

A narrative review of lung cancer screening in underserved populations

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Abstract: Lung cancer screening with low-dose computed tomography (LDCT) is an effective approach for the early detection of lung cancer and the reduction of lung cancer specific mortality in high risk individuals. Despite recommendations for LDCT screening by the National Comprehensive Cancer Network (NCCN) and the United States Preventive Services Task Force, the utilization of LDCT screening in clinical practice has been low. Moreover, significant disparities in the use of LDCT have been described in underserved populations, including African American or black patients, rural patients with limited access to LDCT screening facilities, and other vulnerable patient groups with known risk factors for developing lung cancer. Several patient, provider, and healthcare systems level approaches have been proposed to mitigate lung cancer screening disparities. Such approaches include raising awareness of LDCT screening benefits and the evidence in support of LDCT screening among healthcare providers, educating patients on LDCT screening and optimizing shared decision-making approaches between patients and providers, and expanding patient access to LDCT screening through free and mobile lung cancer screening programs. As lung cancer screening utilization continues to expand in clinical practice, it will be critical to continue investigating the trends, causes, and outcomes of LDCT screening disparities in underserved populations.

Keywords: Lung cancer screening; low-dose computed tomography (LDCT); disparities; underserved

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Introduction

Lung cancer is the leading cause of cancer related deaths globally (1). In the United States alone, lung cancer accounts for nearly 25% of all cancer mortality and is estimated to result in 136,000 deaths each year (2). This substantial mortality burden exists, in part, because most lung cancer patients are found to have advanced stage disease at the time of diagnosis (2,3). According to data from the Surveillance, Epidemiology, and End Results (SEER) Program, patients with distant or metastatic disease constitute 57% of incident lung cancer cases and have an overall survival rate of 6% at five years (3). The exceedingly high prevalence and mortality

associated with advanced stage disease has served as the primary rationale for the development of effective screening approaches in patients at risk of developing lung cancer.

Over the last decade, low-dose computed tomography (LDCT) screening has emerged as an effective modality for the early detection of lung cancers in high-risk patients. In 2011, the National Lung Screening Trial (NLST) showed that the use of LDCT screening was associated with a greater rate of lung cancer detection and a 20% reduction in lung cancer mortality as compared to surveillance with chest radiography alone (4). These results were recently corroborated by the Dutch-Belgian Lung Cancer Screening (NELSON) Trial, which showed a similar reduction in

lung cancer mortality in high-risk patients undergoing LDCT screening compared to no screening (5). Following the publication of the NLST trial, both the National Comprehensive Cancer Network (NCCN) (6) and the United States Preventive Services Task Force (USPSTF) (7) developed guidelines recommending lung cancer screening with LDCT. While the guidelines put forth by the NCCN and USPSTF differed slightly in their indications for screening, these recommendations both supported LDCT screening as a validated mechanism to reduce lung cancer specific mortality in select patients.

Despite the clear survival benefit of LDCT screening in appropriate patients, there has been a relatively low adherence to these guidelines in clinical practice (8-10). In addition, several studies have described disparities in the use of LDCT screening in underserved populations, including racial/ethnic minorities (11,12), those living in rural areas with more limited access to care (13), and other vulnerable populations (14,15). Efforts to understand disparities in LDCT screening and their contributing factors have become increasingly relevant, as previous studies have shown that these same underserved populations have a greater incidence of lung cancer and are less likely to receive appropriate treatment (16-19). Therefore, the objective of the present narrative review is to discuss lung cancer screening disparities in underserved populations and to examine methods of improving access to lung cancer screening in these patients. We present the following article in accordance with the narrative review checklist (available at: <http://dx.doi.org/10.21037/ccts-2020-lcs-07>).

