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National trends in centralization and perioperative outcomes of complex operations for cancer

Yun Song, MD[*], Andrew D. Tieniber, MD, Robert E. Roses, MD, Douglas L. Fraker, MD, Rachel R. Kelz, MD, MBA, MSCE, Giorgos C. Karakousis, MD

Department of Surgery, Hospital of the University of Pennsylvania, Philadelphia, PA

A R T I C L E   I N F O

A B S T R A C T

Background: Complex cancer operations performed at high-volume and teaching hospitals have been associated with better outcomes. The purpose of this study was to determine the national trends in the performance of these operations at large teaching hospitals.
Methods: Patients who underwent elective esophagectomies, gastrectomies, pancreatectomies, and hepatectomies for cancer (2003–2015) were identified using the National Inpatient Sample. We determined average annual percent change (AAPC) in the proportion of operations at large teaching hospitals, inpatient complications, length of stay (LOS), and inpatient mortality.
Results: Between 2003 and 2015, 38,932 esophageal, 104,941 gastric, 96,098 hepatic, and 137,440 pancreatic cancer resections were performed. The proportion at large teaching hospitals increased with an AAPC of 2.5 for esophagectomies ($P < .001$), 3.6 for gastrectomies ($P < .001$), and 1.5 for pancreatectomies ($P = .039$), but did not change for hepatectomies (AAPC 0.48, $P = .50$). During the study period, mean LOS and inpatient mortality rates at large teaching hospitals decreased across hospital types. By 2013 to 2015, the operations at large hospitals were associated with decreased mortality only for pancreatectomies (odds ratio, 0.62, 95% confidence interval, 0.43–0.91, $P = .015$).
Conclusions: Complex cancer operations are performed increasingly at large teaching hospitals, but perioperative outcomes have improved nationally across hospital types. Further studies should identify actionable areas for improvement to ensure accessible quality cancer care.

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Studies have demonstrated better perioperative outcomes when complex cancer operations are performed at high-volume (HV) rather than low-volume (LV) hospitals.[1–4] In 1999, the National Cancer Policy Board of the Institute of Medicine issued a statement to "ensure that patients undergoing procedures that are technically difficult to perform and have been associated with greater mortality in lower-volume settings receive care at facilities with extensive experience."[5] There have also been efforts in the private sector, such as the Leapfrog Group, for referrals being based on hospital volume.[6] In the 1990s to mid-2000s, there was a shift in complex cancer operations to HV hospitals in the United States.[7]

Volume alone, however, is not a determinant of outcome, and individual surgeon experience and structural processes play an important role.[4,8–10] In the public's view, teaching status is often perceived as an indicator of quality,[11] and teaching hospitals (TH) have been associated with improved outcomes for certain procedures.[12] But, there is heterogeneity among THs, and teaching status alone is not associated consistently with better, risk-adjusted operative outcomes.[13] Many large THs, however, are also HV hospitals for complex operations[12,14] and can provide access to specialty-trained surgeons and an experienced multidisciplinary team.[9,15]

The purpose of this study was to determine whether centralization occurred for major cancer operations (esophagectomies, gastrectomies, hepatectomies, and pancreatectomies) based on teaching status between 2003 and 2015. Specifically, we hypothesized that there has been an increase in the proportion of complex cancer operations performed at THs with a large bed-size. Additionally, trends in perioperative complications, mortality, and length of stay (LOS) were compared between large THs and other hospital types.

Material and Methods

Data source

A retrospective study was performed using the Healthcare Cost and Utilization Project (HCUP) National Inpatient Sample (NIS) from 2003 to 2015. Managed by the Agency for Healthcare Research and Quality (AHRQ), the NIS is the largest longitudinal, inpatient health care database in the United States.[16] When weighted, the NIS estimates >35 million hospitalizations nationally. Prior to 2012, the database was composed of all discharges from a 20% sample of hospitals participating in the HCUP. In 2012, sampling methodology was redesigned to $\approx$20% stratified sample of discharges from all hospitals.[17] To allow consistent comparisons, adjusted trend weights provided by the NIS were applied to years prior to 2012. Because of the deidentified data and retrospective nature of the study, it was deemed exempt from full review by the Institutional Review Board of the University of Pennsylvania.

Patient selection

The NIS captures 30 diagnoses and 15 procedures per admission that are classified using *the International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) codes. Patients age 18 years or older were included in the study if they: 1) had a primary diagnosis of esophageal (150.0−150.5, 150.8, 150.9), gastric (151.0−151.6, 151.8, 151.9, 209.23), primary liver (155.0−155.2, 235.3), and pancreatic (156.2, 157.0−157.4, 157.8, 157.9, 209.29) malignancy, or a primary or secondary diagnosis of secondary liver malignancy (197.7, 209.72), and 2) underwent an elective resection of the relevant organ as the primary procedure. Operations were categorized by the organ resected: esophagectomy (42.40−42.42), gastrectomy (43.5−43.8, 43.91, 43.99), hepatectomy (50.22, 50.3), and pancreatectomy (52.51−52.53, 52.59, 52.6, 52.7). Subsegmental and wedge resections of the stomach and liver were not included to create a more homogenous cohort of patients who underwent major operations. Liver transplants were not included.

An observed increase in the proportion of complex cancer operations at large THs could either be due to selective referral of such cases to experienced centers or an overall increase in the number of hospitals classified as large THs over time (ie, nonteaching hospitals acquiring teaching status or a merger between a non-TH and TH). Therefore, 2 common general surgery procedures were also included for comparison: elective ventral hernia repairs (VHR; 53.51, 53.59, 53.61−53.63, 53.69) and nonelective appendectomies (47.01, 47.09). VHR was chosen to represent high-caseload and low complexity general surgery procedures. Nonelective appendectomy, which would not be referral-based, was chosen to determine if the trend observed for the cancer operations could be due to underlying systematic changes such as an overall increase in the number of large THs. Patients who underwent additional secondary procedures besides a VHR or appendectomy were excluded to create a more homogeneous, low-complexity group.

Variables

Patients were categorized based on hospital size and teaching status provided by the NIS into two groups: those who underwent an operation at (1) large bed-size THs and (2) other hospitals (small- or medium-sized THs and non-THs). The primary comparisons in longitudinal trends were made between large THs and other hospital types. The NIS categorizes hospital bed size into terciles (small, medium, and large) based on the region and urban or rural location. Large bed-size urban hospitals are defined as $\geq$425 beds in the Northeast, $\geq$375 beds in the Midwest, $\geq$450 beds in the South, and $\geq$325 beds in the West. Teaching status is assigned to hospitals with one or more residency programs accredited by the Accreditation Council for Graduate Medical Education in the Council of Teaching Hospitals, or a ratio of full-time residents to beds $\geq$0.25.

Not all large THs are likely to be HV centers for each of the cancer operations included in the study. Therefore, operative volume was additionally considered to better characterize these hospitals in regard to their experience with each type of resection. Because individual hospital volume can no longer be calculated after the NIS redesign in 2012,[17] volume data were derived empirically for a portion of the study period (2003−2011). For each cancer operation, hospitals were ranked by their annual volume to determine the 90th percentile. Only about 20% of hospitals participating in the HCUP were included in the database in any given year based on the NIS sampling methodology prior to 2012. For example, "Hospital A" may have been included in the database only in the years 2003, 2008, and 2011. Therefore, the mean annual number of cases performed was derived only from the years each hospital actually contributed to the database. Hospitals with a mean annual case volume exceeding the 90th percentile was categorized as HV. All other hospitals were categorized as LV. The 90th percentile is greater than the threshold for high- or very high-volume hospitals utilized in older studies[2,3,7]; however, operative volume has increased over time for all 4 cancer operations analyzed, and the 90th percentile for 2003 to 2011 data better reflected contemporary standards for volume thresholds such as those utilized in the "Take the Volume Pledge."[18]

The perioperative outcomes analyzed were inpatient complications, LOS, and inpatient mortality. LOS and inpatient mortality data were provided by the NIS. Inpatient complications were defined using secondary ICD-9-CM diagnosis and procedure codes, either included in the AHRQ Patient Safety Indicators or other codes that explicitly identify postoperative outcomes (Table I).[3,19] Because of the nature of the database, postdischarge adverse events could not be captured.

