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Article

State Variation in Low-Dose Computed Tomography Scanning for Lung Cancer Screening in the United States

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Abstract

Background: Annual lung cancer screening (LCS) with low-dose chest computed tomography in older current and former smokers (ie, eligible adults) has been recommended since 2013. Uptake has been slow and variable across the United States. We estimated the LCS rate and growth at the national and state level between 2016 and 2018. **Methods:** The American College of Radiology's Lung Cancer Screening Registry was used to capture screening events. Population-based surveys, the US Census, and cancer registry data were used to estimate the number of eligible adults and lung cancer mortality (ie, burden). Lung cancer screening rates (SRs) in eligible adults and screening rate ratios with 95% confidence intervals (CI) were used to measure changes by state and year. **Results:** Nationally, the SR was steady between 2016 (3.3%, 95% CI = 3.3% to 3.7%) and 2017 (3.4%, 95% CI = 3.4% to 3.9%), increasing to 5.0% (95% CI = 5.0% to 5.7%) in 2018 (2018 vs 2016 SR ratio = 1.52, 95% CI = 1.51 to 1.62). In 2018, several southern states with a high lung-cancer burden (eg, Mississippi, West Virginia, and Arkansas) had relatively low SRs (<4%) among eligible adults, whereas several northeastern states with lower lung cancer burden (eg, Massachusetts, Vermont, and New Hampshire) had the highest SRs (12.8%-15.2%). The exception was Kentucky, which had the nation's highest lung cancer mortality rate and one of the highest SRs (13.7%). **Conclusions:** Fewer than 1 in 20 eligible adults received LCS nationally, and uptake varied widely across states. LCS rates were not aligned with lung cancer burden across states, except for Kentucky, which has supported comprehensive efforts to implement LCS.

Lung cancer is the leading cause of cancer death in the United States, with an estimated 135 720 deaths expected in 2020 (1). About 81% of lung cancers are attributable to cigarette smoking (2). Over one-half (57%) are diagnosed at a distant stage, and the 5-year survival rate for distant-staged lung cancer is only 6% (1). In 2011, the National Lung Screening Trial reported a 20% relative reduction in lung cancer mortality among adults who smoked heavily and were randomly assigned to annual low-dose computed tomography (LDCT) screening for 3 years compared with those randomly assigned to annual chest x-rays (3). In 2013, the United States Preventive Services Task Force (USPSTF) and the American Cancer Society recommended annual lung cancer screening (LCS) using LDCT for high-risk adults (USPSTF: 55-80 years and ACS: 55-74 years) who smoked heavily (4). The USPSTF decision meant that under the terms of the Affordable Care Act, private payers were required to cover LCS without a copay in early 2014 (5). The Centers for Medicare and Medicaid Services (CMS) began covering LCS for eligible Medicare enrollees aged 55-77 years in February 2015 (6).

LCS has the potential to avert death (7). Despite this, previously reported uptake has been low, with less than 4% of eligible adults reporting past-year LCS with LDCT in 2015 (8). This low uptake is attributed to multiple barriers, including lack of health system support, uncertainty of harms vs benefit, physicians' reluctance, awareness and education on shared-decision making, as well as psychosocial and access barriers among screening candidates (9). Data from a limited number (n = 10) of states collecting LCS data in the 2017 Behavioral Risk Factor Surveillance System (BRFSS) survey showed 13%-14% of USPSTF eligible adults reported screening with LDCT in the past year (10,11).

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With implementation efforts underway, nationwide screening rates (SRs), uptake over time, and state-by-state variations are unknown. This study was undertaken to estimate LCS rates among eligible adults nationally and in all 50 states plus Washington, DC from 2016 to 2018, and also to examine state-level screening estimates relative to lung cancer burden, sociodemographic status, and access to LCS.

Methods

Formulas and Data Sources

Nationwide and state-specific annual lung cancer SRs were estimated with formulas and several data sources (Supplementary Table 1, available online). Formula 1 shown in Supplementary Figure 1 (available online) was used to compute the state-specific SRs' denominator, which included the number of adults aged 55-80 years meeting the 2013 USPSTF LCS criteria (currently or formerly smoked cigarettes and quit within the past 15 years, with ≥30 pack-year smoking history). Formula 2 shown in Supplementary Figure 1 (available online) was used to compute SRs.

Data from the 2015 National Health Interview Surveys (NHIS), 2016-2018 BRFSS, and US Census Bureau were used to estimate the SR denominator. The NHIS is an in-person national survey, and BRFSS is a state-based telephone survey; both are conducted by the Centers for Disease Control and Prevention (12,13). These surveys collect general smoking status annually, but detailed smoking history with pack-years was collected in the 2015 NHIS and among 14 states participating in optional 2017-2018 BRFSS modules. The 2016-2018 BRFSS data were used to compute overall state-specific former and current smoking prevalence and the 2015 NHIS data to estimate probability that a current or former smoker met USPSTF eligibility. Data from 14 states participating in BRFSS modules were used verify this method. State-, sex-, and age-specific population counts were obtained from 2015 to 2018 US Census Bureau data.

The numbers (ie, SR numerator) of LDCTs performed among USPSTF-eligible adults between 2016 and 2018 in all 50 states and Washington, DC (hereafter referred to as a state) were obtained from public American College of Radiology's Lung Cancer Screening (LCSR) reports (14). In 2015, Medicare required that data for all LCS scans, regardless of payor, must be submitted to a CMS-approved registry for facilities to receive reimbursement. The American College of Radiology's LCSR is the only CMS-approved registry, and it collects data from all states, though some facilities, including those in Veterans Administration (VA) or Department of Defense (DOD) systems, have no reporting requirement to use the registry. In sensitivity analyses, SRs removing the estimated number of VA patients eligible for LCS, based on a recently published study (15), were computed nationally. No state-specific estimates of VA eligible adults are available.

Statistical Analyses

Lung cancer SR ratios (SRR) were computed to assess within-state changes between 2018 and 2016 and between-state differences in 2018 using the national mean and the state with the highest SR as referent groups (described in Supplementary Figure 1, available online). The 95% confidence intervals (CI) for SRs and SRRs were calculated with bias-corrected bootstrap sampling with 1000 replicates accounting for variances in the probability that an adult was eligible for screening and prevalence rates of current and former smokers.

