

## Special Article

## THE INFLUENCE OF HOSPITAL VOLUME ON SURVIVAL AFTER RESECTION FOR LUNG CANCER

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**ABSTRACT**

**Background** Among patients who have undergone high-risk operations for cancer, postoperative mortality rates are often lower at hospitals where more of these procedures are performed. We undertook a population-based study to estimate the extent to which the number of procedures performed at a hospital (hospital volume) is associated with survival after resection for lung cancer.

**Methods** We studied patients 65 years old or older who received a diagnosis of stage I, II, or IIIA non-small-cell lung cancer between 1985 and 1996, resided in 1 of the 10 study areas covered by the Surveillance, Epidemiology, and End Results Program, and underwent surgery at a hospital that participates in the Nationwide Inpatient Sample (2118 patients and 76 hospitals).

**Results** The volume of procedures at the hospital was positively associated with the survival of patients ( $P < 0.001$ ). Five years after surgery, 44 percent of patients who underwent operations at the hospitals with the highest volume were alive, as compared with 33 percent of those who underwent operations at the hospitals with the lowest volume. Patients at the highest-volume hospitals also had lower rates of postoperative complications (20 percent vs. 44 percent) and lower 30-day mortality (3 percent vs. 6 percent) than those at the lowest-volume hospitals.

**Conclusions** Patients who undergo resection for lung cancer at hospitals that perform large numbers of such procedures are likely to survive longer than patients who have such surgery at hospitals with a low volume of lung-resection procedures. (N Engl J Med 2001;345:181-8.)

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**A**N association between the number of operations for cancer performed at a hospital (hospital volume) and the outcome of those operations has been shown for esophagectomy and pancreatectomy,<sup>1-3</sup> as well as for operations for breast cancer, colon cancer, and prostate cancer.<sup>4-11</sup> There is, however, incomplete evidence concerning this association in the case of surgery for lung cancer. Neither Khuri and colleagues<sup>12</sup> nor Beggs et al.<sup>1</sup> (who focused exclusively on pneumectomy) found a sig-

nificant trend toward lower 30-day mortality at hospitals with high volumes of lung-cancer operations. Romano and Mark, however, found that in-hospital mortality rates were significantly lower after resections for lung cancer at hospitals with high volumes of the procedure.<sup>13</sup>

In this study of the relation between hospital volume and outcome after surgery for lung cancer, we examined the rates of survival and postoperative complications in both teaching and nonteaching hospitals.<sup>14,15</sup>

**METHODS****Sources of Data****The Surveillance, Epidemiology, and End Results Program and Medicare**

Patients were identified from the Surveillance, Epidemiology, and End Results (SEER) Cancer Registries, which have been linked to data on Medicare hospitalizations. The SEER data base contains detailed information on all newly diagnosed cases of cancer in five metropolitan areas (San Francisco, Oakland, and San Jose, California; Detroit; Atlanta; Seattle; and Los Angeles County) and five states (Connecticut, Utah, New Mexico, Iowa, and Hawaii).<sup>16</sup> The Medicare data base contains information on hospital-discharge diagnoses from 1984 onward and information on the dates of death of the participants who have died.

We determined from the SEER data base the following characteristics of patients: sex, race, age at diagnosis, and stage of cancer (patients with unknown nodal status were excluded). We assigned a socioeconomic status to patients on the basis of the median income in the ZIP Code of residence (obtained from the 1990 U.S. Census). We used the *International Classification of Diseases, 9th Revision, Clinical Modification* (ICD-9-CM)<sup>17</sup> discharge codes from the admission during which surgery was performed to determine both the extent of chronic illness as measured by the Romano modification<sup>18</sup> of the Charlson comorbidity index<sup>19</sup> and the operation that was performed: partial lobectomy (wedge or segmental resection, ICD-9-CM code 32.2 or 32.3), lobectomy (ICD-9-CM code 32.1 or 32.4), or pneumonectomy (ICD-9-CM code 32.5 or 32.6).

**The Nationwide Inpatient Sample**

Hospitals were identified from the Nationwide Inpatient Sample (NIS).<sup>20</sup> The NIS consists of a stratified random sample of 1012 hospitals in 22 states; data from 5 of these states (California, Con-

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necticut, Iowa, Utah, and Washington) overlap with those from SEER regions and include American Hospital Association (AHA) hospital identifiers that make linkage between the two data bases possible. The NIS contains complete data on discharges from each participating hospital and reports the teaching status and type of location (urban or nonurban) of the hospital. We assigned to each hospital the characteristics and the annual volume of procedures that were documented for the 1997 discharges in the NIS. To calculate the volume of procedures, we counted the number of patients whose records indicated a diagnosis of lung cancer (principal NIS diagnosis code, 19) and the performance of lung resection (principal NIS procedure code, 36).