Additional independent variables were patient age, sex, race, comorbidities, residence, primary payer, income quartile, and region. Comorbidities were defined using the Elixhauser comorbidity index for administrative data, identifying as comorbidities secondary ICD-9-CM diagnoses that did not relate directly to the diagnosis-related group assignment for each patient.[20] All other variables were provided and defined by the NIS.

Statistics

Descriptive statistics are presented as frequencies for categorical variables, including 95% confidence intervals (CI) for weighted estimates, and means with standard deviations (SD) for continuous variables. Statistical analyses were performed using the design-based Wald test and a 2-sample *t* test for categorical and continuous variables, respectively.

To determine the annual percent change in the proportion of operations performed at large THs, univariable linear regression was performed using a logarithmically transformed dependent variable and year as a continuous independent variable. Multivariable linear regression adjusted for the percent of patients living in large metropolitan areas. To determine breakpoints in trend, the Davies' test was used to identify a statistically significant non-zero difference in slope between 2 time periods. When a statistically significant breakpoint was present, segmented linear regression was performed. The average annual percent change

Table I
Diagnosis and procedure codes of inpatient postoperative complications

Category	Description	ICD-9-CM Codes
Wound	Seroma complicating a procedure	998.13
	Disruption of surgical wound	998.30, 998.32
	Persistent postoperative fistula	998.6
	Nonhealing surgical wound	998.83
	Reclose postoperative disruption of abdominal wall*	54.61†
Anastomotic leak	Disruption of internal surgical wound	998.31
Infection	Septicemia*	038.0, 038.1, 038.10, 038.11, 038.12, 038.19, 038.2, 038.3, 038.40, 038.41, 038.42, 038.43, 038.44, 038.49, 038.8, 038.9
	Septic shock*	785.52
	Shock without trauma*	785.59
	Systemic inflammatory response syndrome due to infectious process*	995.91, 995.92
	Infection and inflammatory reaction due to indwelling urinary catheter	996.64
	Postoperative shock	998.00,* 998.02,* 998.09
	Postoperative infected seroma	998.51
	Postoperative infection, other	998.59
Bleeding	Hemorrhage complicating a procedure*	998.11
	Hematoma complicating a procedure*	998.12
Intraoperative	Accidental puncture or laceration, complicating surgery*	998.2
	Foreign body accidentally left during procedure*	998.4, 998.7
Neurologic	Nervous system complication, unspecified	997.00
	Central nervous system complication	997.01
	Iatrogenic cerebrovascular infarction or hemorrhage	997.02
	Other nervous system complication	997.09
Cardiac	Cardiac complication, not elsewhere classified	997.1
	Postoperative shock, cardiogenic	998.01
Venous thromboembolism	Peripheral vascular complication, not elsewhere classified	997.2
	Phlebitis or thrombosis of femoral vein*	451.11
	Phlebitis or thrombosis of deep vessel of lower extremity other*	451.19
	Phlebitis and thrombophlebitis lower extremity unspecified*	451.2
	Phlebitis and thrombophlebitis of iliac vein*	451.81
	Phlebitis and thrombophlebitis of other sites*	451.9
	Deep venous thromboembolism lower extremity*	453.40, 453.41, 453.42
	Other venous embolism and thrombosis*	453.8, 453.9
Pulmonary	Iatrogenic pneumothorax*	512.1
	Postoperative air leak	512.2
	Acute respiratory failure after trauma and surgery*	518.51
	Other pulmonary insufficiency after trauma and surgery	518.52
	Acute and chronic respiratory failure after trauma and surgery*	518.53
	Acute respiratory failure*	518.81
	Ventilator associated pneumonia	997.31
	Postprocedural aspiration pneumonia	997.32
	Other respiratory complication	997.39
	Reintubation, insert endotracheal tube*	96.05†
	Mechanical ventilation*	96.70,† 97.71,† 97.72†
Renal/urinary	Acute renal failure*	584.5, 584.6, 584.7, 584.8, 584.9
	Renal failure, not otherwise specified*	586
	Mechanical complication due to urethral (indwelling) catheter	997.31
	Urinary complication, not elsewhere classified*	997.5
Other/unspecified	Complications affecting other specified body systems, not elsewhere classified	997.99
	Other specified complications of procedures not elsewhere classified	998.89
	Unspecified complication of procedure, not elsewhere classified	998.9

* Category and codes included in the Agency for Healthcare Research and Quality Patient Safety Indicators.
† ICD-9-CM procedure code.

(AAPC) for the study period was derived from the weighted average of each slope coefficient. If no breakpoint was present, then the AAPC was equal to the annual percent change. Temporal trends for HV hospitals and perioperative outcomes were analyzed in a similar fashion.

Multivariable analyses for perioperative outcomes were performed for 2 time periods (2003–2005, 2013–2015) using logistic regression for inpatient complications and mortality and Poisson regression for LOS. Covariates included extent of resection and, for hepatectomies, primary or secondary malignancy, as well as the patient and hospital factors defined previously.

Statistical analyses were performed using R for Windows version 3.5.1 (Vienna, Austria).[21] All tests were 2-sided. The Bonferroni method was used to correct for multiple testing for subgroup analyses.

Results

Patient characteristics

An estimated 19,342 esophagectomies, 58,360 gastrectomies, 71,860 hepatectomies, and 77,676 pancreatectomies were performed for cancer during the study period. In total, 142,016 (61.9%) cancer operations were performed at large THs. Patient characteristics differed by hospital type (Table II). Patients who underwent cancer operations at large THs were often somewhat younger (gastrectomy mean 64.8 years, SD 12.8, vs 67.2, SD 12.7; hepatectomy 60.3, SD 12.3, vs 61.7, SD 12.0; and pancreatectomy 65.0, SD 11.5, vs 65.7, SD 11.5; $P < .001$ each) and in the greatest income quartile (esophagectomy 25.6% vs 22.3%, $P = .004$; gastrectomy 27.8% vs 24.2%, $P < .001$; hepatectomy 29.6% vs 28.0%, $P = .035$).

