



# Socioeconomic, rural, and insurance-based inequities in robotic lung cancer resections

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**Background:** Poor, rural, and underinsured patients with lung cancer experience significant treatment-based disparities. These disparities actually worsen when newer, cutting edge technologies emerge because underserved patients frequently have limited access to these new developments. The robotic surgical technique is a state-of-the-art technology which has proven very beneficial to cancer patients. Unfortunately, it appears that its access is limited by sociodemographic factors at least in surgical, gynecological and urological oncology patients. Whether sociodemographic factors also contribute to disparities in robotic lobectomy for lung cancer patients has not been previously investigated.

**Methods:** We utilized the National Inpatient Sample (NIS) Healthcare Cost and Utilization Project (HCUP) database from 2010 to 2014 to evaluate patient or hospital characteristics affecting the application of robotic versus open or video assisted thoracoscopic surgery (VATS) lobectomy among patients (age  $\geq 18$ ) with a lung cancer diagnosis. Each year of NIS data was trend weighted trend-weighted to represent the population of US inpatients for that year. Multivariable analysis was applied to determine predictors of (a) open versus robotic lobectomy, or predictors of (b) VATS versus robotic lobectomy based on patient and hospital characteristics.

**Results:** The trend-weighted population estimate used for analysis was 139,800 patients categorized as 82,072 (58.7%) open, 48,780 (34.9%) VATS, and 8,948 (6.4%) robotic lobectomy. Low-income patients were less likely to undergo robotic versus open lobectomy (AOR =0.78,  $P < 0.01$ ). Compared to patients in urban teaching hospitals, patients in rural hospitals were much less likely to undergo robotic versus open (AOR =0.28,  $P < 0.01$ ) or VATS (AOR =0.64,  $P < 0.01$ ) lobectomy. Patients with Medicaid were less likely than Medicare patients to undergo robotic compared to open (AOR =0.80,  $P < 0.01$ ) or VATS (AOR =0.88,  $P = 0.049$ ) lobectomy. Uninsured patients were also less likely to undergo robotic versus open (AOR =0.62,  $P < 0.01$ ) or VATS (AOR =0.50,  $P < 0.01$ ) lobectomy.

**Conclusions:** Robotic lobectomy access disparities exist for lung cancer patients based on neighborhood-level income, rural location, and insurance status.

**Keywords:** Bronchogenic carcinoma; healthcare disparities; robotic surgical procedures

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## Introduction

Poor, rural, and underinsured patients with lung cancer experience significant treatment-based disparities (1-5). For instance, lung cancer patients who live in neighborhoods with lower socioeconomic status (SES) and rural areas are less likely to undergo surgery or to receive chemotherapy or radiotherapy (1,6,7). Similarly, lung cancer patients who are uninsured and who have Medicaid have lower odds of receiving curative operations (5). These disparities contribute to well-established inferior outcomes in underserved lung cancer populations (1-5). Furthermore, as underserved groups typically have less access to cutting-edge treatments, the benefits associated with these often costly medical and technological advances are only experienced by a select, socioeconomically advanced few, further widening treatment disparity gaps (8). The use of robotic-assisted surgery appears to be no exception.

The first robotic lobectomies were reported in 2003, and their use has increased rapidly over the past decade (9,10). This increase is in part attributed to the advantages of robotic thoracic surgery over video-assisted thoracoscopic surgery (VATS) (11,12). Studies have shown significant benefits of robotic surgical technology, including reduced blood loss, shorter length of hospital stay, increased lymph node retrieval rates, fewer surgical complications, and reduced strain on the surgeon (13-25). Unfortunately, wide adoption is limited by high capital and running costs of robotic instruments (15). In the robotic prostate cancer literature, racial minorities and patients with lower SES in non-metropolitan locations have been found to have less access to robot-assisted radical prostatectomy (RARP)-performing hospitals (14,26). In addition, Medicaid patients are less likely to receive RARP than privately insured patients (14,26).

