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RESEARCH ARTICLE

Hospital and Geographic Variability in Thirty-Day All-Cause Mortality Following Colorectal Cancer Surgery

Mario Schootman, Min Lian, Sandi L. Pruitt, Anjali D. Deshpande, Samantha Hendren, Matthew Mutch, Donna B. Jeffe, and Nicholas Davidson

Objective. To assess hospital and geographic variability in 30-day mortality after surgery for CRC and examine the extent to which sociodemographic, area-level, clinical, tumor, treatment, and hospital characteristics were associated with increased likelihood of 30-day mortality in a population-based sample of older CRC patients.

Data Sources/Study Setting. Linked Surveillance Epidemiology End Results (SEER) and Medicare data from 47,459 CRC patients aged 66 years or older who underwent surgical resection between 2000 and 2005, resided in 13,182 census tracts, and were treated in 1,447 hospitals.

Study Design. An observational study using multilevel logistic regression to identify hospital- and patient-level predictors of and variability in 30-day mortality.

Data Collection/Extraction Methods. We extracted sociodemographic, clinical, tumor, treatment, hospital, and geographic characteristics from Medicare claims, SEER, and census data.

Principal Findings. Of 47,459 CRC patients, 6.6 percent died within 30 days following surgery. Adjusted variability in 30-day mortality existed across residential census tracts (predicted mortality range: 2.7–12.3 percent) and hospitals (predicted mortality range: 2.5–10.5 percent). Higher risk of death within 30 days was observed for CRC patients age 85+ (12.7 percent), census-tract poverty rate >20 percent (8.0 percent), two or more comorbid conditions (8.8 percent), stage IV at diagnosis (15.1 percent), undifferentiated tumors (11.6 percent), and emergency surgery (12.8 percent).

Conclusions. Substantial, but similar variability was observed across census tracts and hospitals in 30-day mortality following surgery for CRC in patients 66 years and older. Risk of 30-day mortality is driven not only by patient and hospital characteristics but also by larger social and economic factors that characterize geographic areas.

Key Words. Colorectal cancer, neighborhood, multilevel, poverty

In the current health care reform environment of increasing transparency and accountability, postoperative mortality rates to assess hospital quality have gained increasing attention and importance. For example, the Centers for Medicare & Medicaid Services (CMS) and the Agency for Healthcare Research and Quality publicly report as a measure of quality of care the 30-day mortality rates for acute myocardial infarction, heart failure, pneumonia, and selected medical conditions on their website (www.hospitalcompare.hhs.gov). In addition, CMS plans to use 30-day mortality measures in its Hospital Inpatient Value-Based Purchasing program (Centers for Medicare & Medicaid Services 2011). Variability in 30-day mortality has been frequently used as a quality measure for cancer and noncancer care (Institute of Medicine 1999). Quality of cancer care may be improved by reducing variation in underuse of effective and necessary care; variation that indicates misuse of preference-sensitive care (i.e., care that offers equivalent options to be chosen among by the patient); and variation that indicates overuse of supply-sensitive care (i.e., care influenced by medical capacity; Wennberg 2010). Examining and reducing variability in medical care has been an important policy consideration for almost 30 years (Wennberg 1999; Tanenbaum 2013).

Colorectal cancer (CRC) is the second leading cause of cancer deaths in the United States, accounting for an estimated 103,170 new cases and 51,690 deaths in 2012 (American Cancer Society 2012). Elderly patients with CRC are more likely to die than younger patients, especially during the 30-day postoperative period (Fazio et al. 2004; Davila et al. 2005; Dekker et al. 2011; Morris et al. 2011; Panis et al. 2011). Variation in mortality rates among

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Address correspondence to Mario Schootman, Ph.D., Department of Epidemiology, Saint Louis University College for Public Health, 3545 Lafayette Ave, St Louis, MO 63104; e-mail: schootm@slu.edu. Mario Schootman, Ph.D., is also with the Alvin J. Siteman Cancer Center at Barnes-Jewish Hospital, Washington University School of Medicine, St Louis, MO. Min Lian, M.D., Ph.D., is with the Department of Medicine, Division of General Medical Sciences, Washington University School of Medicine, St Louis, MO. Sandi L. Pruitt, Ph.D., M.P.H., is with the Department of Clinical Sciences, University of Texas Southwestern Medical Center, Dallas, TX, Harold C. Simmons Cancer Center, Dallas, TX. Anjali D. Deshpande, Ph.D., M.P.H., and Donna B. Jeffe, Ph.D., are with the Alvin J. Siteman Cancer Center at Barnes-Jewish Hospital, Washington University School of Medicine and Department of Medicine, Division of General Medical Sciences, Washington University School of Medicine, St Louis, MO. Samantha Hendren, M.D., M.P.H., is with the Department of Surgery, University of Michigan, Ann Arbor, MI. Matthew Mutch, M.D., is with the Department of Surgery, Washington University School of Medicine, St Louis, MO. Nicholas Davidson, M.D., is with the Alvin J. Siteman Cancer Center at Barnes-Jewish Hospital and Washington University School of Medicine and Department of Medicine, Division of Gastroenterology, Washington University School of Medicine, St Louis, MO.