The correlation between state-level SRs in 2018 and measures of lung cancer burden, capacity, access, and sociodemographic factors was computed. Access and sociodemographic factors were considered a priori because they are associated with other cancer screening tests (8,16). States were then grouped as having low, medium, and high levels of factors statistically significantly correlated with SRs and stratified SRRs vs the national average were computed in post hoc analyses. Burden was measured with lung cancer mortality rates among adults aged 55-79 years from the National Center for Health Statistics (17). Capacity was measured with facility density, computed by dividing the number of LCSR facilities per eligible population. Access and sociodemographic factors were measured by the proportion of BRFSS respondents who smoked and were uninsured; formerly smoked; were female, Hispanic, Black; and had a high school education or less. The association between SRs with state-level Medicaid expansion status was examined with 2 sample *t* tests. Statistical analyses were conducted in SAS version 9.4. All tests were 2-sided, and a *P* of less than .05 was considered statistically significant.

Results

Nationwide Patterns of Eligibility and Screening

Among individuals aged 55-80 years, 10.3% of all adults and 39.9% and 14.3% of adults who currently and formerly smoked, respectively, were USPSTF eligible for LCS during the study period. There were an estimated 8.11, 8.15, and 8.07 million eligible adults in 2016, 2017, and 2018, respectively. According to LCSR data, 268 109 scans were conducted in eligible adults in 2016, 278 632 in 2017, and 406 498 in 2018. The SRs during the corresponding period remained steady between 2016 (SR = 3.3%, 95% CI = 3.3% to 3.7%) and 2017 (SR = 3.4%, 95% CI = 3.4% to 3.9%), rising to 5.0% (95% CI = 5.0% to 5.7%) in 2018 (2018 vs 2016: SRR = 1.52, 95% CI = 1.51 to 1.62) (Figure 1). When VA-eligible patients were removed from denominators, SRs were 3.9%, 4.0%, and 5.9% in 2016, 2017, and 2018, respectively (Supplementary Table 2, available online).

Lung Cancer Screening Eligibility and Rates According to State

A total of 12.2%, 12.8%, and 12.3% of adults aged 55-80 years in Kentucky, Tennessee, and West Virginia, respectively, were eligible for LCS vs 6.0% in Utah (Figure 2). Between 2016 and 2018, lung cancer SRs statistically significantly increased in 48 of 51 states (Table 1). In 2018, 4% and less of eligible adults in several Southern and Western states (eg, Arkansas, West Virginia, Florida, California, and Nevada) were screened compared with 10%-15% in Kentucky and several Northeastern states (eg, Massachusetts, New Hampshire) (Figure 3,Supplementary Table 3, available online). Compared with Massachusetts, the state with the highest SR (15.2%), SRRs were statistically significantly lower in 27 states (Supplementary Figure 2, available online). Relative to the national average, SRRs were statistically significantly lower in 8 states, mostly in the West or South, and 50% higher in 13 states, mostly in the Northeast or Midwest, with Kentucky as the outlier (Table 1).

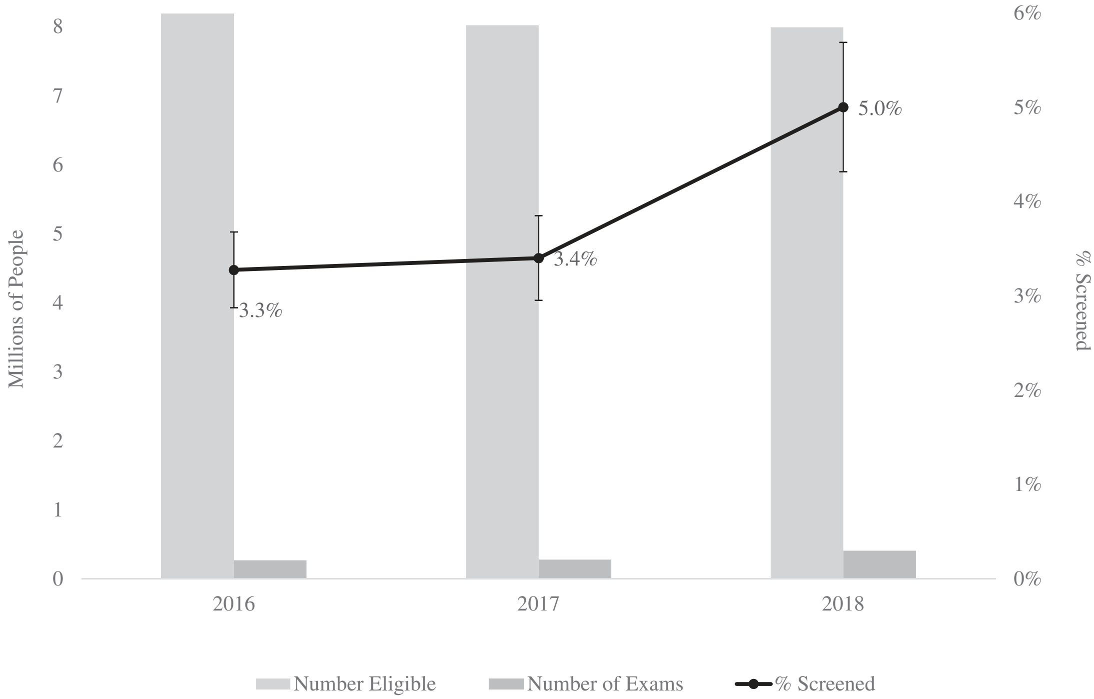

Figure 1. Proportion of eligible adults aged 55-80 years screened for lung cancer with low-dose computed tomography (LDCT) in the United States, 2016-2018. Lung cancer screening with LDCT in the past year among adults meeting the US preventive services task force (USPSTF) recommendations. USPSTF eligible adults were current or former cigarette smokers who quit within the past 15 years with a 30 or more pack-year smoking history and aged 55-80 years.

