Association of travel distance, surgical volume, and receipt of adjuvant chemotherapy with survival among patients with resectable lung cancer

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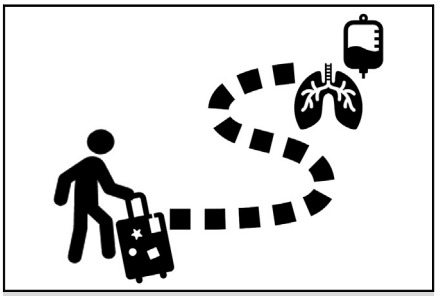
ABSTRACT

Objective: Regionalization of surgery for non–small cell lung cancer (NSCLC) to high-volume centers (HVCs) improves perioperative outcomes but frequently increases patient travel distance. Travel might decrease rates of adjuvant chemotherapy (AC) use, however, the relationship of distance, volume, and receipt of AC with outcomes is unknown. Our objective was to evaluate the association of distance, volume, and receipt of AC with overall survival among patients with NSCLC.

Methods: Patients with stage I to IIIA (No-N1) NSCLC were identified between 2004 and 2018 using the National Cancer Database. Distance to surgical facility was categorized into quartiles (<5.1, 5.1 to <11.5, 11.5 to <28.1, and ≥28.1 miles), and HVCs were defined as those that perform ≥40 annual resections. Patient characteristics and likelihood of receiving AC anywhere were determined. Propensity score-matched survival analysis was performed using Cox models and Kaplan–Meier curves.

Results: Of the 131,982 patients included, 35,658 (27.0%) were stage II to IIIA. Of the stage II to IIIA cohort, 49.6% received AC, 13.1% traveled <5.1 miles to low-volume centers (LVCs), and 18.1% traveled ≥28.1 miles to HVCs ($P < .001$). Among stage II to IIIA patients who traveled ≥28.1 miles to HVCs, 45% received AC versus 51.5% who traveled <5.1 miles to LVCs (incidence rate ratio, 0.88; 95% CI, 0.83-0.94; <5.1 miles to LVC reference). Patients with stage II to IIIA NSCLC who traveled ≥28.1 miles to HVCs and did not receive AC had higher mortality rates than those who traveled <5.1 miles to LVCs and received AC (median overall survival, 52.3 vs 36.7 months; adjusted hazard ratio, 1.41; 95% CI, 1.26-1.57).

Conclusions: Increasing travel distance to surgical treatment is associated with decreased likelihood of receiving AC for patients with stage II to IIIA (No-N1) NSCLC. (JTCVS Open 2023;13:357-78)



Increasing travel distance to surgery decreases likelihood of adjuvant chemotherapy.

CENTRAL MESSAGE

Because regionalization of complex surgery results in increased patient travel to receive care, it is important that vital oncological services remain accessible.

PERSPECTIVE

Use of adjuvant chemotherapy for lung cancer is becoming more common. However, regionalization of surgery has increased distance patients travel to receive care. This increased travel distance to high-volume hospitals is associated with decreased likelihood of receiving adjuvant chemotherapy. Nonreceipt of adjuvant chemotherapy is associated with worse survival.

Despite recent improvements in survival, lung cancer remains the foremost cause of cancer death in the United States and the world for men and women.[1,2] In 2022, it is estimated that there will be 236,740 new cases and 130,180 deaths attributed to lung cancer in the United States.[2] Non–small cell lung cancer (NSCLC) is the most

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Research reported in this publication was supported by the National Institute on Minority Health and Health Disparities of the National Institutes of Health under award number T37MD014248 (C.D.L.), the National Cancer Institute under award number K07 CA216330 (D.D.O.), the National Heart, Lung, and Blood Institute under award number R01HL145478 (A.B.). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Read at the 48th Annual Meeting of the Western Thoracic Surgical Association, Koloa, Hawaii, June 22-25, 2022.

Received for publication June 24, 2022; revisions received Oct 7, 2022; accepted for publication Nov 3, 2022; available ahead of print Jan 29, 2023.

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2666-2736

https://doi.org/10.1016/j.xjon.2022.11.017

Abbreviations and Acronyms

AC = adjuvant chemotherapy
aHR = adjusted hazard ratio
H4N = patient traveled ≥28.1 miles (quartile 4) to a high-volume center and did not receive adjuvant chemotherapy
HVC = high-volume center
IQR = interquartile range
L1C = patient traveled <5.1 miles (quartile 1) to a low-volume center and received adjuvant chemotherapy
LVC = low-volume center
NCDB = National Cancer Database
NSCLC = non–small cell lung cancer
OS = overall survival

common form of lung cancer among patients who undergo surgical resection, and hospital surgical volume has been established as a having an inverse relationship with mortality in complex or high-risk cases.[3-9] These findings have led to proposals for hospital and surgeon surgical volume minimums, and a trend toward regionalization (centralization) of complex surgery to high-volume centers (HVCs).[8,10]

Regionalization to HVCs has led to an increase in the distance patients travel to receive care, especially for patients from rural areas.[11-14] Increased travel distance might also lead to decreased access to care after surgical resection, possibly because of loss of care coordination resulting in care fragmentation when more than 1 treatment team is involved.[15,16] Because of these findings, we hypothesize that: 1) patients with NSCLC who travel long distances for surgical resection are less likely to receive adjuvant chemotherapy (AC), and 2) patients who travel long distances to HVCs for surgery and do not receive indicated AC have worse overall survival (OS) than patients who travel short distances to low-volume centers (LVCs) and successfully receive AC. Therefore, the objective of this study was to evaluate the association of travel distance, hospital surgical volume, and receipt of AC with OS for patients with resected NSCLC.

METHODS

Data Source and Study Cohort

The National Cancer Database (NCDB) is a large hospital-based cancer registry.[17] More than 1500 hospitals contribute to the NCDB, and it is estimated to capture approximately 82% of cancers of the lung and bronchus in the United States.[17] Data are entered by trained registrars, and the database undergoes regular audits to confirm accuracy and completeness. The NCDB was used to retrospectively identify surgically treated NSCLC patients diagnosed from 2004 to 2017 with outcomes through 2018. Patients were excluded if they had multiple malignancies, received neoadjuvant chemotherapy, underwent surgical resection at a nonreporting facility (so that travel distance to surgery is accurate), had interruptions in facility reporting from 2004 to 2018, had nonintact geographic data, had 1-way travel distance >250 miles, had missing tumor grade or size, or they did not meet the widely accepted definition of resectable (stage I-IIIA; N0-N1; Figure 1). Patient information in the NCDB is deidentified and use in research was determined to be exempt from review by our institution's institutional review board.

Geographic Characteristics

Travel distance to the reporting facility was determined by calculating the distance between the centroid of the patient's zip code to the address of the reporting facility where surgery was performed. Travel distance was evaluated as a continuous variable and also categorized into quartiles (<5.1, 5.1 to <11.5, 11.5 to <28.1, and ≥28.1 to 250 miles) for the stage I to IIIA (N0-N1) cohort. Facility geographic region was categorized into 9 US Census Divisions. The United States Department of Agriculture Economic Research Service publishes a 9-level rural-urban continuum code, and "metro" was defined as rural-urban continuum codes 1 to 3, and "nonmetro" was defined as rural-urban continuum codes 4 to 9. Patients with missing region, rurality, travel distance, and those who traveled >250 miles were excluded.[12]

Facility Characteristics

Facility surgical volume was determined by the mean number of resections performed annually by facilities without missing years of NCDB reporting. Annual surgical volume was evaluated as continuous variable as well as a categorical variable. HVCs versus LVCs were defined using LeapFrog criteria with a cutoff of ≥40 annual pulmonary resections.[10,18] Program type, as determined by Commission on Cancer accreditation, was categorized as academic, comprehensive, integrated, and community. Designations reflect program-level capabilities and organizational characteristics. Care fragmentation was categorized as those who received care at multiple facilities versus a single facility.

Treatment Characteristics

All included patients underwent surgical resection for cure, with a pathological specimen obtained, at the reporting facility, with a known extent of resection. Extent of resection was categorized as wedge, segmentectomy, lobectomy, or pneumonectomy. Surgical margin status was categorized as negative (R0) versus positive (R1, R2, or residual tumor present). Number of intraoperative lymph nodes sampled was included as a continuous variable. Patients were considered to have received AC if treatment was administered at any facility (including facilities other than the facility where they received surgical treatment).

