Characteristics of lung cancer screening eligible population in the US and prediction of the eligibility with simplified criteria

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Background: In 2021, updates to the lung cancer screening (LCS) guidelines extended the eligibility to include younger individuals and those with lower lifetime smoking intensity. A significant challenge in the LCS implementation is identifying eligible individuals because lifetime smoking intensity, a key criterion of current guidelines, is typically unavailable in electronic health records and difficult to assess accurately. This study aimed to (I) examine the characteristics of the eligible population in the US based on current guidelines and (II) evaluate the performance of five simplified criteria as alternative tools for predicting LCS eligibility.

Methods: National Health and Nutrition Examination Survey (NHANES) 2013–2018 data were used. Five simplified criteria were: (I) ever smoker, defined as an individual with any positive smoking history; (II) current or former smoker, an individual with any positive smoking history or who quit smoking within 15 years; (III) current smoker, an individual currently smoking; (IV) current smoker, an individual currently smoking >0.5 packs per day (ppd); (V) current smoker, a person currently smoking >1 ppd. Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were calculated. The complex survey design was considered.

Results: About 16.70 million individuals (representing 16.01% of population aged 50–80 years) were eligible for LCS in the US. The percentage of LCS eligibility was higher among people who were younger, male, non-Hispanic White, less educated, single, not insured, with poorer health status and lower socioeconomic status. Except for the criterion of current smoker with >1 ppd having low sensitivity (0.08), other criteria had sensitivity ranging between 0.45 and 1.00. The accuracy of the five criteria used ranged between 0.70 and 0.91.

Conclusions: Individuals with less favorable social and clinical characteristics have higher chances of being eligible for LCS, potentially amplifying disparities in LCS utilization. Simplified criteria can be used as prescreening tools to identify target populations, which could facilitate LCS implementation at the population level.

Keywords: Lung cancer screening (LCS); USPSTF guidelines; simplified lung cancer screening criteria (simplified LCS criteria); disparities in lung cancer screening (disparities in LCS); National Health and Nutrition Examination Survey (NHANES)

Introduction

Lung cancer stands as the primary cause of cancer-related mortality in the United States (US) with about 155,870 deaths each year (1). Lung cancer screening (LCS) with low-dose computed tomography (LDCT) can reduce lung cancer mortality by 20% among the high-risk population (2,3). In 2013, the US Preventive Services Task Force (USPSTF) recommended annual LCS with LDCT to individuals aged 55–80 years, current or former smokers who quit smoking within 15 years, and with ≥30 pack-years smoking history (2). In 2021, the USPSTF updated these guidelines, now recommending annual LCS for those aged 50–80 years, current or former smokers who quit within 15 years, and with a history of ≥20 pack-years of smoking (4). Little is known about the characteristics of LCS eligible population and its frequency by social and clinical factors under these updated guidelines.

The successful implementation of LCS is a critical step in harnessing its potential survival benefits. Yet, the LCS utilization at the population level remains low, with less than 20% of the eligible individuals undergoing screening (5,6). One of the significant challenges in LCS implementation pertains to the identification of the target population (7-9). This challenge arises because data on lifetime smoking intensity (smoking pack-years) required to determine LCS eligibility are often unavailable or incomplete in population-based surveillance data or electronic health records (EHRs), and difficult to accurately assess. Previous studies have proposed the use of simplified criteria, based on age and current smoking status, as prescreening tools, which can be combined with subsequent formal assessment to identify the LCS eligible population (10-12). These simplified criteria have demonstrated good performance in estimating the LCS eligibility as per previous USPSTF guidelines (13). However, it is unknown whether these simplified criteria can effectively discriminate LCS eligible populations defined by the current guidelines. In this study we aimed to (I) estimate the proportion and examine characteristics of individuals eligible for LCS among people aged 50–80 years in the US based on current guidelines; (II) evaluate the performance of five simplified criteria in predicting LCS eligibility among population aged 50–80 years and subpopulations defined by sex, race/ethnicity, and education. We present this article in accordance with the TRIPOD reporting checklist (available at https://tcr.amegroups.com/article/view/10.21037/tcr-23-1942/rc).