subgroups of CRC patients is especially pronounced in the first month after surgery (Moller et al. 2011). Studies examining variation in 30-day mortality in CRC have predominantly focused on hospital volume (Meyerhardt et al. 2003; Schrag et al. 2003; Iversen et al. 2007). Less attention has been paid to other potentially important sociodemographic factors, including residential location and information regarding hospital characteristics. Area characteristics of the patient's residential location could influence 30-day mortality through various mechanisms such as health-system factors, lifestyle factors, tumor biology, and comorbidity (Polite, Dignam, and Olopade 2006). Identification of other factors contributing to variation in 30-day mortality rates following CRC surgery may help to identify best practices to reduce postoperative mortality among elderly patients at the hospital level. Interventions may also focus on geographic areas since they are out of the control of hospitals and may help explain apparent differences in outcomes among hospitals. Therefore, we sought to describe variation in 30-day mortality across hospitals and geographic areas while adjusting for the known effects of patient sociodemographic, clinical, tumor, treatment, and hospital characteristics associated with an increased likelihood of 30-day all-cause mortality after CRC surgery. We hypothesized that these variables would help explain the hospital and geographic variability in 30-day all-cause mortality in CRC patients.

Materials and Methods

Data Sources

We obtained data from an existing linkage of the 2000–2005 National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) program data with 1999–2005 Medicare claims files from CMS. Linked SEER-Medicare data provide a rich source of information on Medicare patients included in SEER, a nationally representative collection of population-based cancer registries (Warren et al. 2002). Ninety-four percent of cancer patients reported to SEER aged 65 years or older has been successfully linked with Medicare data (Warren et al. 2002). This study included data from the following SEER registries (San Francisco, San Jose, Los Angeles, great California area, Connecticut, Detroit, Hawaii, Iowa, New Mexico, Seattle, Utah, Atlanta, rural Georgia, Kentucky, Louisiana, and New Jersey) representing approximately 14 percent of the U.S. population. The study was reviewed by the Institutional Review Board at Washington University and determined to be exempt from oversight.

Study Population

We conducted a retrospective cohort study with all-cause mortality within 30 days following surgery (yes, no) as the outcome of interest. Deaths occurring prior to and after discharge were included. We selected all patients 66 years of age or older with a first primary in situ or invasive colon or rectal cancer diagnosis from 2000 through 2005 and who had both Medicare Part A and Part B coverage and were in fee-for-service Medicare during this period. We included only patients at least 66 years of age to allow for 1 year of complete claims data prior to diagnosis to determine comorbidity. We excluded patients who had only autopsy or death certificate records of their cancer diagnosis in SEER or who were members of a Health Maintenance Organization because these patients lack complete claims data or follow-up data on vital status. A total of 89,301 CRC patients aged 66 or older were identified and 41,842 were excluded for various reasons (i.e., having HMO coverage $n = 22{,}561$, not having Medicare A & B $n = 5{,}535$, death certificate or autopsy only $n = 1{,}396$, no surgery identified $n = 14{,}119$, missing data on covariates $n = 2{,}500$) leaving 47,459 CRC patients available for analysis. Patients may have been excluded for more than one reason.

Study Variables

We used Medicare data to determine vital status within 30 days of surgery, because SEER data provide only month and year of death. Treatments for CRC included definitive surgery, chemotherapy, or radiotherapy. Treatments were measured by searching inpatient, outpatient, and carrier claims using previously identified Healthcare Common Procedure Coding System and/or International Classification of Diseases (version 9) codes (Warren et al. 2008). The date on which the most extensive surgery was performed was used as the date of definitive surgery, hereafter referred to only as "surgery."

Covariates

We selected variables associated with hospital and census-tract variation and variables associated with 30-day mortality based on previous studies and a conceptual model that includes various types of characteristics affecting quality of care (Donabedian 1988; Hodgson, Fuchs, and Ayanian 2001; Polite, Dignam, and Olopade 2006). This multilevel conceptual model consists of

individual-, hospital-, provider-, and area-level characteristics predicting 30-day mortality among CRC patients.