Patient Characteristics

Patient age at diagnosis was included as a continuous variable. Race and ethnicity were categorized as non-Hispanic White, non-Hispanic Black, Hispanic, Asian (including Pacific Islander, East Asian, Southeast Asian, and South Asian), and other or unknown race or ethnicity (American Indian, Alaska Native, and "other" or "unknown" categories, which are NCDB categories). Educational attainment was on the basis of zip code tabulation area estimates, matched with patient year of diagnosis, as quartiles of the population aged ≥25 years without a high school degree. Income level was similarly on the basis of zip code tabulation area estimates matched to patient year of diagnosis and was categorized as quartiles. Insurance status was categorized as uninsured or Medicaid, Medicare, or private, and other. Patients with missing education, income, or insurance data were excluded. The NCDB reports comorbidities with the Charlson–Deyo score, which was grouped as 0, 1, 2, and ≥3. Tumor size was categorized as <1, ≥1, >1-2, >2-3, >3-5,

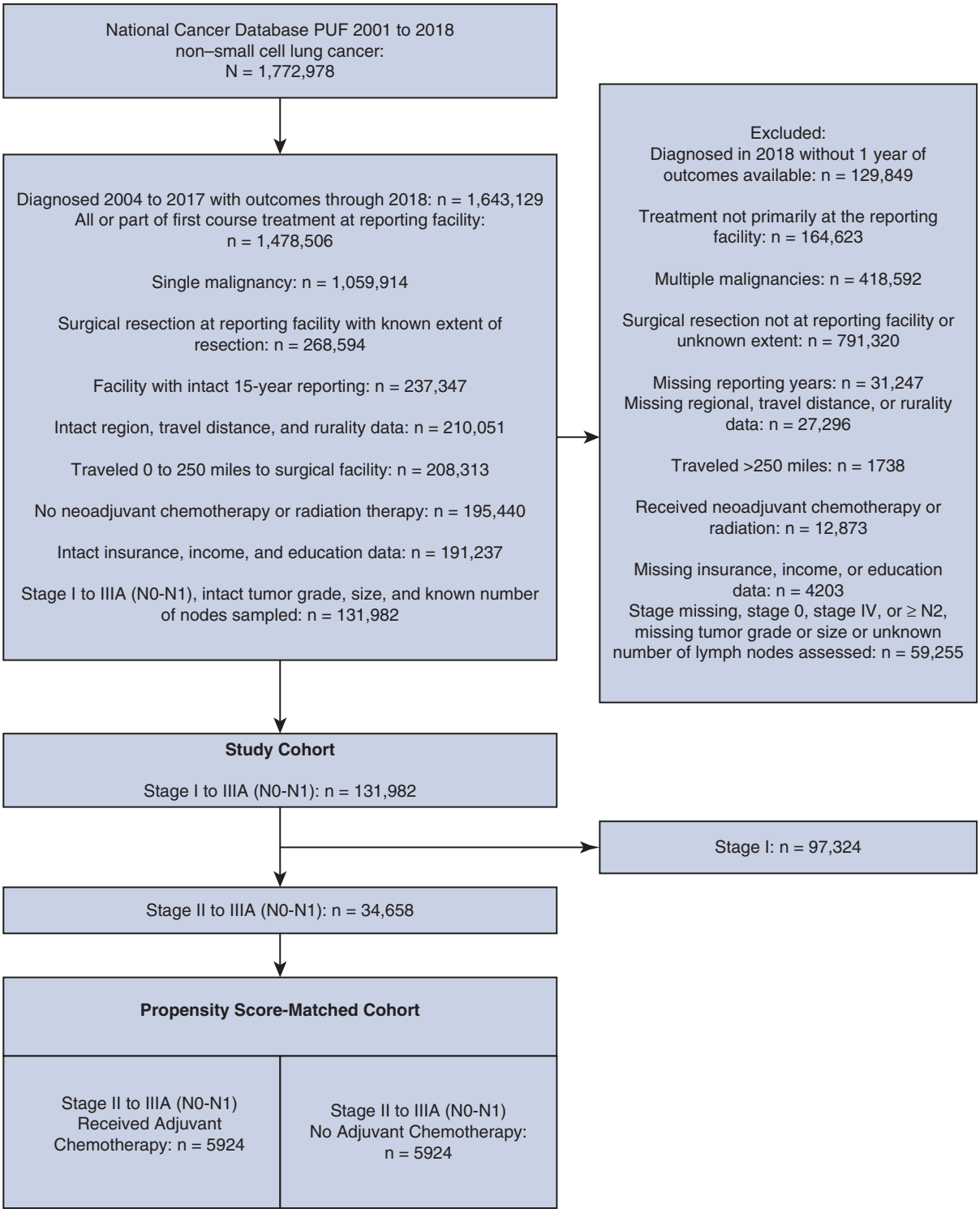


FIGURE 1. Inclusion criteria flow diagram. The National Cancer Database was used to identify patients with non–small cell lung cancer diagnosed between 2004 and 2017 with outcomes available through 2018. Population excluded at each stage of analysis is detailed. *PUF*, Participant User File.

>5-7, or >7 cm. Tumor grade was categorized as well differentiated, moderately differentiated, poorly differentiated, and undifferentiated. Histology was categorized as adenocarcinoma, squamous, large cell, carcinoid, and other (Table E1). American Joint Committee on Cancer stage was categorized as pathological stage I, stage II, and stage IIIA. Nodal stage was categorized to N0, N1, or N2 to N3. Patients with pathological stage 0 or stage IV, N2 to N3 disease, and missing tumor size data were excluded.

TABLE 1. Population characteristics and rate of receipt of adjuvant chemotherapy at any facility for patients with resected stage I to IIIA (N0-N1) NSCLC

Patient n	Receipt of adjuvant chemotherapy*			
	Total	No adjuvant chemotherapy	Adjuvant chemotherapy	
	131,982	107,484	24,498	
Parameter†	n	%	%	*P* value
Median travel distance to surgical treatment (IQR)	131,982	11.4 (4.9-27.9)	10.9 (4.9-26.4)	<.001
<5.1	33,121	81.3	18.7	
5.1 to <11.5	33,410	80.8	19.2	
11.5 to <28.1	32,995	81.4	18.6	
28.1 to 250	32,456	82.3	17.7	
Median annual surgical volume (IQR)	131,982	47.1 (27.2-79.8)	46.0 (26.5-75.9)	<.001
<40	57,411	80.8	19.2	
≥40	74,571	81.9	18.1	
Volume/travel miles				<.001
Low/<5.1	18,447	80.4	19.6	
Low/5.1 to <11.5	15,855	80.7	19.3	
Low/11.5 to <28.1	13,066	80.6	19.4	
Low/28.1 to 250	10,043	82.0	18.0	
High/<5.1	14,674	82.5	17.5	
High/5.1 to <11.5	17,555	80.9	19.1	
High/11.5 to <28.1	19,929	82.0	18.0	
High/28.1 to 250	22,413	82.4	17.6	
Rurality				.99
Nonmetro	22,970	81.4	18.6	
Metro	109,012	81.4	18.6	
Facility location				<.001
New England	7259	83.1	16.9	
Middle Atlantic	20,779	81.7	18.3	
South Atlantic	33,175	81.9	18.1	
East North Central	24,256	79.3	20.7	
East South Central	11,575	81.3	18.7	
West North Central	10,568	79.3	20.7	
West South Central	7951	82.2	17.8	
Mountain	3742	81.6	18.4	
Pacific	12,677	84.3	15.7	
Year of diagnosis				<.001
2004	7607	81.7	18.3	
2005	8476	78.8	21.2	
2006	8359	79.7	20.3	
2007	8518	80.2	19.8	
2008	8776	81.0	19.0	
2009	8704	82.7	17.3	
2010	9398	81.6	18.4	
2011	9669	81.5	18.5	
2012	9904	81.1	18.9	
2013	10,080	81.6	18.4	
2014	10,087	81.5	18.5	
2015	10,577	81.9	18.1	
2016	10,788	82.3	17.7	
2017	11,039	83.6	16.4	

(Continued)

TABLE 1. Continued

Patient n	Receipt of adjuvant chemotherapy*			
	Total	No adjuvant chemotherapy	Adjuvant chemotherapy	
	131,982	107,484	24,498	
Parameter†	n	%	%	*P* value
Sex				<.001
Female	69,208	82.9	17.1	
Male	62,774	79.8	20.2	
Mean age at diagnosis (SD)	131,982	68.1 (9.6)	64.1 (09.0)	<.001
Race and ethnicity				<.001
Non-Hispanic White	106,426	81.8	18.2	
Non-Hispanic Black	10,629	78.9	21.1	
Hispanic	3450	82.3	17.7	
Asian and Pacific Islander	3104	81.6	18.4	
American Indian/Alaska Native or other	8373	79.9	20.1	
Income quartile				<.001
Lowest	23,258	81.3	18.7	
2	29,826	81.1	18.9	
3	34,653	81.0	19.0	
Highest	44,245	82.1	17.9	
Education quartile				<.001
Lowest	24,168	81.9	18.1	
2	35,542	81.3	18.7	
3	38,829	81.2	18.8	
Highest	33,443	81.6	18.4	
Insurance status				<.001
Medicare or private	121,680	81.8	18.2	
Medicaid or uninsured	8905	76.5	23.5	
Other	1397	80.7	19.3	
Charlson-Deyo score				<.001
0	64,232	80.7	19.3	
1	45,669	81.3	18.7	
2	16,116	83.2	16.8	
≥3	5965	85.5	14.5	
Tumor size, cm				<.001
≤1	8622	93.8	6.2	
>1 to 2	42,011	91.2	8.8	
>2 to 3	34,116	85.9	14.1	
>3 to 5	30,503	72.8	27.2	
>5 to 7	10,443	59.1	40.9	
>7	6287	53.9	46.1	
Pathological stage				<.001
IA	60,378	97.9	2.1	
IB	36,946	83.6	16.4	
IIA	13,930	48.5	51.5	
IIB	14,937	54.6	45.4	
IIIA (N0-N1)	5791	43.9	56.1	
Nodal status				<.001
N0	114,411	87.5	12.5	
N1	17,571	42.0	58.0	
Grade				<.001
Well differentiated	23,255	92.2	7.8	
Moderately differentiated	60,349	82.9	17.1	