**Study Patients**

We analyzed data on 2118 patients in the SEER–Medicare data base who received a diagnosis of lung cancer between 1985 and 1996 and who underwent resection for lung cancer at 1 of 76 hospitals included in the NIS for 1997. These patients were drawn from the 12,921 patients 65 years old or older who resided in 1 of the 10 areas covered by the SEER data base and who met the following requirements: a diagnosis of primary cancer of the lung (*International Classification of Diseases for Oncology, 2nd edition*<sup>21</sup> [ICD-O-2] codes 34.0 through 34.9) between 1985 and 1996, with non–small-cell histologic features (ICD-O-2 morphology [M] codes other than 8000, 8002, 8041 through 8045, 8240, 8241, 8244, and 8246); stage I, II, or IIIA disease according to the criteria of the American Joint Committee on Cancer Staging<sup>22,23</sup>; indemnity insurance through the Medicare program; and lung resection within

four months after diagnosis. The hospitals were drawn from the pool of 1012 hospitals that participate in the NIS, in 423 of which at least one operation for lung cancer was performed in 1997. The patients and hospitals we studied had characteristics similar to those in the parent data bases (Table 1), with the exception that more hospitals in our study were investor-owned rather than not-for-profit.

**Analyses of the Entire SEER–Medicare Cohort**

The principal advantage of using the NIS to ascertain the volume of procedures is that it contains a count of the actual number of lung-cancer operations performed during one year at each hospital, but major disadvantages are that only a small proportion of the patients covered by the SEER–Medicare data base underwent their procedures at a facility that participated in the NIS and that the 1997 NIS data do not cover the same period as the SEER–Medicare data we used. We chose to use the NIS data because they allowed us to express results in terms of the actual volume of procedures. We also repeated all the analyses using the entire SEER–Medicare cohort, and when relevant, we report summary statistics and P values from these analyses, for which the characteristics of the hospitals were derived from the 1993 AHA data base.

**Outcomes after Resection for Lung Cancer**

We assessed survival and the frequency of postoperative complications after resection for lung cancer. We evaluated the absolute duration of survival from the date of hospitalization for surgery to the date of death as reported to Medicare, as well as the likelihood of survival at 30 days and 2 years. Records of deaths are complete

**TABLE 1. CHARACTERISTICS OF THE PATIENTS IDENTIFIED THROUGH THE SEER–MEDICARE DATA BASE AND OF THE HOSPITALS IDENTIFIED FROM THE NATIONWIDE INPATIENT SAMPLE THAT WERE INCLUDED IN OR EXCLUDED FROM THE STUDY.\***

PATIENTS			HOSPITALS		
CHARACTERISTIC	EXCLUDED	INCLUDED	CHARACTERISTIC	EXCLUDED	INCLUDED
Total no. (%)	10,803 (84)	2118 (16)	Total no. (%)	347 (82)	76 (18)
Age (% of patients)			Lung-cancer operations performed (% of total)	82	18
65–69 yr	38	34	No. of annual discharges	12,364±8891	12,027±8856
70–74 yr	34	34	Teaching status (% of hospitals)		
≥75 yr	29	32	Nonteaching	71	67
Sex (% of patients)			Teaching	29	33
Male	59	59	Hospital location (% of hospitals)		
Female	41	41	Rural	14	16
Race (% of patients)			Urban	86	84
White	88	95	Annual volume of procedures†		
Black	6	3	Range	1–161	1–100
Other	6	2	25th–75th percentile	4–22	3–19
Stage of disease (% of patients)			Median	10	9.5
I	70	69	Hospital size (% of hospitals)		
II	19	20	Small (1–49 beds)	19	30
IIIA	11	11	Medium (50–99 beds)	39	38
Procedure (% of patients)			Large (≥100 beds)	42	32
Partial lobectomy	27	25	Organizational control (% of hospitals)		
Lobectomy	65	66	Government	16	18
Pneumonectomy	8	9	Private		
Romano–Charlson comorbidity index (% of patients)			Not-for-profit	76	65
0	55	57	Investor-owned	8	17
1	38	37			
≥2	7	6			
Median-income quartile (% of patients)					
1st	21	19			
2nd	22	17			
3rd	20	23			
4th	20	23			
Data missing	17	18			

\*Plus–minus values are means ±SD.

