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Specialization and utilization after hepatectomy in academic medical centers

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Abstract

Background—Specialized procedures such as hepatectomy are performed by a variety of specialties in surgery. We aimed to determine whether variation exists among utilization of resources, cost, and patient outcomes by specialty, surgeon case volume, and center case volume for hepatectomy.

Methods—We queried centers ($n = 50$) in the University Health Consortium database from 2007–2010 for patients who underwent elective hepatectomy in which specialty was designated general surgeon ($n = 2685$; 30%) or specialist surgeon ($n = 6277$; 70%), surgeon volume was designated high volume (>38 cases annually) and center volume was designated high volume (>100 cases annually). We then stratified our cohort by primary diagnosis, defined as primary tumor ($n = 2241$; 25%), secondary tumor ($n = 5466$; 61%), and benign ($n = 1255$; 14%).

Results—Specialist surgeons performed more cases for primary malignancy (primary 26% *versus* 15%) while general surgeons operated more for secondary malignancies (67% *versus* 61%) and benign disease (18% *versus* 13%). Specialists were associated with a shorter total length of stay (LOS) (5 d *versus* 6 d; $P < 0.01$) and lower in-hospital morbidity (7% *versus* 11%; $P < 0.01$). Patients treated by high volume surgeons or at high volume centers were less likely to die than those treated by low volume surgeons or at low volume centers, (OR 0.55; 95% CI 0.33–0.89) and (OR 0.44; 95% CI 0.13–0.56).

Conclusions—Surgical specialization, surgeon volume and center volume may be important metrics for quality and utilization in complex procedures like hepatectomy. Further studies are necessary to link direct factors related to hospital performance in the changing healthcare environment.

Keywords

Hepatectomy; Utilization; Specialty; Cost; Outcomes

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1. Introduction

Every year, over 10,000 hepatectomies are performed in the United States. Ninety percent of these hepatectomies occur at academic medical centers [1]. The Agency for Healthcare Research and Quality has estimated that the annual costs of hepatectomies in the United States exceed 100 million dollars [1]. Academic medical centers are staffed by surgeons representing many specialties, including general surgeons, surgical oncologists, and transplant surgeons who may perform hepatectomies with varying degrees of frequency despite differences in their surgical training and specialization. Previous studies focusing on lung and pancreatic cancer resection have shown significant differences in patient outcomes, including mortality, based on a surgeon's specialty, surgical case volume, and their centers volume [2–13]. It is not known if this is true for hepatectomies, which are done for multiple indications (primary cancers, metastatic cancers, benign diseases, infectious diseases) and vary in complexity depending on region of the liver and numbers of segments involved. Furthermore, much of the previous literature on the impact of specialization on surgical outcomes has focused solely on patient outcomes. Importantly, these studies have not fully addressed the impact of these variables on a hospital's resource utilization and cost for the same disease entity and intervention. There is a growing body of literature to show that observed differences in patient outcomes by specialty are possibly the result of surgical case volume for the surgeon and the center [10–12,14–20]. The rationale behind this hypothesis is simple learning theory; the more surgeons, nurses, and other providers see and familiarize themselves with a particular procedure or patient, the better they are expected to perform.

Specialized procedures such as hepatectomy are high risk and expensive, while also potentially being very lucrative for a hospital. We aimed to determine if variation exists among resource utilization, cost, and patient outcomes after hepatectomy by surgical specialty while still accounting for surgical case volume and center case volume.

2. Materials and methods

2.1. Database

A national administrative database of academic medical centers that tracks patient and hospital specific outcomes was used to characterize potential variation. The UHC is an alliance of the nation's leading nonprofit academic medical centers with 116 academic medical centers and 261 affiliated hospital members. UHC membership includes more than 90% of the nonprofit academic medical centers in the United States. It provides patient, hospital, and financial outcomes across different centers. The data in the UHC database is primarily acquired from submitted UB-04 billing forms, similar to the forms submitted by hospitals to get reimbursed [21].

The UHC clinical data base resource manager (CDB/RM) provides the following information: synthetic hospital and surgeon identifiers, including specialty, unique patient visit identifiers, patient demographics, financials, procedural, and diagnostic information. Morbidity is defined using the UHC morbidity profiler [22]. Both cost and charge information are reported in CDB/RM. Charges are reported by each center and costs are calculated using institution-specific cost-to-charge ratios obtained from the department-level

Medicare cost reports. Federally reported area wage indices are used to account for regional- and center-specific cost variations that are not directly attributable to a center.

