 IMPORTANCE  The US Preventive Services Task Force (USPSTF) is updating its 2013 lung cancer screening guidelines, which recommend annual screening for adults aged 55 through 80 years who have a smoking history of at least 30 pack-years and currently smoke or have quit within the past 15 years.

OBJECTIVE  To inform the USPSTF guidelines by estimating the benefits and harms associated with various low-dose computed tomography (LDCT) screening strategies.

DESIGN, SETTING, AND PARTICIPANTS  Comparative simulation modeling with 4 lung cancer natural history models for individuals from the 1950 and 1960 US birth cohorts who were followed up from aged 45 through 90 years.

EXPOSURES  Screening with varying starting ages, stopping ages, and screening frequency. Eligibility criteria based on age, cumulative pack-years, and years since quitting smoking (risk factor–based) or on age and individual lung cancer risk estimation using risk prediction models with varying eligibility thresholds (risk model–based). A total of 1092 LDCT screening strategies were modeled. Full uptake and adherence were assumed for all scenarios.

MAIN OUTCOMES AND MEASURES  Estimated lung cancer deaths averted and life-years gained (benefits) compared with no screening. Estimated lifetime number of LDCT screenings, false-positive results, biopsies, overdiagnosed cases, and radiation-related lung cancer deaths (harms).

RESULTS  Efficient screening programs estimated to yield the most benefits for a given number of screenings were identified. Most of the efficient risk factor–based strategies started screening at aged 50 or 55 years and stopped at aged 80 years. The 2013 USPSTF–recommended criteria were not among the efficient strategies for the 1960 US birth cohort. Annual strategies with a minimum criterion of 20 pack-years of smoking were efficient and, compared with the 2013 USPSTF–recommended criteria, were estimated to increase screening eligibility (20.6%-23.6% vs 14.1% of the population ever eligible), lung cancer deaths averted (469-558 per 100 000 vs 381 per 100 000), and life-years gained (6018-7596 per 100 000 vs 4882 per 100 000). However, these strategies were estimated to result in more false-positive test results (1.9-2.5 per person screened vs 1.9 per person screened with the USPSTF strategy), overdiagnosed lung cancer cases (83-94 per 100 000 vs 69 per 100 000), and radiation-related lung cancer deaths (29.0-42.5 per 100 000 vs 20.6 per 100 000). Risk model–based vs risk factor–based strategies were estimated to be associated with more benefits and fewer radiation-related deaths but more overdiagnosed cases.

CONCLUSIONS AND RELEVANCE  Microsimulation modeling studies suggested that LDCT screening for lung cancer compared with no screening may increase lung cancer deaths averted and life-years gained when optimally targeted and implemented. Screening individuals at aged 50 or 55 years through aged 80 years with 20 pack-years or more of smoking exposure was estimated to result in more benefits than the 2013 USPSTF–recommended criteria and less disparity in screening eligibility by sex and race/ethnicity.


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I

n 2013, the US Preventive Services Task Force (USPSTF) recommended annual screening for lung cancer with low-dose computed tomography (LDCT) for adults aged 55 through 80 years who have a smoking history of at least 30 pack-years and currently smoke or have quit within the past 15 years (B recommendation). These recommendations were largely based on the results of the National Lung Screening Trial (NLST). Since then, new clinical guidelines have emerged for classifying and managing screening-detected pulmonary nodules, and new evidence has emerged on the benefits and harms of LDCT screening.

Early reports of screening practices suggest that the implementation of LDCT screening in the US has not been optimal because less than 20% of eligible individuals have accessed screening, whereas some ineligible individuals with smoking exposure of less than 30 pack-years and some with severe comorbidities have been screened. In addition, some groups, such as Black men, have been shown to be at high risk for lung cancer even when not meeting the 2013 USPSTF–recommended criteria and the criteria from other organizations.

