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The Development and Performance of Alternative Criteria for Lung Cancer Screening

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Abstract

BACKGROUND: The recommendation for lung cancer screening (LCS) developed by the US Preventive Services Task Force (USPSTF) may exclude some high-benefit people.

OBJECTIVE: To determine whether alternative criteria can identify these high-benefit people.

DESIGN: Model-based projections.

SETTING: United States.

PARTICIPANTS: People from the 1997–2014 National Health Interview Survey (NHIS) to develop alternative criteria using Fast and Frugal Tree algorithms and the 2014–2018 NHIS and 2022 Behavioral Risk Factor Surveillance System for comparisons of USPSTF vs. alternative criteria.

MEASUREMENTS: We estimated life-years gained from LCS using the Life-Years from Screening-CT (LYFS-CT) model. High-benefit was defined as gaining an average of at least 16.2 days of life from three annual screens, which reflects a high lung cancer risk and substantial life-gains if lung cancer is detected by screening.

RESULTS: The final alternative criteria were 1) people who smoked any amount each year for at least 40 years or 2) people 60–80 years old who have at least 40 pack-years of smoking. The USPSTF and alternative criteria selected similar numbers of people for LCS. Compared with the USPSTF criteria, the alternative criteria had higher sensitivity (91% vs 78%, P<0.001) and specificity (86% vs. 84%, P<0.001) for identifying high-benefit people. For racial and ethnic minorities, the alternative criteria provided greater gains in sensitivity compared to USPSTF (Black: 83% vs 56%, P<0.001; Hispanic: 95% vs 73%, P=0.086; Asian: 94% vs. 68%, P=0.171) at similar specificity. The alternative criteria identify high-risk, high-benefit groups excluded by the USPSTF criteria: those with ≥40-year smoking duration but <20 pack-years and >15-year quit history, many of whom are members of racial and ethnic minorities.

LIMITATIONS: The results were based on model projections.

CONCLUSION: These results suggest that simple alternative LCS criteria can identify substantially more high-benefit people, especially in some racial and ethnic groups.

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Annual lung cancer screening (LCS) can reduce mortality in persons at high risk for lung cancer (1, 2). The U.S. Preventive Services Task Force (USPSTF) recommends LCS for persons who meet all three criteria of age 50 to 80 years, a smoking history of at least 20 pack-years, and currently smoke or quit within the previous 15 years, based on the NELSON and National Lung Screening Trial (NLST) entry criteria (2–4). However, LCS uptake remains low, and modeling studies suggest that the USPSTF criteria may not be optimally effective, efficient, or cost-effective because many people who would derive high benefit from LCS are ineligible (5–8). Furthermore, the 2021 USPSTF criteria may not substantially reduce racial and ethnic disparities in eligibility compared with the 2013 USPSTF criteria (9–11).

Multivariable prediction models that select people on the basis of either lung cancer risk (7, 12) or benefit (defined as life-years gained from LCS) (8) may more accurately identify high-benefit persons than the USPSTF criteria. For example, selection based on life gained might increase the total life expectancy gains from LCS (8), and several risk models may more accurately identify those at greatest risk for lung cancer incidence and death (7, 12). The use of prediction models might also substantially reduce disparities in LCS eligibility compared with the USPSTF criteria, most notably for Black people (9). However, substantial hurdles to widespread clinical implementation of prediction models remain (1, 8, 12–14). Thus, simple criteria are an important initial step of LCS within most health systems.

We explored whether the strengths of prediction models could be harnessed by alternative simple criteria for LCS. We systematically developed and validated alternative simple criteria and assessed their performance compared with the current USPSTF criteria for identifying high-benefit people for LCS in the U.S. population of all ever-smoking persons aged 40 to 80 years.

Methods

Study Population and Data Sources

We included all ever-smoking persons aged 40 to 80 years from the annual National Health Interview Survey (NHIS), a nationally representative health survey of noninstitutionalized U.S. adults, from 1997 to 2018. Nearly everyone in this subset of the NHIS is calculated to have a life expectancy longer than 5 years, in line with the U.S. Department of Veterans Affairs LCS recommendation to screen only those with a life expectancy longer than 5 years (15, 16) (Supplement, available at Annals.org). Age, gender, race, years of tobacco use, pack-years of smoking, years since quitting (quit-years), comorbidities, and family history of lung cancer were included for analysis. Three cohorts were defined: odd-numbered years from 1997 to 2014 for the training set, even-numbered years from 1997 to 2014 for the test set, and all years from 2015 to 2018 for the evaluation set.

Overview of the Life-Years Gained From Screening Computed Tomography Model and the High-Benefit Threshold

The American College of Chest Physicians (CHEST) recommends augmentation of LCS criteria with validated clinical prediction calculators (17), such as the life-years gained

from screening computed tomography (LYFS-CT) model, which calculates individualized life-years gained from LCS to quantify benefit (8). We chose to use LYFS-CT rather than a lung cancer incidence or lung cancer death risk model because LYFS-CT incorporates risk for lung cancer death and also considers comorbidities and life expectancy (8, 17, 18). Modeling studies suggest that LYFS-CT better optimizes life-year gains with LCS compared with risk models (8, 19, 20).

LYFS-CT calculates life-years gained from LCS by subtracting the estimated life expectancy without screening from the estimated life expectancy with 3 annual CT screens and 5 years of follow-up. LYFS-CT incorporates 2 submodels: 1) individualized all-cause mortality, which takes comorbidities into account (fit and validated to U.S.-representative survey data) (7), and 2) individual risk for lung cancer death over 5 years in the absence of CT screening using the Lung Cancer Death Risk Assessment Tool (LCDRAT), which has been validated in 5 cohorts and using U.S.-representative survey data. LYFS-CT applies the average lung cancer mortality reduction observed in the NLST of 20.4% over 5 years (8). Of note, no modifiers of the 20.4% risk reduction in NLST were observed (5). The assumptions inherent in LYFS-CT have been described in prior work (8, 21) and are discussed in the Supplement. To avoid penalizing members of racial and ethnic minorities who may have shorter life expectancy than White people (in large part due to the health impact of systemic racism), we recalculated the LYFS-CT prediction by setting the input race/ethnicity in the all-cause mortality submodel to “White” when that resulted in longer life expectancy, a strategy we call “counterfactual eligibility.” This strategy enhanced eligibility for Black people who are ineligible solely because of how their race affects their life expectancy calculation, but it affected eligibility for no one else (Supplement).