Table II
Characteristics of patients who underwent major cancer operations, ventral hernia repairs, and nonelective appendectomies by hospital type, 2003 to 2015

Characteristic	Large THs		Other Hospitals		P value
	No. (95% CI)	%	No. (95% CI)	%	
Esophagectomy	12,173 (11,821–12,525)	62.9	7,169 (6,875–7,463)	37.1	
Age, y, mean ± SD	63.4 ± 10.0		63.6 ± 10.0		.48
Female	2,422 (2,245–2,599)	19.9	1,189 (1,061–1,318)	16.6	.003
Race					
White	8,970 (8,703–9,237)	73.7	5,378 (5,138–5,618)	75.0	.16
Black	442 (362–522)	3.6	320 (252–389)	4.5	
Other	738 (635–840)	6.1	369 (296–442)	5.1	
Missing	2,024 (1,860–2,188)	16.6	1,102 (978–1,226)	15.4	
Elixhauser comorbidities, mean ± SD	2.6 ± 1.7		2.5 ± 1.7		.50
Primary payer					
Private	5,368 (5,129–5,608)	44.1	3,228 (3,028–3,427)	45.0	.27
Medicare/Medicaid	6,354 (6,102–6,605)	52.2	3,674 (3,464–3,884)	51.3	
Other/self-pay	447 (366–527)	3.7	248 (187–308)	3.5	
Missing	5 (0–13)	0.04	19 (2–36)	0.3	
Patient residence					
Large metropolitan	5,922 (5,675–6,168)	48.6	3,286 (3,085–3,487)	45.8	.12
Small metropolitan	3,781 (3,569–3,993)	31.1	2,276 (2,104–2,449)	31.8	
Micropolitan	1,592 (1,445–1,739)	13.1	1,092 (969–1,216)	15.2	
Rural	879 (767–990)	7.2	514 (428–601)	7.2	
Income quartile					
0–25th	2,548 (2,367–2,729)	20.9	1,466 (1,324–1,607)	20.4	.004
26th–50th	2,961 (2,768–3,153)	24.3	2,005 (1,841–2,168)	28.0	
51st–75th	3,310 (3,109–3,512)	27.2	1,903 (1,743–2,062)	26.5	
76th–100th	3,121 (2,924–3,318)	25.6	1,597 (1,450–1,744)	22.3	
Missing	233 (175–291)	1.9	199 (145–253)	2.8	
Hospital region					
Northeast	3,082 (2,886–3,278)	25.3	1,277 (1,144–1,409)	17.8	<.001
Midwest	3,470 (3,265–3,676)	28.5	1,412 (1,273–1,552)	19.7	
South	3,718 (3,507–3,929)	30.5	2,412 (2,235–2,589)	33.6	
West	1,903 (1,743–2,062)	15.6	2,068 (1,902–2,233)	28.8	
Gastrectomy	27,233 (26,691–27,776)	46.7	31,126 (30,561–31,691)	53.3	
Type of resection					
Total	12,813 (12,431–13,195)	47.0	11,872 (11,500–12,243)	38.1	<.001
Partial	14,426 (14,028–14,824)	53.0	19,260 (18,826–19,694)	61.9	
Age, y, mean ± SD	64.8 ± 12.8		67.2 ± 12.7		<.001
Female	9,664 (9,320–10,007)	35.5	12,313 (11,937–12,690)	39.6	<.001
Race					
White	14,018 (13,623–14,412)	51.5	16,010 (15,598–16,422)	51.4	.82
Black	3,125 (2,917–3,333)	11.5	3,452 (3,234–3,669)	11.1	
Other	5,914 (5,636–6,193)	21.7	6,913 (6,615–7,211)	22.2	
Missing	4,181 (3,943–4,419)	15.4	4,757 (4,505–5,010)	15.3	
Elixhauser comorbidities, mean ± SD	2.4 ± 1.6		2.7 ± 1.7		<.001
Primary payer					
Private	10,230 (9,879–10,581)	37.6	10,518 (10,163–10,873)	33.8	<.001
Medicare/Medicaid	15,688 (15,279–16,098)	57.6	19,332 (18,897–19,766)	62.1	
Other/self-pay	1,296 (1,160–1,432)	4.8	1,243 (1,110–1,377)	4.0	
Missing	24 (5–43)	0.1	38 (15–62)	0.1	
Patient residence					
Large metropolitan	17,008 (16,589–17,428)	62.4	16,807 (16,389–17,225)	54.0	<.001
Small metropolitan	6,678 (6,384–6,971)	24.5	9,352 (9,013–9,690)	30.0	
Micropolitan	2,055 (1,885–2,225)	7.5	2,876 (2,676–3,075)	9.2	
Rural	1,498 (1,352–1,644)	5.5	2,098 (1,926–2,270)	6.7	
Income quartile					
0–25th	6,711 (6,417–7,006)	24.6	7,484 (7,175–7,793)	24.0	<.001
26th–50th	6,169 (5,885–6,453)	22.6	7,719 (7,407–8.032)	24.8	
51st–75th	6,409 (6,120–6,697)	23.5	7,835 (7,520–8,149)	25.2	
76th–100th	7,561 (7,251–7,871)	27.8	7,547 (7,237–7,856)	24.2	
Missing	389 (314–464)	1.4	547 (458–636)	1.8	
Hospital region					
Northeast	8,113 (7,794–8,432)	29.8	5,031 (4,772–5,290)	16.2	<.001
Midwest	5,434 (5166–5703)	20.0	5,573 (5,302–5,845)	17.9	
South	9,270 (8,932–9,607)	34.0	12,578 (12,198–12,957)	40.4	
West	4,421 (4,177–4,666)	16.2	7,950 (7,633–8,266)	25.5	
Hepatectomy	51,040 (50,446–51,634)	71.0	20,821 (20,330–21,311)	29.0	
Type of malignancy					
Primary liver	16,576 (16,142–17,009)	32.5	6,174 (5,885–6,463)	29.6	<.001
Secondary liver	34,492 (33,978–35,007)	67.5	14,658 (14,243–15,073)	70.4	
Age, y, mean ± SD	60.3 ± 12.3		61.7 ± 12.0		<.001
Female	22,638 (22,160–23,117)	44.3	9,341 (8,995–9,687)	44.8	.68

(continued on next page)

Table II (*continued*)

