James A. Baker III Institute for Public Policy
Rice University

Trends in Hospital and Surgeon Volume and Operative Mortality for Cancer Surgery

by

Vivian Ho, Ph.D.
Baker Institute, Rice University
and Department of Medicine, Baylor College of Medicine
Houston, TX

Martin J. Heslin, M.D.
Department of Surgery
The University of Alabama at Birmingham
Birmingham, AL

Huifeng Yun, M.Sc.
and
Lee Howard
Department of Health Care Organization and Policy
The University of Alabama at Birmingham
Birmingham, AL

November 2005

The original publication is available at www.springerlink.com.

DOI: 10.1245/ASO.2006.07.021
Annals of Surgical Oncology 13:851-858 (2006)

Trends in Hospital and Surgeon Volume and Operative Mortality for Cancer Surgery

by

Vivian Ho, PhD
Baker Institute, Rice University
and Department of Medicine, Baylor College of Medicine
Houston, TX

Martin J. Heslin, M.D.
Department of Surgery
The University of Alabama at Birmingham
Birmingham, AL

Huifeng Yun, MSc
and
Lee Howard
Department of Health Care Organization and Policy
The University of Alabama at Birmingham
Birmingham, AL

Please address correspondence to:

Vivian Ho
Rice University
Department of Economics - MS 22
6100 Main St.
Houston, TX 77005
Phone: (713) 348-2195
Fax: (713) 348-5278
vho@rice.edu

November, 2005

This manuscript is the original work of the authors, and the views expressed are solely of the authors.

Running head: Provider volume and operative mortality
Keywords: neoplasms, surgery, mortality, provider volume, outcomes assessment,

ABSTRACT

Background: We measure 13-year trends in operative mortality for six cancer resections. We then examine whether these trends are driven by changes in hospital and surgeon volume, or by changes that occurred among all providers, regardless of volume.

Methods: We analyzed administrative discharge data on patients who received one of six cancer resections in Florida, New Jersey, and New York for three time periods: 1988 to 1991, 1992 to 1996, and 1997 to 2000. Descriptive statistics and nested regression models were used to test for changes in the association between inpatient mortality and annual hospital and annual surgeon volume over time, adjusting for patient and hospital characteristics.

Results: Unadjusted inpatient mortality rates for the six cancer resections declined between 0.8 and 4.0 percentage points between the time period 1988 to 1991 and 1997 to 2000. Over this time period, annual hospital and surgeon volume for the six cancer operations rose an average of 24.3% and 24.2% respectively. The logistic regressions indicated a relatively stable relationship over time between both increased hospital and surgeon volume and lower inpatient mortality. Simulations suggest that increases in hospital and surgeon procedure volume over time led to a reduction in inpatient mortality ranging from .1 percentage points for rectal cancer to 2.3 percentage points for pneumonectomy.

Conclusion: Persistence of the volume-outcome relation and rising hospital and surgeon volumes explain much of the decline over time in inpatient mortality for five of the six cancer operations studied. Concentrating cancer resections among high-volume providers should lead to further reduced inpatient mortality.

SYNOPSIS

We measure 13-year trends in operative mortality for cancer resections in three U.S. states. Persistence of the volume-outcome relation and rising hospital and surgeon volumes largely explain the decline in inpatient mortality for five of the six cancer operations studied.

INTRODUCTION

Several federal and non-government organizations collaborate to provide information on trends in cancer mortality. These reports indicate that overall cancer death rates declined by 1.1% per year from 1993 to 2001 [1]. Declines in operative mortality have been associated with improvements in long-term survival in past studies [2, 3]. However, we lack a comparable report on long-term trends in operative mortality for cancer patients. This study measures population-based trends in operative mortality over a 13-year period for six cancer resections.

We also know little about what factors determine trends in operative mortality. Some studies associate increased experience or increased provider volume over time with reduced mortality [4-6]. However, these studies were focused on only one operation, and some were based on samples of a limited number of surgeons or hospitals. In contrast, this study analyzes data on six cancer operations with an extensive sample of surgeons and hospitals to determine whether increases in provider volume can explain trends in operative mortality.