†Data are for hospitals that participate in the Nationwide Inpatient Sample in which lung-cancer operations are performed.

through December 31, 1994, for patients with lung cancer diagnosed before 1991 and through December 31, 1998, for those with lung cancer diagnosed between 1991 and 1996. The follow-up for all patients was at least two years. For the patients who were still alive, data were censored as of these dates.

The frequency of postoperative complications and the length of stay after the admission for surgery were determined on the basis of claims in the Medicare file.<sup>24,25</sup> We separated serious acute complications into surgical and pulmonary complications. Surgical complications included pneumothorax, pulmonary collapse, and accidental puncture, damage, or contamination of the surgical site (ICD-9-CM codes 512.0, 512.1, 512.8, 518, 518.1, 998.2 through 998.81, E870.0, and E871.0); pulmonary complications included new-onset pulmonary insufficiency and respiratory arrest (ICD-9-CM codes 518.5, 518.81, 518.82, 799.1, and 997.3). This group of diagnoses is distinct from those used to calculate the Romano-Charlson in-

dex, which we used to measure comorbidity. The latter index focuses on chronic illnesses such as congestive heart failure (ICD-9-CM codes 402 through 404), liver disease (ICD-9-CM code 572), and chronic obstructive pulmonary disease (ICD-9-CM codes 415.0, 416.8, 416.9, 491 through 494, and 496).

**Statistical Analysis**

The results are presented according to category of the hospital's volume of procedures exclusively for purposes of illustration. In all the statistical tests, the volume was considered as a continuous measure, and variances were adjusted to correct for the fact that these data include multiple observations from some hospitals. Categorical outcomes (30-day survival, 2-year survival, presence or absence of complications, and characteristics of the hospitals and the patients) were assessed by means of a modified version of the Mantel-Haenszel test for trend in all unadjusted analyses and by a method

**TABLE 2.** CHARACTERISTICS OF THE 76 HOSPITALS STUDIED, ACCORDING TO THE VOLUME OF LUNG-CANCER RESECTIONS PERFORMED DURING 1997, AND OF 2118 MEDICARE BENEFICIARIES WITH STAGE I, II, OR IIIA NON-SMALL-CELL LUNG CANCER WHO UNDERWENT LUNG-CANCER RESECTION BETWEEN 1985 AND 1996 AT ONE OF THESE HOSPITALS.

CHARACTERISTIC	ALL HOSPITALS (N=76)	ANNUAL VOLUME OF PROCEDURES					P VALUE FOR TREND*
		1-8 (N=34)	9-14 (N=14)	15-19 (N=10)	20-66 (N=16)	67-100 (N=2)	
<b>Hospitals</b>							
Percentage of all hospitals	100	45	18	13	21	3	
Teaching status (% of hospitals)							0.03
Nonteaching	67	82	79	50	44	0	
Teaching	33	18	21	50	56	100	
Hospital location (% of hospitals)							<0.001
Rural	16	32	7	0	0	0	
Urban	84	68	93	100	100	100	
<b>Patients</b>							
No. of patients (%)	2118 (100)	407 (19)	466 (22)	407 (19)	457 (22)	381 (18)	
Age (% of patients)							0.29
65-69 yr	34	36	31	35	36	34	
70-74 yr	34	33	36	33	35	28	
≥75 yr	32	31	33	32	29	37	
Sex (% of patients)							0.14
Male	59	60	58	60	58	59	
Female	41	40	42	40	42	41	
Race (% of patients)							0.15
White	95	94	97	95	94	97	
Black	3	5	2	2	1	3	
Other	2	1	1	3	5	0	
Stage of disease (% of patients)							0.21
I	69	67	66	70	69	71	
II	20	24	21	20	18	17	
IIIA	11	9	13	10	13	12	
Procedure (% of patients)							0.15
Partial lobectomy	25	25	24	23	28	26	
Lobectomy	66	65	68	66	64	67	
Pneumonectomy	9	10	8	11	8	7	
Romano-Charlson comorbidity index (% of patients)							0.25
0	57	56	56	58	59	56	
1	37	38	38	35	35	37	
≥2	6	6	6	7	6	7	
Median-income quartile (% of patients)							0.81
1st	19	25	17	23	8	25	
2nd	17	19	11	9	14	35	
3rd	23	20	34	27	18	11	
4th	23	20	27	13	31	25	
Data missing	18	16	11	28	29	4	

\*P values reflect the strength of the association between each characteristic and the annual volume.

involving generalized estimating equations for all analyses that included other covariates.<sup>26-28</sup> The association between the length of stay and the volume of procedures was assessed by means of the rank-correlation test. Survival data were assessed by means of a Cox proportional-hazards model in which we adjusted the variance using the Robust macro developed for use with SAS software (SAS Institute, Cary, N.C.).<sup>29</sup> All analyses were performed with SAS software, version 8.0. All P values are two-sided. The categorizations of the covariates included in the models are reflected in Table 2, and the particular covariates included in each model are specified in Tables 3 and 4.

