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Does Surgeon Case Volume Influence Nonfatal Adverse Outcomes after Rectal Cancer Resection?

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Abstract

BACKGROUND—The aim of this study was to assess the relationship between surgeon and hospital volume and major postoperative complications after rectal cancer surgery, and to define other surgeon and hospital characteristics that may explain observed volume-complication relationships.

STUDY DESIGN—This was a retrospective cohort design using data from the Surveillance, Epidemiology, and End Results (SEER) cancer registry program for individuals with stage I to III rectal cancer diagnosed between 1992 and 1999 and treated with resection. The patients' Surveillance, Epidemiology, and End Results data were linked with Medicare claims data from 1991 to 2000. The primary outcomes were 30-day postoperative procedural interventions (PPI) to treat surgical complications, such as reoperation. The association between surgeon volume and PPI was examined using logistic regression modeling with adjustment for covariates.

RESULTS—The odds of a rectal cancer patient requiring a PPI is notably less if the operation is performed by one of a small subset of very high volume surgeons (unadjusted odds ratio 0.53; 95% CI 0.31 to 0.92). Board certification in colorectal surgery did not alter the relationship between surgeon volume and PPI, although surgeon age did, with mid-career surgeons having the lowest rates of PPI, regardless of practice volume. When adjusted for surgeon age, surgeon volume is no longer a marked predictor of complications (adjusted odds ratio 0.57; 95% CI 0.30 to 1.09).

CONCLUSIONS—Overall, rectal cancer operations are safe, with a low frequency of severe complications. A subset of very high volume rectal surgeons performs these operations with fewer complications that require procedural intervention or reoperation. Surgeon age, as an indicator of experience, also contributes modestly to outcomes. These data do not justify regionalizing rectal cancer care based on safety concerns.

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A number of studies have examined the relationship between surgeon and hospital volume and outcomes for a variety of cancer operations. These studies demonstrate that higher surgical volume is associated with lower postoperative mortality for operations with a high associated mortality, such as pancreatectomy and esophagectomy, in which the operative mortality may be as high as 10% to 12%.[1,2] But for procedures with a lower operative mortality, such as rectal cancer operations, in which operative mortality is generally <5% to 6%, the association between volume and postoperative mortality is either smaller or absent.[3] Despite the relatively low mortality rate, rectal cancer surgery is highly technical, and the operations may be associated with a number of complications, including anastomotic leaks, abdominal abscesses, and fistulas.[4] Although these complications might not be fatal, they are clinically severe and they have a profound impact on the cost of rectal cancer treatment.[5] There is very little information about the relationship between practice volume and this subset of major postoperative complications associated with rectal cancer surgery.

The aim of this study was to assess the relationship between surgeon and hospital volume and major complications that require procedural intervention for management after rectal cancer surgery. This study also aimed to elucidate the processes of care that may explain any volume-outcomes association by examining the influence of patient, contextual, surgeon, and hospital characteristics on this relationship.

METHODS

Data sources

This study used data from the Surveillance, Epidemiology, and End Results (SEER) cancer registry program for individuals diagnosed with rectal cancer between 1992 and 1999, linked with their Medicare claims for outpatient and inpatient services from 1991 to 2000. During the time of this study, the SEER registries included approximately 14% of the US population. SEER program data include tumor location, stage of disease, and patient demographics.[6,7] Medicare data include all billed claims for services provided to patients enrolled in fee-for-service Medicare, including the original surgical resection and all postoperative procedural interventions.[8] We used unique provider identification numbers (UPINs) from the Medicare claims data to link physician demographic and practice characteristics as reported in the 1993 or 1997 American Medical Association Masterfile. Unique Medicare hospital numbers linked the cancer resection hospital to facility characteristics reported to Medicare through the Medicare Healthcare Reporting and Information System and Provider of Service surveys. The dataset also included patient contextual variables such as ZIP code-based median household income and high school education status from the 2000 census.

Study population

We identified 10,553 patients aged 66 years and older, with American Joint Committee on Cancer (AJCC) stage I to III rectal cancer diagnosed between 1992 and 1999. Analysis of the SEER data during the study period indicated that 79% of all rectal cancer patients were 66 years old or older. Rectal adenocarcinoma was identified using SEER cancer site code 20.1. We excluded patients who had tumor histology other than adenocarcinoma (n = 459), and patients with earlier colorectal cancer (n = 194). We also excluded patients without complete enrollment in parts A and B, fee-for-service Medicare in the year before diagnosis (n = 2,610) and in the 6 months after the month of diagnosis (n = 70). These exclusions ensured complete capture of claims data for measuring comorbidity before cancer diagnosis, and our capability to track procedures after surgery. We excluded patients without a Medicare claim indicating surgical resection of their colon cancer within 6 months of diagnosis (n = 962). The final study group included 6,258 patients. Of these patients, 6,182 patients had an identifiable hospital and 6,000 patients had an identifiable surgeon. The total number with both an identifiable hospital and surgeon was 5,935.

Study variables

Demographic characteristics—The SEER database provided patient month and year of birth, race or ethnicity, and gender.

