Impact of Facility Surgical Volume on Survival in Patients With Cancer

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ABSTRACT

Background: Increased facility surgical treatment volume is sometimes associated with improved survival in patients with cancer; however, published studies evaluating volume are heterogeneous and disparate in their patient inclusion and definition of volume. The purpose of this work was to evaluate uniformly the impact of surgical facility volume on survival in patients with cancer. **Methods:** The National Cancer Database was searched for patients diagnosed in 2004 through 2013 with the 12 cancers most commonly treated surgically. Facilities were stratified by 4 categories using the overall population (low, intermediate, high, and very high), each including 25% of patients, and then stratified by each individual disease site. Five-year postsurgery survival was estimated using both the Kaplan-Meier method and corresponding log-rank tests for group comparisons. Cox proportional hazard models were used to evaluate the effects of facility volume on 5-year postsurgery survival further, adjusted for multiple covariates. **Results:** A total of 3,923,618 patients who underwent surgery were included from 1,139 facilities. Of these, 40.4% had breast cancer, 12.8% prostate cancer, and 10.0% colon cancer. Most patients were female (65.0%), White (86.4%), and privately insured (51.6%) with stage 0–III disease (64.8%). For all cancers, the risk of death for patients undergoing surgery at very high-volume facilities was 88% of that for those treated at low-volume facilities. Hazard ratios (HRs) were greatest (very high vs low volume) for cancer of the prostate (HR, 0.66; 95% CI, 0.63–0.69), pancreas (HR, 0.75; 95% CI, 0.71–0.78), and esophagus (HR, 0.78; 95% CI, 0.73–0.83), and for melanoma (HR, 0.81; 95% CI, 0.78–0.84); differences were smallest for uterine and non-small cell lung cancers. Overall survival differences were greatest for cancers of the brain, pancreas, and esophagus. **Conclusions:** Patients treated surgically at higher-volume facilities consistently had improved overall survival compared with those treated at low-volume centers, although the magnitude of difference was cancer-specific.

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Background

Patients with cancer treated surgically at high-volume, multidisciplinary centers are hypothesized to have improved outcomes and fewer toxicities from therapy than those treated at low-volume facilities. However, it is currently unknown which patients with cancer benefit most from treatment at high-volume facilities, and whether patients with certain cancers should preferentially be referred only to high-volume facilities, similar to the referral of patients to level 1 trauma centers for the management of serious injury or to stroke centers for the management of cerebral ischemia.^{1–3}

NCCN recommends treatment at high-volume facilities for cancers of the pancreas and esophagus; however, there are minor or even no recommendations in the guidelines for other cancers, including breast and uterine, which are primarily treated with surgery.⁴ Furthermore, previous studies analyzing facility volume are heterogeneous, with differing patient populations, outcome measures, and volume classifications. Some of these studies have found a positive association between treatment at high-volume facilities and survival,^{5–7} whereas others have found little to no association.^{8,9} These differing results may be due to different methods of classifying facility volume and patient inclusion. Thus, there is a need to address these inconsistencies by using a uniform definition for facility volume classification across multiple cancer types and by using the same inclusion and exclusion criteria and outcome measure.

The purpose of our study was to evaluate the impact of surgical facility volume on survival in patients with cancer after surgery across multiple cancer sites. We hypothesized that patients receiving surgery at very high-volume facilities would have improved survival versus those treated at low-volume facilities. The results of this work may be used to identify disease sites that should be preferentially managed at high-volume surgical centers.

See page 577 for related commentary.

Methods

The National Cancer Database (NCDB) is a hospital-based cancer registry that collects data from American College of Surgeons' Commission on Cancer–accredited facilities. Recognized as the largest cancer registry worldwide, the database is sponsored by the American College of Surgeons and the American Cancer Society and includes 70% of all malignant cancers diagnosed in the United States.¹⁰ The NCDB contains data on all types of cancers, and records demographics, comorbidities, and overall survival.^{11–13} In addition, the NCDB contains information regarding therapies delivered during the first course of treatment, namely, surgery, radiation therapy, chemotherapy, hormone therapy, immunotherapy, and palliative care. Approximately 34 million cancer cases are included in the NCDB.¹²

We conducted a retrospective analysis of patients diagnosed in 2004 through 2013 with cancer of the following sites: breast, prostate, colon, melanoma, uterus, non–small cell lung, kidney, thyroid, bladder, rectum, brain, pancreas, and esophagus. These cancer sites were chosen because they had the highest incidence over the studied time period that were most commonly treated with a surgical approach. Patients were included if they received surgery as treatment of their cancer and had valid survival information available from 2004 through 2013; exclusion criteria included no surgery date in the patient record and male patients with breast cancer.