(Continued)

TABLE 1. Continued

Patient n	Total 131,982	Receipt of adjuvant chemotherapy* No adjuvant chemotherapy 107,484	Adjuvant chemotherapy 24,498	
Parameter†	n	%	%	*P* value
Poorly differentiated	46,015	74.6	25.4	
Undifferentiated	2363	70.2	29.8	
Histology				<.001
Adenocarcinoma	80,420	82.1	17.9	
Squamous	38,419	80.0	20.0	
Large cell	3264	71.7	28.3	
Carcinoid	5161	95.2	4.8	
Other	4718	73.3	26.7	
Facility program				<.001
Community	3461	80.6	19.4	
Comprehensive	56,063	81.1	18.9	
Academic	46,968	82.1	17.9	
Integrated	25,490	81.1	18.9	
Care fragmentation				<.001
Single facility	117,065	82.1	17.9	
Multiple facilities	14,917	76.4	23.6	
Extent of resection				<.001
Wedge	15,981	90.4	9.6	
Segmentectomy	4266	91.5	8.5	
Lobectomy	105,779	81.0	19.0	
Pneumonectomy	5956	58.5	41.5	
Surgical margin status				<.001
R1, R2, or unspecified residual	6178	61.4	38.6	
R0	125,804	82.4	17.6	
Median lymph nodes sampled (IQR)	131,982	8 (4-13)	10 (6-15)	<.001

IQR, Interquartile range; *SD*, standard deviation. *Adjuvant chemotherapy at any facility. †Data are presented as n with percentages except where otherwise noted.

Statistical Analysis

The χ^2 test was used to determine the patient population differences for those who underwent AC and those who did not. Continuous variables are reported as mean and SD if normally distributed, and median and interquartile range (IQR) if not normally distributed. The *t* test and Mann–Whitney test were used as appropriate. Changes in rates of AC receipt over time were assessed using Cochran–Armitage tests. *P* values were 2-sided.

Hypothesis 1: likelihood of receipt of AC. To assess hypothesis 1, Poisson regression was performed to evaluate the association of travel distance and hospital surgical volume with receipt of AC in the stage II to IIIA (N0-N1) patients. Model 1 was used to evaluate likelihood of receipt of AC with annual hospital volume and travel distance as continuous variables with an interaction term, whereas model 2 was used to evaluate hospital volume and travel distance subgroups. Both models were similarly adjusted for covariates. Standard errors were adjusted for clustering within facilities.

Hypothesis 2: survival analysis. To assess hypothesis 2, Cox proportional hazards models with Breslow method for ties were used to evaluate the simultaneous association of travel distance, hospital surgical volume, and receipt of AC with OS of stage II to IIIA (N0-N1) patients. Model 3 was used to evaluate subgroups of volume, travel distance, and AC, whereas model 4 was used to evaluate AC as a dichotomous variable and annual surgical volume and travel distance as continuous variables with an interaction term. Both models were similarly adjusted for covariates with robust SEs adjusted for clustering within facilities.

Next, patients who traveled the lowest quartile of travel distance were compared with those who traveled the highest quartile of travel distance. Propensity scores were generated for the probability of receipt of AC, adjusted for clustering and for covariates. Calipers were set to 0.2 multiplied by the SD, and nearest-neighbor matching with no replacement was performed using logit of the propensity score. All parameters were evaluated and were determined to have standardized mean differences within 10%.[19,20] Cox models were used to examine differences in mortality for travel distance, surgical volume, and receipt of AC in the propensity score-matched cohort with robust standard errors adjusted for clustering within facilities (model 5, subgroups; model 6, continuous variables). Sensitivity analyses were conducted that excluded perioperative 90-day mortality (model 7).

Kaplan–Meier survival estimates with log rank tests were used to determine the significance of differences in survival of patients grouped according to those who traveled short distances to undergo surgery at LVCs and received AC versus patients who traveled long distances to undergo surgery at HVCs but did not receive AC. Kaplan–Meier curves were generated for comparisons at stage II to IIIA (N0-N1). A Kaplan–Meier curve was also generated for comparison of stage I patients to evaluate if the association with survival was similar at early stages, which do not typically receive AC. All analyses were done with Stata version 17 (StataCorp).

TABLE 2. Population characteristics of stage II to IIIA (N0-N1) patients and Poisson regression model 1 to evaluate the association of travel distance, hospital surgical volume, and receipt of AC at any facility

Patient n	Receipt of AC*				IRR of AC IRR (95% CI)
	Total 34,658	No AC 17,463	AC 17,195		
Parameter†	n	%	%	*P* value	Model 1
Median travel distance to surgical treatment (IQR)	34,658	13 (5.3-32.1)	11.2 (5.0-27.1)	<.001	0.997 (0.996-0.998)
Median annual surgical volume (IQR)	34,658	49.0 (28.3-80.3)	46.6 (27.2-70.1)	<.001	0.999 (0.999-1.00)
Travel distance × annual surgical volume‡	34,658				1.00 (0.999-1.00)
Rurality				<.001	
Nonmetro	6518	54.0	46.0		
Metro	28,140	49.6	50.4		
Median days from surgery to AC (IQR)	17,195		47 (36-61)		
Facility location				<.001	
New England	1724	50.2	49.8		
Middle Atlantic	5015	47.3	52.7		
South Atlantic	8794	51.2	48.8		
East North Central	6456	46.0	54.0		
East South Central	3172	54.8	45.2		
West North Central	2944	46.7	53.3		
West South Central	2237	55.6	44.4		
Mountain	1035	52.4	47.6		
Pacific	3281	56.3	43.7		
Year of diagnosis				<.001	
2004	1824	59.9	40.1		
2005	2004	54.1	45.9		
2006	2023	53.2	46.8		
2007	1903	46.6	53.4		
2008	1970	48.3	51.7		
2009	1860	46.2	53.8		
2010	3020	55.9	44.1		
2011	2869	51.4	48.6		
2012	2966	50.0	50.0		
2013	2889	49.5	50.5		
2014	2839	48.0	52.0		
2015	2841	47.7	52.3		
2016	2856	46.6	53.4		
2017	2794	49.6	50.4		
Sex				<.001	
Female	15,755	48.6	51.4		
Male	18,903	51.9	48.1		
Mean age at diagnosis (SD)	34,658	69.2 (9.8)	64.2 (9.0)	<.001	
Race and ethnicity				<.001	
Non-Hispanic White	27,934	51.0	49.0		
Non-Hispanic Black	2944	45.9	54.1		
Hispanic	888	51.6	48.4		
Asian and Pacific Islander	755	47.2	52.8		
American Indian/Alaska Native or other	2137	49.7	50.3		
Income quartile				<.001	
Lowest	6452	52.8	47.2		

(Continued)