Characteristic	Large THs		Other Hospitals		P value
	No. (95% CI)	%	No. (95% CI)	%	
Race					
White	32,308 (31,796–32,821)	63.3	13,510 (13,108–13,913)	64.9	<.001
Black	3,424 (3,204–3,643)	6.7	1,671 (1,515–1,826)	8.0	
Other	7,336 (7,024–7,648)	14.4	2,968 (2,763–3,173)	14.2	
Missing	8,000 (7,676–8,324)	15.7	2,683 (2,487–2,878)	12.9	
Elixhauser comorbidities, mean ± SD	2.0 ± 1.5		2.2 ± 1.6		<.001
Primary payer					
Private	25,093 (24,602–25,584)	49.1	10,125 (9,767–10,484)	48.6	.55
Medicare/Medicaid	23,708 (23,224–24,193)	46.4	9,796 (9,443–10,150)	47.0	
Other/self-pay	2,184 (2,007–2,361)	4.3	891 (777–1,005)	4.3	
Missing	82 (47–117)	0.2	19 (2–36)	0.1	
Patient residence					
Large metropolitan	29,316 (28,810–29,822)	57.4	11,675 (11,295–12,055)	56.0	.38
Small metropolitan	13,781 (13,376–14,187)	27.0	5,767 (5,487–6,047)	27.7	
Micropolitan	4,988 (4,726–5,249)	9.8	2,102 (1,928–2,275)	10.1	
Rural	2,983 (2,777–3,188)	5.8	1,288 (1,151–1,425)	6.2	
Income quartile					
0–25th	10,634 (10,267–11,000)	20.8	4,126 (3,886–4,365)	19.8	.035
26th–50th	11,898 (11,515–12,281)	23.3	5,152 (4,887–5,418)	24.7	
51st–75th	12,595 (12,203–12,987)	24.7	5,361 (5,090–5,631)	25.7	
76th–100th	15,099 (14,679–15,518)	29.6	5,835 (5,554–6,116)	28.0	
Missing	843 (732–953)	1.6	358 (286–431)	1.7	
Hospital region					
Northeast	14,203 (13,793–14,613)	27.8	3,109 (2,899–3,318)	14.9	<.001
Midwest	11,573 (11,195–11952)	22.7	3,888 (3,655–4,121)	18.7	
South	16,183 (15,753–16,614)	31.7	8,009 (7,685–8,333)	38.4	
West	9,109 (8,766–9,451)	17.8	5,825 (5,544–6,107)	28.0	
Pancreatectomy	51,665 (50,975–52,354)	66.5	26,011 (25,454–26,569)	33.5	
Type of resection					
Total	2,210 (2,032–2,388)	4.3	1,054 (930–1,178)	4.1	<.001
Pancreatoduodenectomy	37,958 (37,423–38,493)	73.5	17,908 (17,457–18,358)	68.8	
Other partial	11,500 (11,120–11,880)	22.3	7,051 (6,744–7,358)	27.1	
Age, y, mean ± SD	65.0 ± 11.5		65.7 ± 11.5		<.001
Female	25,128 (24,628–25,629)	48.6	12,699 (12,304–13,095)	48.8	.75
Race					
White	35,883 (35,350–36,417)	69.4	17,792 (17,342–18,241)	68.4	.007
Black	3,564 (3,340–3,788)	6.9	1,896 (1,731–2,061)	7.3	
Other	5,131 (4,865–5,397)	9.9	2,955 (2,750–3,159)	11.4	
Missing	7,090 (6,781–7,398)	13.7	3,371 (3,153–3,589)	13.0	
Elixhauser comorbidities, mean ± SD	2.3 ± 1.6		2.5 ± 1.6		<.001
Primary payer					
Private	20,263 (19,793–20,733)	39.2	9,991 (9,633–10,349)	38.4	.36
Medicare/Medicaid	29,326 (28,807–29,844)	56.8	14,958 (14,536–15,380)	57.5	
Other/self-pay	2,012 (1,842–2,182)	3.9	1,006 (885–1,127)	3.9	
Missing	68 (36–99)	0.1	58 (29–87)	0.2	
Patient residence					
Large metropolitan	28,257 (27,742–28,772)	54.7	13,759 (13,350–14,167)	52.9	.003
Small metropolitan	14,668 (14,249–15,086)	28.4	7,747 (7,427–8,068)	29.8	
Micropolitan	5,532 (5,257–5,808)	10.7	2,631 (2,437–2,824)	10.1	
Rural	3,211 (2,998–3,424)	6.2	1,876 (1,712–2,041)	7.2	
Income quartile					
0–25th	10,272 (9,909–10,634)	19.9	5,257 (4,988–5,526)	20.2	.32
26th–50th	12,274 (11,884–12,664)	23.8	6,475 (6,180–6,771)	24.9	
51st–75th	13,502 (13,097–13,908)	26.1	6,611 (6,312–6,909)	25.4	
76th–100th	14,827 (14,407–15,248)	28.7	7,254 (6,943–7,565)	27.9	
Missing	793 (686–901)	1.5	416 (338–494)	1.6	
Hospital region					
Northeast	12,651 (12,256–13046)	24.5	3,535 (3,312–3,758)	13.6	<.001
Midwest	12,874 (12,476–13,271)	24.9	5,460 (5,186–5,733)	21.0	
South	16,989 (16,547–17,431)	32.9	10,543 (10,176–10,909)	40.5	
West	9,155 (8,810–9,500)	17.7	6,475 (6,180–6,771)	24.9	
Ventral hernia repair	91,806 (90,820–92,791)	27.1	246,361 (245,376–247,346)	72.9	
Age, y, mean ± SD	57.4 ± 14.0		59.3 ± 14.2		<.001
Female	54,954 (54,137–55,772)	59.9	156,581 (155,476–157,685)	63.6	<.001
Race					
White	55,943 (55,120–56,766)	60.9	163,387 (162,280–164,494)	66.3	<.001
Black	8,025 (7,687–8,362)	8.7	12,925 (12,501–13,350)	5.2	
Other	9,114 (8,755–9,472)	9.9	22,436 (21,884–22,987)	9.1	
Missing	18,724 (18,218–19,231)	20.4	47,613 (46,842–48,383)	19.3	
Elixhauser comorbidities, mean ± SD	1.5 ± 1.3		1.5 ± 1.3		.15

Table II (*continued*)

Characteristic	Large THs		Other Hospitals		P value
	No. (95% CI)	%	No. (95% CI)	%	
Primary payer					
Private	40,415 (39,696–41,133)	44.0	104,000 (102,978–105,022)	42.2	<.001
Medicare/Medicaid	44,537 (43,788–45,286)	48.5	127,883 (126,809–128,957)	51.9	
Other/self-pay	6,759 (6,449–7,069)	7.4	14,038 (13,596–14,480)	5.7	
Missing	96 (58–133)	0.1	439 (360–519)	0.2	
Patient residence					
Large metropolitan	54,138 (53,325–54,950)	59.0	109,541 (108,504–110,577)	44.5	<.001
Small metropolitan	26,701 (26,104–27,298)	29.1	79,850 (78,909–80,791)	32.4	
Micropolitan	6,477 (6,173–6,781)	7.1	34,329 (33,660–34,998)	13.9	
Rural	4,490 (4,236–4,743)	4.9	22,641 (22,087–23,195)	9.2	
Income quartile					
0–25th	21,795 (21,252–22,339)	23.7	61,054 (60,202–61,906)	24.8	<.001
26th–50th	21,891 (21,346–22,436)	23.8	69,599 (68,704–70,495)	28.3	
51st–75th	24,604 (24,029–25,179)	26.8	62,038 (61,181–62,895)	25.2	
76th–100th	21,991 (21,445–22,537)	24.0	48,988 (48,209–49,768)	19.9	
Missing	1,524 (1,375–1,672)	1.7	4,681 (4,422–4,940)	1.9	
Hospital region					
Northeast	16,995 (16,511–17,479)	18.5	31,454 (30,810–32,097)	12.8	<.001
Midwest	29,170 (28,549–29,792)	31.8	58241 (57,404–59,077)	23.6	
South	30,150 (29,518–30,781)	32.8	101,483 (100,468–102,498)	41.2	
West	15,490 (15,027–15,953)	16.9	55,184 (54,365–56,002)	22.4	
Appendectomy	389,107 (387,003–391,210)	21.7	1,405,937 (1,403,833–1,408,040)	78.3	
Age, y, mean ± SD	38.7 ± 15.7		39.8 ± 16.3		<.001
Female	179,303 (1,77,773–180,834)	46.1	646,870 (644,420–649,321)	46.0	<.001
Race					
White	184,082 (182,533–185,630)	47.3	781,969 (779,438–784,500)	55.6	<.001
Black	28,775 (28,134–29,416)	7.4	69,855 (68,868–70,842)	5.0	
Other	100,709 (99,534–101,883)	25.9	293,444 (291,556–295,331)	20.9	
Missing	75,541 (74,516–76,566)	19.4	260,669 (258,871–262,467)	18.5	
Elixhauser comorbidities, mean ± SD	0.5 ± 0.9		0.6 ± 0.9		<.001
Primary payer					
Private	228,797 (227,095–230,500)	58.8	831,181 (828,636–833,727)	59.1	<.001
Medicare/Medicaid	80,769 (79,710–81,827)	20.8	29,6918 (295,021–298,814)	21.1	
Other/self-pay	78,910 (77,863–79,956)	20.3	274,034 (272,198–275,870)	19.5	
Missing	631 (535–726)	0.2	3,804 (3,569–4,038)	0.3	
Patient residence					
Large metropolitan	284,088 (282,225–285,951)	73.0	774,295 (771,767–776,823)	55.1	<.001
Small metropolitan	90,889 (89,770–92,008)	23.4	387,945 (385,844–390,046)	27.6	
Micropolitan	7,320 (6,995–7,646)	1.9	152,315 (15,893–153,737)	10.8	
Rural	6,809 (6,495–7,123)	1.7	91,381 (90,259–92,503)	6.5	
Income quartile					
0–25th	94,468 (93,328–95,608)	24.3	305,758 (303,839–307,677)	21.7	<.001
26th–50th	80,663 (79,606–81,721)	20.7	346,718 (344,703–348,733)	24.7	
51st–75th	98,506 (97,343–99,668)	25.3	359,204 (357,161–361,246)	25.5	
76th–100th	108,908 (107,690–110,127)	28.0	369,764 (367,699–371,828)	26.3	
Missing	6,561 (6,253–6,869)	1.7	24,494 (23,902–25,086)	1.7	
Hospital region					
Northeast	89,293 (88,183–90,403)	22.9	249,110 (247,346–250,875)	17.7	<.001
Midwest	76,688 (75,656–77,720)	19.7	264,774 (262,964–266,584)	18.8	
South	12,7931 (126,618–129,244)	32.9	506,277 (503,980–508,574)	36.0	
West	95,194 (94,051–96,338)	24.5	385,776 (383,679–387,873)	27.4	

