Using Geospatial Analysis to Evaluate Access to Lung Cancer Screening in the United States

Liora Sahar, PhD; Vanhvilai L. Douangchai Wills, MSc; Ka Kit Liu, BSc; Ella A. Kazerooni, MD; Debra S. Dyer, MD; and Robert A. Smith, PhD

BACKGROUND: Screening current and former heavy smokers 55 to 80 years of age for lung cancer (LC) with low-dose chest CT scanning has been recommended by the United States Preventive Services Task Force since 2013. Although the number of screening facilities in the United States has increased, screening uptake has been slow.

RESEARCH QUESTION: To what extent is geographic access to screening facilities a barrier for screening uptake nationally?

STUDY DESIGN AND METHODS: Screening facilities were defined as American College of Radiology (ACR) Lung Cancer Screening Registry (LCSR) facilities. Analysis was performed at different geographic levels using a road network to calculate travel distances for the recommended age groups. Full access to screening was defined as the entire 55- to 79-year-old population being within 40 miles of an ACR LCSR facility. No access was defined as lack of access by the entire target population. Partial access was expressed in intervening quartiles. A geospatial approach then was used to integrate accessibility with smoking prevalence and LC mortality rates to identify potential focus areas visually.

RESULTS: Screening facilities addresses were geocoded to identify 3,592 unique locations. Analysis of census tracts and aggregation to counties revealed that among 3,142 counties, adults 55 to 79 years of age have full access to an LC screening registry facility in 1,988 (63%) counties, partial access in 587 (19%) counties, and no access in 567 (18%) counties. Overall, less than 6% of those 55 to 79 years of age do not have access to registry screening facilities. Variation in screening facility access was noted across the United States, between states, and within some states.

INTERPRETATION: It is recommended to calculate accessibility using subcounty geographies and to examine variation regionally and within states. A foundation geographic accessibility layer can be integrated with other variables to identify geographic disparities in access to screening and to focus on areas for interventions. Identifying areas of greatest need can inform state and local officials and healthcare organizations when planning and implementing LC screening programs.

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ABBREVIATIONS: ACR = American College of Radiology; CDC = Centers for Disease Control and Prevention; CMS = Centers for Medicare and Medicaid Services; FF = from facilities; FIPS = Federal Information Processing System; FP = from population; LC = lung cancer; LCS = lung cancer screening; LCSC = Lung Cancer Screening Center; LCSR = lung cancer screening registry; LDCT = low-dose CT; USPSTF = United States Preventive Services Task Force

AFFILIATIONS: From the American Cancer Society (Drs Sahar and Smith, Ms Douangchai Wills, and Mr Liu), Atlanta, GA;
Lung cancer (LC) has been the leading cause of cancer deaths in the United States, contributing to more deaths in 2017 than breast, prostate, colorectal, and brain cancers combined.\(^1\) The poor 5-year survival rate (19%) is attributable to the high proportion of advanced-stage diagnoses.\(^2\) A more favorable stage distribution and reduction in mortality could be achieved if more high-risk adults underwent regular lung cancer screening (LCS).

After the results of the National Lung Screening Trial were published in 2011, demonstrating a 20% relative reduction in mortality using annual low-dose CT (LDCT) screening compared with chest radiograph,\(^3\) professional organizations issued guidelines recommending LCS. In 2013, the United States Preventive Services Task Force (USPSTF) recommended LDCT screening in “adults aged 55 to 80 years who have a 30 pack-year smoking history and currently smoke or have quit within the past 15 years.”\(^4\) The recommendations paved the way for insurance coverage under the Affordable Care Act through private payors and subsequent coverage for Medicare beneficiaries in 2015.\(^5\) The Centers for Medicare and Medicaid Services (CMS) made reimbursement contingent on facilities meeting eligibility requirements, including screening data submission to a CMS-approved LCS registry.\(^6\) Currently, the only CMS-approved registry is the American College of Radiology (ACR) Lung Cancer Screening Registry (LCSR).\(^6\)

Despite recommendations for screening by the USPSTF,\(^7\) American Cancer Society,\(^8\) National Comprehensive Cancer Network,\(^9\) and other organizations,\(^10\) LCS uptake remains low. A recent report estimated that in 2015, approximately 4% of the estimated 6.8 million eligible adults underwent an LDCT scan,\(^11\) and a state-level survey conducted in 2015 also reported low uptake of LCS examinations in ACR screening facilities.\(^12\) Data from 10 states representing 17.2% of the US population in the Behavioral Risk Factor Surveillance Survey, completing an optional module in 2017, indicated that 14.4% of eligible individuals reported undergoing LCS within the past year.\(^13\)