Clinical and tumor characteristics—AJCC data from the SEER program differentiated three stages of disease (I, II, and III) and four tumor (T) stages (1, 2, 3, and 4). To measure comorbidity, we adapted the Romano-Charlson index to include outpatient and inpatient diagnoses made during the 11 months before the month before colon cancer diagnosis.[9,10] This index creates a weighted score using International Classification of Diseases 9th revision, Clinical Modification (ICD-9-CM) diagnosis codes for 18 conditions such as myocardial infarction, congestive heart failure, and chronic pulmonary disease. We classified individuals into three categories of comorbidity: an index score of 0, 1, and 2 or more. To adjust for acuity of illness at the time of operation, we identified individuals with obstructive rectal cancer (ICD-9 diagnosis codes 560.89 and 560.9), perforated cancer (ICD-9 569.83), and those admitted under emergent conditions (a Medicare claims-based variable identifying admissions through the emergency department or those requiring urgent or emergent treatment).

Contextual characteristics—The SEER registry represented the region in which each patient received care. The median household income within each patient's ZIP code estimated patients' socioeconomic status.

Outcomes—The primary outcomes was the occurrence of a postoperative procedural intervention (PPI), such as reoperative laparotomy and other procedures to treat surgical complications (diverting colostomy and percutaneous drainage of abscess), within 30 days of the index cancer resection. Such procedures are most frequently associated with complications involving the wound, anastomosis, or a technical problem at the time of the primary procedure.[11]

Surgeon and hospital characteristics—Individual surgeons were identified by UPIN from the rectal cancer resection claim in the Medicare data. For patients with multiple resection claims, we used an algorithm that prioritized more complex procedures and procedures attributed to the primary surgeon to identify the appropriate resection and the responsible surgeon. Matching a Medicare hospitalization to the date of the surgical resection identified the appropriate hospital. For patients without precisely matching dates, we also used the closest hospitalization or outpatient facility claim within 30 days of resection to identify the resection hospital.

Surgeon characteristics were derived from the American Medical Association Masterfile, and included age, gender, location of practice, board certification (colorectal surgery, general surgery, other certification, none), years in practice, and practice arrangement (solo versus group). Hospital characteristics, derived from both the Medicare Healthcare Reporting and Information System and the Provider of Service survey, included ownership (nonprofit, for-profit, government), teaching status, eligibility for disproportionate share hospital payments, average daily census, designation as a National Cancer Institute Cancer Center or cooperative clinical trials group participant, and number of ICU beds. We also developed a variable that served as a marker for hospitals that offered sophisticated clinical services based on whether they reported programs in cardiac surgery and solid organ transplantation in the Provider of Service surveys performed in 1996 and 1998. The combination of transplant and cardiac surgery programs was chosen because of the association of these programs with other medical services, including cardiac care, critical care, and medical subspecialties.

Procedure volume—We defined each hospital's volume by measuring the total number of index rectal cancer resections performed in that facility for patients diagnosed from 1992 through 1999. Surgeon volume was measured by the number of rectal resections performed as the primary surgeon on the same group of study patients. These definitions attributed volume of procedures in later years to describe surgeons and hospitals of patients diagnosed in earlier years. But the 8-year volume variable was highly correlated with the annual volumes measured in the earlier years and was a much more stable measure of surgical volume than annual measurement, especially for surgeons. This methodology does not capture non-Medicare surgical volume for surgeons or hospitals, nor will it capture patients who received care at hospitals outside of SEER areas. But it has been used in similar studies,[3,12,13] and it has been validated using state hospital discharge data.[14,15] Surgeon volume (and other characteristics) could not be determined for 258 study patients because we were unable to identify the UPIN of the primary surgeon. Hospital volume could not be determined for 76 patients because patients were missing the hospital identifier. Surgeon and hospital volume are presented as one of five groups: very low, low, medium, high, and very high. Volume groups were first developed by distributing the surgeons into quartiles of volume based on the number of patients. We then noted that even in the high volume quartile, the total number of rectal cancer patients remained low (one to three patients per year) and did not reflect the subset of surgeons who are truly high volume providers. To address this, we divided the highest volume group to establish a group of very high volume surgeons that we hypothesized would have the most favorable outcomes.

Statistical analyses—Chi-square tests were used to determine the association between patient characteristics and surgical volume of their surgeon and hospital, and to examine the characteristics of surgeons and hospitals at each volume stratum. We calculated the PPI rates for patients of surgeons and hospitals with different volume levels. A series of logistic regression models examined the degree to which our study variables mediated the volume-PPI relationship for both hospitals and surgeons. In the process of logistic regression modeling, we tested all demographic, clinical or tumor, contextual, surgeon, and hospital variables. Final regression models included all key variables that have been previously associated with surgical outcomes, and additional variables that were notable predictors of the outcomes in the unadjusted analyses or that improved the model fit. We applied general estimating equation methods[16] to our final models to account for clustering of patients by physician and hospital. We found no meaningful differences in the confidence intervals, so we have reported findings from the original modeling.

RESULTS

Characteristics of the study population

Table 1 summarizes the number of patients, hospitals, and surgeons during the 8-year study period. In our sample, the majority of surgeons (54.3%) and hospitals (68.4%) were very low volume providers. The very low volume surgeons performed a median of one rectal cancer operation on study patients during the study period. The very low volume hospitals provided care for a median of four study patients during the course of the study. A limited group of surgeons (1.5%) and hospitals (1.9%) were very high volume providers. Very high volume surgeons performed a median of 22 procedures on study patients during the study period.