Patient *sociodemographic characteristics* included sex, race/ethnicity, comorbidity, eligibility for both Medicare and Medicaid (dual eligibility), age group, and year of diagnosis. To measure comorbidity, we searched inpatient or carrier claims for multiple chronic conditions occurring 1–12 months prior to diagnosis using the Klabunde adaptation of the Charlson comorbidity index (National Cancer Institute 2011). It uses a minimum of two claims 30 days apart to validate the comorbidity occurrence. We further classified comorbidity as none, one, or two or more. We limited the patients in our analysis to those aged 66 years and older to ensure all patients had full year look-back period. Dual eligibility was defined as eligibility for Medicaid coverage for at least 1 month during the year before diagnosis.

Area-level characteristics included percentage of the population living in poverty in the patient's census tract. Each patient's residential address at time of diagnosis was matched to its respective census tract as defined for the 2000 U.S. Census.

Hospital characteristics, where the patient's surgery took place, included number of hospital beds, number of CRC surgeries performed, and whether it was a teaching hospital or not, which were obtained from the Healthcare Cost Report and the Provider of Service files from CMS. The hospital's surgery volume was calculated using the number of CRC surgeries performed during the study period.

Tumor characteristics included American Joint Commission on Cancer (AJCC) stage, tumor grade, tumor location, and histology. The location of the tumor was classified as proximal colon (cecum, ascending); transverse colon (hepatic flexure, transverse colon, splenic flexure); distal colon (descending and sigmoid colon); or rectosigmoid junction or rectum.

Treatment characteristics within 30 days of the index surgery included emergency surgery and type of surgery (Warren et al. 2008).

Statistical Analysis

Univariate associations between 30-day mortality and each covariate were tested using Chi-square tests. We also examined intercorrelations among the predictor variables. A multi-level, cross-classified logistic model for a discrete response variable was used to describe the variation across hospitals and census tracts to account for nesting of CRC patients within hospitals and within census tracts of their residence (Snijders and Bosker 1999). This nesting

structure allows patients from the same census tract to be treated at different hospitals and allows for the fact that different hospitals could treat patients from the same tracts. In essence, this structure does not impose any relationship between hospitals and tracts. Adjusted odds ratios and their 95 percent confidence intervals were calculated based on all variables that were entered into the multivariable model. Model fit was based on the Deviance Information Criterion (DIC), with lower values indicating better fit.

The median odds ratio (MOR) and interquartile odds ratio (IOR) were calculated based on this multi-level model to facilitate interpretation of the variability among census tracts and hospitals on a scale that is directly comparable with the odds ratios that are used for the other variables in the study (Merlo et al. 2006). The MOR and IOR are based on the random effects variance component ($\hat{V}$) from the logistic regression model: $\text{MOR} = \exp(0.95\sqrt{\hat{V}})$ and $\text{IOR} = \exp(2.30\sqrt{\hat{V}})$. The MOR can be interpreted as the median value of the ratio of predicted odds of 30-day mortality for two patients randomly selected from different census tracts (or hospitals) but with equivalent covariates. If the MOR is equal to 1, it indicates no variation in 30-day mortality across census tracts or hospitals. The IOR reflects the difference in likelihood of 30-day mortality between 25 percent of all patients from census tracts or hospitals with the highest risk in 30-day mortality and 25 percent of all patients from census tracts or hospitals with the lowest risk in 30-day mortality. We obtained the standard errors of the census-tract-level and hospital-level variances to compute the 95 percent credible interval for the MORs and IORs using Markov Chain Monte Carlo methods in the Bayesian multilevel models.

In addition, we calculated census-tract-level predicted values for 30-day mortality to describe the geographic and hospital variability. These predicted values for 30-day mortality were computed based on the multivariable model by averaging the patient-level predicted probabilities for all patients who resided in that census tract. Only census tracts with at least 20 patients were used in order to increase precision of the estimates. Similarly, we calculated hospital-level predicted values for 30-day mortality to describe the variability by randomly selecting 10 hospitals from hospitals with the following patient volume: 20–49, 50–99, 100 or more patients. Hospital-level predicted values for 30-day mortality were computed based on the multivariable model by averaging the patient-level predicted probabilities for all patients who were treated at that hospital.

Data were managed and analyzed in SAS (version 9.1, SAS Institute Inc., Cary, NC). The Bayesian analysis for the cross-classified model was

performed using WinBUGS (version 1.4.3). After 5,000 burn-in iterations, 5,000 additional iterations were kept for parameter estimates.

