Can postoperative process of care utilization or complication rates explain the volume-cost relationship for cancer surgery?

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Background. *Past studies identify an association between provider volume and outcomes, but less is known about the volume-cost relationship for cancer surgery. We analyze the volume-cost relationship for 6 cancer operations and explore whether it is influenced by the occurrence of complications and/or utilization of processes of care.*

Methods. *Medicare hospital and inpatient claims for the years 2005 through 2009 were analyzed for 6 cancer resections: colectomy, rectal resection, pulmonary lobectomy, pneumonectomy, esophagectomy, and pancreatic resection. Regressions were first estimated to quantify the association of provider volume with costs, excluding measures of complications and processes of care as explanatory variables. Next, these variables were added to the regressions to test whether they weakened any previously observed volume-cost relationship.*

Results. *Higher hospital volume is associated with lower patient costs for esophagectomy but not for other operations. Higher surgeon volume reduces costs for most procedures, but this result weakens when processes of care are added to the regressions. Processes of care that are frequently implemented in response to adverse events are associated with 14% to 34% higher costs. Utilization of these processes is more prevalent among low-volume versus high-volume surgeons.*

Conclusion. *Processes of care implemented when complications occur explain much of the surgeon volume–cost relationship. Given that surgeon volume is readily observed, better outcomes and lower costs may be achieved by referring patients to high-volume surgeons. Increasing patient access to surgeons with lower rates of complications may be the most effective strategy for avoiding costly processes of care, controlling expenditure growth. (Surgery 2017;162:418-28.)*

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Cancer is the second most costly medical condition in the United States with total direct expenses reaching over 88.6 billion in 2011.[1] In a survey conducted in early 2010 by the American Cancer Society Cancer Action Network, 12% of the respondents put off getting a recommended cancer treatment or test due to costs, and 20% of families with someone with cancer have trouble paying for basic necessitates or other bills.[2] Since the costs of cancer care are expected to rise more quickly than overall medical expenditures,[3] costs will continue to be a burden for cancer patients and the overall health system that must be addressed.

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Vivian Ho and Marah N. Short had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Although several studies have examined the association between case volume and patient costs for complex cancer operations, a thorough examination of cost triggers is lacking. Some studies analyzed the association between hospital volume and costs, without adjusting for a potential association between surgeon volume and costs.[4-6] Other studies examined the relationship between provider volume and hospital charges, even though charges may not reflect the true cost of providing care.[7-12] Finally, some studies examined only one procedure, one US state or a socialized health care system (the United Kingdom).[7-13] Understanding the nature of the volume-cost relationship would aid in determining whether directing cancer patients to high-volume providers would be a means to control rising health care costs.

Previous research indicated that high surgeon volume, rather than high hospital volume, is associated with lower costs for cancer operations.[14] More recent work corroborated the lack of association between hospital volume and costs but did not examine surgeon volume.[15] Other previous work showed that complications and use of processes of care increase costs.[15-17] This study builds on the previous research by seeking to determine which practice differences are driving factors for the volume-cost relationship. This knowledge may be used to generate better-targeted policies that focus on changes that facilitate more cost-effective behavior across the spectrum of surgeon and/or hospital volume.

METHODS

The analytical methods used were similar to our previously published studies of the association between operative complications and costs[16] and the association between processes of care and costs.[17] Patient-level Medicare claims data from all 50 states for the years 2005-2009 were searched to identify patients with International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis and procedure codes who underwent one of the resections in this study[14]: colectomy, rectal resection, pulmonary lobectomy, pancreatic resection, esophagectomy, and pneumonectomy. The 100% Medicare Provider and Analysis Review files were merged with the Carrier files in order to obtain both hospital- and surgeon-related charges for each inpatient stay where resection occurred. ICD-9-CM diagnosis and procedure codes were used to confirm that the cancer indication matched the resection type as a requirement for inclusion in the study.[14] This study was approved by Rice University's Institutional Review Board.

