Original Article

Spontaneous regionalization of esophageal cancer surgery: an analysis of the National Cancer Database

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Background: Esophagectomy patients are up to three times more likely to die after surgery when cared for at low-volume hospitals (LVHs). Increased awareness by patients and clinicians of the hazards of esophagectomy at LVHs, may inspire a "spontaneous regionalization" away from LVHs, yet the extent to which this has taken place is unclear.

Methods: Retrospective analysis of patients undergoing esophagectomy for esophageal cancer in the National Cancer Database (NCDB) across two eras: 2004–2006 (Era 1) and 2010–2012 (Era 2). Primary outcomes included the proportion of patients at high-volume hospitals (HVHs) (≥13/year per Leapfrog Group), adjusted, and unadjusted 90-day mortality.

Results: The NCDB captured 5,968 esophagectomy patients in Era 1 and 5,580 in Era 2, a 6.5% decrease (P<0.001). Fewer hospitals performed esophagectomies in Era 2 (756 *vs.* 663, P=0.014), yet the proportion of patients treated at LVHs declined slightly between eras (73% *vs.* 70%, P<0.001). Patients with high-risk attributes (e.g., advanced age, multiple comorbidities, etc.) were disproportionately treated at LVHs in both eras (77% Era 1, P<0.001, 73% Era 2, P=0.017). However, the 90-day mortality rate for patients with high-risk attributes decreased considerably between Eras at LVHs (19.3% to 12.3%, P<0.001).

Conclusions: Spontaneous regionalization of esophageal cancer surgery has not occurred on a large scale, yet for high-risk patients, the hazards of being cared for at LVHs have dissipated. Further study is needed to optimize alignment of esophagectomy patients and hospitals.

Keywords: Esophageal cancer; regionalization; esophagectomy; outcomes

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Introduction

Esophagectomy, which represents one of the most effective treatments for esophageal cancer, is a particularly dangerous procedure. Approximately half of esophagectomy patients experience a postoperative complication (1) and up to 14% of patients die as a result of esophageal cancer surgery, making esophagectomy one of the most dangerous cancer surgeries performed (2).

Outcomes after esophagectomy appear to obey a volume-dependent relationship, with high-volume hospitals (HVHs) performing better than low-volume hospitals (LVHs) (3-9). Over the past decade, formal regionalization was implemented in parts of Canada to restrict the performance of esophagectomy to HVHs, reducing mortality rates from 9.6% to 3.6% (10). A similar effort for pancreatic surgery decreased perioperative mortality from 10.4% to 2.2% (11).

There are multiple barriers to formal regionalization of surgical care in countries without centralized health care systems such as the United States (U.S.). However, an increasing awareness by clinicians, patients, and payers of the relationship between hospital attributes and surgical outcomes can lead to a spontaneous movement of care away from LVHs ("spontaneous regionalization"). The Canadian province of Quebec (which did not impose a formal regionalization plan) experienced a similar realignment of complex surgical patients away from LVHs as provinces in which a formal regionalization effort took place (11). In the U.S., health care providers and private payers have become particularly sensitized to volume-outcome relationships (12-14). For example, the Leapfrog Group, a consortium of healthcare purchasers, published a volume threshold for esophagectomy of ≥13 per year to define HVHs (15). The objective of this study was to determine the extent to which the progressive recognition of esophagectomy risk at LVHs in the U.S. and the efforts of private payers have led to a "spontaneous" movement of esophagectomy patients away from LVHs in the U.S. for their care.

Methods

Data source

The National Cancer Database (NCDB) captures approximately 70% of the newly diagnosed cancer patients in the U.S. (16) In addition to detailed demographic, tumor, treatment, and outcomes data, the NCDB allows for hospital-specific surgical volumes to be studied. This study was granted a waiver for patient consent by the Institutional Review Board from the Yale School of Medicine (IRB under HIC Protocol Number 1103008160).

Patient selection

The 2013 NCDB participant user file was queried for all patients >20 years of age, diagnosed with invasive esophageal cancer who underwent esophagectomy between 2004 and 2012. Patients were excluded if they underwent esophagectomy at a hospital different from the hospital that reported their case, or if a total gastrectomy or laryngectomy was listed as part of their resection.

