Defining Value for Pancreatic Surgery in Early-Stage Pancreatic Cancer
Sarah B. Bateni, MD; Alicia A. Gingrich, MD; Jeffrey S. Hoch, PhD; Robert J. Canter, MD; Richard J. Bold, MD

IMPORTANCE Value-based care is increasingly important, with rising health care costs and advances in cancer treatment leading to greater survival for patients with cancer. Regionalization of surgical care for pancreatic cancer has been extensively studied as a strategy to improve perioperative outcomes, but investigation of long-term outcomes relative to health care costs (ie, value) is lacking.

OBJECTIVE To identify patient and hospital characteristics associated with improved overall survival, decreased costs, and greater value among patients with pancreatic cancer undergoing curative resection.

DESIGN, SETTING, AND PARTICIPANTS This retrospective cohort study identified 2786 patients with stages I to II pancreatic cancer who underwent pancreatic resection at 157 hospitals from January 1, 2004, through December 31, 2012. The study used the California Cancer Registry, which collects data from all California residents newly diagnosed with cancer, linked to the Office of Statewide Health Planning and Development database, which collects administrative data from all California licensed hospitals. Data were analyzed from November 11, 2017, through September 4, 2018.

EXPOSURES Pancreatic resection at high-volume and/or National Cancer Institute (NCI)–designated cancer centers.

MAIN OUTCOMES AND MEASURES The primary outcomes were overall survival, surgical hospitalization costs, and value. High value was defined as the fourth quintile or higher for survival and the second quintile or less for costs. Costs were calculated from charges using cost-charge ratios and adjusted for geographic variation and inflation. Multivariable regression models were used to determine factors associated with overall survival, costs, and high value.

RESULTS Among the 2786 patients included (1394 [50.0%] male; mean [SD] age, 67.0 [10.7] years), postoperative chemotherapy (adjusted hazard ratio [aHR], 0.71; 95% CI, 0.64−0.79; P < .001) and high-volume centers (aHR, 0.78; 95% CI, 0.61−0.99; P = .04) were associated with greater overall survival. Higher Elixhauser comorbidity index scores (estimate, 0.006; 95% CI, 0.003−0.008), complications (estimate, 0.22; 95% CI, 0.17−0.27), readmissions (estimate, 0.34; 95% CI, 0.29−0.39), and longer lengths of stay (estimate, 0.03; 95% CI, 0.03−0.04) were associated with higher costs (P < .001), whereas postoperative chemotherapy was associated with lower costs (estimate, −0.06; 95% CI, −0.11 to −0.02; P = .006). National Cancer Institute–designated and high-volume centers were not associated with costs. Although grades III and IV tumors (odds ratio [OR], 0.65; 95% CI, 0.39−0.91; P = .001), T3 category disease (OR, 0.71; 95% CI, 0.46−0.95; P = .005), complications (OR, 0.68; 95% CI, 0.49−0.86; P < .001), readmissions (OR, 0.64; 95% CI, 0.44−0.84; P < .001), and length of stay (OR, 0.82; 95% CI, 0.78−0.85; P < .001) were inversely associated with high-value care, NCI designation (OR, 1.07; 95% CI, 0.66−1.49; P = .74) and high-volume centers (OR, 1.08; 95% CI, 0.54−1.61; P = .07) were not.

CONCLUSIONS AND RELEVANCE In this study, high-value care was associated with important patient characteristics and postoperative outcomes. However, NCI-designated and high-volume centers were not associated with greater value. These data suggest that targeted measures to enhance value may be needed in these centers.
Value in cancer care has become increasingly important in the age of ever-rising health care costs and increasing incidence of cancer. Cancer-related health care costs in the United States are expected to exceed $170 billion by 2020.1 Meanwhile, the United States spends more than $400 billion annually to care for patients undergoing surgery, and this spending is projected to constitute 7% of the US gross domestic product by 2025.2-4 Unfortunately, the rising costs of cancer and surgical care coincide with the rising incidence of cancer in the population. Hence, studies regarding the value of health care are essential. Value is defined as quality relative to the cost of care.5 It is a useful metric in health care services and economics research because maintaining the quality of care provided while controlling cost is imperative.