During the study period, 338,166 elective VHRs and 1,795,043 nonelective appendectomies were performed. In contrast to the cancer operations, only 27.1% of VHRs and 21.7% of appendectomies were performed at large THs. Unlike patients undergoing elective operations, a high proportion (20.3% at large THs and 19.5% at other hospitals) of appendectomy patients were self-pay.

Trends in operations at large THs

From 2003 to 2015, the proportion of cancer operations performed at large THs increased for gastrectomies (AAPC 3.6, P < .001), esophagectomies (AAPC 2.5, P < .001), and pancreatectomies (AAPC 1.5, P = .039; Fig 1). Approximately 64.4% of hepatectomies were already performed at large THs in 2003, and the proportion did not change over time (AAPC 0.48, P = .50). Adjusting for percent of patients residing in large metropolitan areas, trends remained statistically significant for esophagectomies (AAPC 2.5, P = .001),

gastrectomies (AAPC 3.8, P < .001), and pancreatectomies (AAPC 1.5, P = .024).

The proportion of VHRs (AAPC 2.4, P < .001) and appendectomies (AAPC 1.1, P = .023) performed at large THs also increased during the study period. Adjusting for patient residence in large metropolitan areas, the trend remained for VHRs (AAPC 2.4, P = .001), and for nonelective appendectomies (AAPC 1.0, P = .060).

Characterization of hospitals by operative volume

Using 2003 to 2011 data, hospitals that exceeded the 90th percentile for each cancer operation were defined as HV hospitals. The 90th percentile volume threshold was 10 esophagectomies, 11 gastrectomies, 24 hepatectomies, and 22 pancreatectomies per year. In total, there were 546 HCUP-participating hospitals that performed esophagectomies, 1,535 that performed gastrectomies, 949 that performed pancreatectomies, and 63 that performed
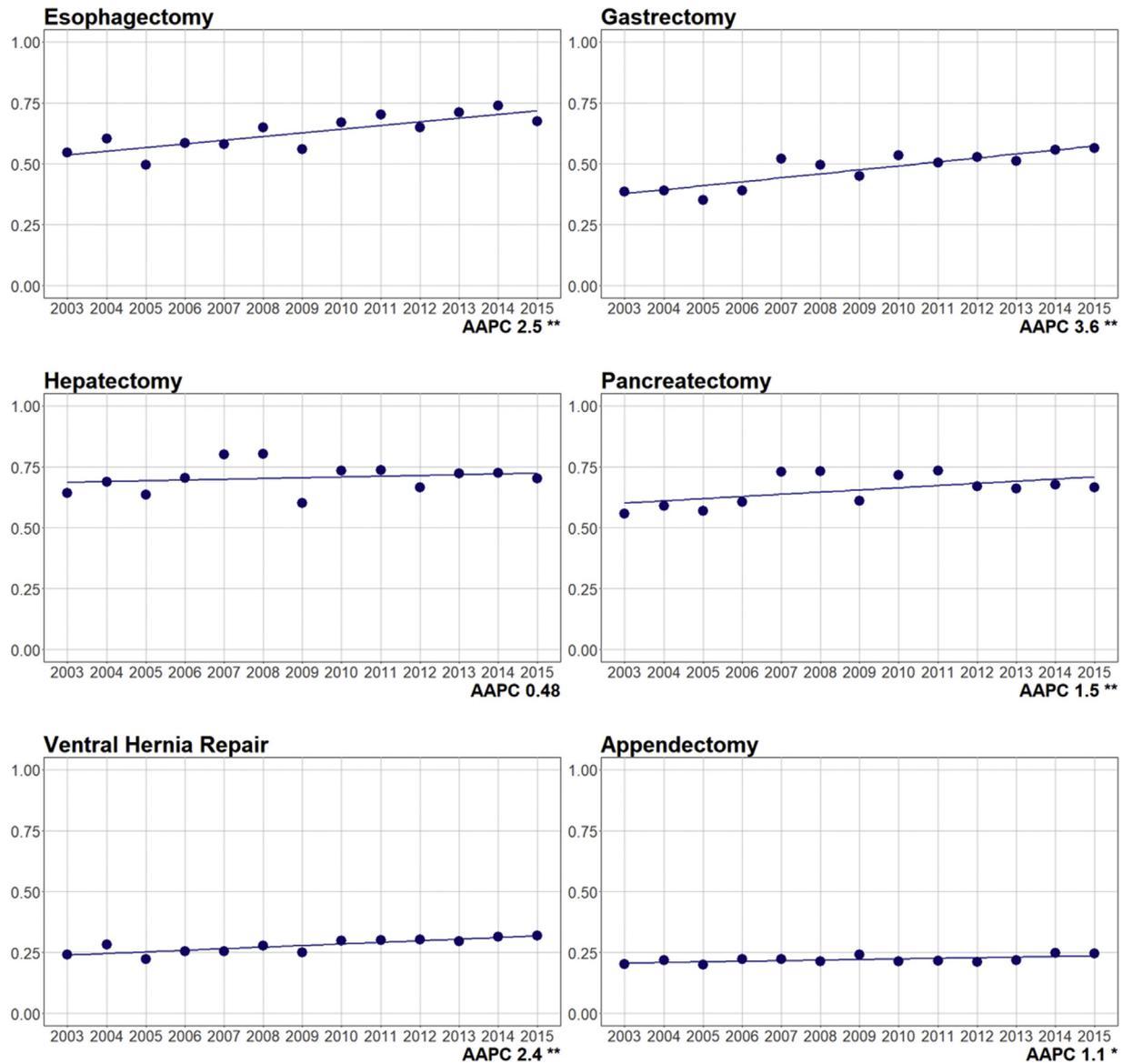
Fig 1. National estimates of percent of operations performed at large THs, 2003 to 2015. *P < .05 for average annual percent change (AAPC) by univariable analysis; **P < .05 when adjusted for percent of patients living in large metropolitan areas.

hepatectomies. Of these, 51 (9.3%) were considered HV for esophagectomies, 140 (9.1%) for gastrectomies, 93 (9.7%) for pancreatectomies, and 63 (9.2%) for hepatectomies.

As shown in Fig 2, there was a statistically significant association between volume and teaching status for all 4 cancer operations. Among the 52 HV hospitals for esophagectomies, 43 (82.7%) were large THs, and 9 (17.3%) were other hospital types (P < .001). Similarly, for gastrectomies, 98 (67.1%) of 146 HV hospitals were large THs, and 48 (32.9%) were other hospitals (P < .001). For the 64 HV hospitals for hepatectomies, 52 (81.2%) were large THs, and 12 (18.8%) were other hospitals (P < .001). Among the 95 HV hospitals for pancreatectomies, 77 (81.1%) were large THs, and 18 (18.9%) were other hospital types (P < .001).