The implementation and adoption of new cancer screening tests typically is slow, evident by the adoption of mammography,\(^14\) and we expect an even more challenging implementation of LDCT screening programs. Compared with other tests, LCS requires a complex assessment of risk to determine eligibility, and although LCS is covered at no cost under the Affordable Care Act, many eligible adults face significant financial and insurance barriers,\(^11\) and evident variation exists in affordability, access to care, and the rate of uninsured patients associated with Medicaid expansion.\(^15\)

Additional unique requirements for reimbursement by CMS include a shared decision-making visit before a first screening.\(^5\) The stigma and nihilism surrounding LC and smoking have been identified as barriers to seeking preventive care.\(^16\) Finally, geographic access, smoking prevalence, and the burden of disease vary in urban and rural areas and should be considered when planning and implementing screening programs.\(^17,18\)

Previous studies reported state-level access to LCS facilities, showing favorable correlations with facility numbers and eligible individuals, but also reported disparities in access in rural areas.\(^19,20\) Recently, Siegel et al\(^21\) demonstrated that although racial gaps in

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**Take-home Point**

Although variation exists in the geographic distribution of screening facilities and disparities in access between states, the greater majority of the population 55 to 79 years of age has access (within 40 miles) to lung cancer screening (LCS). Although the rate of LCS seems to be increasing, current use is low. Geographic access should be evaluated in conjunction with other barriers, such as financial, cultural, educational, insurance coverage, and local transportation, to be able to tailor interventions to communities.

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The Division of Cardiothoracic Radiology, Department of Radiology, and Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine (Dr Kazerooni), University of Michigan Medical School, Ann Arbor, MI; and the Department of Radiology (Dr Dyer), National Jewish Health, Denver, CO.

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**CORRESPONDENCE TO:** Liora Sahar, PhD, American Cancer Society, 250 Williams St NW, Atlanta, GA 30303; e-mail: liora.sahar@cancer.org

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cancer mortality rates are narrowing, a growing disproportionate burden of preventable cancers exists among residents of the poorest counties. Because state-level data may obscure significant disparities in smaller geographies, we evaluated and reported accessibility at the state and the county levels, which is important for informing policy and public health planning.

Methods

A geospatial approach was used to assess accessibility to LCS facilities by calculating distances between population centers and facilities. Prior studies used geographic information systems to evaluate availability and proximity of facilities to so-called potential patients, to identify gaps in services, to allocate resources, and to inform decisions and policies.19,22,23 Spatial analysis was carried out using ArcGIS 10.6.1 software. Maps were evaluated for common vision impairments using Color Oracle (https://colororacle.org/).

Materials and Data Sources

LC Screening Facilities: Screening facilities used are those enrolled in the ACR’s LCSR, some of which have additional designation as ACR Lung Cancer Screening Centers (LCSCs), a part of the ACR’s CT screening accreditation program.21 Although we also map and identify ACR LCSC locations, the results focus primarily on ACR LCSR facilities that better represent access to screening. An ACR LCSC facilities list was provided by the ACR (April 2018), and an ACR LCSC subset was downloaded from the ACR website.22

Population Data: County and census tract population were downloaded from the US Census.31 The 2012 through 2016 estimates for age groups from 55 to 79 years were used to represent the eligible LC death rates (per 100,000 population) for those 50 years of age and older smoking by county was retrieved from the US Census population data and 2016 Behavioral Risk Factor Surveillance Survey adult smoking prevalence data were used to estimate the at-risk population. The percentage of adults 18 years of age and older smoking by county was retrieved from the 2016 County Health Rankings & Roadmaps program website.29,30 Adult smoking is “the percentage of the adult population in a county who both report that they currently smoke every day or most days and have smoked at least 100 cigarettes in their lifetime.”31 The USPSTF’s definition of smokers eligible for screening is different, but this dataset allows us to address smoking prevalence as a proxy for locations with adults who qualify for LCS under the guidelines.

