Evaluating Lung Cancer Screening Across Diverse Healthcare Systems: A Process Model from the Lung PROSPR Consortium

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ABSTRACT

Numerous organizations, including the United States Preventive Services Task Force, recommend annual lung cancer screening (LCS) with low-dose CT for high risk adults who meet specific criteria. Despite recommendations and national coverage for screening eligible adults through the Centers for Medicare and Medicaid Services, LCS uptake in the United States remains low (<4%). In recognition of the need to improve and understand LCS across the population, as part of the larger Population-based Research to Optimize the Screening PRocess (PROSPR) consortium, the NCI (Bethesda, MD) funded the Lung PROSPR Research Consortium consisting of five diverse healthcare systems in Colorado, Hawaii, Michigan, Pennsylvania, and Wisconsin. Using various methods and data sources, the center aims to examine utilization and outcomes of LCS across diverse populations, and assess how variations in the implementation of LCS programs shape outcomes across the screening process. This commentary presents the PROSPR LCS process model, which outlines the interrelated steps needed to complete the screening process from risk assessment to treatment. In addition to guiding planned projects within the Lung PROSPR Research Consortium, this model provides insights on the complex steps needed to implement, evaluate, and improve LCS outcomes in community practice.

Introduction

Annual lung cancer screening with low-dose CT (LDCT) is recommended for high risk adults that meet specific age, smoking, and health status criteria. In 2013, reflective of the potential benefits (estimated 20% reduction in lung cancer–related death; ref. 1) and harms (false positives and potential radiation exposure; ref. 2), the United States Preventive Services Task Force (USPSTF) provided a Grade "B" recommendation for lung cancer screening with LDCT enabling coverage without cost sharing (3). In 2015, the Centers for Medicare and Medicaid Services (CMS) established criteria for national screening coverage (4). Although lung cancer screening has been implemented in a variety of settings around the country (5, 6), uptake remains low (7). Early experiences suggest that the outcomes of lung cancer screening in community settings may differ from trial outcomes (8), potentially due to differences in the characteristics of people screened (5, 9) or interpretation of findings (2). Thus, uncertainties about the benefits, harms, and costs of lung cancer screening in community practice remain.

In recognition of the need to improve lung and other types of cancer screening, in 2018, the NCI funded the large multisite consortium, Population-based Research to Optimize the Screening PRocess (PROSPR). The overall aim of PROSPR is to conduct multi-site, coordinated, transdisciplinary research to evaluate and improve cervical, colorectal, and lung cancer screening processes. Within the Lung PROPSR Research Consortium, titled Lung cancer screening Optimization in The United States (LOTUS), we aim to assess utilization and outcomes of lung cancer screening across five diverse community-based healthcare systems and

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to identify key challenges and opportunities to optimize impact. Central to these efforts is understanding how variations in practice and other contextual factors shape the cancer screening process and its outcomes. In this commentary, we provide an overview of the lung cancer screening landscape in the United States including lung cancer burden, evidence and gaps, and implementation challenges. Building upon this landscape, we present our lung cancer screening process model to describe the interrelated steps needed to provide high-quality screening in community settings. Finally, we describe the five healthcare systems that comprise LOTUS and introduce planned research within the consortium aimed at improving lung cancer screening processes and outcomes, and reducing health disparities.

Lung cancer screening landscape

Lung cancer: burden, risk, and disparities

Lung cancer is the largest cause of cancer-related deaths, and disproportionately affects populations that are already burdened by high poverty rates and low education levels (10, 11). An estimated 142,670 people in the United States will die from lung cancer in 2019, representing nearly 25% of all U.S. cancer-related deaths in the United States (11). Although modest improvements in incidence and mortality rates have occurred over the last decade, 5-year relative survival for lung cancer remains among the lowest of all cancer types (11).

Despite improvements at the population level, disparities in lung cancer persist across racial, geographic, and socioeconomic groups (10, 11). Overall, incidence and mortality rates are highest in non-Hispanic Black men, and Black men have a higher proportion of cancer cases diagnosed at distant stages and lower survival rates than non-Hispanic White men (11). Lung cancer also has the largest geographic variation across cancer types. For example, incidence rates in Kentucky are approximately 3.5 times higher than those in Utah, which corresponds with overall state-level smoking prevalence (11, 12). Geographic distributions of mortality are closely linked with other social determinants of health including higher levels of socioeconomic deprivation and rurality (10, 11).