On the basis of prior studies, CHEST guidelines recommend an LYFS-CT threshold of at least 16.2 days of life gained via LCS to identify persons with high benefit from LCS, as this selects a population with a high chance of benefit from LCS even when the downsides of screening are heavily weighed (6, 8, 17, 18). This 16.2-day threshold is based on the average benefit that a person in this group might obtain from LCS. Although this value may seem small, it is a function of averaging many zeros (for the vast majority of people who do not develop lung cancer and thus cannot derive benefit from LCS) with much larger numbers of days of life gained for those who do develop lung cancer (life gains typically range from 1.5 to 3 years for those who have screening-detected lung cancer and are treated) (18).

Systematic Development of Alternative Simple LCS Criteria

We developed “fast-and-frugal trees” (FFTs) as simple alternative LCS criteria (22). Using the FFTrees package in R, version 4.1.0 (R Foundation for Statistical Computing), and the FFT training set, multiple FFTs were trained on the outcome of at least 16.2 days of life gained with LCS estimated by the LYFS-CT model (hereafter referred to as “$FFT_{16.2}$”). The FFTs were constrained to information used in the USPSTF 2021 criteria: age, quit-years, pack-years, and pack-year components (years of tobacco use and average number of packs per day). The FFTs were first created using the counterfactual eligibility approach for estimating life expectancy for people in racial and ethnic minorities and then also using stated race to estimate life expectancy. Both approaches yielded the same FFTs.

Our analysis and reporting of FFT development and validation adheres to the TRIPOD (Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis) checklist (23, 24) and the prognostic performance metrics recommended by Janes and colleagues (25) (Supplement).

Performance of each FFT was tested internally on the FFT test set. For the identified high-performing FFT, we rounded all cut points (for example, the initially generated cut point of ≥39.5 years of smoking was rounded to ≥40 years). Receiver operating characteristic curves were compared for each FFT (Supplement).

Evaluation and Comparison With USPSTF Criteria

Finally, we chose 1 high-performing FFT, (hereafter referred to as "$FFT_{16.2}$", to compare with the USPSTF 2021 criteria (hereafter referred to as "$USPSTF_{2021}$"). We evaluated the performance of $FFT_{16.2}$ in the NLST cohort to ensure that there was no heterogeneity of treatment effect on the relative risk scale when participants were selected via $FFT_{16.2}$ (Supplement). Because $FFT_{16.2}$ was trained on the outcome of at least 16.2 days of life gained with LCS estimated by the LYFS-CT model, it is also important to assess performance when using other well-validated prediction models that were not used in the development of $FFT_{16.2}$. Thus, we compared the accuracy of $FFT_{16.2}$ and $USPSTF_{2021}$ to identify persons above guideline-based thresholds (17) for several other validated prediction models (Lung Cancer Risk Assessment Tool [LCRAT], LCDRAT, PLCOm2012, and Bach [7, 12, 26, 27]) using the FFT evaluation set. Next, we examined the performance of $FFT_{16.2}$ versus $USPSTF_{2021}$ in the Behavioral Risk Factor Surveillance System (BRFSS) 2022 data set, a more recent nationally representative data set (Supplement). Finally, we measured and report on metrics recommended for reporting binary markers (Supplement) (25).

We compared $FFT_{16.2}$ and $USPSTF_{2021}$ outcomes using the NHIS evaluation set. For both $FFT_{16.2}$ and $USPSTF_{2021}$, we assessed the probability of accurately identifying a person above the LYFS-CT–based threshold of at least 16.2 days (sensitivity) and the probability of accurately identifying a person below this threshold (specificity), accounting for sampling weights. The McNemar χ^2 test with continuity correction was used to estimate P values for differences between $FFT_{16.2}$ and $USPSTF_{2021}$ and between the 40 or more smoke-years path and $USPSTF_{2021}$. Descriptive statistics were used to characterize the populations that would be selected for screening using the $FFT_{16.2}$ strategy versus the $USPSTF_{2021}$ strategy, with weighting to the U.S. population aged 40 to 80 years that ever smoked using the R Survey package (28). The focus for comparisons was on the nonoverlapping population of persons selected under one strategy but not the other (that is, those selected by the $FFT_{16.2}$ strategy but not the $USPSTF_{2021}$ strategy and vice versa). Many people are selected by both strategies, and this overlapping population does not provide useful information for contrasting strategies. Comparing the nonoverlapping population screened by one strategy but not the other isolates the incremental value and clinical implications of each strategy. We compared the nonoverlapping mean benefits per 1000 persons screened according to one strategy but not the other. Our prior articles describe how to calculate life-years gained and deaths averted from screening. Briefly, life-years gained were calculated based on the LYFS-CT model, and lung cancer deaths averted were calculated from the 20.4% relative

risk reduction (RRR) and the prescreening risk for lung cancer death (from the LCDRAT) when scaled to the U.S. population of all ever-smoking persons aged 40 to 80 years (8). Finally, characteristics of the nonoverlapping populations for each strategy were compared.

Role of the Funding Source

This study was funded by the U.S. Department of Veterans Affairs Lung Precision Oncology Program, which had no role in the collection, analysis, or interpretation of the data or approval of the manuscript.