Recognizing that simulation models provide an approach to extrapolate available evidence and predict long-term outcomes, the USPSTF commissioned a simulation analysis to estimate the long-term benefits and harms associated with various LDCT screening strategies to inform its lung cancer screening recommendations update.

Methods

Four lung cancer simulation models developed within the Cancer Intervention and Surveillance Modeling Network (CISNET) were used to estimate the benefits and harms of 1092 LDCT screening strategies: the Microsimulation Screening Analysis-Lung Model from Erasmus University Medical Center, the Massachusetts General Hospital–Harvard Medical School model, the Lung Cancer Outcomes Simulation model from Stanford University, and the University of Michigan model. All 4 models were part of the 2013 lung cancer screening decision analysis conducted for the USPSTF. The full collaborative modeling study technical report has been published.

Model Descriptions

The simulation models differ in terms of parameters, assumptions, model structure, and approach; comparison of the results across models serves as an assessment of model specification uncertainty. Although they share common inputs, each modeling team developed its model independently. The models explicitly considered individual factors associated with lung cancer risk, including the number of cigarettes smoked per day at any given age, the age of smoking initiation, the duration of smoking, and the number of years since quitting.

A comparison of the model characteristics appears in eTable 1 in the Supplement. The models simulate the natural history of lung cancer given an individual’s sex, birth year, and smoking history. The central component of each model is a dose-response module that predicts age- and sex-specific lung cancer incidence risk as a function of individual smoking history. A key component to all models is the shared Smoking History Generator, a validated microsimulator developed by the CISNET Lung Group that simulates individual smoking histories for the US population. These smoking histories serve as the main inputs for the simulations.

Each model can simulate the effects associated with screening given an individual’s smoking and lung cancer natural history. The models were calibrated to both the NLST and the Prostate, Lung, Colorectal, and Ovarian Cancer Screening Trial. Three of the models (Massachusetts General Hospital–Harvard Medical School, Lung Cancer Outcomes Simulation from Stanford University, and University of Michigan) were updated to reflect current practice and outcomes according to the Lung Imaging Reporting and Data System guidelines. The other model (Microsimulation Screening Analysis-Lung Model from Erasmus University Medical Center) uses false-positive test results, sensitivity, and screening result rates based fully on the NLST, allowing for comparison of alternative protocols and assumptions. Additional details appear in the eMethods in the Supplement.

Screening Strategies

Risk Factor–Based Strategies

The primary analysis focused on risk factor–based strategies using criteria similar to the 2013 USPSTF recommendation, which determined eligibility as a function of age and smoking exposure (pack-years of smoking and years since quitting). These strategies varied by starting age of screening (45, 50, or 55 years), stopping age of screening (75, 77, or 80 years), frequency of screening (annual or biennial), minimum pack-years of smoking (20, 25, 30, or 40 pack-years), and maximum years since quitting smoking (10, 15, 20, or 25 years). A total of 288 risk factor–based screening scenarios (eTable 2 in the Supplement) were evaluated and compared with a reference scenario of no screening.

Various studies have suggested that reducing the minimum pack-year eligibility criterion to 20 pack-years would increase the number of lung cancer deaths that would be preventable by screening and also reduce sex and racial disparities in eligibility. Motivated by these studies, risk factor–based strategies with 20 pack-years as the minimum pack-year criterion were further analyzed.

Risk Model–Based Strategies

The potential effects of screening with eligibility criteria based on multivariable risk prediction models (PLCoM2012 model, Lung Cancer Death Risk Assessment Tool model, and the Bach model) that use smoking duration and intensity, sex, and age to estimate lung cancer risk (risk model–based strategies) also were assessed.

These risk prediction models were selected based on demonstrated ability to identify individuals at high probability of developing lung cancer, practicality and ease of implementation, and use as risk calculators in current lung cancer screening recommendations and implementation strategies. Simplified versions of these risk models considering only age, sex, and smoking covariates were used. No other risk factors, such as race/ethnicity or chronic obstructive pulmonary disease, were considered because including these would require joint simulation of these factors with smoking, sex, and age at the population level and the availability of well-calibrated and validated lung cancer natural history models incorporating all covariates.