Differences in lung cancer rates across groups are largely reflective of underlying differences in the primary risk factor, smoking, which accounts for an estimated 85% of all lung cancer–related deaths (13). Among U.S. adults, the prevalence of cigarette smoking decreased from 20.9% in 2005 to 15.5% in 2016, but remains higher among males and adults with lower education levels (12). American Indians and Alaskan Natives, those living in poverty, and sexual and gender minorities also have higher rates of smoking (12, 14). Besides smoking, differences in quality and timeliness of treatment received (15) and patient and provider awareness of guidelines (16) also contribute to disparities across the care continuum, underscoring the need to identify and target underlying mechanisms across individual, healthcare system, and community levels to reduce inequities.

Lung cancer screening: evidence, guidelines, and gaps

Early attempts to develop lung cancer screening date back to the 1950s, beginning with photofluorograms and expanding to chest radiographs (17). Four screening trials in the 1970s–1980s, and the Prostate, Lung, Colorectal and Ovarian trial in the 1990s found no overall benefit of screening with chest radiography and/or sputum cytology (17, 18). In 1999, the Early Lung Cancer Action Project, a single arm study, showed the potential of LDCT to detect nodules (23% CT vs. 7% chest radiography detection rate) and identify early stage lung cancer suitable for resection (19).

Following these findings, the National Lung Screening Trial (NLST) compared screening outcomes for LDCT with chest radiography among heavy smokers. NLST enrolled individuals at 33 U.S. medical centers and randomized them to three annual rounds of LDCT or chest radiography (1). LDCT found 20% and 6.7% reductions, respectively, in the risk of lung cancer–specific and all-cause mortality. Two international trials have recently provided additional evidence of the efficacy of LDCT. The Dutch–Belgian Randomized Lung Cancer Screening Trial (NELSON) reported preliminary results indicating similar reductions in mortality as the NLST (20) and the Multicentric Italian Lung Detection trial found even greater reductions (39%) in lung cancer–related mortality (21).

Although there is growing evidence of the efficacy of LDCT, uncertainty regarding the benefits, harms, and costs of screening in community settings exist. Even in controlled settings, serious harms of lung cancer screening have been reported including high false positive and complication rates (2). Early evidence indicates that these harms may be higher in community settings (8). Furthermore, over 75% of NLST participants were evaluated at NCI-designated cancer centers (2), and only 4.5% of all participants were Black (1). As such, the generalizability and downstream consequences of the NLST findings including differential rates of annual screening eligibility for Blacks (9) have been raised.

Lung cancer screening guidelines

Despite potential uncertainties, based on NLST results (1) and decision modeling (22), several organizations released recommendations for annual LDCT screening beginning in 2012. Notably, in 2013, a Grade B USPSTF recommendation (3) enabled coverage for LDCT without cost sharing for privately insured people as mandated by the Affordable Care Act. In 2015, CMS established national screening coverage for high risk adults, requiring for the first time that shared decision making and tobacco cessation counseling occur prior to cancer screening (4). However, specific eligibility criteria are complex and vary across guidelines. As such, there is strong need to understand how variations in the screening process across healthcare systems impact utilization, outcomes, and equity of lung cancer screening.

