Original Article

Geographic access to lung cancer screening among eligible adults living in rural and urban environments in the United States

Liora Sahar, PhD [1]; Vanhvilai L. Douangchai Wills, MSc[1]; Ka Kit (Antonio) Liu, BSc[1]; Stacey A. Fedewa, PhD [2]; Lauren Rosenthal, MPH[3]; Ella A. Kazerooni, MD, MS[4,5]; Debra S. Dyer, MD[6]; and Robert A. Smith, PhD [3]

BACKGROUND: Although recommended lung cancer screening with low-dose computed tomography scanning (LDCT) reduces mortality among high-risk adults, annual screening rates remain low. This study complements a previous nationwide assessment of access to lung cancer screening within 40 miles by evaluating differences in accessibility across rural and urban settings for the population aged 50 to 80 years and a subset eligible population based on the 2021 US Preventive Services Task Force LDCT lung screening recommendations. **METHODS:** Distances from population centers to screening facilities (American College of Radiology Lung Cancer Screening Registry) were calculated, and the number of individuals who had access within graduating distances, including 10, 20, 40, 50, and 100 miles, were estimated. Census tract results were aggregated to counties, and both geographies were classified with rural-urban schemas. **RESULTS:** Approximately 5% of the eligible population did not have access to lung cancer screening facilities within 40 miles; however, different patterns of accessibility were observed at different distances, between regions, and across rural-urban environments. Across all distances and geographies, there was a larger percentage of the population in rural geographies with no access. Although the rural population represented approximately 8% of the eligible population, the larger percentage of the rural population with no access was noteworthy and translated into a larger number of individuals with no access at longer distance thresholds (≥40 miles). **CONCLUSIONS:** Disparities in access should be examined as both percentages of the population and numbers of individuals with no access in order to tailor interventions to communities and increase access. Geospatial analysis at the census tract level is recommended to help to identify optimal focus areas and reach the most people. ***Cancer* 2022;128:1584-1594**. *© 2021 American Cancer Society*.

LAY SUMMARY:
- As annual lung cancer screening rates remain low, this study examines access to lung cancer screening nationwide and across rural and urban settings.
- A geographic information system network analysis of census tract–level populations is used to estimate access at different distances, including 10, 20, 40, 50, and 100 miles, and the results are aggregated to counties.
- Approximately 5% of the eligible population does not have access to screening facilities within 40 miles; however, different patterns of accessibility are observed at different distances, between regions, and across rural-urban environments.
- Across all distances and geographies, there is a larger percentage of the population in rural geographies with no access.

KEYWORDS: access to screening, geographic information system (GIS), lung cancer, rural-urban.

INTRODUCTION

Lung cancer is a leading cause of cancer mortality in the United States[1] and has one of the lowest 5-year survival rates because of the high proportion of late-stage diagnoses.[2] There are also higher lung cancer incidence and mortality rates in rural areas, probably because of higher smoking rates[3] and possibly more limited access to care.

Following the publication of results from the National Lung Screening Trial,[4] the US Preventive Services Task Force (USPSTF) released recommendations in 2013 for annual lung cancer screening (LCS) for "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."[5] This was followed by private payor insurance coverage under the Affordable Care Act[6] and coverage for Medicare beneficiaries by the Centers for Medicare and Medicaid Services (CMS)[6] and for patients enrolled in Medicaid by most state-based Medicaid programs. Because CMS required facilities to submit their data to a CMS-approved registry as a facility requirement for payment,

Corresponding Author: Liora Sahar, PhD, American Cancer Society, 250 Williams St, Atlanta, GA 30303-1032 (liora.sahar@cancer.org).

[1]American Cancer Society, Atlanta, Georgia; [2]Surveillance and Health Equity Science Research Department, American Cancer Society, Atlanta, Georgia; [3]Cancer Control Department, American Cancer Society, Atlanta, Georgia; [4]Division of Cardiothoracic Radiology, Department of Radiology, University of Michigan Medical School, Ann Arbor, Michigan; [5]Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine, University of Michigan Medical School, Ann Arbor, Michigan; [6]Department of Radiology, National Jewish Health, Denver, Colorado

This research was supported by the American College of Radiology's National Radiology Data Registry. We thank the American College of Radiology staff for their assistance in the preparation of the data and acknowledge guidance and input by the steering committee for this analysis.

Additional supporting information may be found in the online version of this article.

DOI: 10.1002/cncr.33996, **Received:** July 26, 2021; **Revised:** September 10, 2021; **Accepted:** September 27, 2021, **Published online** February 15, 2022 in Wiley Online Library (wileyonlinelibrary.com)

the American College of Radiology (ACR) followed by creating the Lung Cancer Screening Registry (LCSR), the only CMS-approved registry.[7] In March 2021, the USPSTF released an update of its recommendations for LCS.[8] By both lowering the age at which screening begins to 50 years and reducing the pack-year history criterion to 20, it nearly doubled the population now eligible for LCS.

Recent reports still indicate very low annual screening by the eligible population[9,10] and variations in screening by state.[11] The adoption of any cancer screening program requires careful planning; an assessment of risk and eligibility; and efforts to identify challenges and barriers, including geographic access to screening facilities.[9,12] Although several previous reports have focused on geographic accessibility at the national and state levels,[13,14] this study expands on a previous study that reported results at the county level for the entire 55- to 79-year-old (inclusive) population[12] by focusing on the updated eligibility criteria of the 2021 USPSTF LCS recommendations and evaluating overall geographic access and differences in access between rural and urban areas.

MATERIALS AND METHODS

Geospatial analysis is often used to calculate proximity, assess the availability of health services, identify gaps in resources, and inform public health policies.[12,15,16] We used Esri's ArcGIS 10.6.1 (esri.com) for mapping and spatial analysis. Maps throughout this article were created using ArcGIS software by Esri.

Data sources include the following: LCS facilities, population, county smoking prevalence, percentage of the eligible population by state, and rural-urban classifications at the county and census tract levels. A list of LCS facilities in the ACR LCSR (referred to as "facilities" for the rest of the text) was provided and verified by the organization in May 2020. They were geocoded with Esri's ArcGIS World Geocoder to obtain their coordinates for mapping and analysis. Figure 1 shows the 3249 unique geocoded facilities, with the greatest facility density found in Florida (212), New York (203), and Pennsylvania (173).