Costs and volume. The Medicare Provider and Analysis Review data provided detailed information on hospital charges by revenue center for each discharge. Hospital charges are drawn from each hospital's chargemaster, which lists a fee that the hospital associates with each single procedure and supply item used for a patient's care.[18] Charges were deflated by the All-Urban Consumer Price Index to reflect 2005 dollars. After previously published studies, costs for each hospital stay were estimated by multiplying the reported patient charge by the hospital's cost-to-charge ratio in the same year.[14,19-23]

Medicare and other insurers do not require physicians to file cost reports, so we have no comprehensive source of data on physician costs. Instead, all physician billings to Medicare for the patient's hospital stay were identified in the Carrier claims files and summed to represent physician costs associated with the admission. While physician billings do not represent the resource costs of physician labor, they do reflect the amount that society must incur for the care of cancer patients covered by Medicare.

Hospital and physician costs were then summed to calculate the explanatory variable of total costs for the entire inpatient stay. Hospital procedure volume was constructed by summing the total number of operations performed by each hospital in each year for each of the 6 cancer resections. Surgeon volume was calculated in the same manner.

Complications and processes of care. Complications were identified using the Agency for Healthcare Research and Quality hospital-level Patient Safety Indicators (PSI) methodology.[16,24-26] These indicators focus on potentially preventable instances of complications and other iatrogenic events resulting from exposure to the health care system. Processes of care represent actions that providers take to achieve high-quality care and/or favorable patient outcomes.[27]

After previous research on the volume and process of care in high-risk cancer operations for various cancers,[17,28,29] the processes used were identified using ICD-9-CM procedure codes and Current Procedure Terminology (CPT) codes in the claims data. These processes are mostly items that are potentially optional and pre-emptively controllable by the operative and anesthetic teams, but they also include services that are used to avoid and/or ameliorate complications. Some of the processes are intraoperative, and some are postoperative.

The specific codes were obtained from a previous study[29] that defined processes based on a comprehensive literature review (including the literature on hospital safety practices) supplemented by the input of clinician experts. Once a candidate list was developed, ICD-9 and CPT coding manuals were consulted, and pilot tests were conducted to determine the subset of processes that could be measured in inpatient and outpatient claims data.

Hospital, surgeon, and patient characteristics. Data from the American Hospital Association Annual Survey of hospitals was used to create indicator variables for complex medical technologies, which are more likely to be at high-volume hospitals (whether the treating hospital has a computed tomography scanner, magnetic resonance imaging, and positron emission tomography), and the nurse-to-patient ratio. In addition, hospital-specific indicator variables were used to control for all observed and unobserved characteristics such as a hospital's reputation for high quality in the community.

Patient-level characteristics used for risk adjustment include sex, age, race, and income. Secondary diagnosis codes were used to construct indicator variables for the 29 conditions comprising the Elixhauser comorbidity index.[30] Indicator variables were included for transfer patients and patients who had urgent/emergency admissions. Cancer stage was measured using secondary diagnosis codes for nodal involvement and organ metastasis.[7]

To adjust for disease-specific differences in procedure complexity and patient casemix, indicator variables were defined for particular operations and operative approaches specific to each procedure. Operating room time was measured as total hours claimed for anesthesia.[17,29] Procedure and tumor sites were defined on the basis of previous studies of these operations that used ICD-9-CM procedure and diagnosis codes.[7,31-35] The Medicare Physician Identification and Eligibility Registry file was used to identify the subspecialty of the surgeon operating on each patient.

Statistical analysis. Regressions were estimated separately for each of the 6 cancer resections using the natural log of total costs as the dependent variable. The explanatory variables of interest are the number of resections of the same type performed by the patient's surgeon and hospital in the calendar year, PSIs, and processes of care. We adjusted for the hospital, surgeon, and patient characteristics listed above. All regressions were performed using panel data methods, which involves the inclusion of year and hospital fixed effects. The 0/1 indicator variables for each hospital imply that volume coefficients quantify the relationship between within-hospital changes in volume and costs. Regressions were estimated using the xtreg command in Stata 12.1 (StataCorp, College Station, TX) with specifications to provide robust standard errors that account for clustering of patient data within hospitals.