UHC has developed a severity of illness score for both risk adjustment and predicted resource allocation. This risk assessment method has been verified and validated by the University Health Consortium. Severity of illness takes into account a number of patient variables and weights them in the context of their illness, including other comorbid conditions, age, and diagnoses.

Validation of UHC's surgical specialty designations was done using a surgeon specialty propensity score. This was accomplished by looking at the number of procedures each surgeon performed and what proportion each procedure made up of their total case volume. General surgeons had a significantly higher proportion (>40% of their total cases) of appendectomies, hernia repairs, and lysis of adhesions. Transplant surgeons had a higher proportion of hepatectomies, kidney and liver transplants. Lastly, surgical oncologists had a higher proportion of thyroidectomies, mastectomies, and pancreatectomies. Exclusive procedures such as hyperthermic intra-peritoneal chemotherapy and solid organ transplants were used as absolute specialty designations for surgical oncologists and transplant surgeons.

2.2. Cohort

We retrospectively queried the CDB/RM for adult patients 18 years of age who underwent an elective hepatectomy from 2007–2010. Elective hepatectomy was defined by the type of admission (elective) and the International Classification of Diseases book 9, clinical modification procedural codes (50.3 and 50.22). Only those surgeons who performed at least five hepatectomies per year at centers that distinguished surgeon specialty (general, oncologic, and transplant) were included in our study ($n = 50$), see Figure 1. We excluded 52 centers because they did not designate surgeon specialty. We excluded 10 centers because they did not have one of the two specialty services. Lastly, we excluded four centers because all surgeons there performed fewer than five cases per year. Specialty designation was supplied and determined by each individual hospital.

Annual surgical and center volume cutoffs were determined using hierarchical clustering technique, following the Ward's distance averaging method [23–26]. Surgeons were designated as 'low volume' (less than 12 cases per year), 'intermediate volume' (12–38 cases per year), and 'high volume' (more than 38 cases per year). Centers were designated as 'low volume' (less than 40 cases per year), 'intermediate volume' (40–100 cases per year), and 'high volume' (more than 100 cases per year).

Cohorts were designated 'general' if hepatectomy was performed by a general surgeon, and 'specialist' if hepatectomy was performed by either an oncologic or transplant surgeon. The primary interventions of interest were the surgeons' specialty, their surgical case volume, and their centers case volume. The outcomes of interest were perioperative morbidity, hospital length of stay (LOS) defined as the interval from the date of procedure to the date of discharge, intensive care unit (ICU) LOS, postoperative admission to an ICU, index hospitalization survival, discharge disposition, 30-d readmission, and hospital direct cost.

Cost was defined as an expense that could be directly traced to the care of a patient, whether it was services or supplies rendered.

Covariates included patient-specific and surgeon-specific variables. It was assumed that for all covariates, the outcomes of interest did not directly affect them. Demographics included information on age, sex, and race. Other patient-specific variables included patient insurance status (private, Medicaid, Medicare, government, and other), severity of illness (minor, moderate, major, and extreme), primary diagnosis (primary cancer, secondary cancer, and benign disease). Surgeon specific variables included surgeon specialty status (general surgeon and specialist surgeon), surgical case volume (low = LV, intermediate = IV and high = HV), and a center's case volume (low = LVc, intermediate = IVc and high = HVc).

2.3. Analysis

Severity of illness was used for risk adjustment of the cohorts in both univariate and multivariate analyses. Univariate analysis consisted of Pearson χ^2 for categorical variables and Kruskal–Wallis nonparametric tests for continuous variables due to non-normal distributions. All statistically significant univariate observations were considered for initial step-wise logistic regression models. Models were multidirectional with stopping rules set by P value thresholds, where $P = 0.10$ and $P = 0.05$ were used to enter and retain covariates for final regression model consideration. The final regression models also used generalized estimating equations and robust variance calculations to account for center-specific and severity of illness clustering where appropriate. All statistical analyses were performed using SAS v. 9.2 and JMP 9 Pro (SAS Institute, Cary, NC).

This study was reviewed by the University of Massachusetts Medical School Institutional Review Board and was deemed appropriate for exemption from Institutional Review Board oversight as all data were de-identified. Statistical significance was defined as $P < 0.05$.