Results

The training set included 71 978 respondents, the test set included 69 395, and the evaluation set included 31 975. The evaluation set matches the epidemiologic trend in recent years toward older people with fewer pack-years and more quit-years (Supplement Table 1, available at Annals.org). Supplement Table 3 (available at Annals.org) shows the characteristics of the total population chosen by $FFT_{16.2}$ and $USPSTF_{2021}$ compared with the population of all ever-smoking persons aged 40 to 80 years in the NHIS evaluation set. Figure 1 (*bottom*) shows the FFT that best balanced sensitivity and specificity (see the Supplement for FFT selection). $FFT_{16.2}$ has 2 paths for identifying patients as high-benefit: a long smoking duration path (≥40 smoke-years), and a higher smoking intensity and older age path (≥40 pack-years and age 60 to 80 years).

Accuracy in Identifying People With a High Chance of Benefit for Whom Screening Should Be Strongly Encouraged

$FFT_{16.2}$ chose a nearly identical population size compared with $USPSTF_{2021}$ (14.1 million), but $FFT_{16.2}$ had significantly higher sensitivity for identifying those with at least 16.2 days of life gained (91% vs. 78%; $P < 0.001$) and higher specificity (86% vs. 84%; $P < 0.001$) compared with $USPSTF_{2021}$ (Figure 2 [*top*]; Supplement Table 4a, available at Annals.org). $FFT_{16.2}$ provided gains in sensitivity over $USPSTF_{2021}$ for racial and ethnic minority populations (Black: 83% vs. 56% [$P < 0.001$]; Hispanic: 95% vs. 73% [$P = 0.086$]; Asian: 94% vs. 68% [$P = 0.171$]) at similar specificities (Figure 2 [*bottom*]; Supplement Table 4b, available at Annals.org). As shown in Supplement Table 5 (available at Annals.org), $FFT_{16.2}$ was also more sensitive and specific than $USPSTF_{2021}$ for identifying people above other high-risk thresholds recommended in the most recent CHEST guideline (17).

$FFT_{16.2}$ selected 89% of people by the first path (≥40 smoke-years) and the rest (11%) by the second path (≥40 pack-years and age 60 to 80 years) (Supplement Table 4a). Compared with $USPSTF_{2021}$, the first path of 40 or more smoke-years by itself had greater sensitivity (85% vs. 78%; $P < 0.001$) and greater specificity (88% vs. 84%; $P < 0.001$). The first path is also a substantial source of the increase in the number of persons from racial and ethnic minorities (Supplement Tables 14 and 15, available at Annals.org). Although the first path has superior sensitivity and specificity compared with $USPSTF_{2021}$, including the second path increases sensitivity with little loss in specificity, especially when people who formerly smoked are considered (sensitivity of 91% vs. 85% and specificity of 86% vs. 88% for full $FFT_{16.2}$ vs. ≥40 smoke-years path alone, respectively) (Figure 2 [*top*]). The second path is

needed to recover people with a high number of pack-years who smoked for less than 40 years and are not captured by the first path.

When the more modern BRFSS 2022 data set was used, $FFT_{16.2}$ again showed higher sensitivity (88% vs. 78%; $P < 0.001$) and specificity (83% vs. 81%; $P < 0.001$) compared with $USPSTF_{2021}$ for selecting persons above the LYFS-CT–based threshold of at least 16.2 days of life gained (Supplement Table 6, available at Annals.org).

Outcomes Using the $FFT_{16.2}$ Strategy Versus the $USPSTF_{2021}$ Strategy

The $USPSTF_{2021}$ and $FFT_{16.2}$ strategies select many of the same people. The nonoverlapping population selected by one strategy but not the other is thus a better way to examine the clinical implications of these strategies. We estimated substantially more effective and efficient screening for the population selected by $FFT_{16.2}$ but not $USPSTF_{2021}$ ("$FFT_{16.2}$ nonoverlapping population") compared with the population selected by $USPSTF_{2021}$ but not $FFT_{16.2}$ ("$USPSTF_{2021}$ nonoverlapping population") (Table 1). For example, for the $FFT_{16.2}$ nonoverlapping population versus the $USPSTF_{2021}$ nonoverlapping population, we estimated 37.4 versus 24.4 life-years gained per 1000 people screened. Also, across all non-White racial and ethnic groups, $FFT_{16.2}$ included a larger proportion of high-benefit persons than $USPSTF_{2021}$, whereas those excluded by $FFT_{16.2}$ had less to gain from screening than those excluded by $USPSTF_{2021}$ (Table 1). In addition, we found that the overlapping population selected by both strategies had a particularly high benefit for years of life gained (61.41 per 1000 people). Life gains with LCS are determined by the combination of a person's lung cancer risk and life expectancy. We found that $FFT_{16.2}$ optimized this combination of factors better than $USPSTF_{2021}$ (Supplement and Supplement Table 8, available at Annals.org).

Population Characteristics Based on Nonoverlapping Selection by $FFT_{16.2}$ and $USPSTF_{2021}$

Compared with the $USPSTF_{2021}$ nonoverlapping population, the $FFT_{16.2}$ nonoverlapping population had fewer White people (71.6% vs. 81.0%), substantially more people in racial and ethnic minority groups, more older people, more with multiple comorbidities, and more in higher deciles of risk for lung cancer death (Table 2). All people in the $USPSTF_{2021}$ population with at least a 40-year duration of tobacco use were also selected in the first path of $FFT_{16.2}$. Thus, the $USPSTF_{2021}$ nonoverlapping population did not include any with a tobacco use duration of 40 or more years. Furthermore, by definition, the $USPSTF_{2021}$ nonoverlapping population also did not include people with less than 20 pack-years or more than 15 quit-years. On the other hand, the $FFT_{16.2}$ nonoverlapping population had a large proportion of people in these groups (76.7% with ≥40-year duration, 70.1% with <20 pack-years, and 31.2% with >15 quit-years) (Table 2).

