

Total and Out-of-Pocket Costs of Procedures After Lung Cancer Screening in a National Commercially Insured Population: Estimating an Episode of Care

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Abstract

Objective: Consequences of lung cancer screening (LCS) with low-dose chest CT in clinical settings, including procedures, costs, and complications, are incompletely understood. We evaluated downstream invasive procedures after LCS, total and out-of-pocket (OOP) costs of these procedures, and correlates of procedural rates and costs.

Methods: Using the Clinformatics Data Mart, we retrospectively included patients between ages 55 and 79 years receiving LCS between 2015 and 2017. The types and frequency of downstream invasive procedures (including needle biopsy, bronchoscopy, surgery, and cytology) were described. Treating the LCS examination and downstream procedures as a single LCS episode, we described the per-episode total costs (insurance reimbursement + OOP costs of LCS and downstream procedures) and OOP costs. Correlates of costs were determined using linear and logistic regression.

Results: A total of 6,268 patients received at least one low-dose chest CT; 462 patients (7.4%) received at least one procedure within 12 months after LCS (needle biopsy 69.0%, cytology 23.6%, bronchoscopy 18.6%, surgery 23.8%). Women and patients ≥ 65 years were more likely to receive a downstream procedure. Ninety-three patients (20.1%) were diagnosed with lung cancer after LCS. The total cost of managing this population of lung screeners was \$5,060,511.04, with an average per-episode total cost of \$740.06. The aggregate OOP costs to this population of lung screeners was \$427,069.74, with an average per-episode OOP cost of \$62.46.

Conclusions: Rates of invasive procedures after LCS in a commercially insured population exceeded those of clinical trials. Considering LCS and associated downstream procedures as an episode of care results in modest OOP cost.

Key Words: Costs, low-dose chest CT, lung cancer, lung cancer screening, thoracic procedures

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INTRODUCTION

In 2013, the US Preventative Services Task Force (USPSTF) issued a Grade B recommendation for annual lung cancer screening (LCS) with low-dose chest CT (LDCT) in individuals ages 55 to 80 years with ≥ 30 pack-year history of smoking who currently smoke or have quit ≤ 15 years [1]. The updated 2021 USPSTF guidelines reduce the age eligibility to start at 50 years and decrease the smoking requirement to a minimum of 20 pack-years [2]. The recommendations supporting LCS were largely established after publication of the National Lung Screening Trial (NLST), a landmark randomized controlled trial demonstrating a 20% relative reduction in lung cancer mortality with LDCT for LCS compared with chest

radiography [3]. It is estimated that guideline-directed LCS could avert thousands of lung cancer-related deaths per year [4].

A steady increase in LCS utilization since 2013 [5,6] has been facilitated by health policy initiatives enabling widespread insurance coverage for screening [1,7,8]. LCS is a covered service under the 2010 Patient Protection and Affordable Care Act (PPACA), which requires nongrandfathered private and commercial insurers to cover USPSTF Grade A and B recommendations without cost sharing (ie, without deductible or copayment) [8]. Annual LCS with LDCT is covered under Medicare as a preventive health benefit for beneficiaries meeting eligibility criteria, and most state Medicaid programs also cover LCS [7,9]. Evidence supports the cost-effectiveness of LCS, with incremental cost-effectiveness ratios below the generally accepted willingness-to-pay threshold of \$100,000 per quality-adjusted life-year [10-13].

Although the mortality benefits of early lung cancer detection via LDCT LCS are well documented, the downstream consequences of LCS, such as invasive procedures, costs, and complications, are not yet well understood [14,15]. Prior work has drawn largely from clinical trial settings, such as the NLST and the Early Lung Cancer Action Program, or from Medicare beneficiaries [12,13,16,17]. However, the generalizability of trial-based observations to actual clinical screening programs is uncertain, owing to differences in population characteristics, health care facilities and settings, and provider characteristics [15,18]. Additionally, benefit design varies greatly between Medicare and commercial insurance, influencing cost of care. The new USPSTF guidelines double the approximately eight million eligible screening examinations per year under the 2013 recommendations [19]. Hence, there is an urgent need to understand screening utilization in the clinical setting, including its downstream effects [20]. The objectives of this investigation were to evaluate the rate and type of downstream invasive procedures after LDCT LCS examination in an employer-insured population, evaluate the costs of these invasive downstream procedures, and determine variation in procedure rates and their associated costs with respect to patient sociodemographic characteristics. We hypothesized that downstream procedure rates may be higher in a commercially insured screening population than observed in the NLST and that costs associated with LCS episodes necessitating downstream procedures may be associated with patient sociodemographic characteristics.