3. Results

We identified 8962 hepatectomy cases at 50 total hospitals identified as low volume centers (LVc = 27), intermediate volume centers (IVc = 13), and high volume centers (HVc = 10): general surgeons ($n = 490$) performed 2685 of the cases (30%) and specialists ($n = 240$) performed 6277 of the cases (70%). Specialist case volume distribution was 25% LV, 30% IV, and 45% HV, and for general surgeons it was 37% LV, 53% IV, and 10% HV. The median number of cases per year for specialist was 22 (interquartile range 161–34) compared with general surgeons 7 (interquartile range 5–17), P value < 0.0001 .

There were no significant differences between cohorts by demographics, insurance status, or severity of illness, as summarized by Table 1. Specialist surgeons saw more cases where the diagnosis was a primary cancer compared with general surgeons who saw a higher proportion of secondary cancers and benign liver disease cases (Table 1).

3.1. Univariate analysis

Univariate analysis of surgeon specialty, as summarized by Table 2, shows the comparisons of general and specialist surgeons. Cases performed by specialist surgeons were associated

with a shorter hospital LOS (5 d *versus* 6 d; $P < 0.01$) and ICU LOS (0 d *versus* 1 d; $P < 0.01$), as well as a lower ICU admission rate (44% *versus* 54%; $P < 0.01$). Patients treated by specialist surgeons had fewer complications (7% *versus* 11%; $P < 0.01$); however, there was no difference in mortality (2% *versus* 2%; $P = 0.51$). Patients treated by specialist surgeons incurred less hospital direct cost (\$19,000 *versus* \$21,000; $P < 0.01$). Specialists were more likely to discharge their patients home (82% *versus* 77%; $P < 0.01$); 30-d readmission was significantly lower for specialist compared to general surgeons (12% *versus* 14%; $P = 0.02$).

Univariate analysis of surgeon case volume, summarized by Table 3, showed that cases performed by HV surgeons *versus* LV surgeons were associated with a shorter hospital LOS (5 d *versus* 9 d; $P < 0.01$), as well as a shorter ICU LOS (1 d *versus* 3 d; $P < 0.01$). Patients seen by HV surgeons had less morbidity compared with those seen by LV surgeons, (7% *versus* 9%; $P = 0.012$). Patients treated by HV surgeons experienced less mortality compared to those treated by LV surgeons (2% *versus* 4%; $P < 0.01$). Patients treated by HV surgeons incurred less hospital direct costs compared to those treated by LV surgeons (\$14,000 *versus* \$21,000; $P < 0.01$). HV surgeons were more likely to discharge their patients home compared to LV surgeons (88% *versus* 68%; $P < 0.01$). There was no difference between HV and LV surgeons with regards to 30-d readmission.

Univariate analysis of center volume, as summarized by Table 4, shows that cases performed at HVc centers compared with LVc centers were associated with a shorter hospital LOS (6 d *versus* 9 d; $P < 0.01$), as well as shorter ICU LOS (1 d *versus* 4 d; $P < 0.01$). Patients seen at HVc centers had less morbidity compared to those seen at LVc centers (7% *versus* 13%; $P = 0.012$). Patients seen at HVc centers experienced less mortality compared with those seen at LVc centers (2% *versus* 4%; $P < 0.01$). Patients treated at HVc centers incurred less hospital direct costs compared to those seen at LVc centers (\$13,000 *versus* \$16,000; $P < 0.01$). HVc centers were more likely to discharge their patients home compared to LVc centers (89% *versus* 71%; $P < 0.01$). A HVc center also had fewer 30-d readmissions compared to LVc centers (12% *vs.* 17%; $P < 0.01$).

3.2. Multivariable analysis

Multivariable analysis was performed to determine if surgeon designation (specialist *versus* general), surgeon case volume (high *versus* low), and center case volume (high *versus* low) were independent predictors of morbidity, 30-d readmission, discharge disposition home, and index hospitalization mortality (Fig. 2).

Surgeon designation was identified as an independent predictor of morbidity (OR 0.83; 95% CI 0.72–0.96), 30-d readmission (OR 0.73; 95% CI 0.54–0.79) and discharge disposition home (OR 1.37; 95% CI 1.22–1.57). Surgeon designation was not an independent predictor of index hospitalization mortality (OR 0.88; 95% CI 0.63–1.14).