Methods

Data source

The MEDLINE (PubMed) database was queried to identify original research articles describing LDCT screening utilization and outcomes published between January 2013 and October 2020. This search strategy was conducted using the following terms: “disparities” or “inequity” or “underserved populations” or “outcomes” combined with “lung cancer screening” or “lung cancer low dose computed tomography screening” or “lung cancer CT screening”. Abstracts were reviewed to identify primary source references that met the objectives of this analysis. Studies were excluded if they were not published in the English language, if the full manuscript text was not available, or if chest radiography served as the primary screening modality. To provide sufficient background and context for the findings

presented in this review, additional searches were performed on referenced literature contained within other narrative reviews published on this topic during the same period.

Rationale and guidelines for lung cancer screening by LDCT

The primary goal of lung cancer screening efforts has been to improve lung cancer survival through the early detection of malignancy in high-risk patients. This rationale is based on extensive epidemiologic data, which show that patients diagnosed with localized lung cancer have an estimated 54% five-year survival advantage over those with metastatic disease (3). Given the striking survival discrepancy between early and late stage lung cancer, it was hypothesized that screening based detection with LDCT may shift the burden of newly diagnosed disease into earlier stages and improve survival outcomes.

The NLST provided the first randomized controlled trial evidence in support of this hypothesis. Following the randomization of 53,454 high risk individuals to three rounds of annual LDCT or chest radiography screening, the NLST showed that patients screened with LDCT experienced a higher rate of lung cancer detection and a 20% relative risk reduction in lung cancer specific mortality (4). Importantly, the greater distribution of stage I lesions identified in the LDCT arm (LDCT 63% *vs.* chest radiography 47.6%) indicated that the detection and treatment of earlier stage cancers was likely the reason for the survival benefit observed in this trial cohort (4).

Given the results of the NLST, both the NCCN (category I) (6) and USPSTF (grade B) (7) adopted guidelines recommending the use of annual LDCT screening in patients with similar risk profiles to those included in the trial (55–74 years old; ≥ 30 pack-year smoking history; current or former smoker that has quit within 15 years) (*Table 1*). In addition to this cohort, the NCCN also extended screening eligibility beyond the NLST criteria to a second group of patients with risk factors such as history of cancer or lung disease, radon or occupational exposure, or family history of lung cancer (6) (*Table 1*). LDCT screening in this second group was initially given a category 2B recommendation by the NCCN, but has since been upgraded to 2A (20). Of note, the USPSTF is in the process of revising their guidelines and updated recommendations are forthcoming (21,22).

Despite guideline recommendations and established evidence in support of LDCT screening, there has been

Table 1 Current National Comprehensive Cancer Network and United States Preventive Services Task Force guidelines for LDCT screening

Organization	LDCT screening criteria
NCCN	Group 1 (Category 1) <ul style="list-style-type: none"> • Age: 55–77 years • Smoking history: ≥ 30 pack-years • Smoking status: current smokers or former smokers who have quit within 15 years
	Group 2 (Category 2A) <ul style="list-style-type: none"> • Age: ≥ 50 years • Smoking history: ≥ 20 pack-years • At least one additional risk factor: contact with radon, asbestos, or other cancer causing agents (not including second-hand smoke); personal history of cancer or lung disease; family history of lung cancer
USPSTF	Group 1 (Grade B)* <ul style="list-style-type: none"> • Age: 55–80 years • Smoking history: ≥ 30 pack-years • Smoking status: current smokers or former smokers who have quit within 15 years

*, USPSTF guidelines for LDCT screening are currently in the process of being revised. LDCT, low-dose computed tomography; NCCN, National Comprehensive Cancer Network; USPSTF, United States Preventive Services Task Force.

a relatively low uptake in clinical practice. In two separate analyses using data from the National Health Interview Survey (NHIS), Jemal *et al.* (9) and Richards *et al.* (10) independently estimated that only ~4% of eligible individuals received LDCT screening in accordance with USPSTF guidelines in 2015. For comparison, that same year it was estimated that 8.5% of patients received lung cancer screening by chest radiography, despite no data supporting its efficacy (10). More recently, a Centers for Disease Control and Prevention (CDC) analysis using survey data collected from ten states in 2017 estimated that 12.7% of USPSTF eligible individuals received LDCT screening (23). While this positive trend is encouraging, these data underscore the significant and continued underutilization of LDCT screening in eligible patients in real world practice. Studies have indicated that racial/ethnic minorities and those with limited access to care are among those most affected by poor screening uptake. Below, we summarize results from pertinent studies that describe these disparities.