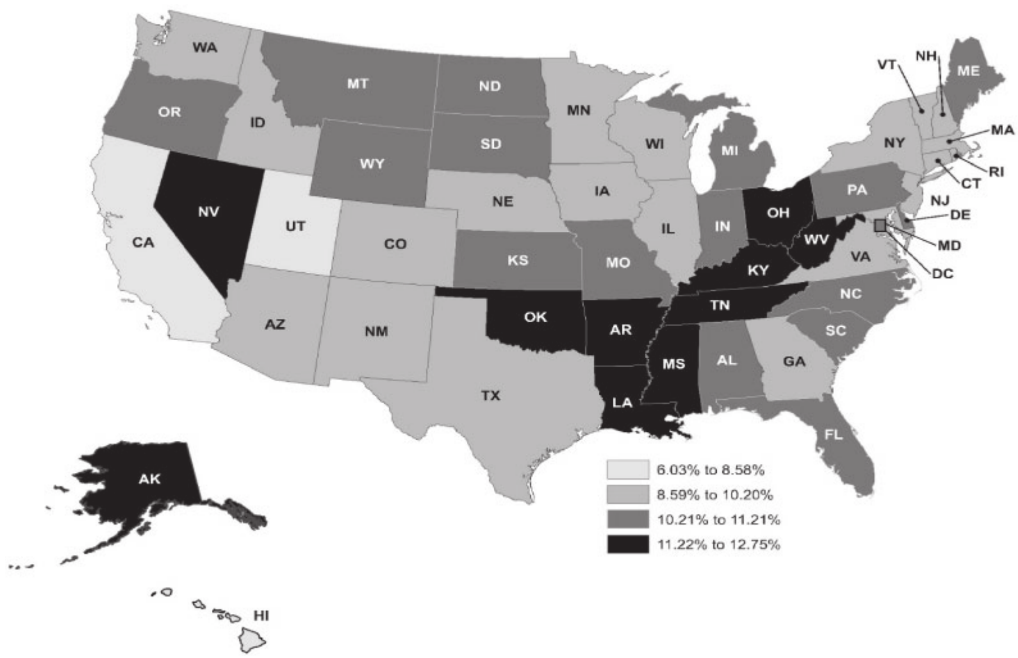

Figure 2. Estimated proportion of adults aged 55-80 years eligible for lung cancer screening with low-dose computed tomography (LDCT) according to US preventive services task force (USPSTF) criteria by state, 2018. USPSTF eligible included adults who are current or former cigarette smokers who quit within the past 15 years with a 30 or more pack-year smoking history and aged 55-80 years.

Correlation and Associations of Lung Cancer Screening With State-Level Burden, Capacity, Access, and Sociodemographic Factors

State-level SRs were not correlated with lung cancer burden (ie, mortality rates $r = 0.25$, $P = .08$) (Table 2). In 2018, several Southern states with a high lung-cancer burden (eg, Mississippi, West Virginia, and Arkansas, which had >50 lung cancer deaths per 100 000) had relatively low SRs (<4%), whereas several Northeastern states with lower lung cancer burden (eg, Massachusetts, Vermont, and New Hampshire, which had ≤44

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Table 1. Lung cancer SRRs across survey years and states, 2016-2018[a]

State	2018 vs 2016[b] SRR (95% CI)	2018 vs national average[c] SRR (95% CI)
Alabama	1.39 (1.37 to 1.60)	1.00 (0.98 to 1.15)
Alaska	1.75 (1.72 to 2.23)	1.10 (1.07 to 1.38)
Arizona	1.63 (1.60 to 1.90)	0.39 (0.36 to 0.81)
Arkansas	2.47 (2.44 to 2.93)	0.59 (0.53 to 1.15)
California	1.16 (1.15 to 1.36)	0.21 (0.17 to 0.78)
Colorado	1.18 (1.17 to 1.33)	0.56 (0.55 to 0.74)
Connecticut	1.55 (1.54 to 1.74)	1.48 (1.47 to 1.57)
Delaware	1.82 (1.79 to 2.14)	1.24 (1.22 to1.44)
District of Columbia	1.76 (1.73 to 2.14)	0.56 (0.53 to 1.03)
Florida	1.38 (1.36 to 1.58)	0.57 (0.55 to 0.76)
Georgia	1.72 (1.70 to 2.00)	1.14 (1.13 to 1.33)
Hawaii	1.20 (1.18 to 1.39)	0.63 (0.62 to 0.85)
Idaho	1.15 (1.13 to 1.41)	1.35 (1.33 to 1.48)
Illinois	1.58 (1.56 to 1.87)	1.05 (1.03 to 1.24)
Indiana	1.86 (1.84 to 2.11)	1.17 (1.16 to 1.31)
Iowa	1.56 (1.54 to 1.79)	1.70 (1.69 to 1.79)
Kansas	1.35 (1.34 to 1.51)	1.15 (1.14 to 1.24)
Kentucky	1.48 (1.46 to 1.72)	2.73 (2.72 to 2.78)
Louisiana	1.68 (1.66 to 2.05)	0.52 (0.48 to 0.97)
Maine	1.47 (1.46 to 1.68)	1.60 (1.59 to 1.69)
Maryland	1.27 (1.25 to1.41)	1.49 (1.48 to 1.56)
Massachusetts	1.43 (1.41 to 1.67)	3.01 (3.01 to 3.06)
Michigan	1.81 (1.78 to 2.04)	1.65 (1.64 to 1.74)
Minnesota	1.61 (1.59 to 1.78)	1.52 (1.51 to 1.60)
Mississippi	1.45 (1.44 to 1.72)	0.76 (0.74 to 1.01)
Missouri	1.70 (1.67 to 1.97)	1.26 (1.24 to 1.41)
Montana	2.07 (2.04 to 2.45)	1.17 (1.15 to 1.39)
Nebraska	1.10 (1.09 to 1.24)	0.74 (0.73 to 0.88)
Nevada	0.92 (0.90 to 1.14)	0.14 (0.05 to 1.25)
New Hampshire	1.33 (1.31 to 1.58)	2.54 (2.53 to 2.64)
New Jersey	1.38 (1.35 to 1.75)	0.69 (0.66 to 1.13)
New Mexico	1.59 (1.56 to 1.93)	0.37 (0.32 to 1.25)
New York	1.30 (1.29 to 1.47)	0.84 (0.81 to 1.15)
North Carolina	1.63 (1.62 to 1.94)	1.45 (1.43 to 1.67)
North Dakota	0.90 (0.89 to 1.06)	1.49 (1.48 to 1.61)
Ohio	1.67 (1.65 to1.90)	1.24 (1.23 to 1.37)
Oklahoma	1.51 (1.48 to 1.77)	0.33 (0.28 to 0.82)
Oregon	1.54 (1.52 to 1.82)	1.28 (1.26 to 1.42)
Pennsylvania	1.56 (1.54 to 1.83)	1.48 (1.46 to 1.61)
Rhode Island	0.87 (0.86 to 1.02)	1.20 (1.19 to 1.35)
South Carolina	1.83 (1.81 to 2.08)	1.01 (0.99 to 1.34)
South Dakota	1.34 (1.32 to 1.63)	1.88 (1.87 to 2.04)
Tennessee	1.40 (1.39 to 1.67)	0.84 (0.82 to 1.04)
Texas	1.63 (1.59 to 2.03)	0.39 (0.34 to 1.02)
Utah	7.59 (7.44 to 9.46)	0.62 (0.47 to 2.43)
Vermont	1.41 (1.39 to 1.62)	2.89 (2.89 to 2.94)
Virginia	1.65 (1.63 to 1.90)	1.20 (1.19 to 1.35)
Washington	1.90 (1.88 to 2.13)	0.92 (0.90 to 1.09)
West Virginia	1.53 (1.50 to 1.76)	0.60 (0.56 to 1.08)
Wisconsin	1.77 (1.75 to 2.11)	1.85 (1.84 to 1.97)
Wyoming	1.44 (1.40 to 1.70)	0.24 (0.17 to 1.07)
TOTAL	1.52 (1.51 to 1.62)	1.00 (Reference)