METHODS

Data Source and Population

The study was deemed exempt from institutional review board. We used data from The Clinformatics Data Mart

Database (OptumInsight, Eden Prairie, Minnesota), one of the largest commercial health insurance databases including member enrollment information, such as demographic variables and individual-level insurance claims, and providing the ability to follow individuals longitudinally because individuals are reported by employers, not health plans. The database contains complete patient payment, including patient copayment, deductible, coinsurance, and standardized costs, including reimbursement, as well as information regarding medical procedures and diagnoses. The Data Mart does not contain patient-level data on specific LDCT radiology results.

The study population included patients enrolled in employer-based health plans between ages 55 and 79 years receiving LDCT LCS between 2015 and 2017, a period covered by the 2013 USPSTF guidelines. Individuals with at least 12 months of continuous enrollment in one plan after LDCT LCS were included. The follow-up period included claims data from 2015 to 2018.

Measures and Outcomes

The cohort was identified using Current Procedural Terminology codes for LDCT LCS (G0297, S8032). Downstream invasive procedures included needle biopsy, bronchoscopy, and thoracic surgery (including thoracotomy, thoracoscopy, and mediastinoscopy), and cytology (occurring in conjunction with thoracotomy, thoracoscopy, and mediastinoscopy) that occurred within 12 months after the LDCT LCS examination or until the next LDCT LCS examination, whichever came first. Invasive procedures were identified using International Classification of Diseases (ICD) Clinical Modification (CM) procedure codes (ICD-CM) from the 9th and 10th revisions and were adopted from the codes utilized in the NLST and those published by Huo et al [3,15]. Lung cancer diagnoses occurring within 12 months after the LDCT LCS were determined using ICD-9-CM and ICD-10-CM codes.

Costs were determined using data in Clinformatics Data Mart Database. Standardized cost is a variable reflecting the cost of service developed by OptumInsight to account for pricing differences across different sources and regions; it allows comparison of service costs across different health care facilities. It includes the service reimbursement covered by insurance and patient out-of-pocket (OOP) cost; hereafter, also referred to as total cost. Patient OOP costs (defined as the sum of copayment, coinsurance, and deductible) were summarized for each service and adjusted for inflation to 2018 dollars using the US Bureau of Labor Statistics Medical Consumer Price Index.

Patient characteristics included race or ethnicity, sex, age at LDCT LCS, household income ($\leq 400\%$ federal poverty

level, >400% federal poverty level, unknown), US geographic division (East North Central, East South Central, Middle Atlantic, Mountain, New England, Pacific, South Atlantic, West North Central, West South Central), and health insurance plan type (preferred provider organization, health maintenance organization, exclusive provider organization, indemnity, point of service, other).

Statistical Analysis

Patient demographics, downstream procedure rates, and costs were summarized with descriptive statistics. LDCT LCS examinations within unknown patient sex or geography or US \$0, missing, or incomplete total cost were excluded from all analyses. Downstream procedure rates were based on the proportion of LDCT LCS examinations resulting in downstream procedures (cytology, needle biopsy, bronchoscopy, or thoracic surgery) during the follow-up period among all LCS examinations occurring between 2015 and 2017.

To assess the association between patient demographics and receiving downstream procedures or \$0 OOP costs, repeated measures multivariate logistic regression models were conducted at the LDCT LCS examination level. Additionally, the association between patient demographics (explanatory variables) and total cost (response variable) was assessed using repeated measures multivariate linear regression. Repeated measures models were used to account for multiple LCS examinations per patient. The results of these regression analyses were expressed as model coefficients or odds ratios (ORs), as appropriate. $P < .05$ were considered significant. Analyses were conducted using SAS version 9.4 (SAS Institute Inc, Cary, North Carolina).

RESULTS

Demographics

Patient demographics are shown in [Table 1](#). After excluding individuals with unknown sex or geography or US \$0, missing, or incomplete total cost ($n = 19$ patients), a total of 6,268 unique patients were included. Between 2015 to 2017, there was an upward temporal trend of LCS examinations and associated downstream procedures ([Fig. 1](#)).

Frequency and Correlates of Downstream Invasive Procedure Receipt After LCS

Of the 6,268 unique patients receiving at least one LDCT LCS, 462 patients (7.4%) received a downstream invasive procedure within 12 months after the LCS ([Table 2](#)). Needle biopsy was the most common procedure and bronchoscopy the least common. Of the 462 patients who

received a procedure, 93 (20.1%) had a new lung cancer diagnosis within 12 months of the LDCT LCS. Adjusted analysis demonstrated that downstream procedure receipt was more likely in patients ≥ 65 years (adjusted OR 1.62, 95% confidence interval [CI] 1.28-2.04) and less likely in males (adjusted OR 0.82, 95% CI 0.68-0.99) ([Table 3](#)). No associations between downstream procedure receipt and race or ethnicity, federal poverty level, geographic division, and health plan type were demonstrated.