Regressions were first performed excluding PSIs and processes of care. We used Stata's mfp command to fit a multivariable fractional polynomial model for each procedure. Those polynomial models are flexible regression specifications that yield the best possible fit for the association between volume and costs. We looked for instances where the coefficient(s) on surgeon or hospital volume were statistically significant ($P \leq .05$). Next, we re-estimated the regressions adding each group of factors (ie, PSIs and processes of care) individually and then jointly. We then checked whether the coefficient(s) on provider volume changed from being statistically significant to insignificant. We used the statistically significant coefficients on provider volume to predict the change in costs that would result from receiving an operation from a provider at the 5th, 50th, and 95th percentile of the volume distribution.

RESULTS

Table I illustrates the differences in the procedures examined and the magnitude of the costs associated with them. The number of procedures performed in our sample varies from 2,981 pneumonectomies up to 150,733 colectomies. The median costs of an admission with resection range from $14,959 for colectomy up to $34,287 for esophagectomy.

Table II compares the PSI and process of care rates between the highest and lowest tertiles of surgeon volume for each procedure. Differences in the PSI rates between tertiles are small and few are statistically significant. Not many are greater than 1 percentage point, and none are greater than 5 percentage points. Where there are statistically significant differences between the surgeon groups for processes of care, higher-volume surgeons tend to use fewer processes than low-volume surgeons, although higher-volume surgeons tend to use more arterial lines and epidural anesthesia paired with daily epidural management. Higher-volume surgeons tend to have lower rates of transfusions, consultations, and total parenteral nutrition (TPN) than low-volume surgeons. The differences are more pronounced for less common operations.

Table I. Summary of total inpatient costs by procedure

	N	*Min*	*Max*	*Median*	*Mean*
Colectomy	150,733	$2,274	$429,176	$14,959	$20,163
Pulmonary lobectomy	52,202	$4,155	$522,620	$17,830	$22,907
Rectal resection	25,892	$2,349	$201,246	$15,473	$20,063
Pancreatic resection	12,135	$6,818	$622,543	$28,799	$38,661
Esophagectomy	3,857	$8,922	$488,187	$34,287	$49,997
Pneumonectomy	2,981	$6,225	$295,048	$19,846	$27,553

For brevity, we report estimates of the relation between provider volume and costs from the cost regressions in the Supplementary Table. We found that esophagectomy is the only procedure of the 6 we studied that exhibits a statistically significant relationship between higher volume and lower costs. The relationship was strictly linear. Using regression estimates that excluded PSIs and processes of care, each additional esophagectomy performed per year at a hospital lowered patient costs 0.6% ($P = .016$). When PSIs and processes of care were included in the cost regressions, the estimated reduction in costs for each additional esophagectomy was 0.4% ($P = .037$).

In cases where the estimated association between surgeon volume and patient costs were statistically significant, the relation was nonlinear. Therefore, the estimated cost savings for each additional operation varied according to the number of operations performed. Table III reports the predicted change in patient costs associated with surgeon volume at the 5th, 50th, and 95th percentile of the distribution for each of the 6 procedures. When the predictions were derived from adjusted regression estimates that exclude measures of PSIs and processes of care, the estimated cost savings are substantial for 4 of the 6 operations. If a surgeon performs the median number of operations (eg, ranging from 2 per year for pancreatic resection to 7 per year for colectomy), the estimated cost savings relative to performing 1 operation per year range from 2.4% to 2.8% for colectomy, pulmonary lobectomy, rectal resection, and pancreatic resection.

If a surgeon is at the 95th percentile for the number of operations performed per year, the estimated cost savings relative to performing one operation per year are even greater, ranging from 5.4% for colectomy to 8.5% for pancreatic resection. Applying the mean costs for each operation from Table I, these estimates suggest a savings of $1,089 per patient for colectomy and $3,286 for pancreatic resection. The regression estimates revealed no significant relationship between surgeon volume and costs for the remaining 2 procedures, esophagectomy and pneumonectomy.