Being a HV surgeon was identified as an independent predictor of reduced morbidity (OR 0.56; 95% CI 0.46–0.80), 30-d readmission (OR 0.69; 95% CI 0.56–0.86), and mortality (OR 0.55; 95% CI 0.33–0.89). Surgeon case volume was not identified as an independent predictor of discharge disposition to home (OR 0.98; 95% CI 0.82–1.17).

HVc centers were identified as independent predictors of reduced morbidity (OR 0.53; 95% CI 0.38–0.71), 30-d readmission (OR 0.73 95% CI 0.64–0.91), discharge disposition home (1.35; 95% CI 1.18–1.57), and mortality (OR 0.44; 95% CI 0.13–0.56).

4. Discussion

This study demonstrates that surgical specialty, surgical case volume, and center case volume are all determinants of variation in resource utilization and outcomes for patients undergoing elective hepatectomy at academic medical centers. In almost all categories, specialist surgeons had equal or better patient-level and cost-related outcomes; similar findings were observed with high volume surgeons and high volume centers.

While surgeon case volume and center case volume were identified as strong independent predictors in multivariable models of morbidity, 30-d readmission, discharge disposition, in-hospital mortality, and surgeon specialty were also identified as a significant independent predictor of morbidity, 30-d readmission, and discharge disposition. These findings are important because they suggest that some of the observed outcomes for patients treated by specialist cannot simply be explained by learning theory alone. One potential non-volume explanation for these findings is related to specialty training, which includes surgical technique, patient selection, and patient management perioperatively. These findings also suggest that general surgeons can improve their outcomes by increasing their volume or practicing at high volume centers; however, they may still not achieve the results of specialists who have similar volume attributes given the independent nature of the specialty variable. In this study, specialists performed two times the number of hepatectomies with approximately half of the manpower. These relationships between increased surgeon volume and increased center volume with improved patient outcomes is also supported in the literature [9,12,13,18–20,27–34]. To curb the high cost of healthcare, it has already been proposed that volume and outcomes be used to guide referral patterns [35–38]. The implementation of the volume–outcome referral relationship has already had an impact on provider practice patterns, for example the Leapfrog model. In the Leapfrog practice model, patients bypass low volume centers or centers with poor outcome and go directly to centers with the highest volume and best outcomes [37,39–43]. Even though Leapfrog is in its infancy, it may become the standard of care in the years to come.

UHC's administrative database has primarily been used by participating hospitals at the administrative level for its benchmarking and supply line capabilities [44]. It has allowed hospitals to quickly compare their performance to other hospitals with similar attributes [45–47]. It also has been used for comparison within a hospital to longitudinally follow outcomes and cost at the provider and service line level. The database is centrally maintained and coded by individual institutions using a standardized submission form, providing up-to-date metrics for analysis and comparison of variability. UHC analysts review all submitted data to ensure its quality before being uploaded into their database. However, like any large administrative database, it is subject to the usual risks of miscoded data—a weakness that was mitigated with the size of our sample. We also feel that the benefits of this database significantly outweigh any of its inherent limitations. For example, unlike other large

administrative databases, UHC has 100% patient capture from participating centers. It also provides financial information that is often excluded from other large databases.

In centers that offer both specialists and general surgeons, we expected that secondary malignancy cases would make up a higher proportion of the specialists cases; however, this was not supported by the data. One potential explanation for this is that the procedure was not isolated but rather part of some much larger operation. For example, when performing a colectomy for colon cancer, it is not uncommon for a wedge resection to take place during that same surgery for isolated metastatic spread. Since the major surgical component had to do with the colon, it was not referred to the specialist. Also, given that specialists were dealing with more primary malignancy, we were surprised to find lower ICU admissions and more discharges to home due to the extent of disease. Often times, more tissue resected equates to more time in the operating room that in turn is associated with more morbidity and mortality. We were unable to assess the extent of resection though and relied on coding which generally fails to identify the staging of the malignancy.

