Conferences and Reviews

Hospital Volume Influences Outcome in Patients Undergoing Pancreatic Resection for Cancer

ROBERT E. GLASGOW, MD *and* SEAN J. MULVIHILL, MD, *San Francisco, California*

Surgical resection is the only possibly curative treatment of malignant pancreatic neoplasms, but major pancreatic resection for cancer is associated with high rates of morbidity and mortality. The objective of this study was to determine the relation between hospital volume and outcome in patients undergoing pancreatic resection for malignancy in California. Data were obtained from reports submitted to the Office of Statewide Health Planning and Development by all California hospitals from 1990 through 1994. Patient abstracts were analyzed for each of 1,705 patients who underwent major pancreatic resection for malignancy. Of the 298 reporting hospitals, 88% treated fewer than 2 patients per year; these low-volume centers treated the majority of patients. High-volume providers had significantly decreased operative mortality, complication-associated mortality, patient resource use, and total charges and were more likely than low-volume centers to discharge patients to home. These differences were not accounted for by patient mix. This study supports the concept of regionalizing high-risk procedures in general surgery, such as major pancreatic resection for cancer.

(Glasgow RE, Mulvihill SJ: Hospital volume influences outcome in patients undergoing pancreatic resection for cancer. West J Med 1996; 165:294–300)

In the United States, about 28,000 new cases of adenocarcinoma of the pancreas are diagnosed annually, accounting for about 2% of all cases of noncutaneous malignant neoplasms.[1] The only possibly curative treatment of pancreatic cancer is surgical resection. Enthusiasm for major pancreatic resection for malignancy has been dampened by reported operative mortality rates of 20% or greater and major morbidity rates of 40% to 60%.[2,3] Recently several large centers have reported operative mortality rates of less than 5% and major morbidity rates of about 30%.[4-9] It is not clear whether these improvements in operative outcome have occurred only in specialized centers or more generally in the medical community.

It is estimated that only 2,000 to 3,000 major pancreatic resections for malignancy are undertaken in the United States each year. The American College of Surgeons reports that 17,000 to 23,000 general surgeons are in active practice today in the United States.[10] An average general surgeon in the United States might do an operation of this sort once every 6 to 12 years. Similarly, the American Hospital Association reports that 6,539 acute care hospitals cared for patients in the United States in 1992.[11] If surgical therapy for pancreatic cancer were evenly distributed, such operations would be done only once every two to three years at a given hospital.

The relationship between experience with a medical therapy and outcome has been previously studied.[12-18] Luft and colleagues, for example, reported substantial improvements in hospital mortality in high-volume centers performing complex operations such as coronary artery bypass, whereas no such relationship was observed for less complex operations such as cholecystectomy.[12] Recent reports describing statewide data from Maryland and New York support a volume-outcome relationship for pancreatectomy.[19,20] This finding has been disputed in other population studies, such as the experience nationwide in the US Department of Veterans Affairs system, where no volume-outcome relationship was observed.[21]

A key goal of any reorganization of health care delivery practices in the United States is not only to reduce cost, but to preserve or improve quality. Quality of a surgical procedure is measured by operative morbidity and mortality, outcome, and effectiveness compared with alternative therapies. It is an open question today whether or not regionalizing high-risk procedures in general surgical practice is desirable or warranted from this standpoint. The goal of this study was to evaluate the relation between hospital volume and postoperative outcome in patients undergoing major pancreatic resection for malignancy in California. We hypothesized that the risk of this procedure, as measured by operative mortality, is reduced when performed in hospitals with greater experience.

From the Department of Surgery, University of California, San Francisco (UCSF), Medical Center.
Reprint requests to Sean J. Mulvihill, MD, UCSF Medical Center, 533 Parnassus Ave, U-122, San Francisco, CA 94143-0788.

