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Influence of Hospital Procedure Volume on Outcomes Following Surgery for Colon Cancer

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THE COMPLEXITY OF HEALTH care processes makes identification and measurement of the critical components of high-quality care especially challenging.¹ Because hospital procedure volume is relatively easy to measure and is assumed to be a proxy for experience, it has long been examined as a predictor of clinical outcomes, and a volume-outcome relationship has been observed for a wide variety of surgeries.²⁻¹³ Concentration of surgeries in high-volume centers has been considered a strategy to improve the quality of care,^{2,14-16} and in select instances, policies to achieve this goal have been implemented.¹⁷

For cancer patients, large population-based studies have demonstrated that hospital procedure volume can have a profound effect on outcomes following operations associated with high mortality, such as pancreatotomy.¹⁸⁻²⁰ Some prior studies have suggested that a volume-outcome effect may also exist for colon cancer surgery, which is performed more frequently but with less substantial morbidity and mortality.^{3-5,21-26} However, these analyses have been limited by either sample size, lack of population-based case ascertainment, geographic diversity, insufficient clinical detail for risk

Context Survival following high-risk cancer surgery, such as pancreatotomy and esophagectomy, is superior at hospitals where high volumes of these procedures are performed. Conflicting evidence exists as to whether the association between hospital experience and favorable health outcomes also applies to more frequently performed operations, such as those for colon cancer.

Objective To determine whether hospital procedure volume predicts survival following colon cancer surgery.

Design, Setting, and Participants Retrospective cohort study of data from the Surveillance, Epidemiology and End Results–Medicare linked database on 27986 colon cancer patients aged 65 years and older who had surgical resection for primary adenocarcinoma diagnosed between 1991 and 1996.

Main Outcome Measures Thirty-day postoperative mortality and overall and cancer-specific long-term survival, by hospital procedure volume.

Results We found small differences in 30-day postoperative mortality for patients treated at low- vs high-volume hospitals (3.5% at hospitals in the top-volume quartile vs 5.5% at hospitals in the bottom-volume quartile). However, the correlation was statistically significant and persisted after adjusting for age at diagnosis, sex, race, cancer stage, comorbid illness, socioeconomic status, and acuity of hospitalization ($P < .001$). The association was evident for subgroups with stage I, II, and III disease. Hospital volume directly correlated with survival beyond 30 days and also was not attributable to differences in case mix ($P < .001$). The association between hospital volume and long-term survival was concentrated among patients with stage II and III disease ($P < .001$ for both). Among stage III patients, variation in use of adjuvant chemotherapy did not explain this finding.

Conclusion Our data suggest that hospital procedure volume predicts clinical outcomes following surgery for colon cancer, although the absolute magnitudes of these differences are modest in comparison with the variation observed for higher-risk cancer surgeries.

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adjustment, or incomplete mortality data. Recently, linkage of the Surveillance, Epidemiology, and End Results (SEER) registries to Medicare claims created a resource that combines the necessary ingredients for volume-outcome analyses for the US population aged 65 years and older.²⁷

We used SEER-Medicare data to identify a population-based cohort of colon cancer patients to determine whether hospital procedure volume predicts short- and long-term survival following primary surgery. We hypothesized that hospital volume would predict both postoperative mortality and

long-term survival, but anticipated that the absolute magnitude of these associations would be smaller than those observed for infrequently performed higher-risk operations, such as pancreatotomy and esophagectomy.

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See also Patient Page.

METHODS

Data Sources

The SEER registries ascertain all incident cancer cases diagnosed in 5 states and 6 US metropolitan areas, representing approximately 14% of the US population.²⁸ Information is collected on each incident cancer, including the primary site and histology classified according to the *International Classification of Diseases for Oncology, Second Revision (ICD-O-2)*²⁹ schema, the tumor stage at diagnosis, and patient demographics.