When we predicted cost savings associated with increased surgeon volume using regressions that added PSI measures and processes of care, patient costs were predicted to decline with higher volume for only 2 of the 6 operations: rectal resection and pancreatic resection. Moreover, the estimated cost decreases were smaller than those obtained from regressions that excluded PSI measures and processes of care. A surgeon performing 2 pancreatic resections per year (50th percentile) was estimated to reduce costs by 1.4 percent, and a surgeon performing 14 operations per year (95th percentile) was estimated to reduce costs by 4.1 percent.

Additional analyses revealed that the estimated association between surgeon volume and costs when only PSIs were included in the regressions were similar to the estimates excluding both PSIs and processes of care. In contrast, when only processes of care were added to the regressions, we observed the same weakening of the relation between surgeon volume and costs that we found when both PSIs and processes of care were accounted for.

Table IV lists the coefficients for the PSI and processes of care variables from the full regression. In general, more PSIs and higher use of processes of care are associated with increased costs of cancer care. Many PSIs are associated with cost increases of 20% or more, dwarfing the effect of volume on costs in absolute value.

The processes, which are often performed to ameliorate the impact of complications (TPN, critical care, and inpatient consultations), have the largest coefficients among significant process of care effects, increasing costs between 14% and 34%. Few of these coefficients imply cost increases less than 20%. For the few cases observed in Table II where high-volume surgeons have significantly higher process of care utilization, the estimated relation between the process and costs tends to be insignificant or small.

Table II. Average PSI and process of care rates by surgeon tertile

	Colectomy			*Pulmonary lobectomy*			*Rectal resection*		
	Low-vol	*High-vol*		*Low-vol*	*High-vol*		*Low-vol*	*High-vol*	
	1–5	*10–102*	*Difference*	*1–2*	*6–93*	*Difference*	*1–2*	*5–46*	*Difference*
PSIs									
Accidental puncture/laceration	2.47%	2.05%	0.42%*	1.11%	1.25%	−0.15%	3.12%	2.99%	0.13%
Anesthesia complications	0.02%	0.01%	0.01%	0.00%	0.05%	−0.05%*	0.05%	0.03%	0.03%
Death among operative inpatients with serious treatable complications	1.58%	1.30%	0.28%†	1.52%	1.50%	0.02%	1.20%	0.95%	0.25%
Decubitus ulcer	0.88%	0.65%	0.23%†	0.48%	0.32%	0.16%	0.68%	0.79%	−0.11%
Foreign body left in during procedure	0.03%	0.02%	0.01%	0.00%	0.03%	−0.03%†	0.07%	0.06%	0.01%
Iatrogenic pneumothorax	0.23%	0.12%	0.10%†	3.71%	2.48%	1.23%*	0.12%	0.11%	0.01%
Postoperative hemorrhage/hematoma	0.25%	0.26%	−0.01%	0.21%	0.13%	0.08%	0.43%	0.43%	0.00%
Postoperative hip fracture	0.02%	0.01%	0.01%	0.03%	0.01%	0.02%	0.01%	0.00%	0.01%
Postoperative physiologic and metabolic derangement	0.07%	0.07%	−0.01%	0.15%	0.13%	0.02%	0.08%	0.10%	−0.03%
Postoperative respiratory failure	1.78%	1.97%	−0.18%	2.70%	3.03%	−0.33%	2.67%	2.64%	0.03%
Postoperative thromboembolism (PE/DVT)	1.83%	1.78%	0.05%	1.50%	1.22%	0.28%	1.33%	1.60%	−0.26%
Postoperative wound dehiscence	0.50%	0.36%	0.14%‡	—	—		0.24%	0.26%	−0.01%
Processes of care									
Pulmonary artery catheter	1.40%	1.21%	0.19%‡	2.25%	1.89%	0.36%	0.80%	1.34%	−0.54%†
Arterial line	17.34%	15.88%	1.45%*	74.03%	79.38%	−5.35%*	18.48%	21.08%	−2.59%*
Central venous catheter§	20.97%	19.66%	1.31%	28.07%	24.48%	3.59%	19.98%	20.04%	−0.06%
Epidural anesthesia	14.50%	15.39%	−0.89%†	52.67%	54.26%	−1.59%	25.22%	25.03%	0.19%
Daily epidural management	13.11%	13.47%	−0.36%	46.24%	49.64%	−3.39%*	21.93%	23.04%	−1.11%
Transfusion PRBC or autotransfusion	24.06%	21.04%	3.02%*	12.68%	8.10%	4.57%*	20.95%	16.52%	4.43%*
Total parenteral nutrition	7.38%	6.10%	1.28%*	0.78%	0.46%	0.32%‡	6.32%	5.43%	0.89%‡
Critical care consultations	17.05%	12.95%	4.10%*	19.09%	14.49%	4.60%*	12.34%	9.75%	2.59%*
Inpatient consultations	30.91%	29.44%	1.47%*	30.65%	24.75%	5.90%*	24.51%	22.22%	2.28%†
	Pancreatic resection			*Esophagectomy*			*Pneumonectomy*		
	Low-vol	*High-vol*		*Low-vol*	*High-vol*		*Low-vol*	*High-vol*	
	1	*4–72*	*Difference*	*1*	*4–37*	*Difference*	*1*	*2–17*	*Difference*
PSIs									
Accidental puncture/laceration	3.68%	2.89%	0.79%	5.11%	3.94%	1.18%	2.08%	1.87%	0.21%
Anesthesia complications	—	—	‡	—	—		—	—	
Death among operative inpatients with serious treatable complications	4.40%	1.83%	2.56%*	5.86%	2.76%	3.10%†	4.52%	4.81%	−0.28%