Total Cost of an LCS Episode With and Without Downstream Invasive Procedures

[Table 2](#) shows the total costs (including reimbursement and OOP costs) associated with LCS examination and downstream invasive procedures. The median total costs were higher among encounters with downstream procedures after LCS examination (median \$1,054.27, interquartile range [IQR] \$506.83-\$4,244.91) compared with those without downstream procedures (median \$92.69, IQR \$90.47-\$361.08). Total costs were also higher among LCS encounters with downstream invasive procedures and lung cancer diagnosis (median \$23,434.72, IQR \$6,625.8-\$35,744.23, maximum \$125,743.55) compared with LCS encounters with downstream invasive procedures and no cancer diagnosis (median \$752.04, IQR \$431.13-\$2,048.51, maximum \$114,257.42) ([Table 2](#)). Treating the LCS LDCT examination and subsequent downstream procedures as a single lung screening episode, the aggregate total costs of managing this population of lung screeners was \$5,060,511.04, with an average per-episode total cost of \$740.06.

Statistically significant differences in total costs for LCS episodes requiring downstream procedures were observed with regards race or ethnicity ([Table 4](#)). Specifically, White patients were more likely to have lower total costs compared with Black patients (coefficient: $-\$10,103.58$; 95% CI: $-\$17,798.72$ to $-\$2,408.43$).

OOP Cost of an LCS Episode With and Without Downstream Invasive Procedures

Patient OOP demonstrated heterogeneity ([Table 2](#)). Patient OOP cost increased with any downstream procedure (median \$50.79, IQR \$0-\$343.05) versus without (median \$0, IQR \$0-\$0). Among the 466 LCS encounters with at least one downstream procedure, 39.5% had \$0 OOP cost share. Those with OOP cost paid \$2.73 to \$7,498.74. Those with a lung cancer diagnosis after downstream procedures paid a median of \$332.24 (IQR \$0-\$1,341.52) OOP compared with those without a cancer diagnosis (median \$31.34, IQR \$0-\$245.68, maximum \$4,053.42). Individuals receiving LCS

Table 1. Demographics of patients receiving LDCT LCS and those with and without screen-detected lung cancer

Characteristic	Received LDCT LCS	With Screen-Detected Lung Cancer	Without Screen-Detected Lung Cancer
Total number of LCS encounters*, n	6,838	129 (1.9)	6,709
Total number of unique patients, n	6,268	129 (2.1)	6,148
Race or ethnicity†, n (%)			
Asian	79 (1.3)	0 (0)	79 (1.3)
Black	432 (6.9)	12 (9.3)	420 (6.8)
Hispanic	235 (3.7)	<11 (<8.5)	231 (3.8)
White	5,154 (82.2)	>95 (>73.6)	5,056 (82.2)
Unknown	368 (5.9)	<11 (<8.5)	362 (5.9)
Sex, n (%)			
Female	2,727 (43.5)	58 (45)	2,673 (43.5)
Male	3,541 (56.5)	71 (55)	3,475 (56.5)
Age (y)			
Mean (SD)	60.83 (3.98)	61.72 (4.71)	60.81 (3.96)
Median (interquartile range)	60 (58, 63)	61 (58, 64)	60 (58, 63)
Minimum, maximum	55, 79	55, 75	55, 79
Household income, n (%)			
≤400% federal poverty level	1,489 (23.8)	26 (20.2)	1,464 (23.8)
>400% federal poverty level	3,925 (62.6)	86 (66.7)	3,845 (62.5)
Unknown	854 (13.6)	17 (13.2)	839 (13.6)
Division†, n (%)			
East North Central	1,130 (18)	23 (17.8)	1,109 (18)
East South Central	348 (5.6)	11 (8.5)	337 (5.5)
Middle Atlantic	425 (6.8)	13 (10.1)	414 (6.7)
Mountain	377 (6)	<11 (<8.5)	369 (6)
New England	419 (6.7)	12 (9.3)	409 (6.7)
Pacific	402 (6.4)	<11 (<8.5)	394 (6.4)
South Atlantic	1,598 (25.5)	>18 (>14.0)	1,570 (25.5)
West North Central	1,068 (17)	19 (14.7)	1,050 (17.1)
West South Central	501 (8)	<11 (<8.5)	496 (8.1)
Health plan†, n (%)			
PPO	62 (1)	0 (0)	62 (1)
HMO	914 (14.6)	17 (13.2)	898 (14.6)
EPO	571 (9.1)	11 (8.5)	560 (9.1)
Indemnity	48 (0.8)	<11 (<8.5)	47 (0.8)
Point of service	4,619 (73.7)	>90 (>69.8)	4,527 (73.6)
Other	54 (0.9)	0 (0)	54 (0.9)