The Medicare program provides health coverage for 97% of the US population aged 65 years and older. The Medicare Provider Analysis and Review files provide details of all hospitalizations for persons eligible for Medicare Part A. To receive payment, hospitals submit medical claims coding up to 10 diagnoses and 10 procedures using the *International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)* classification. For the 96% of Medicare beneficiaries who opt for Part B coverage, claims for care delivered in hospital outpatient departments and physicians' offices are also recorded. Medicare records document date of death based on information provided by the Social Security Administration. The SEER-Medicare data have been linked to facilitate population-based studies of the outcomes of cancer treatment. Ninety-four percent of patients in SEER aged 65 years and older have been successfully linked to their Medicare records.²⁷

Cohort Definition

All Medicare-enrolled patients aged 65 years and older diagnosed as having primary colon cancer in a SEER area during the years 1991 to 1996 were potentially eligible for inclusion in our study. Colon cancers were defined using SEER codes for cancer sites 18.0 through 18.9, and 19.9; thus, tumors arising in the rectosigmoid were included. We restricted our cohort to patients with a histologic diagnosis of adenocarcinoma (SEER histology codes 8140, 8210, 8211, 8220, 8221, 8260, 8261, 8262, 8263, 8470, 8480, 8481, and 8490). Diagnoses noted exclusively on death cer-

tificates or at autopsy were excluded, as were those in which the month of diagnosis was unknown. Patients enrolled in a health maintenance organization were excluded from our cohort (16.5% of patients) because detailed claims are not submitted to Medicare by health maintenance organizations.

We searched Medicare claims for colon cancer surgeries performed within 6 months of primary diagnosis. Operations were defined according to the ICD-9-CM classification system (45.7x, 45.8, 48.4x, 48.5x, and 48.6x); thus, patients operated on exclusively for local resection or creation of an ostomy were excluded. Only patients undergoing surgery at hospitals located in 1 of the 9 states containing 1 of 11 SEER registries were included in the analysis because hospital volume could not be reliably measured at institutions outside SEER areas.

Outcomes of Colorectal Surgery

The 3 outcomes assessed were 30-day postoperative mortality, overall survival, and colon cancer-specific survival. Postoperative mortality was defined as death within 30 days of hospitalization for surgical resection. Date of hospitalization served as a proxy for date of surgery since it is more reliably coded in the Medicare database. Survival was defined by the interval from the date of hospitalization for resection until either death as reported to Medicare, or December 31, 1998, when censoring occurred. SEER reports cancer-specific mortality based on state death certificates but these vital statistics were current only through December 31, 1996. Therefore, colon cancer-specific survival was examined for the 98.5% of our cohort (27 561/27 986) who had available state death certificates or had not died prior to this date.

We hypothesized that greater use of adjuvant chemotherapy at high-volume hospitals might partially explain an observed volume-outcome relationship. We examined use of adjuvant chemotherapy among patients with stage III cancer who survived 3 months postoperatively, and were also enrolled in

Medicare Part B, which is required for coverage of outpatient services. Those patients who had at least 1 claim for chemotherapy or its administration at any point during the 3-month postoperative period were considered recipients.

Hospital Procedure Volume

Hospitals were ranked by volume according to the number of operations performed between 1991 and 1996, an approach that has been previously validated.¹⁸ Examination of fluctuations of individual hospital volumes on a year-by-year basis demonstrated great stability. To avoid the possibility of selecting cut points with maximal *P* values, primary statistical analyses were performed using the Mantel-Haenszel test for trend without aggregation of the data into discrete volume categories. To facilitate display of our results and to adjust survival in a Cox proportional hazards model, we defined quartiles of hospital procedure volume (low, medium, high, and very high) based on the volume of operations performed on members of our cohort during the 6-year study period.

Potential Confounders

We used information on tumor size, nodal involvement, and spread coded in the SEER database to stage patients according to the American Joint Committee on Cancer schema. Patients with missing information about tumor extent, nodal involvement, or metastases were classified as unstaged. To adjust for potential confounding based on the severity of noncancer medical illness, we used Romano's³⁰ modification of the comorbidity index originally developed by Charlson.³¹ We examined all available inpatient Medicare claims for the 12 months prior to the index surgical admission, as well as claims during the index admission, and assigned patients the maximal comorbidity observed. We used the median income in the census tract of residence to adjust for differences in patients' economic status.

Colon cancer resections performed on an emergency basis may be associ-

ated with high mortality. We used the Medicare claim code for emergent hospital admission and ICD-9 codes for emergent indications for surgery bowel obstruction (560.89, 560.90) and perforation (569.83) to permit an adjustment in multivariable analysis.

Statistical Analysis

The relationship between hospital procedure volume and postoperative mortality was examined using the Mantel-Haenszel test for trend. While we used the patient as the unit of analysis, we also performed a modified version of the Mantel-Haenszel test that adjusts for within-hospital correlations in the data.³² Multiple logistic regression, with vital status at 30 days as the outcome and hospital procedure volume as a continuous predictor, was used to adjust for potential confounding by sex, race, age at diagnosis, cancer stage, comorbidity, socioeconomic status, and the presence of emergent indications for surgery according to the categories shown in TABLE 1.