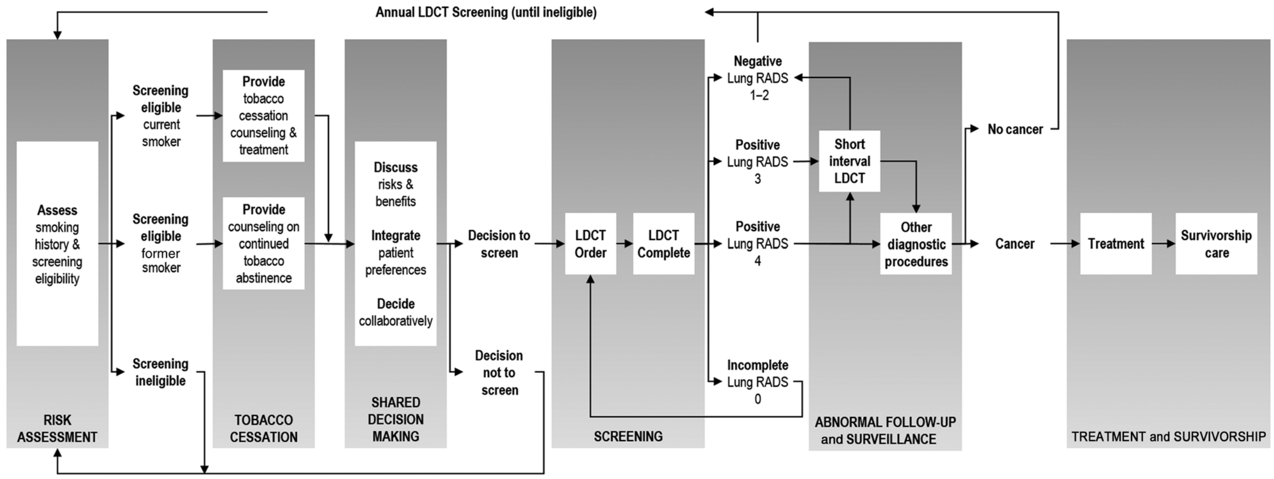

Figure 1.
PROSPR lung cancer screening process model. Visual model depicting interrelated steps across the lung cancer screening process.

Materials and Methods

Lung cancer screening process model

Similar to other cancer screening processes (23), the lung cancer screening process requires the coordination and completion of multiple steps to be effective. Failures at any step undermine the benefits of screening, and if these failures occur more often in medically underserved populations, they may further exacerbate cancer-related disparities. Given the specificity of screening eligibility and variations in guidelines for lung cancer screening, completion and quality of the screening process may be variable across systems. To guide research across the process, we developed the PROSPR lung cancer screening process model (**Fig. 1**) that draws upon previously published PROSPR screening models in breast, cervical, and colorectal cancer screening (23) and prior conceptual work. Below we describe each stage and aligned recommended practices for improving implementation and quality of care (6, 24). Central to each stage is the need to accurately assess and document relevant data (such as smoking status, shared decision making, or follow-up recommendations) in the medical record. In LOTUS, this process model will guide efforts to understand how differences across multiple levels, including patients, providers, healthcare systems, and communities, impact outcomes across the continuum of lung cancer care. The model will also help to identify potential targets for interventions to help improve quality, reach, and equity of lung cancer screening.

Results

Risk assessment

Lung cancer screening begins with accurate risk assessment. Ideally all patients are routinely assessed for smoking status and history (including smoking frequency, pack-years, and quit date) at all points of care. Risk assessment for lung cancer screening may also include an evaluation of overall health status, family history of lung cancer, and high-risk occupational exposures.

Tobacco cessation counseling and treatment

Primary prevention through tobacco cessation among current smokers is a cornerstone to help reduce lung cancer incidence, improve quality and life expectancy, and reduce health costs (13). As such, tobacco cessation is recommended to be incorporated into all lung cancer screening programs. All patients who are current smokers should be offered personalized treatment options, and former smokers provided counseling on the importance of continued smoking abstinence.

Shared decision making

Shared decision making is a collaborative process where providers and patients discuss, deliberate, and decide upon the best approach for care (25, 26). CMS requires shared decision making for baseline lung cancer screening and also provides reimbursement for shared decision making counseling. High-quality shared decision making requires clear communication of the potential benefits and risks of screening, support for patients to communicate their goals, and collaborative decision making by which patients and providers come together to make an informed decision concordant with patients' values (25, 26). There are several decision support tools available for lung cancer screening that may help guide shared decision making, but alone do not constitute shared decision making (26).

LDCT screening

Once a patient is identified as eligible and interested in screening, an order should be placed and tracked to ensure that the patient receives a timely LDCT at an accredited location. Prior to screening, eligibility, documentation of shared decision making, and tobacco cessation counseling should be confirmed. To minimize harms, lung cancer screening scans must be performed with a low-dose technique (3).

The American College of Radiology (ACR) recommends that LDCT scans have a volume CT dose index of 3 mGy or lower and an effective dose of 1 mSv or lower (24). Following completion of LDCT, results should be communicated directly to patients and to their provider team in a timely manner. In accordance with the ACR, LDCT findings should be categorized by the Lung-RADS system [incomplete (0), negative (1), benign appearance or behavior (2), probably benign (3), and suspicious (4-A/B/X)] and include any modifiers for clinically significant non-lung cancer findings ("S"; ref. 24). Lung-RADS, nodule characteristics, follow-up recommendations, and incidental findings should be documented systematically in a radiology report. At present, Lung-RADS employs a categorization strategy based on baseline nodule diameter and change over time (24); however, there is emerging evidence regarding the use of volumetric measurement (27). In LOTUS, we will leverage our established consortium to track and assess any changes to evaluation of nodules, cancer staging, or any other aspects of lung cancer care that may occur in the future.

