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Characteristics associated with early vs. late adoption of lung cancer screening

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ABSTRACT

Background: Although lung cancer screening (LCS) reduces lung cancer mortality among high-risk individuals, uptake overall remains low. With all cancer screening modalities, a period of diffusion among medical providers and the public is expected, with screening uptake exhibiting a distribution among early vs. late adoption. We aimed to characterize individuals undergoing LCS based upon the timeframe of screening adoption.
Methods: This retrospective study examined patients who underwent LCS between January 2015 – December 2022 in a centralized LCS program. Based on United States Preventive Services Task Force (USPSTF) criteria for LCS, early and late adopters of LCS – defined by time from eligibility to screening completion – were compared. A multivariable regression model was constructed to identify factors associated with early adoption of LCS.
Results: Among patients screened during the study period, 90.4% were eligible based on USPSTF 2013 criteria, and 9.6% were eligible based on USPSTF 2021 criteria. Of the USPSTF 2013 eligible persons, multivariable analysis demonstrated Black/African-American individuals and current smokers had significantly greater odds of early adoption (aOR 1.428 and 1.514, respectively). Those without a family history of lung cancer or without a personal history of cancer had significantly lower odds of early adoption of LCS.
Conclusions: Early adopters were more likely to report Black/African-American race or current smoking status after adjustment for covariates. Future research should examine how screening diffuses across the overall LCS-eligible population, as well as identify factors that drive and inhibit diffusion to create programs and policies with the ultimate goal of increasing timely LCS uptake.

1. Introduction

Lung cancer has been the leading cause of cancer-related mortality in the United States for over seventy years for men and over thirty years for women (Ridge et al., 2013; Ferlay et al., 2010). Landmark studies including the National Lung Screening Trial (NLST) and NELSON have highlighted the importance of annual lung cancer screening (LCS) with low-dose computed tomography (LDCT), which offers a relative reduction in lung cancer mortality risk of 20 % (Aberle et al., 2011). Subsequently, the United States Preventive Services Task Force (USPSTF) recommended annual lung cancer screening using LDCT for persons 55 to 80 years, have a 30-pack-year or more smoking history, and currently smoke or have quit within the past 15 years, meaning an estimated 8 million Americans were eligible for screening (United States Preventive Services Task Force, 2021; Potter et al., 2021). In 2021, the USPSTF updated their guidance (persons starting at age 50 and smoking threshold reduced to 20 pack-years), increasing the estimated number of eligible Americans to 14.2 million (American Lung Association, 2022; Rivera et al., 2020; US Preventive Services Task Force, 2021).

In the decade since the publication of the NLST results, and the later released NELSON trial LCS uptake has slowly increased but remains critically low (Aberle et al., 2011; Zhao et al., 2022). The underutilization of LCS is driven by complex factors and barriers across all levels of the social-ecological model, which can create or widen gaps in care (Shusted and Kane, 2022; Lake et al., 2020; Japuntich et al., 2018; Lin et al., 2014; Zahnd and Eberth, 2019; Castro et al., 2021; Eberth et al.,

Abbreviations: DOI, Diffusion of Innovation; LCS, Lung Cancer Screening; LDCT, Low-Dose CT; USPSTF, United States Preventive Services Task Force; SDM, Shared Decision-Making.

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2018). The expansion of screening eligibility was hoped to increase uptake among high-risk populations and reduce disparities in screening. This is particularly important as Black/African-American individuals, women, and other populations previously experiencing underscreening might experience a greater lung cancer mortality benefit from LCS compared with white men (Rivera et al., 2020; Meza et al., 2021). However, other studies noted that the new USPSTF criteria may widen racial, ethnic, and other disparities (Lozier et al., 2021; Landy et al., 2021). After the expansion of LCS eligibility guidelines, a significant increase of Black/African-American patients was noted at an urban academic medical center, however; there was no change in the rate of other racial or ethnic minorities, women, or individuals with lower levels of educational attainment (Shusted et al., 2022).