On the basis of a recent evaluation of methodologies for estimating access,[12] we used road network analysis (preferred over the Euclidean distance method[16-18]) to calculate distances between population centers (represented by census tract centroids) and facilities. Population estimates for the 50- to 80-year age group were downloaded from the US Census (2013-2018 American Community Survey 5-year estimates).[19] The entire census tract population was considered to either have access or not have access within the distance from the centroid to the closest screening facility. Because each county consisted of several census tracts, we calculated the percentage of the entire population aged 50 to 80 years within the county that had access to a facility and categorized counties as having "full access" (all census tracts within the county had access), "partial access" (some census tracts had access), and "no access."

Multiple classifications of "rural" and "urban" exist. They differ in their spatial delimitation and their utilization for health policies and in cancer studies.[20-22] Different studies have evaluated aspects of disparities related to health in rural areas, including access to care and health outcomes.[3,20-25] Although a clear rural-urban discrepancy and/or disparity is not consistently shown, the definition of *rural* and its geographic delineation are important for identifying specific challenges, barriers, local disparities, and focus areas for interventions. Limiting aggregation of the data, such as using the census tract–level definition of *rurality*, is preferred to better identify barriers to care and local focus areas.[20-22]

To evaluate accessibility across rural and urban environments in census tracts and counties, access was defined with multiple threshold distances of 10, 20, 40, 50, and 100 miles. Although we realize that 100 miles is not a common travel distance for screening services, we present the results to illustrate gaps and disparities in services. Because we report results at the census tract and county levels, we use rural-urban categories for both geographies. Counties were designated as rural, metro, or micro on the basis of the Office of Management and Business categories, which are often used for policy for evaluating differences between counties.[26] Census tracts were designated according to the consolidated rural-urban commuting area (cRUCA) scheme,[20] a 7-category consolidation of the US Department of Agriculture's rural-urban commuting areas[27] numbered from 1 (representing "urban core") to 7 (representing "isolated rural"; Table 1). The "more urban" categories are numbered 1 to 4, and the "more rural" categories are numbered 5 to 7.

We estimated the number of those eligible in each state and further in each county on the basis of state-level estimates of the percentage of the eligible population according to the updated USPSTF recommendations[11] as follows:

- Estimating the state eligible population (SEP): We multiplied the recently published percentages of the estimated eligible population within the state[11] by the population aged 50 to 80 years from the American Community Survey.[19]
- Distributing the county eligible population (CEP): In order to avoid a uniform distribution of the eligible

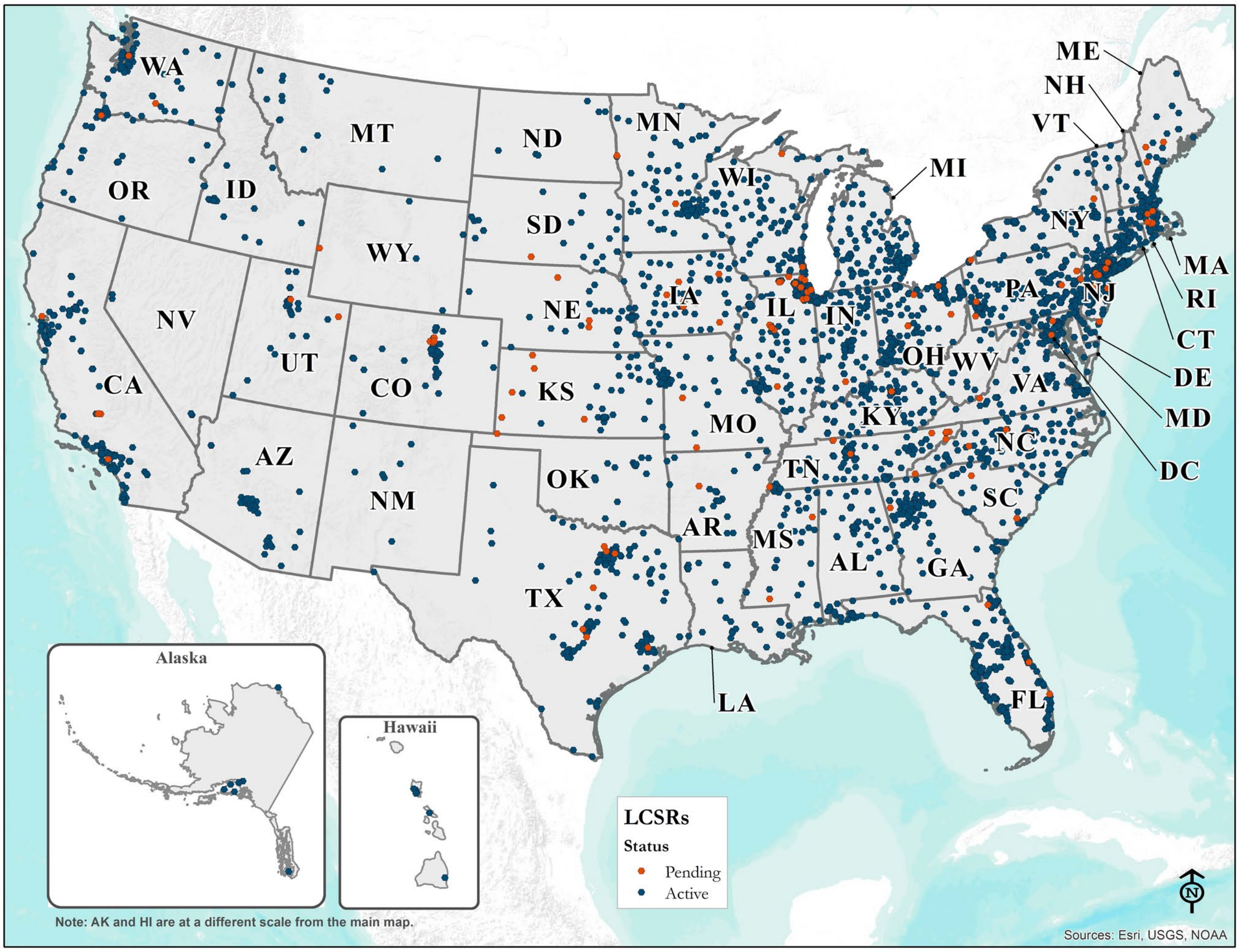

Figure 1. Lung cancer screening facilities participating in the LCSR. Blue dots indicate active locations, which have submitted data to the American College of Radiology, and red dots indicate pending locations, which are enrolled but have not yet submitted data to the registry. LCSR indicates Lung Cancer Screening Registry; NOAA, National Oceanic and Atmospheric Administration; USGS, US Geological Survey. Esri geographic information systems company (www.esri.com).

population across all counties, the calculated state eligible population was allocated across counties in the state relative to the number of the estimated individuals who smoked and were 50 to 80 years old in the counties (using county smoking prevalence[28]):

$$\text{CEP} = \frac{\text{CP}_{50-80} \times \text{CSP}}{\sum_{\text{counties in the state}} \left(\text{CP}_{50-80} \times \text{CSP}\right)} \times \text{SEP}$$

where CEP is the county eligible population, CP is the county population, CSP is the county smoking prevalence, and SEP is the state eligible population.