The NCDB reports the facility where the patient received care using a unique facility code. This facility code, available for all patients included in our analyses, was used to determine overall facility volume by cancer site. First, using the overall data not accounting for individual disease site, facilities were stratified into quartiles depending on the number of patients treated surgically at the facility over the study period. The quartiles were categorized as low-, intermediate-, high-, and very high-volume facilities. Second, for each individual cancer site, facilities were stratified into quartiles following the same process. For example, each quartile for breast cancer has approximately 396,000 patients treated surgically, yet the number of facilities in each quartile ranges from 90 to 625. In addition, stratifying by individual disease site accounted for the possibility that one facility may surgically treat many patients with breast cancer, but only a small number of patients with esophageal cancer, for example. This method was chosen to create balanced group sizes by the number of patients treated. The primary outcome was 5-year postsurgery survival, which was chosen because it allowed us to examine both short- and long-term survival. Only facilities that were open and treating patients from 2004 through

2013, with complete volume data, were included in the analyses (supplemental eFigure 1, available with this article at JNCCN.org).

Five-year postsurgery survival was estimated using the Kaplan-Meier method and corresponding log-rank tests for group comparisons, and was defined as days from surgery to either death or 60 months postsurgery, whichever was earlier. Cox proportional hazards regression was used to perform a multivariable analysis by cancer site, adjusting for the following covariates: 4 age group levels based on quartiles, sex (male or female), race (White, Black, or other), insurance status (none, private, Medicaid, Medicare, or other government), clinical disease stage (0, I, II, III, IV, or unknown), urban/rural region (metropolitan, urban, or rural county), income level (<\$38,000, \$38,000–\$47,999, \$48,000–\$62,999, or ≥\$63,000), Charlson-Deyo comorbidity score (0, 1, 2, or 3), facility type (community cancer, comprehensive community cancer, academic/research, or integrated network cancer program), radiation treatment (no, yes, or unknown), chemotherapy treatment (no, yes, or unknown), and distance traveled to facility. Patients with unknown values for any of these variables were excluded from the analysis. The reference group for all analyses was patients with stage I disease. In addition, to control for facility preference for handling a certain disease different from another facility, we conducted a hierarchical multilevel regression model with random effects on the facility level (eTable 1). All statistical analyses were performed with R version 3.5.1 (R Foundation for Statistical Computing), with 2-sided tests and statistical significance level of $\alpha = 0.05$.

Results

A total of 3,923,618 surgical patients were included (mean age, 62 years [range, 18–90 years]); of these, 1,584,815 (40.4%) had breast cancer, 503,116 (12.8%) had prostate cancer, and 394,229 (10.0%) had colon cancer. Most patients were female (65.0%), were White (86.4%), had private insurance (51.6%), and had stage 0–III disease (64.8%). Patients traveled an average of 30.9 miles to get to their treatment facility. These results are summarized in Table 1.

Surgical facility volume distribution for each cancer site is shown in Figure 1. Across all cancer sites studied, patients who received surgery from low-volume facilities (vs very high-volume) had the worst survival probability, followed by intermediate-volume, high-volume, and very high-volume facilities, as shown by the Kaplan-Meier plots in Figure 2. Regardless of cancer type, high-volume facilities had a higher proportion of observed survivors at 5 years postsurgery compared with low-volume facilities (83.6% and 77.9%, respectively). In addition, regardless of facility volume, at 5 years

Table 1. Patient Characteristics

Characteristic	n (%)
Total, N	3,923,618
Age, y	
<55	1,116,108 (28.4)
55–64	1,094,078 (27.9)
65–73	903,847 (23.0)
≥74	809,558 (20.6)
Sex	
Male	1,372,755 (35.0)
Female	2,550,863 (65.0)
Race	
White	3,388,683 (86.4)
Black	362,361 (9.2)
Other	172,574 (4.4)
Insurance status	
None	88,523 (2.3)
Private insurance	1,983,864 (51.6)
Medicaid	165,556 (4.3)
Medicare	1,570,850 (40.8)
Other government	39,109 (1.0)
Cancer stage	
0	374,988 (9.6)
I	1,156,494 (29.5)
II	795,289 (20.3)
III	212,461 (5.4)
IV	109,843 (2.8)
Unknown	1,274,543 (32.5)

(continued)

postsurgery, pancreatic cancer had the lowest proportion of observed survivors (average across all facility volumes, 32.0%) and prostate cancer had the highest proportion (average across all facility volumes, 95.4%). The largest difference between very high-volume and low-volume facilities in proportion of observed survivors at 5 years postsurgery was seen in brain cancer (difference, 18.5%), whereas the smallest observed difference was seen in uterine and thyroid cancers (1.5% and 1.9%, respectively) (Table 2). The log-rank test indicated significant differences in surgical survival probability between the 4 facility volume categories for all 13 cancers tested ($P < .01$).