LC Mortality Rates: The 2011 through 2015 county-level age-adjusted LC mortality rates. First, areas with high smoking prevalence and low access to screening were identified using accessibility as a foundation layer. Although percentages of the population commonly are used to inform decision makers, population size often is necessary to identify
focus areas for implementing programs. In the United States, the percentage of current smokers has declined more than the number of current smokers because of population growth. Hence, smoking prevalence was used to estimate the number of smokers. Next, access of estimated smokers is integrated with mortality rates. Maps are provided to identify areas of low accessibility, high smoking prevalence, and high mortality rates. The maps show categories based on quartile calculations of the variables. Categories are ranked from low (category 1, <25th percentile) to high (category 4, >75th percentile) and are depicted with a progression of colors in the map. Bivariate choropleth maps show $4 \times 4$ combinations of the variables, allowing the user to identify areas of focus.

**Results**

**Access to Facilities Nationwide**

Based on the geocoding results, we compiled a list of 3,592 unique ACR LCSR and 1,739 ACR LCSC locations. (Fig 2) Figure 2 shows a higher density of LCS facilities in the Eastern United States and better coverage of ACR LCSRs compared with ACR LCSCs across the country. Nationwide accessibility to ACR LCSR facilities was calculated as the percentage of the population 55 to 79
years of age who have access and sought treatment the county and state levels. We calculated accessibility at the county and census-tract levels and compared the results. Comparing county results with census tract results yielded about an 8% difference in accessibility nationwide for ACR LCSR facilities using the FF method and a difference of less than 2% using the FP method. For both methodologies, county-level analysis tended to overestimate the number of people not served, meaning fewer people were within 40 miles from facilities, compared with census-tract-level analysis. Census-tract analyses provide more consistent results using both methodologies (< 1% difference) compared with counties (< 7% difference). Henceforth (unless noted), maps, analysis, and focus areas are based on the results of the FP methodology at the census-tract level, then aggregated and reported by counties. The results of the FF methodology along with the FP result at the county level are provided in e-Figure 1.

A brief comparison of county and census-tract results is provided, and additional statistics can be found in e-Table 1. Seventy-four percent of counties and 94% of census tracts have access to ACR LCSR facilities, attributable to densely populated counties with more census tracts in urban areas with access. The mean calculated travel distances to all facilities and to the closest facility is higher when calculating at the county level (26.7 and 17.8 miles, respectively) compared with census tracts (21.8 and 7.8 miles, respectively) and is consistent for weighted distances: 24.2 and 10.9 miles, respectively, for counties and 22.3 and 8.4 miles, respectively, for census tracts. Geographies with a small number of people with access are considered in nonweighted results, whereas their impact is greatly reduced when using population with access as weights. When aggregating census tracts to counties, the weighted distances tend to be closer to the weighted results as calculated at the census-tract level, whereas unweighted results are closer to the county-level calculation. For example, unweighted mean travel distance to all facilities is 26.2 miles (26.7 miles for county) and 22.3 miles weighted (22.3 miles for census tract). Mean travel time, time to the closest facility, and the number of facilities within 40 miles present similar trends. Travel time may pose a challenge for transportation planning because it can vary dramatically for the same distance because of terrain, infrastructure, time of day, and other factors. We evaluated access across urban and rural geographies and plan to provide a comprehensive report about the differences that indicate patterns of disparity in access across rural geographies in a future report.

Figure 3 illustrates variations in access between states and within some states. In Figure 3A, orange states and counties represent full access and white areas represent no access. Quartiles were calculated for partial access after excluding full and no access. A similar trend of greater access in the East is observed at county and state levels, consistent with the higher density of screening facilities (Fig 2).

Figure 3B shows a notable difference between states east and west of the Mississippi River. West Virginia, Maine, and Mississippi have lower access to screening compared with other eastern states (Mississippi is in the lowest quartile nationwide), but still have overall high access of more than 80% along with noted variations within the states that need to be evaluated at the county and census-tract levels. Alaska, Montana, North Dakota, Wyoming, and New Mexico have the lowest rates (less than 70%) of access to screening. Within-state variation is apparent in the middle of the country, including the corridor of states from North Dakota to Texas that have multiple counties with full access. Little in-state variation exists in the eastern region of the country, except for Maine, West Virginia, Mississippi, Alabama, and Georgia.