(*continued*)

Table II. (*continued*)

	Pancreatic resection			*Esophagectomy*			*Pneumonectomy*		
	Low-vol	*High-vol*		*Low-vol*	*High-vol*		*Low-vol*	*High-vol*	
	1	*4–72*	*Difference*	*1*	*4–37*	*Difference*	*1*	*2–17*	*Difference*
Decubitus ulcer	0.97%	0.74%	0.23%	1.04%	1.70%	−0.66%	0.47%	0.38%	0.09%
Foreign body left in during procedure	—	—		—	—		0.13%	0.10%	
Iatrogenic pneumothorax	0.55%	0.30%	0.26%	—	—		—	—	
Postoperative hemorrhage/hematoma	1.57%	1.12%	0.44%	0.20%	0.31%	−0.11%	0.40%	0.44%	−0.04%
Postoperative hip fracture	—	—	—	—	—		—	—	
Postoperative physiologic and metabolic derangement	0.23%	0.06%	0.17%	0.40%	0.05%	0.35%	0.27%	0.11%	0.16%
Postoperative respiratory failure	6.98%	5.22%	1.76%‡	16.93%	12.39%	4.54%‡	4.49%	4.87%	−0.38%
Postoperative thromboembolism (PE/DVT)	2.09%	2.07%	0.02%	3.92%	2.92%	1.00%	2.04%	1.70%	0.34%
Postoperative wound dehiscence	0.18%	0.35%	−0.16%	0.20%	0.16%	0.04%	—	—	
Processes of care									
Pulmonary artery catheter	5.00%	4.73%	0.27%	8.54%	8.32%	0.22%	4.09%	3.48%	0.61%
Arterial line	61.76%	77.69%	−15.93%*	82.17%	89.26%	−7.09%*	81.90%	82.93%	−1.03%
Central venous catheter§	57.34%	56.81%	0.53%	58.89%	49.79%	9.10%	36.29%	35.57%	0.72%
Epidural anesthesia	37.82%	43.95%	−6.12%*	51.89%	59.26%	−7.38%†	57.41%	60.30%	−2.90%
Daily epidural management	33.29%	44.38%	−11.09%*	48.81%	61.89%	−13.08%*	51.64%	56.01%	−4.36%‡
Transfusion PRBC or autotransfusion	25.53%	20.60%	4.93%*	12.86%	10.33%	2.53%	19.50%	13.54%	5.97%*
Total parenteral nutrition	12.80%	9.56%	3.23%†	6.21%	2.33%	3.87%*	1.01%	0.89%	0.12%
Critical care consultations	29.49%	21.85%	7.64%*	38.88%	34.07%	4.81%‡	25.40%	23.65%	1.75%
Inpatient consultations	41.23%	23.88%	17.35%*	37.49%	21.35%	16.14%*	33.48%	27.67%	5.81%†