ABBREVIATIONS USED IN TEXT

DRGs = diagnosis-related groups
ICD-9 = *International Classification of Diseases, 9th Revision, Clinical Modification*
OSHPD = Office of Statewide Health Planning and Development

Patients and Methods

The study design was a retrospective review of standardized patient discharge abstracts obtained from the California Office of Statewide Health Planning and Development (OSHPD). The reliability of this method in comparing differences in patient outcome was previously confirmed.[22-24] This database contains discharge data abstracts for every patient hospitalization from each acute care facility in California. Each abstract includes the following data: hospital identification, age group, sex, race, admission year, admission type (emergency, urgent, or elective), primary payer source, patient diagnosis (principal diagnosis and as many as 16 secondary diagnoses), procedure (principal procedure and as many as 16 secondary procedures), length of hospital stay, patient disposition, total hospital charges, and a measure of overall hospital resource use. Operative death in this study was defined as patient death before hospital discharge. The OSHPD database used diagnostic and procedural codes derived from the *International Classification of Diseases, Ninth Revision, Clinical Modification*, fourth edition (ICD-9), issued by the US Department of Health and Human Services.[25] Hospital resource use was measured by the determination of an Overall Resource Demand Scale (MedStat Group, Santa Barbara, California). This measure predicts the overall hospital resource use for a patient relative to a norm across all patients and diagnosis-related groups (DRGs). In this scale, the average acute care admission is assigned a value of 100. An overall resource demand value of 190, for example, indicates that the patient is predicted to require 90% more resources than the average of all patients across all DRGs.

All discharge abstracts from the years 1990 through 1994 were included in the initial search of the OSHPD database. From these abstracts, the cases of all patients who underwent total pancreatectomy (ICD-9 52.6), radical pancreaticoduodenectomy (ICD-9 52.7), proximal pancreatectomy (ICD-9 52.51), radical subtotal pancreatectomy (ICD-9 52.53), pancreatectomy unspecified (ICD-9 52.59), and distal pancreatectomy (ICD-9 52.52) were examined. From this group, a subset of patients undergoing pancreatic resection for malignancy was selected. These included patients with a primary diagnosis of cancer of the exocrine pancreas or islet cells (ICD-9 157.X), duodenum (ICD-9 152.0), bile duct (ICD-9 156.1), and the ampulla of Vater (ICD-9 156.2). This yielded a study population of 1,910 patients from 298 acute care facilities.

The role of individual patient characteristics in predicting operative mortality was assessed using univariate analysis, with statistical significance determined by the χ^2 test. Individual patient characteristics thought to be possible predictors of operative mortality included principal diagnosis, type of resection, year of surgery, age, sex, race, admission type, payer source, and the number of secondary diagnoses. The number of secondary diagnoses served as a measure of the severity of illness and as a means of comparing patient populations among hospitals.[20,26] In the OSHPD database, secondary diagnoses included comorbid medical problems not related to the malignant neoplasm (such as diabetes mellitus, hypertension, or chronic obstructive pulmonary disease), comorbid illnesses associated with the cancer (cholecystitis, cholangitis, pancreatitis, or obstruction), descriptors of disease stage (local invasion, lymph node status, and regional and distant metastases), and operative complications (hemorrhage, infection, or medical complications). Thus, both preoperative and postoperative conditions are listed in this database as secondary diagnoses.

A logistic-regression analysis was done to determine the relation between hospital volume and operative mortality while controlling for differences in individual patient characteristics. The patient characteristics identified earlier were treated as covariates. Operative death was the dependent variable. The role of each of the independent variables, including each of the individual patient characteristics and hospital volume, in predicting operative mortality was analyzed using this logistic-regression model.

Hospitals were classified into six arbitrary groups based on the number of pancreatic resections performed in the five-year study period. This classification ensured that the number of patients in each volume range was sufficiently large for statistical analysis. A crude mortality rate, discharge disposition profile (home versus other–death, skilled nursing facility, short-term care facility, and other), length of hospital stay, total hospital charges, and predicted resource use were calculated for each volume range. In addition, the frequency and outcome of the major operative complications, hemorrhage and infection, were determined. Differences among these measures of outcome were analyzed by analysis of variance. χ^2 Analysis of contingency tables, linear-regression analysis, and Wilcoxon or Kruskal-Wallis rank-sum test were used where appropriate. A P value of less than .05 was considered statistically significant.