Other fields, including surgical and gynecological oncology, have found similar disparities in the use of robotic surgeries based on SES, proximity to academic centers, and insurance status (13,27-30), suggesting that the same may contribute to disparities in lung cancer. However, there is a paucity of information on barriers to robotic surgery access specifically for patients with lung cancer. This study aims to elucidate the sociodemographic factors that contribute to reduced access to robotic lung cancer surgery more than 15 years since its first implementation.

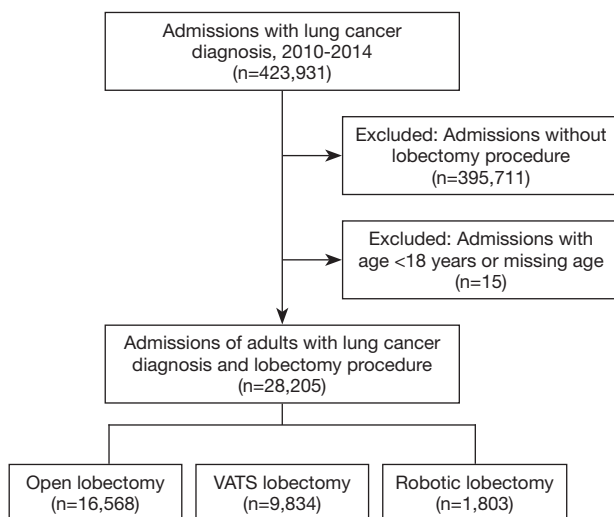
## Methods

### *Data sources*

The National Inpatient Sample (NIS) Healthcare Cost and Utilization Project (HCUP), sponsored by the Agency for Healthcare Research and Quality (AHRQ), is a database of annual hospital inpatient discharges, representing 97% of the US population, and the largest all-payer inpatient care database in the US (31,32). We sought to characterize the use of robotic lobectomy for lung cancer versus that of open or VATS lobectomy. Specifically, we sought information related to patient or hospital characteristics potentially affecting the application of these three approaches for lobectomy.

NIS databases for the years 2010 to 2014 were queried for adult patients (age  $\geq 18$ ) with a diagnosis of lung cancer. We included patients with malignant neoplasm of the lung and airway with diagnosis codes 162.0-162.9. From this group, a subset of patients receiving lobectomy were selected. The NIS data sets use diagnosis and procedure codes from the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). Principal or secondary procedures coded as open lobectomy (ICD-9-CM 32.4 or 32.49) without thoracoscopic or robotic procedure modifiers were categorized as open, while VATS lobectomy (ICD-9-CM 32.41) alone or with an open lobectomy code was categorized as VATS. Principal or secondary procedures that included codes for both lobectomy and a robotic procedure (ICD-9-CM 17.4) were categorized as robotic.

Patient characteristic variables included patient age, gender, race (White, Black, Hispanic, Native American, Asian/Pacific Island, and other), primary expected payer [Medicare, Medicaid, private insurance, uninsured (self-pay; no charge), or other], median household income for each patient's ZIP code (by quartile), admission type (non-elective, elective), length of stay (LOS), discharge disposition (routine, transfer to another hospital, and others), transfer status (to another acute care or other type of health facility), and vital status. Patient comorbidity was quantified using the Deyo modification of the Charlson Comorbidity Index, excluding subscales for cancer and presence of metastatic disease (33-35). Hospital characteristics included size (small, medium, large, based



**Figure 1** Admissions of those with lung cancer diagnosis and lobectomy procedure in the National Inpatient Sample, 2010–2014.

on number of beds) and location-by-teaching status (rural, urban, or urban-teaching). The NIS hospital size variable was relative to hospital location (rural/urban) because rural hospitals tend to have fewer beds compared with hospitals in urban centers.

### Statistical analysis

Each year of NIS data was trend-weighted so that results would be representative of the population of US inpatients for that year. As instructed by HCUP, updated trend weights were applied to NIS data for the years 2010 and 2011 to produce frequency estimates comparable to the new state-by-hospital sampling methodology initiated with the 2012 data set.

For tables of descriptive information, continuous variables are reported as mean and standard deviation (SD; LOS) or median and interquartile range (age); categorical variables are reported as frequencies and percentages. Bivariate statistical analyses were conducted to compare differences in demographic, clinical, and hospital characteristics by lobectomy procedure type (open versus robotic and VATS versus robotic). For continuous variables, independent sample student's t-tests were applied (age, LOS); either Pearson's chi-squared or Fisher's exact tests were applied to categorical variables.