A medical innovation such as cancer screening is diffused when a small group within the population begins to use it early, the early adopters, followed by a rapid acceleration among the vast majority of the population, bookended by a small percentage who adopt the innovation at a much later time, the late adopters (Finney Rutten et al., 2004). The diffusion of a medical intervention lies at the intersection of individual characteristics, social identities, outside influences, and predetermined factors. Uptake of any medical revolution depends on how potential adopters perceive the characteristics of the procedure, the perception of other adopters, and the barriers and facilitators to the innovation (Rogers, 1995; Simunovic et al., 2013). The Diffusion of Innovations (DOI) theory has been extensively studied in public health to understand the process by which innovation is passively communicated to members of a social system (Iqbal and Zahidie, 2022). In medicine, dissemination often occurs amongst clinicians first, then moves to a less controlled dissemination to the general public. Thus, buy-in from stakeholders in the medical community is critical (Glanz et al., 2005).

The diffusion of cancer screenings is dependent on the type of procedure as well as the timeline of recommendations being released (Finney Rutten et al., 2004). Evidence-based guidelines for colorectal cancer screening were released in the late 1990s, but by the mid-2000s, diffusion remained only amongst early adopters (Finney Rutten et al., 2004). Rapid acceleration was only achieved once Medicare began covering colonoscopy for average-risk individuals in 2001, and even then, racial disparities remained. By contrast, mammography recommendations were published in the 1980s, and by the mid-2000s, the majority of the population was adherent with mammography guidelines (Finney Rutten et al., 2004; Harewood and Lieberman, 2004).

The DOI theory has been applied to the diffusion and uptake of several cancer-screening tests. However, there is a paucity of data and literature examining DOI in the context of LCS uptake. The objective of this retrospective study was to identify potential differences in those who were early adopters and those who were late adopters of LDCT.

2. Methods

2.1. Lung cancer screening and study population

All patients in this study were enrolled in the Jefferson Lung Cancer Screening Program in Philadelphia. Patients who underwent LCS with LDCT completion between January 2015 and December 2022 were identified through the program's LCS Registry. Between January 2015 and March 2021, the centralized program followed USPSTF 2013 guidelines and NCCN 2015 Group 2 criteria to determine screening eligibility, and from March 2021 onward has followed the expanded USPSTF 2021 guidelines.

The LCS Program carried out LCS between 2015 and 2017 with a single Nurse Navigator who conducted patient outreach, determined eligibility, scheduled appointments, performed shared decision making (SDM) including tobacco treatment, reviewed LDCT results with patients, and coordinated follow-up. Since 2018, the LCS Program has expanded its staffing model and comprehensive screening services at two sites in Philadelphia. Currently, the LCS Program is comprised of: 1) a Coordinator who schedules patients and obtains insurance authorization; 2) two Nurse Navigators who are clinical nurse specialists and assist with SDM, perform tobacco treatment counseling, and review screening results with patients and primary care providers; and 3) a Nurse Practitioner who supervises SDM, organizes diagnostic evaluation for screening patients who require additional testing and procedures, and manages operational aspects of the program. Patients are electronically referred by primary care providers or are self-referred to the LCS Program, and screening eligibility is confirmed by the Coordinator. SDM is carried out by the Nurse Navigator and Nurse Practitioner as described below. All positive screening LDCTs are reviewed by a multidisciplinary team on a weekly basis, and detailed recommendations on management of screen-detected nodules and workup of incidental findings are communicated to both the patient and the referring primary care provider by the Nurse Navigators and Nurse Practitioner. A standardized intake form is used to collect demographic and clinical data at the time of entry into the LCS Program and is updated prospectively with screening results and subsequent workup. Accuracy of entered data is confirmed by rigorous examination, including a random chart review occurring for the entire LCS population, and a full chart review for each patient with a positive LDCT result. Clinical outcomes are updated on a quarterly basis. This multi-site study – including the protocol – was reviewed and approved by the Thomas Jefferson University Institutional Review Board (IRB) with a waiver of informed consent, given the minimal risk nature of the study (IRB Control#, 17D.150).