METHODS

We first combine data from three large U.S. states on six cancer resections to examine long-term trends in operative mortality, and annual hospital and surgeon volume. We then estimate logistic regressions to test whether the association between provider volume and inpatient mortality has remained stable over time. The regression estimates are then used to simulate mortality reductions associated with provider volume increases, holding patient characteristics constant. These simulations allow one to compare mortality reductions solely attributable to volume, versus total changes in mortality that occurred over time.

Patient data were obtained from statewide hospital discharge abstract files for Florida, New Jersey, and New York for the years 1988 to 2000. Following past studies,[6-10] we used ICD-9-CM procedure codes to identify all patients who underwent resection for colorectal cancer (45.7x, 45.8, 48.4x, 48.5, 48.6x), pulmonary lobectomy (32.4), pneumonectomy (32.5), esophagectomy (42.40, 42.41, 42.42, or 43.99), and pancreaticuduodenectomy (the Whipple procedure) (52.7). Colorectal cancer patients were further identified and subdivided by ICD-9-CM diagnosis codes: colon cancer (153.0-153.9), and cancer of the rectum (154.0-154.1). For lobectomy, pneumonectomy, and esophagectomy, we also excluded patients who did not have a cancer diagnosis code related to the procedure which was performed.[11]

Outcomes and Provider Volume

The outcome variable of interest was inpatient mortality. The explanatory variables of interest were hospital procedure volume and surgeon procedure volume. For each hospital, the number of times each specific surgery was performed was calculated for each year. Only one occurrence of each procedure was counted for each admission.

We identified the operating surgeon for each procedure based on unique physician state license numbers which were provided in each state database. Records containing missing physician license numbers were excluded from the analysis. To check for the effects of possible miscoding, we matched information from state department of health websites, the *ABMS Medical Specialists Plus* directory, and the American Medical Association Physician file to identify license numbers which were associated with a surgery specialty (e.g. general surgery, abdominal surgery, etc.). The percentage of patients with an operating surgeon whose specialty was unrelated to surgery or unidentifiable ranged from a low of 8.1% for Whipple patients, to 12.1% for patients who underwent pneumonectomy. The results we report include these patients. Excluding these patients from the analyses lowered the precision of some of the volume estimates, but the main conclusions of the study remained the same.

Statistical Analysis

The relation between provider volume and inpatient mortality was analyzed over three time periods: 1988 to 1991, 1992 to 1996, and 1997 to 2000. A logistic regression model was used to examine the relation between provider volume and mortality, adjusting for potential confounders. The unit of analysis was the patient, with annual volume measured at the level of the hospital and the operating surgeon. Following previous studies of the volume-outcome relation, the logarithms of hospital and surgeon volume were used as the explanatory variables of interest in the regressions.[12-14] Both prior studies and this analysis show that log(volume) appears to be linearly associated with the logit of in-hospital mortality rates.

Indicator variables for the time periods 1992 to 1996 and 1997 to 2000 were included in the regression to compare mortality rates in these time periods relative 1988 to 1991. We estimated preliminary specifications including interaction terms between each of the time period indicator variables with both hospital and surgeon volume. These interaction terms capture potential differences in the slope of the volume-outcome relation, which may have changed over time. To avoid potential problems with multicollinearity if the volume-outcome relation did not shift across time periods, interaction terms which had a p-value greater than 0.20 in the preliminary specifications were dropped from the final regressions.[15]

The logistic regressions were estimated using multilevel generalized linear modeling to adjust for the clustering of patients within surgeons and the clustering of surgeons within hospitals.[16] Surgeons who performed the same procedure in more than one hospital were modeled as contributing a separate random effect in each hospital where they treated patients.[17] All estimation was performed with Stata 8.[18] The GLLAMM command was used to conduct the multilevel modeling.[19]

The logistic regressions adjusted for patient and hospital characteristics. Patient characteristics used as independent variables included age (<60, 60-69, 70-79, 80+), gender, race (white, black, other), urgent or emergency admission, health insurance (Medicare, Medicaid, private, or other/none), state of residence, cancer stage, and the component variables of the Charlson comorbidity index.[20] Cancer stage was defined using ICD-9-CM diagnosis codes (nodal involvement=196.x, metastasis=197.x-198.x).