RESULTS

Overall, 47,459 patients underwent CRC surgery from 2000 through 2005 and were included in the analysis. Patients resided in 13,182 different census tracts and were treated at 1,447 different hospitals. Of these 47,459 patients, 3,126 (6.6 percent) died within 30 days following surgery; 63.4 percent died from any cause during their hospitalization for CRC surgery and 59.7 percent died of CRC. Table 1 shows that most CRC patients were white (85.8 percent), not participating in Medicaid (83.5 percent), younger than 85 (81.4 percent), and living in census tracts where <10 percent of the population lived below the federal poverty rate (57.9 percent). Little difference existed in the mean census-tract poverty rate between the SEER study areas (13.4 percent) and the overall findings reported for the United States (13.5 percent). Table 1 summarizes the characteristics of CRC patients who died within 30 days after surgery.

Statistically significant variability in 30-day mortality was present across census tracts and hospitals in unadjusted analysis (Table 2). For patients with CRC, variability across census-tracts and hospitals was similar in magnitude; the MOR was about 1.4, which corresponds to the median value of the relative odds of 30-day mortality between two randomly chosen census tracts for CRC patients. Variability in 30-day mortality was similar across census tracts and hospitals in unadjusted analysis.

In multivariable analysis (Table 3), several characteristics were independently associated with higher odds of 30-day mortality, including sociodemographics (being male, having at least one comorbid condition, age ≥75), area-level characteristics (poverty rate >10 percent), hospital characteristics (nonteaching hospital), tumor characteristics (advanced stage at diagnosis, poor or undifferentiated tumors, colon vs rectal cancer), and treatment characteristics (emergency surgery). Characteristics associated with lower odds of death included being other race, diagnosis during 2005, and higher surgeon case load. Characteristics not associated with odds of death included being African American and Medicaid enrollment. Variability across census tracts and hospitals remained evident in the multivariable model and was similar to the unadjusted model based on the estimates of the variance and IOR, suggesting that none of the measured variables were able to account for the observed

Table 1: Sociodemographic, Hospital, Clinical, Tumor, and Treatment Variables Associated with Thirty-Day Mortality in Colorectal Cancer Patients Following Surgery, 2000–2005 (Unadjusted)

	No. CRC Patients	*No. Deaths*	*30-day Mortality, % (95% CI)*
Sociodemographic characteristic			
Sex*			
Male	20,350	1,405	6.9 (6.6–7.3)
Female	27,101	1,721	6.4 (6.1–6.6)
Race*†			
White	40,718	2,702	6.6 (6.4–6.9)
African American	3,644	270	7.4 (6.6–8.3)
Hispanic	725	42	5.8 (4.1–7.5)
Other	796	35	4.4 (3.0–5.8)
Asian	1,398	62	4.4 (3.4–5.5)
Comorbidity*			
0	20,500	1,079	5.3 (5.0–5.6)
1	13,841	890	6.4 (6.0–6.8)
2+	13,110	1,157	8.8 (8.3–9.3)
Medicaid (dual eligibility)*			
Yes	7,809	630	8.1 (7.5–8.7)
No	39,642	2,496	6.3 (6.1–6.5)
Age group*			
66–74	17,170	684	4.0 (3.7–4.3)
75–84	21,462	1,321	6.2 (5.8–6.5)
85+	8,819	1,121	12.7 (12.0–13.4)
Year of diagnosis			
2000	8,022	585	7.3 (6.7–7.9)
2001	7,972	531	6.7 (6.1–7.2)
2002	8,035	493	6.1 (5.6–6.7)
2003	8,169	548	6.7 (6.2–7.3)
2004	7,899	500	6.3 (5.8–6.9)
2005	7,354	469	6.4 (5.8–6.9)
Area-level characteristics			
Poverty rate*			
<10%	27,478	1,620	5.9 (5.6–6.2)
10–19%	12,048	874	7.3 (6.8–7.7)
20+%	7,677	615	8.0 (7.4–8.6)
Hospital characteristics			
Hospital volume (beds)*			
1–199	12,003	890	7.4 (7.0–7.9)
200–349	13,471	905	6.7 (6.3–7.1)
350–499	11,199	711	6.4 (5.9–6.8)
500+	10,763	619	5.8 (5.3–6.2)
Surgeon case load*			
<21	11,070	830	7.5 (7.0–8.0)
21–38	10,352	702	6.8 (6.3–7.3)