2.2. Lung cancer screening eligibility

All patients who underwent LCS were confirmed to be eligible upon referral to the program by a dedicated LCS Nurse Navigator. No ineligible patients were enrolled into the program. From January 2015 – March 2021, patients were assessed based on USPSTF 2013 guidelines or NCCN 2015 Group 2 eligibility criteria. In March 2021, the LCS Program expanded screening eligibility criteria consistent with publication of the updated USPSTF 2021 guidelines. For the purposes of this study, the overall cohort was divided into two groups: 1) USPSTF 2013-eligible individuals (including NCCN 2015 Group 2-eligible individuals – defined as individuals aged 50 and older with a 20 pack-year history and an additional risk factor such as personal history or cancer of occupational exposure which increased lung cancer risk such as PLCOm2012 risk to $\geq$ 1.3 %), and 2) USPSTF 2021-eligible individuals, classified to the guideline by which each individual's eligibility occurred first (United States Preventive Services Task Force, 2021; US Preventive Services Task Force, 2021; Wood, 2015; Wood et al., 2018; Tammemagi et al., 2013). Patients that would have been eligible for LCS based on the USPSTF 2021 guidelines prior to 2021, but did not have an additional risk factor to meet NCCN 2015 Group 2 criteria, were considered ineligible until the release of the 2021 guidelines.

2.3. Outcomes

The primary outcome was early adoption of LCS. An early adopter was defined as an individual who completed LDCT within 24 months of being eligible to undergo LCS. Because the institutional LCS program did not begin until 2015, all patients eligible prior to 2015 were assigned 2015 as their first year of eligibility. Late adopters were those who completed LCS more than 24 months after eligibility. First year of eligibility was calculated on an individual level, utilizing each patient's date of birth, smoking history, smoking intensity, and first LDCT scan date. Patient age was adjusted during eligibility calculations utilizing date of birth, aside from classification of early and late adopters, patient age at the time of LCS program enrollment was utilized for analyses. This methodology assumed a static smoking intensity in order to retrospectively calculate eligibility date. All patients enrolled in the LCS Program have a complete smoking history and smoking intensity taken at time of enrollment including age the patient started smoking, current smoking

status, quit date and years since quitting where applicable, years smoked, number of cigarettes per day, pack-years, and additional free text notes. Due to the rigorous data collection methodology of the program, no patients were missing any smoking history data. Patients who were eligible under NCCN Group 2 criteria had eligibility calculated using the same methodology, with the inclusion of PLCOm2012 risk score, personal history of cancer, and family history of lung cancer.

2.4. Statistical analysis

We obtained descriptives, frequencies, and cross-tabulations to summarize the study population. Bivariate analyses, including independent t-tests and chi-square tests, were performed to examine characteristics of the USPSTF 2013 and USPSTF 2021 subgroups. Additional bivariate analyses were performed to assess early and late adopters in both eligibility cohorts. There were no late adopters in the USPSTF 2021 subgroup as the guidelines were released in March 2021 and the study period ended before the eligibility timeframe exceeded 24 months for any patients. Therefore, no comparison of late adopters between cohorts was possible. Bivariate and multivariable logistic regression analyses were conducted to explore predictors of early adoption, including potential confounders of screening uptake. Regression analyses included covariates such as basic demographics (age, gender, ethnicity, race) regardless of significance threshold, other variables were included in the regression analyses if a p-value significance threshold of ≤ 0.100 was reached. Continuous variables (e.g., age) were deployed as linear variables in the model, this characterization was confirmed via bivariate analyses of each variable treated categorically. Variables with a significant proportion of unknown or missing values were excluded from the model. Any variable which the proportion of unknown or missing values were large enough to at least, in part, drive a statistically significant difference were identified as containing a significant proportion of unknown or missing values, and thus excluded from regression analyses. No missing or unknown values were included in the model. All tests were two-sided, using a $p \leq 0.05$ significance threshold. SPSS version 26 was used (IBM Corp., 2019).

3. Results

3.1. Baseline characteristics of LCS Participants

A total of 2,438 unique individuals underwent LCS through the Jefferson Lung Cancer Screening Program during the study period. (Supplemental Table 1). The mean age of the patients was 63.54 ± 6.14, and 56.6 % (n = 1,381) were female. Of the patients screened, 2,204 (90.4 %) were eligible based on USPSTF 2013 criteria, and 234 (9.6 %) were eligible based on USPSTF 2021 criteria. (Fig. 1).