Methods

Data source and study population

We used the 2013–2018 National Health and Nutrition Examination Survey (NHANES) data (14). NHANES is a national survey designed to study the health and nutrition of adults and children in the US. A complex, multistage, probability sampling design was used to select participants representative of the civilian, non-institutionalized US population (15). In this study, we included participants aged 50–80 years with complete information on the smoking questionnaire. Since NHANES data is a fully publicly available and de-identified dataset, this study is exempted from the Institutional Review Boards review. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Variables

LCS eligibility was determined based on 2021 USPSTF criteria, i.e., individuals aged 50–80 years, currently smoking or quitting smoking within 15 years, and with ≥20 pack-years smoking history (4). Participants who smoked at least 100 cigarettes in life were defined as ever smokers; current smokers were those who smoke every day or some days currently; and former smokers were those who do not

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Highlight box

Key findings
- Updates to the lung cancer screening (LCS) guidelines in 2021 almost doubled the size of population (about 16.70 million individuals, representing 16.01% of population aged 50–80 years) eligible for LCS in the US.

What is known and what is new?
- We knew that disparities in access to LCS have been present since the inception of LCS in 2013.
- We discovered that the 2021 LCS updates led to an elevated representation of racial minorities and individuals lacking insurance or primary care providers in the LCS eligible population, potentially intensifying disparities in LCS access.
- We found that the assessment of current smoking status and intensity can aid in identifying the target population for LCS.

What is the implication, and what should change now?
- LCS programs can utilize specific simplified criterion to establish routine alerts within electronic health records which can aid healthcare providers in recognizing LCS eligible populations and facilitate LCS implementation at population level.

Table 1 Study participants categorized based on lung cancer screening eligibility and status meeting simplified criteria

Simplified criterion	LCS eligibility*	
	Yes	No
Yes	True positive	False positive
No	False negative	True negative

*, LCS eligibility was determined based on 2021 United States Preventive Service Task Force guidelines, i.e., individuals aged 50–80 years, currently smoking or quitting smoking within 15 years, and with ≥20 pack-years smoking history. LCS, lung cancer screening.

smoke currently. Lifetime smoking intensity was calculated as the product of smoking duration (years between starting and quitting smoking for former smokers; between starting smoking to the year of survey for current smokers) and number of packs of cigarettes smoked every day.

The five simplified criteria based on age and smoking status were: (I) ever smoker, defined as an individual with any positive smoking history; (II) current or former smoker, an individual with any positive smoking history or who quit smoking within 15 years; (III) current smoker, an individual currently smoking; (IV) current smoker, an individual currently smoking >0.5 packs per day (ppd); (V) Current smoker, a person currently smoking >1 ppd. Other sociodemographic and clinical variables used in the analyses included: age, sex, race/ethnicity, education, marital status, insurance, food security, housing characteristics, family poverty level index, general health condition, availability of primary care provider, smoking status, history of respiratory illnesses, history of cancer, and history of other comorbidities (coronary heart disease, liver conditions, arthritis, or gout).

Statistical analysis

Chi-squared tests were employed to compare categorical variables. With the USPSTF LCS guideline as the gold standard criteria, we calculated the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of each of the five simplified criteria. Participants eligible for LCS and meeting the simplified criterion were considered as true positive (*Table 1*); those eligible for LCS but not meeting the criterion were false negative; those not eligible for LCS but meeting the criterion were false positive; and those not eligible for LCS and not meeting the criterion were true negative.

Sensitivity was calculated as true positive/(true positive + false negative); specificity as true negative/(false negative + true negative); PPV as true positive/(true positive + false positive); NPV as true negative/(false negative + true negative); and accuracy as (true positive + true negative)/ (true positive + false positive + false negative + true negative). Levels of significance was set at $P<0.05$. Statistical analysis was conducted using SAS software version 9.4, accounting for survey weights and clustering by sampling units to derive nationally representative estimates.