Length of stay was also included as an explanatory variable to control for potential censoring of inpatient mortality for patients with shorter lengths of stay.[21] In addition, we defined indicator variables to distinguish between specific operations and surgery sites that were specific to each procedure. These variables were included to adjust for disease-specific differences in the difficulty of each procedure and patient casemix. For example, the logistic regression for esophagectomy patients includes indicator variables for patients who underwent gastrectomy or total esophagectomy, versus a partial esophagectomy; as well as indicator variables for whether the reported location of the tumor was distal, middle, upper, or other. Procedure and tumor locations were defined based on previous studies of these operations which used ICD-9-CM procedure and diagnosis codes.[2, 6, 8-10] An indicator variable was also included to identify patients treated in a hospital which was a member of the Council of Teaching Hospitals as indicated by the American Hospital Association Annual Survey for each year.

For many cancer procedures, patients undergoing surgery at NCI-designated cancer centers have had lower surgical mortality rates than those treated at comparable high-volume hospitals.[22] Because we had data from only three comprehensive cancer centers in our sample period, we did not include cancer center status as a control variable.

The regression estimates were used to assess the relationship between changes in procedure volume and changes in inpatient mortality that occurred over the sample period, holding patient characteristics constant. We first used the estimates to predict inpatient mortality for all patients treated from 1988 to 1991, assuming that they underwent surgery in a hospital or under a surgeon with the mean procedure volume for that period. We then predicted inpatient mortality for these same patients, assuming that the hospital volume or surgeon volume were instead the mean values for these procedures in 1997 to 2000. We simulated the effects of changes in hospital or surgeon volume only in those cases where the odds ratio for provider volume was statistically significant. In cases where interaction terms indicated a change in the volume-outcome relation over time, these changes were also incorporated into the predictions. These predicted changes in adjusted mortality were then compared to the unadjusted differences in inpatient mortality for each procedure observed in these two time periods.

RESULTS

A total of 344,617 patients in Florida, New Jersey, and New York underwent one of the six cancer operations between 1988 and 2000. Because Florida did not record surgeon identifiers until 1992, 39,683 Floridians between 1988 and 1991 were excluded from the descriptive statistics and regressions. Table 1 reveals drops in unadjusted inpatient death rates for each of the six cancer resections over the sample period. Pulmonary lobectomy patients experienced the smallest decline in inpatient mortality (0.8 percentage points) between 1988 to 1991 and 1997 to 2000 (from 4.1 to 3.3 percent). The largest decline in inpatient mortality (4.0 percentage points), occurred for esophagectomy patients, where mortality fell from 14.5 to 10.5 percent over the sample period.

Both annual hospital and surgeon procedure volume rose for most of the six cancer operations between 1988 to 1991 and 1997 to 2000. Pulmonary lobectomy experienced the largest increases in both hospital and surgeon volumes in both absolute and percentage terms. Between 1988 to 1991 and 1997 to 2000, mean hospital volume rose from 7.6 to 12.1 procedures per year (59.2%), and mean surgeon volume rose from 4.4 to 6.4 procedures per year (45.5%). For all six resections, the mean percentage increase in hospital and surgeon volume between 1988 to 1991 and 1997 to 2000 was 24.3% and 24.2% respectively.

The percentage of patients ages 75 and over who underwent surgery increased over the sample period between 1.1 (for esophagectomy) and 8.8 (for pulmonary lobectomy) percentage points. However, the percentage of patients receiving nonelective surgery declined between 1.9 (for colon cancer resections) and 13.4 (for Whipple procedures) percentage points for the six operations. In addition, there was no systematic pattern to changes in the Charlson comorbidity index across the six resections. Therefore, patient casemix severity did not appear to rise or fall systematically over the sample period.

Table 2 presents adjusted odds ratios for inpatient mortality. Odds ratios for the time periods 1992 to 1996 and 1997 to 2000 (relative to 1988 to 1991) represent time-specific differences in mortality for all patients, regardless of hospital and surgeon volume. Table 2 also lists adjusted odds ratios for inpatient mortality by hospital and procedure volume, as well as interactions between provider volume and time period when appropriate.

The odds ratios indicate some reduction in adjusted inpatient mortality rates over time for colorectal cancer patients who underwent surgery. Relative to the initial time period 1988 to 1991, colon cancer resection mortality rates were lower in 1992 to 1996 (OR=0.87 p<0.001); and rectal cancer resection rates were lower in both 1992 to 1996 (OR=0.80, p=0.001) and 1997 to 2000 (OR=0.83, p=0.012). However, for the four other cancer procedures, there was no evidence of a decline over time in inpatient mortality rates that was independent from procedure volume.