Patients were divided into two eras, 2004–2006 (Era 1) and 2010–2012 (Era 2). These eras were chosen because they represent the periods during and after Leapfrog recommendations were implemented and in which there became increased awareness of the importance of volume-outcome relationships in U.S. hospitals. Additionally, this is the same period in which spontaneous regionalization was observed in the Canadian system.

Hospital volume threshold

Hospital esophagectomy volume during each era was calculated as a 3-year average. The cut point for high and low volume was based on Leapfrog recommendations (15) and hospitals with an average annual volume of ≥13 esophagectomies were considered HVHs, while those with <13 were considered LVHs.

Volume averages were calculated only from years the hospital was reporting (as determined by examining each hospital's surgical and nonsurgical activity in lung and esophageal cancer). Of the 871 hospitals included in this analysis, 6 hospitals (0.7%) had at least one year that they did not report to the NCDB.

Independent variables

Patient demographic variables analyzed included age, sex, race, ethnicity, income, education level, insurance status, urban/rural designation, and travel distance to the treating hospital. The NCDB uses a modified Charlson-Deyo score to characterize comorbidity burden which stratifies patients to a score of 0, 1, or ≥2. Tumor characteristics included histology, grade, location, size, and pathologic stage. Finally, receipt of neoadjuvant chemotherapy with or without radiation was analyzed. Chemotherapy was defined as multi-agent therapy. Radiation therapy was defined as at least 4,140 cGy (17) directed to the esophagus, chest, or regional lymph nodes. Hospital characteristics analyzed included the type of hospital (academic *vs.* non-academic), geography, and hospital esophagectomy volume.

Adjusted 90-day mortality

Adjusted 90-day mortality was calculated using the standardized mortality ratio (SMR), defined as the ratio of observed mortality in a given hospital to expected mortality of patients treated at HVHs (18). Expected mortality was estimated using only the subset of patients treated at HVHs, since patient-level risk factors may be confounded by hospital risk at LVHs. Expected mortality was derived from a multivariable logistic regression model, adjusted for patient-level covariates including age, gender, comorbidity score, and tumor characteristics. The model did not adjust for hospital-level data such as academic status and geographic location, as this may obscure the hospital-specific effect and thus the impact of regionalization (19). Regression coefficients from logistic regression were applied to patients treated at LVHs such that each patient was assigned an expected mortality rate. Adjusted 90-day mortality rates were subsequently used to divide patients into risk terciles (e.g., high-risk, mid-risk, and low-risk). While the adjusted 90-day mortality rates were calculated using the SMR (i.e., the ratio of observed to expected mortality), another metric, excess mortality, was defined as the observed mortality beyond what was expected from the risk model (i.e., observed-expected).

Statistical analysis

Bivariate analysis was performed using the χ^2 test for categorical variables and nonparametric tests such as the ANOVA Kruskal-Wallis test for continuous variables. Risk differences for categorical variables are available upon request. Missing data were included and coded as "unknown". All statistical tests were two-sided. A P value <0.05 was considered statistically significant. All statistical analysis was performed using SAS version 9.4 (SAS Institute, Cary, NC, USA).

Results

Patients and treatment across eras

The NCDB captured 5,968 esophagectomy patients in Era 1 [2004–2006], and 5,580 in Era 2 [2010–2012], representing a 6.5% decline between the two eras (P<0.001). Several important differences were noted between the two eras, including a greater prevalence of stage I disease in Era 2 (27% *vs.* 20%, P<0.001) and a greater use of induction therapy in Era 2 (52% *vs.* 28%, P<0.001) (*Table 1*).

Spontaneous regionalization—patient perspective

Fewer patients were treated at LVHs in Era 2 (n=3,910) compared to Era 1 (n=4,384, P<0.001), and more patients were treated at HVHs (n=1,670 *vs.* n=1,584, P<0.001) (*Figure S1*). More patients were cared for at academic centers in Era 2 (63%, n=3,534) compared to Era 1 (57%, n=3,381, P<0.001). In addition, the proportion of patients that traveled >20 miles increased from 45% (n=2,674) in Era 1 to 51% (2,853, P<0.001) in Era 2.