3.2. Sociodemographic characteristics of the USPSTF 2013-Eligible cohort

Among the 2,204 patients in the USPSTF 2013 cohort, the mean age was 63.9 ± 5.93. (Table 1) The majority of the individuals were female (n = 1,249; 56.7 %) and identified as White (n = 1,121; 50.9 %). Among the patients in the USPSTF 2013 cohort, 558 (25.3 %) were early adopters of LCS – completing screening within 24 months of eligibility – and 1,646 (74.7 %) were late adopters – completing screening after 24 months of eligibility. The majority of patients eligible based on USPSTF 2013 criteria underwent LCS between 36 months and 60 months after eligibility. (Fig. 2) Early adopters were significantly younger than late adopters (63.18 ± 6.27 vs. 64.15 ± 5.78; p = 0.001). (Table 1). The early adopter cohort had a significantly greater proportion of Black/African-American individuals (n = 303; 54.3 %) compared to the late adopter cohort (n = 696; 42.3 %) (p < 0.001). Early adopters reported current smoking status more frequently than late adopters, 70.4 % (n = 393) and 59.4 % (n = 978), respectively (p < 0.001). Personal history of cancer and family history of lung cancer were more common among late adopters, 12.2 % (n = 201) and 20.7 % (n = 341), compared to 7.2 % (n = 40) and 15.1 % (n = 84), respectively, in the early adopter cohort.

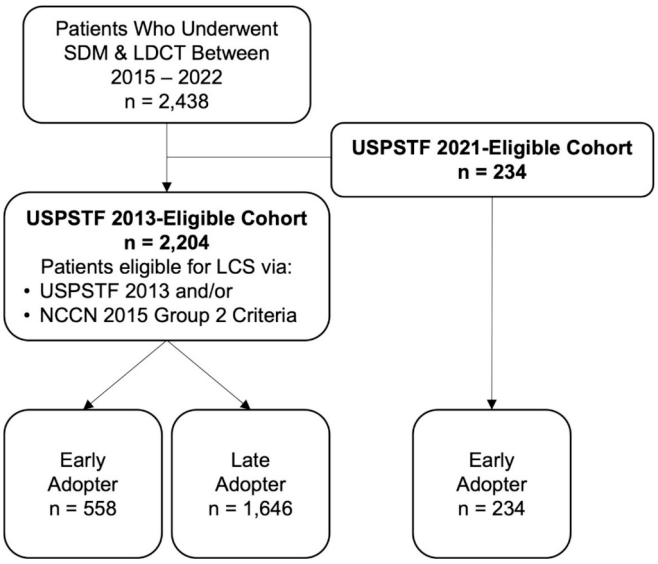

Fig. 1. Study CONSORT Diagram.

3.3. Factors associated with early vs. late adoption

Demographic characteristics and medical history of individuals who were eligible based on USPSTF 2013 criteria were analyzed to identify factors associated with early adoption of LCS. (Table 2). Black/African-American race and current smoking status were significantly associated with greater odds of early adoption. (Table 2). Upon adjustment for covariates in a multivariable analysis, Black/African-American patients had significantly higher odds of completing LCS within the first 24 months of eligibility (aOR 1.428; 95 % CI, 1.164– 1.752). Smoking status (Current Smoker, aOR 1.514; 95 % CI, 1.221 – 1.877) was also significantly associated with early adoption. Patients with Medicaid/Dual Eligible and Private Insurance were significantly less likely than those insured with Medicare to be a LCS early adopter (aOR 0.702; 95 % CI, 0.544 – 0.908) and (aOR 0.694; 95 % CI, 0.532 – 0.905), respectively. Younger age, pack-years, family history of lung cancer, and personal history of cancer were all significantly associated with lower odds of early adoption of LCS.

3.4. Comparison of USPSTF 2013 early adopters to USPSTF 2021 early adopters

Among the 234 patients in the USPSTF 2021 cohort, the mean age was 60.15 ± 7.05. (Supplemental Table 2). The majority of the individuals were female (n = 132; 56.4 %) and identified as Black/African-American (n = 131; 56.0 %). USPSTF 2021-eligible early adopters were significantly younger (60.15 ± 7.05 vs. 63.18 ± 6.27; p < 0.001), with a higher proportion of Black/African-American individuals (56 % vs 54.3 %; p < 0.001), and a greater proportion of Medicaid or Dual Eligible insurance (43.2 % vs. 27.4 %; p < 0.001) than the USPSTF 2013-eligible early adopters. The USPSTF 2013 early adopters reported a greater incidence of known lung cancer risk factors including smoking intensity, family history of lung cancer, personal history of cancer, as well as had a higher mean PLCOm2012 risk score than the newly eligible USPSTF 2021 cohort.