- Estimating the eligible population with access: We multiplied the eligible population in each county (as explained previously) by the percentage of the population with access at the county level.

Results are reported at different geographic levels to illustrate observed patterns and potential disparities of access to screening facilities nationwide and in rural-urban settings for all adults aged 50 to 80 years and the subset eligible population.

RESULTS

Approximately 15% of all adults aged 50 to 80 years are eligible for LCS, but this varies across states from 7.9% in Utah to 19.8% in Tennessee.[11] Most of the eligible

TABLE 1. Numbers and Percentages of Individuals Aged 50 to 80 Years and People Eligible for Screening Without a Screening Facility at Distances of up to 10, 20, 40, 50, and 100 Miles Across Rural and Urban Counties and Census Tracts

Category		Total and Eligible 50- to 80-Year-Old Population, Number (%)	Number (%) With No Access				
			10 Miles	20 Miles	40 Miles	50 Miles	100 Miles
Total nationwide							
Total nationwide	Total 50-80 y	100,133,060	30,802,334 (30.8%)	14,631,228 (14.6%)	4,848,270 (4.8%)	3,041,998 (3.0%)	625,100 (0.6%)
	Eligible population	14,816,638	4,870,365 (32.9%)	2,359,578 (15.9%)	753,038 (5.1%)	461,340 (3.1%)	87,145 (0.6%)
Counties							
Metropolitan	Total 50-80 y	84,218,801 (84.1%)	18,772,623 (22.3%)	6,283,304 (7.5%)	1,392,595 (1.7%)	761,743 (0.8%)	141,724 (0.2%)
	Eligible population	12,063,206 (81.4%)	2,801,695 (23.2%)	941,538 (7.8%)	195,120 (1.6%)	103,534 (0.9%)	17,363 (0.1%)
Micropolitan	Total 50-80 y	9,212,196 (9.2%)	6,294,943 (68.3%)	4,106,720 (44.6%)	1,723,447 (18.7%)	1,126,270 (12.2%)	255,024 (2.8%)
	Eligible population	1,577,708 (10.6%)	1,063,644 (67.4%)	679,151 (43.0%)	270,115 (17.1%)	171,405 (10.9%)	36,278 (2.3%)
Rural	Total 50-80 y	6,702,063 (6.7%)	5,734,768 (85.6%)	4,241,204 (63.3%)	1,732,228 (25.8%)	1,153,985 (17.2%)	228,352 (3.4%)
	Eligible population	1,175,724 (7.9%)	1,005,026 (85.5%)	738,889 (62.8%)	287,803 (24.5%)	186,401 (15.9%)	33,504 (2.8%)
Census tracts							
cRUCA 1—urban core	Total 50-80 y	70,596,831 (70.5%)	8,761,855 (12.4%)	1,979,637 (2.8%)	571,916 (0.8%)	367,684 (0.5%)	79,296 (0.1%)
	Eligible population	9,935,988 (67.1%)	1,235,550 (12.4%)	276,687 (2.8%)	78,741 (0.8%)	49,892 (0.5%)	9535 (0.1%)
cRUCA 2—close proximity to urban core	Total 50-80 y	12,921,699 (12.9%)	9,816,833 (76.0%)	4,088,667 (31.6%)	718,519 (5.6%)	356,815 (2.8%)	51,828 (0.4%)
	Eligible population	2,051,723 (13.8%)	1,573,685 (76.7%)	656,395 (32.0%)	110,532 (5.4%)	52,364 (2.6%)	6689 (0.3%)
cRUCA 3—urban cluster	Total 50-80 y	8,726,387 (8.7%)	5,627,755 (64.5%)	3,707,250 (42.5%)	1,516,963 (17.4%)	966,653 (11.1%)	223,067 (2.6%)
	Eligible population	1,487,785 (10.0%)	945,457 (63.5%)	612,035 (41.1%)	237,289 (15.9%)	147,806 (9.9%)	31,612 (2.1%)
cRUCA 4—close proximity to urban cluster	Total 50-80 y	206,645 (0.2%)	182,326 (88.2%)	139,618 (67.6%)	80,457 (38.9%)	62,471 (30.2%)	10,125 (4.9%)
	Eligible population	33,662 (0.2%)	29,552 (87.8%)	22,353 (66.4%)	12,567 (37.3%)	9735 (28.9%)	1359 (4.0%)
cRUCA 5—small town	Total 50-80 y	4,217,583 (4.2%)	3,298,941 (78.2%)	2,418,874 (57.4%)	974,871 (23.1%)	606,428 (14.4%)	123,828 (2.9%)
	Eligible population	728,066 (4.9%)	565,343 (77.6%)	411,215 (56.5%)	156,034 (21.4%)	92,878 (12.8%)	16,997 (2.3%)
cRUCA 6—close proximity to small town	Total 50-80 y	102,710 (0.1%)	88,090 (85.8%)	58,755 (57.2%)	25,375 (24.7%)	19,286 (18.8%)	7656 (7.5%)
	Eligible population	16,676 (0.1%)	14,354 (86.1%)	9108 (54.6%)	3718 (22.3%)	2750 (16.5%)	967 (5.8%)
cRUCA 7—isolated rural area	Total 50-80 y	3,360,626 (3.4%)	3,026,534 (90.1%)	2,238,427 (66.6%)	960,169 (28.6%)	662,661 (19.7%)	129,300 (3.8%)
	Eligible population	562,665 (3.8%)	506,422 (90.0%)	371,784 (66.1%)	154,155 (27.4%)	105,914 (18.8%)	19,987 (3.6%)

Abbreviation: cRUCA, consolidated rural-urban commuting area.

County data are aggregated from census tracts. The percentage of people without access for each category was calculated by dividing the number of individuals without access by the total number of people aged 50 to 80 years or eligible individuals within the category (the first column). Census tracts that were classified as not-coded RUCA codes were excluded from cRUCA classification.