The impact of hospital volume on survival is displayed using the Kaplan-Meier method. The Cox proportional-hazards method was used to examine the effects of potential confounders. The likelihood ratio test was used to compare a model that had all variables except procedure volume with a model that had all variables including procedure volume. All *P* values are 2-sided. When we developed our research protocol, we calculated the effect size that would allow for detection with a 2-sided significance level of .05 and 90% power for each planned analysis. With a sample size of 27 000 colon cancer patients and a 4% postoperative mortality rate, we had power to detect a 0.8% difference between low- and high-volume hospitals; for a subgroup of 7000 patients, we could detect a 1.5% difference; for a subgroup of 3500 patients, a 2.1% difference.

RESULTS

Characteristics of the Cohort

A total of 47 495 Medicare-eligible patients received an antemortem diagnosis of primary colon cancer at age 65

years and older during the years 1991-1996 in SEER areas. We sequentially excluded 2280 patients with histologies other than adenocarcinoma, 71 lacking a month of diagnosis, and 2934 with in situ tumors. Among the remaining 42 210 patients, 7999 were excluded because they were enrolled in a health maintenance organization or not enrolled in Medicare Part A at the time of diagnosis. From this group of 34 211, a total of 28 475 had surgical resection, and among these, 27 986 had surgery performed at a hospital located in a SEER area. The demographic and clinical characteristics of the 27 986 patients are displayed in Table 1.

Hospital Surgical Volume

In our cohort, colon cancer resections were performed at 611 different hospitals between 1991 and 1996. Hospital volume over the 6-year period ranged from 1 to 57 for the 440 low-volume hospitals (72%); 58 to 112 for the 89 medium-volume hospitals (15%); 113 to 165 for the 51 high-volume hospitals (8%); and 166 to 383 for the 31 very high-volume hospitals (5%). The numbers and characteristics of patients in each volume quartile category are shown in Table 1. The age, sex, and comorbidity of patients were similar across strata of hospital volume. Patients with race coded as other than white or black, those with unstaged tumors, and those with low socioeconomic status were more likely to undergo surgery at a low-volume hospital.

Postoperative Mortality

As shown in TABLE 2, the absolute magnitude of variation in 30-day postoperative mortality at hospitals with different procedure volumes was small. For example, the difference in 30-day mortality for patients operated on at the very high-volume compared with the low-volume hospitals was 2% (3.5% vs 5.5%). However, a consistent association between higher postoperative mortality and lower surgical procedure volume was evident ($P < .001$) and persisted after inclusion of potential

confounders in multivariable logistic regression ($P < .001$). In subgroup analyses, we found that hospital volume was a significant predictor of mortality for patients with stage I, II, and III tumors, but not for patients with stage IV or unstaged disease, in which smaller sample sizes precluded our ability to detect effect sizes of less than 2%.

Survival

The survival curves for patients treated at institutions in each volume quartile illustrate a clear association between procedure volume and overall survival ($P < .001$; FIGURE 1A). The difference in 5-year mortality for patients operated on at the very high- vs the low-volume hospitals was 4.4% (54.8%-50.4%; Table 2). Since a 2% absolute mortality difference is evident at 30 days, 45% (2/4.4) of the survival difference appears to be attributable to the immediate postoperative period and 55% to more distal events. Figure 1B demonstrates that similar results are obtained for colon cancer-specific survival ($P < .001$).

Adjusted risk ratios and confidence intervals for overall mortality for patients in each hospital volume category compared with patients operated on at the very high-volume institutions are shown in Table 2. The volume-outcome association remained highly significant for both overall mortality ($P < .001$) and colon cancer-specific mortality ($P < .001$) after adjusting for other variables.

We examined subgroups of patients with identical American Joint Committee on Cancer tumor stage (FIGURE 2). Whereas hospital volume was predictive of survival for patients with stage II ($P < .001$ adjusted) and stage III disease ($P < .001$ adjusted), it was not significant for patients with either stage I or stage IV disease.