## RESULTS

### Characteristics of the Hospitals

For the purpose of illustration, the hospitals are categorized according to the number of lung-cancer op-

erations performed in 1997 (Table 2). In nearly half the hospitals (34 of 76), fewer than nine lung-cancer operations were performed in that year. In contrast, at 16 of the 76 hospitals (21 percent) 20 to 66 procedures were performed in 1997, and at 2 hospitals (3 percent) 67 to 100 were performed. Hospitals in which higher numbers of lung-cancer operations were performed tended to be teaching hospitals in urban locations. There were no significant trends that associated the volume of procedures with the characteristics of the patients listed in Table 2.

### The Relation between Volume and Outcome

The 30-day, 2-year, and overall rates of survival were all significantly associated with the volume of proce-

**TABLE 3. RELATION BETWEEN THE VOLUME OF OPERATIONS AND THE OUTCOME OF OPERATIONS FOR PRIMARY NON-SMALL-CELL LUNG CANCER. \***

VARIABLE	ALL HOSPITALS (N=76)	ANNUAL VOLUME OF PROCEDURES†					P VALUE	
		1-8 (N=34)	9-14 (N=14)	15-19 (N=10)	20-66 (N=16)	67-100 (N=2)	ANALYTIC SAMPLE OF PATIENTS (N=2118)	ALL SEER- MEDICARE PATIENTS (N=12,921)
		30-Day survival						
Observed (%)	96	94	94	96	97	97		
Unadjusted OR for death	—	1.00	0.98	0.61	0.54	0.47	0.02	0.05
Adjusted OR for death‡	—	1.00	0.86	0.50	0.48	0.48	0.04§	<0.001
2-Yr survival								
Observed (%)	64	58	62	62	69	69		
Unadjusted OR for death	—	1.00	0.85	0.84	0.62	0.61	<0.001	<0.001
Adjusted OR for death‡	—	1.00	0.78	0.77	0.56	0.64	0.02	<0.001
Overall survival								
All patients								
5-Yr survival (%)	38	33	36	39	40	44		
Unadjusted HR	—	1.00	0.90	0.84	0.77	0.73	<0.001	<0.001
Adjusted HR‡	—	1.00	0.91	0.80	0.75	0.77	0.003	<0.001
Patients at teaching hospitals								
No. of patients	1129	99	115	197	337	381		
5-Yr survival (%)	42	35	37	42	42	44		
Unadjusted HR	—	1.00	0.90	0.81	0.79	0.78	0.01	0.002
Adjusted HR¶	—	1.00	0.89	0.80	0.77	0.81	0.08	<0.001
Patients at nonteaching hospitals								
No. of patients	989	308	351	210	120	0		
5-Yr survival (%)	34	31	36	36	33	NA		
Unadjusted HR	—	1.00	0.91	0.90	0.85	NA	0.14	0.02
Adjusted HR¶	—	1.00	0.92	0.88	0.66	NA	0.01	0.02

\*Hospitals were categorized according to the number of lung-cancer resections performed in 1997. For each variable, the odds ratio (OR) and hazard ratio (HR) are from models in which volume is considered according to category; the ratios indicate the risk of death relative to that in the lowest volume category (1 to 8 procedures per year). P values are derived from tests in which volume is considered as a continuous variable and are relevant to the described models but not to the individual odds ratios or hazard ratios. Results are presented for both the study sample of 2118 patients and the entire cohort of 12,921 patients from the SEER-Medicare data base who underwent operations during the years 1985 through 1996. NA denotes not applicable.

†For hospitals not included in the Nationwide Inpatient Sample data base the determination of the volume was based on the number of operations performed in patients whose cancer was diagnosed during the 12 years of observation in areas covered by SEER and who had Medicare indemnity insurance.

‡This ratio was adjusted for characteristics of the hospitals (teaching status and urban vs. rural location) and characteristics of the patients (age, sex, race, stage of disease, type of surgical procedure, degree of comorbidity, and income in the ZIP Code of residence).

§This P value was calculated by means of logistic regression.

¶This ratio was adjusted for characteristics of the patient (age, sex, race, stage of disease, type of surgical procedure, degree of comorbidity, and income in the ZIP Code of residence).