Although the odds ratios for the association between hospital volume and inpatient mortality were less than 1.00 for each of the six resections, the point estimates were non-significant for pneumonectomy and esophagectomy. For the remaining procedures, the odds ratios for the association between increased hospital volume and reduced inpatient mortality ranged from 0.85 for the Whipple procedure (p=0.017) to 0.94 for resection for colon cancer (p=0.010). Preliminary specifications indicated that none of the interactions between hospital volume and the time period dummy variables had a p-value less than 0.20. Therefore, for these six cancer operations, the relationship between hospital volume and inpatient mortality remained stable over the 13-year time period.

The relationship between increased surgeon volume and reduced inpatient mortality was precisely estimated in at least one time period for each of the six cancer procedures. The statistically significant odds ratios ranged from 0.67 (p=0.004) for patients who underwent pneumonectomy in 1997 to 2000, to 0.94 (p=0.040) for patients who underwent resection for colon cancer in 1997 to 2000. For rectal cancer resection, pulmonary lobectomy, esophagectomy, and the Whipple procedure, the association between increased surgeon volume and reduced inpatient mortality remained stable throughout the 13-year period. The odds ratios for interactions between surgeon volume and time period for the remaining two procedures tended to decline in magnitude in later time periods. This result suggests that each additional procedure performed in later time periods was associated with an even larger reduction in inpatient mortality for colon cancer resection and pneumonectomy.

Table 3 presents predictions that allow one to assess the magnitude of the decline in inpatient mortality over the sample period which is due to increases in hospital and surgeon volume. The predictions are based on mean procedure volumes in 1988 to 1991 versus 1997 to 2000, holding patient characteristics constant at their 1988 to 1991 levels. The effects of increases in hospital and/or surgeon volume were only included in these predictions if they were statistically significant in the adjusted mortality regressions reported in Table 2. In most cases the predicted inpatient mortality rates based on mean procedure volumes in 1988 to 1991 are slightly lower than the actual death rates for this time period. The very high procedure volumes of a few hospitals and surgeons can skew these volume distributions to the right, so that simulations based on mean volumes will underestimate mortality relative to the actual distribution of patients among hospitals of various sizes. Nevertheless, simulations based on changes in mean provider volumes provide a useful gauge of the potential impact of rising provider volumes on lower in-hospital death rates.

For each surgery, the increases in hospital and/or surgeon volume between 1988 to 1991 and 1997 to 2000 are predicted to reduce inpatient mortality. The predicted declines in inpatient mortality range from a low of 0.1 percentage points for rectal cancer resection to a high of 2.3 percentage points for pneumonectomy. In percentage terms, the smallest predicted decrease in mortality is for rectal cancer resection (2.6%), and the largest percentage drop is for pulmonary lobectomy (23.8%). The mean percentage drop in predicted death rates across all operations is 12.3%.

For pulmonary lobectomy, which experienced the largest increases in hospital and surgeon volume over time, the drop in predicted mortality is equivalent to the observed fall in mortality which occurred over the sample period. The result suggests that increases in provider volume were primarily responsible for the observed reduction in mortality for pulmonary lobectomy. For the remaining cases, the predicted decrease in inpatient mortality associated with observed increases in provider volume over the sample period is smaller than the actual decline in inpatient mortality. However, as noted in Table 1, casemix for each of the six resections has also changed over time. Therefore, changes in casemix or other changes in provider characteristics are likely to explain the remaining observed declines in mortality rates.

The particularly small predicted decline in death rates for rectal cancer resection is noticeable, given that the observed death rate fell 1.5 percentage points over the sample period. Recall from Table 2 that this is the one procedure for which inpatient mortality declined for all patients, regardless of hospital or procedure volume. For this procedure, provider volume played a relatively small role in explaining mortality declines over time.

For pneumonectomy, the absolute value of the decline in predicted mortality is larger than the actual fall, even though average surgeon volume did not increase during the sample period. The regression results revealed that the association between surgeon volume and mortality increased in magnitude over time. Therefore, even though surgeon volume did not rise for pneumonectomy during the sample period, the beneficial effect of higher surgeon volume increased so much, that it led to a noticeable drop in inpatient death rates. The fact that the predicted drop exceeds the actual drop in mortality for pneumonectomy is attributable to a highly skewed distribution of procedure volumes among hospitals, which leads to relatively high mean provider volumes for the simulations.