Table 2 demonstrates patient characteristics across surgeon and hospital volume groups. Very high volume surgeons and hospitals provide care for a disproportionately high percentage of Caucasian patients. Very high volume surgeons and hospitals also provide service to the highest percentage of individuals in the highest income strata. The group of patients receiving care from very high volume surgeons also had the lowest rates of emergency hospital admission.

Surgeon and hospital characteristics and relationship to volume

Patients served by very high volume surgeons were most likely to receive surgical care from board certified colorectal surgeons (86.2%, Table 3). Patients of very high volume surgeons are also likely to be cared for by surgeons in the 40 to 49-year-old age range (52.8%). Patients undergoing operations by very high volume surgeons were also most likely to undergo procedures in very high volume hospitals (42.7%). In all surgeon volume groups, women surgeons cared for a minority of patients. But the greatest proportion of patients cared for by women surgeons was within the very high volume surgeon group (15%). Patients of very high volume surgeons were the most likely to receive care from group rather than solo practitioners. The patients of high and very high volume surgeons were also the most likely to receive care from surgeons practicing in urban centers.

Relationship between volume and postoperative procedural interventions

The risk of a postoperative complication that required operative or procedural intervention is the lowest among patients operated on by the small subset of very high volume surgeons. For virtually all surgeon characteristics examined, the patients of very high volume surgeons had the lowest rates of PPI (Table 4). There were no patients of very high volume surgeons who underwent rectal cancer resections in very low volume hospitals. The lowest PPI rates for patients of medium, high, and very high volume surgeons were obtained in very high volume hospitals. For patients of medium and high volume surgeons, PPI rates diminished with increasing hospital volume. But for patients of very low and low volume surgeons, PPI rates remain high (7%), even in the very high volume hospitals.

To interpret the roles of patient, surgeon, and hospital factors in the relationship between volume and postoperative procedural interventions, we developed a series of logistic regression models (Table 5). The unadjusted odds ratio of patients requiring a PPI is 0.53 if a very high volume surgeon treats them rather than a very low volume surgeon. The addition of patient clinical factors (model 2) does not substantially change the odds ratio for this group of patients receiving care from very high volume surgeons, although the addition of patients' contextual factors lowers the odds ratio to 0.47. Adjustment for surgeon board certification accounts for some of the volume-PPI relationship, but does not change the significance of the relationship between PPI and very high volume (model 4). Interestingly, specialty board certification in colorectal surgery was not independently associated with PPI when added to the model. The addition of surgeon age to the model, as an indicator of surgical experience, accounts for more of the PPI-volume relationship, and widens the 95% confidence interval for the very high surgical volume variable to include 1.0. Surgeon age was selected as an indicator of overall experience rather than years in practice because it improved the fit of the model by the greatest degree. The addition of hospital characteristics to the model does not change the odds ratio substantially, nor does the addition of hospital characteristics to the model before the addition of surgeon characteristics change the odds ratio. Logistic regression models also were developed that included adjustment for the use of neoadjuvant radiation therapy. Neoadjuvant therapy had no association with postoperative complications and the addition of the variable did not improve the model fit. To assess the relationship between surgeon volume and PPI, patients of different surgeon volume groups were used as the referent group. We found that patients of very high volume surgeons had considerably lower odds of PPI (odds ratio 0.48; 95% CI 0.27 to 0.86) even when they were compared with patients of high volume surgeons as the referent group (rather than very low, low, or medium volume).

DISCUSSION

Much previous research on the volume-outcomes relationship in surgery has centered on postoperative mortality for high risk operations. In this report, we focused on rectal cancer resection, an operation that has a lower associated mortality rate, but is nonetheless technically demanding and may be associated with a variety of clinically marked complications. This study focused on the relationship between volume and the subset of nonfatal complications that require procedural treatment. We found that in unadjusted analyses, surgeon volume has an association with this subset of major postoperative complications.

The patients of very high volume surgeons had the lowest complication rate (3.0%) among patients of the different volume groups, and considerably lower odds of complications compared with patients of low volume surgeons (unadjusted odds ratio 0.53; 95% CI 0.31 to 0.92). One of the aims of this study was to identify potentially modifiable characteristics of surgeons or hospitals that might explain volume related differences in outcomes. Data from our regression analysis suggest that there are few substitutes for surgeon practice volume to decrease complication rates. Although the majority of the very high volume surgeons in the study were board certified in colorectal surgery, board certification was not independently associated with PPI. The addition of the board certification variable reduced the significance of the association between volume and complications only slightly in logistic regression modeling (model 4, Table 5). The addition of hospital variables to the model changed the odds ratio very little, suggesting minimal confounding from hospital related characteristics.

The addition of surgeon age to the model had a limited effect on the odds ratio for PPI, but did widen the confidence interval to include 1.0. The greatest volume related variability in outcomes occurs among the youngest group of surgeons (Table 4). Particularly for low volume surgeons, it may be that experience accumulated over years of practice allows mature surgeons to compensate for the low volume practice. It is not clear why older surgeons appear to have an increase in complication rates. Although we may speculate that this effect is related to declining technical skills, the data in this report do not provide sufficient detail to answer this question.