Other Factors

Our adjusted models included variables associated with either shorter colon cancer survival (advanced clinical stage, comorbidity, obstruction, perforation) or shorter life expectancy (male sex, older age, black race, and low socioeconomic status). Male sex, older age, black race,

advanced clinical stage, high comorbidity, low income, obstruction or perforation, and emergent hospitalization were independent predictors of poor prognosis

but adjusting for these variables did not change our results.

Variation in synchronous hepatic resection (ICD-9-CM codes 50.22, 50.3,

50.4) did not confound the volume-outcome association because it was performed at a similar low frequency (0.4%-0.6%) at hospitals in each volume

Table 1. Patients With Colon Cancer According to the Procedure Volume of the Hospital Where Surgery Was Performed*

Patient Characteristics	No. (%) of Patients†	Patients by Hospital Volume, %‡			
		Low	Medium	High	Very High
Total					
No. of patients	27 986 (100)	6837	7105	6947	7097
No. of hospitals	611 (100)	440	89	51	31
Sex					
Male	12 550 (44.8)	44.9	44.9	45.6	44.0
Female	15 436 (55.2)	55.1	55.1	54.4	56.0
Age at diagnosis, y					
65-69	5462 (19.5)	20.8	18.9	19.2	19.2
70-74	6640 (23.7)	23.9	24.0	23.2	23.9
75-79	6493 (23.2)	22.1	23.3	24.1	23.3
≥80	9391 (33.6)	33.2	33.8	33.6	33.7
Race					
White	23 679 (84.6)	80.3	83.6	86.1	88.4
Black	1991 (7.1)	7.1	7.2	5.5	8.6
Other	2316 (8.3)	12.6	9.2	8.4	3.0
AJCC stage					
I	5377 (19.2)	18.0	18.4	20.0	20.4
II	10 137 (36.2)	35.5	36.3	35.5	37.5
III	7150 (25.6)	24.8	26.3	25.0	26.1
IV	3886 (13.9)	13.9	13.6	14.4	13.6
Unstaged	1436 (5.1)	7.8	5.3	5.0	2.5
Romano-Charlson comorbidity					
0	18 261 (65.2)	64.8	64.8	65.5	65.9
1	6796 (24.3)	24.4	24.6	24.3	23.8
2	2929 (10.5)	10.8	10.6	10.2	10.3
Median census tract income quartile					
Highest	6783 (24.2)	18.8	20.4	28.1	29.6
Third	6795 (24.3)	20.8	23.5	24.5	28.3
Second	6800 (24.3)	22.7	28.1	24.2	22.1
Lowest	6802 (24.3)	33.5	24.5	20.6	18.8
Area not tracted	806 (2.9)	4.2	3.5	2.7	1.2
Obstruction or perforation					
No	25 447 (90.9)	89.9	90.2	91.2	92.4
Yes	2539 (9.1)	10.1	9.8	8.8	7.6
Emergent hospitalization					
No	22 478 (80.3)	82.6	82.7	81.3	74.8
Yes	5508 (19.7)	17.4	17.3	18.7	25.2
SEER registry					
California					
Los Angeles	4297 (15.4)	25.7	16.3	14.8	4.9
San Francisco-Oakland	2412 (8.6)	9.0	14.0	7.5	4.0
San Jose-Monterey	1328 (4.8)	3.1	3.4	6.5	6.0
Connecticut	4414 (15.8)	5.7	7.1	13.9	36.0
Atlanta, Ga	1476 (5.3)	4.6	7.8	3.3	5.4
Hawaii	687 (2.4)	3.9	2.2	3.8	0.0
Iowa	4280 (15.3)	23.5	12.0	14.0	12.0
Detroit, Mich	4486 (16.0)	6.8	12.2	16.6	28.3
New Mexico	885 (3.2)	6.4	4.3	2.0	0.0
Utah	993 (3.5)	5.1	7.1	2.1	0.0
Seattle, Wash	2728 (9.7)	6.5	13.6	15.5	3.4

*AJCC indicates American Joint Committee on Cancer; SEER, Surveillance, Epidemiology, and End Results.

†Expressed as patients unless otherwise indicated.

‡Hospital procedure volume is defined as the number of operations performed during the study period, 1991-1996. Low-volume hospitals performed 1 to 57 procedures; medium, 58 to 112; high, 113 to 165; and very high, 166 to 383.

quartile. We considered the possibility that regional differences in care might account for our results.³³ Although high-volume hospitals were more highly concentrated in some SEER regions (Connecticut and Detroit, Mich) than in others (Iowa and Los Angeles, Calif), stratification by registry did not change our results because there was minimal geographic variation in mortality rates.