Once facilities were stratified by 4 categories (low-, intermediate-, high-, and very high-volume), a Cox regression analysis was conducted to determine whether surgical facility volume influenced 5-year postsurgery survival. For all sites, very high-volume facilities had significantly improved survival compared with low-volume facilities (HR, 0.88; 95% CI, 0.87–0.88). Patients

Table 1. Patient Characteristics (cont.)

Characteristic	n (%)
Region	
Metropolitan counties	3,221,331 (84.8)
Urban counties	508,611 (13.4)
Rural counties	68,446 (1.8)
Income level (USD)	
<\$38,000	520,013 (13.5)
\$38,000–\$47,999	766,890 (19.9)
\$48,000–\$62,999	1,044,208 (27.1)
≥\$63,000	1,524,780 (39.5)
Charlson-Deyo comorbidity score	
0	3,120,363 (79.5)
1	634,637 (16.2)
2	131,061 (3.3)
3	37,557 (1.0)
Facility type	
Community cancer program	285,195 (7.6)
Comprehensive community cancer program	1,680,284 (45.0)
Academic/Research program	1,361,150 (36.5)
Integrated network cancer program	406,605 (10.9)
Radiation therapy	
No	2,632,871 (67.1)
Yes	1,251,441 (31.9)
Unknown	39,306 (1.0)
Chemotherapy	
No	2,452,082 (62.5)
Yes	1,028,754 (26.2)
Unknown	442,782 (11.3)

with prostate cancer (HR, 0.66; 95% CI, 0.63–0.69), pancreatic cancer (HR, 0.75; 95% CI, 0.71–0.78), esophageal cancer (HR, 0.78; 95% CI, 0.73–0.83), and melanoma (HR, 0.81; 95% CI, 0.78–0.84) treated surgically at very high-volume facilities had the largest decrease in relative risk of death at 5 years postsurgery. Finally, compared with low-volume facilities, intermediate-volume facilities had statistically significantly improved survival for all cancer sites except thyroid cancer (Table 2). Results of the hierarchical multilevel regression model were similar to those of the Cox regression analysis.

The NCDB reports treatment occurring at the initial reporting facility, but patients may subsequently receive parts of their care (eg, chemotherapy, radiation therapy) at different facilities. In the analysis, we allowed patients to be included if their care was scattered among multiple facilities, to represent how real-world care is delivered. A downside to this technique is that the survival estimates may be biased from the care received at other facilities.

Figure 1. Facility volume distribution by cancer site. Plots were used to determine facility volume classification as low, intermediate, high, or very high for each cancer site.

Abbreviation: NSCL, non-small cell lung.

To mitigate this issue, we assessed a separate variable in the NCDB, namely CLASS_of_CASE, which allows investigators to evaluate whether care for a patient was performed at a single facility versus various facilities. We performed a sensitivity analysis for patients who received care at only one facility (CLASS_of_CASE values of 12 or 14; see supplemental eAppendix 1). In the sensitivity analysis, we found that 17% of patients were treated at a single facility, and the remainder received care that may have been performed at other facilities. The sensitivity-adjusted HRs were similar, supporting our conclusion

that care at a high-volume facility is associated with improved survival (supplemental eTables 1 and 2).

Discussion

This is the first study to examine the impact of surgical facility volume on survival among several cancer sites while adjusting for multiple covariates, with a uniform definition for surgical facility volume and consistent treatment inclusion and exclusion criteria and survival outcome measures. Patients receiving surgery at very high-volume versus low-volume facilities (ie, ≥ 898 vs

Figure 2. Kaplan-Meier survival curves of 5-year postsurgery survival, stratified by facility volume, for each cancer site.