Multivariable logistic regression was applied to determine predictors of (a) open versus robotic lobectomy

or (b) VATS versus robotic lobectomy.

All analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY) and SAS version 9.4 (SAS Institute Inc., Cary, NC). All tests of significance were two-sided, and the value of alpha for statistical significance was  $P < 0.05$ .

## Results

### Patient and operative characteristics

Within the NIS from 2010 to 2014, there were 28,205 admissions of adults who were diagnosed with lung cancer and underwent lobectomy procedures, categorized as open [16,568 (58.7%)], VATS [9,834 (34.9%)], or robotic [1,803 (6.4%)] (*Figure 1*). The trend-weighted population estimate was 139,800 patients; their demographic and hospital information are shown in *Table 1*.

From 2010 to 2014, the proportion of open lobectomies performed decreased significantly from 69.4% to 51.2% ( $P$  value for trend 0.01), whereas the proportion of VATS lobectomies performed increased from 28.2% to 39.4% ( $P$  value for trend 0.03) and the proportion of robotic lobectomies performed increased from 2.4% to 9.4% ( $P$  value for trend 0.01) (*Figure 2*).

### Characteristics associated with robotic lobectomy in univariable analysis

Univariate analysis comparing patients who underwent robotic versus open lobectomy is shown in *Table 2*. Compared to patients who underwent open lobectomy, patients who underwent robotic lobectomy were more likely to be women (53.3% *vs.* 49.8%,  $P < 0.01$ ) and have a higher median income. They were also more likely to have a lower Charlson comorbidity score and an elective admission (93.2% *vs.* 91.9%,  $P < 0.01$ ) and to be in an urban teaching hospital (71.7% *vs.* 61.9%,  $P < 0.01$ ). Patients who underwent robotic lobectomy had a shorter mean LOS (6.3% *vs.* 8.4 days,  $P < 0.01$ ), were more likely to be discharged to home (90.8% *vs.* 85.7%,  $P < 0.01$ ), and had a lower inpatient mortality rate (1.7% *vs.* 2.2%,  $P < 0.01$ ).

The results of univariate analyses comparing patients who underwent robotic versus VATS lobectomy are shown in *Table 3*. Compared to patients who underwent VATS lobectomy, patients who underwent robotic lobectomy were less likely to be women (53.3% *vs.* 55.8%,  $P < 0.01$ ) and have