Postoperative Chemotherapy

The pronounced association between volume and long-term survival for patients with stage III disease (Figure 2)

prompted us to examine patterns of postoperative chemotherapy use as a possible process measure that might account for this observation. Among the 6423 patients with stage III tumors who survived 3 months postoperatively and were enrolled in Medicare Part B, 3519 (54.8%) had at least 1 Medicare claim for chemotherapy within 3 months of surgery. Specifically, 51.2% of patients at low-volume; 56.6% at medium-volume; 55.6% at high-volume; and 55.5% at very high-volume hospitals received chemotherapy within 3 months of primary surgery. Although this trend

was marginally significant ($P = .02$; and $P = .07$ when adjusted for within-hospital correlation), when we added chemotherapy use to our Cox model for stage III, hospital procedure volume remained a significant predictor of survival in adjusted analyses.

COMMENT

Among a population-based cohort of Medicare beneficiaries with primary colon cancer, we found that hospital procedure volume predicts both short- and long-term survival following surgical resection. We failed to find any evidence

Table 2. Magnitude and Significance of the Association Between Hospital Procedure Volume and Mortality

Hospital Volume*	No. of Patients	30-Day Mortality		5-Year Mortality, %	Overall Survival		P Value§
		Mortality, %	P for Trend†		Risk Ratio (95% Confidence Interval)		
					Unadjusted	Adjusted‡	
All Stages							
Very high	7097	3.5]< .001	50.4	1.00	1.00]< .001
High	6947	4.4		51.5	1.07 (1.02-1.12)	1.10 (1.05-1.15)	
Medium	7105	5.0		53.6	1.12 (1.07-1.18)	1.13 (1.08-1.18)	
Low	6837	5.5		54.8	1.15 (1.10-1.21)	1.16 (1.11-1.21)	
Total	27 986	4.6		52.7			
Stage I							
Very high	1446	1.7]< .03	30.9	1.00	1.00]< .10
High	1392	2.2		29.0	0.98 (0.86-1.12)	1.02 (0.89-1.16)	
Medium	1308	2.7		32.7	1.09 (0.95-1.25)	1.15 (1.00-1.31)	
Low	1231	3.0		34.5	1.10 (0.96-1.26)	1.14 (0.99-1.30)	
Total	5377	2.3		31.7			
Stage II							
Very high	2658	3.3]< .001	40.5	1.00	1.00]< .001
High	2469	3.7		41.6	1.06 (0.97-1.16)	1.11 (1.02-1.21)	
Medium	2581	5.1		42.9	1.11 (1.02-1.21)	1.15 (1.06-1.25)	
Low	2429	5.0		44.1	1.14 (1.05-1.24)	1.18 (1.08-1.29)	
Total	10 137	4.3		42.2			
Stage III							
Very high	1850	2.8]< .005	56.0	1.00	1.00]< .001
High	1735	3.9		58.5	1.10 (1.01-1.20)	1.12 (1.02-1.22)	
Medium	1871	4.8		60.2	1.14 (1.05-1.24)	1.16 (1.06-1.26)	
Low	1694	4.9		62.5	1.20 (1.10-1.31)	1.23 (1.12-1.34)	
Total	7150	4.1		59.2			
Stage IV							
Very high	964	8.4]< .09	94.7	1.00	1.00]< .10
High	1001	9.6		95.4	1.08 (0.99-1.19)	1.12 (1.02-1.23)	
Medium	968	8.2		94.0	1.04 (0.95-1.14)	1.06 (0.96-1.16)	
Low	953	10.2		94.8	1.07 (0.98-1.17)	1.09 (0.99-1.20)	
Total	3886	9.1		94.7			

*Hospital procedure volume indicates the number of operations performed during the study period, 1991-1996. See Table 1 for exact numbers.
 †P values for trend were calculated using the Mantel-Haenszel test and adjusted for within-hospital correlation.
 ‡Adjusted for sex, age at diagnosis, race, clinical stage, comorbidity, median income, and presence of emergent indications for surgery according to the categories in Table 1.
 §P values were calculated using the likelihood ratio test.