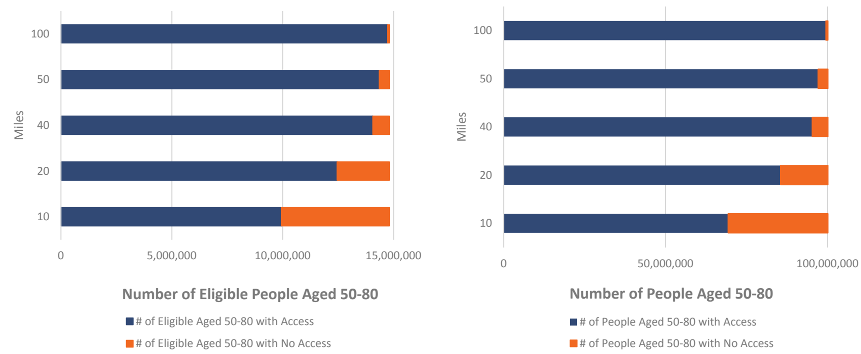

Figure 2. Accessibility of (*Right*) people aged 50 to 80 years and (*Left*) eligible people aged 50 to 80 years as calculated across different distances. Blue indicates those who have access, whereas orange is the part of the population that does not have access, in (*Right*) the total population aged 50 to 80 years (~100.1 million) and (*Left*) the total eligible population aged 50 to 80 years (~15 million).

population (81.4%) lives within metropolitan counties, 10.6% live in micropolitan counties, and 7.9% live in rural counties (Table 1). We calculated the state eligible population for each state and found that among more than 100.1 million individuals aged 50 to 80 years in the United States, approximately 14.8 million people aged 50 to 80 years are eligible for LCS. Table 1 presents the numbers and percentages of the 50- to 80-year-old population and the subset eligible population across rural-urban census tracts and counties with no access within 10, 20, 40, 50, and 100 miles of a facility; that is, 86% of the population aged 50 to 80 years in rural counties is not served by a facility within 10 miles, 63% is not served within 20 miles, 16% is not served within 50 miles, and so on. As expected, Figure 2 shows more people have access as the distance to facilities increases, with almost 70% access at 10 miles to more than 99% access at 100 miles. In agreement with the previous report,[12] approximately 5% of the population does not have access at 40 miles.

Overall, 5.1% of the eligible population does not reside within 40 miles of a facility, and this proportion is markedly higher among individuals living in micropolitan and rural counties at 17.1% and 24.5%, respectively. These percentages translate into 753,038 eligible people not having access to a facility, including 195,120 living in metro counties, 270,115 living in micro counties, and 287,803 people living in rural counties.

Although the number of individuals within census tracts or counties differs when access is calculated for all people aged 50 to 80 years (>100.1 million) versus the eligible population (>14.8 million), both show very similar patterns of accessibility. Figure 3 reveals variability in access to LCS and a noticeable trend of lower access in the West (including the middle of the country) in comparison with the East. Red and orange tracts (left column) indicate access in urban areas or close to urban areas, whereas the blue colors indicate access in small towns and in close proximity to small towns. Gray indicates rural areas.

The maps showing access within 10 and 20 miles are predominantly red and indicate access rates of approximately 69% and 85%, respectively, mainly in urban areas, with the 10-mile map showing access in the larger cities across the nation and more predominantly in the eastern states. At 40 and 50 miles, in agreement with a previous report,[12] there is higher access in the eastern United States with several pockets of low access in southeast Maine, West Virginia, Georgia, Alabama, and Mississippi. Greater within-state variation in access can be seen in sections of the middle states from North Dakota to Texas and in the mountain states. Within 100 miles, there are still apparent areas with no access, mostly in the mountain states. This population represents <1% of the total population aged 50 to 80 years but accounts for more than 600,000 estimated individuals aged 50 to 80 years and fewer than 100,000 who are estimated to be eligible for LCS. Figure 3 shows patterns of access similar to the maps of the eligible population in Supporting Figure 1.

We further examined the distribution of facilities and populations across rural- and urban-designated counties (metro/micro/rural designation by the Office of Management and Business) and census tracts (cRUCAs). Eighty-eight percent of facilities (2859) are located in more urban census tracts (cRUCAs 1-4), where approximately 92% of the 50- to 80-year-old population resides. Urban core census tracts (cRUCA 1), where 70.5% of the 50- to 80-year-old population resides, have 2331 or 72% of the facilities. Approximately 84% of the 50- to