The evaluated risk model–based strategies varied by risk prediction model, model-specific risk threshold (minimum level of risk
required for eligibility), lower age limits (50 or 55 years), and upper
age limits (75, 77, or 80 years). A summary of the resulting 804 risk
model–based screening strategies appears in eTable 2 in the
Supplement.

Scenario Simulation and Analysis
The CISNET simulation models were used to estimate the benefits
and harms of each strategy in the 1950 and 1960 US birth cohorts.
These birth cohorts were selected because they are now in the
middle of their screening eligibility according to current guidelines
(70 years old for the 1950 cohort and 60 years old for the 1960 co-
hort) and are representative of different periods of the tobacco epi-
demic (higher smoking prevalence and intensity for the individuals
in the 1950 cohort vs lower rates for the 1960 cohort). One million
smoking histories per sex and cohort were simulated using the Smok-
ing History Generator and used as common inputs by each model
to simulate individual-level outcomes under the different screen-
ing scenarios. All simulations were performed assuming that all
screening-eligible individuals would undergo screening and ad-
here to ongoing screening (annual or biennial) for the duration
of their eligibility. Smoking cessation and the risk of competing ca-
diseases and death were assumed to be unaffected by the screen-
ing results. The risk model–based screening analysis was restricted
to the 1960 birth cohort.

Outcomes
Simulated outcomes included counts of screening examinations,
the number and percentage of persons screened given an eligibility
criterion, the number of lung cancer cases and deaths, life-years
gained relative to a scenario of no screening, the number of false-
positive screening results, the number of biopsies, and the number
of overdiagnosed cases (defined as lung cancer cases detected by
screening that would not have been diagnosed nor caused death in
the absence of screening). Two models (Massachusetts General
Hospital–Harvard Medical School and University of Michigan) were
used to estimate radiation-related lung cancer deaths. Outcomes
were provided per 100 000 individuals alive at aged 45 years (in-
cluding both screened and unscreened individuals), rather than per
the screened population so that the outcomes are comparable
across scenarios.

Selection of Consensus-Efficient Scenarios
Efficient scenarios estimated to provide the most lung cancer deaths
averted and life-years gained for a given level of screening (number
of LDCT screenings per 100 000 population) were identified via a
data envelopment analysis.13,28 The analysis ranks scenarios based
on their distance to the model-specific efficient frontier of (1) LDCT
screenings vs deaths averted and (2) LDCT screenings vs life-years
earned. Model-specific efficient scenarios were those on the mod-
el's efficient frontier or in the top 30% for the model ranking (ie, those
scenarios in which the model estimated the most or close to the most
lung cancer deaths averted and life-years gained for a given level
of screening). Scenarios that were deemed efficient by at least 3 of the
4 models were termed consensus efficient and were selected for fur-
ther analysis. This approach ensured an equal weighting of the mod-
els. More details are provided in the full report.16

For each identified consensus-efficient scenario, sex-specific re-
results were aggregated to derive the predicted population-level mean
(achieved through previous studies) outcomes. Special attention was given
to consensus-efficient scenarios leading to a mortality reduction of
at least 9%.

Sensitivity Analysis
Additional sensitivity analyses were used to assess the effective-
ness of different LDCT screening strategies in limiting screening to
only those persons with more than 5 years of life expectancy, as-
suming a perfect assessment of life expectancy.

Results
The presented results focus on the 1960 US birth cohort. The re-
sults for the 1950 US birth cohort are in the Supplement and the
full report.16 Unless otherwise indicated, the results presented
are for men and women combined.