**TABLE 4.** RELATION BETWEEN THE VOLUME OF PROCEDURES, COMPLICATIONS, AND SURVIVAL AFTER OPERATIONS FOR PRIMARY LUNG CANCER.\*

VARIABLE	ALL HOSPITALS (N=76)	ANNUAL VOLUME OF PROCEDURES					P VALUE
		1-8 (N=34)	9-14 (N=14)	15-19 (N=10)	20-66 (N=16)	67-100 (N=2)	
Total no. of patients	2118	407	466	407	457	381	
Median length of stay — days	9	10	10	10	8	9	<0.001†
Complications							
Operative — no. of patients (%)	409 (19)	122 (30)	74 (16)	84 (21)	76 (17)	53 (14)	<0.001
Pulmonary — no. of patients (%)	420 (20)	112 (28)	86 (18)	82 (20)	92 (20)	48 (13)	0.002
Any — no. of patients (%)	677 (32)	181 (44)	131 (28)	142 (35)	145 (32)	78 (20)	<0.001
5-Yr survival‡							
Patients with complications — %	34	32	35	41	31	27	0.57
Patients without complications — %	40	33	37	38	44	48	<0.001
Hazard ratio for overall survival							
Adjusted for characteristics of the hospitals and the patients§	—	1.00	0.91	0.80	0.75	0.77	0.003
Adjusted for complications and characteristics of the hospitals and the patients¶	—	1.00	0.95	0.82	0.77	0.80	0.008

\*Hospitals were categorized according to the number of lung-cancer resections performed in 1997. For each variable, the hazard ratio (HR) is from models in which volume is considered according to category and indicates the risk of death relative to that in the lowest volume category (1 to 8 procedures per year). P values are derived from tests in which volume is considered as a continuous variable and are relevant to the described models but not to the individual hazard ratios.

†This association was assessed by rank-correlation (P value for Kendall's Tau-b statistic).

‡A total of 677 patients had complications, and 1441 did not.

§The ratio was adjusted for characteristics of the hospitals (teaching status and urban vs. rural location) and characteristics of the patients (age, sex, race, stage of disease, type of surgical procedure, degree of comorbidity, and income in the ZIP Code of residence).

¶The ratio was adjusted for the presence of complications (pulmonary and operative), characteristics of the hospitals (teaching status and urban vs. rural location), and characteristics of the patients (age, sex, race, stage of disease, type of surgical procedure, degree of comorbidity, and income in the ZIP Code of residence).

dures (Table 3). The most important difference between high-volume and low-volume hospitals was in overall survival. The rate of survival at five years was 44 percent among patients who underwent resection at either of the two hospitals with the highest volume of procedures and 33 percent among patients who had surgery at a hospital in which fewer than nine operations were performed in 1997. An analysis of the entire SEER–Medicare cohort demonstrated a significant but more limited difference (7 percentage points;  $P<0.001$ ) in five-year survival between the hospitals with the lowest volume (36 percent) and those with the highest volume (43 percent). We also observed that for each increment in the procedure-volume category, overall survival improved both in absolute terms (Fig. 1) and within analyses that adjusted for other factors that influence survival (Table 3).

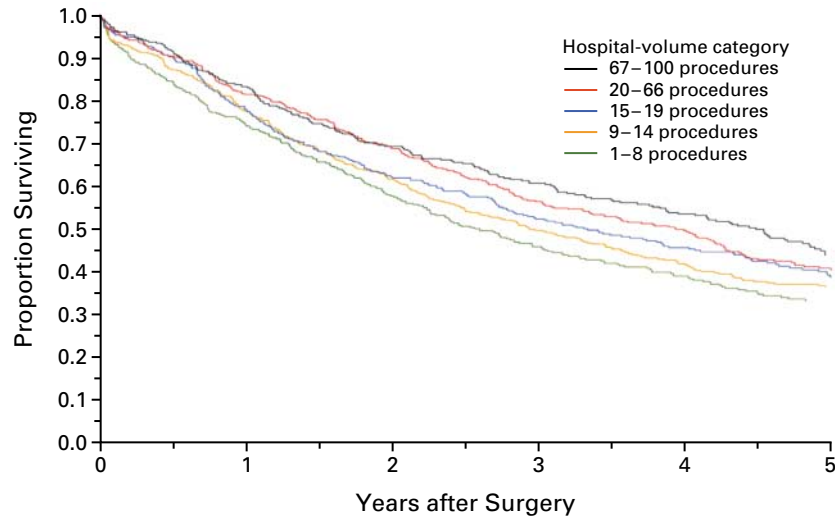
**The Relation among Teaching Status, Volume, and Survival**

Overall, the rate of five-year survival among patients who underwent surgery at a teaching hospital was 42 percent, as compared with 34 percent among those at nonteaching hospitals ( $P<0.001$ ). After stratifying hospitals according to their volume of procedures, we

also observed a relation between the rate of survival and the volume of procedures in teaching hospitals in particular (Table 3).