4. Discussion

This retrospective analysis of individuals undergoing LCS is a unique

Table 1
Baseline Characteristics of USPSTF 2013-Eligible Participants Receiving Lung Cancer Screening Between 2015 and 2022 (n = 2,204).

	Total (n = 2,204)		Early Adopters (n = 558)		Late Adopters (n = 1,646)		p-value
Age, years, mean ± SD	63.90	± 5.93	63.18	± 6.27	64.15	± 5.78	0.001
Gender, n(%)							0.860
Female	1,249	(56.7)	318	(57.0)	931	(56.6)	
Male	955	(43.3)	240	(43.0)	715	(43.4)	
Race, n(%)							<0.001
Black/African-American	999	(45.3)	303	(54.3)	696	(42.3)	
White	1,121	(50.9)	241	(43.2)	880	(53.5)	
Other[a]	84	(3.8)	14	(2.5)	70	(4.3)	
Hispanic/Latino, n(%)	84	(3.8)	16	(2.9)	68	(4.1)	0.178
Insurance Status, n(%)							0.075
Medicare	853	(38.7)	226	(40.5)	627	(38.1)	
Medicaid/ Dual Eligible	638	(28.9)	153	(27.4)	485	(29.5)	
Private	629	(28.5)	149	(26.7)	480	(29.2)	
Other[b]/None	84	(3.8)	30	(5.4)	54	(3.3)	
Educational Attainment, n(%)							<0.001
<HS	361	(16.4)	75	(13.4)	286	(17.4)	
HS Diploma/GED	873	(39.6)	169	(30.3)	704	(42.8)	
>HS	728	(33.0)	146	(26.2)	582	(35.4)	
Unknown	242	(11.0)	168	(30.1)	74	(4.5)	
Smoking Status, n(%)							<0.001
Current Smoker	1,371	(62.2)	393	(70.4)	978	(59.4)	
Former Smoker	833	(37.8)	165	(29.6)	668	(40.6)	
Smoking Intensity, pack-years, mean ± SD	52.45	± 24.20	48.41	± 25.81	53.82	± 23.48	<0.001
BMI, mean ± SD	29.11	± 6.78	28.87	± 6.41	29.19	± 6.90	0.337
Personal History of Cancer, n (%)	241	(10.9)	40	(7.2)	201	(12.2)	<0.001
Family History of Lung Cancer, n (%)	425	(19.3)	84	(15.1)	341	(20.7)	0.003
PLCOm2012 risk, %, mean ± SD	6.64	± 6.38	6.85	± 7.03	6.57	± 6.15	0.424

[a]Other includes patients who reported Asian, Alaskan Native/American Indian, Native Hawaiian/Pacific Islander, and More Than One Race.
[b]Other includes patients insured through State Marketplace, Workers Compensation, and other supplementary plan types.