Results

A total of 8,309 participants from 2013–2018 NHANES were identified, representing 104.36 million US residents aged 50–80 years, among whom 16.01% (representing 16.70 million US residents) were eligible for LCS (*Table 2*). The proportion of participants eligible for LCS was higher in those aged 50–64 years (18.35%), male (20.42%), non-Hispanic White (17.63%), with high school or lower education (21.52%), single or never married (21.14%), without insurance (24.70%), with low family poverty level index (23.76%), with very low food security (31.83%), renting houses or with other housing arrangements (21.34%), with fair or poor general health condition (24.47%), without primary care provider (22.57%), with a history of respiratory illnesses (29.35%), and other comorbidities (18.26%) ($P<0.001$ for each). In addition, 56.49% of current smokers and 23.40% of former smokers were eligible for LCS.

Table 3 describes the characteristics of the population eligible for LCS (weighted N=16.70 million). Among all LCS eligible individuals, the majority were aged 50–64 years (66.99%), male (59.03%), non-Hispanic White (79.14%), married or living with partner (57.17%), with full household food security (66.12%), owning a house (72.13%), with good to excellent general health (65.99%), having primary care provider (81.80%), without respiratory illnesses (65.01%) or cancer (81.12%), and with other comorbidities (62.04%). About half were current smokers (55.76%), having high school or lower education (52.32%), private insurance (51.56%), or with family poverty level index >1.85 (55.80%).

Simplified criteria based on current smoking status and intensity performed differently in identifying individuals eligible for LCS among people aged 50–80 years (*Table 4*). Ever smoker (current or former smoker) as a simplified criterion had a sensitivity of 1.00, specificity of 0.64, PPV of

Table 2 Proportion of being eligible for lung cancer screening among individuals aged 50–80 years in the US: NHANES 2013–2018

Variables	Weighted N (in millions)	% of being eligible for LCS	P value
Total	104.36	16.01	
Age			<0.001
50–64 years	60.96	18.35	
65–80 years	43.40	12.71	
Sex			<0.001
Male	48.28	20.42	
Female	56.08	12.20	
Race and ethnicity			<0.001
Non-Hispanic White	74.99	17.63	
Non-Hispanic Black	10.57	13.22	
Hispanic	10.67	8.21	
Other	8.13	14.89	
Education			<0.001
High school or less	40.61	21.52	
Above high school (college or equivalent)	63.69	12.51	
Marital status			<0.001
Single or never married	6.50	21.14	
Married or living with partner	67.50	14.15	
Other	30.33	19.06	
Insurance			<0.001
Private insurance	63.63	12.75	
Medicare, Medicaid, or other government insurance	27.26	20.31	
No insurance	8.45	24.70	
Family poverty level index			<0.001
≤1.30	19.57	23.76	
>1.30–≤1.85	11.58	19.10	
>1.85	65.42	13.24	
Household food security			<0.001
Full security	79.24	13.47	
Marginal security	8.42	24.46	
Low security	8.27	20.78	
Very low security	5.31	31.83	

Table 2 (*continued*)

Table 2 (*continued*)

Variables	Weighted N (in millions)	% of being eligible for LCS	P value
Housing			<0.001
Owned or being bought	80.01	14.55	
Rented or other arrangement	21.08	21.34	
Smoking			<0.001
Current smoker	16.49	56.49	
Former smoker	31.58	23.40	
Never smoker	56.30	0	
General health condition			<0.001
Excellent, very good or good	81.10	13.58	
Fair or poor	23.21	24.47	
Primary care provider			<0.001
Clinic, health center, doctor's office or HMO	90.87	15.03	
Emergency room or others	4.76	22.57	
None	8.70	22.57	
Respiratory illnesses (asthma, COPD or emphysema)			<0.001
Yes	19.88	29.35	
No	84.35	12.85	
Other comorbidities (arthritis, gout, liver condition, congestive heart failure or coronary heart disease)			<0.001
Yes	56.60	18.26	
No	47.33	13.36	
Cancer			0.68
Yes	20.42	15.39	
No	83.87	16.10	

NHANES, National Health and Nutrition Examination Survey; LCS, lung cancer screening; HMO, Health Maintenance Organization; COPD, chronic obstructive pulmonary disease.