**Postoperative Complications**

We found a strong negative association between the volume of the procedures and the likelihood of either operative ( $P<0.001$ ) or pulmonary ( $P=0.002$ ) complications (Table 4), with complication rates that were twice as high at hospitals with the lowest volume as at those with the highest volume. We also observed a relation between longer hospital stays and hospitals with lower volume (Table 4). Although this latter association is unlikely to be clinically significant, it supports our hypothesis that the postoperative course at hospitals with lower volumes is, on average, more complex. The primary association between hospital volume and survival was only marginally altered when we simultaneously considered the effect of complications on survival through either stratified or multivariate analyses (Table 4). In other words, these results are not consistent with the hypothesis that differences in complication rates are the chief explanation for the relation between volume and survival.



NO. AT RISK						
	0	1	2	3	4	5
67–100 procedures	381	320	266	209	162	102
20–66 procedures	457	379	319	233	182	117
15–19 procedures	407	323	256	194	140	94
9–14 procedures	466	374	290	216	163	115
1–8 procedures	407	309	242	173	128	83

**Figure 1.** Survival of Medicare Beneficiaries 65 Years of Age or Older Who Received a Diagnosis of Stage I, II, or IIIA Non–Small-Cell Lung Cancer between 1985 and 1996 and Underwent Resection for Lung Cancer, According to the Volume of Such Procedures Performed Annually at the Hospitals Where the Patients Were Treated.

Procedure volume was determined on the basis of data from the 1997 Nationwide Inpatient Sample. A total of 2118 patients were included in the analysis.

### DISCUSSION

We found a rate of survival at five years that was higher by 11 percentage points (44 percent vs. 33 percent) among patients who underwent resections for lung cancer at hospitals with the highest volumes of such procedures than among those at the hospitals with the lowest volumes. Moreover, regardless of the volume of procedures, the rate of survival was better among patients who had their operations at teaching hospitals rather than nonteaching hospitals, although this finding did not confound the relation between volume and outcome.

Serious postoperative complications occurred at the hospitals with the lowest volume twice as often as at those with the highest volume (44 percent vs. 20 percent). It seemed plausible that these higher rates of complications might explain the relation between the hospital’s volume of procedures and long-term survival. However, the complications we identified in the Medicare files only partially explained the association between high volume and a higher rate of overall survival. Whether a clearer picture would have emerged if we had more complete documentation of postoperative events (such as can be obtained through a review of patients’ charts) remains an open question.

Our study has other limitations because of the in-

completeness of the data on the hospitals and the patients included in NIS, Medicare, and the SEER data base. The hospitals included in the 1997 NIS are characterized simply as teaching or nonteaching, belying the complex array of organizational frameworks that exists. The 1997 data may also have limited relevance to patients who entered the cohort in the earlier years of our study. Incomplete data on adjuvant treatment and miscoded data on coexisting conditions (both potential problems with Medicare records) are also matters of concern. The lack of data on adjuvant treatment, however, should not have affected our results for two reasons. First, randomized trials have not demonstrated a consistent survival benefit for patients with stage I or stage II disease — a category that includes 89 percent of the patients in our study.<sup>30,31</sup> Second, in a separate analysis of patients with early-stage disease, the results were similar to those in the cohort as a whole (data not shown).<sup>32</sup>

As for miscoding or incomplete coding of coexisting conditions,<sup>33</sup> there were no discernible differences between the groups of patients in the characteristics we measured (Table 2), which lessens the likelihood that unobserved differences in these factors are an important source of bias. The staging information in the SEER data base may also have biased our results, es-

pecially because the sampling of mediastinal lymph nodes may be more thorough in hospitals with high volumes of procedures than in those with low volumes. However, among patients with stage IA (T1N0M0) disease who had undergone lobectomy (17 percent of the cohort), the relation between the volume of procedures and five-year survival was of the same magnitude as that in the entire cohort (data not shown). In this subgroup of patients, we know that the stage was probably ascertained correctly. At least one N1 node was examined, and the likelihood of a "skip" metastasis to the N2 node is very low (4 to 8 percent in most reports).<sup>34,35</sup>