We have previously reported on the relationship between surgeon and hospital volume and outcomes after colon cancer surgery.[17] Similar to results of this study, we found that surgeon practice volume was associated with postoperative complications requiring procedural interventions for management. For colon cancer, we found that hospital characteristics, particularly the presence of multiple specialty services, explained a component of the volume-outcomes effect. Other investigators have studied the relationship between both volume and specialty training and colorectal surgical outcomes. Porter and colleagues[18] demonstrated that both specialty training and practice volume were associated with lower local disease recurrence and disease-specific mortality. Hodgson and colleagues[19] showed that higher hospital volume was notably associated with lower colostomy rates and lower 30-day and 2-year mortality rates. Although very few studies have examined the relationship between rectal surgery volume and complications, Harmon and associates[20] found that increased surgeon volume was associated with notably decreased hospital death rate, length of stay, and cost, and that medium volume surgeons achieve mortality rates equivalent to those of high volume surgeons if they operate in a high volume hospital.

Why do a small group of very experienced, high volume surgeons operate with fewer complications requiring procedural management when compared with lower volume surgeons? It is possible that there are certain technical practices that high volume surgeons develop that allow them to perform rectal cancer surgery with a higher degree of safety. More likely, however, is that very high volume surgeons acquire a degree of sophistication in their clinical decision-making that is difficult to quantify but may contribute to more favorable clinical outcomes. This type of clinical judgment in rectal cancer surgery relates to patient selection for surgery and the selective use of diverting stomas for low rectal anastomoses. We found that when surgeon age is added to the logistic regression model, surgeon volume is no longer noted as a predictor of complications. These findings suggest that high volume practice may represent practice experience, which, in turn, contributes to accurate clinical decision-making (clinical judgment).

This study is limited by its use of PPI as the marker for surgical complications. We used this subset of procedurally managed complications because they are reliably captured in administrative data[21] and are more accurate than specific diagnosis codes.[22] Our group analyzed this marker for complications and demonstrated its association with increased postoperative mortality and extended hospitalizations.[23] Despite these advantages, this definition of complications does not account for a variety of other clinically significant complications that are managed without procedures (eg, pneumonia, urinary tract infection, deep venous thrombosis, and pulmonary embolism). In addition, this study does not examine functional outcomes, quality of life, and disease-free survival, some of the most important outcomes in rectal cancer treatment. Analysis of these important outcomes will require careful, prospective data collection.

Another limitation of this study relates to the inherent inadequacies of case mix adjustment techniques. The logistic regression analysis in this study is designed to adjust for measurable confounders such as age, stage, comorbidity, and the use of neoadjuvant chemoradiotherapy. It remains possible that there are unmeasured confounders that may affect postoperative complication rates. We have observed that measured comorbidity was similar between groups of patients treated by surgeons of different practice volumes. But we also have observed that the very high volume surgeons operate on a patient group with the highest proportion from the upper socioeconomic stratum and the lowest proportion of non-Caucasian patients. These differences may be associated with accompanying differences in health status that are difficult to capture using the methods of this study.

There is a variety of exclusion criteria that are necessary to define the study population, yet these exclusions, by definition, limit the generalizability of the findings somewhat. For example, requiring that all study patients are enrolled in fee-for-service Medicare for the year before and 6 months after the cancer diagnosis resulted in a study population that has fewer racial and ethnic minorities, yet more comorbidity than those excluded. The criterion that study patients had a surgical resection within 6 months and had no earlier colorectal cancer resulted in a study population with a lower proportion of stage I cancers than those excluded. All excluded patients (n = 4,618) were less likely to be admitted to the hospital under emergent conditions and to present with bowel obstruction. Additional research in managed care settings rather than fee-for-service settings would help determine the generalizability of this research. But this study’s findings are derived from the broadest possible population-based sample of patients, and they represent the patterns of care and outcomes for the majority of patients with rectal cancer.

Our results suggest that rectal cancer surgery is performed with a fairly consistent margin of safety, with an overall PPI rate of 5.5%. We have found that among patients of the very highest volume group of surgeons, the subset of major surgical complications is reduced from 6% to approximately 3%, suggesting that surgeon experience does exert an effect on outcomes in rectal cancer surgery. But once adjusted for surgeon age, the volume related differences in PPI are no longer meaningful. This underscores the complexity of the volume-outcomes relationship. Although such a relationship is likely to be present in rectal cancer, it is much smaller than in more high risk operations, and may represent more than simply the number of procedures performed. Additional research involving detailed, prospectively collected clinical data will be required to identify the elements of technical performance or clinical decision-making that are associated with high volume surgeons, and contribute to a reduction in complications. Our data suggest that volume criteria alone should not be used to assess the quality of rectal cancer surgery. Volume was associated with a decrease in complications for the patients of only the very high volume group of surgeons, and these surgeons cared for only about 10% of all rectal cancer patients. It is not possible for high volume surgeons to care for all rectal cancer patients. We believe that our data support the study of focused educational programs that highlight rectal cancer surgical techniques for practicing surgeons, rather than a program of regionalization of rectal cancer surgical care. These programs should involve both technical training and instruction from experienced surgeons about the decision-making process involved in patient selection and management for rectal cancer procedures.