An indirectly standardized mortality rate was calculated as described previously.[15,20,27] Briefly, a multiple-regression analysis was done using the patient characteristics found to be predictive of operative death by the corresponding logistic-regression model, yielding a predicted probability of death for each patient. This probability was then used to calculate an indirectly standardized or risk-adjusted mortality for hospitals, controlling for differences in patient characteristics at the time of admission among the different hospitals.

TABLE 1.—*Types of Pancreatic Resections and Associated Operative Mortality*

Procedure	Patients, No.	Operative Mortality, %
Pancreaticoduodenectomy	1,424	9.4
Proximal subtotal pancreatectomy	158	8.9
Total pancreatectomy	123	16.3*
Distal pancreatectomy	205	1.0*

*$P < .05$ by χ^2 test compared with pancreaticoduodenectomy.

TABLE 2.—*Year of Surgery and Associated Operative Mortality*

Year	Hospitals, No.	Patients, No.	Deaths, No. (%)
1990	157	316	38 (12.0)
1991	147	313	33 (10.5)
1992	168	346	23 (6.6)
1993	155	354	36 (10.2)
1994	162	376	38 (10.1)
Total	298	1,705	168 (9.9)

TABLE 3.—*Primary Tumor Location and Associated Operative Mortality*

Diagnosis	Patients, No.	Operative Mortality, %
Pancreatic cancer	1,051	10.2
Ampulla of Vater cancer	350	8.3
Bile duct cancer	151	10.6
Duodenal cancer	140	11.4
Islet cell cancer	13	0

*Not significant by χ^2 analysis.

Results

From 1990 through 1994, a total of 1,910 patients underwent major pancreatic resection in California for peripancreatic cancer. Most of the operations (Table 1) were pancreaticoduodenectomies or Whipple procedures (83.5% of patients). These patients were treated with an overall operative mortality of 9.4%. A smaller number of patients underwent proximal subtotal pancreatectomy (9.3% of patients) or total pancreatectomy (7.2% of patients). The mortality for total pancreatectomy was significantly higher than that for Whipple resection (Table 1). Distal pancreatectomy was done in 205 patients, with an operative mortality of 1.0% (2 of 205 patients). Because of this low operative mortality and the relatively small number of patients, a volume-outcome relation for distal pancreatectomy could not be determined. These patients were excluded, leaving 1,705 patients for further analysis.

The number of resections performed each year increased slightly from 316 in 1990 to 376 in 1994 ($P = .01$ by linear-regression analysis) (Table 2). A total of 298 hospitals reported to the database, but because not all hospitals treated patients undergoing pancreatic resection each year, the average number of reporting hospitals on a yearly basis was 158 (Table 2). The operative mortality for major pancreatic resection was similar from year to year, with an overall average of 9.9% (Table 2). The most common principal diagnosis was pancreatic cancer, accounting for 62% of patients (Table 3). This was followed by carcinoma of the ampulla of Vater (21% of patients), carcinoma of the distal bile duct (9% of patients), duodenal cancer (8% of patients), and islet cell cancer (0.8% of patients). No significant differences were found in operative mortality when stratified by principal diagnosis (Table 3).

Patient Demographics

Patient demographic information analyzed included age, sex, race, admission type, the number of secondary diagnoses, and source of payment. The age range of the study population was 2 to 85 years, with a median age of 65 years. Of the 1,705 patients, 70% were 60 years of age or older (Table 4). The operative mortality was directly related to advancing age ($P < .0001$ by χ^2 test). The number of men and women was similar, but men had a significantly higher operative mortality ($P = .006$ by χ^2 test). The most common race of treated patients was white (75% of the study group), followed by Hispanic (12%), Asian (7%), and black (6%). Operative mortality did not differ significantly according to race (Table 4). In contrast, the source of payment for care was associated with significant differences in operative mortality. Patients whose hospital stays were paid for by government programs (Medicare or Medi-Cal [California's Medicaid]) had higher operative mortality than did patients enrolled with private insurers, including Blue Cross or Blue Shield, health maintenance organizations, preferred health plans, and private insurance companies ($P < .0001$ by χ^2 test). These data are summarized in Table 4.