Risk Factor-Based Strategies
When compared with no screening, risk factor-based screening strat-
egies were estimated to result in lung cancer deaths averted and life-
years gained, with variations according to the level of screening
(number of LDCT screenings) and specific eligibility criteria for each
scenario. The number of LDCT screenings and deaths averted rela-
tive to no screening for each risk factor–based strategy appears in
Figure 1. In general, the scenarios that were on the model's efficient
frontier had LDCT screening stopping at aged 80 years. Biennial
strategies are concentrated on the lower-left side of each panel
because they require fewer LDCT screenings and are estimated to
avert fewer deaths. Annual strategies tend to be on the upper-right
side because they require more LDCT screenings and are estimated to
generally avert more deaths. Although the absolute range of pre-
dicted deaths averted varies by model, the general efficiency pat-
terns were consistent across the CISNET models. The 2013
USPSTF–recommended strategy was on or among the closest to
the efficient frontier for 3 of the 4 models.

The corresponding efficient frontier curves using life-years
earned as the benefit metric appear in Figure 2. The patterns were
similar but show less variability among strategies than for deaths
averted. In this case, the 2013 USPSTF–recommended strategy
was only on (or among the closest to) the efficient frontier for 1 of
the 4 models.

Risk Factor-Based Consensus-Efficient Scenarios
Fifty-seven consensus-efficient scenarios were identified. The 2013
USPSTF–recommended scenario was not 1 of the 57 consensus-
efficient scenarios. The top of Figure 3 shows the mean number
of LDCT screenings (across CISNET models) compared with the num-
ber of deaths averted (left) and life-years gained (right) for all risk
factor–based strategies, highlighting the consensus-efficient sce-
narios. Most of the consensus-efficient scenarios were on the effi-
cient frontier or among the closest to the efficient frontier for both
benefit metrics. Detailed outcomes for the 57 consensus-efficient
scenarios appear in eTables 3 and 4 in the Supplement.

The estimated benefits of the consensus-efficient scenarios that
were restricted to those leading to a lung cancer mortality reduc-
tion of at least 9% appear in Table 1 along with the 2013 USPSTF–
recommended scenario (a total of 26 scenarios). The scenarios are
estimated to result in a lung cancer mortality reduction close to or greater than that of the 2013 USPSTF–recommended strategy (9.8%). Of the 25 selected consensus-efficient scenarios, 5 were biennial and 20 were annual; all had 80 years as the stopping age of screening and ranged from 14.5% to 24.1% of eligible individuals. In terms of minimum pack-years of smoking exposure, 13 scenarios (52.0%) had 20 pack-years, 8 (32.0%) had 25 pack-years, 4 (16.0%) had 30 pack-years, and none had 40 pack-years. The estimated number of lung cancer deaths averted ranged from 348 to 578 per 100 000 population, corresponding to a population-level mortality reduction ranging from 9.0% to 14.9%. The estimated life-years gained ranged from 4490 to 8186 per 100 000 population and the number of persons needed to screen ranged from 34 to 63 (per 1 lung cancer death averted).

The estimates for the range of benefits and harms across the 4 CISNET models appear in eTables 5 and 6 in the Supplement.

**Scenarios for 20 Pack-Years of Smoking**

The consensus-efficient strategies with 20 pack-years of smoking and annual screening were examined further. There were 6 such strategies starting screening at aged 50 or 55 years and requiring at least 15 years since quitting smoking: A-55-80-20-15, A-55-80-20-20, A-55-80-20-25, A-50-80-20-15, A-50-80-20-20, and A-50-80-20-25 (Figure 3).

Expanding current screening eligibility to include individuals with 20 to 29 pack-years of smoking was estimated to increase the eligibility percentage from 14.1% for the population ever screened to between 20.6% and 23.6%, depending on the screening starting age and the number of years since quitting smoking. The mean number of LDCT screenings (across models) for these 20 pack-year scenarios ranged from 330 095 to 500 430 compared with 227 443 for the 2013 USPSTF–recommended strategy. The mean age at last screening ranged from 69.0 to 72.5 years compared with 71.3 years for the 2013 USPSTF–recommended criteria (eTable 7 in the Supplement). The mean age at first screening ranged from 51.5 years to 55.7 years (for all strategies with a starting age of 50 years).
The estimated number of lung cancer deaths averted for the 20 pack-year strategies ranged from 469 to 558 per 100,000 population, corresponding to a mortality reduction ranging from 12.1% to 14.4%. The estimated life-years gained for the selected 20 pack-year strategies ranged from 6018 to 7596 per 100,000 and the number needed to screen ranged from 42 to 45. In comparison, the 2013 USPSTF–recommended strategy was estimated to result in 381 per 100,000 deaths averted, a mortality reduction of 9.8%, 4882 life-years gained, and a number needed to screen of 37.