Continued

Table 1. *Continued*

	No. CRC Patients	*No. Deaths*	*30-day Mortality, % (95% CI)*
39–69	10,126	628	6.2 (5.7–6.7)
70+	10,312	494	4.8 (4.4–5.2)
Unknown	5,581	472	8.5 (7.7–9.2)
Teaching hospital*			
Yes	23,696	1,426	6.0 (5.7–6.3)
No	16,706	1,185	7.1 (6.7–7.5)
Unknown	7,049	515	7.3 (6.7–7.9)
Tumor characteristics			
AJCC stage*			
0/I	10,911	339	3.1 (2.8–3.4)
II	14,929	870	5.8 (5.5–6.2)
III	12,542	662	5.3 (4.9–5.7)
IV	6,468	976	15.1 (14.2–16.0)
Unknown	2,601	279	10.7 (9.5–11.9)
Tumor grade/differentiation*			
Well	3,916	200	5.1 (4.4–5.8)
Moderate	30,397	1,680	5.5 (5.3–5.8)
Poor	9,307	809	8.7 (8.1–9.3)
Undifferentiated	507	59	11.6 (8.9–14.4)
Unknown	3,324	378	11.4 (10.3–12.5)
Tumor location*			
Proximal colon	18,334	1,151	6.3 (5.9–6.6)
Transverse colon	7,039	563	8.0 (7.4–8.6)
Distal colon	12,734	929	7.3 (6.8–7.8)
Rectal	9,344	483	5.2 (4.7–5.6)
Tumor histology*			
Mucinous adenocarcinoma	40,434	2,525	6.2 (6.0–6.5)
Other adenocarcinoma	5,967	418	7.0 (6.4–7.7)
Nonadenocarcinoma	1,050	183	17.4 (15.1–19.7)
Treatment characteristics			
Emergency surgery*			
Yes	11,845	1,518	12.8 (12.2–13.4)
No	35,606	1,608	4.5 (4.3–4.7)
Type of surgery*			
Local tumor excision	962	50	5.2 (3.8–6.6)
Partial colectomy	18,690	1,049	5.6 (5.3–5.9)
Subtotal colectomy or hemicolectomy	22,603	1,363	6.0 (5.7–6.3)
Total (procto)colectomy	1,782	105	5.9 (4.8–7.0)
Colectomy NOS	955	91	9.5 (7.7–11.4)
Other surgery	187	16	8.6 (4.6–12.6)
Unknown surgery	2,227	452	19.9 (18.3–21.5)

*$p < .01$; CI, confidence interval.
†Native American not included for confidentiality reasons.

Table 2: Unadjusted Variability in Thirty-Day Mortality across Patient Census Tracts and Hospitals among Colorectal Cancer Patients Following Surgery

	Census-Tract Variability		*Hospital Variability*	
	Parameter	*95% CI*	*Parameter*	*95% CI*
CRC				
Variance	0.14	0.08–0.21	0.13	0.09–0.17
MOR	1.44	1.32–1.55	1.41	1.34–1.49
IOR	2.40	1.94–2.85	2.31	2.02–2.59
DIC	22,734			

CI, credible interval; IOR, interquartile odds ratio; MOR, median odds ratio.

variation across census tracts or hospitals (Table 4), although the fit of the multivariable model was substantially better based on the reduction in the DIC. Thus, while the fixed effect of area-level poverty was associated with 30-day mortality, this variable was unable to explain the geographic variation across census tracts or hospitals. Figure 1 shows that the observed 30-day mortality rate for 30 census tracts with at least 20 CRC patients ranged from 0.0 percent to 15.0 percent (predicted rate range: 3.5–10.9 percent). For census tracts 1 through 16, the observed mortality rate was lower than predicted, suggesting that CRC patients in these census tracts fared better than expected adjusting for all variables in the multivariable model. In contrast, the observed mortality rate for CRC patients in census tract 28 and 30 was higher than predicted, suggesting that patients in these census tracts fared worse than expected.

The observed 30-day mortality rate for 30 hospitals with at least 20 CRC patients ranged from 0.0 percent to 12.9 percent (Figure 2). For hospitals 1 through 10, the observed mortality rate was lower than the predicted rate based on the multivariable model (range: 3.8–9.3 percent), suggesting that CRC patients in these hospitals fared better than expected adjusting for all variables in the multivariable model. In contrast, the observed mortality rate for CRC patients in hospitals 20, 22, 23, and 27 through 30 was higher than predicted, suggesting that patients in these hospitals fared worse than expected.