<275 patients with cancer per year, respectively) have a higher proportion of observed survivors at 5 years post-surgery (83.6% vs 77.9%, respectively). Risk of death for patients receiving surgery at very high-volume facilities is 88% of that for those treated at low-volume facilities, and the benefit appears on a gradient of facility volume.

Cancers that had the greatest absolute benefits tended to be those with the highest number of cancer-related deaths, including pancreas, esophagus, and brain. Results of this study may be used to support individual NCCN Clinical Practice Guidelines in Oncology in recommending surgical treatment at higher-volume facilities.

Table 2. HRs and Proportion of Observed Survivors at 5 Years Postsurgery

Cancer Site	Facility Volume Classification ^a	Patients n	Facilities n	Maximum Facility Size in Group	Patients Treated Per Year, Per Facility	HR (95% CI) ^b	P Value ^c	Proportion of Observed Survivors at 5 Years ^d
All ^e	Low	981,687	653	2,743	<275	Ref		77.9%
	Intermediate	982,592	260	5,161	≥275 and <562	0.96 (0.95–0.97)	<.0001	80.4%
	High	972,205	150	8,980	≥562 and <898	0.91 (0.90–0.91)	<.0001	81.6%
	Very high	987,134	76	45,666	≥898	0.88 (0.87–0.88)	<.0001	83.6%
Breast ^e	Low	397,372	625	1,126	<113	Ref		86.6%
	Intermediate	396,192	261	1,978	≥113 and <197	0.93 (0.92–0.95)	<.0001	88.9%
	High	394,010	163	3,007	≥197 and <299	0.89 (0.88–0.90)	<.0001	90.1%
	Very high	397,241	90	16,829	≥299	0.84 (0.82–0.85)	<.0001	91.6%
Prostate ^f	Low	126,015	816	439	<44	Ref		93.3%
	Intermediate	126,416	188	983	≥44 and <99	0.86 (0.83–0.89)	<.0001	95.2%
	High	124,158	97	2,020	≥99 and ≤202	0.77 (0.74–0.80)	<.0001	96.1%
	Very high	126,527	34	8,557	>202	0.66 (0.63–0.69)	<.0001	97.0%
Colon ^e	Low	98,579	549	280	≤28	Ref		61.0%
	Intermediate	98,999	287	428	>28 and <43	0.97 (0.95–0.98)	<.001	62.3%
	High	97,373	188	639	≥43 and <64	0.94 (0.92–0.96)	<.0001	63.5%
	Very high	99,278	115	2,764	≥64	0.88 (0.87–0.90)	<.0001	66.1%
Melanoma ^a	Low	77,469	849	250	≤25	Ref		81.1%
	Intermediate	77,192	192	682	>25 and <69	0.89 (0.86–0.91)	<.0001	83.9%
	High	76,588	73	1,862	≥69 and <187	0.84 (0.81–0.87)	<.0001	86.0%
	Very high	77,189	25	10,153	≥187	0.81 (0.78–0.84)	<.0001	87.3%
Uterus ^e	Low	58,236	824	228	<23	Ref		80.2%
	Intermediate	58,309	167	494	≥23 and <50	0.97 (0.94–0.99)	.021	81.1%
	High	57,189	97	797	≥50 and <80	0.96 (0.93–0.99)	.022	81.4%
	Very high	58,762	51	2,269	≥80	0.95 (0.92–0.98)	.002	81.7%
NSCL ^f	Low	58,460	699	178	<18	Ref		52.7%
	Intermediate	58,046	237	335	≥18 and <34	0.96 (0.95–0.98)	<.001	55.2%
	High	56,785	133	559	≥34 and <56	0.92 (0.90–0.94)	<.0001	57.0%
	Very high	58,509	66	3,440	≥56	0.92 (0.90–0.94)	<.0001	58.2%
Kidney ^f	Low	37,517	756	115	<12	Ref		71.2%
	Intermediate	36,565	221	239	≥12 and <24	0.95 (0.92–0.98)	.001	73.5%
	High	36,682	114	484	≥24 and <49	0.94 (0.91–0.97)	<.001	74.1%
	Very high	37,306	46	2,481	≥49	0.87 (0.83–0.90)	<.0001	76.3%
Thyroid ^f	Low	35,205	781	114	<12	Ref		93.4%
	Intermediate	34,507	207	247	≥12 and <25	0.93 (0.87–0.99)	.029	94.3%
	High	34,568	108	489	≥25 and <49	0.89 (0.82–0.96)	.002	94.9%
	Very high	35,090	40	3,004	≥49	0.82 (0.75–0.89)	<.0001	95.3%
Bladder ^e	Low	33,157	684	96	<10	Ref		55.5%
	Intermediate	32,570	253	175	≥10 and <18	0.94 (0.92–0.97)	<.0001	58.1%
	High	32,434	140	327	≥18 and <33	0.91 (0.89–0.93)	<.0001	59.6%
	Very high	32,953	61	1,869	≥33	0.86 (0.83–0.89)	<.0001	60.5%
Rectum ^e	Low	31,070	652	86	<9	Ref		66.9%
	Intermediate	30,384	260	159	≥9 and <16	0.92 (0.89–0.95)	<.0001	69.8%
	High	29,835	147	266	≥16 and <27	0.87 (0.84–0.90)	<.0001	71.8%
	Very high	30,611	80	1,205	≥27	0.83 (0.80–0.86)	<.0001	74.4%