Disparities and outcomes of lung cancer screening in underserved populations

Race/ethnicity

Racial and ethnic disparities are well described in the thoracic oncology literature. In particular, several previous

studies have shown that underrepresented minority populations experience a higher incidence of lung cancer and are less likely to receive guideline concordant treatment at various stages of disease (16,18,19,24-26). Recently, there has been accumulating evidence to suggest that this pattern of racial disparities may extend into the receipt of LDCT screening (Table 2).

In a retrospective analysis of 262 individuals undergoing LDCT screening at a community center, Richmond *et al.* showed that a significantly lower proportion of black patients were screened as compared to their white counterparts (27). Similar trends have also been described among patients at academic facilities. In 2018, Japuntich *et al.* conducted a cross-sectional survey of 200 current or former smokers at their institution to compare screening eligibility and utilization between black and non-black individuals (28). Their work showed that among those eligible for screening, non-black patients were 2.8-times more likely to be screened than black patients (28). Similar disparities were described in a recently published analysis of patients at an academic safety net hospital by Steiling *et al.* (12). Although these authors reported a relatively high overall screening rate in their eligible patient cohort (16.1%), they found that black patients were significantly less likely than white patients to receive LDCT screening

Table 2 Studies describing racial disparities in LDCT screening

Author	Study type	Data source	No. patients	Years studied	Research question/objective	Main finding(s)
Lake <i>et al.</i> (11)	Retrospective, observational	Institutional	675	2015–2017	To explore racial differences in lung cancer screening outcomes, including differences in LDCT rates, follow-up, and cancer diagnoses in patients with positive baseline scans.	<ul style="list-style-type: none"> Black individuals had significantly lower odds of receiving LDCT after controlling for individual lung cancer risk factors and neighborhood-level factors. Black individuals also demonstrated a trend toward delayed follow-up, decreased adherence, and loss to follow-up.
Steiling <i>et al.</i> (12)	Retrospective, observational	Institutional	2,978	2015–2017	To determine institutional screening rate and to identify socioeconomic barriers to lung cancer screening	<ul style="list-style-type: none"> Lung cancer screening rate was found to be 16.1%. Patient factors including older age, African American race, and lower median income were associated with not being screening.
Richmond <i>et al.</i> (27)	Retrospective, observational	Institutional	262	2016	Do racial disparities exist in the pattern of LDCT screening at a community hospital?	<ul style="list-style-type: none"> Black patients were found to be significantly less likely than white patients to receive LDCT when eligible
Japuntich <i>et al.</i> (28)	Cross-sectional (survey)	Institutional	200	2016	What is the USPSTF eligibility and LDCT screening rate among Black and non-Black patients?	<ul style="list-style-type: none"> Black patients were less likely to qualify for screening and disproportionately less likely to be screened for lung cancer compared with non-Black patients.
Sesti <i>et al.</i> (29)	Retrospective, observational analysis of a randomized controlled trial	NLST	14,000	2002–2004	To determine predictors of follow-up after a positive lung cancer screening test	<ul style="list-style-type: none"> Black race and current smoking status were associated with lower rates of follow up after positive LDCT test among NLST participants.
Balekian <i>et al.</i> (30)	Retrospective, observational of a randomized controlled trial	NLST	723	2002–2004	To evaluate surgical resection patterns of patients with early stage NSCLC in the NLST and to examine whether racial disparities exist among blacks	<ul style="list-style-type: none"> Compared with white men, black men had a 28% lower risk of undergoing surgery. Among those that underwent surgery, black men had lower odds of receiving a full resection (lobectomy, bilobectomy, or pneumonectomy) compared to white men.