TABLE 2. Continued

Patient n	Receipt of AC*				IRR of AC IRR (95% CI)
	Total	No AC	AC		
	34,658	17,463	17,195		
Parameter†	n	%	%	*P* value	Model 1
2	8194	50.7	49.3		
3	9252	49.7	50.3		
Highest	10,760	49.3	50.7		
Education quartile				<.001	
Lowest	6638	53.6	46.4		
2	9484	50.7	49.3		
3	10,316	49.2	50.8		
Highest	8220	48.8	51.2		
Insurance status				<.001	
Medicare or private	31,524	50.9	49.1		
Medicaid or uninsured	2728	44.5	55.5		
Other	406	52.2	47.8		
Charlson-Deyo score				<.001	
0	17,035	49.1	50.9		
1	11,951	50.2	49.8		
2	4138	53.5	46.5		
≥3	1534	58.0	42.0		
Tumor size, cm				<.001	
≤1	761	53.0	47.0		
>1 to 2	5108	50.1	49.9		
>2 to 3	6732	48.6	51.4		
>3 to 5	9248	48.6	51.4		
>5 to 7	7848	54.2	45.8		
>7	4961	49.9	50.1		
Pathological stage				<.001	
IIA	13,930	48.5	51.5		
IIB	14,937	54.6	45.4		
IIIA (N0-N1)	5791	43.9	56.1		
Nodal status				<.001	
N0	17,203	59.0	41.0		
N1	17,455	41.9	58.1		
Grade				<.001	
Well differentiated	3132	65.7	34.3		
Moderately differentiated	14,612	49.5	50.5		
Poorly differentiated	16,038	48.3	51.7		
Undifferentiated	876	48.3	51.7		
Histology				<.001	
Adenocarcinoma	18,602	46.2	53.8		
Squamous	12,385	54.3	45.7		
Large cell	1018	46.7	53.3		
Carcinoid	1015	86.4	13.6		
Other	1638	48.5	51.5		
Facility program				.02	
Community	902	51.1	48.9		
Comprehensive	14,703	50.2	49.8		
Academic	12,359	51.3	48.7		
Integrated	6694	49.0	51.0		
Care fragmentation				<.001	
Single facility	29,643	50.7	49.3		

(Continued)

TABLE 2. Continued

Patient n	Receipt of AC*				IRR of AC IRR (95% CI)
	Total	No AC	AC		
	34,658	17,463	17,195		
Parameter†	n	%	%	*P* value	Model 1
Multiple facilities	5015	48.3	51.7		
Extent of resection				<.001	
Wedge	1821	57.3	42.7		
Segmentectomy	528	58.1	41.9		
Lobectomy	27,982	49.9	50.1		
Pneumonectomy	4327	49.5	50.5		
Surgical margin status				<.001	
R1, R2, or unspecified residual	3581	46.4	53.6		
R0	31,077	50.8	49.2		
Median lymph nodes sampled, n (IQR)	34,658	10 (6-16)	11 (6-16)	<.001	

AC, Adjuvant chemotherapy; *IRR*, incidence rate ratio; *CI*, confidence interval; *IQR*, interquartile range; *SD*, standard deviation. *AC at any facility. †Data are presented as n with percentages except where otherwise noted. ‡Interaction term.

RESULTS

Overall, 131,982 patients with stage I to IIIA (N0-N1) NSCLC met criteria for inclusion with 34,658 (27.0%) stage II to IIIA (N0-N1; Figure 1). Patients were surgically treated at 758 facilities with continuous reporting for all years of the study. A total of 222 (29.3%) facilities that met HVC criteria (≥40 annual pulmonary resections) treated 74,570 (56.5%) patients. Rates of perioperative 90-day mortality were superior at HVCs compared with LVCs in the overall stage I to IIIA (N0-N1) cohort (4.1% vs 5.2%), and in the stage II to IIIA (N0-N1) cohort (6.2% vs 7.5%; all $P < .001$).

Of the total cohort of 131,982 patients, 33,540 (18.6%) received AC (Table 1). For stage II to IIIA

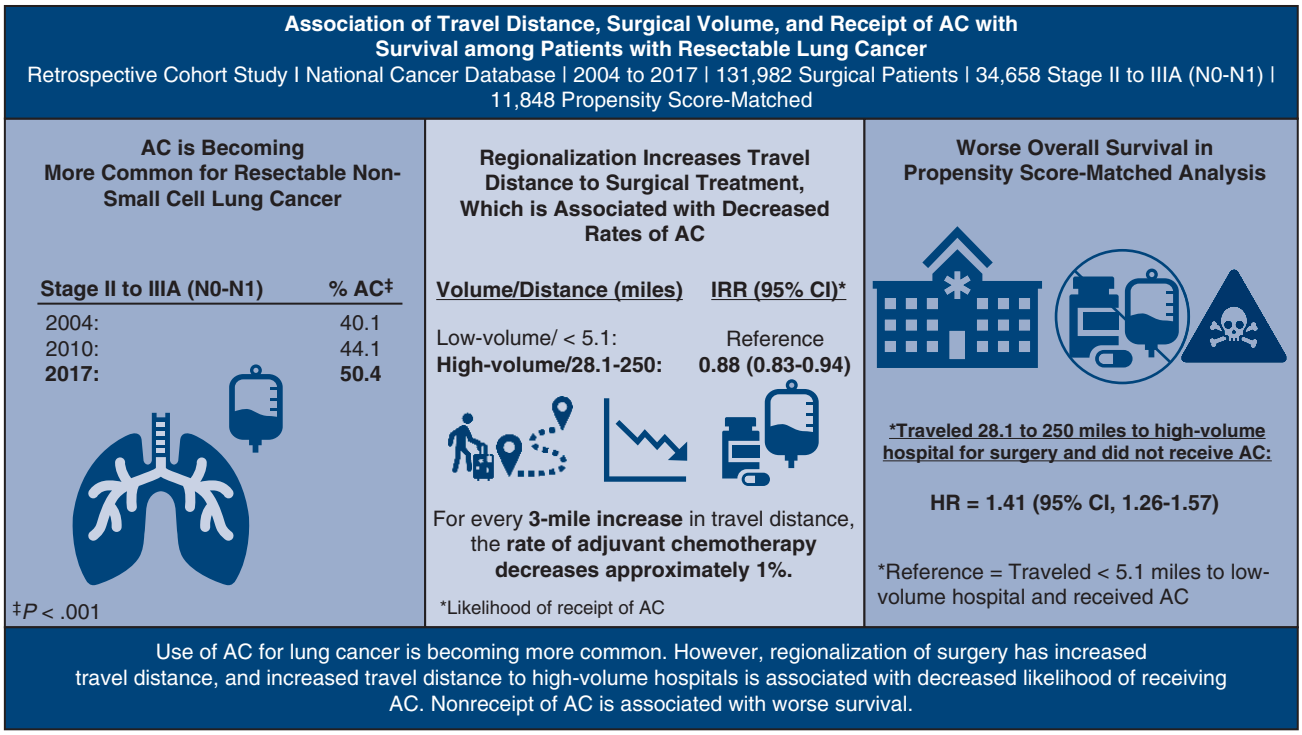


FIGURE 2. Use of adjuvant chemotherapy (*AC*) for lung cancer is becoming more common. However, regionalization of surgery has increased travel distance, and increased travel distance to high-volume hospitals is associated with decreased likelihood of receiving AC. Nonreceipt of AC is associated with worse survival. *IRR*, Incidence rate ratio; *CI*, confidence interval; *HR*, hazard ratio.

(N0-N1) patients, 17,195 (49.6%) received AC at any facility with a median time to initiation of 47 (95% CI, 36-61) days from surgical resection. Patient AC refusal rate was 7.5% and was not significantly different according to travel distance. Only 16.5% of stage II to IIIA (N0-N1) patients who traveled long distances (28.1-250 miles) to HVCs received AC at the same facility as their surgical treatment, whereas those who traveled short distances (<5.1 miles) for surgical care had significantly higher rates of same-site AC at HVCs (29.6%) and LVCs (26.2%; $P < .001$). Rates of AC at any facility increased for stage II to IIIA (N0-N1) patients from 40.1% in 2004 to 50.4% in 2017 with persistent disparities according to travel distance ($P < .001$ for trend; Table 2, Figure 2, Figure E1). Patients who traveled short distances (<5.1 miles) to LVCs and received AC (L1C subgroup) had a shorter median time to initiation of AC than patients who traveled short distances (<5.1 miles) to HVCs and received AC or patients who traveled long distances (28.1-250 miles) to HVCs and received AC (46 [IQR, 35-61] vs 48 [IQR, 37-63] and 49 [IQR, 39-63] days, respectively; all $P < .001$). Women were less likely to travel long distances (28.1-250 miles) for surgical treatment (24.7% vs 28.0% for men) and had lower rates of receipt of AC overall ($P < .001$; Table 2).

Hypothesis 1: Multivariable Analysis to Evaluate Receipt of AC

The likelihood of receiving AC was evaluated in the stage II to IIIA (N0-N1) cohort with multivariable Poisson regression (model 1). Model 1 showed an inverse relationship of increasing distance and likelihood of receipt of AC (Table 2; Figure 2). Further analysis with adjusted multivariable Poisson regression of stage II to IIIA (N0-N1) distance and surgical volume subgroups (model 2) was performed. Model 2 showed an inverse relationship of increasing distance and decreasing likelihood of receipt of AC for patients treated at LVCs and HVCs (Figure 3).