A nationwide summary of accessibility found that 1,988 counties (63%) have full access to ACR LCSR facilities, 587 counties (19%) have partial access, and 567 counties (18%) have no access. Overall, 5.3% of people 55 to 79 years of age do not have access to ACR LCSR screening facilities. That percentage is not adjusted for smoking history and other recommendations for screening eligibility.

Focus Areas

Incorporating Smoking Prevalence: State smoking prevalence varies greatly,35 and individual counties’ smoking rates range from more than 40% (Alaska, South Dakota) to about 7% (Utah, Maryland).31 Figure 4A is a bivariate choropleth map portraying accessibility as the estimated number of people with no access to a screening facility and smoking prevalence (percent). The horizontal axis represents quartiles of the number of people (scale of 1 to 4: 1 = highest access and 4 = lowest access). The vertical axis represents progression in smoking prevalence. Figure 4B consolidates the two datasets into one layer depicting the estimated number of smokers 55 to 79 years of age with no access to ACR LCSR facilities.
Figure 2 – A, B. Lung cancer screening facilities nationwide. A. ACR LCSR facilities. B. ACR LCSC facilities. ACR = American College of Radiology; LCSC = Lung Cancer Screening Center; LCSR = lung cancer screening registry.
Figure 3 – A, B. Access to ACR LCSR facilities nationwide. Percentage of population 55 to 79 years of age with access calculated using census tracts, aggregated to counties and states. Quartiles (Q) were calculated nationwide (excluding full and no access) for counties and states separately. A, County-level access. B, State-level access. Orange indicates full access. White indicates no access. See Figure 2 legend for expansion of abbreviations.
Figure 4 – A, B. County-level estimated number of population 55 to 79 years of age with no access to screening and smoking prevalence nationwide. A, Bivariate choropleth map integrating the number of people with no access to ACR LCSR facilities and smoking prevalence. Horizontal axis indicates quartiles of the number of people with no access to ACR LCSR facilities within counties. Vertical axis indicates quartiles of adult smoking prevalence. The progression of shades from light to dark corresponds with the increase in smoking prevalence and estimated people 55 to 79 years of age with no access. Areas with a high number of people with no access and high prevalence of smokers are dark purple and dark brown. Quartiles were calculated for both variable using all counties. B, Quartiles (excluding full access) of the estimated number of smokers with no access to ACR LCSR facilities within 40 miles. See Figure 2 legend for expansion of abbreviations.
In Figure 4A, category 1-1 represents counties with the highest access and the lowest percentage of adult smokers, and category 4-4 represents counties with the lowest access or no access to facilities and the highest percentage of adult smokers. Counties with no access (Fig 3) and counties with no or low access and high smoking prevalence (Fig 4A) show similar geographic patterns. They appear in eastern states including Maine, Appalachia counties in West Virginia and pockets in Tennessee, southeast Georgia and Alabama, and around the Mississippi Delta. Some pockets appear west of the Mississippi River in Arkansas, Oklahoma, and Missouri and counties in western New Mexico and eastern Arizona. Other counties with low or no access identified in Figure 3 are not identified as focus areas because they show low smoking prevalence and appear mainly in states west of the Mississippi. Figure 4B shows similar trends in the East, especially in Maine, West Virginia, Georgia, Alabama, and the Mississippi Delta. Compared with the rates shown in Figure 4A, new areas appear in Figure 4B, mainly in New Mexico, Arizona, Nevada, and California. Although California and Utah have the lowest state smoking prevalence rates (11.3% and 8.9%, respectively), more counties in California appear as focus areas in Figure 4B because of the relatively large number of smokers with no access. Consideration of using numbers vs rates to identify and prioritize focus areas may be useful, depending on the circumstances.

Incorporating Mortality Rates: Figure 5 integrates mortality into Figure 4B, depicting the estimated number of smokers 55 to 79 years of age with no access to an ACR LCSR facility (horizontal axis) and mortality rates (vertical axis). Category 1-1 represents counties with the highest access and the lowest mortality rates, and category 4-4 represents counties with the lowest access or no access to facilities and the highest mortality rates. Dark blue (category 3-4) and black (category 4-4) areas stand out as areas of high mortality rates and high numbers of estimated smokers with no access to screening. These geographic areas show consistent disparity across the variables and can be considered candidate focus areas for intervention. They include counties in Maine, West Virginia, southeast Georgia, Alabama, Oklahoma, Arkansas, and Missouri, around the Mississippi Delta, and scattered individual counties across the nation. Also, appropriate interventions should be considered for areas with high access and high mortality rates (category 1-4), such as a comprehensive screening program to reduce distant stage diagnosis.