How should we react to these findings? Survival might be improved by identifying the variations in perioperative and intraoperative care that are responsible for the differences we found. A study in which an association between volume and outcome was identified in the care of patients with myocardial infarction found that differential use of aspirin, beta-blockers, and other therapies accounted for some of the differences in outcome that appeared to be linked to the volume of procedures.<sup>36</sup> An alternative response to our results would be to limit the performance of resections for lung cancer to centers with better outcomes. This approach has been endorsed by a number of investigators,<sup>37-40</sup> as well as in a recent report from the Institute of Medicine on the quality of care for cancer in the United States.<sup>41</sup>

We hesitate to advocate this latter approach for three reasons. First, shifting surgical patients to a few institutions with high volumes of procedures may have unintended effects on the quality of care both at those institutions, which would face substantial increases in the volume of patients, and at the institutions with low volumes, where the care of the remaining patients might suffer. Second, increased volume and the teaching status of the hospital appear to be markers of improved outcome, but these characteristics do not, in isolation, identify individual high-quality hospitals.<sup>42</sup> Finally, the association we observed between the volume of procedures and postoperative complications hints at the possibility that rectifiable variations in care may account for differences in outcome. Targeting these variations may be the best way to achieve a durable improvement in the treatment of patients with early-stage lung cancer.

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## REFERENCES

- Begg CB, Cramer LD, Hoskins WJ, Brennan MF. Impact of hospital volume on operative mortality for major cancer surgery. *JAMA* 1998;280:1747-51.
- Sosa JA, Bowman HM, Gordon TA, et al. Importance of hospital volume in the overall management of pancreatic cancer. *Ann Surg* 1998;228:429-38.
- Birkmeyer JD, Warshaw AL, Finlayson SR, Grove MR, Tosteson AN. Relationship between hospital volume and late survival after pancreaticoduodenectomy. *Surgery* 1999;126:178-83.
- Schrag D, Cramer LD, Bach PB, Cohen AM, Warren JL, Begg CB. Influence of hospital procedure volume on outcomes following surgery for colon cancer. *JAMA* 2000;284:3028-35.
- Hannan EL, O'Donnell JF, Kilburn H Jr, Bernard HR, Yazici A. Investigation of the relationship between volume and mortality for surgical procedures performed in New York State hospitals. *JAMA* 1989;262:503-10.
- Hannan EL, Popp AJ, Tranmer B, Fuestel P, Waldman J, Shah D. Relationship between provider volume and mortality for carotid endarterectomies in New York State. *Stroke* 1998;29:2292-7.
- Hughes RG, Hunt SS, Luft HS. Effects of surgeon volume and hospital volume on quality of care in hospitals. *Med Care* 1987;25:489-503.
- Edwards EB, Roberts JP, McBride MA, Schulak JA, Hunsicker LG. The effect of the volume of procedures at transplantation centers on mortality after liver transplantation. *N Engl J Med* 1999;341:2049-53.
- Roohan PJ, Bickell NA, Baptiste MS, Theriault GD, Ferrara EP, Siu AL. Hospital volume differences and five-year survival from breast cancer. *Am J Public Health* 1998;88:454-7.
- Yao SL, Lu-Yao G. Population-based study of relationships between hospital volume of prostatectomies, patient outcomes, and length of hospital stay. *J Natl Cancer Inst* 1999;91:1950-6.
- Ellison LM, Heaney JA, Birkmeyer JD. The effect of hospital volume on mortality and resource use after radical prostatectomy. *J Urol* 2000;163:867-9.
- Khuri SF, Daley J, Henderson W, et al. Relation of surgical volume to outcome in eight common operations: results from the VA National Surgical Quality Improvement Program. *Ann Surg* 1999;230:414-29.
- Romano PS, Mark DH. Patient and hospital characteristics related to in-hospital mortality after lung cancer resection. *Chest* 1992;101:1332-7.
- Rosenthal GE, Harper DL, Quinn LM, Cooper GS. Severity-adjusted mortality and length of stay in teaching and nonteaching hospitals: results of a regional study. *JAMA* 1997;278:485-90.
- Holm T, Johansson H, Cedermark B, Ekelund G, Rutqvist L-E. Influence of hospital- and surgeon-related factors on outcome after treatment of rectal cancer with or without preoperative radiotherapy. *Br J Surg* 1997;84:657-63.
- Potosky AL, Riley GF, Lubitz JD, Mentnech RM, Kessler LG. Potential for cancer related health services research using a linked Medicare-tumor registry database. *Med Care* 1993;31:732-48.
- 1999 Hospital & payor ICD-9-CM: international classification of diseases, 9th rev., clinical modification. 5th ed. Salt Lake City: Medicode, 1998.
- Romano PS, Roos LL, Jollis JG. Adapting a clinical comorbidity index for use with ICD-9-CM administrative data: differing perspectives. *J Clin Epidemiol* 1993;46:1075-9.
- Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis* 1987;40:373-83.
- Best AE. Secondary data bases and their use in outcomes research: a review of the Area Resource File and the Healthcare Cost and Utilization Project. *J Med Syst* 1999;23:175-81.
- Percy C, Van Holten V, Muir C, eds. International classification of diseases for oncology. 2nd ed. Geneva: World Health Organization, 1990.
- Mountain CF. A new international staging system for lung cancer. *Chest* 1986;89:Suppl:225S-233S.
- Idem*. Revisions in the International System for Staging Lung Cancer. *Chest* 1997;111:1710-7.
- Iezzoni LI, Daley J, Heeren T, et al. Using administrative data to screen hospitals for high complication rates. *Inquiry* 1994;31:40-55.
- Lawthers AG, McCarthy EP, Davis RB, Peterson LE, Palmer RH, Iezzoni LI. Identification of in-hospital complications from claims data: is it valid? *Med Care* 2000;38:785-95.
- Begg MD. Analyzing k (2x2) tables under cluster sampling. *Biometrics* 1999;55:302-7.
- Diggle PJ, Liang K-Y, Zeger SL. Analysis of longitudinal data. Oxford, England: Oxford University Press, 1995.