*$P < .001$.
†$P < .01$.
‡$P < .05$.
§Central venous catheter alone.
PRBC, Packed red blood cells; *PE/DVT*, pulmonary embolism/deep vein thrombosis.

Table III. Estimated percentage change in costs from increasing surgeon volume, with and without adjustment for Patient Safety Indicators and processes of care, by percentile of procedure-specific volume distribution

	Colectomy			*Pulmonary lobectomy*			*Rectal resection*		
Percentile	*Annual surgeon volume*	*w/o PSI/POC*	*w/PSI/POC*	*Annual surgeon volume*	*w/o PSI/POC*	*w/PSI/POC*	*Annual surgeon volume*	*w/o PSI/POC*	*w/PSI/POC*
5th*	1	−0.6	0	1	−2.0	0	1	−1.4	−0.3
50th	7	−2.4	0	3	−2.5	0	3	−2.6	−0.7
95th	22	−5.4	0	17	−5.9	0	10	−7.6	−3.0
	Pancreatic resection			*Esophagectomy*			*Pneumonectomy*		
Percentile	*Annual surgeon volume*	*w/o PSI/POC*	*w/PSI/POC*	*Annual surgeon volume*	*w/o PSI/POC*	*w/PSI/POC*	*Annual surgeon volume*	*w/o PSI/POC*	*w/PSI/POC*
5th*	1	−2.8	−1.4	1	0	0	1	0	0
50th	2	−2.8	−1.4	2	0	0	1	0	0
95th	14	−8.5	−4.1	8	0	0	3	0	0

*Because the 5th percentile was 1 per year for each procedure, the estimated change in costs is calculated for an increase in surgeon volume from 1 to 2 procedures per year.
POC, Processes of care.

DISCUSSION

For policy purposes, identification of strategies for controlling the cost of the entire patient stay will be more effective in restraining growth in health care costs than examining operative costs alone. Patient treatment costs are hypothesized to depend on the characteristics of the patient as well as the characteristics of the surgeon and hospital from which the patient received treatment. Therefore, this study examined costs per entire inpatient stay, rather than total costs for postoperative hospital care or just the cost of performing an operation. The goal of the study was to determine the mechanism(s) that explains the relationship between provider volume and cost control in major cancer operations.

Our findings are consistent with a recent study that found no meaningful association between hospital volume and cost.[15] Instead, we found that many PSIs are associated with cost increases of 20% or more. Moreover, processes of care that are performed to ameliorate the impact of complications increase costs between 14% and 34%. Regression analyses that adjust for processes of care reduce, and in some cases eliminate, the association between surgeon volume and patient costs that appeared in regressions that only adjusted for patient and hospital characteristics.

Therefore, the differences in the frequency at which processes of care occur between low- versus high-volume surgeons explain the previously observed relation between higher procedure volume and lower costs.

Among the 6 cancer operations we examined, patients treated by low-volume surgeons were less likely to receive 2 processes of care (epidural anesthesia and daily epidural management) that have been associated with better patient outcomes.[36,37] However patients treated by low-volume surgeons almost always were significantly more likely to experience transfusions, consultations, and complication-related processes of care (TPN, critical care, and inpatient consultations).

For example, the need for TPN after any of these procedures indicates that the patient had an unexpected complication or delayed recovery.[38] These same processes are those that increase the costs of care the most. While these processes are appropriate responses to complications, higher rates of these processes may reflect higher occurrences of adverse events that are not fully captured by the PSI measures we tracked. This lower-quality care may require greater use of costly processes of care, explaining the observed surgeon volume–cost relationship.