LDCT, low-dose computed tomography; NLST, National Lung Screening Trial; NSCLC, Non-small cell lung cancer.

by bivariate analysis (12). In another study, Lake *et al.* showed that the disproportionate screening rates among black individuals referred to their center persisted even after controlling for other patient characteristics, such as age, sex, BMI, smoking status, family history of lung cancer, and chronic obstructive pulmonary disease (COPD) (11). While the exact reasons for the institution-level racial disparities are unclear, these findings indicate that additional factors

other than patient clinical characteristics may contribute to the lower LDCT screening rates among black patients.

In addition to rates of screening, recent studies have also described racial differences in the patterns of clinical follow up and treatment after positive tests. Rather surprisingly, such studies have largely been conducted using data from the NLST database. Sesti *et al.* performed a multivariate analysis of factors predictive of follow up after a positive

LDCT test in the NLST (29). Their work demonstrated that black race was associated with a significantly lower likelihood of follow up compared to white race independent of sex, marital status, and smoking status (29). Balekian *et al.* evaluated disparities in the receipt of surgery for NLST participants diagnosed with early stage lung cancer during the trial period (30). Their analysis demonstrated that black male participants with identified clinical stage I tumors were 28% less likely than white male participants to undergo curative intent resection (30). In addition, Balekian *et al.* observed that even among NLST participants receiving surgery for clinical stage I lesions, black men were more likely to undergo limited resection (defined as wedge resection or segmentectomy) compared to white men who were more likely to undergo full resection (defined as lobectomy, bilobectomy, or pneumonectomy) (30). Of note, analysis of surgical interventions between black and white women NLST participants did not yield similar trends.

Patients living in rural areas

In addition to racial/ethnic disparities, differences in LDCT screening availability and access to LDCT screening centers have been described for patients living in rural areas (31) (Table 3). Shortly after the USPSTF's endorsement of LDCT screening, Eberth *et al.* evaluated the geographic distribution of LDCT screening centers in the United States and correlated their locations with population estimates of lung cancer incidence, mortality, and smoking prevalence (32). Their analysis showed that most active LDCT screening centers in 2014 were predominately located within urban counties in Northeastern states (32). Conversely, rural counties with high lung cancer burdens in states such as Mississippi, Missouri, Oklahoma, and West Virginia were found to have low screening center availability (32). Rather surprisingly, there were 11 states that did not have any active screening centers at that time (32).

The same group conducted a follow-up analysis using data from 2017 (13). This study showed that despite an 8.6-fold increase in the total number of active LDCT screening centers in the United States, pronounced disparities continued to exist in the distribution of these centers between rural and urban areas (13). Kale *et al.* performed the most recent analysis on this topic. Their work demonstrated that Southeastern states continue to have a fewer active LDCT screening centers and higher lung cancer and smoking burdens compared to states in the Northeast and Southwest (33). Importantly, they also

show a slower rate of increase of new screening facilities in Southeastern states, suggesting that disparities will continue to persist unless concerted efforts are made to improve LDCT facility development in these regions.

To understand the impact of screening center geographic variability on patient access, Tailor *et al.* evaluated the distribution of United States smokers by census tract and their driving distance to American College of Radiology accredited LDCT screening facilities (34). Their work estimated that 82% of cigarette smokers reside within 15-miles of an accredited screening facility (34). While this suggests that travel distance alone may not serve as a significant barrier to LDCT screening access for the majority of smokers, the significant inter- and intra-state geographic variation does indicate that certain populations may be relatively disadvantaged (34). It is also important to note that transportation methods, costs, and other patient-level factors influencing travel capacity were not included in their analysis.