DISCUSSION

A previous study by Goodney et al concluded that there were no significant changes in operative mortality between 1994 and 1999 for seven of eight cancer procedures that were examined [23]. However, this past study spanned only six years, and patient characteristics and hospital volume were available only for the Medicare population. In contrast, we analyze data on patients of all ages treated over a longer time period (1988 to 2000). Although we lack data from most states, the states of Florida, New Jersey, and New York comprise 15% of the U.S. population.

While Goodney et al found that unadjusted mortality rates rose for colectomy and pulmonary lobectomy between 1994 and 1999, we observed declining operative mortality for all six cancer resections. Moreover, the decline is evident in our data between 1992-1996 and 1997-2000, a time span comparable to the Goodney et al study. Further, our analysis suggests that this decline is in part attributable to a persistent volume-outcome relation and a rise in procedure volume for both hospitals and surgeons over the study period. Simulations based on characteristics of patients treated between 1988 and 1991 suggest that increases in hospital and/or surgeon volume over the sample period led to reductions in inpatient mortality ranging between 2.6% and 23.8% for the six cancer operations. Thus, rises in procedure volume are contributing to safer surgery over time.

Contrary to Goodney et al, we also found that risk-adjusted inpatient death rates for resection for rectal cancer were lower in 1992 to 2000 than in 1988 to 1991 for all patients regardless of hospital and surgeon volume. In addition, inpatient mortality for patients who underwent resection for colon cancer was lower in 1992 to 1996 versus 1988 to 1991, although this mortality reduction did not persist through the end of the sample period. Resections for colon and rectal cancer were by the far the most common procedures of the six operations we studied, with 175,202 and 58,568 admissions in our sample respectively. The greater frequency of these procedures may have led to "knowledge spillovers" or systemwide learning effects that benefited all providers regardless of their size. Reductions in inpatient mortality over time for hospitals of all sizes has been identified for angioplasty [21], another frequently performed procedure, but was not identified for the less common cancer resections in this study.

Our analysis faced some significant limitations. Linking of physician license numbers to AMA and *ABMS* data revealed that 10.4% of the patients in our sample were treated by operating physicians who did not report surgery as a specialty. We were reluctant to exclude these patients from our sample, because some non-surgeon specialists may in fact have performed these procedures. For example, we could not rule out the possibility that a gynecologist oncologist might occasionally perform a colectomy, or a physician who performed a partial excision of the large intestine also listed their primary specialty as gastroenterology. However, we repeated our analysis excluding those patients with operating physicians that did not list surgery as a primary specialty. The results remained virtually the same, although the precision of the estimates dropped slightly in some cases.

We did not control for thoracic surgeon specialty, which has been associated with lower operative mortality for lung resection in past research.[24] Preliminary regressions revealed an association between thoracic surgery specialty and lower operative mortality for lobectomy and pneumonectomy. However, we lacked sufficient sample size to estimate a precise effect. Nevertheless, even with inclusion of an indicator variable for thoracic surgeons, the coefficients on provider volume, the time period effects, and the interaction terms remained virtually unchanged.

Our analysis focused on inpatient mortality as the outcome of interest. This variable may lead to biased measures of the volume-outcome relationship if, for example, high-volume hospitals discharge patients at high risk of death sooner than low-volume hospitals. To adjust for this potential confounding effect, we included length of stay as a regressor in our multivariate regressions. In addition, past studies using 30-day mortality to study outcomes for these cancer operations confirmed the presence of a volume-outcome effect.[7, 17, 23, 25]

The hospital discharge abstract data examined in this study lack complete information on all clinical characteristics that determine inpatient mortality for these six cancer resections. Nevertheless, past analyses using more detailed clinical data from the SEER-Medicare databases also confirmed the presence of a significant hospital volume-outcome effect for several of these procedures.[7, 25] In addition, there is little evidence from more detailed clinical studies that the volume-outcome relationship is driven by systematic differences in casemix by provider size.[17]

Past studies have shown that at any given point in time, higher volume hospitals have lower inpatient mortality rates than lower volume hospitals. However, this is the first study to document increases in procedure volume over time for six cancer resections. Further, we demonstrate that these volume increases played a significant role in explaining observed declines in operative mortality over time. These findings provide strong support for efforts to regionalize provision of these cancer operations. The Leapfrog Group, a coalition of large employers and other health care purchasers, is aiming to direct their employees to high-volume providers. The organization recommends that patients needing cancer surgery should look for hospitals that perform 11 or more pancreatic resections and 13 or more esophagectomies per year.[26] In our sample for the year 2000, only 8 percent of hospitals performing the Whipple procedure and 5 percent of hospitals performing esophagectomies met these criteria. Therefore, efforts to encourage patients to follow the Leapfrog criteria when choosing a hospital should lead to further significant reductions in cancer surgery mortality.