Despite our novel methodology to validate specialty designation, it is still possible that some surgeons were miscoded and assigned to the wrong group. However, this number was significantly reduced using our novel methods in conjunction with UHC's designation. Other potential limitations of this investigation include those regularly associated with an administrative dataset, as previously noted. Administrative databases can retrospectively provide invaluable information regarding practice trends over time across many institutions. However, all decisions regarding patient care, at least in part, are clinically driven decisions. The reasoning behind clinical decisions including referral to a surgeon or a surgeon's decision to operate is not captured in an administrative database. Part of one's surgical training is patient selection, and although we did not show any demographic differences between the specialists and generalists, we are unable to assess if surgery was offered by another surgical group prior to the procedure. In areas where one type of surgeon may be uncomfortable performing a resection, another type of surgeon may be very comfortable or vice versa. Also, to date there is no adequate variable that captures the complexity and technicality of a case. Even though two patients on paper may have been coded the exact same way, the technicality and complexity of their individual procedure may be incredibly different, even if performed by the same surgeon. This study had no way of directly capturing this. Severity of illness is a preoperative risk-stratifying measure that helps to predict resource allocation but does not account for factors which add to the complexity of a surgery, including, but not limited to, a patient's body mass index and previous abdominal surgeries.

At centers that have both general and specialist surgeons, having a hepatectomy performed by a specialist was associated with decreased morbidity, hospital readmissions, and a higher likelihood of being discharged home. Having a hepatectomy performed by a high volume surgeon or at a high volume center, regardless of specialty training, was also associated with decreased morbidity, hospital readmission, and mortality. These data provide a basis for understanding resource utilization, quality, and cost in regards to specialized operations such as hepatectomy. Our assessment shows that some measures of utilization were certainly decreased in specialist's hands or in a high volume surgeon's hands or at a high volume

center and reveals a trend that requires more analysis. Whether other specialized operations such as laparoscopic colectomy, pancreaticoduodenectomy, and esophageal resection follow the same trend in regards to LOS, ICU stay, and readmissions will be the crux of future investigations.

References

1. HCUP Nationwide Inpatient Sample (NIS). Healthcare cost and utilization Project (HCUP). Rockville, MD: Agency for Healthcare Research and Quality; 2007–2009. [accessed 12.03.13]
2. Goodney PP, Lucas FL, Stukel TA, Birkmeyer JD. Surgeon specialty and operative mortality with lung resection. *Ann Surg*. 2005; 241:179.
3. Dimick JB, Goodney PP, Orringer MB, Birkmeyer JD. Specialty training and mortality after esophageal cancer resection. *Ann Thorac Surg*. 2005; 80:282. [PubMed: 15975382]
4. Dimick JB, Cowan JA Jr, Stanley JC, Henke PK, Pronovost PJ, Upchurch GR. Surgeon specialty and provider volumes are related to outcome of intact abdominal aortic aneurysm repair in the United States. *J Vascular Surg North Am Chapter*. 2003; 38:739.
5. Earle CC, Schrag D, Neville BA, et al. Effect of surgeon specialty on processes of care and outcomes for ovarian cancer patients. *J Natl Cancer Inst*. 2006; 98:172. [PubMed: 16449677]
6. Park HS, Roman SA, Sosa JA. Outcomes from 3144 adrenalectomies in the United States: which matters more, surgeon volume or specialty? *Arch Surg*. 2009; 144:1060. [PubMed: 19917944]
7. Hollenbeak CS, Bowman AR, Harbaugh RE, Casale PN, Han D. The impact of surgical specialty on outcomes for carotid endarterectomy. *J Surg Res*. 2010; 159:595. [PubMed: 20194053]
8. Csikesz NG, Simons JP, Tseng JF, Shah SA. Surgical specialization and operative mortality in hepato-pancreatico-biliary (HPB) surgery. *J Gastrointest Surg*. 2008; 12:1534. [PubMed: 18612710]
9. Csikesz NG, Singla A, Murphy MM, Tseng JF, Shah SA. Surgeon volume metrics in laparoscopic cholecystectomy. *Dig Dis Sci*. 2010; 55:2398. [PubMed: 19911275]
10. Ananthakrishnan AN, McGinley EL, Saeian K. Effect of hospital volume and teaching status on outcomes of acute liver failure. *Liver Transplant*. 2008; 14:1347.
11. Axelrod DA, Guidinger MK, McCullough KP, Leichtman AB, Punch JD, Merion RM. Association of center volume with outcome after liver and kidney transplantation. *Am J Transplant*. 2004; 4:920. [PubMed: 15147426]
12. Baek JH, Alruhaie A, Guzman EA, et al. The association of hospital volume with rectal cancer surgery outcomes. *Int J Colorectal Dis*. 2013; 28:191. [PubMed: 22842664]
13. Birkmeyer JD, Siewers AE, Finlayson EV, et al. Hospital volume and surgical mortality in the United States. *New Engl J Med*. 2002; 346:1128. [PubMed: 11948273]
14. Scarborough JE, Pietrobon R, Tuttle-Newhall JE, et al. Relationship between provider volume and outcomes for Orthotopic liver transplantation. *J Gastrointest Surg*. 2008; 12:1527. [PubMed: 18612704]
15. Ko CY, Chang JT, Chaudhry S, Kominski G. Are high-volume surgeons and hospitals the most important predictors of in-hospital outcome for colon cancer resection? *Surgery*. 2002; 132:268. [PubMed: 12219022]
16. Ozthathil DK, Li YF, Smith JK, et al. Impact of center volume on outcomes of increased-risk liver transplants. *Liver Transplant*. 2011; 17:1191.
17. Harbrecht BG, Zenati MS, Alarcon LH, et al. Is outcome after blunt splenic injury in adults better in high-volume trauma centers? *The Am Surgeon*. 2005; 71:942. Discussion 948. [PubMed: 16372613]
18. Eppsteiner RW, Csikesz NG, Simons JP, Tseng JF, Shah SA. High volume and outcome after liver resection: surgeon or center? *J Gastrointest Surg*. 2008; 12:1709. [PubMed: 18704600]
19. Trinh QD, Sun M, Kim SP, et al. The impact of hospital volume, residency, and fellowship training on perioperative outcomes after radical prostatectomy. *Urol Oncol*. 2013