Spontaneous regionalization—hospital perspective

Seven hundred and fifty-six hospitals performed esophagectomies in Era 1 compared to 663 in Era 2, representing a net reduction of 12.4% (P=0.014). Overall, 97% of hospitals in this study were LVHs. Of the 548 hospitals that performed esophagectomies in both eras, 98% (n=539) maintained the same volume status in both eras (*Figure 1*). Interestingly, all 208 hospitals that stopped performing esophagectomies after Era 1 were LVHs, but 99% of the 115 hospitals that started performing esophagectomies in Era 2 were also LVHs (*Table S1*). The combined effect resulted in a net decrease in the number of LVHs from Era 1 [734] to Era 2 [641], which did not alter the overwhelming predominance of LVHs in the NCDB (97% in both eras, P=0.7) (*Figure S2*).

Quality metrics across eras

Several outcomes measures improved between Eras 1 and 2 (*Table 2*). Unadjusted 90-day mortality decreased from 10% to 8% (P<0.001). The 90-day SMR improved from 1.38 (95% CI, 1.27–1.49) to 1.14 (95% CI, 1.04–1.25, P=0.002). Median length of stay decreased by 1 day (11 *vs.* 10, P<0.001). The positive margin rate decreased from 10% to 7% (P<0.001), and the number of lymph nodes removed at the time of surgery increased from 9 to 13 (P<0.001). The 30-day readmission rate was 7% in both eras (P=0.49). A subset analysis of only hospitals that performed esophagectomies during both eras demonstrated similar quality improvements (*Table S2*).

Relationship between volume status and quality metrics

The volume-outcome relationship appeared to vary between eras. In Era 1, patients treated at LVHs had a higher 90-day SMR compared to patients treated at HVHs (SMR 1.50, 95% CI, 1.37–1.63 *vs.* 1.00, 95% CI, 0.82–1.20; P<0.001) (*Table 3*). In Era 2, there was a trend toward a higher SMR for LVHs, but it did not reach statistical significance. Substantial variation of the SMR was observed within HVHs in both eras (*Figure 2*).

Impact of hospital attrition on quality metrics

Hospitals that stopped performing esophagectomies after

Table 1 Patient characteristics in both Eras

Variable	Value	Era 1 [2004–2006]		Era 2 [2010–2012]		P value
		N	%	N	%	
Total number of esophagectomies	–	5,968	–	5,580	–	<0.001
Age (years)	20–29	<10	–	<10	–	<0.001
	30–39	77	1	69	1	
	40–49	520	9	390	7	
	50–59	1,546	26	1,433	26	
	60–69	2,058	34	2,188	39	
	70–79	1,450	24	1,296	23	
	80–89	306	5	189	3	
	90+	<10	–	10	–	
Gender	Male	4,865	82	4,615	83	0.096
	Female	1,103	18	965	17	
Race	White	5,449	91	5,142	92	0.099
	Non-White	519	9	438	8	
Ethnicity	Non-Hispanic	5,253	88	5,220	94	<0.001
	Hispanic	152	3	153	3	
	Unknown	563	9	207	4	
Median income	<$38,000	952	16	833	15	<0.001
	$38,000–47,999	1,474	25	1,391	25	
	$48,000–62,999	1,613	27	1,551	28	
	$63,000 and above	1,734	29	1,750	31	
	Unknown	195	3	55	1	
% high school diploma	<7%	1,382	23	1,380	25	<0.001
	7–12.9%	2,115	35	1,945	35	
	13–20.9%	1,487	25	1,460	26	
	21% or more	790	13	743	13	
Insurance	Private/managed care	2,739	46	2,527	45	<0.001
	Medicare	2,579	43	2,408	43	
	Medicaid	252	4	313	6	
	Other government	50	1	75	1	
	Uninsured	121	2	109	2	
	Unknown	227	4	148	3	

Table 1 (*continued*)

Table 1 (*continued*)

Variable	Value	Era 1 [2004–2006]		Era 2 [2010–2012]		P value
		N	%	N	%	
Urban/rural designation	Metro >1 million	2,734	46	2,555	46	0.72
	Metro 250 k–1 million	1,250	21	1,189	21	
	Metro <250 k	590	10	606	11	
	Urban >20 k, adjacent to Metro area	291	5	265	5	
	Urban >20 k, nonadjacent to Metro area	91	2	87	2	
	Urban 2.5–20 k, adjacent	379	6	383	7	
	Urban 2.5–20 k, nonadjacent	207	3	201	4	
	Rural, adjacent	56	1	55	1	
	Rural, nonadjacent	82	1	61	1	
	Unknown	288	5	178	3	
Modified Charlson-Deyo score	0	4,292	72	3,982	71	0.8
	1	1,331	22	1,268	23	
	2+	345	6	330	6	
Tumor histology	Adenocarcinoma	4,118	69	3,960	71	0.001
	Squamous cell carcinoma	1,169	20	1,014	18	
	Other	113	2	56	1	
	Unknown	568	10	550	10	
Tumor grade	1	415	7	397	7	0.8
	2	2,139	36	2,047	37	
	3	2,512	42	2,330	42	
	4	133	2	116	2	
	Unknown	769	13	690	12	
Tumor location	Upper third	134	2	102	2	0.005
	Middle third	721	12	696	12	
	Lower third	4,447	75	4,244	76	
	Overlapping	217	4	208	4	
	NOS	449	8	330	6	