The estimated mean number of false-positive results per screened individual ranged from 1.9 to 2.5 for the selected 20 pack-year strategies vs 1.9 for the 2013 USPSTF–recommended strategy. The number of biopsies ranged from 526 to 849 per 100,000 vs 518 per 100,000 for the 2013 USPSTF–recommended criteria. The number of overdiagnosed lung cancer cases ranged from 83 to 94 per 100,000 population vs 69 per 100,000 for the 2013 USPSTF–recommended criteria. The rate of overdiagnosis per screening-detected lung cancer case ranged from 6.0% to 6.3% vs 6.3% for the 2013 USPSTF–recommended criteria. In addition, the number of radiation-related lung cancer deaths ranged from 29.0 to 42.5 per 100,000 population vs 20.6 per 100,000 population for the 2013 USPSTF–recommended criteria.

Figure 2. Low-Dose Computed Tomography Screening Examinations vs Life-Years Gained in Each of the 288 Risk Factor–Based Strategies Evaluated by the 4 CISNET Models for the 1960 US Birth Cohort

Each point represents a different scenario and the line represents the estimated efficient frontier per model. Strategies vary by age at starting and stopping screening, frequency of screening, minimum pack-years of smoking, and maximum years since quitting smoking (eTable 2 in the Supplement). CISNET indicates Cancer Intervention and Surveillance Modeling Network; USPSTF, US Preventive Services Task Force.

vs 56.2 years for the 2013 USPSTF–recommended criteria (eTable 7 in Supplement).

The estimated number of lung cancer deaths averted for the 20 pack-year strategies ranged from 469 to 558 per 100,000 population, corresponding to a mortality reduction ranging from 12.1% to 14.4%. The estimated life-years gained for the selected 20 pack-year strategies ranged from 6018 to 7596 per 100,000 and the number needed to screen ranged from 42 to 45. In comparison, the 2013 USPSTF–recommended strategy was estimated to result in 381 per 100,000 deaths averted, a mortality reduction of 9.8%, 4882 life-years gained, and a number needed to screen of 37.

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Comparisons by sex appear in eTables 8 and 9 in the Supplement. These estimates show similar patterns as those for the whole population; however, there were higher increases in eligibility, deaths averted, and life-years gained for women than men.

Although the analysis did not consider different racial or ethnic groups, comparisons of the percentage of individuals eligible for screening in the US under the 2013 USPSTF–recommended strategy vs the selected 20 pack-year strategies by sex and race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, Asian, and American Indian/Alaska Native) appear in the full report16 and in eTables 10 and 11 in the Supplement.

Risk Model–Based Strategies

Risk model–based strategies were estimated to result in considerably more lung cancer deaths averted for a given number of LDCT screenings than risk factor–based strategies. However, the differences in life-years gained were less pronounced. The mean (across the CISNET models) number of LDCT screenings appears...
in the bottom of Figure 3 compared with the number of deaths averted (left) and life-years gained (right) for all scenarios for each CISNET model (results for each CISNET model appear in eFigures 1 and 2 in the Supplement). The estimated benefits and harms of 144 consensus-efficient scenarios with a reduction in lung cancer mortality of at least 9% and requiring fewer than 600 000 LDCT screenings per 100 000 appear in eTables 12 and 13 in the Supplement.