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Table 2. HRs and Proportion of Observed Survivors at 5-Years Postsurgery (cont.)

Cancer Site	Facility Volume Classification ^a	Patients n	Facilities n	Maximum Facility Size in Group	Patients Treated Per Year, Per Facility	HR (95% CI) ^b	P Value ^c	Proportion of Observed Survivors at 5 Years ^d
Brain ^e	Low	14,537	797	53	<6	Ref		26.5%
	Intermediate	14,377	184	117	≥6 and <12	0.95 (0.92–0.98)	<.001	33.0%
	High	14,120	84	294	≥12 and <30	0.88 (0.85–0.91)	<.0001	38.0%
	Very high	14,720	32	1,023	≥30	0.78 (0.75–0.81)	<.0001	45.0%
Pancreas ^g	Low	10,073	871	40	≤4	Ref		25.6%
	Intermediate	9,892	152	121	>4 and <13	0.89 (0.86–0.93)	<.0001	30.4%
	High	9,901	56	258	≥13 and <26	0.80 (0.77–0.84)	<.0001	34.3%
	Very high	9,957	21	1,011	≥26	0.75 (0.71–0.78)	<.0001	37.7%
Esophagus ^g	Low	7,786	832	26	<3	Ref		39.9%
	Intermediate	7,590	185	71	≥3 and <8	0.92 (0.88–0.97)	<.001	43.0%
	High	7,510	71	199	≥8 and <20	0.88 (0.83–0.93)	<.0001	48.7%
	Very high	7,807	21	762	≥20	0.78 (0.73–0.83)	<.0001	54.1%

Abbreviations: HR, hazard ratio; NSCL, non-small cell lung.

^aRecommendations from NCCN.⁴

^bObtained using Cox proportional multivariate analysis, adjusting for: age, sex, race, insurance status, cancer stage, urban/rural region, income level, comorbidity score, facility type, radiation, chemotherapy, and distance traveled to facility.

^cStatistically significant at $P < .0012$.

^dObtained via Kaplan-Meier method.

^eNCCN has no recommendation regarding facility volume for treatment.

^fNCCN recommends certain patients be treated at high-volume facility.

^gNCCN has strong recommendation all patients be treated at high-volume facility.

The methodologies and findings of prior studies have been heterogeneous, and most studies only considered one disease site at a time. Furthermore, facility volume and survival outcomes are not defined similarly across studies, making it difficult for results to be compared across cancer sites. For example, to define high-volume facilities, Cheung et al¹⁴ grouped facilities into tertiles based on number of surgeries performed; they then divided the institutions into thirds, classifying the upper one-third as high-volume centers. In contrast, Lichtenborg et al¹⁵ used the number of surgical resections per hospital in the year of diagnosis, then allocated patients into 5 hospital volume groups: <70, 70–99, 100–129, 130–149, and ≥150 procedures. Even though both studies included patients undergoing lung cancer surgery, volume was defined differently.

Some studies have found no association between survival and facility volume. In a study of patients with nonmetastatic malignant pleural mesothelioma, no independent effects on overall survival were observed when assessing facility volume.⁸ In addition, a study of patients with muscle-invasive bladder cancer found no difference in survival between patients treated at a high-volume versus low-volume facility (HR, 0.99; 95% CI, 0.94–1.04).⁹ Mixed findings across different cancer sites may be the result of different definitions of facility volume, inclusion criteria, and outcome variables. Overall, the previous work is heterogeneous, making it difficult to extrapolate findings to multiple cancer sites.

Our study is the first analysis to examine multiple disease sites using a consistent definition for surgical facility volume, treatment, and survival outcomes.