Pancreatic cancer surgery, although rare, is often studied for this purpose owing to the complexity of pancreatic resection and relatively high morbidity and mortality. An estimated 55,440 adults in the United States will be diagnosed with pancreatic cancer this year, and an estimated 44,330 will die of the disease.6 Studies have demonstrated that as many as 40% of patients undergoing this type of procedure develop a postoperative complication.7,8 For pancreatic resections in particular, a consistent and strong association between high surgical volume and improved perioperative outcomes has been demonstrated by numerous studies.9-14 More recent research has begun to delve into the nuances between volume and cost as well as the hospital-, economic-, and patient-based factors contributing to each.15-17 However, to our knowledge, no research to date has examined value in pancreatic cancer surgery.

Recognizing the complexity of this issue and the intricate associations at play, we performed a population-based analysis of patients with early-stage pancreatic cancer who underwent curative resection. The purpose of this study was to identify patient and hospital characteristics associated with improved survival, decreased costs, and overall greater value. We hypothesized that high-volume pancreatic surgery centers and National Cancer Institute (NCI)-designated cancer centers would be associated with improved survival and potentially lower costs secondary to regionalization of care and center-specific processes, and thus greater value compared with low-volume pancreatic surgery centers and non-NCI-designated cancer centers.

Methods

We performed a retrospective analysis of patients diagnosed with resectable pancreatic adenocarcinoma from the California Cancer Registry (CCR) and Office of Statewide Hospital Planning and Development (OSHPD)-linked database from January 1, 2004, through December 31, 2012. The research protocol was approved by the institutional review board of the University of California, Davis, and the California Health and Human Services Agency Committee for the Protection of Human Subjects with a waiver of consent granted for use of deidentified data. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Key Points

Question Is the regionalization of surgical care for resectable pancreatic cancer at high-volume surgical centers and National Cancer Institute–designated cancer centers associated with improved survival, health care costs, and/or value (ie, survival relative to costs)?

Findings In this retrospective analysis of 2786 patients with stages I to II pancreatic adenocarcinoma who underwent pancreatic resection, although high-volume centers were associated with greater overall survival, high-volume and National Cancer Institute–designated centers were not associated with improved health care costs or value.

Meaning Targeted measures are needed at high-volume and National Cancer Institute–designated centers to enhance pancreatic surgery value, especially considering they treat a significant fraction of patients with pancreatic cancer.

Study Population

We identified 8723 patients with stages I to II (T1-T3 N0-N1 M0) pancreatic adenocarcinoma based on International Classification of Diseases for Oncology, Third Revision, codes for site and histology (eTable in the Supplement).18 Patients who did not undergo a pancreatic resection (5207 [59.7%]) or with missing costs data (ie, Kaiser Foundation facilities, 730 [8.4%]) were excluded. The final cohort consisted of 2786 patients treated at 157 hospitals.

We abstracted patient demographic, clinicopathologic, and treatment data from CCR, including patient age, sex, race, tumor grade, tumor and node categories, composite American Joint Committee on Cancer (seventh edition) stage, chemotherapy, and radiotherapy. Pancreatic surgical resections were identified from the linked OSHPD data files based on International Classification of Diseases, Ninth Revision (ICD-9) codes 525, 5251, 5252, 5253, 5259, 526, and 527. The Elixhauser comorbidity index was used to measure risk associated with comorbid health conditions and created using ICD-9 diagnostic codes (index scores range from 11 to 62, with higher scores indicating more comorbidities).19-21 High-volume pancreatic surgery centers were defined as centers performing at least 20 pancreatic resections annually based on previous research showing improved mortality at this cutoff.22-24 Of the 157 hospitals, only 8 were high-volume surgical centers.

Postoperative complications were identified from ICD-9 codes for the index hospitalization and subsequent hospital readmissions within 30 days of the date of surgery. Complications included pulmonary failure, pneumonia, myocardial infarction, cardiac arrest, pulmonary embolism, deep vein thrombosis, gastrointestinal tract hemorrhage, surgical site and organ space infections, systemic shock, acute kidney injury, delayed gastric emptying, gastrointestinal and/or enterocutaneous fistula, and bile leak.15 We were unable to include pancreatic fistula because ICD-9 has no specific code for this complication. We abstracted length of stay, 30-day readmissions, in-hospital death, and costs from the OSHPD-linked data files.