Sensitivity Analyses

The general patterns observed for the 1960 US birth cohort held for the 1950 US birth cohort, with some variations in the absolute numbers due to the higher level of smoking in the 1950 birth cohort (eFigures 3 and 4 in the Supplement). In general, limiting screening to only those with more than 5 years of life expectancy (assuming a hypothetical perfect assessment of life expectancy) did not greatly affect the resulting estimated benefits (deaths averted or life-years gained) but was estimated to result in fewer harms and considerably fewer overdiagnosed cases. This finding was particularly true for screening strategies at older ages.
Table 1. Benefits of 25 Selected Consensus-Efficient Risk Factor–Based Screening Programs Plus the 2013 USPSTF–Recommended Criteria Ordered by Low-Dose Computed Tomography (LDCT) Screenings for the 1960 US Birth Cohort

<table>
<thead>
<tr>
<th>Screening scenario</th>
<th>Eligible, %</th>
<th>LDCT screenings</th>
<th>Screening-detected lung cancer cases</th>
<th>Lung cancer mortality reduction, %</th>
<th>Lung cancer deaths averted</th>
<th>Life-years gained per lung cancer deaths averted</th>
<th>LDCT screenings per life-years gained</th>
<th>LDCT screenings per lung cancer deaths averted</th>
<th>NNS to prevent 1 lung cancer death</th>
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Abbreviations: NNS, number needed to screen; USPSTF, US Preventive Services Task Force.

a The screening strategies have a lung cancer mortality reduction of at least 9% and correspond to frequency (A for annual or B for biennial)—age at start of screenings—age screenings should be stopped—minimum pack-years of smoking-maximum years since quitting smoking.

b Individuals were followed up from aged 45 to 90 years. The 4 models were the Microsimulation Screening Analysis–Lung Model from Erasmus University Medical Center, the Massachusetts General Hospital–Harvard Medical School model, the Lung Cancer Outcomes Simulation model from Stanford University, and the University of Michigan model.

c Recommended scenario by the 2013 USPSTF guidelines.

d Selected 20 pack-year consensus-efficient scenarios.

Discussion

The findings of this simulation analysis suggest that optimally targeted LDCT screening could lead to important reductions in lung cancer mortality and result in significant life-years gained. Although the analysis cannot identify a single optimal strategy, it identified a set of screening programs estimated to yield the most benefits for a given level of screening (consensus-efficient scenarios). The analysis estimates that screening strategies for individuals aged 50 or 55 years through aged 80 years with 20 or more pack-years of smoking exposure are efficient and would result in more benefits than the 2013 USPSTF–recommended criteria but also more harms.

Recent studies have suggested that expanding eligibility to include ever-smokers with 20 to 29 pack-years of exposure would increase the proportion of lung cancer deaths preventable by screening and reduce disparities in eligibility by race/ethnicity and sex.11,12,21,29-31 Pinsky and Kramer11 showed that reducing the minimum pack-years to 20 should increase the percentage of women and minorities who would be eligible for screening. They also found that the lung cancer risk for current smokers with 20 to 29 pack-years is comparable with that of former smokers eligible for screening based on the 2013 USPSTF–recommended criteria. Aldrich et al2 found that proportionally fewer Black adults with lung cancer would have been eligible for screening vs White adults with lung cancer and that expanding the criteria to include 20 to 29 pack-year ever-smokers would considerably increase the screening sensitivity for Black adults. The Nederlands–Leuvens Longkanker Screenings Onderzoek trial6 found a relative reduction of 24% for lung cancer mortality at 10 years after 4 rounds of LDCT screening vs a no screening group and included ever-smokers aged 50 to 74 years with lower smoking exposure criteria than the NLST and the 2013 USPSTF
recommendations, providing additional support to expanding the age and smoking eligibility criteria. The comparisons made by sex and race/ethnicity suggest that the relative increase in eligibility for screening from reducing the pack-year criterion to 20 pack-years from the current criterion of 30 pack-years would be larger for women than for men and larger for non-Hispanic Black, Hispanic, and American Indian/Alaska Native persons than for non-Hispanic White and Asian persons.