Hypothesis 2: Association of Travel Distance, Hospital Volume, and Receipt of AC With Survival

Adjusted Cox proportional hazards models were used to evaluate the differences in OS for the stage II to IIIA (N0-N1) cohort for distance, surgical volume, and receipt of AC subgroups (model 3; Table 3; Table E2). The propensity score-matched cohort was then evaluated (model 5), and patients who traveled long distances (28.1-250 miles) for surgical treatment at HVCs and did not receive AC (H4N subgroup) had increased risk of death (median OS, 36.7 months; adjusted hazard ratio [aHR], 1.41; 95% CI, 1.26-1.57) compared with patients who traveled short

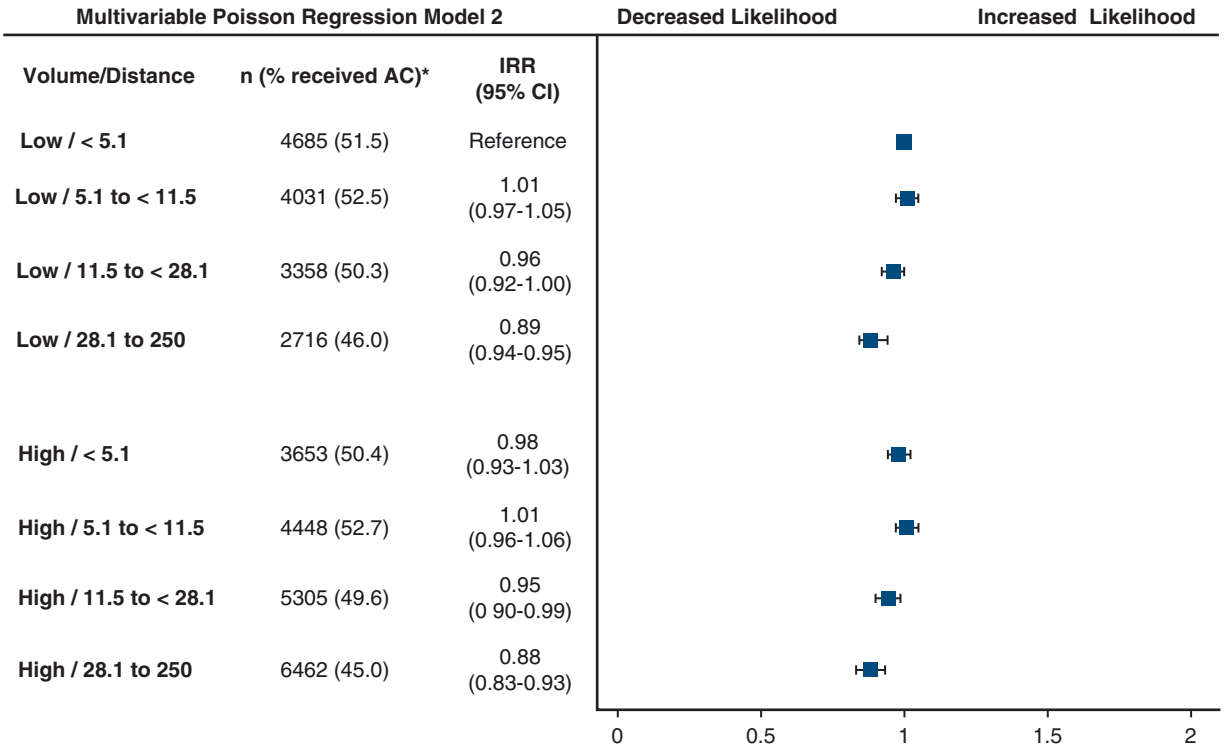


FIGURE 3. Forest plot of association between increasing travel distance and receipt of adjuvant chemotherapy (*AC*) for patients with resected stage II to IIIA (N0-N1) non–small cell lung cancer treated at high- and low-volume centers and Poisson regression model 2 on likelihood of receipt of AC. Low volume, <40 annual surgical resections; high volume, ≥40 annual surgical resections. Distance is in miles. *IRR*, Incidence rate ratio; *CI*, confidence interval.

TABLE 3. Travel distance, hospital surgical volume, and receipt of AC at any facility stage II to IIIA (N0-N1) subgroups and Cox proportional hazards model 3

Patient n	Receipt of AC* Total 34,658	No AC 17,463	AC 17,195		HR (95% CI)
Parameter†	n	%	%	*P* value	Model 3
Volume/travel quartile/ receipt of AC‡				<.001	
L1C	2412	0.0	100.0		Reference
L1N	2273	100.0	0.0		1.43 (1.32-1.55)
H1C	1841	0.0	100.0		0.92 (0.84-1.00)
H1N	1812	100.0	0.0		1.34 (1.23-1.47)
L2C	2115	0.0	100.0		1.01 (0.93-1.09)
L2N	1916	100.0	0.0		1.44 (1.33-1.57)
H2C	2346	0.0	100.0		0.95 (0.88-1.04)
H2N	2102	100.0	0.0		1.42 (1.30-1.55)
L3C	1690	0.0	100.0		1.00 (0.92-1.08)
L3N	1668	100.0	0.0		1.45 (1.33-1.58)
H3C	2630	0.0	100.0		0.94 (0.86-1.02)
H3N	2675	100.0	0.0		1.38 (1.27-1.50)
L4C	1250	0.0	100.0		0.94 (0.85-1.04)
L4N	1466	100.0	0.0		1.46 (1.32-1.61)
H4C	2911	0.0	100.0		0.94 (0.86-1.02)
H4N	3551	100.0	0.0		1.39 (1.28-1.51)

Model 3 adjusted for age, race, sex, income, education, insurance, comorbidities, rurality, region, year of diagnosis, stage, nodal status, tumor size, histology, grade, care fragmentation, facility type, extent of resection, margin status, and number of lymph nodes sampled. *AC*, Adjuvant chemotherapy; *HR*, hazard ratio; *CI*, confidence interval. *AC at any facility. †Data are presented as n with percentages except where otherwise noted. ‡Subgroups denotation uses the following pattern: HVC (H) versus LVC (L)/travel distance quartile/received AC (C) versus did not receive AC (N). Please see Table E2 for detailed definitions.

distances (<5.1 miles) and were surgically treated at LVCs and received AC (L1C subgroup; median OS, 52.3 months, reference; Table 4; Figure 4). Patients who traveled short distances (<5.1 miles) to HVCs and successfully received AC had superior outcomes (aHR, 0.86; 95% CI, 0.78-0.96) versus L1C patients (Table 4).

Additional analyses were performed before and after propensity score matching to evaluate the association of AC with OS when travel distance and surgical volume were included as continuous variables (model 4, Table E3; model 6, Table E4). Also, we performed a conditional survival analysis to address potential confounding with perioperative mortality by excluding those with 90-day postoperative mortality and determined that the inference was unchanged with worse OS for H4N patients (aHR, 1.20 [95% CI, 1.07-1.34] vs L1C patients; model 7; Table E5).

Kaplan–Meier survival estimates showed worse OS for patients in the H4N subgroup compared with the L1C subgroup (Figure 4). Kaplan–Meier survival curves were also generated to evaluate bivariate differences in OS for the H4N subgroup and the L1C subgroup at stage I as a control (median OS, 90.1 vs 97.3 months; $P = .09$; Figure E2).

DISCUSSION

The trend toward regionalization of complex surgical procedures has resulted in patients traveling further for treatment than ever before.[13,14] Whereas surgery is a discrete event for which travel is feasible for many patients, treatment over a longer period with chemotherapy or immunotherapy is more difficult if the patient is remote from the treating center.[21] The recent broadening of the role for adjuvant treatment in patients with NSCLC is likely to further accentuate this issue for rural patients. In this study, patients with stage II to IIIA (N0-N1) NSCLC who traveled long distances for surgical treatment were less likely to receive AC than patients who traveled short distances. Although perioperative outcomes are improved by travel to HVCs in our study and others, the protective effect of surgery at HVCs is mitigated when care fragmentation occurs because of distance. We found that patients with NSCLC who traveled long distances for surgical treatment at HVCs and did not receive AC had worse survival compared with patients who traveled short distances to LVCs but received AC.