Conversely, our study confirms the results of certain studies that have found a survival benefit with receiving care from a high-volume facility.^{16–19} For example, Chen et al²⁰ showed that receiving treatment from a high-volume facility was associated with improved 90-day, 365-day, and 4-year survival among patients with advanced-stage laryngeal cancer. Several other studies found similar findings of improved survival among patients with lung, cervical, and ovarian cancer being treated at high-volume facilities.^{14,15,21–23} Overall, multiple studies have demonstrated that facility volume seems to be a reliable predictor of survival following cancer treatment.

Surgical facility volume may not be a surrogate of physician volume, but rather may be a surrogate for services provided by the entire facility. Patients may appropriately receive definitive therapy through radiation and systemic therapy rather than undergoing surgery, thereby removing these patients from the at-risk pool. Patients who do undergo surgery may also be receiving early referrals to other physicians, such as radiation oncologists and medical oncologists, for opinions regarding definitive radiation therapy or early adjuvant therapy.^{24,25} Finally, high-volume facilities tend to have good advanced procedure care (eg, ICU care, postsurgical therapy), both preoperatively and postoperatively, including presurgery

stress tests, visits with oncologists, and invasive post-surgery monitoring.²⁶ These services may improve patients' quality of life and performance status before and after surgery, and may help to detect early recurrences or treatment failures. Thus, the Kaplan-Meier curves presented in our work are not simply shifted right for high-volume facilities (implying a delay to an eventual failure). Rather, their separation continues, and they have tails at 5 years, thus suggesting there is a durable improvement in survival at 5 years, a point considered synonymous with cure for most cancers.

This study has limitations. First, the NCDB is limited to first course of treatment, so patients who received surgery after their first course of treatment are not coded in the NCDB and could not be included in the current analysis.¹² Second, we chose to focus on surgery as the primary treatment variable. For some patients, surgery may not have been the most appropriate course of treatment, and they should have received some alternative treatment such as chemoradiotherapy instead. In addition, there may be an exceptional surgeon performing most surgeries at a facility that is responsible for improved survival.²⁷ However, there is no way to test these hypotheses given the data available.

We chose to include facilities for which complete volume data were available from 2004 through 2013. Although we were able to adjust for measured confounders in our statistical analyses, there were still many unmeasured confounders for which we could not account. These variables may include both surgical and nonsurgical factors that influence survival. Furthermore, these unknown confounders likely differ based on cancer site and may be responsible, in part, for the large differences in survival seen across all cancer types.

Annual facility volume can vary by year and affect facility designation. We chose to stratify facilities into quartiles depending on the number of patients treated surgically over the entire study period, presenting the average of the 10 years. Although we did not adjust for the potential fluctuation in annual facility volume, the overall number of patients treated on average is a good estimation, considering volume fluctuates for all facilities.

Furthermore, a facility should not be at high risk of moving up or down into a different quartile in a given year.

Another limitation is the large percentage of cases with an unknown clinical stage group (supplemental eTable 3), which were excluded from analyses. In the earlier years of the study cohort, the percentage of unknown cases ranged from 49.3% to 59.0%. In the later years, this percentage decreased, ranging from 16.2% to 28.7%. This decrease in unknown clinical stage group coding is likely the result of a change in reporting requirements. For cases reported from 2004 to 2007, clinical stage group was reported by the managing physician. Beginning in 2008, however, clinical stage group could be reported by the managing physician or pulled from the patient record, resulting in more complete patient records, and thus more patients available to include in the analyses.

Conclusions

Patients treated surgically at very high-volume facilities have improved survival compared with those treated at low-volume facilities. For all cancers, the risk of death for patients undergoing surgery at very high-volume facilities (ie, those treating >898 patients with cancer per year) was 88% of that for those treated at low-volume facilities (ie, those treating <275 patients with cancer per year). These results identified certain cancer types (eg, pancreas, esophagus, brain) that should be preferentially referred to facilities with higher surgical volume with the goal of improving overall survival.