Discussion
This article focuses on evaluating access to screening facilities as a first step toward developing a comprehensive national screening plan. Such a plan would require detailed data, and it is recommended to use subcounty geographies for analysis to avoid masking subcounty variations.18,36

Our analysis found that more than 5% of people 55 to 79 years of age do not have access to an ACR LCSR facility. A distinct pattern exists of higher access in eastern states and greater in-state variation in access in the central and western regions. Pockets of lower access are apparent in some states in the East, and specific interventions should be considered. Sensitivity analysis of accessibility within 20 miles revealed that close to 16% of people 55 to 79 years of age do not have access to ACR LCSR screening facilities. Future analysis across geographies at different distances may provide additional insight.

Focus areas of particular interest are those with higher numbers of estimated smokers who do not have access to screening and areas with high mortality rates (such as categories 4-4, 3-4, 4-3, and 3-3). Some of these geographic areas consistently appear as potential focus areas (Figs 4 and 5), whereas others appear when introducing additional criteria and should be evaluated. Areas with high mortality rates and high numbers of estimated smokers, but with access to screening facilities, pose a potential for specific, targeted intervention. These areas with existing screening infrastructure may benefit from complementary services such as patient navigation, increasing referral rates, and ensuring access for adults without health insurance. Future analysis could integrate additional variables nationwide or in specific areas to focus planning in communities better.

Limitations of Research
Some imaging facilities offering LDCT screening are not included in the ACR LCSR. Department of Veterans Affairs facilities serve more than nine million patients, many of whom are current or former smokers. Some heavily capitated systems offering screenings and facilities that do not see Medicare patients are not required to enter data in the ACR LCSR. Therefore, the number of LCS facilities is somewhat underestimated; hence, access may be underestimated. ACR LCSR facilities still represent most screening centers and the geographic distribution of screening locations.

No publicly available dataset exists of the number of cigarette packs people smoke, a county-level breakdown...
of smoking across age groups, or the number of people who once smoked. Thus, we used estimated population data and county adult smoking prevalence to evaluate the eligible population, which does not include former smokers, but may serve as a reasonable proxy for both current and former smokers. Mortality rates in some counties are suppressed.

The geospatial analysis has inherent limitations associated with representing populations by centroids of population centers, as well as estimating potential routes from those centroids to facilities. We assumed that patients prefer the nearest facility, and all facilities within 40 miles were considered regardless of political boundaries. An earlier study of access to mammography found that most patients used facilities within a few minutes of the closest facility; hence, distance to the closest facility is appropriate for accessibility and utilization studies.39 We also did not address screening capacity and other barriers such as financial, cultural, educational, insurance coverage, and local transportation. Moreover, geographic access does not imply insurance coverage or whether a facility offers low-cost screening to uninsured people.

Conclusions

There is variation in the geographic distribution of screening facilities and clear disparities in access between states. Health authorities should carefully examine accessibility regionally and within states to focus interventions on disparate communities. Access issues are not static, LCSR participation changes, and continued rural hospital closings may influence access in some states.

Although the rate of LCS seems to be increasing,40 the current use is low and interventions focused on specific issues in communities will impact target populations.
with no geographic access to screening minimally. Geographic analysis should be performed routinely to identify gaps in accessibility.

Population density varies across geographies and should be evaluated strategically by decision makers. States may consider deploying mobile units in large geographic areas with scarce population. Areas with lower access to facilities may consider repurposing imaging infrastructure and augmenting health staff strategically with the appropriate navigation and radiology staff to better support underserved communities. Telehealth strategies where imaging is done locally and interpreted remotely, is also a possible strategy.41,42

To successfully increase the low screening rate, it is important to regularly identify disparities in uptake and evaluate rectifiable contributing factors, such as lack of geographic access. Decision makers can visit https://nlcrt.org to use a geospatial tool to explore and identify gaps in access to LCS in their areas.

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Additional information: The e-Figure and e-Table can be found in the Supplemental Materials section of the online article.

References

23. Huang B, Dignam M, Han D, Johnson O. Does distance matter? Distance to mammography facilities and stage at