Table 1 (*continued*)

Table 1 (*continued*)

Variable	Value	Era 1 [2004–2006]		Era 2 [2010–2012]		P value
		N	%	N	%	
Tumor size (cm)	0–2	1,141	19	1,268	23	<0.001
	2.1–3	831	14	828	15	
	3.1–4	779	13	720	13	
	4.1–5	639	11	574	10	
	>5	1,002	17	969	17	
	Circumferential	89	1	102	2	
	Unknown	1,487	25	1,119	20	
Pathologic stage	I	1,221	20	1,500	27	<0.001
	II	1,663	28	1,325	24	
	III	1,276	21	979	18	
	IV	112	2	83	1	
	Unknown	1,696	28	1,693	30	
Neoadjuvant therapy	None	4,277	72	2,700	48	<0.001
	Chemotherapy	238	4	594	11	
	Chemoradiation	1,453	24	2,286	41	
Treated at high volume hospital (≥13/year)	Yes	1,584	27	1,670	30	<0.001
	No	4,384	73	3,910	70	
Facility location	New England	289	5	267	5	<0.001
	Middle Atlantic	975	16	941	17	
	South Atlantic	1,123	19	1,134	20	
	East North Central	1,200	20	1,005	18	
	East South Central	395	7	338	6	
	West North Central	651	11	709	13	
	West South Central	441	7	396	7	
	Mountain	283	5	291	5	
	Pacific	611	10	499	9	
Academic hospital	Yes	3,381	57	3,534	63	<0.001
	No	2,587	43	2,046	37	
Travel distance to hospital (miles)	<20	3,294	55	2,727	49	<0.001
	20–59.9	1,478	25	1,549	28	
	60–119.9	659	11	743	13	
	120 or greater	537	9	561	10	

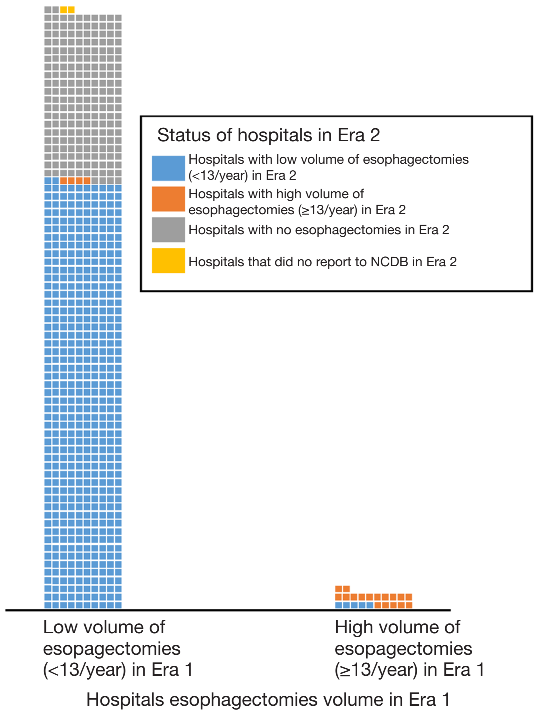

Figure 1 Shift in hospital volume status over time. Individual hospitals plotted by volume status (e.g., high or low volume) in Era 1 along the x-axis. Color of box represents volume status in Era 2. Each box represents a single hospital.

Era 1 (all LVHs) appeared to achieve inferior quality metrics compared to hospitals that continued performing esophagectomies (*Table S2*). More specifically, hospitals that stopped performing esophagectomies trended toward inferior unadjusted 90-day mortality (13% *vs.* 10%, P=0.066) compared to hospitals that contributed to both eras, although the SMR was not significantly different. Hospitals that started performing esophagectomies after Era 1 (99% LVHs) had similar unadjusted 90-day mortality and SMR as hospitals that performed esophagectomies in both eras.