The results suggest 3 potential strategies for cost control that may be undertaken simultaneously. First, steps should be taken to reduce PSI measures of complications, which significantly increase costs. Second, utilization rates of various processes of care may be surrogates for the incidence of non-PSI complications and higher costs. These data are

Table IV. Estimates for remaining variables in regression with PSI and processes of care

	Colectomy	*Pulmonary Lobectomy*	*Rectal Resection*	*Pancreatic Resection*	*Esophagectomy*	*Pneumonectomy*
PSIs						
Accidental puncture/laceration	0.114* (14.08)	0.0961* (5.95)	0.0880* (5.84)	0.0968* (4.06)	0.0671 (1.64)	0.0341 (0.49)
Anesthesia complications	−0.0949† (−2.02)	0.0573 (0.93)	−0.0664 (−0.52)			
Death among surgical inpatients with serious treatable complications	0.0441‡ (2.88)	0.330* (13.10)	0.0357 (0.93)	0.135‡ (3.09)	0.142‡ (2.59)	0.224* (3.33)
Decubitus ulcer	0.254* (17.25)	0.385* (9.34)	0.226* (6.71)	0.296* (6.89)	0.256* (4.05)	0.495* (3.36)
Foreign body left in during procedure	0.141 (1.35)	0.161 (1.43)	0.256‡ (2.72)			
Iatrogenic pneumothorax	0.156* (4.37)	0.0184 (1.81)	0.0897 (1.72)	0.0828 (0.91)		
Postoperative hemorrhage/hematoma	0.293* (11.77)	0.226* (3.59)	0.285* (6.95)	0.347* (8.63)	0.105 (0.71)	0.148 (1.32)
Postoperative hip fracture	0.589* (8.59)	0.362* (3.31)				
Postoperative physiologic and metabolic derangement	0.348* (6.87)	0.191‡ (3.03)	0.280‡ (2.84)	0.208 (1.20)	0.217 (1.02)	0.611 (1.92)
Postoperative respiratory failure	0.356* (29.04)	0.564* (29.24)	0.338* (13.96)	0.358* (11.10)	0.398* (13.44)	0.441* (6.11)
Postoperative thromboembolism (PE/DVT)	0.283* (31.19)	0.265* (13.39)	0.259* (11.17)	0.258* (9.71)	0.192* (4.46)	0.242‡ (3.18)
Postoperative wound dehiscence	0.521* (23.44)		0.551* (9.18)	0.397* (4.85)	0.422* (3.67)	
Processes of care						
Pulmonary artery catheter	0.220* (15.51)	0.210* (12.76)	0.189* (5.97)	0.228* (9.27)	0.286* (6.73)	0.220‡ (3.02)
Arterial line	0.111* (25.80)	0.00442 (0.94)	0.0810* (10.47)	0.0409* (4.09)	−0.0407 (−1.54)	−0.0237 (−0.91)
Central venous catheter§	0.203* (47.61)	0.129* (19.41)	0.177* (20.76)	0.0988* (10.01)	0.170* (6.87)	0.147* (6.37)
Epidural anesthesia	−0.00428 (−0.90)	−0.0110† (−2.23)	0.00769 (0.82)	−0.0114 (−0.84)	−0.0168 (−0.69)	−0.0297 (−1.09)
Daily epidural management	0.0229* (4.57)	0.0108† (2.00)	0.0111 (1.20)	−0.00781 (−0.56)	0.00395 (0.16)	0.00709 (0.26)
Transfusion PRBC or autotransfusion	0.0756* (24.88)	0.0894* (14.87)	0.0699* (10.61)	−0.0263† (−2.51)	−0.0677† (−2.44)	0.0350 (1.43)
Total parenteral nutrition	0.211* (37.46)	0.323* (11.49)	0.291* (23.73)	0.141* (6.44)	0.0742 (1.45)	0.0308 (0.28)
Critical care consultations	0.336* (68.91)	0.346* (36.40)	0.322* (27.45)	0.294* (18.61)	0.321* (13.81)	0.340* (10.85)
Inpatient consultations	0.238* (73.48)	0.201* (37.28)	0.230* (31.84)	0.214* (17.03)	0.340* (13.08)	0.221* (8.73)