DISCUSSION

Our findings demonstrate an overall 30-day mortality rate of 6.6 percent that is slightly higher than some studies (Schrag et al. 2000; Dekker et al. 2011),

Table 3: Adjusted Odds Ratio (95% Confidence Interval) for Characteristics Associated with Thirty-Day Mortality Following Colorectal Cancer Surgery, 2000–2005

	Adjusted OR (95% CI)
Sociodemographic characteristics	
Male sex (vs. female)	1.31 (1.21–1.42)
Race (vs. white)	
African American	0.89 (0.77–1.04)
Other	0.67 (0.56–0.82)
Comorbidity (vs. 0)	
1	1.17 (1.06–1.29)
2+	1.60 (1.45–1.75)
Medicaid (yes vs. no)	1.06 (0.95–1.18)
Age group (vs. age 66–74)	
75–84	1.65 (1.50–1.82)
85+	3.53 (3.16–3.94)
Year at diagnosis (vs. 2000)	
2001	0.95 (0.83–1.09)
2002	0.87 (0.76–1.00)
2003	0.97 (0.85–1.11)
2004	0.88 (0.77–1.01)
2005	0.86 (0.75–0.99)
Area-level characteristics	
Poverty rate (vs. <10%)	
10–19%	1.23 (1.12–1.36)
20+%	1.30 (1.15–1.47)
Hospital characteristics	
Hospital volume (beds) versus 1–199 beds	
200–349	0.91 (0.81–1.04)
350–499	0.94 (0.81–1.09)
500+	0.86 (0.72–1.02)
Surgeon case load (vs. 70+)	
<21	1.29 (1.13–1.47)
21–38	1.23 (1.07–1.41)
39–69	1.14 (0.99–1.31)
Unknown	1.19 (1.02–1.39)
Teaching hospital (vs. Yes)	
No	1.15 (1.02–1.30)
Unknown	1.22 (1.05–1.42)
Tumor characteristics	
AJCC stage (vs. 0/I)	
II	1.60 (1.40–1.83)
III	1.46 (1.27–1.69)
IV	4.12 (3.57–4.75)
Unknown	1.65 (1.36–2.01)

Continued

Table 3. *Continued*

	Adjusted OR (95% CI)
Tumor grade (vs. well differentiated)	
Moderate differentiation	0.96 (0.82–1.12)
Poor differentiation	1.35 (1.14–1.60)
Undifferentiated	1.75 (1.25–2.45)
Unknown	1.26 (1.03–1.55)
Tumor location (vs. rectal)	
Proximal colon	1.41 (1.25–1.60)
Transverse colon	1.57 (1.36–1.82)
Distal colon	1.28 (1.11–1.46)
Tumor histology (vs. mucinous adenocarcinoma)	
Nonadenocarcinoma/unknown	1.63 (1.31–2.01)
Other CRC	1.00 (0.88–1.12)
Treatment characteristics	
Emergency surgery (vs. No)	2.35 (2.17–2.55)

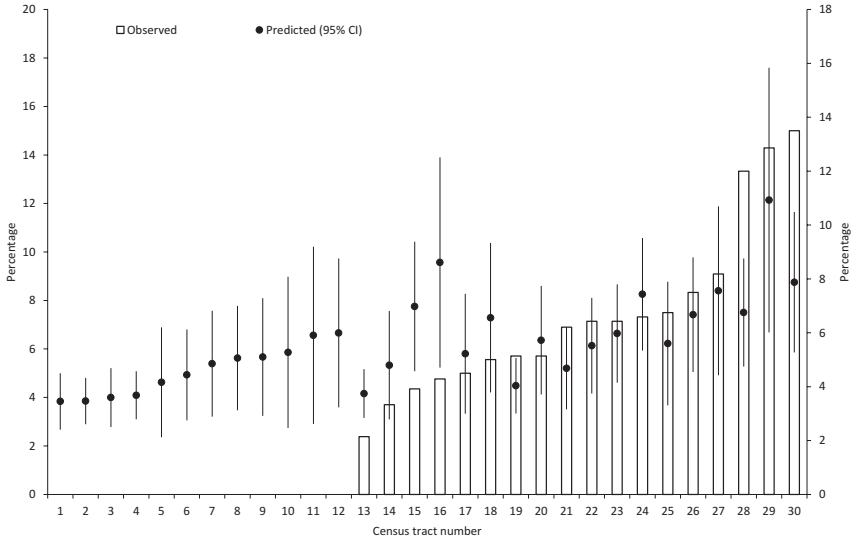
Table 4: Adjusted Variability in Thirty-Day Mortality across Patient Census Tracts and Hospitals among Colorectal Cancer Patients Following Surgery