[a]Lung cancer screening with low-dose computed tomography in the past year. CI = confidence interval; LCS = lung cancer screening; SRR = screening rate ratio.
[b]SRRs compare state-specific screening rates in 2018 vs 2016.
[c]SRRs compare 2018 state-specific screening rates vs 2018 the national average.

lung cancer deaths per 100 000) had the highest SRs (12.8%-15.2%) (Figure 4). The exception was Kentucky, which had the nation's highest lung cancer mortality rate and one of the highest SRs (13.7%).

State-level SRs were positively correlated with screening capacity (facility density $r = 0.44$, $P = .01$) (Table 2; Supplementary Figure 3, available online) and negatively correlated with access (uninsured adults who smoked $r = -0.34$, $P = .01$) (Table 2). States with the lowest tertile of capacity (SRR = 0.60, 95% CI = 0.59 to 0.62) had an SRR statistically significantly lower than the national average as did states with a greater proportion of adults who smoked and were uninsured (Table 3;

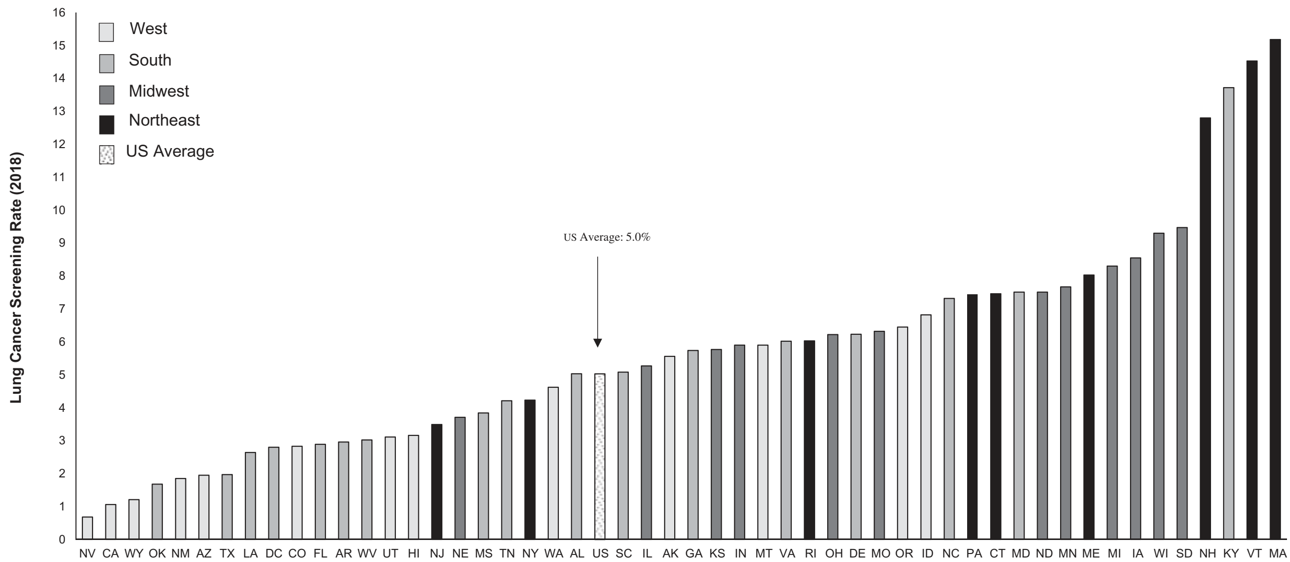

Figure 3. Proportion eligible adults aged 55-80 years screened for lung cancer in the past year with low-dose computed tomography (LDCT) by state, 2018. US preventive services task force eligible adults were current or former cigarette smokers who quit within the past 15 years with a 30 or more pack-year smoking history and aged 55-80 years.

Table 2. Correlation and associations between states' lung cancer screening rates and lung cancer burden, screening capacity, access, sociodemographic factors among adults who smoke, and Medicaid expansion status[a]

Measures of lung cancer burden, screening capacity, access, and sociodemographic factors	Pearson correlation coefficient	*P*
Lung cancer burden (lung cancer mortality/100 000 adults 55-79y)[b]	0.25	.08
Screening capacity (facility density per 1000 smokers)[c]	0.44	.01
Access (% among adult smokers without insurance)	−0.34	.01
Sociodemographic factors (% among adult smokers)[d]		
Formerly smoked	0.24	.09
Hispanic	−0.47	.01
Black	−0.21	.15
Female	0.29	.04
High school or less	0.13	.36
Mean age of smokers	0.02	.88
Medicaid expansion status, mean LDCT rate (SD)		
Expanded Medicaid[e]	6.0 (3.8)	.35[f]
Did not expand Medicaid	5.1 (2.4)	—

[a]The unit of analysis is state. Lung cancer screening rates were computed by state and among the population estimated to be eligible for US Preventive Services recommended screening. This included current or former cigarette smokers who quit within the past 15 years with 30 and more pack-year smoking history and aged 55-80 years. BRFSS = Behavioral Risk Factor Surveillance System; LDCT = low-dose computed tomography.