20. Pettit SJ, Jhund PS, Hawkins NM, et al. How small is too small? A systematic review of center volume and outcome after cardiac transplantation. *Circ Cardiovasc Qual Outcomes*. 2012; 5:783. [PubMed: 23132331]
21. [accessed 02.03.13] About UHC. 2012. <http://www.uhc.edu/12443.htm>
22. [Accessed 02.03.13] Morbidity Reference Material. 2012. <http://cdprm.uhc.edu/CDPRM/web/reports/Welcome.aspx#>
23. Guess MJ, Wilson SB. Introduction to hierarchical clustering. *J Clin Neurophysiol*. 2002; 19:144. [PubMed: 11997725]
24. Saunders DG, Win J, Cano LM, Szabo LJ, Kamoun S, Raffaele S. Using hierarchical clustering of secreted protein families to classify and rank candidate effectors of rust fungi. *PLoS One*. 2012; 7:e29847. [PubMed: 22238666]
25. Zahoránszky LA, Katona GY, Hári P, Málnási-Csizmadia A, Zweig KA, Zahoránszky-KÖhalmi G. Breaking the hierarchy—a new cluster selection mechanism for hierarchical clustering methods. *Algorithms Mol Biol*. 2009; 4:12. [PubMed: 19840391]
26. Ku TS, Kane CJ, Sen S, Henderson WG, Dudley RA, Cason BA. Effects of hospital procedure volume and resident training on clinical outcomes and resource use in radical retropubic prostatectomy surgery in the Department of Veterans Affairs. *J Urol*. 2008; 179:272. Discussion 278. [PubMed: 18001784]
27. Birkmeyer JD, Dimick JB, Staiger DO. Operative mortality and procedure volume as predictors of subsequent hospital performance. *Ann Surg*. 2006; 243:411. [PubMed: 16495708]
28. Birkmeyer JD, Finlayson EV, Birkmeyer CM. Volume standards for high-risk surgical procedures: potential benefits of the Leapfrog initiative. *Surgery*. 2001; 130:415. [PubMed: 11562662]
29. Birkmeyer JD, Finlayson SR, Tosteson AN, Sharp SM, Warshaw AL, Fisher ES. Effect of hospital volume on in-hospital mortality with pancreaticoduodenectomy. *Surgery*. 1999; 125:250. [PubMed: 10076608]
30. Birkmeyer JD, Stukel TA, Siewers AE, Goodney PP, Wennberg DE, Lucas FL. Surgeon volume and operative mortality in the United States. *New Engl J Med*. 2003; 349:2117. [PubMed: 14645640]
31. Eppsteiner RW, Csikesz NG, McPhee JT, Tseng JF, Shah SA. Surgeon volume impacts hospital mortality for pancreatic resection. *Ann Surg*. 2009; 249:635. [PubMed: 19300225]
32. Singla A, Simons J, Li Y, et al. Admission volume determines outcome for patients with acute pancreatitis. *Gastroenterology*. 2009; 137:1995. [PubMed: 19733570]
33. Singla A, Simons JP, Carroll JE, et al. Hospital volume as a surrogate for laparoscopically assisted colectomy. *Surg Endosc*. 2010; 24:662. [PubMed: 19688386]
34. Shen HN, Lu CL, Li CY. The effect of hospital volume on patient outcomes in severe acute pancreatitis. *BMC Gastroenterol*. 2012; 12:112. [PubMed: 22901053]
35. Birkmeyer JD, Skinner JS, Wennberg DE. Will volume-based referral strategies reduce costs or just save lives? *Health Aff (Millwood)*. 2002; 21:234. [PubMed: 12224888]
36. Sunbulli MF, Jacobs BS, Van Stavern RB, Chaturvedi S. Implications of the Leapfrog Initiative for carotid endarterectomy in Michigan. *Neurology*. 2004; 63:590. [PubMed: 15304608]
37. Qian F, Lustik SJ, Diachun CA, Wissler RN, Zollo RA, et al. Association between Leapfrog safe practices score and hospital mortality in major surgery. *Med Care*. 2011; 49:1082. [PubMed: 22082837]
38. Varghese TK Jr, Wood DE, Farjah F, Oelschlager BK, Symons RG, et al. Variation in esophagectomy outcomes in hospitals meeting Leapfrog volume outcome standards. *Ann Thorac Surg*. 2011; 91:1003. Discussion 1009. [PubMed: 21440116]
39. Leapfrog Group releases its first 'top hospitals' list. *Healthcare benchmarks and quality improvement*. 2007; 14:1.
40. Brooke BS, Meguid RA, Makary MA, Perler BA, Pronovost PJ, et al. Improving surgical outcomes through adoption of evidence-based process measures: intervention specific or associated with overall hospital quality? *Surgery*. 2010; 147:481. [PubMed: 20004443]
41. Epstein AJ, Rathore SS, Krumholz HM, Volpp KG. Volume-based referral for cardiovascular procedures in the United States: a cross-sectional regression analysis. *BMC Health Serv Res*. 2005; 5:42. [PubMed: 15935099]