We found similar patterns when we stratified results by race and ethnicity. The $FFT_{16.2}$ nonoverlapping Black population had a large number of people who smoked for long durations (88.5% with ≥40 years of tobacco use), had fewer pack-years (86.0% with <20 pack-years), and had longer quit histories (15.9% quit tobacco use >15 years prior) (Supplement Table 9, available at Annals.org). Similar results were seen for the Hispanic and Asian populations (Supplement Tables 10 and 11, available at Annals.org). White

people accounted for the largest proportion of people who stopped smoking > 15 years ago (36.6%) (Supplement Table 12, available at Annals.org).

Given the large difference between $FFT_{16.2}$ and $USPSTF_{2021}$ in the selection of persons in the ninth and tenth deciles of risk for lung cancer death, we examined the characteristics of this population (Table 3). Within this population, compared with the $USPSTF_{2021}$ nonoverlapping population, the highest-risk persons in the $FFT_{16.2}$ nonoverlapping population were older (85.2% vs. 26.0% aged ≥65 years), but most had few comorbidities (51.8% had 0 or 1 comorbidities) and long smoking durations with few pack-years (74.0% had ≥40 years of tobacco use and 64.4% had <20 pack-years). In addition, many had quit tobacco use more than 15 years prior (36.8%).

Discussion

To our knowledge, this is the first comprehensive study to examine the range of simple criteria for identifying high-benefit people for LCS. One well-performing FFT ($FFT_{16.2}$ with 2 paths: ≥40 smoke-years, or ≥40 pack-years and age 60 to 80 years) was substantially more sensitive than the current USPSTF criteria for identifying high-benefit people for LCS based on the LYFS-CT threshold of 16.2 days of life gained in the NHIS (91% vs. 78%; $P < 0.001$) and the BRFSS 2022 data set (88% vs. 78%; $P < 0.001$). $FFT_{16.2}$ was also more specific than the USPSTF criteria in identifying people who are not high-benefit in the NHIS (88% vs. 86%; $P < 0.001$) and the BRFSS 2022 data set (83% vs. 81%; $P < 0.001$). When weighted to the U.S. population, our model projects that LCS could be substantially more effective and efficient for the $FFT_{16.2}$ nonoverlapping population than the $USPSTF_{2021}$ nonoverlapping population. Of note, $FFT_{16.2}$ could substantially reduce disparities in eligibility for all racial and ethnic minority groups.

The substantial increase in sensitivity of $FFT_{16.2}$ versus $USPSTF_{2021}$ is partly because $FFT_{16.2}$ identified smoking duration as an important variable and partly because it is a 2-path algorithm. Pack-years of tobacco use was used as an inclusion criterion in both the NELSON trial and the NLST and has been routinely incorporated into LCS eligibility criteria to encapsulate cumulative tobacco exposure (1, 2, 4). However, as a combination of both smoking duration and smoking intensity, it may be suboptimal for decision making by itself. Duration of tobacco use seems to be a more considerable risk factor than intensity of tobacco use (29–32). Our analysis is consistent with these findings and shows that a major limitation of current eligibility criteria is the disproportionate exclusion of people with a long duration of low-intensity tobacco use who do not meet the criterion of at least 20 pack-years. $FFT_{16.2}$ includes all of these high-benefit people in the 40 or more smoke-years path. Another limitation of the use of pack-years as an eligibility criterion is the well-known challenge of obtaining and documenting an accurate pack-year history (33–35). The $FFT_{16.2}$ overcomes this challenge, as the first path is simply based on years of smoking, allowing clinicians to identify a cohort of patients who would derive high benefit from LCS without having to assess average pack-per-day smoking intensity or calculate pack-years.

Furthermore, single-path algorithms, such as the current LCS criteria, can sacrifice sensitivity, whereas multiple-path algorithms can better balance specificity and sensitivity

(22, 36). Although using just the 40 or more smoke-years path is appealing because of its simplicity and performance, the combination of both paths allows inclusion of an estimated 1 million high-benefit people in the United States with long quit histories. Our findings highlight that there are many high-benefit people with more than 15 quit-years. Consistent with this, an analysis for the 2023 American Cancer Society guideline update, which eliminated quit-years from the LCS recommendation, showed an overall increasing risk for lung cancer past 15 quit-years, especially for older people (37, 38).

Equitable LCS delivery continues to be a major challenge, in part due to racial disparities in LCS eligibility induced by the USPSTF criteria (39, 40). Our analysis confirms the substantial inequity in the current USPSTF criteria, which have poor sensitivity (60.0%) for identifying high-benefit Black candidates for screening. Prior data suggest that this relates to Black people being more likely to be diagnosed with lung cancer with fewer pack-years of tobacco use, leading to disproportionate exclusion from LCS (9, 39, 41, 42). A recent study showed that an approach that used smoke-years alone could reduce disparities. In that study's cohort, the average number of pack-years was lower among Black people diagnosed with lung cancer than among White people with lung cancer (25.3 vs. 49.0 pack-years), suggesting very different smoking patterns in these high-risk populations (43). Consistent with this, we found that a large proportion of high-benefit Black people identified by $FFT_{16.2}$ had a smoking history of at least 40 years but much lower intensity of use (<20 pack-years).

Compared with full prediction models, no simple criteria can have perfect specificity for selecting patients with high benefit (although $FFT_{16.2}$ was still better than $USPSTF_{2021}$); by definition, only the full prediction model has perfect specificity. Thus, to determine the individualized benefits and risks, shared decision making and use of a prediction model remain essential. Our simple criteria selected more older people as having high benefit. Thus, clinicians should carefully assess what an individual patient's general health and life expectancy are such that screening is still appropriate, as is always the case. However, some older people are expected to benefit most from LCS due to very high risk for lung cancer death; thus, excluding them outright would systematically exclude a high-benefit population. An important consideration is that the FFT may become less sensitive over time and may need to be adjusted, similar to the need to reassess predictive performance and calibration of multivariable prediction models. The FFT's consistently high sensitivity in the more recent evaluation set and in the more modern BRFSS data set despite changing trends suggests resiliency of the $FFT_{16.2}$ with modest epidemiologic shifts, which is reassuring. Another potential limitation is our assumption that the 20.4% RRR in lung cancer mortality is generalizable to the groups not meeting NLST eligibility criteria (such as those aged 40 to 49 years or those with a shorter pack-year history). However, the scientific rationale underlying this assumption is strong (Supplement), and 20.4% is probably an underestimate of the true RRR for the reasons described in the Supplement. Finally, our analysis considered only simple FFTs constrained to the information used in $USPSTF_{2021}$ (age and tobacco use history), but such simple algorithms could in theory include other factors typically included in prediction models.