[b]Computed per 100 000 among adults aged 55-79 years using 2013-2017 National Center for Health Statistics mortality data. Mortality data were not available for single-age year groupings.

[c]Computed by dividing the number of lung cancer screening registry facilities by the number of eligible adults in each state. Displayed per 1000 eligible.

[d]Proportion of adults who smoked and had the sociodemographic factor; computed with 2018 BRFSS data.

[e]As of January 1, 2018, includes: Alaska, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, District of Columbia, Hawaii, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, and West Virginia.

[f]*P* value was computed with a 2-sample *t* tests.

Supplementary Table 4, available online). When states were grouped according to Medicaid expansion status, SRs were similar in expansion (6.0%) and nonexpansion (5.1%, $P = .35$) states (Table 2). According to sociodemographic factors, SRs were positively correlated with the proportion of smokers who were female ($r = 0.29$, $P = .04$) and negatively correlated with smokers who were Hispanic ($r = -0.46$, $P = .01$) (Table 2). States with the highest tertile of adults who smoked and were Hispanics had a statistically significantly lower SRR than the national average (SRR = 0.68, 95% CI = 0.68 to 0.70) (Table 3).

Discussion

In this population-based study, although national lung cancer SRs rose between years 2016 and 2018, the rate still was still low in 2018, with only 5%-6% eligible adults in the United States receiving lung cancer LDCT screening. We recognize this may be an underestimate, because some patients undergoing lung cancer LDCT screening are not covered in this estimate, including patients at DOD facilities. Lung cancer SRs varied geographically in 2 important ways, with higher rates in several Northeastern

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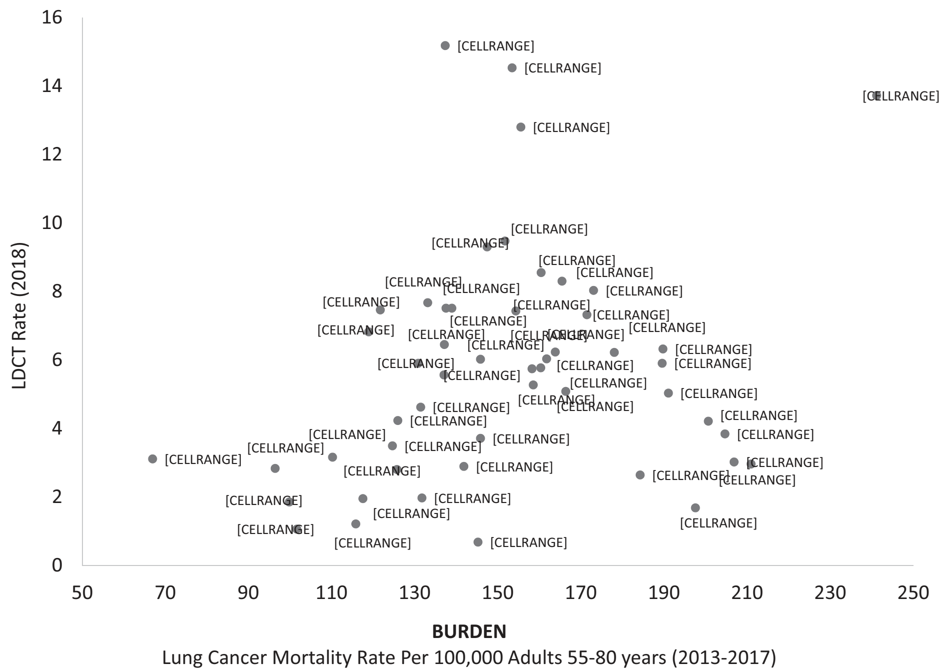

Figure 4. Lung cancer mortality (2013-2017) vs proportion of eligible adults aged 55-80 years screened for lung cancer in the past year with low-dose computed tomography (LDCT) by state, 2018. US preventive services task force eligible adults were current or former cigarette smokers who quit within the past 15 years with a 30 and more pack-year smoking history and aged 55-80 years. Lung cancer mortality was derived from National Program of Cancer Registries data.

Table 3. Lung cancer SRRs vs national average according to states' screening capacity, access, and the proportion of smokers who were Hispanic and female

State screening capacity, access, and characteristics of eligible adults	SRR (95% CI)
Screening capacity (facility density/1000 smokers)[b]	
Low (<33.2)	0.60 (0.59 to 0.62)
Medium (33.2-50.2)	1.21 (1.20 to 1.22)
High (≥50.2)	1.46 (1.45 to 1.47)
Screening access (% uninsured smokers)[c]	
Low (<4.2)	1.59 (1.59 to 1.60)
Medium (4.2-5.5)	0.84 (0.84 to 0.85)
High (≥5.5)	0.81 (0.81 to 0.83)
Characteristics of eligible adults	
Hispanic[c], %	
Low (<1.4)	1.39 (1.39 to 1.40)
Medium (1.4-3.7)	1.20 (1.20 to 1.21)
High (≥3.7)	0.68 (0.68 to 0.70)
Female[c], %	
Low (<45.9)	0.77 (0.76 to 0.79)
Medium (45.9-47.2)	0.95 (0.94 to 0.96)
High (≥47.2)	1.29 (1.28 to 1.30)

[a]Compared with the national average. CI = confidence interval; SRR = screening rate ratio.
[b]Computed by dividing the number of lung cancer screening registry facilities by the number of eligible adults in each state.
[c]States' proportions of adults who smoked and were uninsured, Hispanic, and female were computed with 2018 BRFSS data.

states that have lower lung cancer burden and lower rates in several Southern states that have high lung cancer burden. The one exception to this pattern was Kentucky, which simultaneously holds the nation's highest lung cancer death rates and one of the highest lung cancer SRs.