Trends in operations at high-volume hospitals

In total, there were an estimated 6,431 esophagectomies, 17,489 gastrectomies, 30,241 hepatectomies, and 29,621 pancreatectomies for cancer performed at HV hospitals between 2003 and 2011. Of

these, 4,708 (73.2%) esophagectomies, 13,581 (77.7%) gastrectomies, 25,917 (85.7%) hepatectomies, and 25,447 (85.9%) pancreatectomies were performed at HV large THs.

Evaluating temporal trends at HV hospitals, an increase in the proportion of operations occurred at HV large THs for gastrectomies (AAPC 6.8, P = .020) and pancreatectomies (AAPC 4.9, P = .004; Fig 3). There was also a trend towards increase in the proportion of esophagectomies at HV large THs (AAPC 4.9, P = .052). In contrast, there were no increases in the proportion of operations at other HV hospitals for any resection type. Hepatectomies were already performed frequently at HV hospitals at the beginning of the study period and did not increase subsequently at either HV large THs (AAPC 2.0, P = .44) or other HV hospitals (AAPC 1.4, P = .90).

Trends in perioperative outcomes

The overall inpatient complication rates for the cancer operations ranged from 21.5% for hepatectomies to 46.5% for
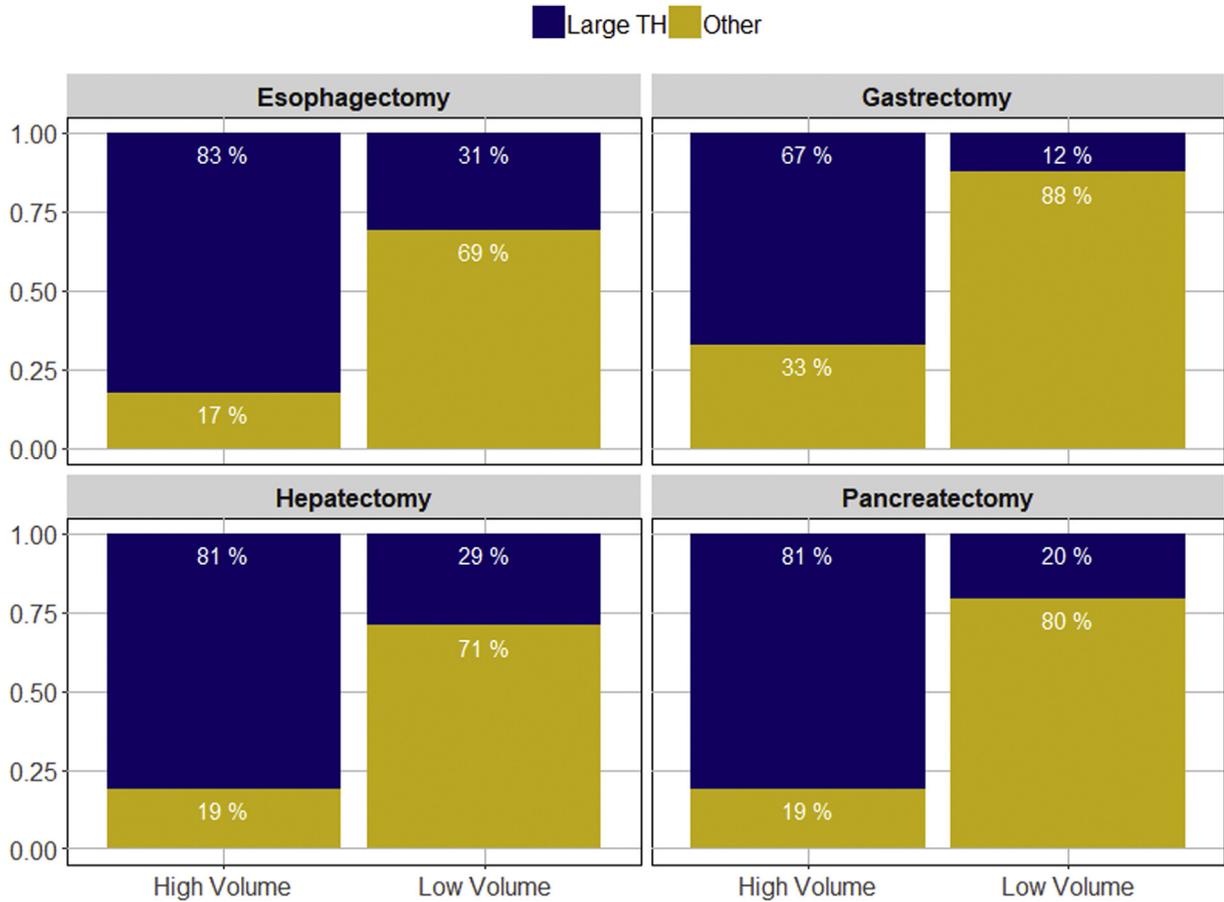
Fig 2. Percent of HV and LV hospitals by hospital type. A significantly higher proportion of HV hospitals were large THs compared to other hospital types for all 4 cancer operations (*P* < .001). Esophagectomy: 52 HV, 494 LV. Gastrectomy: 146 HV, 1389 LV. Hepatectomy: 64 HV, 624 LV. Pancreatectomy: 95 HV, 854 LV.
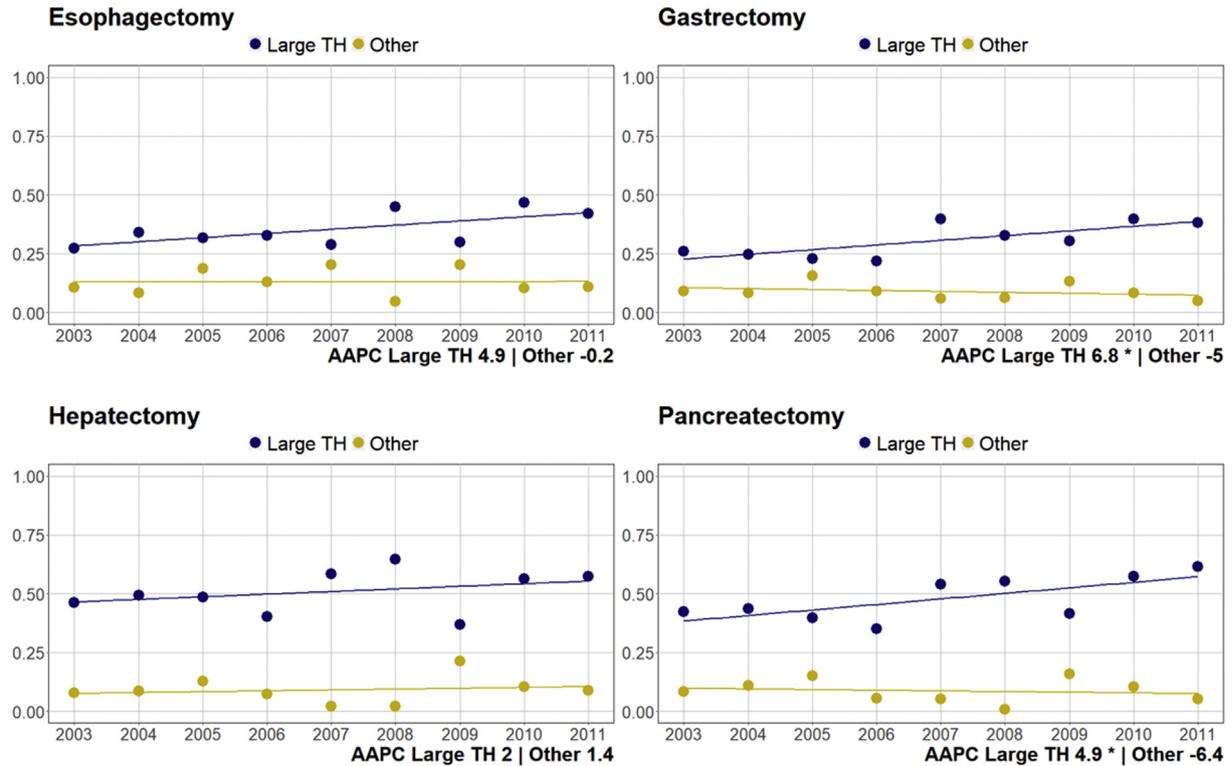
Fig 3. National estimates of percent of operations performed at high-volume hospitals by hospital type (large THs versus other hospitals), 2003 to 2011. *P < .05 for AAPC.