Building from their previous work, Tailor *et al.* conducted an analysis of factors associated with geospatial access to LDCT screening facilities (35). Using multivariable regression modeling, they examined census tract population characteristics predictive of travel distance to nearest screening centers (35). Although their model identified multiple demographic and socioeconomic status characteristics associated with greater traveling distances to screening centers (e.g., older age, uninsured/Medicaid, and lower formal education level), population density was found to be the greatest determinant of facility access (35). The work by Tailor *et al.* not only underscores the importance of sociodemographic and geographic factors in determining access to screening facilities, but also suggests that these factors may have downstream effects on screening utilization rates.

Other vulnerable patient populations

While much of the lung cancer screening literature has focused on racial/ethnic and geographic inequities, there is an emerging interest in studying screening outcomes in other vulnerable patient groups, including the uninsured/Medicaid insured and sexual minorities (Table 4). The concern for LDCT screening disparities in these groups largely stems from previous studies demonstrating a disproportionately high prevalence of tobacco smoking and poor screening uptake for other cancer types in these cohorts (39-44).

Zahnd *et al.* analyzed demographic and clinical factors associated with lung cancer screening uptake using the 2017

Table 3 Studies describing rural/geographic disparities in LDCT screening

Author	Study type	Data source	Years studied	Research question/objective	Main finding(s)
Eberth <i>et al.</i> (13)	Retrospective, observational	Lung Cancer Alliance Screening Centers of Excellence	2017	To determine the extent of geographic variation in LDCT facility distribution in the United States and to identify regions for program expansion.	There was an 8.5-fold increase in the number of LDCT screening facilities in the United States between 2014 and 2017. 15% of eligible patients do not have access to a screening center within 30 miles nationally and screening center availability remains limited in rural states.
Martin <i>et al.</i> (31)	Retrospective, observational	Virginia Central Cancer Registry; BRFSS; ACR accredited facility database	2015	To evaluate the capacity of lung cancer screening for high-risk individuals in the state of Virginia	Despite higher smoking and lung cancer mortality rates, rural counties had only 5% of available LDCT screening centers in the state of Virginia.
Eberth <i>et al.</i> (32)	Retrospective, observational	Lung Cancer Alliance Screening Centers of Excellence	2014	What is the geographic distribution of accredited LDCT screening facilities in the United States in 2014?	The majority of LDCT screening facilities in 2014 were concentrated in Northeast and East North Central states. Several states with high lung cancer incidence and mortality rates had few or no available LDCT screening centers.
Kale <i>et al.</i> (33)	Retrospective, observational	Lung Cancer Screening Registry; BRFSS; SEER	2016–2018	To compare LDCT facility geographic access with lung cancer incidence, mortality, and socioeconomic environment	Southeastern states had the lowest number of LDCT screening facilities, the slowest rate of new facility development between 2016 and 2018, and the highest smoking and lung cancer burdens.
Taylor <i>et al.</i> (34)	Cross-sectional	BRFSS; Google Maps; ACR accredited facility database	2016	To determine the nationwide distribution current smokers by census tract and the estimated driving distance to the nearest accredited LDCT screening facility	81% of smokers live within 15-miles of an accredited LDCT screening facility. Smokers living in rural areas have significantly less access to LDCT screening facilities.
Taylor <i>et al.</i> (35)	Cross-sectional	BRFSS; Google Maps; ACR accredited facility database	2016	To evaluate the association between geographic access to accredited LDCT screening facilities and census tract socioeconomic characteristics	Census tract population density was the greatest relative determinant of distance to LDCT screening facility. Census tracts with higher proportions of uninsured/Medicaid insured individuals and individuals with less formal education had significantly greater travel distances to LDCT screening centers.

LDCT, low-dose computed tomography; BRFSS, Behavioral Risk Factor Surveillance System Survey; SEER, Surveillance, Epidemiology, and End Results; ACR, American College of Radiology.