Admission type and number of secondary diagnoses were analyzed as indicators of the severity of illness. Patients admitted electively for resection had lower operative mortality than unscheduled patients admitted on an emergent or urgent basis (8.1% versus 12.5%, $P < .0001$) (Table 4). Common preoperative comorbidities included diabetes mellitus (ICD-9 250) in 18% of patients, essential hypertension (ICD-9 401) in 18%, coronary artery disease (ICD-9 412 through 414) in 14%, congestive heart failure (ICD-9 428) in 4%, chronic obstructive pulmonary disease (ICD-9 490 through 496) in 7%, nutritional deficiencies (ICD-9 260 through 263) in 5%, and chronic liver disease (ICD-9 571) in 2% (Table 5). An increased number of secondary diagnoses correlated with increased operative mortality (Table 4). For patients with fewer than four secondary diagnoses, operative mortality was 3.7%. This rate increased significantly with an increasing number of secondary diagnoses ($P < .0001$). The overall incidence of postoperative hemorrhage was 10.1%, with a 25% associated mortality. The overall incidence of postoperative intra-abdominal infection was 14.5%, with an 18% associated mortality. Both complications were predictive of operative death ($P < .001$).

Univariate analysis of individual patient characteristics showed that age, sex, admission type, operation performed, number of secondary diagnoses, and payer source were significant predictors of higher operative mortality. The year of operation and race were not significant factors. These characteristics were analyzed further in a logistic-regression model. When hospital volume was excluded from the logistic-regression analysis, advancing age, male sex, the need for total pancreatectomy, and increasing number of secondary diagnoses were found to be statistically significant predictors of operative mortality (Table 6). When hospital volume was included in the model, these independent variables remained significant. Likewise, decreasing hospital volume was found to be significant ($P < .001$).

Hospital Volume-Outcome Relationship

Hospitals were grouped into six volume ranges reflecting the number of resections performed at each hospital from 1990 through 1994. More than half of all patients were treated at centers where ten or fewer resections were performed in the five-year study period (Table 7). These centers with low volume of pancreatic surgery accounted for 88% of all reporting hospitals. The highest volume centers treated more than 50 patients each during the study period, but these accounted for only 1% of the reporting hospitals and 8% of the treated patients.

Several measures of outcome were evaluated, including length of hospital stay, total hospital charges, overall resource use, and operative mortality. The length of hospital stay did not vary significantly among the different volume groups (Table 8). Total hospital charges decreased from the lowest volume group to the highest volume group—$87,857 versus $71,588. These differences among groups were significant by linear-regression analysis and the rank-sum test ($P < .0001$). The mean resource-demand scale score for all treated patients was 769. This means that the average patient undergoing pancreatectomy required 669% more resources than the average hospital admission across all DRGs (resource scale score of 100). Overall resource use decreased significantly as hospital volume increased ($P < .0001$ by linear-regression analysis and rank-sum test). In addition, high-volume centers were more likely to discharge patients to home than lower-volume centers (95% of patients versus 74% of patients, $P < .0001$ by linear-regression analysis and P test). The remaining patients either died or were discharged to an intermediate-care facility.

The outcome data for patients treated at centers with 31 to 50 cases were influenced by outliers. One center in this group had an average total hospital charge of $208,739. If this hospital was excluded from the group, the average charge for the remaining three centers was $75,241 (range, $57,933 to $96,804). The relationship between hospital volume and charges was strongly significant even when this outlier was included in the analysis. Likewise, an additional center in this group had an average length of hospital stay of 34.8 days. If excluded, the average length of hospital stay for this group falls from 23.9 to 20.2 days (range, 17.6 to 23.4).