Care of the most vulnerable patients

To evaluate the care of the most vulnerable population, patients were stratified by their risk for 90-day mortality. A disproportionately high number of high-risk patients were treated at LVHs (77% in Era 1, P<0.001; 73% in Era 2, P=0.017). Differences in 90-day mortality for high-risk patients between LVHs and HVHs narrowed between Era 1 (19.3% LVH *vs.*13% HVH, P=0.003) and Era 2 (12.3% LVH *vs.* 11.3% HVH, P=0.57).

The largest excess mortality was observed when high-risk patients were treated at LVHs, particularly in Era 1 (*Figure 3*). The magnitude of excess mortality at LVHs

Table 2 Patient outcomes in both Eras

Variable	Value	Era 1 [2004–2006]		Era 2 [2010–2012]		P value
		N	%	N	%	
90-day mortality (unadjusted)	Yes	607	10	444	8	<0.001
	No	5,315	89	4,972	89	
	Unknown	46	1	164	3	
Standardized 90-day mortality ratio (observed-expected)*	Mean, 95% CI	1.38	1.27–1.49	1.14	1.04–1.25	0.002
Excess mortality (observed-expected)*	Mean, 95% CI	2.80%	2.1–3.6%	1.00%	0.3–1.8%	<0.001
30-day readmission	Yes	401	7	393	7	0.49
	No	5,567	93	5,187	93	
Median length of stay (IQR)	Days	11	8–17	10	8–16	<0.001
Margin status	Positive	611	10	394	7	<0.001
	Negative	5,204	87	5,070	91	
	Unknown	153	3	116	2	
Median number of nodes removed (IQR)		9	5–15	13	7–19	<0.001

*, adjusted for gender, race, ethnicity, median income, education level, insurance, comorbidity, histology, tumor grade, tumor location, tumor size, receipt of neoadjuvant therapy, and pathologic stage.

Table 3 Patient outcomes in both eras, stratified by hospital volume

Variable	Value	Era 1 [2004–2006]				Era 2 [2010–2012]				P value			
		Low volume		High volume		Low volume		High volume		Era 1	Era 2	Low volume	High volume
		N	%	N	%	N	%	N	%				
90-day mortality (absolute)	Yes	500	11	107	7	336	9	108	6	<0.001	<0.001	<0.001	<0.001
	No	3,848	88	1,467	93	3,497	89	1,475	88				
	Unknown	36	1	10	1	77	2	87	5				
Standardized 90-day mortality ratio (observed/expected)*	Mean, 95% CI	1.50	1.37–1.63	1.00	0.82–1.20	1.21	1.08–1.33	0.99	0.80–1.18	<0.001	0.07	0.002	0.94
Excess mortality (observed-expected)*	Mean, 95% CI	3.80%	2.9–4.7%	0.10%	−1.1% to 1.3%	1.50%	0.6–2.4%	−0.1%	−1.2% to 1.2%	<0.001	0.06	<0.001	0.88
30-day readmission	Yes	309	7	92	6	261	7	132	8	0.091	0.1	0.5	0.018
	No	4,075	93	1,492	94	3,649	93	1,538	92				
Median length of stay (IQR)	Days	11	8–18	10	8–15	11	8–16	10	8–14	<0.001	<0.001	<0.001	0.007
Margin status	Positive	499	11	112	7	307	8	87	5	<0.001	<0.001	<0.001	0.041
	Negative	3,802	87	1,402	89	3,578	92	1,492	89				
	Unknown	83	2	70	4	25	1	91	5				
Median number of nodes removed (IQR)		8	4–14	13	7–19	11	6–17	16	10–23	<0.001	<0.001	<0.001	<0.001

*, adjusted for gender, race, ethnicity, median income, education level, insurance, comorbidity, histology, tumor grade, tumor location, tumor size, receipt of neoadjuvant therapy, and pathologic stage.