A large body of research spanning nearly 5 decades has identified an association of higher surgical volume for complex procedures with improved patient outcomes.[3-5,22] The definition of a complex surgical procedure in the context of the volume–outcome relationship has not been definitively established, but surgical treatment of the lungs, heart, esophagus, pancreas, hepatobiliary system, and rectum

TABLE 4. Population characteristics of the stage II to IIIA (N0-N1) propensity score-matched cohort and Cox proportional hazards model 5 to evaluate the association of travel distance, hospital surgical volume, and receipt of AC at any facility with survival

Patient n	Receipt of AC*				
	Total 11,848	No AC 5924	AC 5924		aHR (95% CI)
Parameter†	N	%	%	*P* value	Model 5
Volume/travel/chemotherapy groups‡				<.001	
L1C	1603	0.0	100.0		Reference
L1N	1611	100.0	0.0		1.40 (1.28-1.53)
L4C	934	0.0	100.0		0.89 (0.79-1.01)
L4N	931	100.0	0.0		1.43 (1.27-1.62)
H1C	1218	0.0	100.0		0.86 (0.78-0.96)
H1N	1223	100.0	0.0		1.26 (1.13-1.40)
H4C	2169	0.0	100.0		0.93 (0.84-1.03)
H4N	2159	100.0	0.0		1.41 (1.26-1.57)
Median days from surgery to AC (IQR)	5924		48 (37-62)		
				SMD, %	
Rurality					
Nonmetro	3522	49.7	50.3	−0.8	
Metro	8326	50.1	49.9	0.8	
Facility location					
New England	591	49.7	50.3	0.2	
Middle Atlantic	1586	50.3	49.7	−0.4	
South Atlantic	2877	50.1	49.9	−0.3	
East North Central	2188	50.0	50.0	0.1	
East South Central	1172	49.5	50.5	0.7	
West North Central	1175	50.1	49.9	−0.2	
West South Central	728	50.0	50.0	0.0	
Mountain	392	50.8	49.2	−0.6	
Pacific	1139	49.7	50.3	0.4	
Year of diagnosis					
2004	606	49.7	50.3	0.3	
2005	737	49.5	50.5	0.5	
2006	711	49.8	50.2	0.2	
2007	661	49.9	50.1	0.1	
2008	727	49.7	50.3	0.4	
2009	640	51.4	48.6	−1.3	
2010	1056	50.5	49.5	−0.6	
2011	987	49.4	50.6	0.7	
2012	1008	50.2	49.8	−0.2	
2013	951	50.5	49.5	−0.6	
2014	937	50.8	49.2	−0.9	
2015	941	49.1	50.9	1.1	
2016	936	50.4	49.6	−0.5	
2017	950	49.2	50.8	1.0	
Sex					
Female	5163	50.1	49.9	0.4	
Male	6685	49.9	50.1	−0.4	
Mean age at diagnosis (SD)	11,848	66.7 (9.7)	67.1 (8.1)	4.5	
Race and ethnicity					
Non-Hispanic White	9516	50.0	50.0	−0.3	
Non-Hispanic Black	1080	49.8	50.2	0.2	

(Continued)

TABLE 4. Continued

				SMD, %
Hispanic	246	49.2	50.8	1.5
Asian and Pacific Islander	232	49.1	50.9	0.5
American Indian/Alaska Native or other	774	50.3	49.7	−0.3
Income quartile				
Lowest	3081	50.0	50.0	0.0
2	3387	49.8	50.2	0.4
3	2852	49.8	50.2	0.6
Highest	2528	50.5	49.5	−1.1
Education quartiles				
Lowest	2818	49.7	50.3	0.6
2	3493	50.1	49.9	−0.2
3	3302	49.8	50.2	0.6
Highest	2235	50.6	49.4	−1.2
Insurance status				
Medicare or private	10,648	50.0	50.0	0.6
Medicaid or uninsured	1033	50.7	49.3	−0.9
Other	167	48.5	51.5	0.7
Charlson-Deyo score				
0	5614	50.4	49.6	−1.6
1	4175	49.6	50.4	1.2
2	1532	50.1	49.9	−0.1
≥3	527	48.6	51.4	1.2
Tumor size, cm				
≤1	238	49.6	50.4	0.2
>1 to 2	1638	49.6	50.4	0.6
>2 to 3	2261	50.2	49.8	−0.5
>3 to 5	3266	50.4	49.6	−1.1
>5 to 7	2690	49.8	50.2	0.4
>7	1755	49.6	50.4	0.7
Pathological stage				
IIA	4577	49.8	50.2	0.5
IIB	5270	49.8	50.2	0.7
IIIA (N0-N1)	2001	50.9	49.1	−1.7
Nodal status				
N0	5770	49.4	50.6	2.3
N1	6078	50.6	49.4	−2.3
Grade				
Well differentiated	850	48.2	51.8	1.07
Moderately differentiated	5074	49.8	50.2	0.3
Poorly differentiated	5611	50.4	49.6	−0.86
Undifferentiated	313	49.8	50.2	0.06
Histology				
Adenocarcinoma	6326	50.6	49.4	−2.4
Squamous	4472	49.2	50.8	2.6
Large cell	355	51.8	48.2	−1.3
Carcinoid	136	47.1	52.9	1.3
Other	559	49.9	50.1	0.1
Facility program				
Community	348	49.7	50.3	0.11
Comprehensive	4885	50.5	49.5	−0.91
Academic	4491	49.4	50.6	1.08
Integrated	2124	50.2	49.8	−0.24

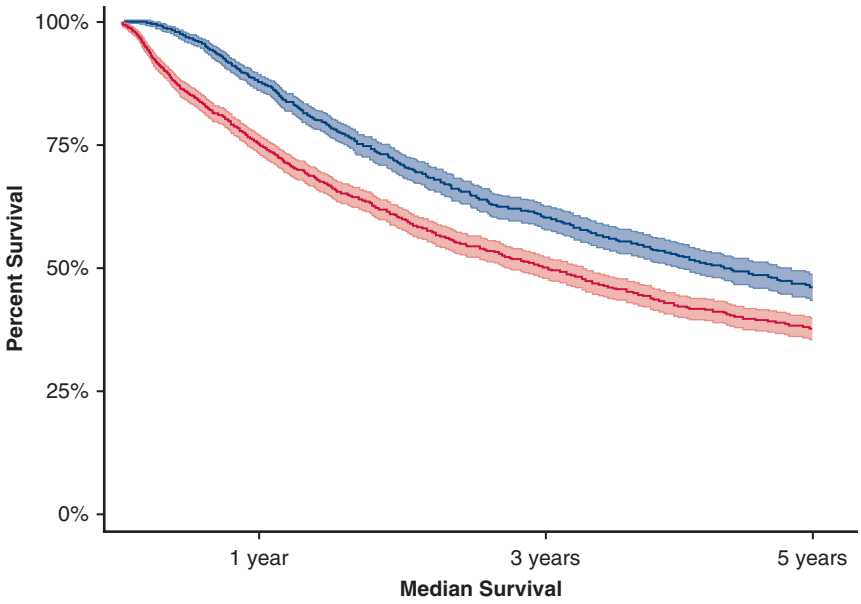
(Continued)

TABLE 4. Continued

				SMD, %
Care fragmentation				
Single facility	10,107	50.0	50.0	0.08
Multiple facilities	1741	49.9	50.1	−0.08
Extent of resection				
Wedge	561	49.7	50.3	0.13
Segmentectomy	163	46.6	53.4	0.87
Lobectomy	9505	50.0	50.0	0.02
Pneumonectomy	1619	50.5	49.5	−0.4
Surgical margin status				
R1, R2, or unspecified residual	1236	51.3	48.7	−0.96
R0	10,612	49.8	50.2	0.96
Median lymph nodes sampled, n (IQR)	11,848	10 (6-16)	10 (6-16)	−0.83

Model 5 adjusted for age, race, sex, income, education, insurance, comorbidities, rurality, region, year of diagnosis, stage, nodal status, tumor size, histology, grade, care fragmentation, facility type, extent of resection, margin status, and number of lymph nodes sampled. *AC*, Adjuvant chemotherapy; *aHR*, adjusted hazard ratio; *CI*, confidence interval; *IQR*, interquartile range; *SMD*, standardized mean difference; *SD*, standard deviation. *AC at any facility †Data are presented as n with percentages except where otherwise noted. ‡Subgroups denotation uses the following pattern: HVC (H) versus LVC (L)/travel distance quartile/received AC (C) versus did not receive AC (N). Please see Table E2 for detailed definitions.

are extensively reported in this literature.[5,12,13,22-26] These data suggest that the relationship is widely generalizable to operations across organ systems that are characterized by increased patient risk, and that risk can be ameliorated by increased surgeon and institutional experience through operative volume.



Risk Table

Parameter	n	SE (95% CI)	n	SE (95% CI)	n	SE (95% CI)	Months (95% CI)
L1C, n = 1603	1385	**0.88** (0.86-0.89)	848	**0.61** (0.59-0.63)	502	**0.46** (0.43-0.49)	**52.3** (48.5-57.6)
H4N, n = 2159	1570	**0.75** (0.73-0.77)	883	**0.51** (0.48-0.53)	468	**0.37** (0.35-0.40)	**36.7** (33.6-40.1)

95% CI — L1C 95% CI — H4N

FIGURE 4. Kaplan–Meier curves and SEs for the stage II to IIIA (N0-N1) propensity score-matched cohort; comparison of overall survival of patients who traveled long distances to high-volume centers and did not receive adjuvant chemotherapy (H4N) with patients who traveled short distances to low-volume centers and received adjuvant chemotherapy (L1C). *CI*, Confidence interval; *SE*, survival estimate.