**Table 1** Weighted population estimates of patient characteristics<sup>†</sup>

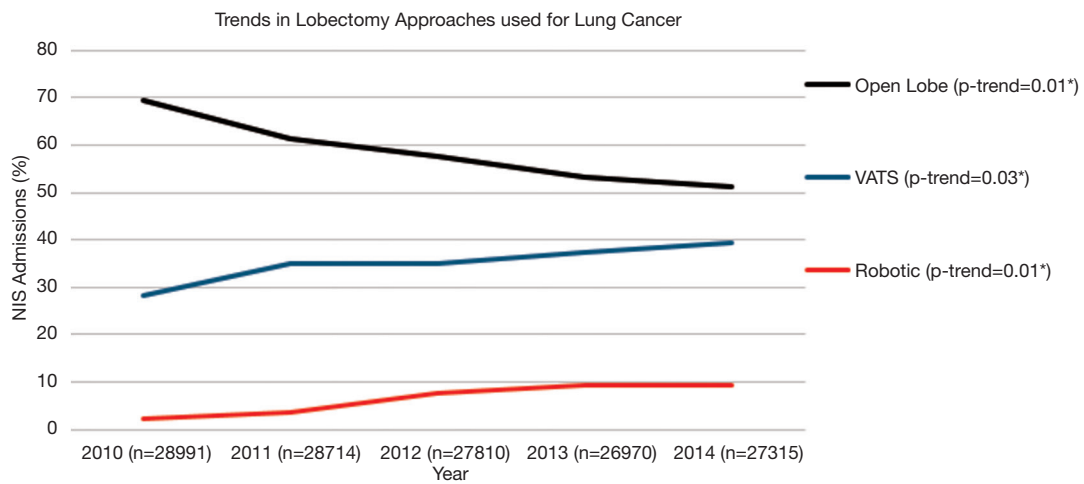
Characteristic	Weighted population estimate (n=139,800)
Age (years)	67.44±9.8
Sex, n (%)	
Female	72,880 (52.1)
Male	66,904 (47.9)
Missing	16 (0.0)
Race, n (%)	
White	107,762 (77.1)
Black	10,970 (7.8)
Hispanic	4,756 (3.4)
Asian or Pacific Islander	3,413 (2.4)
Other	3,028 (2.2)
Missing	9,871 (7.1)
Primary expected payer, n (%)	
Medicare	88,269 (63.1)
Medicaid	7,610 (5.4)
Private Insurance	33,857 (27.8)
Uninsured	2,366 (1.7)
Other	2,698 (1.9)
Missing	185 (0.1)
Median income, n (%)	
0–25th percentile (lowest)	34,066 (24.4)
26–50th percentile	35,485 (25.4)
51–75th percentile	34,126 (24.4)
76–100th percentile (highest)	33,579 (24.0)
Missing	2,543 (1.8)
Charlson comorbidity score, n (%)	
0	47,891 (34.3)
1	57,982 (41.5)
2 or more	33,927 (24.3)
Admission status, n (%)	
Elective	129,950 (93.0)
Non-Elective	9,610 (6.9)
Missing	240 (0.2)

**Table 1** (Continued)**Table 1** (Continued)

Characteristic	Weighted population estimate (n=139,800)
Hospital bed size, n (%)	
Large	97,303 (69.6)
Medium	27,998 (20.0)
Small	12,626 (9.0)
Missing	1,873 (1.3)
Hospital location and teaching status, n (%)	
Urban teaching	91,326 (65.3)
Urban nonteaching	40,664 (29.1)
Rural	5,936 (4.2)
Missing	1,873 (1.3)
Length of stay (LOS), days	7.5±6.5
Discharge disposition, n (%)	
Home	122,773 (87.8)
Facility	14,317 (10.2)
Other	2,710 (1.9)
Missing	42 (0.0)
Vital status, n (%)	
Alive	137,187 (98.1)
Died during hospitalization	2,571 (1.8)
Missing	42 (0.0)
Lobectomy approach, n (%)	
Open	82,072 (58.7)
VATS	48,780 (34.9)
Robotic	8,948 (6.4)

<sup>†</sup>Age and length of stay (LOS) are reported as mean ± SD. For race, “other” includes other race, multiple races, and Native American. For discharge disposition, “other” includes patients who died or left against medical advice. For payer, “other” includes worker’s compensation, CHAMPUS, CHAMPVA, Title V, and other government programs.

a lower median income. They were also less likely to be in a large hospital (65.6% *vs.* 74.1%,  $P<0.01$ ) and had a higher inpatient mortality rate (1.7% *vs.* 1.2%,  $P=0.001$ ). The difference in LOS between these groups was statistically but not clinically significant (6.3 *vs.* 6.2 days,  $P<0.01$ ).



**Figure 2** Trends in open, VATS, and robotic approaches to lobectomy for patients with lung cancer in the National Inpatient Sample, 2010–2014.