	Census-Tract Variability		*Hospital Variability*	
	Parameter	*95% CI*	*Parameter*	*95% CI*
CRC				
Variance	0.18	0.11–0.25	0.12	0.08–0.15
MOR	1.50	1.38–1.62	1.38	1.31–1.45
IOR	2.68	2.17–3.19	2.18	1.92–2.44
DIC	20,173			

Adjusted for sociodemographic, hospital, tumor, and treatment characteristics. CI, credible interval; IOR, interquartile odds ratio; MOR, median odds ratio.

lower than others (Tekkis et al. 2003), and similar to other studies (Morris et al. 2011; Panis et al. 2011). Our findings demonstrate that the location of patient residence plays an important role in predicting 30-day mortality following CRC surgery. We observed that the variability across patient census tracts was at least as large as across hospitals and that census-tract-level poverty rate was associated with higher risk of death independent of hospital and other characteristics included in the multivariable model. Thus, regardless of the facility in which subjects were treated or the experience of the surgeon,

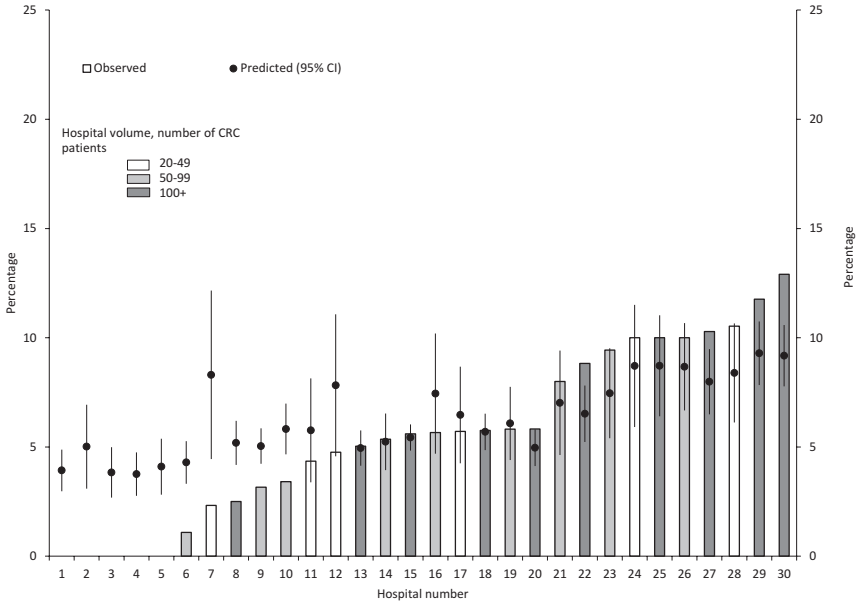
Figure 1: Observed and Predicted Variability in Thirty-Day Mortality Based on SEER-Medicare Data from 2000 to 2005 across the Thirty Census Tracts with at Least Twenty CRC Patients Based on the Multivariable Model



Note. Predicted 30-day mortality, based on the multilevel logistic regression model adjusted for sociodemographic, census-tract, hospital, clinical, tumor, and treatment characteristics, are plotted as circles above the encrypted census tract identifiers along the horizontal axis. Error bars indicate 95 percent confidence intervals. Census-tract-level predicted values were computed by averaging the patient-level predicted probabilities for all patients who resided in that census tract. Census tracts 1 through 12 had zero observed deaths; thus, there is no bar associated with these census tracts.

and independent tumor and patient characteristics, CRC patients had an increased risk of death if they lived in areas with worse economic conditions. While some studies have shown the adverse effects of living in economically deprived areas on CRC survival (Hole and McArdle 2002), ours is the first population-based study in the United States that showed this to be the case for 30-day mortality after CRC surgery. This finding suggests that where patients live affects their short-term mortality risk. CRC patients in some census tracts had higher mortality than expected while other census tracts had lower than expected 30-day mortality. Because none of the variables, including census-tract poverty, included in the model was able to entirely explain the geographic variability in the independent effect of census-tract poverty rate on

Figure 2: Observed and Predicted Variability in Thirty-Day Mortality Based on SEER-Medicare Data from 2000 to 2005 across a Random Sample of Thirty Hospitals with at Least Twenty CRC Patients Based on the Multilevel Model



Note. Predicted 30-day mortality, based on the multilevel logistic regression model adjusted for sociodemographic, hospital, clinical, tumor, and treatment characteristics, are plotted as circles above the encrypted hospital identifiers along the horizontal axis. Error bars indicate 95 percent confidence intervals. Hospital-level predicted values were computed by averaging the patient-level predicted probabilities for all patients who were treated at that hospital. Hospitals 1 through 5 had zero observed deaths; thus, there is no bar associated with any of these hospitals.