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Table 1

Surgeon and Hospital Rectal Cancer Surgery Volumes

Volume groups*	Total	Very low	Low	Medium	High	Very high
Surgeon volume		1–2 operations	3–5 operations	6–12 operations	13–19 operations	≥20 operations
Surgeons, n (%)	1,884	1,023 (54.3)	510 (27.1)	258 (13.7)	65 (3.5)	28 (1.5)
Median cases, n		1	4	7	14	22
Patients, n (%)	6,000	1,290 (21.5)	1,577 (26.3)	1,682 (28.0)	843 (14.1)	608 (10.1)
Hospital volume		1–17 operations	18–35 operations	36–51 operations	52–79 operations	≥80 operations
Hospitals, n (%)	516	353 (68.4)	90 (17.4)	44 (8.5)	19 (3.7)	10 (1.9)
Median cases, n		4	25	42	58	80
Patients, n (%)	6,182	1,497 (24.2)	1,677 (27.1)	1,437 (23.2)	815 (13.2)	756 (12.2)

*Total volume over 8-year study period.

Percentages may not add to 100 because of rounding errors.

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Table 2

Patient Characteristics by Surgeon and Hospital Volume

		Surgeon volume					Hospital volume				
Patient characteristics	**Total n (%)**	**Very low**	**Low**	**Medium**	**High**	**Very high**	**Very low**	**Low**	**Medium**	**High**	**Very high**
Total cohort, n		1,290	1,577	1,682	843	608	1,497	1,677	1,437	815	756
Age, y, %											
66–69	1,142 (18.3)	19.2	17.9	16.4	19.6	18.8	17.8	18.0	18.8	19.8	17.1
70–74	1,643 (26.3)	26.6	26.6	25.9	25.7	25.7	24.8	26.1	26.9	25.6	28.2
75–79	1,522 (24.3)	21.9	25.1	25.5	24.3	25.7	22.7	25.4	24.2	25.2	25.0
≥ 80	1,951 (31.2)	32.3	30.4	32.2	30.4	29.9	34.8	30.5	30.1	29.5	29.8
Gender, %											
Male	3,270 (52.3)	50.7*	53.1	53.4	52.1	50.3	51.5	54.0	51.6	51.8	50.5
Female	2,988 (47.8)	49.3	46.9	46.6	47.9	49.7	48.5	46.0	48.4	48.2	49.5
Marital status (%)											
Divorced/separated/single	734 (11.9)	14.7*	13.0	9.5	11.0	10.1	13.0	10.9	11.3	14.2	10.8
Married	3,503 (56.9)	54.7	56.6	58.0	57.9	58.6	54.7	57.5	58.2	55.9	58.2
Widowed	1,919 (31.2)	30.7	30.4	32.5	31.1	31.4	32.2	31.6	30.6	30.0	31.0
Race/ethnicity, %											
Caucasian	5,399 (86.3)	79.0†	85.7	90.4	87.0	94.4	81.0†	85.1	93.7	79.8	92.4
African-American	261 (4.2)	5.9	4.9	1.7	4.3	3.0	6.0	3.1	2.3	8.5	1.9
Other/unknown	53 (0.9)	0.6	1.5	0.8	0.6	0.3	1.1	1.0	0.6	1.1	0.4
Asian/Pacific Islander	281 (4.5)	6.7	4.2	3.9	5.7	0.8	4.4	6.6	1.4	8.3	2.1
Hispanic	260 (4.2)	7.8	3.7	3.3	2.5	1.5	7.4	4.3	2.1	2.3	3.2

Patient characteristics	Total n (%)	Surgeon volume					Hospital volume				
		Very low	Low	Medium	High	Very high	Very low	Low	Medium	High	Very high
Cancer stage, %											
I	2,790 (44.6)	41.4	43.5	46.7	45.1	47.4	45.2	45.0	45.0	42.8	44.1
II	1,820 (29.1)	31.3	29.1	27.9	26.6	28.5	28.6	29.1	29.9	29.0	28.3
III	1,648 (26.3)	27.3	27.4	25.4	28.4	24.2	26.3	25.9	25.1	28.2	27.7
T stage, %											
T0	57 (0.9)	0.8	0.6	1.0	0.8	1.3	1.1	1.0	0.7	1.0	0.5
T1	1,496 (23.9)	22.2	24.2	23.1	25.9	24.2	24.2	24.5	23.7	22.5	24.6
T2	1,566 (25.0)	24.3	24.0	27.5	23.7	26.6	24.7	25.2	26.0	23.8	25.0
T3	2,877 (46.0)	48.1	46.5	44.7	44.8	45.7	45.5	44.9	45.2	49.1	47.0
T4	262 (4.2)	4.6	4.6	3.9	4.7	2.1	4.6	4.5	4.5	3.7	2.9
Comorbidity score, %											
0	3,200 (51.1)	51.0	48.5	52.6	51.8	50.8	51.2	52.4	49.7	51.4	51.6
1	1,365 (21.8)	21.2	21.1	22.5	22.5	22.9	22.9	20.4	21.3	22.1	23.0
2+	1,693 (27.1)	27.8	30.4	25.0	25.6	26.3	25.9	27.3	29.0	26.5	25.4
Emergent admission, %											
No	5,725 (91.4)	88.9[†]	92.3	91.4	92.5	94.2	90.1	92.3	91.2	90.8	93.0
Yes	533 (8.6)	11.1	7.7	8.6	7.5	5.8	9.9	7.7	8.8	9.2	7.0
Perforation, %											
No	6,214 (99.3)	99.5	99.1	99.2	99.8	99.5	99.1	99.4	99.2	99.3	99.7
Yes	43 (0.7)	0.5	0.9	0.8	0.2	0.5	0.9	0.6	0.8	0.7	0.3
Obstruction, %											
No	5,922 (94.6)	93.5	94.5	94.9	95.3	95.9	94.1	94.7	95.1	96.1	93.3