Others suggest that further reductions in inpatient mortality could be achieved by encouraging administrators and leaders in the field of surgery to actively manage the distribution of cancer resections within hospitals to achieve higher surgeon volumes.[17] In addition, several states report procedure volume for the Whipple procedure and other operations on their websites and advise readers that volume is one potential indicator of quality. Insurers are also introducing tiered pricing for hospitals into their insurance plans, a mechanism which may be used to direct patients towards high-volume hospitals in the future.[27]

However, all of these efforts to regionalize operations leave the final choice of hospital and surgeon to the patient and referring physician, which still allow the possibility for some patients to be treated at low volume hospitals. Many states enforce Certificate of Need regulations for open heart surgery and transplant surgery.[28] These rules forbid hospitals from providing these services unless they demonstrate to the state that there is sufficient need in the patient population to meet minimum volume standards. To date, no such rules have been proposed for cancer surgery. Given the magnitude and persistence of the volume-outcome relation for the surgical procedures reviewed in this study, perhaps the application of state CON rules or other mandatory regionalization policies should be considered.

ACKNOWLEDGEMENTS:

This research was supported by grant RSGHP-03-076-01-PBP from the American Cancer Society.

Table 1. Patient Characteristics, According to Time Period

	Time Period		
	1988-1991	1992-1996	1997-2000
In-hospital death (%)			
Resection for colon cancer (n = 175,205)	5.1	4.0	3.6
Resection for rectal cancer (n = 58,568)	3.8	2.7	2.3
Pulmonary Lobectomy (n = 44,509)	4.1	3.6	3.3
Pneumonectomy (n = 8,376)	10.2	10.0	8.4
Esophagectomy (n = 10,023)	14.5	11.7	10.5
Whipple (n = 8,253)	11.4	10.0	8.3
Annual Hospital Volume			
Resection for colon cancer	28.9	30.0	32.2
Resection for rectal cancer	11.1	10.5	11.0
Pulmonary Lobectomy	7.6	10.4	12.1
Pneumonectomy	3.0	3.2	3.1
Esophagectomy	3.2	3.5	3.8
Whipple	2.6	3.1	4.0
Annual Surgeon Volume			
Resection for colon cancer	4.1	4.7	5.4
Resection for rectal cancer	2.5	2.6	2.9
Pulmonary Lobectomy	4.4	5.5	6.4
Pneumonectomy	2.2	2.2	2.1
Esophagectomy	1.8	1.9	2.1
Whipple	1.5	1.7	2.1
Age > 75 years (%)			
Resection for colon cancer	37.7	40.4	41.3
Resection for rectal cancer	26.9	28.7	29.8
Pulmonary Lobectomy	11.9	16.3	20.7
Pneumonectomy	6.3	8.5	11.8
Esophagectomy	15.1	16.5	16.2
Whipple	13.5	16.2	19.3
Charlson >= 3 (%)			
Resection for colon cancer	41.5	42.9	42.1
Resection for rectal cancer	37.6	38.2	37.9
Pulmonary Lobectomy	31.6	32.0	30.5
Pneumonectomy	57.1	58.5	54.9
Esophagectomy	55.8	53.0	49.1
Whipple	47.1	48.3	48.6
Nonelective Admission (%)			
Resection for colon cancer	43.0	45.4	41.1
Resection for rectal cancer	27.7	29.7	23.9
Pulmonary Lobectomy	15.4	17.2	13.1
Pneumonectomy	21.9	23.3	16.6
Esophagectomy	27.8	25.3	17.4
Whipple	45.9	42.6	32.5

Table 2. Adjusted Odds Ratio for Inpatient Mortality, According to Time Period, Hospital Volume, and Surgeon Volume.