The increasing but low utilization of LCS reflects both ongoing efforts to screen eligible adults and the many challenges to do so. Medicare and most commercial insurers began covering LCS in 2015, likely contributing to increased utilization because reimbursement and cost are frequently cited barriers among providers and patients (18-21). We did not observe measurable increases until 2018, possibly due to the lag between insurance coverage and scaling up LCS in health systems. Recent studies report large relative increases in the use of LCS LDCT billing codes beginning in 2016 among commercially insured and Medicare beneficiaries, but absolute levels remain generally low (22-24). Moreover, a substantial proportion of eligible adults aged 55-64 years is uninsured or insured with Medicaid (13). We observed lower SRs among states with a greater proportion of adults who were uninsured and smoked, though there was no statistically significant difference in states that expanded Medicaid compared with nonexpansion states. Even with Medicaid coverage, reimbursement can be low, disincentivizing providers from offering screening to this vulnerable yet commonly eligible community (25). Without addressing critical gaps in health insurance and adequate reimbursement for LCS, its use will likely remain stunted.

Several health systems have launched pilot or demonstration LCS programs, which may also contribute to increasing rates (26-31). However, these programs have not yet scaled up, and most eligible adults will rely on nonorganized or opportunistic screening through primary care and community settings with multiple barriers (18,32-34). First, clinics may not collect sufficiently detailed smoking histories to identify eligible adults. Second, individuals who currently smoke are known to have less contact with primary care providers (PCPs) (35). Third, PCPs may not recommend screening because of competing priorities, preauthorization requirements, challenges in implementing shared decision making, and LCS may be viewed as less beneficial than other cancer screenings (18,19,33).

Even with a physician recommendation, LCS may be particularly hard to increase because of individual-level barriers, such as competing health and financial demands as well as unique values and beliefs among adults who smoke (9,21,35,36). Within the VA demonstration project with patient coordinators, only 58% of eligible patients who were offered screening accepted it, and in one large integrated system, about one-quarter of patients did not attend scheduled screening appointments (26,29). Patients in a community setting indicated that a deciding factor to accept screening is believing it will improve outcomes (21), and individuals who currently smoke expressed lack of confidence in the effectiveness of LCS and willingness to receive surgery for screen-detected cancer (20). Beliefs about screening may also vary by sociodemographic factors (21). Women may be more likely to benefit from screening and adhere to LCS guidelines (37). This is in line with studies of other health behaviors and our finding of higher SRs in states with a higher proportion of adults who smoke and are female (38). Other barriers, including knowledge avoidance, stigma, false positive worry (39), and logistical barriers such as lack of sick leave, may be prominent among blue-collar workers who have higher smoking rates (40). Resonating messages and educational tools along with adapting the screening process to meet patients' needs, schedules, and values are needed to improve rates.

Kentucky is a striking outlier, having both the nation's highest lung cancer mortality and SRs over twice the national average and 4 times that of other high-lung cancer burden states such as West Virginia and Arkansas. Notably, Kentucky expanded Medicaid and does not require preauthorization, a noted barrier among physicians (19). Moreover, Kentucky had support from its state government, the governor made a commitment to reduce lung cancer mortality (41), and there were state-wide, proactive, community-engaged efforts to support the availability and uptake of quality LCS (42,43). In 2013, the Kentucky Cancer Consortium engaged clinicians and communities to address the benefits and challenges of LCS. The Kentucky Lung Cancer Education Awareness Detection Survivorship Collaborative was formed in 2014 with 2 LCS implementation projects. The first educated and motivated hundreds of PCPs on lung cancer prevention, early detection, treatment, and survivorship. The second project gave feedback to LCS programs on how to optimally deliver screening and engage providers. Kentucky's community-engaged efforts provide a framework for other states with a considerable lung cancer burden.

Several Southern states with a high lung cancer burden had LCS rates that were less than one-half of Northeastern and upper Midwest states with relatively low lung cancer burden. Numerous studies have documented historically higher lung cancer mortality rates in Southern, Appalachian, and some Midwestern states, which have weaker tobacco control policies, a greater proportion of lower-socioeconomic status individuals, racial or ethnic minorities, and lower smoking cessation rates (44). These geographic patterns are consistent with what is observed for other cancer screening tests and studies of regional lung cancer SRs, highlighting a broader need to improve access to care (23,24,45,46).

Previous studies also show a misalignment between lung cancer burden and access to screening facilities, with clusters of states with high burden, low number of overall facilities, and the slowest growth in LCSR registration (47). We observed that states with higher facility density generally have higher SRs (48), though we were unable to examine access in smaller geographic units, such as the county or census tracts. Measuring overall access of LCS facilities at the state level may overestimate access, because many facilities may be located in urban areas that rural-dwelling eligible adults may have trouble accessing (49).

The USPSTF recently issued draft LCS guidelines expanding the pool of eligible candidates to those aged 50-80 years who currently or formerly smoked and quit 15 or fewer years and smoked with a 20 pack-year history (50). These guidelines may lead to additional life years gained, but only if people are screened. As data become available, studies on the uptake of screening among previously and newly eligible screening candidates will be needed to inform lung cancer control efforts.

Our national LCS estimates are in line with previously published 2015 NHIS estimates (<4%) (8) but lower than a study of 10 states that collected LDCT data in the 2017 BRFSS, where 12.5%-14.4% of eligible adults reported receiving screening CT in the past-year (10,11). Differences in the current study and previously published survey data are expected because we used screening LDCTs recorded in a registry, not self-reports, which is subject to recall bias and individuals may have received LDCT for nonscreening reasons.

The current study has several limitations. First, although the LDCTs were recorded in the registry, the number of eligible adults was based on self-reported smoking status, which has fair agreement with urine cotinine levels (51). The LCR used self-reported smoking data to identify USPSTF eligibility. Although it is possible that patients may overstate their smoking history to qualify for screening, the extent to which this might occur is unknown and the accuracy of smoking status in an LCS trial was consistent with cotinine levels (51). Second, we assumed a uniform probability that a person was eligible for LCS given that they smoked cigarettes, recognizing that smoking duration and intensity may vary by state and our NHIS estimate could be limited by small sample sizes. When our method was compared with BRFSS data from 14 states, similar proportions of adults were eligible for LCS (Supplementary Table 5, available online). Further, the national number eligible in our study approximates those of previous studies (52). Third, the number of eligible adults did not correct for individuals with limited life expectancy. Based on VA demonstration data, at least 6% of adults were not considered medically eligible for a baseline scan due to comorbidities (29). However, people with limited life expectancy may receive LCS given that screening for other cancers (eg, prostate, breast) frequently occurs in those with limited life expectancy even though its similarly is not recommended (53). Lastly, some facilities, including those in the VA or DOD, have no reporting requirement to use the LCSR. Removing the estimated number of VA patients eligible for LCS from our denominator modestly affected national SRs (Supplementary Table 2, available online). Despite these limitations, our study has many strengths. It provides the first, to our knowledge, population-based, state-level screening data for all 50 states as well as a framework to do so because current state-based survey tools (ie, BRFSS) do not ask questions on LDCT in all states. These data are needed to inform state-level policy and lung cancer implementation efforts.