Patient characteristics	Total n (%)	Surgeon volume					Hospital volume				
		Very low	Low	Medium	High	Very high	Very low	Low	Medium	High	Very high
Yes	36 (5.4)	6.5	5.5	5.1	4.7	4.1	6.0	5.3	4.9	3.9	6.7
Median household income, $, %											
< 25,000	210 (3.5)	4.9†	3.5	2.0	3.1	3.1	4.6†	2.3	1.9	7.4	2.6
25,001–35,000	1,007 (16.6)	18.7	18.3	17.2	14.7	10.0	24.9	16.2	11.8	14.8	12.5
35,001–45,000	1,660 (27.4)	24.4	26.6	31.0	31.2	22.2	31.4	29.6	24.3	26.5	21.6
≥ 45,000+	3,179 (52.5)	52.1	51.6	50.0	50.9	64.8	39.2	51.9	61.9	51.3	63.3
Registry, %											
San Francisco	479 (7.7)	9.1†	8.8	6.0	8.0	4.6	6.5†	8.3	11.3	9.2	0.1
Connecticut	953 (15.2)	11.5	14.3	15.5	11.5	28.5	6.0	8.9	24.0	15.3	31.1
Michigan	958 (15.3)	10.6	12.4	14.3	24.2	22.0	7.2	12.6	15.5	24.8	26.7
Hawaii	153 (2.4)	3.6	2.9	1.7	3.1	0	2.0	3.5	0.0	7.7	0.0
Iowa	1,127 (18.0)	11.1	16.7	23.7	24.3	14.8	26.1	14.5	17.9	18.8	9.4
New Mexico	257 (4.1)	7.0	5.1	3.0	3.4	0	7.6	3.5	0.0	2.7	7.8
Seattle	681 (10.9)	8.1	10.8	13.0	8.2	14.3	7.8	19.3	7.0	6.0	10.5
Utah	309 (4.9)	5.0	3.9	5.4	4.2	8.1	4.7	4.5	7.3	0.0	7.5
Atlanta	258 (4.1)	5.4	5.0	2.8	2.9	4.9	5.9	3.8	4.7	4.5	0.0
San Jose	315 (5.0)	4.4	6.2	7.4	2.9	0	2.8	5.7	5.4	4.8	6.9
Los Angeles	743 (11.9)	23.1	13.2	7.3	7.5	2.6	21.9	15.4	6.8	6.1	0.0
Rural Georgia		1.1	0.6	0	0	0.2	1.5	0	0.1	0.0	0.0
Year of diagnosis, %											
1991	17 (0.3)	0.2‡	0.3	0.2	0.1	0.3	0.1	0.4	0.4	0.3	0.1

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		Surgeon volume					Hospital volume				
Patient characteristics	Total n (%)	Very low	Low	Medium	High	Very high	Very low	Low	Medium	High	Very high
1992	865 (13.8)	16.0	11.5	13.8	10.4	13.2	14.6	12.9	14.9	12.8	13.0
1993	841 (13.4)	14.0	14.2	12.5	12.5	12.3	14.5	12.9	13.4	12.6	12.4
1994	789 (12.6)	13.9	13.2	13.1	10.9	9.5	14.6	12.8	10.9	11.5	12.4
1995	745 (11.9)	9.7	13.8	11.3	12.8	13.0	11.2	10.8	12.5	14.0	12.8
1996	761 (12.2)	10.7	11.7	13.5	12.3	14.6	12.1	12.1	12.0	12.0	13.4
1997	748 (11.9)	10.4	12.6	13.0	12.9	10.7	10.4	13.0	11.6	13.9	11.5
1998	766 (12.2)	12.0	11.8	13.0	12.7	13.7	12.2	13.0	11.8	11.2	12.7
1999	726 (11.6)	13.2	11.0	9.6	15.4	12.7	10.3	12.1	12.6	11.8	11.6

[*] Overall chi-square p value ≤ 0.01.

[†] Overall chi-square p value ≤ 0.001.

[‡] Overall chi-square p value ≤ 0.0001.