TABLE 4.—*Patient Characteristics and Associated Operative Mortality*

Patient Characteristic	Patients, No.	Operative Mortality, %	P Value*
Age, yr			< .0001
<45	120	2.5	
45-59	408	4.9	
60-74	893	11.8	
≥75	284	14.1	
Sex			.006
Male	862	11.8	
Female	843	7.8	
Race			.22
White	1,272	9.4	
Black	97	8.3	
Hispanic	192	11.9	
Asian	114	13.2	
Other	30	10.0	
Admission type			.01
Emergent	98	13.3	
Urgent	601	12.3	
Elective	1,006	8.1	
Secondary diagnosis, No.			< .0001
0 to 4	641	3.7	
5 to 8	606	6.8	
9 to 12	294	19.0	
>12	164	28.7	
Payer source (all)			.002
Medicare	799	12.9	
Medi-Cal†	147	9.5	
Blue Cross or Blue Shield	75	5.3	
Insurance Company	238	5.9	
HMO or PHP	371	7.5	
Other	75	6.7	
Payer source (government versus private)			< .0001
Government payer	986	12.3	
Private insurer	719	6.5	

HMO = health maintenance organization, PHP = preferred health plan

*By χ^2 testing.
†California's Medicaid program.

There were small differences in the distribution of some of the preoperative comorbid medical diagnoses among the six hospital volume groups. For cholecystitis, cholangitis and biliary obstruction, pancreatitis, congestive heart failure, and chronic liver disease, these differences achieved statistical significance. This is summarized in Table 5. No significant differences were seen in the overall number of comorbid medical diagnoses among the six hospital volume groups. Further, no significant differences were seen when comparing predicted mortality rates for each volume group. The overall predicted mortality was 9.9% and ranged from 8.1% in the 21- to 30-volume group to 10.6% in the 6- to 10-volume group.

The overall mortality for the study population was

TABLE 5.—*Distribution of Comorbidities in Hospital Volume Groups*

Comorbidity	1 to 5 Cases, %	6 to 10 Cases, %	11 to 20 Cases, %	21 to 30 Cases, %	31 to 50 Cases, %	>50 Cases, %	Overall	P Value
Chronic obstructive pulmonary disease	6.7	8.9	6.6	5.7	4.7	3.5	6.6	NS
Coronary artery disease	15	18	20	19	20	23	14	NS
Congestive heart failure	5.7	4.6	3.5	4.0	0.5	1.4	3.9	< .05
Hypertension	15	18	20	19	20	23	18	NS
Diabetes mellitus	20	18	19	21	16	11	18	NS
Chronic renal failure	0.2	0	0	0	0	0	0.1	NS
Chronic liver disease	3.3	1.5	0	1.3	3.5	2.8	2.1	< .05
Mesenteric or peripheral vascular disease	0.4	1.0	0.8	0.9	2.3	1.4	0.9	NS
Malnutrition	5.7	6.1	6.2	3.1	5.9	2.1	5.2	NS
Average No. of comorbidities/ patient	1.6	1.6	1.6	1.5	1.5	1.5	1.6	NS

NS = not significant

*By χ^2 testing.

TABLE 6.—*Logistic Regression Analysis**

Independent Variable	P Value
Year of operation	NS
Increasing age	< .05
Male sex	< .05
Race	NS
Admission type	NS
Payer source	NS
Total pancreatectomy versus other resections	< .005
Increasing number of secondary diagnoses	<.0001
Decreasing hospital volume	< .001

NS = not significant

*Dependent variable is operative mortality.

