021;113:1044-1052. doi:10.1093/jnci/djaa170
39. Fedewa SA, Bandi P, Smith RA, Silvestri GA, Jemal A. Lung cancer screening rates during the COVID-19 pandemic. *Chest*. 2021;July 21:S0012-3692(21)01364-7. doi:10.1016/j.chest.2021.07.030
40. Maki KG, Shete S, Volk RJ. Examining lung cancer screening utilization with public-use data: opportunities and challenges. *Prev Med*. 2021;147:106503. doi:10.1016/j.ypmed.2021.106503
41. American Lung Association. Healthcare & lung disease initiatives. Accessed July 9, 2021. https://www.lung.org/policy-advocacy/healthcare-lung-disease/lung-cancer-policy/toolkit