Figure 1. Postoperative Overall Survival (N=27986) and Colon Cancer-Specific Survival (n=27561) According to Hospital Procedure Volume

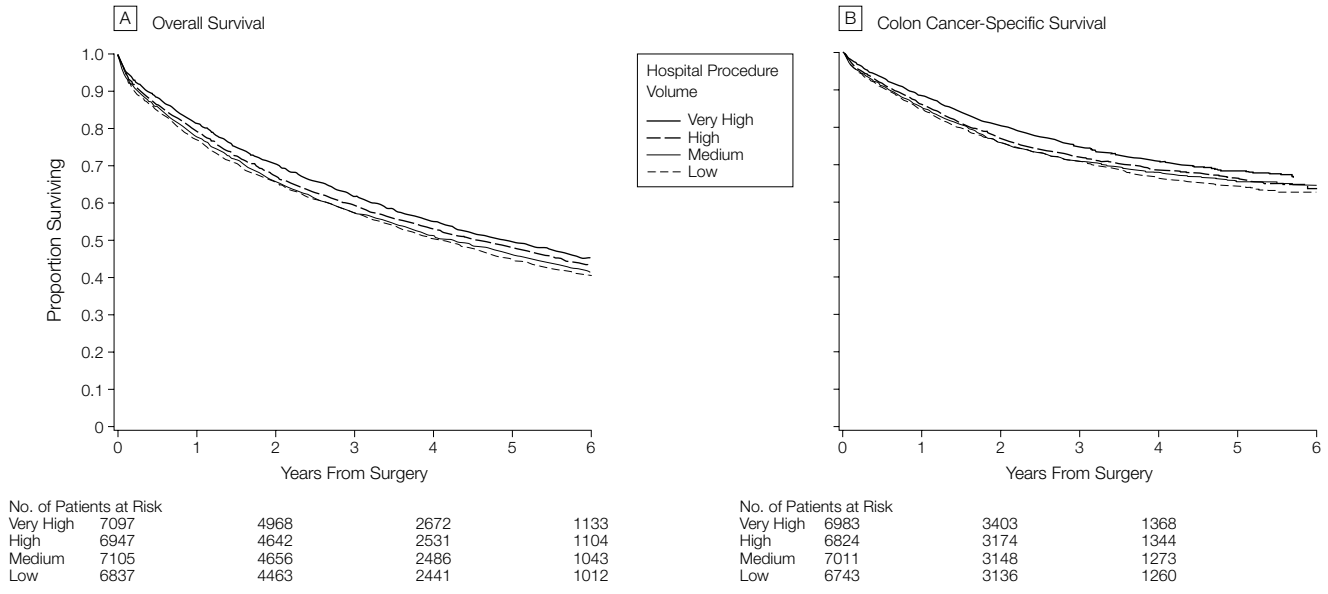


Figure 2. Postoperative Stage-Specific Survival According to Hospital Procedure Volume