42. Maa J, Gosnell JE, Gibbs VC, Harris HW. Exporting excellence for Whipple resection to refine the Leapfrog Initiative. *J Surg Res.* 2007; 138:189. [PubMed: 17292411]
43. Pushman AG, Chung KC. Future of the US healthcare system and the effects on the practice of hand surgery. *Hand (NY).* 2009; 4:99.
44. Behal R, Finn J. Understanding and improving inpatient mortality in academic medical centers. *Acad Med J Assoc Am Med Colleges.* 2009; 84:1657.
45. Reynoso JF, Tiwari MM, Tsang AW, Oleynikov D. Does illness severity matter? A comparison of laparoscopic esophagomyotomy with fundoplication and esophageal dilation for achalasia. *Surg Endosc.* 2011; 25:1466. [PubMed: 20976492]
46. Nguyen NT, Christie C, Masoomi H, Matin T, Laugenour K, et al. Utilization and outcomes of laparoscopic *versus* open paraesophageal hernia repair. *Am Surgeon.* 2011; 77:1353. [PubMed: 22127087]
47. Tiwari MM, Reynoso JF, High R, Tsang AW, Oleynikov D. Safety, efficacy, and cost-effectiveness of common laparoscopic procedures. *Surg Endosc.* 2011; 25:1127. [PubMed: 20927546]

Fig. 1. Schematic of cohort selection

Fig. 2. Multivariable OR. (A) Multivariate model of in-hospital mortality showing OR. (B) Multivariate model of morbidity showing OR. (C) Multivariate model of 30-d readmission showing OR. (D) Multivariate model of home discharge status.