In conclusion, we used a well-validated prediction model to identify alternative simple criteria that better capture high-benefit candidates for LCS, including high-benefit groups who are disproportionately excluded by current eligibility criteria (high-benefit Black people, those who smoked for a long duration but at a lower intensity, or those who smoked heavily and quit >15 years prior). The FFT we identified would result in more effective screening, lead to better support of the ethical principle of "equal management for equal risk" (44), and substantially reduce racial disparities (1, 13). These simple, easy-to-remember criteria that use information already routinely collected for LCS decisions represent a way to improve or augment current eligibility criteria. Although the simple criteria presented here identify people who can anticipate a particularly strong benefit with LCS, there are still many people for whom LCS would be reasonable despite more moderate benefit. Our approach to using accurate prediction models to identify well-performing selection criteria could also be applied to identify a different set of criteria to select this "preference-sensitive" group (6). More broadly, this approach to systematically examining simple selection strategies may be useful for other cancer screening and prevention methods (45, 46).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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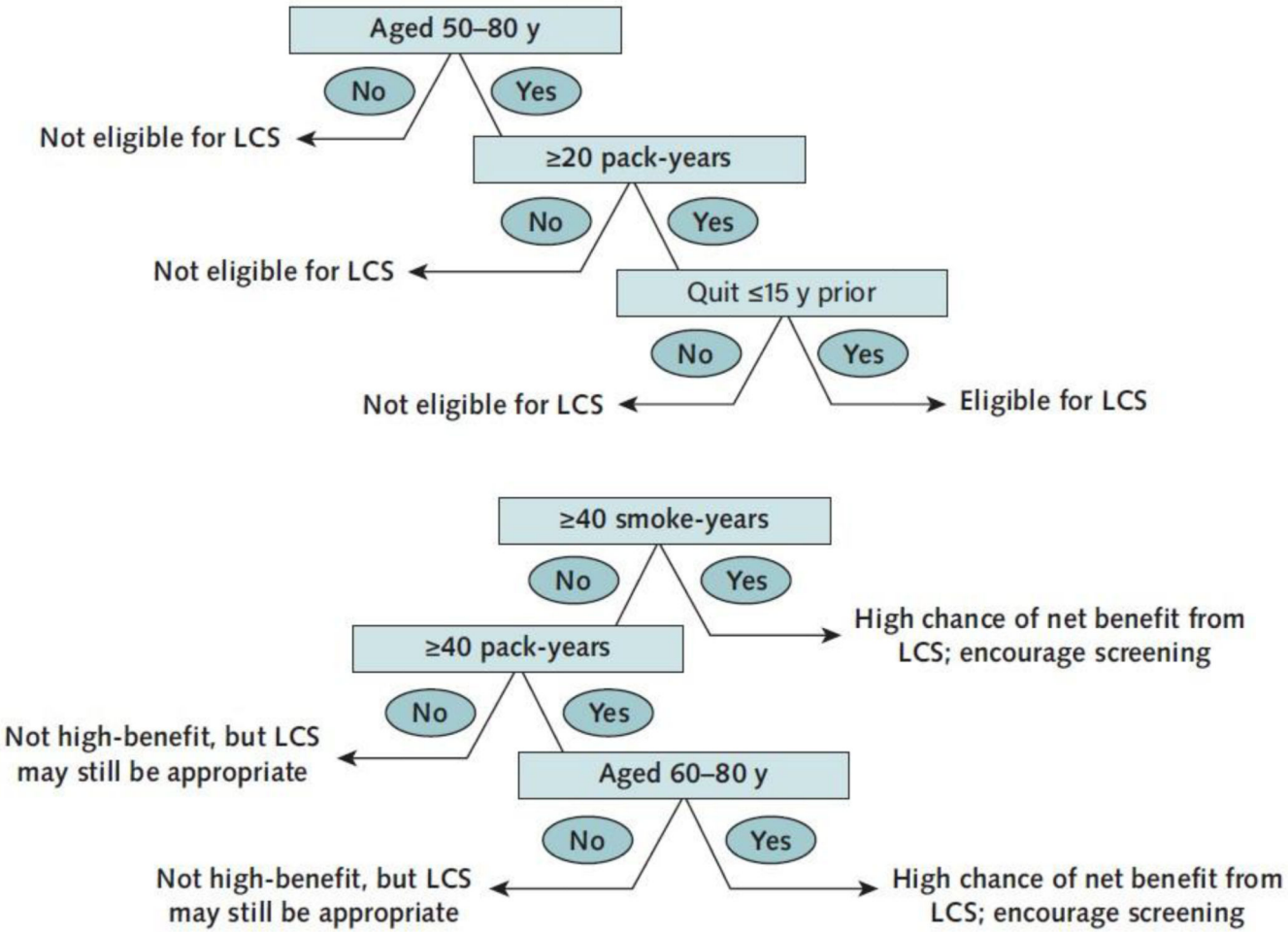

Figure 1.

Simple criteria for identifying people for LCS.