TABLE 7.—*Hospital Volume Assignments*

Hospital Volume	Hospitals, No. (%)	Patients, No. (%)
1 to 5	210 (70)	510 (30)
6 to 10	53 (18)	395 (23)
11 to 20	20 (7)	258 (15)
21 to 30	9 (3)	228 (13)
31 to 50	4 (1)	171 (10)
>50	2 (1)	143 (8)

9.9%. Crude operative mortality decreased with increasing hospital experience, from 14.1% in low-volume centers to 3.5% in high-volume centers (Table 8). This relationship was significant (P = .0009 by linear-regression analysis and χ^2 test). The crude mortality for each volume group was risk-adjusted to account for significant differences in patient characteristics at admission as determined by logistic-regression analysis (Table 6). With this adjustment, a significant volume-outcome relationship persisted (Table 8).

The incidence of the two major postoperative complications, intra-abdominal hemorrhage and infection, did not differ significantly among the volume groups. The mortality associated with these complications, however, decreased as hospital volume increased. The operative mortality associated with hemorrhage and infection was 40% and 27%, respectively, in patients treated at low-volume centers compared with 11% and 11% at high-volume centers. These relationships were significant by linear-regression analysis (P = .02 for hemorrhage and .007 for infection).

Discussion

In this period of limited resources, increased attention is being paid in the United States to the most efficient provision of health care services. The desired goal is to provide the highest quality of care while using the fewest resources. It has been suggested that for certain complex surgical procedures, including heart transplantation, coronary artery bypass, and hip replacement, the results of treatment are directly linked to experience, as measured by yearly hospital volume.[13-16] We examined the possible relation between hospital volume and outcome in patients undergoing major pancreatic resection for malignancy.

The main finding in this study was a significant relationship between hospital volume and operative mortality for patients undergoing pancreatic resection for malignancy in California from 1990 through 1994. The sample size was large, encompassing 1,705 patients treated at 298 hospitals. The effect of hospital volume on operative mortality was large, with a fourfold difference in results between the lowest and highest volume providers. There are three possible explanations for this finding. First, it is possible that the data are flawed and that systematic reporting or coding errors favor the highest volume providers. In previous studies of population database reliability, a 10% to 30% error rate in diagnosis and procedure coding has been reported.[22,24,28] In this study, concordance between diagnosis and procedure codes was

TABLE 8.—*Hospital Volume Outcome Measures*

Hospital Volume, No.	*Length of Hospital Stay, days**	*Total Charges, $†*	*Overall Resource Scale†*	*Patients Discharged to Home, %‡*	*Crude Mortality, %‡*	*Risk-Adjusted Mortality Rate, %‡*
1 to 5	22.7	87,857	832	74.3	14.1	14.1
6 to 10	22.7	76,593	813	80.0	10.4	9.6
11 to 20	22.9	78,003	804	81.8	8.9	8.7
21 to 30	20.2	70,959	626	92.1	5.7	6.9
31 to 50	23.9	111,497	711	87.1	8.2	8.3
>50	20.5	71,585	652	95.1	3.5	3.5
Mean	22.3	83,479	769	82.1	9.9	9.9

*Not significant by rank-sum test. †$P < .0001$ by linear regression and rank-sum test. ‡$P < .0001$ by linear regression and χ^2 test.

required for each patient as part of the inclusion criteria, thereby reducing the number of erroneously coded patient discharge abstracts from further analysis. An error rate of only 1% has been identified in the reporting of the end point of patient death when the OSHPD database has been reconciled with primary data from individual patient medical records.[22] This error rate is not sufficiently large to explain the differences in operative mortality found between low- and high-volume hospitals in this study.

Second, it is possible that differences in patient characteristics could account for the observed variations in operative mortality. A number of patient characteristics were found to be significantly associated with the risk of postoperative death by logistic-regression analysis in this study, including age, male sex, the need for total pancreatectomy, and increasing number of secondary diagnoses. We controlled for patient characteristic differences in two ways. First, the data were pooled by hospital volume so that the number of patients in each volume group was sufficiently large to offset small differences in patient mix at any one hospital. Second, we adjusted crude operative mortality rates with the patient characteristics found to be significant in the logistic-regression model to arrive at a risk-adjusted mortality within each volume group. This risk adjustment did not alter the primary finding of a significant association between hospital volume and operative mortality. It is possible that risk factors for higher operative mortality were present but not identifiable in the OSHPD database and that the distribution of patients with this unknown risk factor was skewed toward hospitals with low volume, but this seems unlikely.