The better performance of risk model-based screening vs risk factor-based strategies is largely because risk model-based strategies shift screening to older ages, which is when lung cancer risk is the highest. These findings are consistent with other recent studies in the literature. The analysis shows that although the specific risk prediction model used for determining eligibility is an important consideration, an even more critical aspect is to determine eligibility risk thresholds specific to the corresponding risk prediction model.

The decision analysis used established lung cancer natural history models that capture the complexity in smoking patterns and lung cancer risk and integrate and synthesize information from smoking trials, large epidemiological prospective studies, and cancer surveillance data. The 4 CISNET models and the Smoking History Generator have been shown to reproduce the patterns of smoking and lung cancer incidence and mortality in the US and thus provide a valid framework to extrapolate the potential effects of screening to the entire population. The relative performance of different scenarios according to their characteristics (starting and stopping age for screening, minimum pack-years of smoking, maximum years since quitting, and risk threshold) was consistent across the 4 CISNET models.

### Table 2. Harms of 25 Selected Consensus-Efficient Risk Factor–Based Screening Programs Plus the 2013 USPSTF–Recommended Criteria Ordered by Low-Dose Computed Tomography Screenings for the 1960 US Birth Cohort

<table>
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<tr>
<th>Screening scenario&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mean estimate across 4 models per 100 000 population&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Low-dose computed tomography</th>
<th>False-positive results per person screened</th>
<th>Biopsies</th>
<th>Overdiagnosis Lung cancer cases</th>
<th>% of all lung cancer cases</th>
<th>% of screening-detected lung cancer cases</th>
<th>Radiation-related lung cancer deaths</th>
<th>Lung cancer mortality reduction&lt;sup&gt;c&lt;/sup&gt;</th>
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<sup>a</sup> The screening scenarios have a lung cancer mortality reduction of at least 9% and correspond to frequency (A for annual or B for biennial)—age at start of screenings—age screenings should be stopped—minimum pack-years of smoking—maximum years since quitting smoking.

<sup>b</sup> Individuals were followed up from aged 45 to 90 years. The 4 models were the Microsimulation Screening Analysis-Lung Model from Erasmus University Medical Center, the Massachusetts General Hospital-Harvard Medical School (MGH-HMS) model, the Lung Cancer Outcomes Simulation model from Stanford University, and the University of Michigan (UM) model.

<sup>c</sup> Recommended scenario by the 2013 USPSTF guidelines.

<sup>d</sup> Only 2 models (MGH-HMS and UM) used for the data in this column.

<sup>e</sup> Selected 20 pack-year consensus-efficient scenarios.
Limitations
This study has several limitations. First, the analysis assumed an idealized 100% screening uptake and adherence for eligible individuals; did not explicitly examine incidental findings or other potential harms, such as adverse events; and was based on models calibrated to lung screening trial outcomes, which might not be representative of screening in real-world settings. Thus, the estimations of the benefits should be interpreted as an upper boundary of what the actual effects could be.

Second, the analysis focused only on age, smoking history, and sex, ignoring other important risk factors, such as race/ethnicity, history of chronic obstructive pulmonary disease, exposure to occupational and environmental carcinogens, and family history of lung cancer.

Third, the analysis did not consider potential implementation challenges of risk model-based screening or whether those challenges could vary by setting or among different demographic groups. Several ongoing implementation studies and trials are evaluating the feasibility and potential of risk model-based screening in clinical settings—so far with promising results.20,33-36

Fourth, the projections did not account for future improvements in lung cancer treatment and further changes in smoking trends. Recent developments in targeted therapies and immunotherapies could affect future lung cancer survival and screening efficacy.37 In addition, the modeling did not consider the potential additional benefits of complementary smoking cessation programs within the context of lung cancer screening.38-40

Conclusions
Microsimulation modeling studies suggested that LDCT screening for lung cancer compared with no screening may increase lung cancer deaths averted and life-years gained when optimally targeted and implemented. Screening individuals at ages 50 or 55 years through aged 80 years with 20 pack-years or more of smoking exposure was estimated to result in more benefits than the 2013 USPSTF–recommended criteria and less disparity in screening eligibility by sex and race/ethnicity.