**Table 2** Patient characteristics by lobectomy approach, open versus robotic<sup>†</sup>

Characteristic	Open (n=82,072)	Robotic (n=8,948)	P value
Age (years)	67.18±9.9	67.99±9.4	<0.01*
Sex, n (%)			<0.01*
Female	40,896 (49.8)	4,766 (53.3)	
Male	41,171 (50.2)	4,182 (46.7)	
Race, n (%)			<0.01*
White	62,380 (83.5)	6,948 (81.5)	
Black	6,336 (8.5)	766 (9.0)	
Hispanic	2,730 (3.7)	464 (5.4)	
Asian or Pacific Islander	1,612 (2.2)	220 (2.6)	
Other	1,605 (2.1)	129 (1.5)	
Primary expected payer, n (%)			<0.01*
Medicare	51,762 (63.1)	5,857 (65.6)	
Medicaid	4,920 (6.0)	420 (4.7)	
Private Insurance	22,369 (27.3)	2,370 (26.5)	
Uninsured	1,424 (1.7)	94 (1.1)	
Other	1,501 (1.8)	193 (2.2)	
Median income, n (%)			<0.01*
0–25th percentile (lowest)	22,061 (26.9)	2,142 (23.9)	
26–50th percentile	21,780 (26.5)	2,225 (24.9)	
51–75th percentile	19,713 (24.0)	2,117 (23.7)	
76–100th percentile (highest)	16,980 (20.7)	2,309 (25.8)	

**Table 2** (Continued)

Table 2 (Continued)

Characteristic	Open (n=82,072)	Robotic (n=8,948)	P value
Charlson comorbidity score, n (%)			<0.01*
0	26,061 (31.8)	3,303 (36.9)	
1	35,028 (42.7)	3,530 (39.5)	
2 or more	20,982 (25.6)	2,114 (23.6)	
Admission, n (%)			<0.01*
Elective	75,461 (91.9)	8,341 (93.2)	
Non-elective	6,435 (7.9)	607 (6.8)	
Hospital bed size, n (%)			<0.01*
Large	55,943 (68.9)	5,506 (65.6)	
Medium	17,695 (21.8)	1,945 (23.2)	
Small	7,507 (9.3)	937 (11.2)	
Hospital location and teaching status, n (%)			<0.01*
Urban teaching	50,214 (61.9)	6,018 (71.7)	
Urban nonteaching	26,414 (32.6)	2,235 (26.6)	
Rural	4,517 (5.6)	135 (1.6)	
Length of stay (LOS) (days)	8.4±6.8	6.3±6.6	<0.01*
Discharge disposition, n (%)			<0.01*
Routine/Home	70,295 (85.7)	8,127 (90.8)	
Facility	9,860 (12.0)	673 (7.5)	
Other	1,916 (2.3)	148 (1.7)	
Vital status, n (%)			<0.01*
Alive	80,201 (97.8)	8,800 (98.3)	
Died during hospitalization	1,828 (2.2)	148 (1.7)	

†Age and LOS are reported as mean ± SD. For race, “other” includes other race, multiple races, and Native American. For discharge disposition, “other” includes patients who died or left against medical advice. For payer, “other” includes worker’s compensation, CHAMPUS, CHAMPVA, Title V, and other government programs. Missing data is reported in Table 1. \*P value is significant (alpha level <0.05).

Table 3 Patient characteristics by lobectomy approach, video-assisted thoracic surgery (VATS) versus robotic†

Characteristic	VATS (n=48,780)	Robotic (n=8,948)	P value
Age, years	67.77±9.8	67.99±9.4	<0.01*
Sex, n (%)			<0.01*
Female	27,219 (55.8)	4,766 (53.3)	
Male	21,551 (44.2)	4,182 (46.7)	

Table 3 (Continued)

Table 3 (Continued)