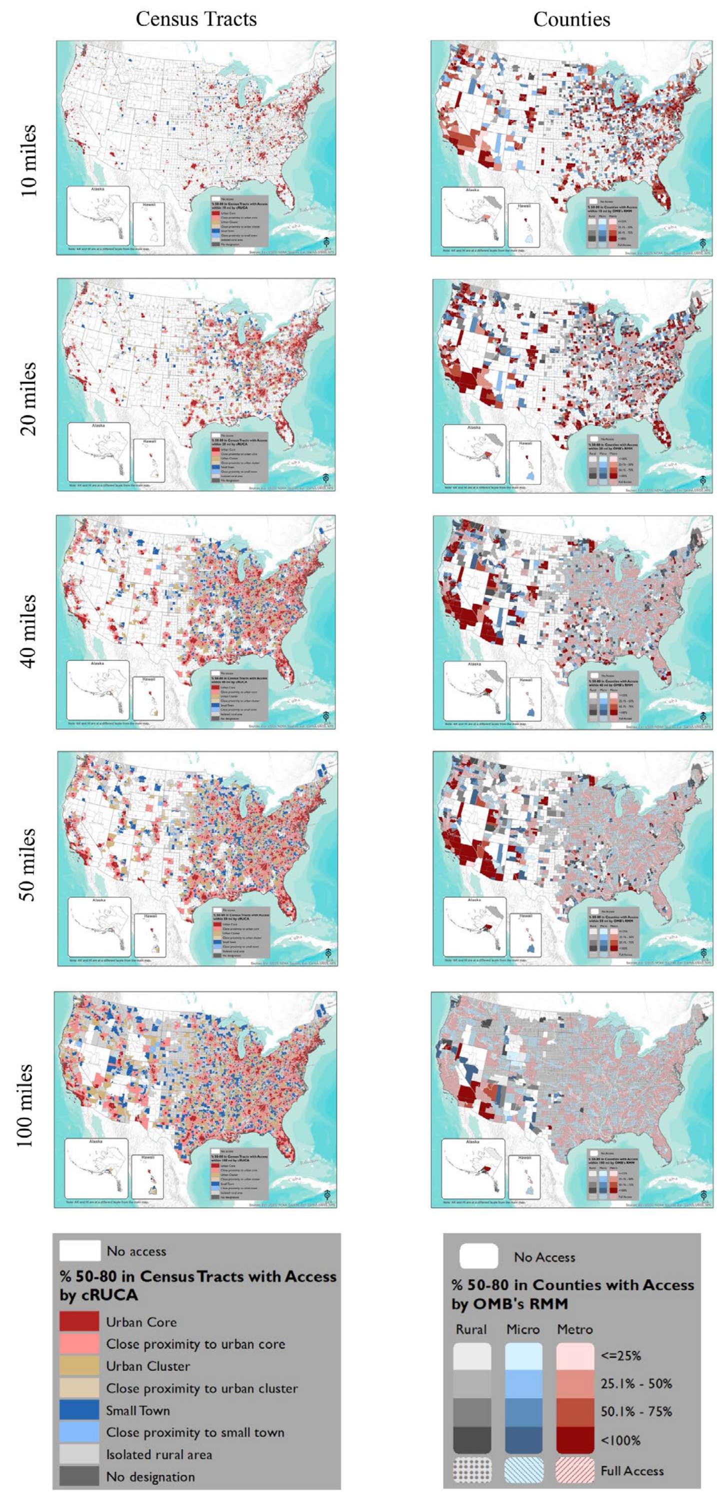

Figure 3. Access to lung cancer screening calculated with census tracts and counties. Maps indicate access at progressively longer distances (from 10 miles at the top to 100 miles at the bottom). No access is represented in white. Maps on the left show access at the census tract level; census tracts with access are colored according to their cRUCA designation. Maps of access at the county level are shown on the right, with darker graduating colors indicating increases in access, and hatches and dots depict full access. Maps were evaluated for common color blindness with the Color Oracle tool, which is available at https://colororacle.org/design.html. cRUCA indicates consolidated rural-urban commuting area; NOAA, National Oceanic and Atmospheric Administration; OMB, Office of Management and Business; NPS, National Park Service; RMM, Rural Micro Metro; USGS, US Geological Survey. Esri geographic information systems company (www.esri.com).

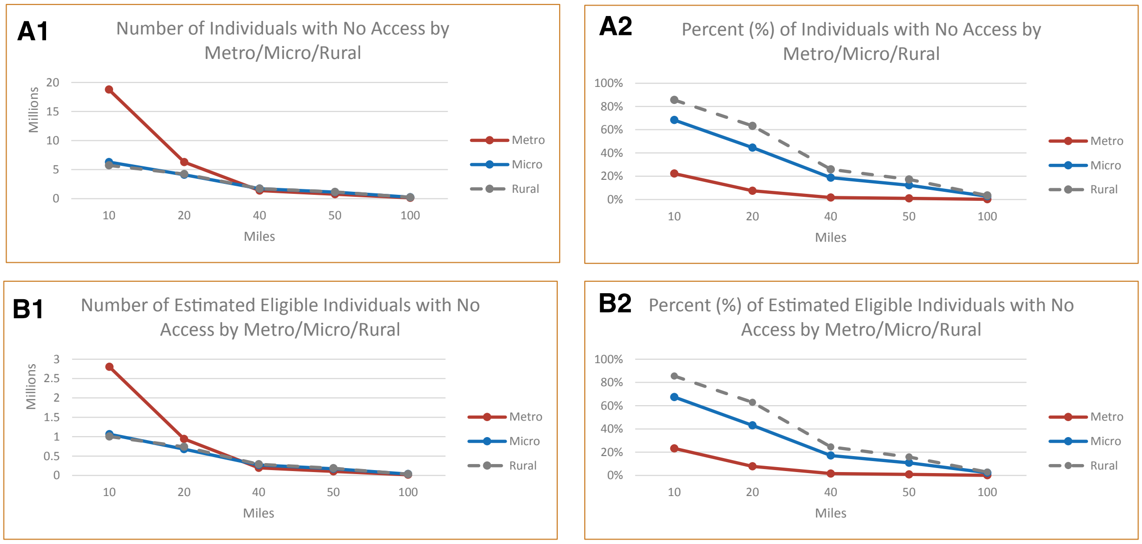

Figure 4. Numbers and percentages of individuals without access to a Lung Cancer Screening Registry facility across metro/micro/rural counties. Graph lines show a decreasing trend of no access across 10, 20, 40, 50, and 100 miles because more people have access as the distance threshold increases. Panels A1 and A2 refer to all individuals aged 50 to 80 years, whereas panels B1 and B2 refer to the eligible individuals aged 50 to 80 years within the county. Percent values refer to the proportion of individuals within a category who do not have access. For example, the gray dotted line in A2 refers to the percentage of individuals in rural counties who do not have access out of the entire population aged 50 to 80 years and residing in rural counties, whereas the gray dotted line in B2 refers to the percentage of eligible individuals in rural counties who do not have access out of the entire eligible population aged 50 to 80 years and residing in rural counties.

80-year-old population resides in metro-designated counties, where there are 2595 facilities or 80%. In contrast, 298 or 9% of the facilities are located in rural-designated counties, where 6.7% of the 50- to 80-year-old population resides, and 388 or 12% are in more rural census tracts (cRUCAs 5-7), where less than 8% of that population resides. Out of a total of 3142 counties, 1707 (54%) do not have access to a facility (no access for all census tracts within the counties) within 10 miles; 1026 of these counties (60%) are rural counties, and 332 (19%) are metro counties. At 100 miles, only 96 counties (3%) do not have access to a facility; 77 of these counties (80%) are designated rural, and 3 (3%) are designated metro. Figures 4 and 5 show the trends of the numbers and percentages of individuals with no access to a facility across the distance thresholds and across rural and urban categories at the county and census tract levels (cRUCAs 1-7). In Figure 4, graphs A1 and B1 clearly show there are more individuals in metro counties who do not have access within 10 and 20 miles in comparison with nonmetro counties, whereas the numbers at distances greater than 40 miles are very similar. Graphs A2 and B2 in Figure 4 show that greater percentages of individuals residing in nonmetro counties do not have access to screening across all the distances up to 100 miles. The graphs at the census tract level (Fig. 5A1,B1) show a change in the trend of the number of individuals with no access at 20 miles, where the number of individuals with no access within the isolated rural category (cRUCA 7) surpasses the number of individuals in the urban core category (cRUCA 1). Trends of census tracts in Figure 5 provide greater differentiation in trends across rural and urban categories in comparison with the aggregated county geographies. Although the overall trends are similar, we can identify differences between the rural-urban census tract categories in comparison with the county trends. The trend line of the number of individuals with no access (Fig. 4A1,B1) in metro counties converges with the nonmetro counties at 40 miles, but subtle trend changes can be observed at 20 miles for some census tract categories. There is a consistently higher percentage of individuals with no access in the more rural geographies than the urban geographies. The anomaly of cRUCA 4 (close proximity to urban cluster) is attributed to changes that were made to the original rural-urban commuting area codes in 2019.[27] A review of the revised census tract rural-urban classifications by the US Department of Agriculture shows a greater number of rural-designated census tracts.[27] This trend is particularly pronounced by the red lines in graphs A2 and B2 in Figures 4 and 5, which represent metro counties and