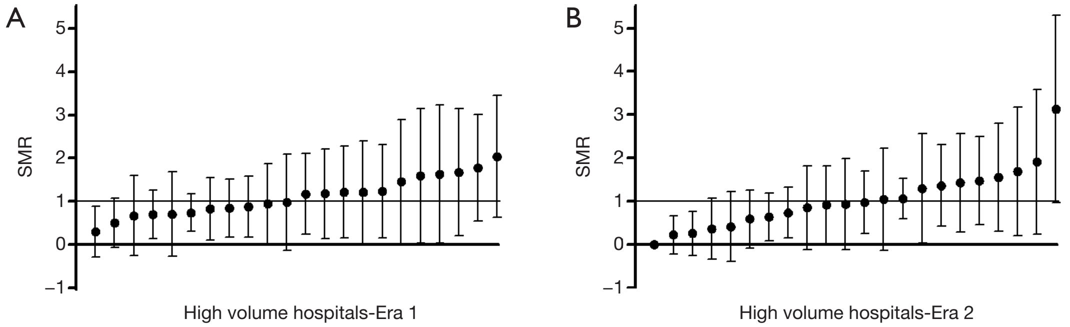

Figure 2 Standardized mortality ratio (SMR) of high volume hospitals in Era 1 (A) and Era 2 (B). Each dot represents a single hospital.

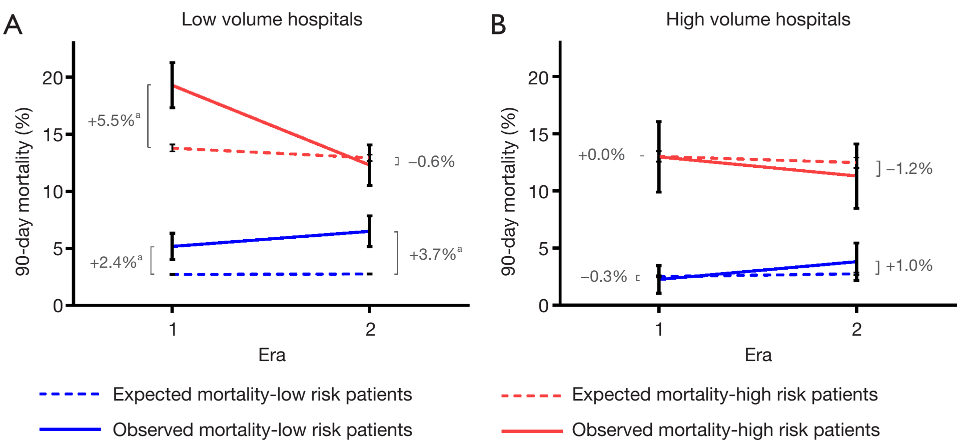

Figure 3 Observed and expected 90-day mortality, stratified by patient risk tercile, at (A) low volume hospitals; (B) high volume hospitals. Excess mortality, labeled by brackets, is the difference between the observed (solid line) and expected mortality (dotted line) for each risk group. Error bars represent 95% confidence intervals of mortality estimates. [a], excess mortality P<0.05.

varied over time. When high-risk patients were treated at LVHs in Era 1, the excess mortality was 5.5% (95% CI, 3.5–7.5%, P<0.001). When high-risk patients were treated at LVHs in Era 2, no excess mortality was observed (excess mortality −0.6%, 95% CI, −2.4% to 1.1%, P=0.49). On the other hand, excess mortality in low-risk patients treated at LVHs increased over time from 2.4% (95% CI, 1.3–3.6%, P<0.001) to 3.7% (95% CI, 2.4–5.1%, P<0.001).

Discussion

The NCDB paints a mixed picture regarding the extent to which esophagectomy care has been regionalizing spontaneously. More specifically, several trends support the notion that spontaneous regionalization has occurred. For example, over 200 low-volume, poorer performing hospitals stopped performing esophagectomies. This is a key component of regionalization based on the Canadian experience with formal regionalization (10). On the other hand, of the 115 hospitals that started performing esophagectomies, 114 were LVHs. This represents a net decrease in the number of hospitals performing esophagectomy of 12.3%. Our findings are similar to (but not as dramatic as) another study that noted a 20% decrease in hospitals performing esophagectomies in the U.S. during this time period (12). Because of this spontaneous regionalization, the proportion of patients receiving their care at LVHs decreased only slightly (73% to 70%) in our study.