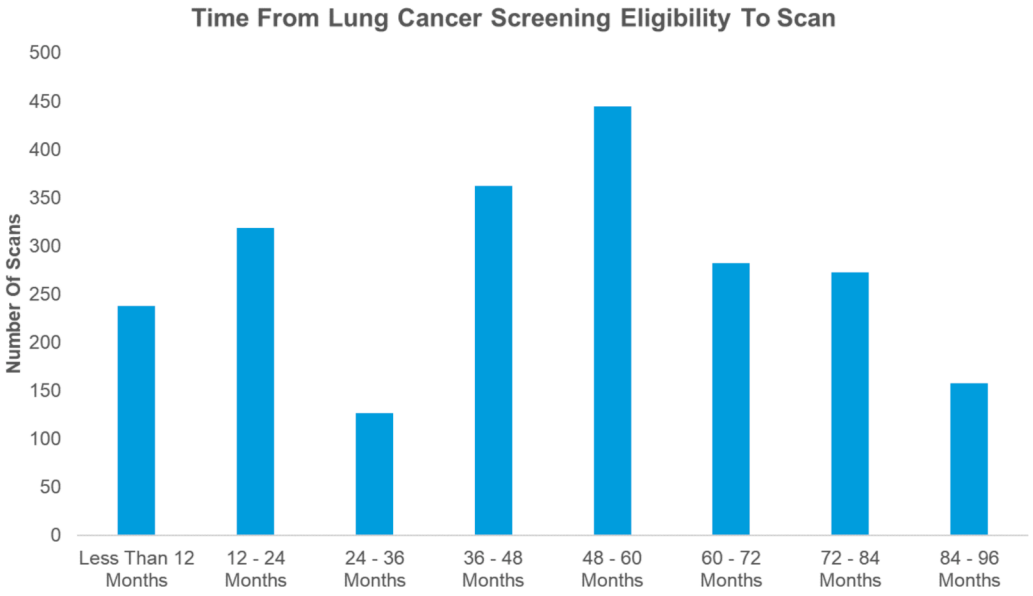

Fig. 2. Time from Lung Cancer Screening Eligibility To Scan; Based On Patients Eligible Based On USPSTF 2013 Criteria and NCCN Group 2 Only (n = 2,204). Note: The Lung Cancer Screening Program did not begin until 2015, all patients eligible prior to 2015 were assigned 2015 as their first year of eligibility.

perspective on the factors associated with adoption of LCS. Characteristics of early and late adopters in LCS have not yet been examined in published literature to the authors' knowledge. We found early adopters tended to be younger, Black/African-American, currently smoking individuals, with lesser smoking intensity, and less frequent personal or family cancer history. Predictors of early adoption in our adjusted analysis included Black/African-American race and current smoking status.

Several of our findings were unexpected, including the greater early adoption of LCS among Blacks/African-Americans and currently smoking individuals, as well the greater late adoption among those with family history of lung cancer or personal history of cancer. Although studies of LCS have found low rates of uptake and adherence among people of color and individuals who currently smoke, our analysis is distinct by differentiating between early and late adopters (Lake et al., 2020; Sakoda et al., 2021; Lopez-Olivo et al., 2020). The characteristics associated with early adoption and overall uptake of LCS may not align, warranting further investigation of each. The way these factors interplay may help increase both early adoption as well as uptake of LCS. Screening uptake may be increased among Black/African-Americans

Table 2
Predictors of Early Adoption Among USPSTF 2013-Eligible Participants Undergoing Lung Cancer Screening Between 2015 and 2022.

	Unadjusted OR (95 % CI)		Adjusted OR (95 % CI)	
Age	0.972	(0.956 – 0.989)**	0.971	(0.953 – 0.990)**
Race				
White	1.00		1.00	
Black/ African-American	1.590	(1.306 – 1.934)**	1.408	(1.146 – 1.729)**
Other[a]	0.730	(0.404 – 1.319)	0.587	(0.317 – 1.088)+
Hispanic	0.685	(0.394 – 1.191)	0.738	(0.418 – 1.301)
Gender				
Female	1.00		1.00	
Male	0.983	(0.810 – 1.193)	1.038	(0.847 – 1.272)
Smoking Intensity	0.989	(0.985 – 0.994)**	0.992	(0.987 – 0.996)**
Smoking Status				
Current	1.627	(1.323 – 2.000)**	1.516	(1.223 – 1.881)**
Former	1.00		1.00	
Family History of Lung Cancer	0.678	(0.522 – 0.880)*	0.721	(0.551 – 0.945)*
Personal History of Cancer	0.555	(0.390 – 0.791)**	0.618	(0.429 – 0.888)*
Insurance Status				
Medicare	1.00		1.00	
Medicaid/ Dual Eligible	0.875	(0.691 – 1.109)	0.704	(0.544 – 0.908)*
Private	0.861	(0.678 – 1.093)	0.692	(0.531 – 0.902)*
Other[b]/None	1.541	(0.962 – 2.470)+	1.303	(0.793 – 2.143)

+p < 0.1; *p ≤ 0.05; **p ≤ 0.01.
[a]Other includes patients who reported Asian, Alaskan Native/American Indian, Native Hawaiian/Pacific Islander, and More Than One Race.
[b]Other includes patients insured through State Marketplace, Workers Compensation, and other supplementary plan types.