In conclusion, lung cancer SRs are increasing, albeit slowly, with wide variation by state. In 2018, approximately 5%-6% eligible individuals received LCS nationally. An even lower proportion of eligible adults were screened in states with a high lung cancer burden, except for Kentucky, proving what is feasible with commitment and extensive community-engaged efforts.

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Deliberate effort from various stakeholders such as policy makers, cancer control, health systems, and providers is needed to boost lung cancer SRs among eligible adults with a heavy smoking history, a group facing multiple barriers to LCS and cancer care.

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Data Availability

The data underlying this article are available from the Centers for Disease Control and Prevention, Lung Cancer Screening Registry, and the US Census Bureau. The datasets were derived from sources in the public domain: National Health Interview Survey (https://www.cdc.gov/nchs/nhis/index.htm); Behavioral Risk Factor Surveillance System (https://www.cdc.gov/brfss/index.html); US Census Bureau (https://data.census.gov/cedsci/table? q=United%20Statesandtable=DP05andtid=ACSDP1Y2017.DP05andg=0100000USandlastDisplayedRow=29and vintage=2017andlayer=stateandcid=DP05_0001E); National Center for Health Statistics accessed through SEER*Stat (https://seer.cancer.gov/mortality/); American College of Radiology's Lung Cancer Screening Registry Reports (https://nrdrsupport.acr.org/support/solutions/articles/11000039783-lcsr-available-reports).

References

1. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2020. *CA Cancer J Clin*. 2020;70(1):7-30.
2. Islami F, Goding Sauer A, Miller KD, et al. Proportion and number of cancer cases and deaths attributable to potentially modifiable risk factors in the United States. *CA Cancer J Clin*. 2018;68(1):31-54.
3. Aberle DR, Adams AM, Berg CD, et al.; National Lung Screening Trial Research Team. Reduced lung-cancer mortality with low-dose computed tomographic screening. *N Engl J Med*. 2011;365(5):395-409.
4. Moyer VA, et al.; U.S. Preventive Services Task Force. Screening for lung cancer: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med*. 2014;160(5):330-338.
5. Koh HK, Sebelius KG. Promoting prevention through the Affordable Care Act. *N Engl J Med*. 2010;363(14):1296-1299.
6. Centers for Medicare and Medicaid Services. Decision memo for screening for lung cancer with low dose computed tomography (LDCT) (CAG-00439N). https://www.cms.gov/medicare-coverage-database/details/nca-decision-memo.aspx? NCAId=274. Accessed March 4, 2020.
7. Ma J, Ward EM, Smith R, et al. Annual number of lung cancer deaths potentially avertable by screening in the United States. *Cancer*. 2013;119(7):1381-1385.
8. Jemal A, Fedewa SA. Lung cancer screening with low-dose computed tomography in the United States-2010 to 2015. *JAMA Oncol*. 2017;3(9):1278-1281.
9. Carter-Harris L, Gould MK. Multilevel barriers to the successful implementation of lung cancer screening: why does it have to be so hard? *Annals Ats*. 2017;14(8):1261-1265.
10. Richards TB, Soman A, Thomas CC, et al. Screening for lung cancer - 10 states, 2017. *MMWR Morb Mortal Wkly Rep*. 2020;69(8):201-206.
11. Zahnd WE, Eberth JM. Lung cancer screening utilization: a behavioral risk factor surveillance system analysis. *Am J Prev Med*. 2019;57(2):250-255.
12. Centers for Disease Control and Prevention. Behavioral risk factor surveillance. https://www.cdc.gov/brfss/index.html. Accessed January 18, 2020.
13. Centers for Disease Control and Prevention NCHS. 2015 National Health Interview Survey. https://www.cdc.gov/nchs/nhis/data-questionnaires-documentation.htm. Accessed January 20, 2020.
14. American College of Radiology. LCSR available reports. https://nrdrsupport.acr.org/support/solutions/articles/11000039783-lcsr-available-reports?_ga=2.201388568.823086855.1583799862-1358519942.1578412757. Accessed December 1, 2020.
15. Lewis JS, Denton J, Edwards GC, et al. National Lung Cancer Screening Utilization Trends in the Veterans Health Administration. *JNCI Spectrum*. 2020. In press.
16. Goding Sauer A, Siegel RL, Jemal A, et al. Current prevalence of major cancer risk factors and screening test use in the United States: disparities by education and race/ethnicity. *Cancer Epidemiol Biomarkers Prev*. 2019;28(4):629-642.
17. Surveillance, Epidemiology, and End Results (SEER) Program (www.seer.cancer.gov) SEERStat Database: Mortality - All COD, Aggregated With State, Total U.S. (1969-2017) <Katrina/Rita Population Adjustment>, National Cancer Institute, DCCPS, Surveillance Research Program, released December 2019. Underlying mortality data provided by NCHS. www.cdc.gov/nchs. 2019. Accessed January 20, 2020.
18. Eberth JM, McDonnell KK, Sercy E, et al. A national survey of primary care physicians: perceptions and practices of low-dose CT lung cancer screening. *Prev Med Rep*. 2018; 22(11):93-99.
19. Zeliadt SB, Hoffman RM, Birkby G, et al. Challenges implementing lung cancer screening in federally qualified health centers. *Am J Prev Med*. 2018;54(4):568-575.
20. Silvestri GA, Nietert PJ, Zoller J, et al. Attitudes towards screening for lung cancer among smokers and their non-smoking counterparts. *Thorax*. 2007;62(2):126-130.
21. Byrne MM, Lillie SE, Studts JL. Lung cancer screening in a community setting: characteristics, motivations, and attitudes of individuals being screened. *Health Psychol Open*. 2019;6(1):2055102918819163.
22. Nishi S, Zhou J, Kuo YF, et al. Use of lung cancer screening with low-dose computed tomography in the Medicare population. *Mayo Clin Proc Innov Qual Outcomes*. 2019;3(1):70-77.
23. Okereke IC, Nishi S, Zhou J, et al. Trends in lung cancer screening in the United States, 2016-2017. *J Thorac Dis*. 2019;11(3):873-881.
24. Liu B, Dharmarajan K, Henschke CI, et al. State-level variations in the utilization of lung cancer screening among Medicare fee-for-service beneficiaries: an analysis of the 2015 to 2017 physician and other supplier data. *Chest*. 2020;157(4):1012-1020.
25. American Lung Association. Lung cancer screening: coverage in health insurance plans. https://www.lung.org/assets/documents/lung-health/lung-cancer-screening-implementation.pdf. Accessed March 4, 2020.
26. Wernli KJ, Gao H, Leblanc J, Nazarko J, Buist D. Lung cancer screening implementation in community practice: Kaiser Permanente Washington experience 2015-2018. *J Thorac Oncol*. 2018;13(10):S788- S1042.
27. Gesthalter YB, Koppelman E, Bolton R, et al. Evaluations of implementation at early-adopting lung cancer screening programs: lessons learned. *Chest*. 2017;152(1):70-80.
28. Gould MK, Sakoda LC, Ritzwoller DP, et al. Monitoring lung cancer screening use and outcomes at four cancer research network sites. *Ann Am Thorac Soc*. 2017;14(12):1827-1835.
29. Kinsinger LS, Anderson C, Kim J, et al. Implementation of lung cancer screening in the Veterans Health Administration. *JAMA Intern Med*. 2017;177(3):399-406.
30. McKee BJ, McKee AB, Flacke S, et al. Initial experience with a free, high-volume, low-dose CT lung cancer screening program. *J Am Coll Radiol*. 2013;10(8):586-592.