Finally, it is probable that the findings in this study represent true differences in outcome related to differences in patient care in hospitals of various volume groups.

A number of pieces of supporting evidence suggest that this last interpretation of the data is correct. First, the overall operative mortality of 9.9% in this study is comparable with previously reported operative mortality rates in other large population studies, including the nationwide Department of Veterans Affairs experience and a nationwide survey by the American College of Surgeons.[21,29] Second, the operative mortality of the highest volume centers in this study mirrors the published results of other high-volume centers around the world.[4,6-9] Finally, two recent studies have examined the relationship between hospital volume and operative mortality for pancreatic resection in the states of Maryland and New York.[19,20] The findings in these two reports and the current study are in remarkable agreement.

Only a limited insight into possible differences in patient care leading to improved operative mortality in the high-volume centers could be gleaned from the OSHPD database. Whereas the rates of major operative complications of hemorrhage and infection were similar in all hospital volume groups, the mortality associated with these complications decreased significantly with increasing hospital volume. This suggests that high-volume centers have developed either effective treatment strategies or the necessary supporting team to cope with these problems or both. The number of deaths associated with hemorrhage or infection was relatively small and did not account for the entire observed differences in operative mortality. Thus, other factors must be important, although these could not be identified with the available data.

In addition to reduced operative mortality, high-volume centers were found in this study to have reduced hospital charges and resource-demand scale scores. These were independent of length of hospital stay, which did not vary significantly among volume groups. High-volume centers were significantly more likely to discharge patients home, whereas low-volume centers used significantly more intermediate-care facility resources. Although an examination of actual costs would be preferable to these indirect measures of resource use, cost data were not available in this database. The above findings suggest, however, that the highest volume hospitals not only treat patients undergoing pancreatic resection for malignancy with substantially lower operative mortality, but also accomplish this with lower costs. If the standard of care defined by the highest volume hospitals were applied statewide in 1990 through 1994, 108 additional patients would have survived their operation, with a savings of $20,580,099 in hospital charges.

In today's health care environment, quality of care is measured not only in patients' clinical outcome, but also in cost-effectiveness. In California, most patients undergoing pancreatectomy for malignancy were treated at hospitals with limited experience. This study shows a strong relationship between hospital volume and outcome in these patients. The data support regionalizing high-risk general surgical procedures, like pancreatectomy for malignancy, as a means of providing the most efficacious and cost-effective care.

Acknowledgment

Cora Lee Yale assisted with data processing.

REFERENCES

1. Boring C, Squires T, Tong T: Cancer statistics, 1994. CA Cancer J Clin 1994; 44:7–26

2. Lansing PB, Blalock JB, Ochsner JL: Pancreatoduodenectomy: Retrospective review, 1949 to 1969. Am J Surg 1972; 38:79–86

3. Aston SJ, Longmire WP Jr: Pancreaticoduodenal resection: Twenty years' experience. Arch Surg 1973; 106:813–817

4. Cameron JL, Pitt HA, Yeo CJ, Lillemoe KD, Kaufman HS, Coleman J: One hundred and forty-five consecutive pancreaticoduodenectomies without mortality. Ann Surg 1993; 217:430–435

5. Crist D, Sitzmann J, Cameron J: Improved hospital morbidity, mortality, and survival after the Whipple procedure. Ann Surg 1987; 206:358–365

6. Geer R, Brennan M: Prognostic indicators for survival after resection of pancreatic adenocarcinoma. Am J Surg 1993; 165:68–73

7. Grace PA, Pitt HA, Tompkins RK, DenBesten L, Longmire WP Jr: Decreased morbidity and mortality after pancreatoduodenectomy. Am J Surg 1986; 151:141–149