CDC Behavioral Risk Factor Surveillance System data (36). Evaluating survey responses from 4,374 individuals across 10 states, they showed that annual LDCT screening utilization was significantly lower among uninsured individuals than those with any form of insurance (4.0% *vs.* 15.2%,

$P < 0.001$) (36). Variables associated with increased screening rates in their analysis included asthma and COPD (36). Zgodic *et al.* validated these findings in a follow up analysis showing that uninsured status remained significantly predictive of lower odds of receiving lung cancer screening

Table 4 Studies describing LDCT screening disparities in other vulnerable populations, including the uninsured and sexual minorities

Author	Study type	Data source	No. patients	Years studied	Research question/objective	Main finding(s)
Matthews <i>et al.</i> (15)	Retrospective, observational	NESARC-III	9,635	2012–2013	To compare cigarette smoking prevalence and LDCT screening eligibility between U.S. adults of different sexual orientations	<ul style="list-style-type: none"> Sexual minorities had higher rates of smoking and LDCT eligibility, with the greatest rates observed among bisexual women and men.
Zahnd <i>et al.</i> (36)	Cross-sectional	BRFSS	4,374	2017	To determine LDCT screening uptake among 10 states in 2017	<ul style="list-style-type: none"> Screening rates were significantly lower among patients who were uninsured compared to those who had any form of insurance.
Zgodic <i>et al.</i> (37)	Cross-sectional	BRFSS	4,373	2017	To determine demographic, financial, and health care factors associated with LDCT screening uptake in a population based survey	<ul style="list-style-type: none"> LDCT screening rates were significantly higher among those who were younger, insured, had chronic respiratory conditions, were single/separated/widowed, or who had previous cancer diagnoses.
Veliz <i>et al.</i> (38)	Retrospective, observational	BRFSS	20,685	2017	To evaluate the association between sexual orientation and the eligibility for and receipt of LDCT lung cancer screening	<ul style="list-style-type: none"> Rates of LDCT eligibility are twice as high for sexual minorities than heterosexuals. There were no statistically significant differences in the rates of LDCT screening by sexual orientation group.

LDCT, low-dose computed tomography; BRFSS, Behavioral Risk Factor Surveillance System Survey; NESARC-III, National Epidemiologic Survey on Alcohol and Related Conditions.

after controlling for sex, age, race/ethnicity, marital status, history of cancer or chronic respiratory disease by multivariable regression [odds ratio (OR) 0.28, 95% CI, 0.12–0.65) (37).

Matthews *et al.* estimated the prevalence of cigarette smoking and LDCT screening eligibility among sexual minorities using survey data from the 2012–2013 National Epidemiologic Survey on Alcohol and Related Conditions (NESARC-III) (15). Overall, 11.2% of respondents in their sample were found to meet eligibility criteria for LDCT screening. When examining screening eligibility by sexual orientation, they found that bisexual women (26.9%) and bisexual men (24.5%) had the highest rates of screening eligibility (15). After adjusting for potential confounding variables including race, education level, personal income, employment status, relationship status, health insurance status, geographic location, and metropolitan area, only bisexual women were found to have a significantly higher proportion of screening eligibility (15). Using the same NESARC-III dataset, Veliz *et al.* also evaluated the association between sexual orientation and indication for LDCT screening (38). After validating the relationship

between sexual minority status and screening eligibility, they went on to show no statistically significant differences in the relative rates of LDCT screening by sexual orientation (38). This suggests that although a greater proportion of sexual minorities meet indications for LDCT screening based on current screening guidelines, they are not being screened at a higher rate than heterosexual individuals in clinical practice. Ultimately, given the early data gathered from these studies, continued investigation into rates of LDCT screening in sexual minorities and other vulnerable populations at high-risk of developing lung cancer is warranted.

Methods to improve lung cancer screening in underserved populations

In addition to the study of LDCT screening disparities, several reports have sought to evaluate methods of improving rates of screening in clinical practice. These approaches include patient-, provider-, and system-level interventions intended to increase awareness of LDCT screening efficacy and/or lower barriers to accessing this technology (*Figure 1*).