	Adjusted OR	95% CI
Resection for colon cancer (n = 175,205)		
1992-1996	0.87	0.82 - 0.94
1997-2000	1.04	0.91 - 1.19
Hospital Volume, ln	0.94	0.90 - 0.99
Surgeon Volume, ln		
1988-1996	0.90	0.87 - 0.94
1997-2000	0.94	0.88 - 1.00
Resection for rectal cancer (n = 58,568)		
1992-1996	0.80	0.70 - 0.91
1997-2000	0.83	0.72 - 0.96
Hospital Volume, ln	0.92	0.85 - 1.00
Surgeon Volume, ln	0.87	0.81 - 0.93
Pulmonary Lobectomy (n = 44,509)		
1992-1996	0.96	0.82 - 1.13
1997-2000	1.32	1.01 - 1.73
Hospital Volume, ln	0.91	0.85 - 0.98
Surgeon Volume, ln		
1988-1996	0.93	0.86 - 1.00
1997-2000	0.88	0.79 - 0.97
Pneumonectomy (n = 8,376)		
1992-1996	1.16	0.84 - 1.61
1997-2000	1.08	0.75 - 1.54
Hospital Volume, ln	0.95	0.84 - 1.08
Surgeon Volume, ln		
1988-1991	1.09	0.88 - 1.34
1992-1996	0.73	0.58 - 0.93
1997-2000	0.67	0.51 - 0.87
Esophagectomy (n = 10,023)		
1992-1996	0.89	0.74 - 1.06
1997-2000	0.90	0.74 - 1.10
Hospital Volume, ln	0.93	0.84 - 1.04
Surgeon Volume, ln	0.80	0.71 - 0.90
Whipple (n = 8,253)		
1992-1996	0.97	0.76 - 1.23
1997-2000	0.91	0.71 - 1.17
Hospital Volume, ln	0.85	0.74 - 0.97
Surgeon Volume, ln	0.80	0.69 - 0.92

Table 3. Actual and Predicted[a] Inpatient Mortality Associated with Increases in Provider Volume that Occurred Between 1988 and 2000, Holding Patient Characteristics Constant

	Time Period	
	1988-1991	**1997-2000**
Resection for colon cancer		
Annual Hospital Volume	28.9	32.2
Annual Surgeon Volume	4.1	5.4
Actual in-hospital death (%)	5.1	3.6
Predicted in-hospital death (%)	5.0	4.5
Resection for rectal cancer		
Annual Hospital Volume	11.1	11
Annual Surgeon Volume	2.5	2.9
Actual in-hospital death (%)	3.8	2.3
Predicted in-hospital death (%)	3.8	3.7
Pulmonary Lobectomy		
Annual Hospital Volume	7.6	12.1
Annual Surgeon Volume	4.4	6.4
Actual in-hospital death (%)	4.1	3.3
Predicted in-hospital death (%)	4.2	3.2
Pneumonectomy		
Annual Hospital Volume	N.A	N.A
Annual Surgeon Volume	2.2	2.1
Actual in-hospital death (%)	10.2	8.4
Predicted in-hospital death (%)	9.7	7.4
Esophagectomy		
Annual Hospital Volume	N.A	N.A
Annual Surgeon Volume	1.8	2.1
Actual in-hospital death (%)	14.5	10.5
Predicted in-hospital death (%)	13.9	13.5
Whipple		
Annual Hospital Volume	2.6	4
Annual Surgeon Volume	1.5	2.1
Actual in-hospital death (%)	11.4	8.3
Predicted in-hospital death (%)	11.1	9.9

[a]Predictions are based on logistic regression results in Table 2, 1988-1991 patient characteristics, and mean procedure volumes in 1988-1991 and 1997-2000.

Reference List

1. Jemal A, Clegg LX, Ward E et al. Annual report to the nation on the status of cancer, 1975-2001, with a special feature regarding survival. Cancer 2004; 101(1):3-27.

2. Birkmeyer JD, Warshaw AL, Finlayson SRG, Grove MR, Tosteson ANA. Relationship between hospital volume and late survival after pancreaticoduodenectomy. Surgery 1999; 126(2):178-183.

3. Mitry E., Bouvier A.M., Esteve J., Faivre J. Benefit of operative mortality reduction on colorectal cancer survival. Br J Surg 2002; 89(12):1557-1562.