Table III
AAPC in the inpatient complication rate, length of stay, and inpatient mortality rate of cancer operations performed at large THs and other hospitals, 2003 to 2015

Resection	Complication rate (%)		Length of stay (d)		Mortality rate (%)	
	AAPC	P value	AAPC	P value	AAPC	P value
Esophagectomy						
Large THs	0.98	.12	−1.8	0.024	−4.9	.32
Other	0.55	.60	−0.72	0.23	−3.5	.22
Gastrectomy						
Large THs	1.0	.082	0.65	0.45	0.75	.10
Other	−3.1	.97	−2.2	<0.001	−7.7	.001
Hepatectomy						
Large THs	−0.25	.66	−1.9	<0.001	−6.5	<.001
Other	−1.8	.77	−2.5	<0.001	−5.0	.037
Pancreatectomy						
Large THs	0.14	.87	−2.3	<0.001	−2.1	.25
Other	0.62	.34	−2.6	<0.001	−4.6	.008

esophagectomies. There were no changes in complication rates during the study period (Table III; Supplemental Fig 1).

Mean LOS ranged from 7.4 (SD 6.5) days for hepatectomies to 15.6 (SD 13.9) days for esophagectomies. LOS decreased for esophagectomies performed at large THs (AAPC −1.8, $P = .024$) but not at other hospitals (AAPC −0.72, $P = .23$; Supplemental Fig 2). For gastrectomies, LOS did not change at large THs due to opposing trends before and after 2005 (AAPC 0.65, $P = .45$). LOS decreased at both large THs and other hospitals for hepatectomies (AAPC large TH −1.9, $P < .001$; other hospitals −2.5, $P < .001$) and pancreatectomies (AAPC large TH −2.3, $P < .001$; other hospitals −2.6, $P < .001$).

The overall inpatient mortality rate ranged from 2.5% for hepatectomies to 4.4% for esophagectomies. The largest decrease in mortality occurred for hepatectomies (AAPC large TH −6.5, $P < .001$; other hospitals −5.0, $P = .037$; Supplemental Fig 3). For gastrectomies, mortality did not change at large THs due to opposing trends in two time periods (AAPC 0.95, $P = .10$). For pancreatectomies, mortality decreased at large THs after 2010 (post-2010 annual percent change −11.5, $P = .004$).

Adjusted perioperative outcomes by hospital type

Perioperative outcomes adjusted for patient demographics, hospital characteristics, and extent of resections, were compared between large THs and other hospitals for 2 time periods, 2003 to 2005 and 2013 to 2015. Two different time periods were assessed to determine if differences in adjusted perioperative outcomes persisted over time. As shown in Fig 4, in 2003 to 2005, operations at large THs was associated with a decrease in complication rates for esophagectomies (odds ratio [OR] 0.76, 95% CI, 0.58−1.00, $P = .050$), decreased LOS for gastrectomies (incidence rate ratio [IRR] 0.91, 95% CI, 0.86−0.96, $P < .001$) and pancreatectomies (IRR 0.89, 95% CI, 0.84−0.94, $P < .001$), and decreased mortality rates for esophagectomies (OR 0.51, 95% CI, 0.28−0.95, $P = .033$) and pancreatectomies (OR 0.44, 95% CI, 0.30−0.65, $P < .001$).

Outcomes in 2003 to 2005 were analyzed further by both volume and bed-size and teaching status. Four categories of hospital types were compared: HV large TH, HV other, LV large TH, and LV other (Table IV). Both operative volume and teaching status were important indicators of perioperative outcomes. Neither volume nor teaching status alone was associated consistently with better outcomes. For example, compared to LV other hospital types, only HV large THs (OR 0.37, 95% CI, 0.16−0.85, $P = .019$), but not other HV hospitals (OR 1.13, 95% CI, 0.41−3.08,

$P = .82$), were associated with decreased inpatient mortality for esophagectomies. A similar pattern was observed for LOS and inpatient mortality after gastrectomies. In contrast, for pancreatectomies, operative volume appeared to be more important than teaching status, because all HV hospitals, regardless of teaching status, were associated with decreased inpatient complications, LOS, and mortality. Outcomes for hepatectomies, unlike the other three cancer operations, did not seem to differ by either volume or teaching status.

A decade later (2013−2015), outcome differences comparing large THs to other hospitals decreased and mortality differed only for pancreatectomies (OR 0.62, 95% CI, 0.43−0.91, $P = .015$) (Fig. 4). Moreover, a mortality difference was present only for total pancreatectomies and pancreatoduodenectomies (OR 0.57, 95% CI, 0.38−0.85, Bonferroni-corrected $P = .012$), but not other partial pancreatectomies (OR 1.31, 95% CI, 0.42−4.08, Bonferroni-corrected $P > .99$). For gastrectomies (IRR 1.11, 95% CI, 1.04−1.18, $P = .002$) and hepatectomies (IRR 1.08, 95% CI, 1.02−1.13, $P = .006$), LOS was greater at large THs compared to other hospitals.
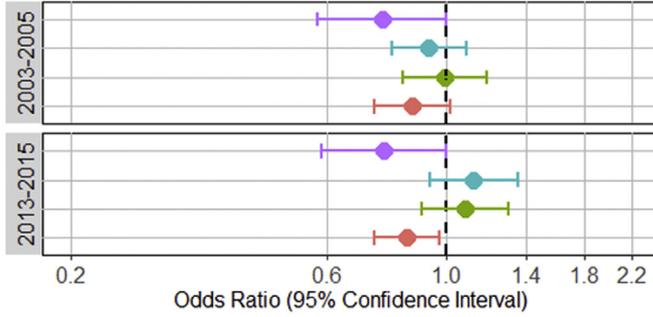
Discussion

While the literature and efforts at centralization have focused primarily on the volume-outcome relationship,[1–7] our study demonstrates significant shifts in resections for esophageal, gastric, and pancreatic malignancies toward large THs. Even among HV hospitals, increases in the proportion of cancer operations occurred only at HV large THs and not at other HV hospitals. This study further demonstrates important temporal trends in perioperative outcomes by hospital type. Outcomes, especially LOS and mortality, have improved at a national level, while differences by hospital type have decreased over time.