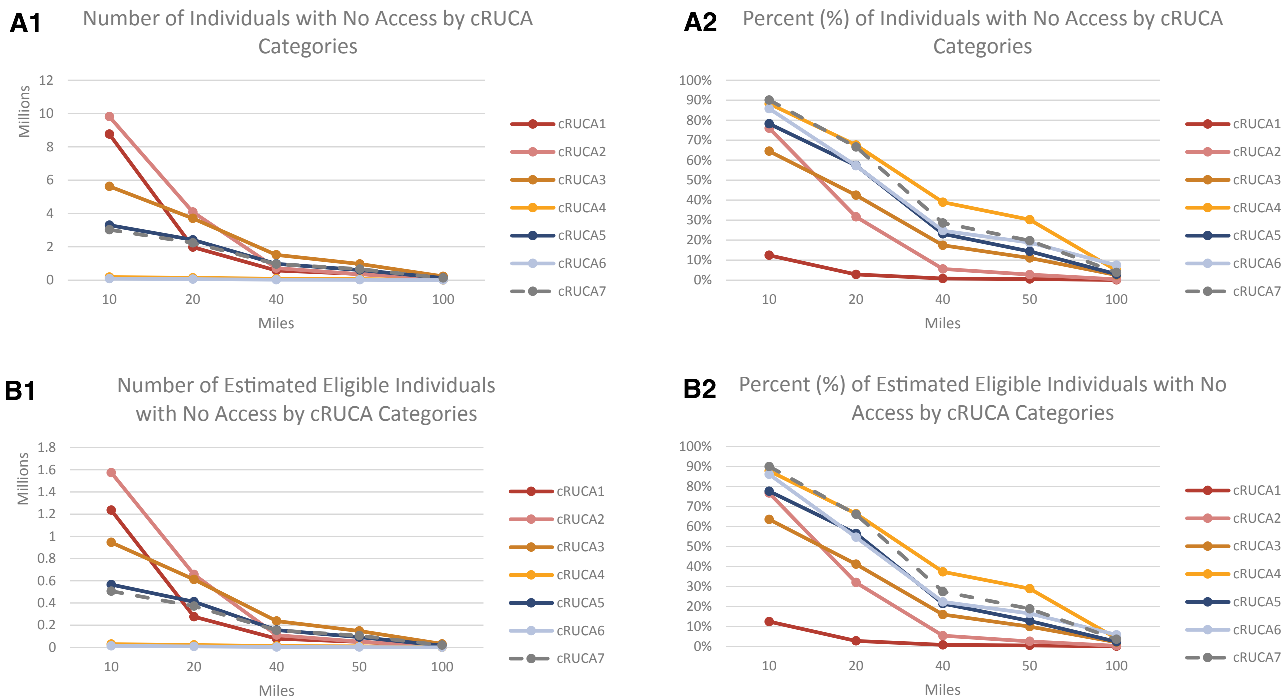

Figure 5. Numbers and percentages of individuals without access to a screening facility across cRUCA census tract designations. Graph lines show a decreasing trend of no access across 10, 20, 40, 50, and 100 miles because more people have access as the distance threshold increases. Panels A1 and A2 refer to all individuals aged 50 to 80 years, whereas panels B1 and B2 refer to the eligible individuals within the county. Percent values refer to the proportion of individuals within a category who do not have access. For example, the gray dotted line in A2 refers to the percentage of individuals in rural census tracts who do not have access out of the entire population aged 50 to 80 years and residing in rural census tracts, whereas the gray dotted line in B2 refers to the percentage of eligible individuals in rural census tracts who do not have access out of the entire eligible population aged 50 to 80 years and residing in rural census tracts. cRUCA indicates consolidated rural-urban commuting area.

urban core census tracts, respectively, that are below all the other categories up to 100 miles. For example, Table 1 shows that the percentage of individuals with no access at 10 miles in rural counties (86%) is almost 4 times higher than the percentage in metro counties (22%). The relative gap increases at 100 miles with 3.4% in rural counties and only 0.2% in metro counties. Similar trends appear across census tracts: the rate of no access within 10 miles is more than 7 times higher in isolated rural census tracts (90%) and approximately 6 times higher in small-town census tracts (78%) in comparison with urban core tracts (12%). A similar trend can be observed when access is determined for the subset 50- to 80-year-old estimated eligible population in the counties and census tracts.

Although most residents across all distances have access to a facility, there are differences in access among the rural-urban categories. The differences decrease as distances increase for both the numbers and the percentages; however, the higher distances themselves translate into a de facto lack of access if the distance is regarded as too great. For example, at 10 miles, 22% of residents in metro counties representing approximately 18.7 million individuals aged 50 to 80 years or an estimated 2.8 million eligible individuals (12% in urban core census tracts) do not have access; compare this to 86% of residents in rural counties representing approximately 5.7 million individuals aged 50 to 80 years or an estimated 1 million eligible individuals (and up to 90% in rural census tracts). At 40 miles, most individuals across all categories have access to screening, with more individuals having no access in rural counties versus metro counties, but the difference is fewer than 400,000 people aged 50 to 80 years and fewer than 100,000 eligible individuals. Those with no access at 40 miles range from only 1.7% of residents of metro counties to 26% of residents of rural counties and similarly from 0.8% in urban core census tracts to 29% in rural census tracts. As distances increase, geographic barriers to access to screening affect a smaller percentage of the 50- to 80-year-old population, with approximately 5% of the population with no access at 40 miles and with <1% with no access at 100 miles. Those seemingly small percentages translate into thousands of individuals and, at 100 miles, almost 500,000 people aged 50 to 80 years in nonmetro counties and approximately 70,000 eligible individuals. Although a similar trend is apparent at the census tract and county levels, census tract–level analysis can identify local, subcounty variations and potentially help us to better focus on specific challenges in access and design interventions in communities.