However, as Epstein[8] noted: volume is a "crude indicator of the quality of care." The volume–outcome relationship might be a surrogate for differences in the quality of care at multiple levels related to surgical management, including preoperative patient selection and prehabilitation, intraoperative expertise, perioperative monitoring and intervention leading to fewer "failures to rescue" and increased rates of guideline-concordant care.[23,27] Although patients treated at HVCs have been shown to have improved perioperative mortality, fewer complications, and shorter lengths of stay; some studies have called into question the validity of the volume–outcome relationship, and few studies have validated proposed thresholds or minimums for surgical volume.[6,9,24,28-40] Despite the controversy, a concerted effort is under way to embrace surgical volume as a generalizable surrogate for quality.[8,18]

Early concerns for the regionalization of complex surgical procedures were raised regarding the potential to reduce patient access to care.[12,13,35,41,42] As the number of hospitals offering certain surgical services contracted, patient travel distance to specialized care increased.[12,42] Additionally, a study by Herb and colleagues[14] showed that the number of hospitals that perform lung resections in a US state decreased from 49 to 31 between 2005 and 2015, while the proportion of patients treated at HVCs, as well as patient travel distance, increased.

Intuitively, increased distance might be expected to decrease care access. However, the actual relationship between travel distance and patient outcomes has not been definitively established.[43] Many studies have reported that long travel distance to HVCs is superior to local surgical treatment at LVCs when patient outcomes are compared.[44-49] However, previous studies have also reported an association of longer travel distance with decreased access to chemotherapy among patients with colorectal cancer, as well as decreased access to surveillance screening after lung resection.[15,50-52] Also, Mohammad and colleagues[21] reported that patients are more willing to travel long distances for surgery than for recurring therapies. In our study increasing travel distance was associated with a decreased likelihood of receipt of AC for patients with surgically treated NSCLC at HVCs or LVCs. This raised the question of whether there might be an association with worse OS for certain populations of cancer patients who travel long distances, even to HVCs, but then fail to receive indicated AC. Upon investigation, OS was worse for patients who traveled long distances to HVCs for surgical resection but did not receive AC with stage II to IIIA (N0-N1) disease.

However, in patients with early stage NSCLC, AC is not typically indicated and was only administered in approximately 2.1% of 60,378 stage IA cases in our study cohort. We found no association with worse OS for those with stage I NSCLC who traveled long distances to HVCs (Figure E2), further supporting the hypothesis that the survival differences in the stage II to IIIA (N0-N1) cohort were affected by care fragmentation. Although this retrospective study cannot show a causal relationship, we can reasonably infer that reduced access and uptake of indicated postoperative oncological services might adversely influence patient outcomes, including OS. It is also possible that survival disparities related to nonreceipt of AC might worsen in the future as systemic therapies improve and are extended to a larger group of patients with earlier-stage disease.

The benefits of surgery at HVCs for complex procedures have garnered widespread support for regionalization of surgical care, and the resulting trend toward regionalization is likely irreversible.[8,18] However, it is important to recognize that regionalization does not occur in a vacuum and attention must be paid to unintended consequences of this approach. Thus, efforts should focus on maintaining care throughout the treatment continuum and improving communication between patients, local treatment teams, and regional HVCs to mitigate the effect of care fragmentation on treatment.[53] Maintaining local access to other services is likely dependent on the locoregional health care system's ability to continue effectively coordinating care within their catchment area, and some travel for treatment likely will remain necessary for many patients. Indeed, Rhodin and colleagues[54] reported that successful multi-institutional coordination to deliver neoadjuvant therapy and surgery for esophageal cancer was not associated with worse OS. Theoretically, no system is better poised to serve this role for patients with cancer than a National Cancer Institute-designated facility that is also a regional HVC.[55] In fact, the original hospital systems that publicly took the "volume pledge" were established regional systems with extensive resources and vast experience.[56] These systems are characterized by the ability to conduct rigorous outcomes research and quality improvement to identify barriers to care and implement solutions.[57-59] However, our study shows that over-reliance on these centers to provide all care might result in important quality gaps for more rural patients, particularly with respect to adjuvant treatment.

This study has several limitations, which should be considered when interpreting the findings. First, although the NCDB captures approximately 70% of total cancers in the United States, and more specifically, 82% of cancers of the lung and bronchus, there are reporting gaps.[17] Facilities in rural areas, characterized by limited local resources, are less likely to be accredited to directly report patients to the NCDB.[60] Treatment at these hospitals might be abstracted indirectly by teams at a separate NCDB facility, which might introduce some reporting bias.

Second, distance in the NCDB is reported as straight-line distance and underestimates true driving distance by

up to 40%.[13] Travel distance, as reported in the NCDB, should not be applied directly to policy. Additionally, we were unable to determine in the NCDB if patients who traveled long distances bypassed a nearby HVC to seek care at another facility, although this would be expected to be few patients.

CONCLUSIONS

Patients with stage II to IIIA (N0-N1) NSCLC who travel long distances for surgical treatment are less likely to receive AC than patients who travel short distances for surgical treatment. Furthermore, patients with NSCLC who traveled long distances for surgical treatment at HVCs and did not receive AC had worse OS compared with patients who traveled short distances to LVCs but received AC. Understanding the reasons underlying this lack of receipt of AC will provide actionable opportunities to improve care coordination and treatment outcomes, thereby maximizing the benefit of travel to HVCs for surgical treatment.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

The data used are derived from a deidentified NCDB file. The American College of Surgeons and the Commission on Cancer have not verified and are not responsible for the analytic or statistical methodology used, or the conclusions drawn from these data by the investigators.

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Key Words: lung cancer, outcomes, non–small cell lung cancer, national cancer database, regionalization, quality, surgical volume, travel distance

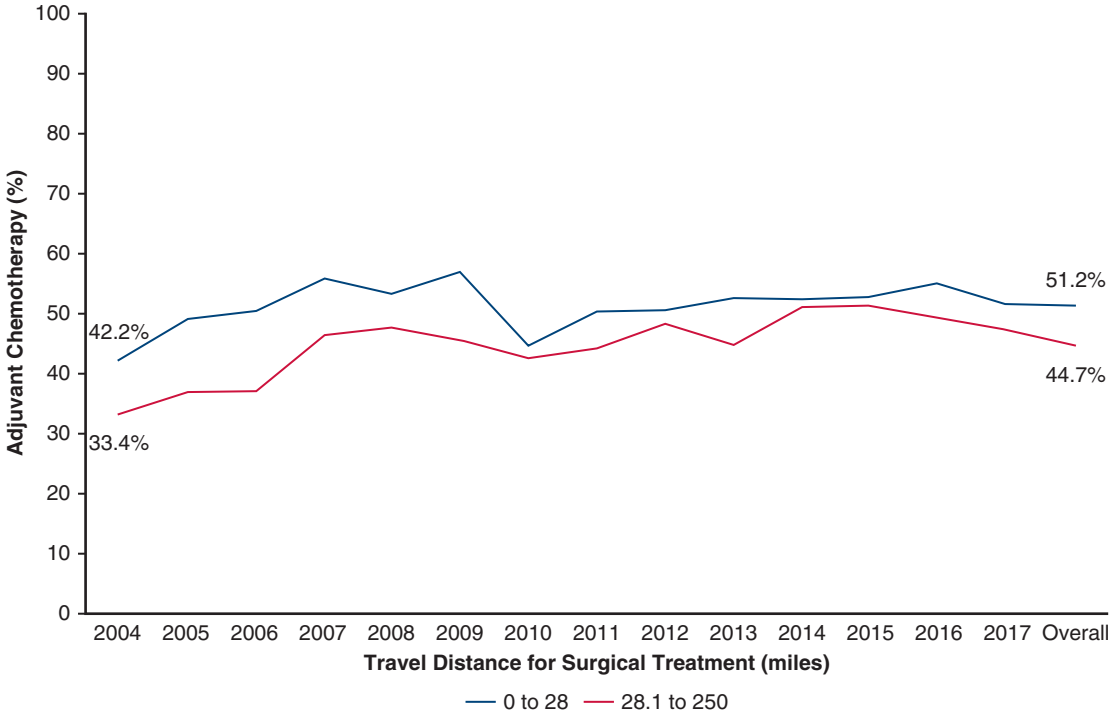
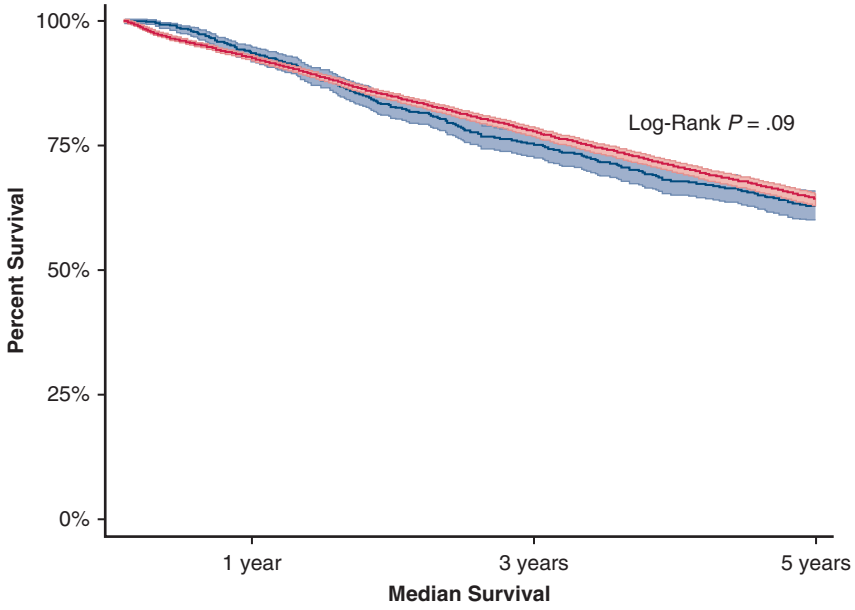