0.35, NPV of 1.00, and accuracy of 0.70. Compared to ever smoker, adding years since quitting smoking, i.e., current smoker or former smoker quitting smoking <15 years, can differentiate LCS eligible population better with sensitivity as 1.00, specificity as 0.87, PPV as 0.59, and accuracy as 0.89. The sensitivity decreased (0.56) but specificity increased (0.92) when using only current smoker as a simplified criterion. For the criteria including both current smoking

Table 3 Characteristics of individuals eligible for lung cancer screening in the US: NHANES 2013–2018

Variables	Weighted N (in millions)	%
Total	16.70	
Age		
50–64 years	11.19	66.99
65–80 years	5.51	33.01
Sex		
Male	9.86	59.03
Female	6.84	40.97
Race and ethnicity		
Non-Hispanic White	13.22	79.14
Non-Hispanic Black	1.40	8.37
Hispanic	0.88	5.24
Other	1.21	7.25
Education		
High school or less	8.74	52.32
Above high school (college or equivalent)	7.96	47.68
Marital status		
Single or never married	1.37	8.23
Married or living with partner	9.55	57.17
Other	5.78	34.60
Insurance		
Private insurance	8.11	51.56
Medicare, Medicaid, or other government insurance	5.53	35.18
No insurance	2.09	13.26
Family poverty level index		
≤1.30	4.65	29.95
>1.30–≤1.85	2.21	14.25
>1.85	8.66	55.80

Table 3 (*continued*)

Table 3 (*continued*)

Variables	Weighted N (in millions)	%
Household food security		
Full security	10.67	66.12
Marginal security	2.06	12.75
Low security	1.72	10.65
Very low security	1.69	10.48
Housing		
Owned or being bought	11.64	72.13
Rented or other arrangement	4.50	27.87
Smoking		
Current smoker	9.31	55.76
Former smoker	7.39	44.24
General health condition		
Excellent, very good or good	11.02	65.99
Fair or poor	5.68	34.01
Primary care provider		
Clinic, health center, doctor's office or HMO	13.66	81.80
Emergency room or others	1.08	6.44
None	1.96	11.76
Respiratory illnesses (asthma, COPD, or emphysema)		
Yes	5.83	34.99
No	10.84	65.01
Other comorbidities (arthritis, gout, liver condition, congestive heart failure or coronary heart disease)		
Yes	10.34	62.04
No	6.32	37.96
Cancer		
Yes	3.14	18.88
No	13.50	81.12

NHANES, National Health and Nutrition Examination Survey; HMO, Health Maintenance Organization; COPD, chronic obstructive pulmonary disease.

status and smoking intensity, current smoker with >0.5 ppd can identify LCS eligibility more accurately than current smoker with >1 ppd. Both criteria had high specificity (>0.99 and 1.00, respectively), PPV (0.97 and 1.00, respectively), NPV (0.91 and 0.85, respectively), and accuracy (0.91 and 0.85, respectively), but current smoker >1 ppd had very low sensitivity (0.08).

There were no substantial differences in the performance of the simplified criteria in identifying LCS eligible individuals among subpopulations stratified by sex, race/

Table 4 Performance of simplified criteria in identifying individual's United States Preventive Services Task Force lung cancer screening eligibility among population aged 50–80 years: NHANES 2013–2018

Criteria	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC
Ever smoker	1.00	0.64 (0.62, 0.66)	0.35 (0.33, 0.37)	1.00	0.70	0.82
Current smoker or former smoker quitting smoking <15 years	1.00	0.87 (0.85, 0.88)	0.59 (0.56, 0.62)	1.00	0.89	0.92
Current smoker	0.56 (0.52, 0.60)	0.92 (0.91, 0.93)	0.57 (0.53, 0.60)	0.92 (0.91, 0.93)	0.86	0.73
Current smoker >0.5 packs per day	0.45 (0.41, 0.49)	>0.99	0.97 (0.95, 0.98)	0.91 (0.90, 0.92)	0.91	0.70
Current smoker >1 pack per day	0.08 (0.06, 0.10)	1.00	1.00	0.85 (0.84, 0.87)	0.85	0.54

All values within parentheses represent the 95% confidence interval. NHANES, National Health and Nutrition Examination Survey; PPV, positive predictive value; NPV, negative predictive value; AUC, area under the curve.

ethnicity, and education (Tables S1-S3). Current smoker with >1 ppd had lower sensitivity in women (0.05) than in men (0.10), in non-Hispanic Black people (0.03) than in non-Hispanic White people (0.09), and in individuals with college or above education (0.07) than in those with high school or lower education (0.09).