FFT ¼ fast-and-frugal tree; LCS ¼ lung cancer screening; USPSTF ¼ U.S. Preventive Services Task Force. Top. 2021 USPSTF criteria (single path). Bottom. Alternative simple criteria (2-path) trained on the outcome of ≥16.2 days of life gained with LCS (FFT16.2): a long smoking duration path (≥40 smoke-years), and a higher smoking intensity and older age path (≥40 pack-years and age 60 to 80 years).

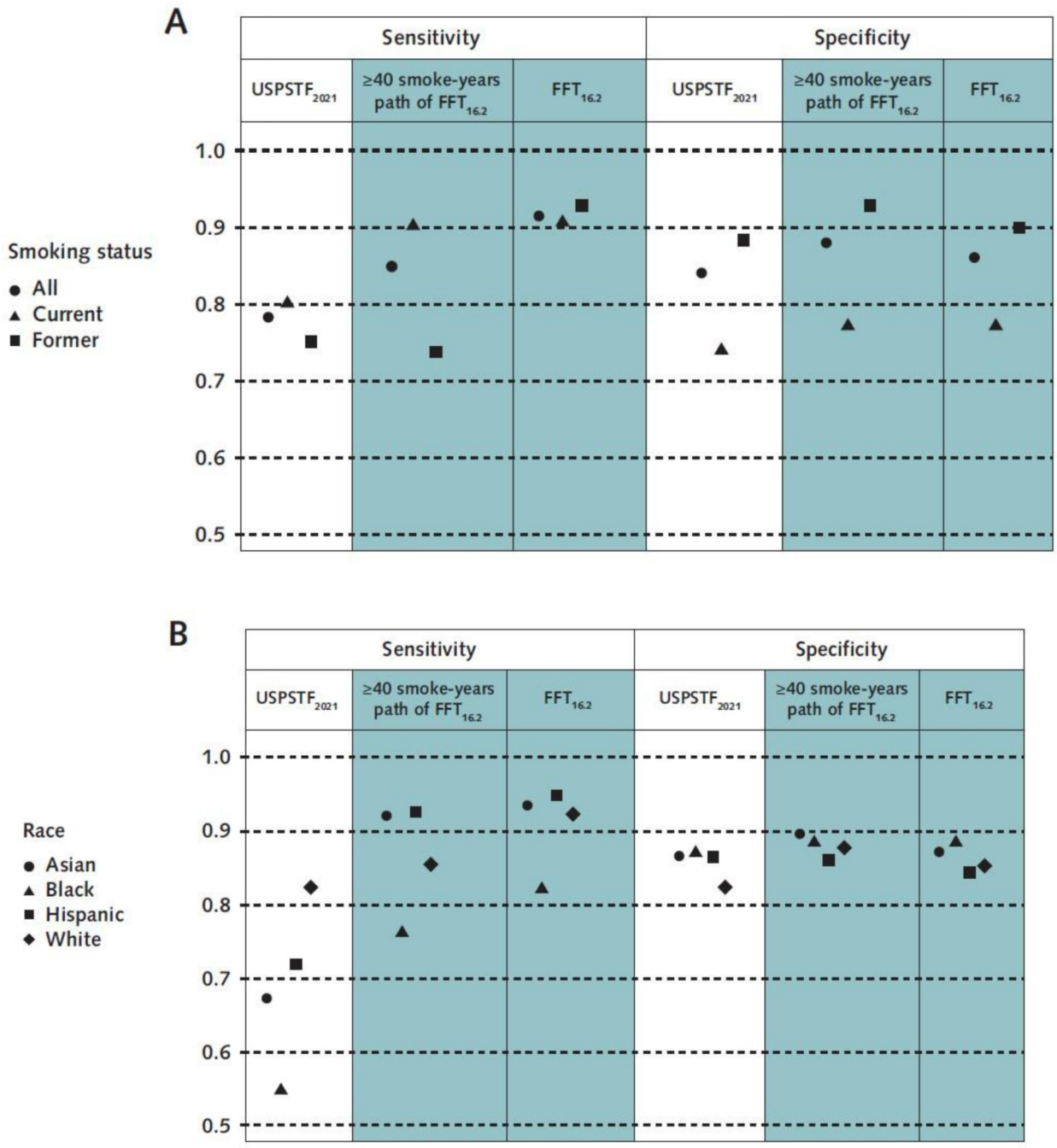

Figure 2.

Comparisons of sensitivity, specificity, and population size of FFT16.2 and USPSTF2021. $FFT_{16.2}$ = fast-and-frugal trees trained on the outcome of ≥16.2 days of life gained with lung cancer screening; LCS = lung cancer screening; LYFS-CT ¼ life-years gained from screening computed tomography; NHIS ¼ National Health Interview Survey; $USPSTF_{2021}$ = U.S. Preventive Services Task Force 2021 criteria. **Top**. Comparison of the sensitivity, specificity, and population size of $FFT_{16.2}$ and $USPSTF_{2021}$ for the entire population and based on smoking status. The analysis was done in the FFT evaluation test set and was based

on sensitivity and specificity to identify high-benefit people for LCS, defined on the basis of the LYFS-CT threshold of ≥16.2 days of life gained. Numerical sensitivity and specificity values, CIs, and P values are provided in Supplement Table 4a (available at Annals.org). **Bottom**. Comparison of the sensitivity, specificity, and population size of $FFT_{16.2}$ and $USPSTF_{2021}$ based on race and ethnicity. The analysis was done in the NHIS evaluation test set and was based on sensitivity and specificity to identify high-benefit people for LCS, defined on the basis of the LYFS-CT threshold of ≥16.2 days of life gained. Numerical sensitivity and specificity values, CIs, and P values are provided in Supplement Table 4b (available at Annals.org).

Table 1.