and currently smoking individuals initially, but then decrease over time, this may be supported by our findings that there were significantly more Black-African/American individuals that were early adopters of LCS. Moreover, these individuals are in a subset of even higher lung cancer risk and therefore may recognize potential benefits of early adoption of cancer screening. Notably, there were no significant differences in educational attainment, when excluding missing or unknown data, between early and late adopters despite existing literature that has demonstrated low socioeconomic status is associated with late adoption of cancer screening (Hahm et al., 2011). We used patient insurance as a proxy for socioeconomic status in a model controlling for other potential predictors of early adoption and found that individuals with Medicaid/ Dual Eligible were nearly 30 % less likely to be an early adopter compared to those with Medicare, which is in line with existing literature (Hahm et al., 2011; Marcin et al., 2003). However, privately insured patients also experienced lower odds of early adoption compared to those with Medicare. It is worth noting that insurance status and screening adoption are intricately linked, and changes in insurance coverage of LCS at the national level over the 8-year study timeframe likely impacted LCS adoption.

Our finding of late adoption of LCS among those with increased risk for lung cancer due to personal or family history may be due to a number of factors, including generational risk-taking, poverty, systemic barriers, fear, and stigma. Furthermore, risk information avoidance, which is more common among older individuals, females, and those with lower levels of educational attainment, has associated with lower levels of cancer screening (Emanuel et al., 2015). While this phenomenon is multi-faceted and reasoning crosses all levels of the socio-ecological model, patient-centered communication and improving self-efficacy decreases cancer risk information avoidance (Emanuel et al., 2015; Yu et al., 2021).

The comparison of early adopters between the USPSTF 2013 and USPSTF 2021 cohorts found several significant differences likely driven by the lowering of the age and smoking intensity criteria to undergo LCS. Early adopters in the USPSTF 2021 cohort had a reduction in mean age of three years and reported a lesser smoking intensity of over twenty pack-years. The proportion of racial and ethnic minorities increased in the USPSTF 2021 cohort, which aligns with existing literature suggestion that expansion of the guidelines allows for an increase in screening eligibility amongst racial and ethnic minorities (Pu et al., 2022; Ritzwoller et al., 2021). A marked increase in patients with Medicaid as well as less than a high school education was observed amongst early adopters eligible by the new guidelines. There was hope that the expansion of LCS criteria would increase eligibility for individuals with low socioeconomic status, and our findings support this based on the increase in screening for those on Medicaid and low levels of educational attainment (Ritzwoller et al., 2021). The USPSTF 2013 early adopter had a greater prevalence of known lung cancer risk factors, including family history of lung cancer, personal history of cancer, and had a higher mean PLCOm2012 risk score than the newly eligible USPSTF 2021 cohort (Tammemagi et al., 2013). Further, changes in LCS guidelines can affect general population and clinician knowledge of screening, which has an indirect impact on screening adoption, which is not measurable. While our findings align with literature supporting the expansion of LCS criteria, it is worth noting that this study investigates early vs. late adopters of LCS, not overall eligibility or uptake of LCS.

Despite the promise of LCS, it remains underutilized nationally with only 5.8 % of eligible persons undergoing LCS in 2022 (American Lung Association, 2022). The underuse of LCS with LDCT occurs due to a complex interplay of individual characteristics, interpersonal relationships, environmental factors, structural barriers, policies, and additional outside influences. Due to the nature of our sample, our findings may be due in part to compositional factors (i.e., who we serve) and/or institutional efforts to provide outreach to high-risk communities in Philadelphia (i.e., who we aim to serve), a city with one of the largest proportions of low-income, Black/African American residents in the Northeast. Moreover, the centralized nature of LCS in the described Program also affects screening awareness among primary care physicians who make the vast majority of LCS Program referrals.