Diagnostic follow-up, treatment, and survivorship

Coordinated, multilevel approaches should be used to ensure that all patients with positive results (defined as Lung-RADS 3 or greater) receive appropriate follow-up or diagnostic care as recommended by professional guidelines, and that all patients with negative results return for annual screening until no longer eligible (6, 24). Patients with significant incidental findings, such as coronary arterial calcification, pulmonary fibrosis, aortic aneurysm, and nonpulmonary nodules and masses (e.g., thyroid and kidney), should receive appropriate care in a timely manner. For patients who are diagnosed with lung cancer, care teams and healthcare systems should coordinate care and track outcomes. Once patients have completed treatment, comprehensive survivorship care should be provided and coordinated between patients' primary care and oncology teams.

Discussion

Implementation of lung cancer screening into community practice is complex and challenging, accentuated by the need to interface and coordinate with different provider teams to complete the process. A substantial challenge is lack of accurate documentation of smoking status and history. Although commonly used electronic health records (EHRs) allow for discrete capture of smoking status, lack of detailed capture (e.g., pack-years) remains common (28). In addition, some patients may be hesitant to disclose smoking status, reducing the accuracy and completeness of documented data (28). Another key challenge is integration of tobacco cessation counseling into the process (25). Smoking cessation on its own can be challenging to implement. Integrating it within lung cancer screening adds challenges (25), but also offers opportunities to deliver behavioral counseling and initiate pharmacotherapeutic approaches to achieve cessation (26). Personalized approaches to tobacco treatment may help to support smoking cessation in the context of lung cancer screening (26).

Implementation of shared decision making is an often cited barrier to lung cancer screening (16, 26). Evidence suggests that the quality and frequency of shared decision making discussions are limited (29). Limited time to engage in the process is reported as a barrier among providers, even in fee-for-service settings where reimbursement for counseling may be available (16, 29). Other challenges include lack of familiarity with guidelines, competing priorities, and integration into clinical workflows (16). As such, there is great need to develop effective strategies for integrating high quality shared decision making into lung cancer screening that ensures patient-centered care while aligning with clinical workflows and demands.

There is a concern that the evaluation and management of patients with screen-detected lung nodules will vary considerably across providers and healthcare systems, resulting in outcomes that differ from the remarkably low rate of invasive procedures and downstream complications observed in the NLST (5, 8, 9). Variation in the detection and management of screen-detected nodules has the potential to lead to higher rates of harms including false positives, subsequent imaging, inappropriate use of functional imaging (e.g., FDG-PET), and an increased number of invasive procedures, with inherent risk of harm (2, 8). Therefore, documenting and evaluating the variation in management of patients and subsequent outcomes in community practices is key to ensuring screening guidelines are informed by and adequately communicate the potential harms and benefits of screening.

A related challenge is managing costs associated with incidental findings, false positives, and complications resulting from lung cancer screening (5, 8, 9). Although lung cancer screening itself may be covered, downstream care may result in high costs to both the patient and the healthcare system (8, 30). These costs serve as potential barriers to care, particularly among underserved communities. To address cost and other barriers, tailored and collaborative approaches between healthcare systems and the communities they serve are needed to ensure that lung cancer screening reduces, rather than increases, persistent disparities in lung cancer—an overarching goal of LOTUS.

Lung PROSPR research consortium: LOTUS

The goal of the Lung PROSPR Research Consortium, LOTUS, is to address lung cancer disparities by evaluating utilization and outcomes of the LDCT screening across diverse populations. Drawing upon a network of interdisciplinary scientists with expertise in lung cancer screening, tobacco cessation, healthcare delivery, and disparities research, LOTUS aims to conduct observational and interventional studies across five heterogeneous healthcare systems (**Table 1**). The healthcare systems in LOTUS include Henry Ford Health System (HFHS), Kaiser Permanente Colorado (KPCO), Kaiser

Table 1. LOTUS healthcare system characteristics and lung cancer screening programs.