To the authors' knowledge, the shift to large THs for these cancer operations has not been described previously. The study by Stitzenberg et al focused on centralization for esophageal, pancreatic, colon, and rectal cancer operations by hospital volume and not teaching status over the decade from 1996 to 2006.[7] In the present study, an increase in the proportion of operations at large THs was also observed for VHRs. This observation made sense conceptually; if major abdominal operations were performed increasingly at large THs, patients may have returned to the same institution for their subsequent VHRs. Importantly, there was no change in the adjusted proportion of nonelective appendectomies at large THs after taking into consideration increased residence in large metropolitan areas. This observation suggests that the trend for cancer operations may represent selective referral of complex cases to experienced centers
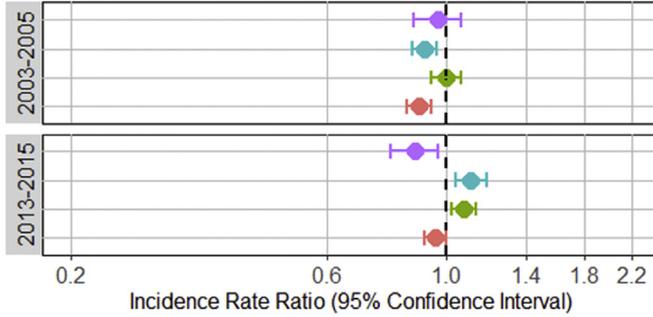
Fig 4. Perioperative outcomes of cancer operations performed at large THs compared to other hospitals by multivariable analyses, 2003 to 2005 and 2013 to 2015. Multivariable regressions adjusted for patient demographics, hospital characteristics, and extent of resection (eg, partial versus total gastrectomy). Values <1.0 are favorable and >1.0 are un-favorable for large teaching hospitals.

rather than an increase in the number of hospitals classified as large THs over time.

For some of the cancer operations included in the present study, the pattern of centralization observed seemed to reflect differences in perioperative outcomes. Better outcome data may have been a driver for referral to large THs for these procedures. For example, the proportion of esophagectomies and pancreatectomies at large THs increased, and these procedures also demonstrated persistent differences in outcomes by hospital type throughout the study period. In contrast, gastrectomies increased at large THs despite a lack of clear benefit in outcomes.

A shift of hepatectomies did not occur toward either large THs or HV hospitals. This lack of a shift may have been due to the fact that a relatively greater proportion of liver resections were already performed at these hospitals at the beginning of the study period. In fact, only 688 HCUP-participating hospitals performed liver resections in 2003 to 2011 compared to 949 hospitals for pancreatectomies and 1,535 hospitals for gastrectomies. By 2015, the proportion of operations performed at large THs approached 75%

for all 4 cancer operations, but none exceeded this percentage, possibly reflecting structural barriers, such as patient access to care, that may have limited further centralization.[7]

Due to limitations of the NIS administrative database, this study was only able to evaluate in-hospital outcomes. The 30- or 60-day postoperative outcomes that may be potentially more relevant could not be assessed. Moreover, the quality of the cancer resection, appropriate utilization of neoadjuvant and adjuvant treatments, and adherence to guidelines are important determinants of long-term cancer outcomes.[22–24] Other studies have demonstrated increased rates of R0 resections,[22,23] improved lymph node harvesting,[23] and improved long-term survival[22,23] for patients undergoing cancer operations at experienced hospitals. These factors may contribute to referral decisions but could not be evaluated in this study.

Volume and academic status are not perfect surrogates for quality. Volume-based referrals may also alienate the surgical community in lesser volume hospitals that could still be expected to perform complex operations in an emergent or urgent setting,

Table IV
Multivariable comparisons of perioperative outcomes of cancer operations by operative volume and bed-size/teaching status, 2003 to 2005

Resection	Inpatient complications		Length of stay		Inpatient mortality	
	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Esophagectomy						
Low-volume other	Reference		Reference		Reference	
Low-volume large teaching	0.77 (0.54–1.10)	.14	1.05 (0.91–1.21)	.49	0.78 (0.37–1.65)	.51
High-volume other	0.50 (0.31–0.80)	.004	0.90 (0.78–1.04)	.16	1.13 (0.41–3.08)	.82
High-volume large teaching	0.56 (0.40–0.78)	<.001	0.85 (0.75–0.95)	.007	0.37 (0.16–0.85)	.019
Gastrectomy						
Low-volume other	Reference		Reference		Reference	
Low-volume large teaching	0.97 (0.77–1.22)	.79	0.99 (0.92–1.07)	.89	1.35 (0.89–2.05)	.16
High-volume other	0.91 (0.70–1.18)	.49	1.01 (0.92–1.10)	.90	0.76 (0.43–1.35)	.35
High-volume large teaching	0.88 (0.73–1.07)	.20	0.87 (0.81–0.92)	<.001	0.47 (0.30–0.72)	<.001
Hepatectomy						
Low-volume other	Reference		Reference		Reference	
Low-volume large teaching	1.18 (0.92–1.51)	.19	1.02 (0.94–1.12)	.60	1.16 (0.67–2.03)	.60
High-volume other	0.72 (0.51–1.00)	.052	0.93 (0.84–1.04)	.20	0.54 (0.23–1.29)	.17
High-volume large teaching	0.83 (0.68–1.02)	.084	0.97 (0.90–1.04)	.37	0.87 (0.55–1.39)	.56
Pancreatectomy						
Low-volume other	Reference		Reference		Reference	
Low-volume large teaching	0.90 (0.71–1.15)	.40	1.00 (0.92–1.08)	.91	0.66 (0.39–1.11)	.12
High-volume other	0.70 (0.52–0.93)	.015	0.83 (0.77–0.90)	<.001	0.35 (0.17–0.73)	.005
High-volume large teaching	0.75 (0.62–0.90)	.003	0.80 (0.75–0.85)	<.001	0.27 (0.17–0.43)	<.001

Multivariable regressions adjusted for patient demographics, hospital characteristics, and extent of resection (eg, partial versus total gastrectomy).

depending on their geographic proximity to more experienced centers.[8] It is reassuring that perioperative mortality decreased across hospital types over time, possibly due to the establishment and increased recognition of several surgical quality initiatives during the last 2 decades, such as the National Surgical Quality Improvement Program and Surgical Care Improvement Project.[25] Nevertheless, perioperative complication rates remained unchanged over time and represent an area for improvement.

Continued focus on risk-adjusted, patient-centered outcomes and optimal process measures (eg, appropriate perioperative use of β-blockers) and systems of care (eg, coordination between teams) could improve performance at all hospitals.[8] Specifically, lessons can be learned from those hospitals with the best outcomes. For example, LOS was actually greater for gastrectomies and hepatectomies at large THs than other hospitals in 2013 to 2015 and may reflect more efficient, streamlined perioperative care at non-THs.[13] Further studies should focus on identifying transferrable qualities that differ between high- and low-performing centers in order to identify actionable targets for improvement.

Several limitations of the study should be acknowledged. Causal relationships cannot be inferred from this retrospective, observational study. One cannot conclude for example that better outcomes was the driver for increased referrals of complex surgeries to large THs. While the multivariable analyses for perioperative outcomes were adjusted for many patient and clinical factors, these analyses do not fully account for differences in patient comorbidities or case complexity at different hospitals. There are likely residual confounders. It is possible that medically complex patients are increasingly referred to large THs, thus resulting in a convergence of perioperative outcomes over time. Additionally, analyses by operative volume ideally would be performed for the entire study period, but these analyses were unfortunately limited by the redesign of the NIS database.

Despite these limitations, our study revealed important trends in patterns of care at a nationally-representative groups of hospitals. Specifically, large THs have experienced increases in the proportion of operations for esophageal, gastric, and pancreatic cancer in the United States during a span of 13 years. While continued

centralization may be justified for certain operations that demonstrate persistent differences in outcomes at different hospitals, focus should be placed on determining specific patient and clinical factors that would benefit most from referral to specialized centers. Additionally, studies outlining the qualities of high-performing hospitals that are transferrable to other centers could ensure quality care for all patients.

Conflicts of interest/Disclosures

Funding

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.surg.2019.03.025.

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