4. Sutton DN, Wayman J, Griffin SM. Learning curve for oesophageal cancer surgery. Br J Surg 1999; 85(10):1399-1402.

5. Ho V, Heslin MJ. Effect of hospital volume and experience on in-hospital mortality for pancreaticuduodenectomy. Annals of Surgery 2002; 237(4):509-514.

6. Birkmeyer JD, Finlayson SRG, Tosteson ANA, Sharp SM, Warshaw AL, Fisher ES. Effect of hospital volume on in-hospital mortality with pancreaticoduodenectomy. Surgery 1999; 125(3):250-256.

7. Begg CB, Cramer LD, Hoskins WJ, Brennan MF. Impact of hospital volume on operative mortality for major cancer surgery. JAMA 1998; 280(20):1747-1751.

8. Harmon JW, Tang DG, Gordon TA et al. Hospital volume can serve as a surrogate for surgeon volume for achieving excellent outcomes in colorectal resection. Annals of Surgery 1999; 230(3):404-413.

9. Patti MG, Corvera CU, Glasgow RE, Way LW. A hospital's annual rate of esophagectomy influences the operative mortality rate. Journal of Gastrointestinal Surgery 1998; 2(2):186-192.

10. Romano PS, Mark DH. Patient and hospital characteristics related to in-hospital mortality after lung cancer resection. Chest 1992; 101(5):1332-1337.

11. Finlayson EVA, Birkmeyer JD. Operative mortality with elective surgery in older adults. Eff Clin Pract 2001; 4(4):172-177.

12. Ho V. Evolution of the volume-outcome relation for hospitals performing coronary angioplasty. Circulation 2000; 101:1806-1811.

13. Birkmeyer JD, Siewers AE, Finlayson SR et al. Hospital volume and surgical mortality in the United States. N Engl J Med 2002; 346(15):1128-1137.

14. Goodney PP, Stukel TA, Lucas FL, Finlayson EV, Birkmeyer JD. Hospital volume, length of stay, and readmission rates in high-risk surgery. Ann Surg 2003; 238(2):161-167.

15. Hosmer DW, Lemeshow S. Applied logistic regression. 2nd ed. New York: Wiley Inter-Science; 2000.

16. McCulloch CE, Searle RS. Generalized, linear and mixed models. New York: Wiley; 2001.

17. Birkmeyer JD, Stukel TA, Siewers AE, Goodney PP, Wennberg DE, Lucas FL. Surgeon volume and operative mortality in the United States. N Engl J Med 2003; 349(22):2117-2127.

18. StataCorp. Stata statistical software: release 8.0. College Station, TX: Stata Corporation; 2003.

19. Rabe-Hesketh S, Skrondal A, Pickles A. Reliable estimation of generalized linear mixed models using adaptive quadrature. The Stata Journal 2002; 2:1-21.

20. Romano PS, Roos LL, Jollis JG. Adapting a clinical comorbidity index for use with ICD-9-CM administrative data: Differing perspectives. Journal of Clinical Epidemiology 1993; 46(10):1075-1079.

21. Ho V. Evolution of the volume-outcome relationship for hospitals performing coronary angioplasty. Circulation 2000; 101:1806-1811.

22. Birkmeyer NJO, Goodney PP, Stukel TA, Hillner BE, Birkmeyer JD. Do cancer centers designated by the National Cancer Institute have better surgical outcomes? Cancer 2005; 103(3):435-441.

23. Goodney PP, Siewers AE, Stukel TA, Lucas FL, Wennberg DE, Birkmeyer JD. Is surgery getting safer? National trends in operative mortality. J Am Coll Surg 2002; 195(2):219-227.

24. Goodney PP, Lucas FL, Stukel TA, Birkmeyer JD. Surgeon specialty and operative mortality with lung resection. Annals of Surgery 2005; 241(1):179-184.

25. 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(23):3028-3035.

26. The Leapfrog Group for Patient Safety. Evidence-based hospital referral fact sheet. http://www.leapfroggroup.org/FactSheets/EHR_FactSheet.PDF , 1-2. 4-15-2004.
Ref Type: Electronic Citation

27. Robinson JC. Hospital tiers in health insurance: balancing consumer choice with financial incentives. Health Affairs 2003; W3:135-146.

28. American Health Planning Association. National directory of health planning, policy and regulatory agencies. 13 ed. Falls Church, VA: 2002.