	HFHS	KPCO	KPHI	MCHS	UPHS
Healthcare system characteristics					
Region	Metropolitan Detroit	Denver/Boulder Front Range	Oahu, Hawaii Island, Maui, Kauai	Central, North Central, and Northwestern Wisconsin	Philadelphia, Greater Delaware Valley
State(s)	Michigan	Colorado	Hawaii	Wisconsin, Michigan	Pennsylvania, New Jersey, Delaware
Type of care	Mixed model	Managed care	Managed care	Mixed model	Mixed model
NCI-designated[a] cancer center	No	No	No	No	Yes
Teaching intensity[a]	Major	Minor	Minor	Nonteaching	Major
State-level smoking prevalence[b]	20.4%	15.6%	13.1%	17.1%	18.0%
State-level lung cancer incidence[c] (per 100,000)	65.6	43.3	46.2	60.0 (WI)	64.7 (PA)
State-level lung cancer–related mortality[d] (per 100,000)	48.5	30.2	31.6	43.0 (WI)	45.2 (PA)
Lung cancer screening program					
Program launch	April 1, 2012	January 1, 2014	January 9, 2015	April 1, 2014	May 1, 2014
Risk assessment and screening eligibility	Centralized assessment	Centralized assessment	Provider-driven assessment	Provider-driven assessment	Provider-driven assessment
	Ordering provider documents eligibility at order	Ordering provider documents eligibility at order	Navigator confirms eligibility at order	Ordering provider documents eligibility at order	Navigator confirms eligibility at scheduling
Tobacco cessation counseling	Performed by the ordering provider or navigator	Performed by the ordering provider	Performed by the ordering provider or navigator	Performed by the ordering provider	Performed by the ordering provider
Shared decision making	Centralized SDM clinic	Performed by the ordering provider	Performed by navigator	Performed by the ordering provider	Performed by the ordering provider
LDCT order	Primary care or specialty provider can place order	Provider referral to navigator, who places order	Provider referral to navigator, who places order	Primary care or specialty provider can place order	Primary care or specialty provider can place order
Reporting results	Sent by navigator to patient and primary care provider	Sent by navigator to patient and primary care provider	Sent by navigator to patient and primary care provider	Sent to ordering provider to be discussed with patient	Sent to ordering provider to be discussed with patient
Monitoring follow-up and treatment	Outreach and tracking by navigator	Decentralized	Outreach and tracking by navigator	Outreach and tracking by radiology	Decentralized

[a]Agency for Healthcare Research and Quality (AHRQ). Compendium of U.S. Health Systems, 2016. AHRQ Pub. No. 17–0046–1-EF: September 2017.
[b]Centers for Disease Control and Prevention. 2011–2016 State Tobacco Activities Tracking and Evaluation System. BRFSS Survey Data; 2017.
[c]U.S. Department of Health and Human Services, NIH, NCI. State Cancer Profiles, Incidence Rate Report by State, Lung and Bronchus, 2011–2015; 2018.
[d]U.S. Department of Health and Human Services, NIH, NCI. State Cancer Profiles, Death Rate Report by State, Lung and Bronchus, 2011–2015; 2018.

Permanente Hawaii (KPHI), Marshfield Clinic Health System (MCHS), and University of Pennsylvania Health System (UPHS). Diversity and size of our patient populations (**Table 2**) and variations in the implementation of lung cancer screening across our systems (**Table 1**) will enable understanding of how patient, provider, and system-level differences shape utilization and outcomes. Drawing from feedback from key stakeholders, screening policies and processes will be tracked over time to understand how local and national changes impact outcomes across community settings.

To achieve our goals, LOTUS will conduct analyses across four interrelated research projects designed to: (i) characterize utilization and patterns of care across the screening process, (ii) estimate the benefits, harms, and costs of lung cancer screening, (iii) evaluate the uptake and impact of smoking cessation counseling within lung cancer screening, and (iv) advance the precision of lung cancer screening risk assessment and treatment. Analyses within these projects will help to inform development and testing of pilot interventions across our systems. To support these analyses, EHR data across our systems will be pooled and harmonized to build a state-of-the-art data repository that captures lung cancer screening and treatment outcomes, and the multilevel factors that influence the screening process. Multilevel data will include characteristics of patients (e.g., demographics, comorbidities, smoking behaviors, and social determinants of health), providers (e.g., demographics, clinical specialties, and patient panels), and healthcare systems (e.g., payer

Table 2. LOTUS primary care patient characteristics by healthcare system, 2010–2017.