28. Allison PD. Logistic regression using the SAS system: theory and application. Cary, N.C.: SAS Institute, 1999:179-97.
29. White H. Maximum likelihood estimation of misspecified models. *Econometrica* 1982;50:1-25.
30. Ettinger DS, Cox JD, Ginsberg RJ, et al. NCCN non-small-cell lung cancer practice guidelines. *Oncology (Hunting)* 1996;10:Suppl:81-111.
31. Keller SM, Adak S, Wagner H, et al. A randomized trial of postoperative adjuvant therapy in patients with completely resected stage II or IIIA non-small-cell lung cancer. *N Engl J Med* 2000;343:1217-22.
32. Rosell R, Gómez-Codina J, Camps C, et al. A randomized trial comparing preoperative chemotherapy plus surgery with surgery alone in patients with non-small-cell lung cancer. *N Engl J Med* 1994;330:153-8.
33. Jollis JG, Ancukiewicz M, DeLong ER, Pryor DB, Muhlbaier LH, Mark DB. Discordance of databases designed for claims payment versus clinical information systems: implications for outcomes research. *Ann Intern Med* 1993;119:844-50.
34. Asamura H, Nakayama H, Kondo H, Tsuchiya R, Shimosata Y, Naruke T. Lymph node involvement, recurrence, and prognosis in resected small, peripheral, non-small-cell lung carcinomas: are these carcinomas candidates for video-assisted lobectomy? *J Thorac Cardiovasc Surg* 1996; 111:1125-34.
35. Ishida T, Yano T, Maeda K, Kaneko S, Tateishi M, Sugimachi K. Strategy for lymphadenectomy in lung cancer three centimeters or less in diameter. *Ann Thorac Surg* 1990;50:708-13.
36. Thiemann DR, Coresh J, Oetgen WJ, Powe NR. The association between hospital volume and survival after acute myocardial infarction in elderly patients. *N Engl J Med* 1999;340:1640-8.
37. Grumbach K, Anderson GM, Luft HS, Roos LL, Brook R. Regionalization of cardiac surgery in the United States and Canada: geographic access, choice, and outcomes. *JAMA* 1995;274:1282-8.
38. Luft HS, Bunker JP, Enthoven AC. Should operations be regionalized? The empirical relation between surgical volume and mortality. *N Engl J Med* 1979;301:1364-9.
39. Hillner BE, Smith TJ. Hospital volume and patient outcomes in major cancer surgery: a catalyst for quality assessment and concentration of cancer services. *JAMA* 1998;280:1783-4.
40. Hillner BE, Smith TJ, Desch CE. Hospital and physician volume or specialization and outcomes in cancer treatment: importance in quality of cancer care. *J Clin Oncol* 2000;18:2327-40.
41. Hewitt M, ed. Interpreting the volume-outcome relationship in the context of health care quality: workshop summary. Washington, D.C.: National Academy of Sciences, 2000.
42. Phillips KA, Luft HS. The policy implications of using hospital and physician volumes as "indicators" of quality of care in a changing health care environment. *Int J Qual Health Care* 1997;9:341-8.

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