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31. Thomson CC, McKee AB. American Thoracic Society/American Lung Association lung cancer screening implementation guide. *Am J Respir Crit Care Med*. 2018;198(9):1120-1121.
32. Ersek JL, Eberth JM, McDonnell KK, et al. Knowledge of, attitudes toward, and use of low-dose computed tomography for lung cancer screening among family physicians. *Cancer*. 2016;122(15):2324-2331.
33. Klabunde CN, Marcus PM, Han PK, et al. Lung cancer screening practices of primary care physicians: results from a national survey. *Ann Fam Med*. 2012;10(2):102-110.
34. Klabunde CN, Marcus PM, Silvestri GA, et al. U.S. primary care physicians' lung cancer screening beliefs and recommendations. *Am J Prev Med*. 2010;39(5):411-420.
35. Miller EA, Pinsky PF. Healthcare access, utilization, and preventive health behaviors by eligibility for lung cancer screening. *J Cancer Educ*. 2019;10.1007/s13187-019-01634-y.
36. Taplin SH, Anhang Price R, Edwards HM, et al. Introduction: understanding and influencing multilevel factors across the cancer care continuum. *J Natl Cancer Inst Monogr*. 2012;2012(44):2-10.
37. Pinsky PF, Church TR, Izmirlian G, et al. The National Lung Screening Trial: results stratified by demographics, smoking history, and lung cancer histology. *Cancer*. 2013;119(22):3976-3983.
38. Hiller J, Schatz K, Drexler H. Gender influence on health and risk behavior in primary prevention: a systematic review. *J Public Health*. 2017;25(4):339-349.
39. Carter-Harris L, Brandzel S, Wernli KJ, Roth JA, Buist DSM. A qualitative study exploring why individuals opt out of lung cancer screening. *Fam Pract*. 2017;34(2):239-244.
40. Fedewa SA, Sauer AG, DeSantis C, Siegel RL, Jemal A. Disparities in cancer screening by occupational characteristics. *Prev Med*. 2017;105:311-318.
41. Kentucky University. Kentucky LEADS Collaborative. https://ukmarkey.org/ky-leads-collaborative-led-by-uk-u-of-l/. Accessed January 20, 2020.
42. LEADS. Kentucky LEADS: implementing quality of lung cancer screening. www.kentuckyleads.org. Accessed January 20, 2020.
43. Cardarelli R, Roper KL, Cardarelli K, et al. Identifying community perspectives for a lung cancer screening awareness campaign in Appalachia Kentucky: The Terminate Lung Cancer (TLC) Study. *J Cancer Educ*. 2017;32(1):125-134.
44. Levy DT, Romano E, Mumford E. The relationship of smoking cessation to sociodemographic characteristics, smoking intensity, and tobacco control policies. *Nicotine Tob Res*. 2005;7(3):387-396.
45. Bryan L, Westmaas L, Alcaraz K, et al. Cigarette smoking and cancer screening underutilization by state: BRFSS 2010. *Nicotine Tob Res*. 2014;16(9):1183-1189.
46. Odahowski CL, Zahnd WE, Eberth JM. Challenges and opportunities for lung cancer screening in rural America. *J Am Coll Radiol*. 2019;16(4):590-595.
47. Kale MS, Wisnivesky J, Taioli E, et al. The landscape of US lung cancer screening services. *Chest*. 2019;155(5):900-907.
48. Ross K, Kramer MR, Jemal A. Geographic inequalities in progress against lung cancer among women in the United States, 1990-2015. *Cancer Epidemiol Biomarkers Prev*. 2018;27(11):1261-1264.
49. Martin AN, Hassinger TE, Kozower BD, et al. Disparities in lung cancer screening availability: lessons from southwest Virginia. *Ann Thorac Surg*. 2019;108(2):412-416.
50. US Preventive Services Task Force. Lung cancer: screening. https://www.uspreventiveservicestaskforce.org/uspstf/draft-update-summary/lung-cancer-screening-2020. Accessed August 1, 2020.
51. Studts JL, Ghate SR, Gill JL, et al. Validity of self-reported smoking status among participants in a lung cancer screening trial. *Cancer Epidemiol Biomarkers Prev*. 2006;15(10):1825-1828.
52. Cheung LC, Katki HA, Chaturvedi AK, et al. Preventing lung cancer mortality by computed tomography screening: the effect of risk-based versus U.S. Preventive Services Task Force eligibility criteria, 2005-2015. *Ann Intern Med*. 2018;168(3):229-232.
53. Royce TJ, Hendrix LH, Stokes WA, et al. Cancer screening rates in individuals with different life expectancies. *JAMA Intern Med*. 2014;174(10):1558-1565.