Discussion

The USPSTF recently updated LCS guidelines which expanded the LCS eligible population to include those at younger age and with lower lifetime smoking intensity. With a nationally representative sample, about 16.70 million individuals, accounting for 16.01% of people aged 50–80 years, were eligible for LCS in the US. The proportion of LCS eligibility is higher in those with lower socioeconomic status and worse clinical status. To identify LCS eligibility, simplified criterion as current smoker with >1 ppd had low sensitivity. Other simplified criteria based on age, current smoking status, and current smoking intensity, had sensitivity ranging from 0.45 to 1.00, which can be used as prescreening tools to identify the high-risk populations for targeted interventions.

As the 2013 USPSTF guidelines identified about 8 to 9 million individuals eligible for LCS in the US (9.9–12.7% of the population aged 55–80 years) (5,16), the 2021 USPSTF guidelines almost doubled the size (16.70 million, representing 16.01% of the population aged 50–80 years). The updates in the guidelines increased the proportion of people younger than 65 years (from 56.6% to 66.7%), males (from 49.6% to 59.0%), and current smokers (from 45.4% to 55.8%). The frequency of LCS eligibility remained higher in people with worse general health status or with respiratory or other health conditions. In addition, two changes in the

characteristics of LCS eligible population were worthy of note. The first was the decrease in the proportion of non-Hispanic White people (from 86.2% to 79.14%) among all LCS eligible individuals. Non-Hispanic Black people tend to initiate smoking at an older age and have lower lifetime smoking intensity, thus less likely to be eligible for LCS but still at high risk of lung cancer than non-Hispanic White smokers (17-23). The 2013 guidelines had lower accuracy in identifying the non-Hispanic Black high-risk population (18). Our findings and studies using other national survey data confirmed that the update of LCS guidelines decreased the racial differences in LCS eligibility (24). The second was the increase in the proportion of uninsured individuals (from 7.9% to 13.3%) and those without a primary care provider (from 11.7% to 18.2%) among all LCS eligible individuals. For the first time, we found that a substantial 31.8% of individuals experiencing very low food security were eligible for LCS, in contrast to 13.5% of those with full food security. Different from other cancer screenings recommended to an entire age group, LCS is recommended based on an individual's risk. People of lower socioeconomic status are less likely to undergo LCS but more likely to be eligible for LCS (5,25). The updated guidelines resulted in a disproportionate increase in the number of individuals eligible for LCS with lower socioeconomic status. This shift has the potential to exacerbate disparities in LCS utilization. Hence, there is an immediate and pressing need to enhance LCS implementation within these underserved subpopulations.

A significant barrier to the effective implementation of LCS is the challenge of identifying patients eligible for LCS, ultimately impeding physician referrals. Previous research demonstrated that up to 54.7% of barriers in LCS utilization were accounted for by the failure of EHR