Characteristic	VATS (n=48,780)	Robotic (n=8,948)	P value
Race, n (%)			<0.01*
White	38,433 (82.2)	6,948 (81.5)	
Black	3,868 (8.3)	766 (9.0)	
Hispanic	1,562 (3.3)	464 (5.4)	
Asian or Pacific Islander	1,581 (3.4)	220 (2.6)	
Other	1,295 (2.8)	129 (1.5)	
Primary expected payer, n (%)			<0.01*
Medicare	30,650 (62.9)	5,857 (65.6)	
Medicaid	2,270 (4.7)	420 (4.7)	
Private Insurance	14,119 (29.0)	2,370 (26.5)	
Uninsured	849 (1.8)	94 (1.1)	
Other	819 (1.7)	193 (2.2)	
Median income, n (%)			<0.01*
0–25th percentile (lowest)	9,863 (20.6)	2,142 (23.9)	
26–50th percentile	11,480 (24.0)	2,225 (24.9)	
51–75th percentile	12,296 (25.7)	2,117 (23.7)	
76–100th percentile (highest)	14,291 (29.8)	2,309 (25.8)	
Charlson comorbidity score, n (%)			0.01*
0	18,526 (38.0)	3,303 (36.9)	
1	19,424 (39.8)	3,530 (39.5)	
2 or more	10,831 (22.2)	2,114 (23.6)	
Admission status, n (%)			<0.01*
Elective	46,148 (94.7)	8,341 (93.2)	
Non-Elective	2,567 (5.3)	607 (6.8)	
Hospital bed size, n (%)			<0.01*
Large	35,854 (74.1)	5,506 (65.6)	
Medium	8,358 (17.3)	1,945 (23.2)	
Small	4,181 (8.6)	937 (11.2)	
Hospital location and teaching status, n (%)			<0.01*
Urban teaching	35,094 (72.5)	6,018 (71.7)	
Urban nonteaching	12,015 (24.8)	2,235 (26.6)	
Rural	1,284 (2.7)	135 (1.6)	
Length of stay (LOS), days	6.2±5.6	6.3±6.6	<0.01*
Discharge disposition, n (%)			0.038*
Home	44,351 (90.9)	8,127 (90.8)	
Facility	3,784 (7.8)	673 (7.5)	
Other	646 (1.3)	148 (1.7)	
Vital status, n (%)			0.001*
Alive	48,185 (98.8)	8,800 (98.3)	
Died during hospitalization	595 (1.2)	148 (1.7)	

<sup>†</sup>Age and LOS are reported as mean ± SD. For race, “other” includes other race, multiple races, and Native American. For discharge disposition, “other” includes patients who died or left against medical advice. For payer, “other” includes worker’s compensation, CHAMPUS, CHAMPVA, Title V, and other government programs. Missing data is reported in Table 1. \*P value is significant (alpha level <0.05).



### *Characteristics associated with robotic lobectomy in multivariable analysis*

Multivariable analyses comparing patients who underwent robotic versus open and robotic versus VATS lobectomy are shown in *Table 4*. Age, sex, Charlson comorbidity score, admission status, and hospital bed size were included in the models. Low-income patients were less likely to undergo robotic versus open lobectomy (AOR =0.78,  $P<0.01$ ), but were more likely to undergo robotic versus VATS lobectomy (AOR =1.31,  $P<0.01$ ). Compared to patients in urban teaching hospitals, patients in rural hospitals were much less likely to undergo robotic versus open (AOR =0.28,  $P<0.01$ ) or VATS (AOR =0.64,  $P<0.01$ ) lobectomy. Compared to patients with Medicare, patients with Medicaid were less likely to undergo robotic compared to open (AOR =0.80,  $P<0.01$ ) or VATS (AOR =0.88,  $P=0.049$ ) lobectomy. Similarly, uninsured patients were also less likely to undergo robotic versus open (AOR =0.62,  $P<0.01$ ) or VATS (AOR =0.50,  $P<0.01$ ) lobectomy.

Compared to White patients, Black patients were more likely to undergo robotic versus open lobectomy (AOR =1.12,  $P=0.01$ ), but were no more likely to have robotic versus VATS lobectomy (AOR =1.02,  $P=0.64$ ). Hispanic patients were more likely to have robotic versus open (AOR =1.60,  $P<0.01$ ) or VATS (AOR =1.69,  $P<0.01$ ) lobectomy.

## **Discussion**

This study leveraged the NIS database to identify sociodemographic factors that were associated with the use of robotic lung cancer resection. We found that neighborhood-level income, rural location of the hospital, and insurance status significantly impact whether a patient with lung cancer is treated with robotic resection rather than open or VATS lobectomy. These factors have been shown to impact access to robotic resections in other cancers (14,29,36) but had not previously been evaluated in lung cancer patients.

### *Socioeconomic status*

In this study, low neighborhood-level income decreased the odds of a lung cancer patient undergoing robotic versus open lobectomy. This finding is consistent with other studies that have shown an association between neighborhood-level SES and access to oncologic treatments, particularly robotic-assisted procedures (14,29,36). Patients

who live in deprived neighborhoods may have lower access to or live further from hospitals that have the additional resources necessary to provide costly robotic surgery. Thus, the finding that patients living in poorer neighborhoods are less likely to obtain robotic versus open lung cancer resections was not surprising.