Limitations of this study include its retrospective design and limitations in generalizability since this study reports findings from a single LCS program (screening across multiple sites). Another major limitation is the extent to which programmatic changes such as staffing and clinical resources might have influenced the uptake of LCS. The operational intensity of the LCS Program undergoes continuous change, as is typical in the clinical setting, due to outside factors. These factors are multifaceted and happen on multiple levels, including the loss and addition of personnel, substantial modifications in data collection strategies, expansion of the program due to institutional buy-in, greater knowledge of screening among providers and patients, as well as changes in marketing methodologies. These factors may confound the relationship between patient characteristics and early adoption of LCS, but their combined influence was immeasurable in this study. Adoption of any cancer screening modality does not exist in a vacuum and is impacted by factors at many levels, even within this study outside factors influenced the decision of 24 months post-eligibility as the boundary for early adoption. The program saw an initial increase in screening after its commencement in 2015 followed by a decline at 24–36 months, which could be attributed to a temporary decrease in LCS staffing in 2017, however, newly eligible individuals from later years are also distributed like this, suggesting a natural pattern. Additionally, because the study period ends before newly eligible persons can reach the 24–36 month threshold, those screened within 24 months of eligibility were defined as early adopters in this study. Future studies may consider alternate timeframe definitions or attempt to create a standardized definition

across cancer screenings. Furthermore, because individuals eligible for LCS prior to 2015 were classified as early vs. late adopters based on LCS Program availability only in 2015, it is possible that some patients were grouped inaccurately (i.e. those who were USPSTF 2013-eligible prior to 2015, for example). Moreover, early adopters who were eligible prior to the launch of the LCS program and early adopters who became eligible after the program launched, may have different characters and motivations to undergo screening. However, only 23.0 % of patients eligible at the inception of the program underwent LCS within the first 24 months, bolstering the decision to examine the groups as one. Further research should examine differences between early adopters and those who are early responders to new healthcare services and programs. Additionally, this study analyzes adopters of LCS, and therefore, does not include the much larger denominator of eligible persons who have not undergone LCS. Finally educational attainment could not be included in the multivariable model as a proxy measure of socioeconomic status due to a large amount of missing data. Future research should identify characteristics of early and late adopters for LCS utilizing a longer timeline and a more generalizable population sample (e.g., American College of Radiology registry).

Integrating the DOI theory to better understand LCS uptake provides a unique opportunity to increase uptake in a more equitable manner. Our results suggest that Black/African-American patients and individuals who currently smoke are more likely to be early adopters of LCS with LDCT. Those with lesser smoking intensity, without a personal history of cancer, and without a family history of lung cancer are more likely to be late adopters of LCS. This knowledge can be leveraged to develop and test future interventions tailored to those with lung cancer risk factors associated with late adoption of screening. Interventions to decrease late adoption while increasing early adoption should be partnered with efforts to expand LCS uptake, as these two approaches provide a unique opportunity to reduce late-stage diagnoses and lung cancer mortality from multiple perspectives. While factors associated with early adoption of LCS and overall uptake may inform strategies to increase both, the populations being targeted are distinct from one another – individuals eligible for LCS who undergo screening and all eligible persons. Future directions should focus on identifying how LCS diffuses across the population as well as factors that drive and inhibit diffusion.

5. Conclusion

Among individuals eligible for LCS, little is known about how screening with LDCT diffuses among the population. We identified factors associated with early and late adoption of LCS among those eligible based on USPSTF 2013 criteria. Early adopters were more likely to report a race of Black/African-American and current smoking status after adjustment for covariates. Additionally, patients with a history of cancer or a family history of lung cancer had decreased odds of early adoption. Future research should examine how LCS diffuses across the general population as well as factors that drive and inhibit diffusion to increase uptake in an equitable manner.

CRediT authorship contribution statement

Christine S. Shusted: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Jan M. Eberth:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Hee-Soon Juon:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Julie A. Barta:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: JAB reports research grants from the Genentech Health Equity Innovations Fund and fees paid to her institution from Delfi Diagnostics, Inc.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

JAB takes responsibility for the content of this manuscript, including data and analysis. All authors contributed to the study conception and design. CSS, HJ, and JME devised the analysis plan. Material preparation, data collection, and analysis were performed by CSS. CSS and JAB wrote the initial manuscript draft. HJ, and JME, reviewed and edited subsequent manuscript drafts. All authors edited the final draft of the manuscript.

IRB Statement

This study – including the protocol – was reviewed and approved by the Thomas Jefferson University Institutional Review Board (IRB) with a waiver of informed consent, given the minimal risk nature of the study (IRB Control#, 17D.150). This retrospective analysis was carried out in accordance with all methodological guidelines and regulations of the Thomas Jefferson University IRB, as well as the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2024.102820.

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