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Table 3

Proportion of Patients Cared for by Different Types of Surgeons by Surgeon Volume

Surgeon characteristics*	Total surgeons, n	Total patients, n	Surgeon volume				
			Very low, %	Low, %	Medium, %	High, %	Very high, %
Total cohort	1,884	6,000	1,290	1,577	1,682	843	608
Gender†							
Male	1,728	5,592	92.9	95.7	96.9	96.7	85.0
Female	113	327	7.1	4.3	3.1	3.3	15.0
Age† y							
< 40	795	1,155	21.3	21.4	18.5	13.2	22.7
40–49	1,568	2,296	29.6	37.3	39.1	44.5	52.8
50–59	1,185	1,639	26.0	24.1	30.2	36.7	21.2
≥ 60	666	829	23.1	17.3	12.2	5.7	3.3
Practice location†							
Urban	1,586	4,768	82.6	79.1	74.2	79.5	89.9
Large rural	192	437	5.7	7.9	9.4	7.2	3.3
Small rural	214	386	5.4	6.4	7.6	8.0	3.6
Isolated rural	242	397	6.4	6.6	8.8	5.3	3.1
Board certification†							
General surgery	1,440	3,960	81.0	83.7	73.9	39.5	13.8
Colorectal surgery	185	1,489	4.6	7.2	18.8	57.4	86.2
Board certified, but not in GS, CR	18	27	1.4	0.3	0.4	0.0	0.0
No certification	198	443	13.1	8.9	6.9	3.1	0.0
Years of practice†							
0–14	1,108	1,616	27.9	29.7	24.6	23.5	32.7
15–24	1,435	2,060	27.2	32.4	35.5	39.6	45.4
25–34	1,119	1,573	24.9	23.3	30.1	32.9	20.2
≥ 35	552	670	20.0	14.7	8.9	4.0	1.6
Hospital volume†							

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Surgeon characteristics*	Total surgeons, n	Total patients, n	Surgeon volume				
			Very low, %	Low, %	Medium, %	High, %	Very high, %
Very low	768	1,432	45.6	28.2	19.3	7.3	4.7
Low	589	1,607	24.4	32.7	31.4	26.2	7.4
Medium	411	1,391	15.0	20.7	29.3	27.3	26.7
High	238	773	9.4	10.6	10.6	24.0	18.5
Very high	162	732	5.6	7.8	9.4	15.2	42.7
Solo practice†							
No	1,074	3,594	56.8	59.7	60.1	60.1	73.9
Yes	767	2,325	43.2	40.3	39.9	39.9	26.2

*Missing cases for the surgeon volume analysis: gender, age, board certification, years of practice, solo practice = 81 patients, area of practice = 12 patients, hospital volume = 65 patients.

†Overall chi-square significance at ≤0.001.

CR, colorectal surgery; GS, general surgery.

Table 4

Unadjusted Postoperative Procedural Intervention Rates among Patients of Surgeons with Different Surgeon Characteristics by Surgeon Volume Group

		Surgeon volume groups				
Surgeon characteristics	**n**	**Very low, PPI rate (CI)**	**Low, PPI rate (CI)**	**Medium, PPI rate (CI)**	**High, PPI rate (CI)**	**Very high, PPI rate (CI)**
All surgeons	6,000	5.9 (4.6–7.2)	5.9 (4.7–7.1)	5.5 (4.4–6.6)	6.2 (4.5–7.8)	3.0 (1.6–4.3)
Gender						
Male	5,592	5.7 (4.4–7.0)	6.0 (4.8–7.2)	5.6 (4.5–6.7)	6.0 (4.4–7.6)	3.3 (1.8–4.8)
Female	327	9.0 (3.0–14.9)	4.5 (0.5–9.4)	3.8 (1.4–9.1)	10.7 (0.7–22.2)	1.1 (1.0–3.2)
Surgeon age, y						
< 40*	1,155	9.0 (3.4–5.6)	5.7 (3.2–8.2)	5.2 (2.7–7.7)	2.7 (0.3–5.7)	2.2 (0.3–4.6)
40–49	2,296	4.1 (2.0–6.1)	5.7 (3.8–7.6)	4.8 (3.1–6.4)	4.8 (2.6–7.0)	3.1 (1.2–5.0)
50–59	1,639	4.3 (2.1–6.5)	6.1 (3.7–8.6)	5.6 (3.6–7.6)	7.1 (4.3–10.0)	3.1 (0.1–6.1)
≥ 60	829	7.3 (4.3–10.3)	6.3 (3.4–9.2)	8.4 (4.6–12.2)	18.8 (7.7–29.8)	5.0 (4.6–14.6)
Practice location						
Urban	4,768	5.7 (4.3–7.1)	5.9 (4.6–7.3)	5.2 (4.0–6.5)	5.7 (3.9–7.4)	3.3 (1.8–4.8)
Large rural	437	5.5 (0.3–10.7)	8.0 (3.2–12.8)	5.1 (1.6–8.5)	4.9 (0.5–10.3)	0
Small rural	386	7.2 (1.1–13.4)	4.0 (0.2–7.8)	8.6 (3.7–13.4)	10.4 (3.1–17.8)	0
Isolated small rural	397	7.3 (1.7–13.0)	3.8 (0.2–7.5)	4.1 (0.9–7.3)	8.9 (0.6–17.2)	0
Board certification						
General surgery	3,960	5.7 (4.3–7.2)	5.8 (4.6–7.1)	5.5 (4.3–6.8)	4.8 (2.5–7.1)	2.4 (0.9–5.6)
Colorectal surgery	1,489	3.5 (1.3–8.3)	3.6 (0.1–7.0)	4.5 (2.2–6.8)	6.6 (4.4–8.8)	3.1 (1.6–4.5)
Board certified, but not GS, CR	27	5.9 (−.5.3–17.1)	0	0	0	0
No certification	443	7.9 (3.8–12.1)	8.7 (4.0–13.4)	8.7 (3.5–13.8)	15.4 (1.5–29.3)	0
Years in practice						
1–14	1,616	7.4 (4.7–10.2)	5.4 (3.3–7.5)	5.4 (3.2–7.6)	4.0 (1.3–6.8)	2.5 (0.3–4.7)
15–24	2,060	4.7 (2.5–7.0)	6.2 (4.1–8.2)	4.5 (2.8–6.1)	4.5 (2.3–6.7)	2.5 (0.7–4.4)
25–34	1,573	5.1 (2.7–7.6)	6.1 (3.6–8.5)	6.2 (4.1–8.3)	9.4 (6.0–12.8)	4.9 (1.1–8.7)
≥ 35	670	6.4 (3.4–9.4)	6.1 (3.0–9.2)	8.2 (3.7–12.6)	8.8 (0.7–18.4)	0
Hospital volume						
Very low	1,432	5.0 (3.2–6.8)	5.7 (3.5–7.8)	4.0 (1.9–6.2)	8.2 (1.3–15.1)	0