30-day mortality, intervening upon variables included in the model would not be expected to reduce the geographic variability in 30-day mortality.

It is not known why living in an economically deprived area would increase the 30-day mortality risk even after controlling for hospital and clinical factors. Identifying the causes of this geographic variability and finding ways to minimize this risk could increase our ability to improve outcomes following CRC surgery. One potential mechanism could be that patients living in economically deprived areas are more likely to experience environmental stress resulting in systemic inflammation, to be obese, to have low levels of vitamin D, or to smoke, all of which have been shown to affect long-term survival following CRC diagnosis (McMillan, Canna, and McArdle 2003; Dignam et al. 2006; Freedman et al. 2007; Roxburgh et al. 2011).

Unfortunately, information regarding these exposures was not available in the SEER-Medicare data.

An alternative mechanism could be that those living in economically deprived areas have less access to social or medical services such as nearby primary care facilities, timely transportation to necessary follow-up appointments or for urgent medical conditions, or basic home-health or social services that could support immobile or low-functioning patients. Previous studies also have shown that patients with lower preoperative physical status measured using the American Society of Anesthesiologists (ASA) Score (Owens, Felts, and Spitznagel 1978) had increased 30-day mortality risk (Longo et al. 2000; Cohen et al. 2009; Al-Refaie et al. 2011), but ASA scores were unavailable in the SEER-Medicare data. However, we included comorbidity in our models, which may relate to 30-day mortality in a similar fashion, because comorbidity and physical status are correlated (Smith et al. 2008; Deshpande et al. 2011). Thus, while a unifying explanation is yet to emerge, our findings emphasize the importance of identifying the observed variability in 30-day mortality across geographic areas in order to intervene upon modifiable risk factors that can optimize patient outcomes.

Our findings also show that 30-day mortality varied across hospitals, regardless of patient sociodemographic, area-level characteristics, clinical factors, tumor characteristics, type of treatment received, and hospital characteristics. CRC patients in some hospitals fared worse than expected while others fared better. Similar to other studies (Meyerhardt et al. 2003; Billingsley et al. 2007; Iversen et al. 2007), we observed that patients treated at hospitals with higher patient volumes or at teaching hospitals had lower risk of death. While patients treated at these hospitals had decreased mortality, neither the hospital characteristics nor the surgeon case load explained the variation as described by the MOR. Billingsley (Billingsley et al. 2007) suggested the availability of sophisticated clinical services that facilitate the timely management of medical or surgical complications explained why high-volume hospitals have better outcomes following CRC surgery. Previous studies have suggested that "failure to rescue," that is, mortality among patients with major complications, may be an important mechanism underlying hospital mortality associated with surgery (Silber et al. 1992; Ghaferi and Dimick 2012) and may help explain remaining variability among hospitals. Multilevel observational studies, such as ours, may be used to monitor such variation across levels such as hospitals and geographic regions. Such methods may serve as important future methods for quality measurement of cancer care.

Our results should be interpreted with the understanding that our sample included only fee-for-service Medicare-insured patients, limiting generalizability to younger patients or to uninsured or privately insured patients. Because hospital size and location are closely related, we were unable to ascertain the independent effect of urban–rural hospital location. Strengths of our study include integrating a large number of patient, tumor, clinical, hospital, and treatment factors into one analytic model that simultaneously estimated both hospital and geographic variability using a multilevel cross-classified model. Additionally, unlike previous studies that only looked at the fixed effects of hospital characteristics, our study used a random term (median odds ratio) to describe the variability across hospitals. This approach is starting to gain popularity because, unlike fixed effects, it can quantify the extent of the variability in health outcomes across different "levels" (e.g., hospitals, surgeons, or neighborhoods; Lian et al. 2011; McCahill et al. 2012). However, our analysis does not take into account the spatial relationship between adjacent census tracts. Future research may use such methods to identify where 30-day mortality was concentrated spatially using geographically weighted regression methods.

In conclusion, census-tract and hospital variation was observed in 30-day mortality following CRC surgery in patients 66 years of age and older that was not explained by patient sociodemographic, clinical, tumor, treatment, or hospital characteristics. Risk of 30-day mortality is driven by these individual-level characteristics and by both hospital-level and area-level social, economic, and organizational factors that distinguish different hospitals and geographic areas.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.