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Impact of Facility Surgical Volume on Survival in Patients With Cancer

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eFigure 1: Chart Defining Complete Volume Data

eTable 1: Comparison of Hazard Ratios From Original Versus Sensitivity Analysis

eTable 2: Breakdown of Patients Treated at Various Institutions by “CLASS_OF_CASE” Value

eTable 3: Distribution of Cases by Year of Diagnosis and Clinical Stage Group

eAppendix 1: Sensitivity Analysis for Patients Treated at Only One Facility

eFigure 1. Chart defining complete volume data. Only facilities that were open and treating patients from 2004–2013, with complete volume data, were included in the analyses. For example, facility A shows data collection continuously occurring from 2004–2013 and therefore was included in the analyses, whereas facilities B through E have gaps in their data collection during this time period and therefore were excluded.

eTable 1. Comparison of HRs From Original Versus Sensitivity Analysis^a

Cancer Site	Facility Volume Classification	Original HR (95% CI) ^b	Sensitivity Analysis HR (95% CI)	Sensitivity P Value ^c
Breast	Low	Ref	Ref	
	Intermediate	0.93 (0.92–0.95)	0.87 (0.84–0.91)	<.0001
	High	0.89 (0.88–0.90)	0.85 (0.82–0.89)	<.0001
	Very high	0.84 (0.82–0.85)	0.80 (0.77–0.84)	<.0001
Prostate	Low	Ref	Ref	
	Intermediate	0.86 (0.83–0.89)	0.84 (0.83–0.90)	<.0001
	High	0.77 (0.74–0.80)	0.75 (0.74–0.80)	<.0001
	Very high	0.66 (0.63–0.69)	0.74 (0.67–0.83)	<.0001
Colon	Low	Ref	Ref	
	Intermediate	0.97 (0.95–0.98)	0.97 (0.95–0.99)	<.001
	High	0.94 (0.92–0.96)	0.92 (0.91–0.94)	<.0001
	Very high	0.88 (0.87–0.90)	0.89 (0.87–0.91)	<.0001
NSCL	Low	Ref	Ref	
	Intermediate	0.96 (0.95–0.98)	1.02 (0.93–0.97)	.35
	High	0.92 (0.90–0.94)	0.92 (0.89–0.93)	<.0001
	Very high	0.92 (0.90–0.94)	0.88 (0.84–0.93)	<.0001
Melanoma	Low	Ref	Ref	
	Intermediate	0.89 (0.86–0.91)	0.88 (0.82–0.96)	<.0001
	High	0.84 (0.81–0.87)	0.85 (0.78–0.94)	<.0001
	Very high	0.81 (0.78–0.84)	0.72 (0.66–0.81)	<.0001
Kidney	Low	Ref	Ref	
	Intermediate	0.95 (0.92–0.98)	0.98 (0.91–1.05)	.58
	High	0.94 (0.91–0.97)	0.94 (0.88–1.01)	.13
	Very high	0.87 (0.83–0.90)	0.86 (0.79–0.93)	<.0001
Uterus	Low	Ref	Ref	
	Intermediate	0.97 (0.94–0.99)	1.04 (0.96–1.14)	.31
	High	0.96 (0.93–0.99)	1.08 (0.98–1.18)	.11
	Very high	0.95 (0.92–0.98)	0.97 (0.89–1.07)	.55
Thyroid	Low	Ref	Ref	
	Intermediate	0.93 (0.87–0.99)	0.91 (0.77–1.07)	.25
	High	0.89 (0.82–0.96)	1.03 (0.86–1.24)	.74
	Very high	0.82 (0.75–0.89)	0.78 (0.63–0.97)	.02
Bladder	Low	Ref	Ref	
	Intermediate	0.94 (0.92–0.97)	0.97 (0.91–1.02)	.25
	High	0.91 (0.89–0.93)	0.89 (0.84–0.95)	<.0001
	Very high	0.86 (0.83–0.89)	0.85 (0.79–0.90)	<.0001
Rectum	Low	Ref	Ref	
	Intermediate	0.92 (0.89–0.95)	0.90 (0.82–1.00)	.91
	High	0.87 (0.84–0.90)	0.89 (0.80–0.99)	.03
	Very high	0.83 (0.80–0.86)	0.74 (0.66–0.82)	<.0001

Abbreviations: HR, hazard ratio; NSCL, non–small cell lung.