EPO = exclusive provider organization; HMO = health maintenance organization; LCS = lung cancer screening; LDCT = low-dose CT; PPO = preferred provider organization.

*LCS encounter refers to the first LCS LDCT examination occurring between 2015 and 2017 and subsequent downstream procedures occurring within 12 months after the LCS LDCT examination.

†The cell suppression policy for this database requires suppression of values <11. When necessary, certain values ≥11 are also suppressed to preclude the determination of values <11.

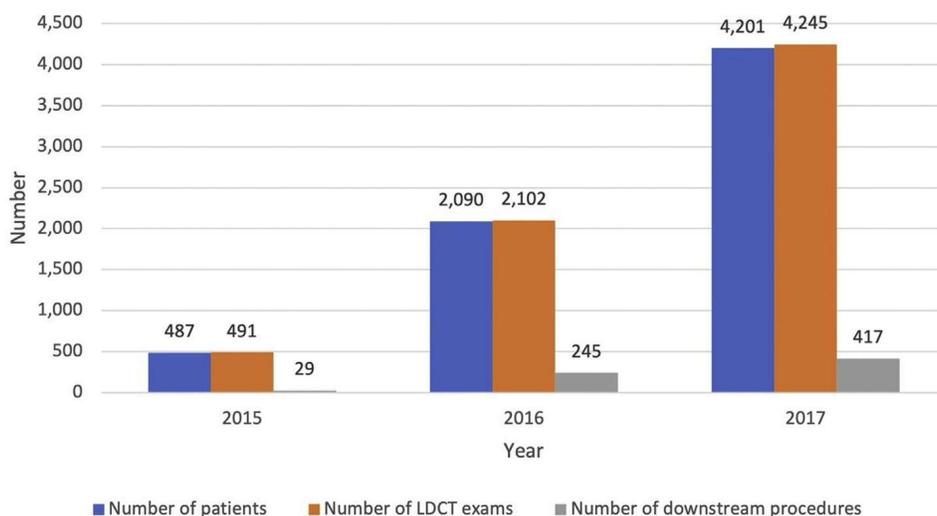


Fig. 1. Number of patients receiving low-dose CT (LDCT), number of LDCT examinations, and downstream procedures, 2015-2017.

with no downstream procedures incurred \$0 OOP costs. Treating the LCS examination and subsequent downstream procedures as a single lung screening episode, the aggregate OOP costs of managing this population of lung screeners was \$427,069.74 with an average per-episode OOP cost \$62.46. In LCS episodes necessitating downstream procedures, patient OOP costs ranged from \$0 to \$7,498.74, with an average per-episode OOP cost of \$424.05.

Regardless of receipt of downstream invasive procedures, differences in OOP costs were observed (Table 5). With respect to geographic division, patients in the Pacific division were more likely to have \$0 OOP cost share compared with the reference East North Central division (adjusted OR, 95% CI: 1.67, 1.26-2.22). In contrast, patients in the West South Central region were less likely to incur \$0 OOP cost share (adjusted OR, 95% CI: 0.76, 0.61-0.95). Differences were also observed by health plan type, with point-of-service and preferred provider organization plans having a lower odds of \$0 cost share compared with health maintenance organization plans (adjusted OR, 95% CI: 0.67, 0.57-0.80, and 0.49, 0.29-0.83, respectively). Patients with unknown income level had a higher likelihood \$0 cost share compared with the reference of household income $\leq 400\%$ of the federal poverty level (adjusted OR, 95% CI: 1.26, 1.04-1.53). There were no significant differences in the odds of \$0 cost share by race or ethnicity, sex, or age.

DISCUSSION

In a cohort of patients receiving LDCT LCS between 2015 and 2017, 7.4% received a downstream procedure, with needle biopsy being the most common. Adjusted analysis

revealed a higher likelihood of downstream procedures in patients ≥ 65 years and in female patients compared with male patients. The costs associated with a negative LDCT LCS examination (ie, those without downstream procedures) was relatively low to the insurer and \$0 to the patient, the latter of which is consistent with the 2010 PPACA provision of first dollar coverage [8]. In LCS episodes necessitating downstream procedures, the range of costs incurred were wide, with patient OOP costs ranging from \$0 to \$7,498.74 with an average per-episode cost of \$424.05.