What was surprising and difficult to explain was our finding that low neighborhood-level income increased the odds of robotic surgery versus VATS resection. Many studies have found that robotic resections are more costly than thoracoscopic ones (37,38). The increased cost burden of robotic surgery is therefore expected to reduce its use in areas with low neighborhood-level income. Our findings suggest that, despite the high costs associated with robotic resections, low neighborhood-level income favors this approach over other minimally invasive lobectomy techniques. This finding has not been previously shown and may shed light on the fact that the impact of SES on outcomes can be quite difficult to interpret. Neighborhood-level and individual-level SES can impact outcomes independently (39) and cannot be assumed to be identical. Therefore, the finding that those in areas of low neighborhood-level income had higher rates of robotic versus VATS lobectomy should not be interpreted to mean that low individual income or poverty leads to more robotic surgery versus thoracoscopic resections. Furthermore, neighborhood-level income is only one component of neighborhood SES, and absence of other variables like neighborhood education and neighborhood deprivation data, due to limitations of the NIS database, restricts our ability to comprehensively understand how neighborhood SES impacts robotic lung cancer surgery access. For now, we can only state that patients living in areas with the lowest median neighborhood-level incomes had higher rates of open lobectomies, but lower rates of VATS resections, compared to robotic lobectomies. Certainly, we will need to evaluate this finding in larger studies with more granular, comprehensive SES data.

### *Rurality*

Living in rural areas is associated with geographic isolation and less access to primary and specialty care (40,41) and is therefore a well-known risk factor associated with lower oncologic treatment access (1). Because of increased poverty and under-resourced hospitals in rural locations, advanced technologies are less prevalent and have delayed implementation. Our findings that patients in rural hospitals



**Table 4** Multivariable logistic regression for predictors of robotic surgery approaches among lung cancer patients<sup>†</sup>

Characteristic	Robot versus open		Robot versus VATS	
	AOR (95% CI)	P value	AOR (95% CI)	P value
Age (per year)	1.01 (1.006–1.012)	<0.01*	1.00 (0.99–1.003)	0.99
Sex				
Female	1	–	–	–
Male	0.89 (0.85–0.94)	<0.01*	1.11 (1.06–1.17)	<0.01*
Race				
White	1	–	–	–
Black	1.12 (1.03–1.23)	0.01*	1.02 (0.94–1.12)	0.64
Hispanic	1.60 (1.44–1.79)	<0.01*	1.69 (1.51–1.89)	<0.01*
Asian or Pacific Islander	1.16 (1.00–1.35)	0.048*	0.84 (0.72–0.97)	0.02*
Others	0.81 (0.67–0.98)	0.027*	0.62 (0.51–0.75)	<0.01*
Primary expected payer				
Medicare	1	–	–	–
Medicaid	0.80 (0.70–0.91)	<0.01*	0.88 (0.77–0.999)	0.049*
Private insurance	0.98 (0.91–1.04)	0.44	0.91 (0.85–0.97)	0.004*
Uninsured	0.62 (0.49–0.79)	<0.01*	0.50 (0.39–0.64)	<0.01*
Other	1.17 (0.97–1.438)	0.08	1.05 (0.88–1.26)	0.57
Median income				
0–25th percentile (lowest)	0.78 (0.73–0.84)	<0.01*	1.31 (1.21–1.39)	<0.01*
26–50th percentile	0.83 (0.78–0.89)	<0.01*	1.18 (1.10–1.26)	<0.01*
51–75th percentile	0.84 (0.79–0.90)	<0.01*	1.04 (0.98–1.12)	0.207
76–100th percentile (highest)	1	–	–	–
Charlson comorbidity score				
0 or none of the conditions	1	–	–	–
1	0.84(0.79–0.89)	<0.01*	1.02 (0.96–1.08)	0.54
2 or more	0.85 (0.79–0.91)	<0.01*	1.07 (1.00–1.14)	0.05*
Admission status				
Elective	1	–	–	–
Non-Elective	0.92 (0.84–1.01)	0.09	1.30 (1.18–1.43)	<0.01*
Hospital bed size				
Large	1	–	–	–
Medium	1.01 (0.96–1.07)	0.72	1.46 (1.37–1.54)	<0.01*
Small	1.13 (1.05–1.22)	<0.01*	1.49 (1.37–1.61)	<0.01*