^aWith CLASS_OF_CASE values of only 12 or 14.^bObtained using Cox proportional multivariate analysis, adjusting for: age, sex, race, insurance status, cancer stage, urban/rural region, income level, comorbidity score, facility type, radiation, chemotherapy, and distance traveled to facility.^cStatistically significant at $P < .0012$.

eTable 2. Breakdown of Patients Treated at Various Institutions by "CLASS_OF_CASE" Value

	0	10	11	12	13	14	20	21	22	12+14	Sum of All	% (12+14)/All
Bladder	886	53,512	3,714	9,583	6,852	27,861	24,196	13,184	7,974	37,444	147,762	0.253408
Brain	1,798	21,232	272	355	6,228	10,571	13,173	5,878	5,097	10,926	64,604	0.169123
Breast	36,219	639,720	36,971	24,528	170,349	256,377	326,626	196,954	79,222	280,905	1,766,966	0.158976
Colon	6,829	188,218	5,338	10,657	20,427	76,587	71,815	26,282	26,172	87,244	432,325	0.201802
Esophagus	1,317	7,874	406	327	1,512	2,902	11,009	4,928	3,594	3,229	33,869	0.095338
Kidney	4,025	59,842	710	4,764	3,260	41,243	27,559	4,410	21,842	46,007	167,655	0.274415
NSCL	7,946	102,335	1,059	2,641	13,576	54,600	42,844	12,311	19,152	57,241	256,464	0.223193
Melanoma	1,199	72,044	11,645	14,238	3,571	34,336	113,416	61,964	35,831	48,574	348,244	0.139483
Pancreas	2,048	13,641	172	201	4,807	9,486	7,422	4,467	3,814	9,687	46,058	0.210322
Prostate	6,432	150,974	10,253	62,179	2,964	34,767	176,617	18,835	80,999	96,946	544,020	0.178203
Rectum	2,116	42,696	2,673	2,467	7,661	14,145	35,077	18,746	8,740	16,612	134,321	0.123674
Thyroid	2,571	52,132	2,691	4,646	8,472	30,071	28,504	14,508	13,543	34,717	157,138	0.220933
Uterine	6,450	64,345	3,980	11,551	6,784	28,165	75,966	22,071	42,745	39,716	262,057	0.151555
Total										769,248	4,361,483	0.176373

Abbreviation: NSCL, non-small cell lung.

eTable 3. Distribution of Cases by Year of Diagnosis and Clinical Stage Group										
Clinical Cancer Stage	2004	2005	2006	2007	2008 ^a	2009	2010	2011	2012	2013
0	21,818	22,853	24,107	27,293	38,946	43,788	46,018	47,767	49,983	52,415
I	49,671	54,494	59,138	71,661	114,760	132,938	160,985	169,700	169,589	173,558
II	46,376	51,407	59,405	72,401	97,004	103,228	91,770	92,432	89,010	92,256
III	12,838	14,264	15,608	17,754	23,307	24,706	26,267	25,795	25,836	26,086
IV	6,686	7,093	7,426	8,443	12,088	12,784	13,903	13,763	13,709	13,948
Unknown	197,309	199,263	204,067	191,987	115,395	88,610	67,666	71,044	69,802	69,400
Percent unknown	59.0%	57.0%	55.2%	49.3%	28.7%	21.8%	16.6%	16.9%	16.7%	16.2%

^aReporting rules changed, allowing clinical stage to be reported by managing physician or pulled from patient record.

eAppendix 1: Sensitivity Analysis for Patients Treated at Only One Facility

Regarding the delivery of all treatments “at the reporting facility,” there is a variable to assess where treatments were performed, “CLASS_OF_CASE,” with the values shown below. Approximately 17% of patients were treated solely at a single institution, whereas treatment for the remainder may have included at least one other institution. To capture only treatments performed at the same institution, we conducted a sensitivity analysis and included only cases with values of 12 and 14. Overall, the sensitivity analysis hazard ratios were similar to those of the original analysis.

Code	Definition
00	Initial diagnosis at the reporting facility and all treatment or a decision not to treat was done elsewhere
10	Initial diagnosis at the reporting facility, and part or all of first course treatment or a decision not to treat was done at the reporting facility, NOS
11	Initial diagnosis in a staff physician’s office and part of first course treatment was done at the reporting facility
12	Initial diagnosis in a staff physician’s office and all of first course treatment or a decision not to treat was done at the reporting facility
13	Initial diagnosis and part of first course treatment was done at the reporting facility; part of first course treatment was done elsewhere
14	Initial diagnosis and all of first course treatment or a decision not to treat was done at the reporting facility
20	Initial diagnosis elsewhere and all or part of first course treatment or a decision not to treat was done at the reporting facility, NOS
21	Initial diagnosis elsewhere and part of first course treatment was done at the reporting facility; part of first course treatment was done elsewhere
22	Initial diagnosis elsewhere and all of first course treatment or a decision not to treat was done at the reporting facility

Abbreviation: NOS, not otherwise specified.