*$P < .001$.
†$P < .05$.
‡$P < .01$.
§Central venous catheter alone.
PRBC, Packed red blood cells; *PE/DVT*, pulmonary embolism/deep vein thrombosis.

available through administrative and institutional sources. The data could be used to compare outcomes across institutions, provided there was adequate risk adjustment and cautionary notes that there is no evidence that these processes influence the probability of hospital mortality or long-term cancer survival. Third, it may be beneficial to refer patients to high-volume surgeons, because of their enhanced value (higher quality with lower costs). The analysis shows that the use of costly processes associated with adverse events is more prevalent among low-volume surgeons, directly contributing to the high costs of cancer operations.

There are several caveats to our study. Processes of care and complications may also affect postdischarge costs, but unfortunately we do not have access to postdischarge financial data. Similarly, we do not explore the relation between patient costs and quality, such as cancer recurrence and survival. The use of Medicare claims data limits our analysis to patients aged 65 or older. But given that this demographic comprises over half of new cancer cases each year, this analysis is relevant to a majority of cancer patients.[39] We track processes of care using claims data, which are not as detailed as information that could be obtained through chart abstraction. For example, we were reluctant to adjust for returns to the operating room or percutaneous drain placement. We lacked clinical detail in the claims data to distinguish cases where these processes reflected actions to provide high-quality care versus action to remediate complications.[40,41]

Similar to past research, we did not consider processes of care specific to individual procedures.[29] Any differences in the performance of procedure-specific processes may therefore be reflected in our estimates of the volume-cost relationship. However, such effects are unlikely to change our conclusion that much of the surgeon volume–cost relationship is explained by higher complication rates among low-volume surgeons that are tracked through remediating processes of care.

However, given that higher volume cancer providers have been associated with lower mortality,[32,42-47] there are multiple overlaps between our study and a recent comparison of cancer mortality in low- versus high-mortality hospitals based on chart review.[48] For example, we found negligible differences in the use of pulmonary artery catheters and central venous catheters between low- and high-volume surgeons, and recent analysis found no measurable difference in the use of these processes between low- and high-mortality hospitals.[48] The recent analysis found that high-mortality hospitals had significantly lower rates of epidural catheter usage for postoperative pain management; similarly, we found lower rates of daily epidural management for low-volume surgeons for 4 of the 6 cancer operations studied.

We did not adjust for the use of minimally invasive/robotic surgery in our analyses. These operations were a small (although growing) share of our study sample, which ended in 2009. Studies differ on whether robotic surgery reduces complications or lowers costs relative to open surgery.[49,50] Some studies find that hospitals or surgeons performing a higher volume of robotic or minimally invasive operations have fewer complications and lower costs, which may reflect a learning-curve effect.[51-53] These findings were noted for both pancreatic operations as well as colorectal operations, which is considered to be less complex.

These results suggest that as rates of minimally invasive, and potentially robotic, operations increase, the findings in this study are likely to persist: More complications increase patient costs, and the volume-cost relation is likely explained by actions taken by providers to ameliorate the effects of complications. Because we still lack sufficient data regarding the implications of robotic surgery for patient outcomes and costs, particularly for pancreatic resection, this area is worthy of further investigation.

In conclusion, not all processes of care are closely related to surgeon volume. However, we did find that the processes of care utilized in the postoperative care of patients can explain much of the surgeon volume–cost relationship, primarily through the large cost savings achieved by preventing the need for processes associated with non-PSI adverse events. Given these findings, both process of care utilization and surgeon-volume information may be used to direct patients to safer and lower-cost providers. These data confirm the belief that referral of patients to high-volume surgeons with low complication rates is likely to constrain cost growth and improve patient outcomes.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.surg.2017.03.004.

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