Clinical trials have demonstrated a mortality benefit from LCS with LDCT in high-risk individuals. However, there are little data regarding the consequences of positive screening examinations in actual clinical settings [3,21,22]. Recently, Nishi et al estimated a cumulative procedure rate of 3.7% (biopsy, thoracoscopy, mediastinoscopy, and thoracotomy) among patients receiving LCS in 2016, exceeding that of the NLST by 58% to 210% [18]. Our investigation evaluated patients receiving LCS over a 3-year period (2015-2017) and required 12 months of continuous insurance coverage for inclusion to more completely evaluate the economic consequences of LCS. Notwithstanding, our results corroborate the small body of existing literature, including results published by Nishi et al, that the rate of downstream procedures after LDCT in actual clinical settings is likely higher than observed in trial settings [15,18].

The higher rates of downstream procedures compared with the NLST are likely multifactorial. These differences impede generalizability of the NLST to actual LCS settings [15,23,24]. Participants in the NLST were generally younger, less racially diverse, had higher education attainment, and were less likely to be currently smoking

Table 2. Frequency and cost of invasive procedures occurring within 12 months of LCS examination

Characteristic	n	Total Cost, Median (IQR)	OOP Cost, Median (IQR)
Total LCS encounters*	6,838	92.69 (90.47-362.27)	0 (0-0)
LCS encounters without downstream procedures	6,372	92.69 (90.47-361.08)	0 (0-0)
LCS encounters resulting in downstream procedures	466	1,054.27 (506.83-4,244.91)	50.79 (0-343.05)
Without screen detected lung cancer	373	752.04 (431.13-2,048.51)	31.34 (0-245.68)
With screen detected lung cancer	93	23,434.72 (6,625.80-35,744.23)	332.24 (0-1,341.52)
Number of LCS encounters resulting in the after invasive procedures [†]			
Cytology	117	352.42 (191.58-584.89)	0.00 (0-116.02)
Needle biopsy	346	277.92 (107.62-961.42)	0.00 (0-75.18)
Bronchoscopy	104	3,347.46 (945.25-7,854.23)	40.44 (0-939.62)
Surgery	124	3,610.64 (1,374.01-26,812.33)	0.00 (0-314.28)
Number of unique patients receiving invasive procedures			
Cytology	109	352.42 (211.10-595.43)	0.00 (0.00-119.56)
Needle biopsy	319	277.92 (107.62-963.96)	0.00 (0.00-74.00)
Bronchoscopy	86	3,347.46 (940.28-7,854.23)	25.78 (0.00-895.35)
Surgery	110	3,638.00 (1,541.55-28,145.41)	0.00 (0.00-391.56)

Costs are expressed in 2018 US\$ and are based upon the first LCS examination in the study period. Total costs represent the Optum Clinformatics standardized costs encompassing both standardized reimbursements and patient out-of-pocket cost share. The out-of-pocket cost represents the sum of the deductible, copayment, and coinsurance. IQR = interquartile range; LCS = lung cancer screening.

*Refers to the first LCS low-dose CT examination occurring in the study period and subsequent downstream procedures occurring within 12 months after the LCS low-dose CT examination.

[†]A single LCS encounter can result in more than one downstream invasive procedure.

than the general US population meeting NLST entry criteria [24]. These demographic differences may contribute to the higher rates of procedures observed in our study and may also contribute to the higher likelihood of downstream procedures in patients ≥ 65 years. Older patients are at higher lung cancer risk, with expected higher rates of downstream procedures [25]. However, older patients also carry a higher comorbidity burden, which may translate to higher rates of false-positive tests, as well as higher procedural-related morbidity and mortality [15,23,26,27]. These characteristics may translate to substantial differences between LCS in clinical trial versus clinical practice settings. NLST study sites included predominantly urban tertiary care hospitals with radiological and clinical expertise in cancer detection and care [28]. In actual clinical practice, facilities performing LCS are heterogenous with variations in practice patterns, resources, and subspecialty care. For instance, over 3,300 LCS facilities participate in the ACR LCS Registry, with sites ranging from academic to community practices and spanning varying geographic settings from rural to

metropolitan [29]. Also, in clinical practice, radiologists report LCS results using a standardized reporting system (ACR Lung Reporting and Data System), which was developed after the NLST [3,21]. Practice variations also exist among sites as to how positive LCS examinations are further evaluated [30].