FIGURE E1. Trends of travel distance to surgical treatment and rate of receipt of adjuvant chemotherapy at any facility according to year of diagnosis for resected stage II to IIIA (N0-N1) non–small cell lung cancer (NSCLC). Trend $P < .001$.



Risk Table

Parameter	n	SE (95% CI)	n	SE (95% CI)	n	SE (95% CI)	Months (95% CI)
L1C, n = 1212	1110	**0.93** (0.91-0.94)	812	**0.75** (0.72-0.77)	591	**0.63** (0.60-0.66)	**97.3** (87.1-110.3)
H4N, n = 14,901	13,318	**0.92** (0.91-0.92)	9356	**0.77** (0.77-0.78)	5859	**0.64** (0.63-0.65)	**90.1** (87.7-93.2)

95% CI — L1C 95% CI — H4N

FIGURE E2. Kaplan–Meier curves and survival estimates (*SEs*) for patients with stage I disease; comparison of overall survival of patients who traveled long distances to high-volume centers and did not receive adjuvant chemotherapy (H4N) with patients who traveled short distances to low-volume centers and received adjuvant chemotherapy (L1C). *CI*, Confidence interval.

TABLE E1. Histological categories defined in the *International Classification of Disease for Oncology*, third edition

Adenocarcinoma: 8250-8255, 8050, 8140-8149, 8160-8162, 8190-8221, 8256-8263, 8270-8280, 8290-8337, 8350-8390, 8400-8560, 8570-8576, 8940-8941
Squamous cell carcinoma: 8051-8052, 8070-8084, 8120-8131
Large cell carcinoma: 8011-8015
Carcinoid: 8240-8249
Other non–small cell: 8010, 8020-8022, 8030-8040, 8046, 8090-8110, 8150-8156, 8170-8175, 8180, 8230-8231, 8340-8347, 8561-8562, 8580-8671

TABLE E2. Additional explanation of abbreviations

Volume/travel quartile/ receipt of AC	Definition
L1C	Low-volume center/Q1/received AC
L1N	Low-volume center/Q1/did not receive AC
H1C	High-volume center/Q1/received AC
H1N	High-volume center/Q1/did not receive AC
L2C	Low-volume center/Q2/received AC
L2N	Low-volume center/Q2/did not receive AC
H2C	High-volume center/Q2/received AC
H2N	High-volume center/Q2/did not receive AC
L3C	Low-volume center/Q3/received AC
L3N	Low-volume center/Q3/did not receive AC
H3C	High-volume center/Q3/received AC
H3N	High-volume center/Q3/did not receive AC
L4C	Low-volume center/Q4/received AC
L4N	Low-volume center/Q4/did not receive AC
H4C	High-volume center/Q4/received AC
H4N	High-volume center/Q4/did not receive AC

High-volume center defined using LeapFrog criteria as ≥40 annual resections. *AC*, Adjuvant chemotherapy; *Q1*, quartile 1, travel <5.1 miles; *Q2*, quartile 2, travel 5.1 to <11.5 miles; *Q3*, quartile 3, travel 11.5 to <28.1 miles; *Q4*, quartile 4, travel 28.1 to 250 miles.

TABLE E3. Population characteristics of travel distance, hospital surgical volume, and receipt of adjuvant chemotherapy for stage II to IIIA (N0-N1) patients and Cox proportional hazards model 4

	Receipt of adjuvant chemotherapy*				
	Total	No adjuvant chemotherapy	Adjuvant chemotherapy		
	34,658	17,463	17,195		HR (95% CI)
Parameter	n	%	%	*P* value	Model 4
Adjuvant chemotherapy†				<.001	
Yes	17,195	0.0	100.0		0.68 (0.66-0.70)
No	17,463	100.0	0.0		Reference
Median travel distance to surgical treatment (IQR)†	34,658	13 (5.3-32.1)	11.2 (5.0-27.1)	<.001	0.999 (0.998-1.00)
Median annual surgical volume (IQR)†	34,658	49.0 (28.3-80.3)	46.6 (27.2-70.1)	<.001	0.999 (0.998-1.00)
Travel distance × annual surgical volume†,‡					1.00 (0.999-1.00)

Data are presented as n with percentages except where otherwise noted. *HR*, Hazard ratio; *CI*, confidence interval; *IQR*, interquartile range. *Adjuvant chemotherapy at any facility. †Model 4 adjusted for age, race, sex, income, education, insurance, comorbidities, rurality, region, year of diagnosis, stage, nodal status, tumor size, histology, grade, care fragmentation, facility type, extent of resection, margin status, and number of lymph nodes sampled. ‡Interaction term.

TABLE E4. Population characteristics of travel distance, hospital surgical volume, and receipt of adjuvant chemotherapy for stage II to IIIA (N0-N1) propensity score-matched cohort and Cox proportional hazards model 6

	Receipt of adjuvant chemotherapy*				
Patient n	Total	No adjuvant chemotherapy	Adjuvant chemotherapy		
	11,848	5924	5924		aHR (95% CI)
Parameter	n	%	%	*P* value	Model 6
Adjuvant chemotherapy†				<.001	
Yes	5924	0.0	100.0		0.67 (0.64-0.71)
No	5924	100.0	0.0		Reference
				SMD (%)	
Median travel distance to surgical treatment (IQR)†	11,848	29.1 (2.8-50.2)	29.1 (2.8-49.8)	1.4	0.999 (0.998-1.00)
Median annual surgical volume (IQR)†	11,848	48.9 (27.2-81.7)	47.1 (27.2-80.3)	1.3	0.998 (0.997-1.00)
<40	5079	50.0	50.0		
≥40	6769	50.0	50.0		
Travel distance × annual surgical volume†,‡	11,848				1.00 (0.999-1.00)

aHR, Adjusted hazard ratio; *CI*, confidence interval; *SMD*, standardized mean difference; *IQR*, interquartile range. *Adjuvant chemotherapy at any facility. †Model 6 adjusted for age, race, sex, income, education, insurance, comorbidities, rurality, region, year of diagnosis, stage, nodal status, tumor size, histology, grade, care fragmentation, facility type, extent of resection, margin status, and number of lymph nodes sampled. ‡Interaction term.

TABLE E5. Stage II to IIIA (N0-N1) propensity score-matched cohort and Cox proportional hazards model 7 evaluating conditional survival

Patient n	Total 11,848	Receipt of AC* No AC 5924	AC 5924		aHR (95% CI)
Parameter Excluding 90-d mortality	n	%	%	*P* value	Model 7
Volume/travel/chemotherapy group†				<.001	
L1C	1583	0.0	100.0		Reference
L1N	1395	100.0	0.0		1.16 (1.06-1.27)
L4C	924	0.0	100.0		0.90 (0.80-1.02)
L4N	792	100.0	0.0		1.16 (1.02-1.31)
H1C	1213	0.0	100.0		0.86 (0.77-0.96)
H1N	1097	100.0	0.0		1.06 (0.95-1.19)
H4C	2149	0.0	100.0		0.93 (0.84-1.03)
H4N	1914	100.0	0.0		1.20 (1.07-1.34)

Model 7 adjusted for age, race, sex, income, education, insurance, comorbidities, rurality, region, year of diagnosis, stage, nodal status, tumor size, histology, grade, care fragmentation, facility type, extent of resection, margin status, and number of lymph nodes sampled. *AC*, Adjuvant chemotherapy; *aHR*, adjusted hazard ratio; *CI*, confidence interval. *AC at any facility. †Subgroups denotation uses the following pattern: HVC (H) versus LVC (L)/travel distance quartile/received AC (C) versus did not receive AC (N). Please see Table E2 for detailed definitions.