	HFHS		KPCO		KPHI		MCHS		UPHS	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Patient population	532,286	100.0	575,206	100.0	253,700	100.0	173,061	100.0	279,949	100.0
Age										
35–44 years	185,484	34.9	213,809	37.2	98,561	38.9	52,302	30.2	84,919	30.3
45–54 years	139,475	26.2	148,246	25.8	66,225	26.1	40,242	23.3	70,330	25.1
55–64 years	107,799	20.3	126,682	22.0	53,210	21.0	38,892	22.5	62,715	22.4
65–79 years	76,980	14.5	70,572	12.3	28,275	11.2	31,380	18.1	49,098	17.5
80+ years	22,548	4.2	15,897	2.8	7,429	2.9	10,245	5.9	12,887	4.6
Sex										
Female	297,572	55.9	301,500	52.4	125,771	49.6	92,091	53.2	159,597	57.0
Male	234,697	44.1	273,700	47.6	127,929	50.4	80,970	46.8	120,352	43.0
Race/ethnicity										
Asian/Pacific Islander	16,353	3.1	20,170	3.5	128,548	50.7	1,632	0.9	11,222	4.0
Non-Hispanic Black	141,606	26.6	23,096	4.0	2,861	1.1	556	0.3	66,536	23.8
Hispanic	11,983	2.3	77,428	13.5	8,475	3.3	2,635	1.5	8,065	2.9
Native American	2,004	0.4	3,731	0.7	3,067	1.2	723	0.4	256	0.1
Non-Hispanic White	302,382	56.8	348,632	60.6	68,435	27.0	148,024	85.5	176,950	63.2
Multiple/Other	8,323	1.6	18,137	3.2	0	0.0	485	0.3	8,615	3.1
Unknown	49,635	9.3	84,012	14.6	42,314	16.7	19,006	11.0	8,305	3.0
Insurance type										
Commercial	393,608	73.9	366,663	63.7	188,963	74.5	109,929	63.5	169,938	60.7
Medicaid	29,322	5.5	19,747	3.4	11,808	4.7	22,001	12.7	16,482	5.9
Medicare	99,019	18.6	65,327	11.4	22,684	8.9	37,420	21.6	86,224	30.8
Other insurance	8,629	1.6	118,696	20.6	30,245	11.9	3,711	2.1	7,296	2.6
Smoking status										
Never smoker	222,826	41.9	303,769	52.8	130,352	51.4	87,860	51.0	181,279	58.1
Former smoker	120,141	22.6	148,060	25.7	59,576	23.5	38,978	22.5	90,245	28.9
Current smoker	66,765	12.5	59,623	10.4	28,478	11.2	29,202	16.9	33,363	10.7
Unknown	122,554	23.0	63,754	11.1	35,294	13.9	17,021	9.8	7,043	2.3
LDCT scans										
2014	277	0.1	536	0.1	0	0.0	0	0.0	70	0.0
2015	261	0.1	1,176	0.2	0	0.0	7	0.0	164	0.1
2016	837	0.2	1,892	0.3	393	0.2	278	0.2	327	0.1
2017	1,595	0.3	2,623	0.5	484	0.2	353	0.2	501	0.2
Rural urban commuting area‡										
Metropolitan	513,859	96.5	571,851	99.4	188,890	74.5	39,871	23.0	276,749	98.9
Micropolitan	1,255	0.2	1,319	0.2	51,716	20.4	56,933	32.9	919	0.3
Low density	1,774	0.3	1,958	0.4	13,015	5.1	73,952	42.7	395	0.1
Median household income (census tract)‡										
$24,500 or less	45,068	8.5	85	0.0	3,662	1.4	2,305	1.3	7,202	2.6
$24,501–$50,000	188,075	35.3	2,372	0.4	1,810	0.7	305	0.2	14,202	5.1
$50,001–$100,000	244,609	46.0	132,693	23.1	40,670	16.0	89,629	51.8	56,281	20.1
$100,001–$200,000	39,062	7.3	342,591	59.6	186,677	73.6	80,756	46.7	124,930	44.6
$200,000 or more	0	0.0	96,719	16.8	20,881	8.2	66	0.0	75,986	27.1
Proportion of households at or below the Federal Poverty Limit (census tract)‡										
9.99% or less	289,333	54.3	549,402	95.5	187,479	73.9	75,425	43.6	194,318	69.4
10%–24.99%	130,278	24.5	25,719	4.5	53,011	20.9	91,827	53.1	47,982	17.1
25% or more	97,169	18.3	1	0.0	9,554	3.8	3,504	2.0	30,448	10.9
Proportion of adults with a 4-year college degree or higher (census tract)‡										
9.99% or less	95,335	17.9	22,807	4.0	8,029	3.2	6,473	3.7	16,426	5.9
10%–24.99%	194,880	36.6	107,048	18.6	98,329	38.8	119,396	69.0	61,627	22.0
25% or more	226,616	42.6	445,269	77.4	143,708	56.6	44,887	25.9	194,769	69.6