DISCUSSION

Overall, the distribution of facilities across rural and urban census tracts and counties is aligned with the distribution of adults eligible for LCS who reside in those areas, although some eligible adults will face long travel times (>40 miles). As expected, the proportion of individuals in more rural areas with no or less access to LCS is higher across all distances in comparison with the metro and urban areas. Because of the distribution of the population and the higher population density in metro and urban areas, a higher proportion of people with no access in a category does not necessarily translate into a higher number of individuals. Although the population in urban areas is concentrated in smaller geographic areas, rural areas span larger geographies and have a lower population density, and most of the areas with no access are in frontier regions west of the Mississippi River.

Disparities in lung cancer incidence and mortality in rural areas exist.[3] It is important to identify and address barriers and challenges and evaluate their impact on the uptake of screening and poorer outcomes.[29,30] Such barriers also include a lack of provider-patient communication about LCS, geographic access to screening,[31] and a lack of transportation.[32] To evaluate disparities across rural-urban environments and identify barriers to LCS, it is important to assess geographic access to screening at different distances and its impact in different communities. There are fewer facilities in rural areas, so residents need to travel longer distances to reach a facility. Our results show that higher percentages of the population in rural counties and in less urban census tracts do not have access to facilities across all the distance thresholds. A pattern of geographic disparity in access is evident in central and western US as clusters of geographies (Fig. 3) do not have access to facilities; this creates large geographic areas with no access even at 50 miles, and this is still apparent (but smaller) at 100 miles. Notable pockets of no access represent several rural counties and census tracts and should be identified and addressed. Specifically, local disparities can be better addressed at the census tract level because aggregation to counties tends to mask access as partial access (see the graduated color scheme in Fig. 3), especially in the East. Geospatial analysis that integrates additional variables such as mortality rates and smoking rates may help to identify focus areas for intervention to strategically reach the greatest number of people.

There are some limitations to this study. Our analysis focused on ACR LCSR facilities, which account for the majority of facilities offering LCS in the United States. However, some health systems, such as the Department of Veterans Affairs, Department of Defense–operated health care facilities, the Indian Health Service, and capitated health care systems and facilities that provide service only to non-Medicare beneficiaries, do not participate in the LCSR, and all of these would result in an underestimate of access to screening. Administratively, some health care systems that have multiple screening facilities are entered into the ACR LCSR as a single entity, and this may contribute to an underestimate of access to screening. There is no available public data set to estimate pack-years of exposure at the county level to integrate into population eligibility. We distributed state-level estimates of the eligible population[11] among counties in each state on the basis of the relative number of people who smoked within counties, which may differ from the actual number of eligible individuals within each county. The number of people who currently smoke or once smoked is based on the reported percentage of adults (18 years old or older) who have a history of cigarette smoking.[28] Additional limitations are related to the nature of the spatial analysis. We considered facilities within multiple distances from population centers, regardless of political boundaries. We represented census tract populations by using centroids for distance calculations. Generally, rural geographies span larger areas than urban geographies, and this can introduce larger potential estimation errors. Additionally, we assumed a similar capacity for all facilities and did not consider barriers to care such as financial barriers, insurance coverage, cultural barriers, or differences in transportation infrastructure, which may vary greatly between rural and urban environments.

In conclusion, the nationwide distribution of LCS facilities has heterogeneity, and there is a clear regional distinction between states in the east and central-west US. Hierarchical evaluation of access across states, counties, and census tracts may be useful for decision-making and for informing interventions and policies at different levels and across rural and urban environments. We recommend calculating access by census tracts and then aggregating to other geographic levels to achieve a more accurate assessment of access. Across all distances in this analysis, there is a significantly higher percentage of rural residents who do not have access to facilities in comparison with those in urban settings. However, the total number of individuals with no access in urban areas exceeds that of rural individuals, particularly at shorter distances, and this should be considered as well because it reveals an additional underserved population. Different distance thresholds are essential for assessing geographic accessibility across rural and urban environments and may help in strategically identifying focus areas to better allocate resources across rural and urban areas. Areas and local pockets with persistently low or no access across short and long distances should be considered for tailored interventions such as implementing mobile units, repurposing existing imaging or health facilities, and adding appropriate navigation, radiology, and screening program staff to better support the communities. Additional research should focus on addressing unique barriers to LCS in rural and urban communities nationally and regionally to guide the strategic implementation of programs that are appropriate to the types and geographies of communities.

FUNDING SUPPORT

Part of the time for this work for Liora Sahar, Vanhvilai L. Douangchai Wills, and Ka Kit (Antonio) Liu was funded by the National Lung Cancer Roundtable.

CONFLICT OF INTEREST DISCLOSURES

Robert A. Smith and Stacey A. Fedewa are employed by the American Cancer Society, which receives grants from private and corporate foundations, including foundations associated with companies in the health sector, outside the submitted work; their salaries are funded solely through American Cancer Society funds. Lauren Rosenthal is employed by the American Cancer Society, which receives grants from private and corporate foundations, including foundations associated with companies in the health sector, outside the submitted work; her salary is partially funded by the National Lung Cancer Roundtable. Debra S. Dyer serves on the clinical advisory board for Imidex, a computer software company developing artificial intelligence tools for chest radiographs, and on the GO_2 Foundation scientific advisory board; she also serves as a consultant for Lung Ambition Alliance. Ella A. Kazerooni reports past participation on the Bristol Myers Squibb Foundation advisory board. The other authors made no disclosures.

AUTHOR CONTRIBUTIONS

Liora Sahar: Conceptualization, analysis, writing–original draft, writing–review and editing, and project administration. **Vanhvilai L. Douangchai Wills:** Analysis, writing–original draft, and writing–review and editing. **Ka Kit (Antonio) Liu:** Analysis and writing–review and editing. **Stacey A. Fedewa:** Data, writing–original draft, and writing–review and editing. **Lauren Rosenthal:** Writing–original draft and writing–review and editing. **Ella A. Kazerooni:** Writing–review and editing. **Debra S. Dyer**: Writing– review and editing. **Robert A. Smith:** Conceptualization, writing–original draft, and writing–review and editing.