Current health policies are aimed at removing cost barriers for preventive services. The 2010 PPACA requires that USPSTF Grade A and B services be covered by private nongrandfathered insurers without patient cost sharing [31]. Medicare also covers LCS at no OOP cost for beneficiaries meeting LCS eligibility criteria [7]. Employer-insured patients undergoing LCS with negative results (ie, those receiving no downstream procedures) in our study incurred no OOP costs, consistent with these federal policies. However, the financial burden caused by resulting downstream procedures is not negligible and requires further investigation.

We extend the previous analysis by Nishi et al by estimating patient-level financial burden attributable to LCS [18]. We demonstrate heterogeneity in OOP cost burden,

Table 3. Sociodemographic correlates of receipt of downstream procedures after LCS LDCT

Unique Patients Receiving LDCT LCS, n = 6,268	Logistic Regression of Receiving Downstream Procedures*					
	Crude OR	95% Confidence Interval		Adjusted OR	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Race						
Black	Reference			Reference		
Asian or Hispanic	1.22	0.64	2.30	1.24	0.65	2.36
White	1.62	1.03	2.54	1.52	0.96	2.39
Unknown	1.60	0.90	2.87	1.77	0.98	3.22
Sex						
Female	Reference			Reference		
Male	0.86	0.71	1.03	0.82*	0.68	0.99
Age (y)						
<65	Reference			Reference		
≥65	1.57*	1.25	1.98	1.62*	1.28	2.04
Household income						
≤400% federal poverty level	Reference			Reference		
>400% federal poverty level	1.18	0.94	1.49	1.16	0.92	1.46
Unknown	0.80	0.56	1.14	0.79	0.55	1.13
Division						
East North Central	Reference			Reference		
East South Central	1.34	0.90	2.00	1.34	0.90	2.01
Middle Atlantic	0.79	0.51	1.23	0.75	0.49	1.17
Mountain	1.00	0.65	1.54	0.99	0.64	1.52
New England	1.14	0.78	1.68	1.08	0.73	1.60
Pacific	0.88	0.57	1.35	0.88	0.57	1.37
South Atlantic	0.82	0.61	1.09	0.85	0.63	1.14

(continued)

Table 3. Continued

Unique Patients Receiving LDCT LCS, n = 6,268	Logistic Regression of Receiving Downstream Procedures*					
	Crude OR	95% Confidence Interval		Adjusted OR	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
West North Central	0.84	0.61	1.15	0.83	0.60	1.14
West South Central	0.66	0.42	1.03	0.65	0.42	1.02
Health plan	Reference			Reference		
HMO	1.11	0.84	1.46	1.06	0.79	1.41
Point of service	0.92	0.33	2.61	0.93	0.33	2.64
PPO	0.98	0.66	1.45	0.99	0.66	1.48
EPO, indemnity, other						

EPO = exclusive provider organization; HMO = health maintenance organization; LCS = lung cancer screening; LDCT = low-dose CT; OR = odds ratio; PPO = preferred provider organization.
 *Repeated measures model to account for multiple screenings per patient, $P < .05$.

particularly for those eventually diagnosed with lung cancer. The specific costs of downstream workup depend on insurance provider, health care plan type, patient characteristics, as well as practice patterns and resources at LCS facilities available for downstream workup after positive LCS. Our analysis demonstrated that for LCS encounters with associated downstream procedures (n = 466), Black patients incurred higher total costs than White patients (Table 4). Reasons for this result are unknown and may relate to variations in health plan types or potential differences in downstream procedure type or number with respect to race. The lack of a significant difference with respect to race observed among patient OOP costs (Table 5) would suggest that the higher total costs for Black patients were driven by insurance service reimbursements. Also pertinent to the discussion of LCS-associated costs are costs of procedural-related complications. Although not evaluated here, Huo et al estimated procedural complication rates at approximately twice that of the NLST, with mean incremental complication costs of approximately \$6,000 and \$57,000 for minor and major complications, respectively [15].

Enrollment into LCS necessitates a shared decision-making visit, intended for provider-patient discussion regarding the benefits and associated risks of LCS, including additional follow-up [32]. OOP costs associated with follow-up testing represents an underdiscussed risk, and the shared decision making should include patient financial consequences [33]. Given the existing disparities in lung cancer incidence and outcomes that cause disproportionate burden to vulnerable populations, failure to comprehensively address costs associated with LCS may disincentivize or discourage screening or necessary follow-up testing for certain populations [34,35]. This may inadvertently widen existing lung cancer disparities. Future work is necessary to empirically test interventions that promote cost transparency related to LCS and subsequent recommended care.