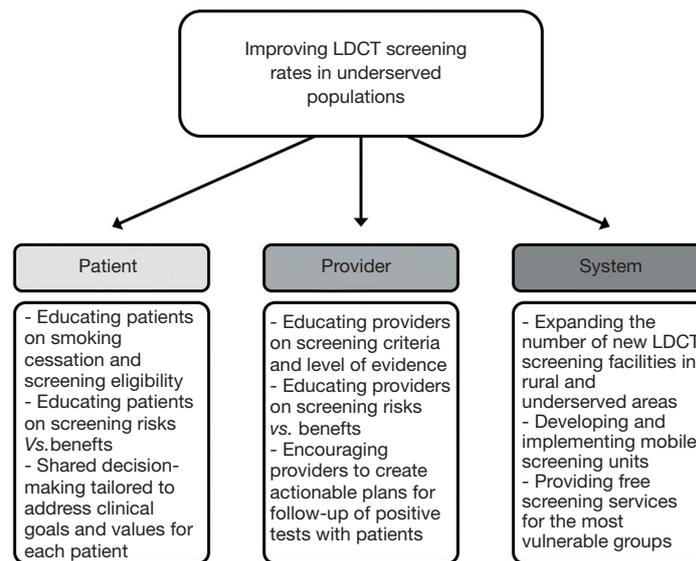


Figure 1 Flow chart outlining patient, provider, and system-level approaches to improve LDCT screening rates in underserved populations. LDCT, low-dose computed tomography.

Improving awareness of LDCT screening among healthcare providers

One of the most critical factors limiting the utilization of LDCT screening is the lack of familiarity with the guidelines among members of the medical community. Importantly, previous studies have demonstrated that physicians who are aware of the guidelines are more likely to initiate discussions of lung cancer screening with their patients (45) and order LDCT screening tests (45,46). However, since the USPSTF's endorsement of LDCT screening, multiple institutional reports have shown that primary care physicians in underserved areas have a relatively limited understanding of the guidelines and their supporting evidence (47-52). While the exact reasons for this uncertainty are not well known, discordance between NCCN and USPSTF indications for screening, lack of familiarity of the survival benefit associated with LDCT screening, and concerns regarding false positive rates and excess harms to the patient may all play a role (49-51,53). Efforts to familiarize healthcare providers with these topics through the distribution of educational materials and group based learning methods have been shown to be feasible at individual centers (54). To date, data demonstrating the effectiveness of these interventions on the national level are currently lacking.

Patient engagement and shared decision-making

An additional approach to improving screening rates has been to directly familiarize patients with LDCT screening. Consistent with the data on the lack of provider knowledge of screening guidelines, previous surveys conducted at single institutions (55-57) and in nationally representative samples have demonstrated that most high risk patients are not aware of the purpose of LDCT screening (58,59). In addition, some studies have indicated that current smokers are less informed of LDCT screening than former smokers (58,59). This suggests that existing opportunities for physicians to counsel patients on smoking cessation can also be used to discuss LDCT screening.

Beginning in 2015, shared decision-making has been required by the Centers for Medicare and Medicaid Services (CMS) for LDCT screening reimbursement (60). Since this time, multiple studies have tested the efficacy of shared decision-making processes in the education of patients regarding LDCT. Some reports have demonstrated that shared decision-making approaches with the use of decision aids to supplement standard information materials improves patient knowledge and perceived benefits of screening (55,56,61,62). However, despite improvements in patient knowledge regarding LDCT screening, some studies have shown that shared decision-making alone does

not appear sufficient to uniformly improve rates of LDCT screening completion (62-65). These studies indicate that the most effective shared decision-making approaches should not only discuss screening eligibility and the risks/benefits of screening, but should also actively assess the patient's willingness and ability to undergo screening and subsequent treatment should cancer be detected (66). Finally, some studies have suggested that the formal requirement of shared decision-making may also serve as a barrier to lung cancer screening in certain patients. In a national survey of 293 primary care physicians, Eberth *et al.* found that most providers identified competing health priorities of the patient and lack of time as significant barriers to engaging in shared decision-making (67). As a result, despite over 75% of physician respondents agreeing with the benefits of LDCT screening for high-risk individuals, only 5% reported using the CMS billing code for shared decision-making reimbursement (67). Other studies have also highlighted time constraints and perceived challenges with patient comprehension of screening as critical barriers in the effective shared decision-making process (68,69).