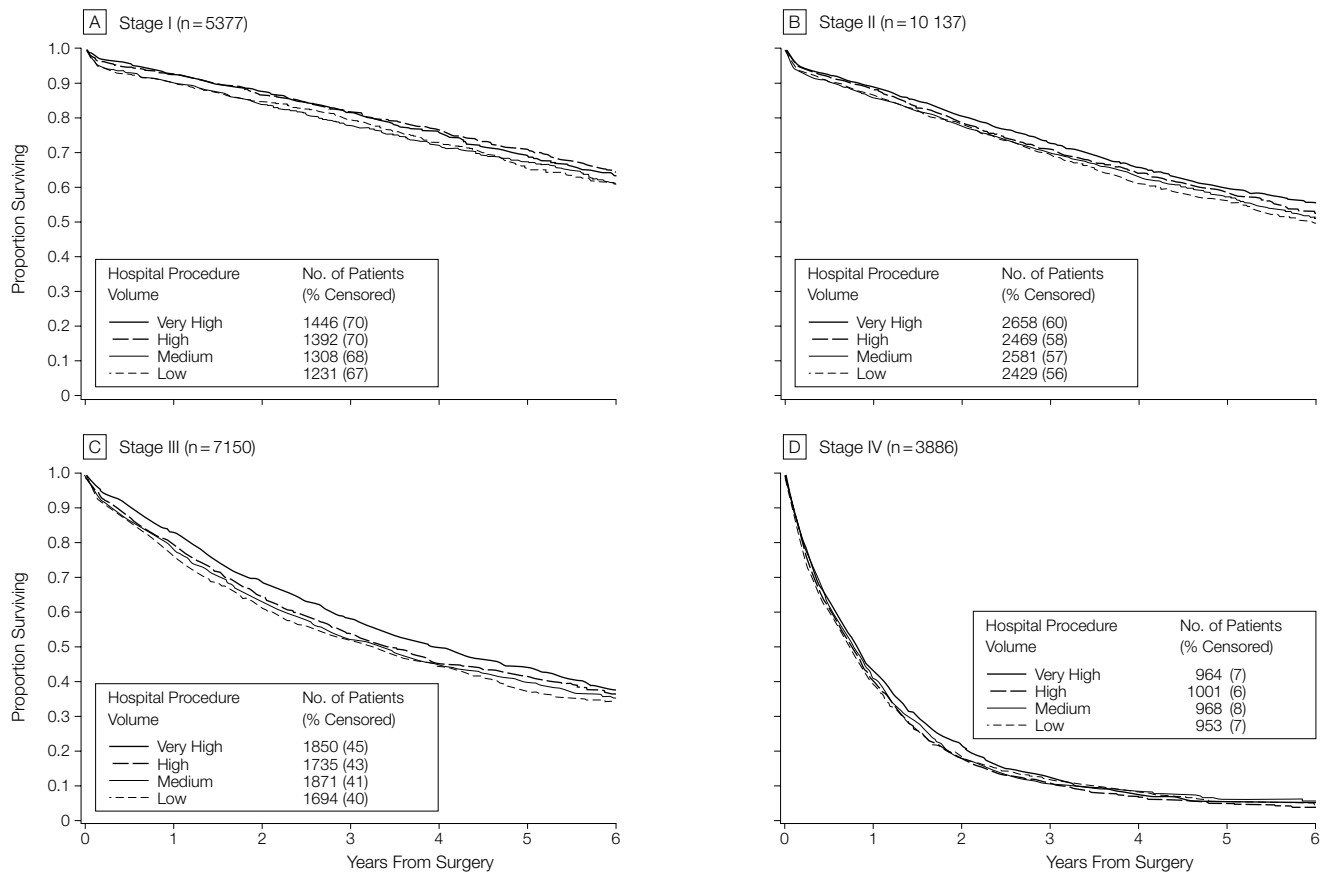


Table 3. Potential Consequences of Hypothetical Policies Mandating Colon Cancer Surgery at Hospitals With Minimum Volume Thresholds*

Procedure Volume Threshold†	No. (%)		Mean 30-Day Postoperative Mortality, %
	Patients Redirected to Another Hospital (N = 27 986)	Hospitals Discontinuing Colon Cancer Surgery (n = 611)	
No threshold	0 (0)	0 (0)	4.59
5	280 (1)	134 (22)	4.58
8	560 (2)	177 (29)	4.55
15	1400 (5)	263 (43)	4.44
24	2800 (10)	330 (54)	4.34
35	4200 (15)	379 (62)	4.22
58	7000 (25)	440 (72)	4.14
113	14 000 (50)	529 (87)	3.73
166	21 000 (75)	580 (95)	3.50

*These estimates illustrate the potential consequences for study cohort members if colon cancer surgery were to be performed at hospitals with various minimum volume thresholds based on patterns of care during 1991-1996. The analysis assumes a best-case scenario such that all rerouted patients have surgery at an institution in the top procedure volume quartile in which 30-day mortality is 3.5%.

†Volume thresholds based on 1991-1996 Surveillance, Epidemiology, and End Results (SEER)-Medicare case volume.

that underlying differences in the characteristics of patients accounted for our results. Although the association between postoperative mortality and hospital procedure volume is statistically significant, the absolute magnitude of the difference (2%) was more modest than the 7% to 15% differences observed for pancreatectomy and esophagectomy.¹⁸

Our results are consistent with those recently reported by Harmon et al,³ who analyzed the association between hospital volume and inhospital mortality for 9739 colorectal cancer patients treated at 50 hospitals in Maryland. In our cohort, the top 5% (31/611) of hospitals cared for 25% of patients; in their cohort, the top 12% (7/50) of hospitals cared for 32% of patients. Both studies show that in the United States, colon cancer surgery is currently performed at many hospitals with very low-case volumes, that there is a statistically significant correlation between high volume and favorable outcomes not attributable to differences in case mix, and that the order of magnitude of the absolute postoperative mortality difference is small (1.7%-2%).