Table 1
Cohort characteristics

	General surgeon <i>n</i> = 2685	Specialist surgeon <i>n</i> = 6277	<i>P</i> value
Sex			
Male	1301 (48)	2946 (47)	0.19
Median age, y	57 (46–67)	57 (46–66)	0.77
Race			
White	1904 (71)	4323 (69)	0.055
Insurance			
Private	1269 (53)	3285 (52)	0.70
Medicare	844 (31)	1947 (31)	0.62
Medicaid	293 (11)	588 (9)	0.32
Primary diagnosis			
Primary malignancy	403 (15)	1632 (26)	<0.01 *
Secondary malignancy	1799 (67)	3829 (61)	<0.01 *
Benign disease	483 (18)	816 (13)	0.017 *
Severity of illness			
Minor	618 (23)	1381 (22)	0.28
Moderate	1692 (63)	4080 (65)	0.07
Major	349 (13)	753 (12)	0.19
Extreme	26 (1)	63 (1)	0.99

Values are reported as *n* (%) and as median (quartile 1 to quartile 3) for continuous variables.

* Denotes statistically significant *P*-values (*P* < 0.05).

Table 2
Univariate comparisons

	General surgeon $n_{\text{cases}} = 2685$	Specialist surgeon $n_{\text{cases}} = 6277$	<i>P</i> value
Cases per year (median)	7 (5–17)	22 (16–34)	<0.0001 [*]
Hospital length of stay (median, d)	6 (4–10)	5 (4–8)	<0.01 [*]
ICU length of stay (Median, d)	1 (0–2)	0 (0–2)	<0.01 [*]
Morbidity [†]	11%	7%	<0.0001 [*]
Mortality	2%	2%	0.513
Total cost (median, \$)	21,000 (14,000–29,000)	19,000 (14,000–27,000)	<0.01 [*]
Routine discharge home	77%	82%	<0.01 [*]
30 d readmission	14%	12%	0.018 [*]

Values are reported as % and as median (quartile 1 to quartile 3) for continuous variables.

[†] Morbidity was defined as the occurrence of any of the following in the postoperative period procedure related perforation and/or laceration, re-opening of surgical site, mechanical complication due to device, implant or graft, and bleeding or hemorrhage.

^{*} Denotes statistically significant *P* values ($P < 0.05$).

Table 3
Univariate comparisons by surgeon volume

	High volume	Intermediate volume	<i>P</i> value
		Low volume	
Hospital length of Stay (median d, interquartile range)	5 (3–9)	9 (5–11)	0.003*
		9 (6–13)	<0.001*
ICU length of stay (Median, d)	1 (0–2)	2 (0–4)	0.009*
		3 (0–5)	0.001*
Morbidity [†]	7%	9%	0.018*
		9%	0.012*
Mortality	2%	3%	0.213
		4%	0.009*
Total cost (median, \$)	14,000 (10,000–20,000)	16,000 (11,000–22,000)	0.003*
		21,000 (14,000–35,000)	0.004*
Routine discharge home	88%	82%	<0.001*
		68%	<0.001*
30 d readmission	12%	14%	0.126
		14%	0.703

Values are reported as % and as median (quartile 1 to quartile 3) for continuous variables.

[†] Morbidity was defined as the occurrence of any of the following in the postoperative period procedure related perforation and/or laceration, re-opening of surgical site, mechanical complication due to device, implant or graft, and bleeding or hemorrhage.

* Denotes statistically significant *P*-values ($P < 0.05$).

Table 4
Univariate comparisons by center volume

	High volume	Intermediate volume	P value
		Low volume	
Hospital length of stay (Median d, interquartile range)	6 (3–8)	8 (5–12)	<0.001*
		9 (4–12)	<0.001*
ICU length of stay (Median, d)	1 (0–2)	3 (0–4)	<0.001*
		4 (1–7)	<0.001*
Morbidity [†]	7%	9%	0.002*
		13%	<0.001*
Mortality	2%	4%	<0.001*
		6%	<0.001*
Total cost (median, \$)	13,000 (9000–19,000)	17,000 (11,000–25,000)	<0.001*
		16,000 (10,000–26,000)	<0.001*
Routine discharge home	89%	81%	<0.001*
		65%	<0.001*
30 d readmission	12%	13%	0.215
		17%	<0.001*

Values are reported as % and as median (quartile 1 to quartile 3) for continuous variables.

[†] Morbidity was defined as the occurrence of any of the following in the postoperative period procedure related perforation and/or laceration, re-opening of surgical site, mechanical complication due to device, implant or graft, and bleeding or hemorrhage.

* Denotes statistically significant *P* values (*P* < 0.05).