Comparison of $FFT_{16.2}$ and $USPSTF_{2021}$ Selection Criteria, With Outcomes Weighted to the U.S. Population of All Ever-Smoking Persons Aged 40 to 80 Years*

Population	People Screened According to $USPSTF_{2021}$ Only ($USPSTF_{2021}$ Nonoverlapping Population)	People Screened According to $FFT_{16.2}$ Only ($FFT_{16.2}$ Nonoverlapping Population)	People Screened According to Both
Population selected, *n*			
All	4 895 943	4 899 918	9 204 624
White	3 966 438	3 506 304	7 728 762
Black	444 560	713 606	786 983
Hispanic	355 353	535 195	515 235
Asian/other	129 592	144 813	173 644
Lung cancer deaths prevented over 5 y, *n*			
All	5448	13 511	44 238
White	4400	9607	37 219
Black	681	2691	5061
Hispanic	264	948	1409
Asian/other	103	265	549
Life-years gained, *n*			
All	119 256	183 439	565 257
White	97 267	127 904	476 790
Black	14 278	36 614	60 944
Hispanic	5206	14 461	19 233
Asian/other	2505	4461	8291
Lung cancer deaths prevented per 1000 people screened over 5 y, *n*			
All	1.11	2.76	4.81
White	1.11	2.74	4.82
Black	1.53	3.77	6.43
Hispanic	0.74	1.77	2.73
Asian/other	0.79	1.83	3.16
Years of life saved per 1000 people screened over 5 y, *n*			
All	24.36	37.44	61.41
White	24.52	36.48	61.69
Black	32.12	51.31	77.44
Hispanic	14.65	27.02	37.33
Asian/other	19.33	30.80	47.74

$FFT_{16.2}$ = fast-and-frugal trees trained on the outcome of ≥16.2 days of life gained with lung cancer screening; $USPSTF_{2021}$ = U.S. Preventive Services Task Force 2021 criteria.

*The analysis was done using the National Health Interview Survey evaluation set.

Table 2.

Characteristics of the Nonoverlapping and Overlapping Populations, Weighted to the U.S. Population of All Ever-Smoking Persons Aged 40 to 80 Years*

Variable	People Screened According to $USPSTF_{2021}$ Only ($USPSTF_{2021}$ Nonoverlapping Population)	People Screened According to $FFT_{16.2}$ Only ($FFT_{16.2}$ Nonoverlapping Population)	People Screened According to Both
Overall	4 895 943 (8.4)	4 899 918 (8.4)	9 204 624
Race/ethnicity			
White	3 966 438 (81)	3 506 304 (71.6)	7 728 762 (84)
Black	444 560 (9.1)	713 606 (14.6)	786 983 (8.5)
Hispanic	355 353 (7.3)	535 195 (10.9)	515 235 (5.6)
Asian	129 592 (2.6)	144 813 (3)	173 644 (1.9)
Gender			
Male	2 857 892 (58.4)	2 723 855 (55.6)	5 224 903 (56.8)
Female	2 038 051 (41.6)	2 176 063 (44.4)	3 979 720 (43.2)
Age			
40–44 y	0 (0)	0 (0)	0 (0)
45–49 y	0 (0)	21 638 (0.4)	0 (0)
50–54 y	2 328 232 (47.6)	106 586 (2.2)	364 580 (4)
55–59 y	1 502 375 (30.7)	600 301 (12.3)	1 697 732 (18.4)
60–64 y	654 761 (13.4)	1 145 605 (23.4)	2 488 350 (27)
65–69 y	289 823 (5.9)	975 999 (19.9)	2 211 230 (24)
70–74 y	80 319 (1.6)	1 099 300 (22.4)	1 547 768 (16.8)
75–79 y	40 433 (0.8)	950 489 (19.4)	894 965 (9.7)
Comorbidities			
0	1 966 438 (40.2)	1 258 460 (25.7)	2 545 300 (27.7)
1	1 540 185 (31.5)	1 592 325 (32.5)	2 704 322 (29.4)
2	772 606 (15.8)	980 031 (20)	1 778 309 (19.3)
3	303 151 (6.2)	482 203 (9.8)	1 004 448 (10.9)
≥4	313 563 (6.4)	586 899 (12)	1 172 244 (12.7)
Decile of risk for lung cancer death			
First	0 (0)	0 (0)	0 (0)
Second	34 432 (0.7)	0 (0)	0 (0)
Third	215 293 (4.4)	1926 (0)	0 (0)
Fourth	328 265 (6.7)	12 099 (0.2)	4762 (0.1)
Fifth	590 214 (12.1)	43 896 (0.9)	52 324 (0.6)
Sixth	779 884 (15.9)	256 549 (5.2)	167 884 (1.8)
Seventh	1 174 971 (24)	625 278 (12.8)	561 486 (6.1)
Eighth	1 091 800 (22.3)	1 125 968 (23)	1 375 728 (14.9)
Ninth	562 482 (11.5)	1 577 578 (32.2)	2 749 232 (29.9)
Tenth	118 604 (2.4)	1 256 624 (25.6)	4 292 827 (46.6)
Tobacco use characteristics			
Duration			

Variable	People Screened According to $USPSTF_{2021}$ Only ($USPSTF_{2021}$ Nonoverlapping Population)	People Screened According to $FFT_{16.2}$ Only ($FFT_{16.2}$ Nonoverlapping Population)	People Screened According to Both
0–19 y	44 556 (0.9)	122 920 (2.5)	0 (0)
20–29 y	1 074 293 (21.9)	545 580 (11.1)	49 712 (0.5)
30–39 y	3 777 094 (77.1)	472 724 (9.6)	365 318 (4)
40–49 y	0 (0)	2 729 928 (55.7)	6 113 992 (66.4)
50–59 y	0 (0)	875 398 (17.9)	2 269 836 (24.7)
60–69 y	0 (0)	153 368 (3.1)	389 852 (4.2)
≥70 y	0 (0)	0 (0)	15 912 (0.2)
Pack-years			
0–9	0 (0)	1 672 778 (34.1)	0 (0)
10–19	0 (0)	1 765 094 (36.0)	0 (0)
20–29	1 648 647 (33.7)	69 217 (1.4)	2 697 188 (29.3)
30–39	2 535 797 (51.8)	29 542 (0.6)	907 181 (9.9)
40–49	177 466 (3.6)	562 954 (11.5)	2 571 968 (27.9)
50–59	227 076 (4.6)	261 707 (5.3)	1 101 118 (12)
60–69	82 835 (1.7)	205 760 (4.2)	615 484 (6.7)
≥70	224 122 (4.6)	332 867 (6.8)	1 311 686 (14.3)
Quit-years			
0–5	3 116 326 (63.7)	3 024 938 (61.7)	7 656 589 (83.2)
6–10	998 120 (20.4)	251 840 (5.1)	960 433 (10.4)
11–15	781 497 (16)	95 276 (1.9)	587 602 (6.4)
16–20	0 (0)	690 901 (14.1)	0 (0)
21–25	0 (0)	278 850 (5.7)	0 (0)
26–30	0 (0)	306 982 (6.3)	0 (0)
>30	0 (0)	251 131 (5.1)	0 (0)