Previous analyses demonstrating a relationship between hospital case volume and clinical outcomes have suggested that selected procedures should be regionalized and services restricted to centers performing a minimum num-

ber of cases.^{2,15} To illustrate the potential consequences of colon cancer surgery regionalization, we have calculated the number of hospitals that would have to discontinue colon cancer surgery and the number of patients who would need to be referred elsewhere if mandatory minimum volume thresholds were implemented (TABLE 3). Under the optimistic assumptions that rerouting patients to very high-volume hospitals would be feasible, cause no adverse consequences, and achieve surgical outcomes similar to those for patients in the top-volume quartile, our results show that regionalization would affect many institutions and require relocation of many patients to obtain modest, although appreciable, increments in survival. If our results are extrapolated to the approximately 70 000 colon cancer resections performed annually in the United States, in a best-case scenario, rerouting patients treated at hospitals in the low-volume quartile to the very high-volume quartile could potentially avert 350 postoperative deaths and a total of 770 deaths 5 years after colon cancer surgery. Whether regionalization of colon cancer surgery is warranted to achieve a benefit of this magnitude should be a matter of public policy debate.

In urban areas such as Detroit and Atlanta, Ga, hospitals with large caseloads are located in proximity to low-volume

centers, but in areas such as Iowa and Utah, regionalization policies mandating care in high-volume institutions could require patients to travel long distances. As a result, the efficacy and expense of alternatives to regionalization, such as continuing education for surgical care teams at hospitals with low-case volumes, merit further study. In addition, we concur with Hillner et al² who recently emphasized that identification of the mechanisms underlying variation in outcomes should facilitate initiatives tailored to address specific shortcomings and is therefore a research priority.

Several concerns regarding our analysis must be noted. First, the potential for inaccurate coding exists for any claims-based analysis.³⁴⁻³⁶ However, the lack of ambiguity regarding the colon cancer diagnoses coupled with the fact that complete coding for major surgical procedures favorably affects hospital and physician reimbursement suggests that the claims-based approach we used should be more accurate than it may be for other conditions. Second, we determined surgical volume based only on the number of operations performed in the Medicare population. However, this method has been validated and Medicare case volume appears highly correlated with total volume.¹⁸

Although the SEER cohort is population-based, generalizability of our analysis may be limited by the restriction of our study cohort to the subset of Medicare-eligible patients older than 65 years who were not enrolled in a health maintenance organization at diagnosis.³⁷ Nevertheless, because the median age of colon cancer diagnosis is 71 years,²⁸ and less than 20% of patients were health maintenance organization enrollees, our cohort is representative of a substantial proportion of patients in the United States.

Why do high-volume hospitals achieve superior outcomes? Our analysis suggests that the answer is not attributable to differences in patient characteristics. The 30-day mortality differences suggest that either intraoperative and/or immediate postoperative care vary with

institutional caseload. In part, the effect may result from the skill of the individual surgeon.³⁸ However, other analyses have shown that hospital volume is a stronger determinant of outcomes than individual surgeon volume suggesting that access to an entire team of health care professionals (surgeons, anesthesiologists, nurses, radiologists) is important.³ It is unlikely that the association between hospital volume and both overall and colon cancer-specific survival is attributable to a single mechanism. Conceivably, surgeons at high-volume hospitals perform more meticulous dissections. Evidence that local recurrences were more common at low-volume hospitals would lend support to the interpretation that surgical expertise is the primary determinant of outcome, but this detail was not available from medical claims. Patients at high-volume hospitals may undergo more careful postop-

erative surveillance or receive more intensive subsequent treatment. However, no strong association between adjuvant chemotherapy treatment and hospital procedure volume was evident. Our claims-based approach did not permit us to examine cumulative dose or dose intensity of chemotherapy, and such differences might account for at least a small proportion of the volume-outcome effect.

Caution is warranted in interpreting our results and indeed those of all volume-outcome studies.^{16,39,40} Our analysis cannot demonstrate the direction of any causal relationship between volume and outcome. While we presume that high volumes contribute to good outcomes it is also plausible that good outcomes lead to high volumes. We emphasize that the implication of our analysis is not that colon cancer surgery should be limited to high-volume institutions. Rather, we intend that it provoke in-

depth scrutiny of the processes of care at high-volume institutions that determine their success and those at low-volume institutions that may account for their relative shortcomings. Our results underscore the need for further research to identify those specific features and processes of care that underlie the volume-outcome relationship. This insight should help policymakers and should enable hospitals to design and implement strategies to improve the quality of care.

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