Table 4 (Continued)

Table 4 (Continued)

Characteristic	Robot versus open		Robot versus VATS	
	AOR (95% CI)	P value	AOR (95% CI)	P value
Hospital location and teaching status				
Urban teaching	1	–	–	–
Urban nonteaching	0.70 (0.66–0.73)	<0.01*	1.13 (1.07–1.19)	0.001*
Rural	0.28 (0.23–0.33)	<0.01*	0.64 (0.53–0.77)	<0.01*

<sup>†</sup>Adjusted odds ratios (AORs) indicate the likelihood of robotic lobectomy relative to either open or video-assisted thoracic surgery (VATS) lobectomy. \*P value is significant (alpha level <0.05).

were much less likely to undergo robotic versus open or VATS lobectomy was consistent with most other studies that have evaluated the impact of rurality on treatment access (1,6,41).

### Insurance

Patients with no or public insurance have consistently been found to be at higher risk for worse outcomes and lower treatment rates than those with private insurance (4,5). In line with these findings, as well as many other robotic cancer resection studies, (14,29,30) we found that robotic lobectomies were less common in those with no insurance or with Medicaid. This finding has important implications in the context of the expansion of Medicaid eligibility under the Affordable Care Act, as growth of the number of Medicaid enrollees may lead to worse disparities due to robotic lobectomy access.

### Race/ethnicity

We were surprised that Black patients had higher rates of robotic lobectomies *vs.* open and Hispanic patients had higher rates of robotic lobectomies versus open or VATS lobectomies, indicating that there is no racial disparity in robotic lung cancer resection access. Whereas previous studies have found that race impacts urologic robotic cancer resection rates (14,26), others focused on robotic gastrointestinal cancer resections, including one using the NIS database, also found that race did not influence access to robotic or minimally invasive procedures (29,42).

Limitations of this study include the fact that the NIS is an administrative inpatient database populated by ICD-9 codes. NIS underwent significant methodological changes

that impacted the numbers of discharges in the dataset. These changes complicate the comparison of discharges and hospital bed sizes between 2010–2011 and 2012–2014 and necessitate the use of discharge weights when analyzing historical NIS files as we have done here.

As noted earlier, this study was also limited by the fact that the NIS does not collect individual-level social determinants, so an evaluation of the impact of these individual determinants on robotic lung cancer surgery access was not possible. And although NIS tracks neighborhood-level median income, it does not gather other neighborhood factors such as neighborhood education or deprivation. Therefore, it is not possible to comprehensively evaluate the impact of neighborhood SES on robotic lung cancer surgery access. Furthermore, the NIS records whether hospitals are in rural locations but not whether the patients themselves reside in rural locations. It is certainly conceivable that a patient and the hospital that they choose/have access to are not located in the same type of place. Lastly, detailed information about tumor characteristics, which may impact surgical approach decisions, are unavailable.

To conclude, we have found that neighborhood-level income, rural hospital location, and insurance status impact whether a patient obtains robotic lung cancer resections via lobectomy. These findings shine a light on sociodemographic factors that may limit access to technology that could significantly improve outcomes. Rural, poor, and underinsured patients with lung cancer fundamentally have worse outcomes and have been previously found to be less likely to receive any treatment, including surgery and chemotherapy, than those who are less socioeconomically deprived (7). Our current findings reveal that these groups also have less access to

robotic surgeries. As the use of robotic surgery continues to grow, our understanding of disparities with respect to access will become more important and currently deserves greater attention. If these issues are not addressed, a major disadvantage of the robotic lung cancer surgery approach will be disparate access to the underserved. This study contributes to the literature by characterizing important sociodemographic influences on robotic lung cancer resections and raises questions that may be addressed by future public health policies. It is essential to understand barriers that may result in disparities in access to robotic lung cancer resections if we are to eliminate them.

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