Note: Unless indicated by a double dagger (‡), data are from patient medical record. Census tract indicators (‡) use 2011–2015 American Community Survey Data and are based on patient's most recent listed address. Entry into the healthcare system is defined by first year of healthcare plan enrollment (HFHS, KPCO, KPHI, and MCHS) or primary care visit within the healthcare system (UPHS and HFHS). LDCT scans are limited to patients who have entered the system. Age is at the time of healthcare system entry, and patients younger than age 35 and older than age 90 are excluded. Insurance status is determined at time of healthcare system entry (KPCO, KPHI, and MCHS) or most recent visit (UPHS and HFHS). Smoking status is based on most recent visit for all systems. Percentages of census data or insurance do not total 100% due to missing data.

structure and screening policies). Utilization of subsequent imaging, diagnostic tests, and invasive procedures after screening, and details on surgical resection, chemotherapy, and radiation for patients with lung cancer will be evaluated. For active smokers, we will assess provision of tobacco cessation counseling and use of pharmacotherapy. We will also examine the prevalence and impact of process factors, such as shared decision making and patient outreach, on screening utilization and outcomes. The combination of observational data analysis, contextual data, and intervention development will enable LOTUS to advance scientific understanding and implementation of lung cancer screening in community practice that can be extended beyond our five healthcare systems.

Conclusion

Lung cancer screening programs have the potential to substantially decrease lung cancer–related mortality through tobacco cessation, early detection, and treatment, yet uncertainties regarding outcomes in community settings remain. Because of the complexity of screening eligibility and other factors, there are challenges to implementing lung cancer screening in community practices and a pressing need to identify effective strategies for overcoming these barriers. The PROSPR lung cancer screening process model presented in this article serves to conceptualize the components necessary to support high quality lung cancer screening, and to encourage others to use this framework to understand and improve lung cancer screening outcomes across diverse settings.

Disclosure of Potential Conflicts of Interest

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Disclaimer

The contents are solely the responsibility of the authors and do not represent the official views of the NIH or the USPSTF.

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References

1. National Lung Screening Trial Research Team. Reduced lung-cancer mortality with low-dose computed tomographic screening. N Engl J Med 2011;365:395–409.
2. Bach PB, Mirkin JN, Oliver TK, Azzoli CG, Berry D, Brawley OW, et al. Benefits and harms of CT screening for lung cancer: a systematic review. JAMA 2012;307:2418–29.
3. Moyer VA, U.S. Preventive Services Task Force. Screening for lung cancer: U.S. Preventive Services Task Force recommendation statement. Ann Intern Med 2014;160:330–8.
4. Centers for Medicare & Medicaid Services. Decision memo for screening for lung cancer with low dose computed tomography (LDCT). 2015. Available from: https://www.cms.gov/medicare-coverage-database/details/nca-decision-memo.aspx?NCAId=274.
5. Gould MK, Sakoda LC, Ritzwoller DP, Simoff M, Neslund-Dudas C, Kushi LH, et al. Monitoring lung cancer screening use and outcomes at four Cancer Research Network sites. Ann Am Thorac Soc 2017;14:1827–35.
6. Thomson CC, Mckee AB. American Thoracic Society/American Lung Association lung cancer screening implementation guide. Am J Respir Crit Care Med 2018;198:1120–1.
7. Jemal A, Fedewa SA. Lung cancer screening with low-dose computed tomography in the United States-2010 to 2015. JAMA Oncol 2017;3:1278–81.
8. Huo J, Xu Y, Sheu T, Volk RJ, Shih Y-CT. Complication rates and downstream medical costs associated with invasive diagnostic procedures for lung abnormalities in the community setting. JAMA Intern Med 2019;179:324–32.
9. Iaccarino JM, Steiling KA, Wiener RS. Lung cancer screening in a safety-net hospital: implications of screening a real-world population versus the National Lung Screening Trial. Ann Am Thorac Soc 2018;15:1493–5.
10. Finke I, Behrens G, Weisser L, Brenner H, Jansen L. Socioeconomic differences and lung cancer survival—systematic review and meta-analysis. Front Oncol 2018;8:536.

11. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2019. CA Cancer J Clin 2019;69:7–34.
12. Jamal A, Phillips E, Gentzke AS, Homa DM, Babb SD, King BA, et al. Current cigarette smoking among adults - United States, 2016. MMWR Morb Mortal Wkly Rep 2018;67:53–9.
13. Chyou PH, Nomura AM, Stemmermann GN. A prospective study of the attributable risk of cancer due to cigarette smoking. Am J Public Health 1992;82:37–40.
14. Drope J, Liber AC, Cahn Z, Stoklosa M, Kennedy R, Douglas C, et al. Who's still smoking? Disparities in adult cigarette smoking prevalence in the United States. CA Cancer J Clin 2018;68:106–15.
15. Wolf A, Alpert N, Tran BV, Liu B, Flores R, Taioli E. Persistence of racial disparities in early-stage lung cancer treatment. J Thorac Cardiovasc Surg 2019;157:1670–9.
16. Eberth JM, McDonnell KK, Sercy E, Khan S, Strayer SM, Dievendorf AC, et al. A national survey of primary care physicians: perceptions and practices of low-dose CT lung cancer screening. Prev Med Rep 2018;11:93–9.
17. Ruparel M, Quaife SL, Navani N, Wardle J, Janes SM, Baldwin DR. Pulmonary nodules and CT screening: the past, present and future. Thorax 2016;71:367–75.
18. Oken MM, Hocking WG, Kvale PA, Andriole GL, Buys SS, Church TR, et al. Screening by chest radiograph and lung cancer mortality: the Prostate, Lung, Colorectal, and Ovarian (PLCO) randomized trial. JAMA 2011;306:1865–73.
19. Henschke CI, McCauley DI, Yankelevitz DF, Naidich DP, McGuinness G, Miettinen OS, et al. Early lung cancer action project: overall design and findings from baseline screening. Lancet 1999;354:99–105.
20. de Koning H, Van Der Aalst C, Ten Haaf K, Oudkerk M. PL02.05 effects of volume CT lung cancer screening: mortality results of the NELSON randomized-controlled population based trial. J Thorac Oncol 2018;13:S185.
21. Pastorino U, Silva M, Sestini S, Sabia F, Boeri M, Cantarutti A, et al. Prolonged lung cancer screening reduced 10-year mortality in the MILD trial: new confirmation of lung cancer screening efficacy. Ann Oncol 2019;30:1162–9.
22. de Koning HJ, Meza R, Plevritis SK, ten Haaf K, Munshi VN, Jeon J, et al. Benefits and harms of computed tomography lung cancer screening strategies: a comparative modeling study for the U.S. Preventive Services Task Force. Ann Intern Med 2014; 160:311–20.
23. Beaber EF, Kim JJ, Schapira MM, Tosteson ANA, Zauber AG, Geiger AM, et al. Unifying screening processes within the PROSPR consortium: a conceptual model for breast, cervical, and colorectal cancer screening. J Natl Cancer Inst 2015;107: djv120.
24. American College of Radiology. Lung CT screening reporting and data system (Lung-RADS): version 1.1 assessment categories. 2019. Available from: https://www.acr.org/Clinical-Resources/Reporting-and-Data-Systems/Lung-Rads.
25. Elwyn G, Durand MA, Song J, Aarts J, Barr PJ, Berger Z, et al. A three-talk model for shared decision making: multistage consultation process. BMJ 2017;359:j4891.
26. Lowenstein LM, Deyter GMR, Nishi S, Wang T, Volk RJ. Shared decision-making conversations and smoking cessation interventions: critical components of low-dose CT lung cancer screening programs. Transl Lung Cancer Res 2018;7:254–71.
27. Han D, Heuvelmans MA, Oudkerk M. Volume versus diameter assessment of small pulmonary nodules in CT lung cancer screening. Transl Lung Cancer Res 2017;6:52–61.
28. Modin HE, Fathi JT, Gilbert CR, Wilshire CL, Wilson AK, Aye RW, et al. Pack-year cigarette smoking history for determination of lung cancer screening eligibility. Comparison of the electronic medical record versus a shared decision-making conversation. Ann Am Thorac Soc 2017;14:1320–5.
29. Brenner AT, Malo TL, Margolis M, Elston Lafata J, James S, Vu MB, et al. Evaluating shared decision making for lung cancer screening. JAMA Intern Med 2018;178:1311–6.
30. Rai A, Doria-Rose VP, Silvestri GA, Yabroff KR. Evaluating lung cancer screening uptake, outcomes, and costs in the United States: challenges with existing data and recommendations for improvement. J Natl Cancer Inst 2019;111:342–9.