Robust health policies need to extend beyond no-cost-sharing provisions for screening to ensure adequate individual-level coverage for patients requiring downstream testing or procedures, the latter of which are necessities for comprehensive LCS [33]. This need for such policies is particularly heightened by the recently expanded 2021 USPSTF guidelines, which markedly increase the screen-eligible population [2]. Such policy shifts may require framing LCS as an episode of care that begins with an LDCT examination and ends after a diagnosis of lung cancer or no lung cancer, rather than a series of individual tests or procedures strung together. Furthermore, even a small OOP cost can induce burden among the financially fragile, such as those living at or below the federal poverty

Table 4. Demographic correlates of total costs for LCS and for subsequent invasive procedures

Demographic	LCS Encounters, n = 6,838			LCS Encounters Resulting in Invasive Procedures, n = 466		
	Model Coefficient*	95% CI Lower Bound	95% CI Upper Bound	Model Coefficient ^a	95% CI Lower Bound	95% CI Upper Bound
Race						
Black	Reference [†]			Reference		
Asian or Hispanic	-29.48	-755.31	696.35	-3,795.83	-14,667.88	7,076.22
White	-316.11	-809.01	176.78	-10,103.58 [†]	-17,798.72	-2,408.43
Unknown	-245.52	-949.31	458.27	-9,002.09	-18,901.16	896.98
Sex						
Female	Reference			Reference		
Male	-185.64	-433.05	61.78	-1,742.64	-4,980.95	1,495.68
Age (y)						
<65	Reference			Reference		
≥65	465.24 [†]	138.83	791.65	581.34	-3,280.68	4,443.35
Household income						
≤400% federal poverty level	Reference			Reference		
>400% federal poverty level	51.04	-241.30	343.37	-54.78	-4,010.57	3,901.01
Unknown	-185.44	-609.73	238.86	-1,778.19	-7,903.64	4,347.25
Division						
East North Central	Reference			Reference		
East South Central	134.65	-458.40	727.70	-315.83	-7,031.23	6,399.56
Middle Atlantic	249.33	-302.42	801.09	4,157.85	-3,043.52	11,359.21
Mountain	68.78	-507.84	645.41	-466.91	-7,503.58	6,569.77
New England	277.81	-275.43	831.04	2,542.17	-3,906.76	8,991.10
Pacific	403.25	-169.92	976.42	6,223.60	-1,056.75	13,503.95
South Atlantic	136.98	-245.63	519.59	2,816.78	-1,981.93	7,615.49
West North Central	79.26	-339.17	497.70	1,065.13	-4,232.74	6,363.01
West South Central	-110.09	-635.57	415.38	-189.72	-7,476.82	7,097.38
Health plan						
HMO	Reference			Reference		
Point of service	140.67	-222.70	504.04	3,339.31	-1,441.42	8,120.05
PPO	-396.23	-1,668.19	875.73	-4,871.18	-22,270.67	12,528.31
EPO, indemnity, other	38.53	-463.70	540.77	1,709.54	-5,026.22	8,445.29

CI = confidence interval; EPO = exclusive provider organization; HMO = health maintenance organization; LCS = lung cancer screening; PPO = preferred provider organization.

*Model coefficients were derived using a repeated measures multivariate linear regression, which modeled the outcome of total cost with respect to the input variables of race, gender, age, household income, geographic division, and health plan type. The coefficient for a particular term reflects the change in mean total cost associated with that term, while the other input terms are held constant.

[†]Reference refers to the group to which regression coefficients for other groups are compared.

#P < .05.

Table 5. Demographic correlates of \$0 OOP cost share for LCS encounters (LCS examination plus subsequent invasive procedures)