Improving access to LDCT screening in underserved populations

We previously highlighted the geographic and transportation challenges disproportionately experienced by underserved patients seeking to access LDCT screening facilities. Consistent with these disparities, surveys of underserved patients and their providers have consistently identified perceived financial costs as a potentially prohibitive factor against willingness to undergo LDCT screening (57,70,71). Adding validity to these concerns, Febbo *et al.* recently estimated that the average out-of-pocket costs associated with LDCT screening at accredited imaging centers is \$583 (range, \$49–2,409) (72).

To combat this financial burden, some groups have trialed free screening services for at-risk patients. McKee *et al.* described their experience with the first major free screening service beginning shortly after the NCCN adopted screening guidelines in 2012 (73). In 10 months, their group successfully screened a total of 500 patients, yielding a positivity rate similar to that of the NLST (73). Their work has served as proof of concept for subsequent efforts. More recently, a second analysis by Simmerman *et al.* validated the previous success described by McKee *et al.* (74). They screened 264 individuals in their program and had a 2.2% lung cancer detection rate (*vs.* 1.1% in

NLST), of which 63% were stage I tumors (*vs.* 63% in NLST) (74). Concerns regarding the profitability of free screening programs have also recently been addressed. After 2.5 years of an institutional free screening program guided by the NCCN screening inclusion criteria, Chung *et al.* conducted a profitability analysis and found a \$212 gross margin per encounter (75). The authors found that this revenue was primarily driven by downstream surgical interventions, as 74% of their screening cohort had operable lesions (75). While this analysis underscores the importance of close patient follow-up to achieve optimal financial and clinical benefits from free screening, the generalizability of the profit analysis performed by Chung *et al.* may be limited by the high rate of follow-up in their sample (59% of LDCT screens associated with downstream referrals, follow-ups, or interventions) (75).

In addition to free screening programs, some studies have proposed using mobile screening units to improve patient access to LDCT. Raghavan *et al.* published preliminary data describing the use of a mobile LDCT unit as a means of screening 550 uninsured/Medicaid insured patients (76). Of the 12 (2.2%) individuals with identifiable lung cancer, 6 (50%) were found to have surgically amenable disease and were able to successfully undergo resection with curative intent (76). A second pilot analysis by Headrick *et al.* showed similar success screening 548 high risk individuals with a mobile LDCT unit (77). Despite only having a positivity rate of 1%, because 80% of positive cases were early stage tumors managed by surgery or stereotactic body radiation therapy, Headrick *et al.*'s mobile program maintained the ability to generate a revenue (77). In addition to patients with identified lung cancer, 51 individuals were found to have significant pulmonary findings (Lung-RADS 3 or 4) by LDCT screening (77). Of these, 67% followed up for further testing as advised (77). Collectively, these studies demonstrate that with appropriate patient follow-up, free or mobile LDCT screening programs can potentially serve as clinically effective and commercially viable options to improve lung cancer screening availability for underserved patients.

Conclusions

LDCT screening is an effective approach for the early detection of lung cancer and the reduction of lung cancer specific mortality in high risk individuals. However, the utilization of LDCT screening in clinical practice has been slow, with current estimates suggesting that ~12% of eligible individuals in the United States receive appropriate

screening. Significant disparities in the use of LDCT have been described among black patients, rural patients, and other underserved populations. There have been several proposed efforts to mitigate these disparities, including raising awareness of LDCT screening benefits among healthcare providers, improving shared decision-making approaches between patients and providers, and expanding patient access to free and mobile screening programs. As the indications for and utilization of LDCT screening evolve, continued investigations into the causes and outcomes of LDCT disparities are warranted.

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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