$FFT_{16.2}$ = fast-and-frugal trees trained on the outcome of ≥16.2 days of life gained with lung cancer screening; $USPSTF_{2021}$ = U.S. Preventive Services Task Force 2021 criteria.

*Data are numbers (percentages). The analysis was done using the National Health Interview Survey evaluation set.

Table 3.

Characteristics of the Nonoverlapping and Overlapping Populations With High Risk for Lung Cancer Death (Ninth and Tenth Deciles), Weighted to the U.S. Population of All Ever-Smoking Persons Aged 40 to 80 Years*

Variable	People Screened According to $USPSTF_{2021}$ Only ($USPSTF_{2021}$ Nonoverlapping Population)	People Screened According to $FFT_{16.2}$ Only ($FFT_{16.2}$ Nonoverlapping Population)	People Screened According to Both
Overall	681 085	2 834 202	7 042 059
Race/ethnicity			
White	542 134 (79.6)	2 039 860 (72)	5 993 730 (85.1)
Black	119 689 (17.6)	568 990 (20.1)	688 950 (9.8)
Hispanic	14 060 (2.1)	178 848 (6.3)	256 554 (3.6)
Asian	5202 (0.8)	46 504 (1.6)	102 825 (1.5)
Gender			
Male	431 159 (63.3)	1 681 615 (59.3)	4 222 989 (60)
Female	249 926 (36.7)	1 152 586 (40.7)	2 819 070 (40)
Age			
40–44 y	0 (0)	0 (0)	0 (0)
45–49 y	0 (0)	2671 (0.1)	0 (0)
50–54 y	155 272 (22.8)	4115 (0.1)	94 192 (1.3)
55–59 y	224 609 (33)	55 189 (1.9)	890 103 (12.6)
60–64 y	124 684 (18.3)	355 919 (12.6)	1 790 336 (25.4)
65–69 y	86 363 (12.7)	624 038 (22)	1 934 438 (27.5)
70–74 y	54 870 (8.1)	907 959 (32)	1 445 153 (20.5)
75–79 y	35 288 (5.2)	884 311 (31.2)	887 837 (12.6)
Comorbidities			
0	230 978 (33.9)	600 688 (21.2)	1 833 756 (26)
1	191 274 (28.1)	867 421 (30.6)	2 043 581 (29)
2	142 314 (20.9)	624 285 (22)	1 344 395 (19.1)
3	46 739 (6.9)	322 090 (11.4)	840 750 (11.9)
≥4	69 779 (10.2)	419 718 (14.8)	979 576 (13.9)
Tobacco use characteristics			
Duration			
0–19 y	0 (0)	45 086 (1.6)	0 (0)
20–29 y	31 868 (4.7)	298 880 (10.5)	26 070 (0.4)
30–39 y	649 217 (95.3)	395 910 (14)	254 229 (3.6)
40–49 y	0 (0)	1 144 271 (40.4)	4 157 794 (59)
50–59 y	0 (0)	798 040 (28.2)	2 198 582 (31.2)
60–69 y	0 (0)	152 014 (5.4)	389 472 (5.5)
≥70 y	0 (0)	0 (0)	15 912 (0.2)
Pack-years			
0–9	0 (0)	862 881 (30.4)	0 (0)
10–19	0 (0)	962 245 (34)	0 (0)

Variable	People Screened According to $USPSTF_{2021}$ Only ($USPSTF_{2021}$ Nonoverlapping Population)	People Screened According to $FFT_{16.2}$ Only ($FFT_{16.2}$ Nonoverlapping Population)	People Screened According to Both
20–29	52 042 (7.6)	38 261 (1.3)	1 323 043 (18.8)
30–39	410 008 (60.2)	24 891 (0.9)	732 207 (10.4)
40–49	29 018 (4.3)	342 154 (12.1)	2 107 587 (29.9)
50–59	102 450 (15)	167 782 (5.9)	1 068 750 (15.2)
60–69	10 404 (1.5)	155 829 (5.5)	562 786 (8)
≥70	77 164 (11.3)	280 160 (9.9)	1 247 686 (17.7)
Quit-years			
0–5	532 551 (78.2)	1 621 690 (57.2)	5 907 261 (83.9)
6–10	58 835 (8.6)	112 673 (4)	699 981 (9.9)
11–15	89 699 (13.2)	57 598 (2)	434 817 (6.2)
16–20	0 (0)	453 072 (16)	0 (0)
21–25	0 (0)	193 237 (6.8)	0 (0)
26–30	0 (0)	216 824 (7.7)	0 (0)
>30	0 (0)	179 109 (6.3)	0 (0)

$FFT_{16.2}$ = fast-and-frugal trees trained on the outcome of ≥16.2 days of life gained with lung cancer screening; $USPSTF_{2021}$ = U.S. Preventive Services Task Force 2021 criteria.

*Data are numbers (percentages). The analysis was done using the National Health Interview Survey evaluation set.