		Surgeon volume groups				
Surgeon characteristics	**n**	**Very low, PPI rate (CI)**	**Low, PPI rate (CI)**	**Medium, PPI rate (CI)**	**High, PPI rate (CI)**	**Very high, PPI rate (CI)**
Low	1,607	5.8 (3.2–8.4)	5.5 (3.5–7.5)	6.1 (4.1–8.2)	8.3 (4.6–11.9)	11.4 (2.0–20.7)
Medium	1,391	7.3 (3.6–11.0)	4.6 (2.3–6.9)	6.6 (4.4–8.8)	5.3 (2.4–8.2)	1.9 (0.2–4.0)
High	773	5.8 (1.6–10.0)	7.8 (3.7–11.9)	4.5 (1.5–7.6)	5.5 (2.4–8.7)	5.4 (1.2–9.6)
Very high*	732	7.0 (1.1–13.0)	8.2 (3.3–13.1)	2.6 (0.1–5.0)	4.0 (0.6–7.4)	1.6 (0.0–3.1)
Solo practice						
No	3,594	5.5 (3.8–7.2)	5.9 (4.4–7.4)	4.9 (3.6–6.2)	6.1 (4.0–8.2)	2.9 (1.3–4.4)
Yes	2,325	6.5 (4.4–8.6)	5.9 (4.1–7.7)	6.5 (4.6–8.4)	6.3 (3.7–8.8)	3.1 (0.4–5.9)

PPI rates are the percentage of patients undergoing postoperative procedural intervention. Negative numbers in confidence intervals relate to sample size < 50 in the cell.

*Individual row chi-square $p \leq 0.05$.

CR, colorectal surgery; GS, general surgery; PPI, postoperative procedural intervention.

Table 5

Odds of Postoperative Procedural Intervention Before and After Adjustment for Demographic, Clinical, Contextual, Surgeon, and Hospital Characteristics

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Surgeon volume	**Unadjusted crude 30-day postprocedural intervention rate, % n = 5,573**	**Unadjusted model, OR (95% CI)**	**Model 1 plus patient demographics, clinical characteristics, and acuity, OR (95% CI)*†**	**Model 2 plus contextual characteristics, OR (95% CI)*‡**	**Model 3 plus surgeon board certification, OR (95% CI)***	**Model 4 plus surgeon age, OR (95% CI)***	**Model 5 plus hospital ownership, OR (95% CI)*§**
Very low	5.5	1.0	1.0	1.0	1.0	1.0	1.0
Low	6.0	1.08 (0.74–1.58)	1.08 (0.77–1.51)	1.02 (0.73–1.44)	1.05 (0.74–1.47)	1.08 (0.77–1.52)	1.08 (0.77–1.52)
Medium	5.2	0.94 (0.67–1.31)	0.95 (0.68–1.34)	0.87 (0.61–1.24)	0.91 (0.64–1.30)	0.96 (0.67–1.38)	0.95 (0.67–1.37)
High	6.2	1.13 (0.77–1.66)	1.16 (0.79–1.70)	1.04 (0.70–1.54)	1.12 (0.72–1.74)	1.22 (0.78–1.92)	1.19 (0.76–1.87)
Very high	3.0	0.53 (0.31–0.92)	0.55 (0.32–0.95)	0.47 (0.27–0.82)	0.51 (0.27–0.97)	0.57 (0.30–1.08)	0.57 (0.30–1.09)

n = 5,573 because of missing patients. Total n with surgeon and hospital data = 5,935; missing marital status = 93; missing race = 4; missing income = 189; missing surgeon age = 76. Because of missing cases, the unadjusted postprocedural intervention rates are different from those in Table 4.

*Because our outcome, PPI, was uncommon in the study population, the adjusted odds ratio derived from the logistic regression approximates the risk ratio.

†Age, gender, marital status, race/ethnicity, stage, T stage, comorbidity, tumor obstruction, tumor perforation, emergent admission.

‡ZIP code-based median income, year of diagnosis, SEER registry.

§Hospital ownership (government, profit, non-profit).

OR, odds ratio; PPI, postoperative procedural intervention; SEER, Surveillance, Epidemiology, and End Results.