ARTICLE INFORMATION
Accepted for Publication: January 25, 2021.

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Author Contributions: Drs Meza and Jeon had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Dr ten Haaf, Ms Cao, and Dr Bastani contributed equally. Drs Feuer, Plevritis, de Koning, and Kong contributed equally.

Concept and design: All authors.

Acquisition, analysis, or interpretation of data: All authors.

Drafting of the manuscript: Meza, Jeon, Kong.

Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: Meza, Jeon, Toumazis, Cao, Bastani, Plevritis, Kong.

Obtained funding: Meza, Jonas, Plevritis, de Koning, Kong.

Administrative, technical, or material support: Han, Jonas, Feuer, Plevritis.

Supervision: Meza, Jonas, Plevritis, de Koning, Kong.

Conflict of Interest Disclosures: Dr ten Haaf reported receiving grants from the European Union, the University of Zurich, and Cancer Research UK; receiving travel reimbursement from the International Association for the Study of Lung Cancer, the Russian Society of Clinical Oncology, and the Biomedical Research in Endstage and Obstructive Lung Disease Hannover; and receiving speaking fees paid to Erasmus University Medical Center. Dr Blom reported receiving nonfinancial support from the Nederlands-Leuvens Longkanker Screenings Onderzoek trial and Siemens Germany. Dr Plevritis reported receiving consulting fees from Grail Inc. Dr de Koning reported receiving personal fees from Merck Sharp & Dohme and Teva; and receiving speakers fees and personal fees from Ipsos MORI. No other disclosures were reported.

Funding/Support: This research was funded by grant HHSAG-290-2015-00011-f from the Agency for Healthcare Research and Quality (AHRQ); US Department of Health and Human Services. We also acknowledge support via grant U01CA199284 from the National Cancer Institute.

Role of the Funder/Sponsor: The investigators worked with USPSTF members and AHRQ staff to develop the scope and key questions for this decision analysis. The AHRQ had no role in the model development and analyses. Staff at the AHRQ provided project oversight, reviewed the report to ensure that the decision analysis met methodological standards, and distributed the draft for public comment. Otherwise, the AHRQ had no role in the conduct of the study; model simulations, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript. The opinions expressed are those of the authors and do not reflect the official position of the AHRQ or the US Department of Health and Human Services.

Additional Contributions: We gratefully acknowledge the following individuals for their contributions to this project: Howard Trace, MD, and Tracy Wolff, MD, MPH (both on staff at the AHRQ), Sheila Terrones, MA (University of Michigan), and Carol Woodell, BSPH, Sharon Barrell, MA, and Loraine Monroe (all 3 on staff at RTI International—University of North Carolina). The USPSTF members, expert consultants, peer reviewers, and federal reviewers did not receive financial compensation for their contributions.

Ms Terrones, Ms Woodell, Ms Barrell, and Ms Monroe received compensation for their role in this project.

Additional Information: A draft version of the full decision analysis report underwent external peer review from 3 content experts (William C. Black, MD [Darmouth-Hitchcock Medical Center]; Gerard A. Silvestri, MD, MS [Medical University of South Carolina]; and Ann Zauber, PhD [Memorial Sloan Kettering Cancer Center]) and 2 National Cancer Institute reviewers (Paul Pinsky, PhD, and Kathy Cronin, PhD). Comments from the reviewers were considered in preparing the final decision analysis. USPSTF members and peer reviewers did not receive financial compensation for their contributions.

Editorial Disclaimer: This decision analysis is presented as a document in support of the accompanying USPSTF Recommendation Statement. It did not undergo additional peer review after submission to JAMA.

REFERENCES