notification regarding patients' LCS eligibility (26). LCS full eligibility was determined based on age, smoking status, and lifetime smoking intensity. Lifetime smoking intensity, measured by smoking pack-years, usually is unavailable or incomplete in EHRs. There is also significant discordance between EHR recorded and patient-self-reported smoking intensity (27). Thus, researchers proposed to use simplified criteria based on easily accessible information as a prescreening tool to identify the high-risk population for further evaluation and interventions of LCS. A study in 2019 evaluated five simplified criteria based on age, current smoking status, and current smoking intensity, and found that all the five criteria demonstrated good performance in discriminating LCS full eligibility (10). With the significant changes in USPSTF LCS guidelines, we revisited this topic and evaluated whether the five simplified guidelines can still work well as LCS prescreening tools. We found that the criterion of current smoker with >1 ppd had much lower sensitivity than it did in the previous report. Only 8% of individuals meeting current LCS guidelines are current smokers smoking >1 pack of cigarettes per day. The reason for the difference is the substantial decrease in the required lifetime smoking intensity in the current LCS guidelines (from 30 to 20 pack-years), thus smokers with very high smoking intensity represent only a small proportion of all LCS eligible population. However, the PPV of this criterion was 1.00 indicating that 100% of all current smokers with >1 ppd meet LCS eligibility. This indicator suggests that when resources are limited and no additional efforts are available for further evaluation, current smokers with >1 ppd can still be used to identify the very high-risk patient population for LCS implementation.

The performance of the other four simplified criteria in determining LCS eligibility remained relatively similar based on current and previous guidelines. A noteworthy difference was the higher PPV for all criteria according to current LCS guidelines. For example, about 35% of ever smokers, 59% of current smokers or former smokers who quit smoking within 15 years, 57% of current smokers, and 97% of current smokers with >0.5 ppd met current LCS eligibility (compared to 25%, 48%, 44%, and 66%, respectively, based on previous guidelines). This evidence indicates that the simplified criteria can identify the target population more efficiently according to current guidelines. The PPV can even increase when the screening tool is used in a population with a higher prevalence of LCS eligibility, such as people with lower socioeconomic status or more respiratory comorbidities. Our stratified analyses

did not show significant differences in the performance of simplified criteria among subpopulations. The lower PPVs in women than in men, in non-Hispanic Black than in non-Hispanic White people, and in people with college or above education than in people with high school or lower education were likely due to the lower prevalence of LCS eligibility in these subpopulations.

The USPSTF guidelines on screening individuals at high risk for lung cancer creates a demand to implement efficient and effective LCS programs. LCS implementation requires an intensive interaction between smokers and the healthcare system. Simplified criteria based on easily accessible information can be used as a prescreening tool to initiate the communication on LCS. Depending on the patient volume and resource availability, LCS programs can opt for specific simplified criterion to establish routine alerts within EHRs. These alerts can aid healthcare providers in recognizing LCS eligible populations. Our findings validate the accuracy and effectiveness of each simplified criterion. With the fast development of artificial intelligence (AI), the prediction of LCS eligibility can be enhanced by AI tools (28,29). The simplified criteria we proposed can serve as foundational information for further AI tools or can be used synergistically with other AI tools. which could empower healthcare professionals with comprehensive and timely information crucial for informed decision-making in LCS protocols.

The major strength of this study is the large, contemporary, and nationally representative sample, which allows generalizability of our findings to the US population. Another strength is the inclusion of specific measures of socioeconomic and clinical status, such as the availability of primary care provider, household food security, housing, general health status, and respiratory and other comorbidities. These data can provide detailed descriptions of LCS eligibility among US subpopulations. Despite its strengths, the study is also subjected to limitations including being entirely comprised of survey data and lack of information on state variation. In addition, self-reported smoking history is a potential limitation of the dataset. However, previous research validated NHANES smoking data and showed substantial consistency between self-reported smoking and biomarkers (30).

Conclusions

Following the 2021 updates to the USPSTF LCS guidelines, 16.70 million smokers are currently eligible for

LCS in the US. As populations with lower socioeconomic status experienced greater increases in the proportion of LCS eligibility, the changes in the guidelines could exacerbate disparities in LCS utilization. Given the current low utilization of LCS, there is a pressing need for interventions to enhance LCS implementation. Simplified criteria based on easily accessible information such as age, current smoking status, and current smoking intensity, can be used as prescreening tools to identify target populations.

Footnote

Reporting Checklist: The authors have completed the TRIPOD reporting checklist. Available at https://tcr.amegroups.com/article/view/10.21037/tcr-23-1942/rc

Peer Review File: Available at https://tcr.amegroups.com/article/view/10.21037/tcr-23-1942/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://tcr.amegroups.com/article/view/10.21037/tcr-23-1942/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

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