The relationship between annual procedural volume and esophagectomy outcome is similarly complex in the NCDB cohort. When HVHs are defined according to the Leapfrog criteria, patients appear to have better outcomes when treated at HVHs. These findings parallel those of other observational studies that found LVHs to have worse outcomes (3,4,6,7). However, in the current study the volume-associated differences in mortality appeared to dissipate in Era 2 (excess mortality at LVH 3.8% to 1.5%). This may reflect general quality improvements that equally affected all care environments, as all cohorts experienced reductions in perioperative mortality consistent with other published data (12,20). Among these quality improvements may have been better selection, as the number of esophagectomy patients declined by 6.5%. This reduction is more impressive when one considers the incidence of esophageal cancer captured by the NCDB increased by 5.9% during this time. In addition, there was a 279% increase in the use of "local excisions" (e.g., removal by endoscopy) during the study period.

There are some indications that care improved specifically at the contingency of LVHs. This is most noticeable when patients at highest risk for surgical mortality (most vulnerable) were studied. In Era 1, LVHs had the highest excess mortality. While excess mortality is far from a precise reflection of hospital performance, this parameter should reflect any independent risk resulting from care at LVHs. In Era 2, this excess mortality at LVHs was eliminated for the high-risk cohort. One interpretation of this finding is that LVHs became better at caring for high-risk patients (e.g., better patient selection, enhanced care processes, etc.). However, excess mortality at LVHs persisted for low-risk patients which is counterintuitive and suggests the patient risk model may not be as predictive for LVHs. Finally, not all HVHs demonstrated high quality, which is similar to a finding among Leapfrog hospitals which showed over a fivefold variation in 90-day mortality (14).

Given that only 27/871 (3.1%) hospitals performing esophagectomies in the NCDB were HVHs in either era, it is unrealistic to think that all patients could receive their care at HVHs. It is important to focus on the most vulnerable patient population, not only because most operative deaths are identified in this cohort, but also because patient-derived risk could be anticipated and modulated by particularly safe care environments. The current study would suggest that not all LVHs are unsafe, and not all HVHs are safe. Therefore, although there may be potentially meaningful gains in matching the most vulnerable patients with safest care environments, annual volume is a reasonable, but imperfect surrogate for hospital safety.

The current study contains several limitations in addition to those traditionally associated with observational studies (16). Most importantly, the NCDB is not population-based. Although 70% of new cancer diagnoses are captured, these findings may not be entirely reflective of cancer care in the U.S. Specifically, compared to non-CoC-approved hospitals, CoC-approved hospitals (i.e., those that report to the NCDB) are larger, more frequently in urban locations, and have more cancer-related services available to patients (21). Risk modeling for surgical mortality did not include several potentially important health-related data (performance status, pulmonary function, etc.), which may have impacted the extent to which the model accurately adjusted for competing mortality risk.

In conclusion, although fewer LVHs are performing esophagectomies, most patients continue to have surgery at LVHs. While spontaneous regionalization has not occurred on a large scale, subtle shifts in patient allocation have occurred, and LVHs have made improvements in patient outcomes in the absence of realignment. Attempts to increase the efficiency of patient realignment for esophagectomy must take into consideration the progress LVHs have made in caring for or selecting high-risk patients and recognize that annual surgical volume is an imperfect surrogate for hospital safety. Further study is needed to identify optimal alignment of esophagectomy patients and hospitals in order to reduce surgical mortality.

Acknowledgements

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: This study was approved by the Institutional Review Board from the Yale School of Medicine (IRB under HIC Protocol Number 1103008160), and a waiver for patient consent was granted by the Institutional Review Board.

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Supplementary

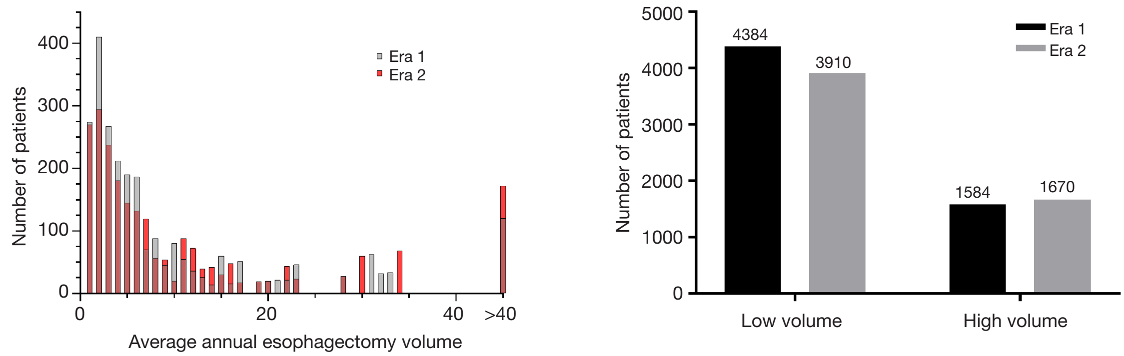

Figure S1 Distribution of patients by average annual volume in each Era.