8. Pellegrini C, Heck C, Raper S, Way L: An analysis of the reduced morbidity and mortality rates after pancreaticoduodenectomy. Arch Surg 1989; 124:778–781

9. Trede M, Schwall G, Saeger HD: Survival after pancreatoduodenectomy—118 consecutive resections without an operative mortality. Ann Surg 1990; 211:447–458

10. Jonasson O, Kwakwa F, Sheldon GF: Calculating the workforce in general surgery. JAMA 1995; 274:731–734

11. Rogers C: Socioeconomic Factbook for Surgery 1995. Chicago, Ill, American College of Surgeons, 1995

12. Luft HS, Bunker JP, Enthoven AC: Should operations be regionalized? The empirical relation between surgical volume and mortality. N Engl J Med 1979; 301:1364–1369

13. Fowles J, Bunker J, Oda M, Schurman D, Osborn P, Loftus M: Relation of surgical volume to outcomes and charges: Pilot study of total hip replacement using Northern California Medicare data. Bus Health 1987; 4:44–46

14. Showstack J, Rosenfeld K, Garnick D, Luft H, Schaffarzick R, Fowles J: Association of volume with outcome of coronary artery bypass graft surgery. JAMA 1987; 257:785–789

15. Hannan E, O'Donnell J, Kilburn H, Bernard H, Yazici A: Investigation of the relationship between volume and mortality for surgical procedures performed in New York State hospitals. JAMA 1989; 262:503–510

16. Laffel G, Barnett A, Finkelstein S, Kaye M: The relation between experience and outcome in heart transplantation. N Engl J Med 1992; 327:1220–1225

17. Hughes RG, Garnick DW, Luft HS, McPhee SJ, Hunt SS: Hospital volume and patient outcomes—The case of hip fracture patients. Med Care 1988; 26:1057–1067

18. Grumbach K, Anderson GM, Luft HS, Roos LL, Brook R: Regionalization of cardiac surgery in the United States and Canada—Geographic access, choice, and outcomes. JAMA 1995; 274:1282–1288

19. Gordon TA, Burleyson GP, Tielsch JM, Cameron JL: The effects of regionalization on cost and outcome for one general high-risk surgical procedure. Ann Surg 1995; 221:43–49

20. Lieberman J, Kilburn H, Lindsey M, Brennan M: Relation of perioperative deaths to hospital volume among patients undergoing pancreatic resection for malignancy. Ann Surg 1995; 222:638–645

21. Wade TP, el-Ghazzawy AG, Virgo KS, Johnson FE: The Whipple resection for cancer in US Department of Veterans Affairs hospitals. Ann Surg 1995; 221:241–248

22. Chen A, Meux E, Cox G: Report of the Results From the OSHPD Reabstracting Project—An Evaluation of the Reliability of Selected Patient Discharge Data July Through December 1990. Sacramento, Calif, Office of Statewide Health Planning and Development, 1993

23. Horbar JD, Leahy KA: An assessment of data quality in the Vermont-Oxford Trials Network database. Control Clin Trials 1995; 16:51–61

24. Anonymous: How good are the data? USRDS data validation special study. Am J Kidney Dis 1992; 46:675–683

25. Jones MK, Brouch K, Hall D, Aaron W (Eds): St Anthony's Compact ICD-9-CM: Code Book for Physician Payment, Vol 1 and 2, 1995 edition. Reston, Va, St Anthony Publishing, 1994

26. Green J, Wintfeld N, Sharkey P, Passman LJ: The importance of severity of illness in assessing hospital mortality. JAMA 1990; 263:241–246

27. Fleiss J: Statistical Methods for Rates and Proportions. New York, NY, John Wiley and Sons, 1973

28. Lloyd S, Rissing F: Physician and coding errors in patient records. JAMA 1985; 254:1330–1336

29. Janes RJ, Niederhuber J, Chmiel J, et al: National patterns of care for pancreatic cancer—Results of a survey by the Commission on Cancer. Ann Surg 1996; 223:261–272