Demographic	Patients receiving LCS, n = 6,268*			
	n (%)	Adjusted OR [†]	95% CI Lower Bound	95% CI Upper Bound
Race				
Black	338 (6.7)	Reference		
Asian or Hispanic	257 (5.1)	0.99	0.72	1.37
White	4,138 (82.6)	1.07	0.86	1.33
Unknown	279 (5.6)	0.81	0.60	1.10
Sex				
Female	2,194 (43.8)	Reference		
Male	2,818 (56.2)	1.00	0.90	1.12
Age (y)				
<65	4,243 (84.7)	Reference		
≥65	769 (15.3)	1.02	0.88	1.19
Income relative to the federal poverty level				
≤400%	1,159 (23.1)	Reference		
>400%	3,144 (62.7)	1.06	0.93	1.21
Unknown	709 (14.1)	1.26*	1.04	1.53
Division				
East North Central	884 (17.6)	Reference		
East South Central	275 (5.5)	1.03	0.79	1.33
Middle Atlantic	351 (7)	1.19	0.93	1.53
Mountain	272 (5.4)	0.83	0.65	1.06
New England	354 (7.1)	1.17	0.91	1.49
Pacific	361 (7.2)	1.67 [‡]	1.26	2.22
South Atlantic	1,289 (25.7)	1.08	0.91	1.28
West North Central	870 (17.4)	0.98	0.82	1.18
West South Central	356 (7.1)	0.76 [‡]	0.61	0.95
Health plan				
HMO	804 (16)	Reference		
Point of service	3,602 (71.9)	0.67 [‡]	0.57	0.80
PPO	44 (0.9)	0.49 [‡]	0.29	0.83
EPO, indemnity, other	562 (11.2)	0.94	0.74	1.20

CI = confidence interval; EPO = exclusive provider organization; HMO = health maintenance organization; LCS = lung cancer screening; OOP = out-of-pocket costs; OR = odds ratio; PPO = preferred provider organization. ^bModel limited to first screening for patient. ^cExact number not available due to small cell count suppression.

*Refers to odds of \$0 OOP cost with reference to any OOP costs.

[†]Repeated measures model to account for multiple screenings per patient. Model limited to first screening for patient.

[‡] $P < .05$.

level, necessitating trade-offs between paying their cost share and other household or health expenses. Innovative insurance design needs to align insurance premiums or an OOP bundle covering the entire LCS episode to decrease the financial burden across the population of LCS-eligible individuals.

Limitations

Rates of downstream procedures may be underestimated because patients with positive examinations requiring a procedure may not have received them. Although the cohort

was identified via Current Procedural Terminology code search specific to LDCT LCS, we did not have patient-level LCS results; therefore, we cannot confirm that the procedures performed were prompted by a positive LCS result. Although the procedures evaluated were thoracic procedures, it is plausible that they could have been prompted by imaging tests other than LDCT or ensued because of incidental non-lung cancer–related findings detected at LDCT. In this case, the rates and costs of procedures reported herein may be overestimated. We focused on invasive procedures as

the absence of clinical data precluded reliable attribution of downstream imaging, such as repeat CT after LCS, thereby likely underestimating the downstream cost of LCS. Additionally, our study design required patients to have at least 12 months of continuous insurance coverage in one plan for inclusion. Hence, patients transitioning to other insurance plans or becoming uninsured during the study period are not captured, which may lend way to an underestimation of procedural rates and costs. Most of our cohort had point-of-service health plans. Therefore, the degree to which the estimated OOP costs generalize to other health types is uncertain. Finally, our estimates do not include costs of procedure-related complications [15]. Collectively, the overall effect of these limitations on actual LCS-related procedures and costs are unknown, and we acknowledge that the estimates derived in this investigation may be affected by other factors not described here. Nonetheless, given the limited to-date data that exist on LCS implementation in the clinical setting, continued longitudinal investigations evaluating LCS examinations, outcomes, and consequences are necessary. Although our study has limitations, this investigation provides insight in this regard across a relatively large national population of patients receiving screening in the early years after issuance of the 2013 USPSTF LCS recommendations.

In conclusion, among a national employer-insured cohort, rates of invasive procedures after LDCT are higher than the NLST [3]. As expected under current PPACA policies, patients receiving LCS with negative results incur no OOP costs. However, the OOP costs related to downstream procedures prompted by positive or abnormal LCS examinations are not nominal. LCS growth projected by the revised 2021 USPSTF guidelines necessitate accurate estimates and sufficient coverage of LCS and its downstream consequences, particularly OOP costs [2]. This is a prerequisite toward ensuring that comprehensive LCS is affordable for all individuals who are at high risk for lung cancer.

TAKE-HOME POINTS

- Among 6,268 unique commercially insured patients receiving LCS between 2015 and 2017, 7.4% (462 patients) received at least one downstream invasive procedure.
- Rates of invasive procedures after LDCT LCS examination are higher among older patients (≥ 65 years) compared with younger patients (< 65 years) (adjusted OR, 95% CI: 1.62, 1.28-2.04).
- Although OOP costs to patients receiving LCS without downstream procedures is \$0 (consistent with

the PPACA), OOP costs related to downstream invasive thoracic procedures prompted by positive or abnormal LCS examinations are not nominal.

- As LCS expands, aligning insurance premiums or bundled OOP payments covering the entire LCS episode may decrease the financial burden across the population of LCS-eligible individuals.

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