REFERENCES

1. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2020. *CA Cancer J Clin*. 2020;70:7-30.
2. American Cancer Society. Cancer Facts & Figures 2020. American Cancer Society; 2020.
3. Atkins GT, Kim T, Munson J. Residence in rural areas of the United States and lung cancer mortality. Disease incidence, treatment disparities, and stage-specific survival. *Ann Am Thorac Soc*. 2017;14:403-411.
4. National Lung Screening Trial Research Team. Reduced lung-cancer mortality with low-dose computed tomographic screening. *N Engl J Med*. 2011;365:395-409.
5. Moyer VA; US Preventive Services Task Force. Screening for lung cancer: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med*. 2014;160:330-338. Medline:24378917. doi:10.7326/M13-2771
6. Screening for lung cancer with low dose computed tomography (LDCT) (CAG-00439N): decision summary. Centers for Medicare & Medicaid Services. Published February 2015. Accessed December 28, 2018. https://www.cms.gov/medicare-coverage-database/details/nca-decision-memo.aspx?NCAId=274#Top
7. Lung cancer screening registries. Centers for Medicare & Medicaid Services. Published 2016. Updated January 5, 2016. Accessed December 27, 2018. https://www.cms.gov/Medicare/Medicare-General-Information/MedicareApprovedFacilitie/Lung-Cancer-Screening-Registries.html
8. Krist AH, Davidson KW, Mangione CM, et al. Screening for lung cancer: US preventive services task force recommendation statement. *JAMA*. 2021;325:962-970.
9. Jemal A, Fedewa SA. Lung cancer screening with low-dose computed tomography in the United States—2010 to 2015. *JAMA Oncol*. 2017;3:1278-1281.
10. Zahnd WE, Eberth JM. Lung cancer screening utilization: a behavioral risk factor surveillance system analysis. *Am J Prev Med*. 2019;57:250-255.
11. Fedewa SA, Kazerooni EA, Studts JL, et al. State variation in low-dose CT scanning for lung cancer screening in the United States. *J Natl Cancer Inst*. 2020;113:1044-1052. doi:10.1093/jnci/djaa170
12. Sahar L, Wills VLD, Liu KK, Kazerooni EA, Dyer DS, Smith RAC. Using geospatial analysis to evaluate access to lung cancer screening in the United States. *Chest*. 2021;159:833-844.
13. Charkhchi P, Kolenic GE, Carlos RC. Access to lung cancer screening services: preliminary analysis of geographic service distribution using the ACR Lung Cancer Screening Registry. *J Am Coll Radiol*. 2017;14:1388-1395.
14. Eberth JM, Bozorgi P, Lebrón LM, et al. Geographic availability of low-dose computed tomography for lung cancer screening in the United States, 2017. *Prev Chronic Dis*. 2018;15:E119.
15. Peipins LA, Graham S, Young R, et al. Time and distance barriers to mammography facilities in the Atlanta metropolitan area. *J Community Health*. 2011;36:675-683.
16. Huang B, Dignan M, Han D, Johnson O. Does distance matter? Distance to mammography facilities and stage at diagnosis of breast cancer in Kentucky. *J Rural Health*. 2009;25:366-371.
17. Ye H, Kim H. Measuring spatial health disparity using a network-based accessibility index method in a GIS environment: a case study of Hillsborough County, Florida. *Int J Geospatial Environ Res*. 2014;1:2. Accessed May 1, 2020.https://dc.uwm.edu/ijger/vol1/iss1/2/?utm_source=dc.uwm.edu%2Fijger%2Fvol1%2Fiss1%2F2&utm_medium=PDF&utm_campaign=PDFCoverPages
18. Boscoe FP, Henry KA, Zdeb MS. A nationwide comparison of driving distance versus straight-line distance to hospitals. *Prof Geogr*. 2012;64. doi:10.1080/00330124.00332011.00583586
19. Age and sex. US Census Bureau. Published 2018. Accessed July 16, 2020. https://data.census.gov/cedsci/table?q=S0101&tid=ACSST5Y2018.S0101

20. Sahar L, Williams R, Rao A, Alcaraz KI, Portier KM. Using GIS technology to define and assess a rurality scheme suitable for decision support in health and patient services. *Int J Appl Geospatial Res*. 2018;9:1-17. doi:10.4018/IJAGR.2018070101
21. Hart LG, Larson EH, Lishner DM. Rural definitions for health policy and research. *Am J Public Health*. 2005;95:1149-1155.
22. Yaghjyan L, Cogle CR, Deng G, et al. Continuous rural-urban coding for cancer disparity studies: is it appropriate for statistical analysis? *Int J Environ Res Public Health*. 2019;16:1076.
23. Douthit N, Kiv S, Dwolatzky T, Biswas S. Exposing some important barriers to health care access in the rural USA. *Public Health*. 2015;129:611-620.
24. Singh GK, Williams SD, Siahpush M, Mulhollen A. Socioeconomic, rural-urban, and racial inequalities in US cancer mortality: part I—all cancers and lung cancer and part II—colorectal, prostate, breast, and cervical cancers. *J Cancer Epidemiol*. 2011;2011:107497.
25. Lam O, Broderick B & Toor S. How far Americans live from the closest hospital differs by community type. Pew Research Center. Published December 12, 2018. Accessed Jan 15, 2020. https://www.pewresearch.org/fact-tank/2018/12/12/how-far-americans-live-from-the-closest-hospital-differs-by-community-type/
26. Delineation files. US Office of Management and Budget. Published 2020. Accessed August 6, 2020. https://www.census.gov/geographies/reference-files/time-series/demo/metro-micro/delineation-files.html
27. Rural-urban commuting area codes. US Department of Agriculture Economic Research Service. Published 2019. https://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes.aspx
28. County health rankings & roadmaps: learn more about adult smoking. Robert Wood Johnson Foundation and University of Wisconsin Population Health Institute. Published 2018. Accessed July 28, 2020. https://www.countyhealthrankings.org/explore-health-rankings/measures-data-sources/county-health-rankings-model/health-factors/health-behaviors/tobacco-use/adult-smoking
29. Rohatgi KW, Marx CM, Lewis-Thames MW, Liu J, Colditz GA, James AS. Urban-rural disparities in access to low-dose computed tomography lung cancer screening in Missouri and Illinois. *Prev Chronic Dis*. 2020;17:E140.
30. Zgodic A, Zahnd WE, Advani S, Eberth JM. Low-dose CT lung cancer screening uptake: a rural-urban comparison. *J Rural Health*. Published online March 18, 2021. doi:10.1111/jrh.12568
31. Odahowski CL, Zahnd WE, Eberth JM. Challenges and opportunities for lung cancer screening in rural America. *J Am Coll Radiol*. 2019;16(pt B):590-595.
32. Schiffelbein JE, Carluzzo KL, Hasson RM, et al. Barriers, facilitators, and suggested interventions for lung cancer screening among a rural screening-eligible population. *J Prim Care Community Health*. 2020;11:2150132720930544