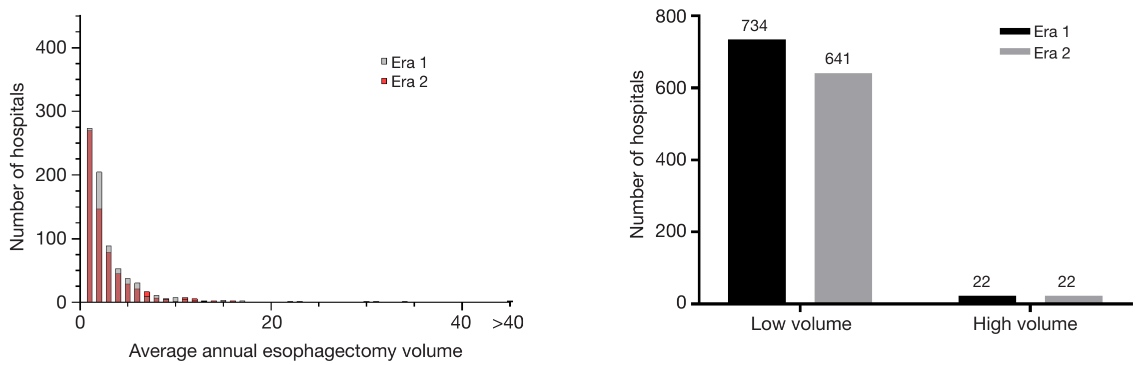

Figure S2 Distribution of hospitals by average annual volume in each Era.

Table S1 Hospital characteristics in both Eras, stratified by hospital type

Variable	Value	Performed esophagectomies in both Eras		Performed esophagectomies in Era 1 only		Performed esophagectomies in Era 2 only		P value
		N	%	N	%	N	%	
Total number of hospitals contributing esophagectomy		548		208		115		0.014
Hospital volume status	High	22	4	0	0	1	1	0.004
	Low	526	96	208	100	114	99	
Academic hospital	Yes	184	34	19	9	12	10	<0.001
	No	364	66	189	91	103	90	

Table S2 Patient outcomes in both Eras, stratified by hospital type

Variable	Value	Era 1 [2004-2006]				Era 2 [2010-2012]				P value		
		Performed esophagectomies in both Eras		Performed esophagectomies in Era 1 only		Performed esophagectomies in both Eras		Performed esophagectomies in Era 2 only		Era 1	Era 2	Between Era 1 and Era 2 for hospitals in both Eras
		N	%	N	%	N	%	N	%			
90-day mortality (unadjusted)	Yes	540	10	67	13	413	8	31	9	0.066	0.43	<0.001
	No	4,873	89	442	86	4,677	89	295	89			
	Unknown	41	1	<10	1	157	3	<10	2			
Standardized 90-day mortality ratio (observed/expected)	Mean, 95% CI	1.36	1.24–1.47	1.60	1.22–1.98	1.14	1.03–1.25	1.27	0.83–1.72	0.21	0.57	0.007
Excess mortality (observed-expected)	Mean, 95% CI	2.6%	1.8–3.4%	4.9%	2.1–7.8%	1.0%	0.2–1.7%	2.0%	−1.1% to 5.2%	0.09	0.49	0.003
30-day readmission	Yes	367	7	34	7	358	7	35	11	0.92	0.011	0.85
	No	5,087	93	480	93	4,889	93	298	89			
Median length of stay (IQR)	Days	11	8–17	12	9–17	10	8–16	11	9–16.5	0.010	0.009	<0.001
Margin Status	Positive	542	10	69	13	370	7	24	7	0.042	0.15	<0.001
	Negative	4,773	88	431	84	4,763	91	307	92			
	Unknown	139	3	14	3	114	2	<10	1			
Median number of nodes removed (IQR)	–	10	5–15	7	2–12	13	7–19	10	5–16	<0.001	<0.001	<0.001