Costs were estimated from charges for the index surgical hospitalization and all readmissions within 30 days of discharge. Charges were multiplied by the ratio of hospital-
specific cost to charge, adjusted for geographic variation using the wage index and adjusted for inflation using the Personal Health Care Price Index.\textsuperscript{25} Survival was defined as months alive from the date of pancreatic cancer diagnosis. Only 464 patients (16.7\%) were censored; these patients were included owing to their extended follow-up (median, 56 months; range, 23-131 months; interquartile range [IQR], 37-85 months). High-value care was defined as the fourth quintile or higher for survival (≥26 months) and second quintile or less for costs (≤$40,674). Low-value care was defined as the second quintile or less for survival (≤15 months) and the fourth quintile or higher for costs (≥$53,971).

Statistical Analysis
Data were analyzed from November 11, 2017, through September 4, 2018. Patient demographic, clinicopathologic, and treatment characteristics were presented as means with SDs, medians with IQRs, and frequencies with percentages, as appropriate. Patients were divided into quintiles based on survival and costs. We used χ² tests, analysis of variance, and Kruskal-Wallis tests to compare demographic, clinicopathologic, and treatment characteristics between survival and cost quintiles and among patients with a high-, intermediate-, and low-value care designation. Multivariable Cox proportional hazards models were used to identify factors associated with overall survival. Multivariable generalized linear models were used to determine characteristics associated with costs, assuming a gamma distribution and log link (determined appropriate using the modified Parks and link tests).\textsuperscript{15,26} Logistic regression was used to identify characteristics associated with high-value care. Robust standard errors adjusted for clustering of patients at the same hospital were calculated for all multivariable analyses. All tests were 2 sided. Statistical significance was set at P < .05. Analyses were performed using SAS, version 9.4 (SAS Institute Inc), and Stata, version 13 (StataCorp).

Owing to potential collinearity for NCI-designated cancer centers and high-volume surgical centers, in addition to the comprehensive model with both variables included, we performed separate multivariable models for NCI-designated centers and high-volume hospitals. Because the results were similar for the individual and comprehensive models for overall survival, costs, and value, we selected to present the comprehensive model.

Results
Table 1 presents patient demographic, clinicopathologic, and treatment characteristics of the included 2786 patients with pancreatic cancer who underwent surgical resection. The mean (SD) age was 67.0 (10.7) years, 1394 patients (50.0\%) were male, 1392 (50.0\%) were female, and 2308 (82.8\%) were white. Most tumors were moderately differentiated (1373 [49.3\%]) or poorly differentiated or undifferentiated (949 [34.1\%]). The T3 category (2147 [77.1\%]) and presence of nodal disease (1725 [61.9\%]) were common. A total of 1238 patients (44.4\%) underwent postoperative chemotherapy, and 874 (31.4\%) underwent radiotherapy. Most patients underwent resection of pan-

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Data (n = 2786)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>67.0 (10.7)</td>
</tr>
<tr>
<td>Sex</td>
<td>Male 1394 (50.0), Female 1392 (50.0)</td>
</tr>
<tr>
<td>Race</td>
<td>White 2308 (82.8), Black 152 (5.5), Asian/Pacific Islander 313 (11.2), Other/unknown 13 (0.5)</td>
</tr>
<tr>
<td>Tumor grade</td>
<td>Well differentiated 295 (10.6), Moderately differentiated 1373 (49.3), Poorly differentiated or undifferentiated 949 (34.1), Unknown 169 (6.1)</td>
</tr>
<tr>
<td>N category</td>
<td>N0 1054 (37.8), N1 1725 (61.9), NX 7 (0.3)</td>
</tr>
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<td>Stage</td>
<td>I 399 (14.3), II 2387 (85.7)</td>
</tr>
<tr>
<td>Chemotherapy</td>
<td>None 1070 (38.4), Preoperative 89 (3.2), Postoperative 1238 (44.4), Preoperative and postoperative 50 (1.8), Unknown 339 (12.2)</td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>874 (31.4)</td>
</tr>
<tr>
<td>Pancreatic resection</td>
<td>Pancreatectoduodenectomy 2207 (79.2), Distal pancreatectomy 387 (13.9), Total pancreatectomy 98 (3.5), Other 94 (3.4)</td>
</tr>
<tr>
<td>Complication within 30 d</td>
<td>1037 (37.2)</td>
</tr>
<tr>
<td>Readmission within 30 d</td>
<td>565 (20.3)</td>
</tr>
<tr>
<td>Length of stay, median (IQR), d</td>
<td>12 (9-18)</td>
</tr>
<tr>
<td>Surgery hospitalization costs, mean (SD), $</td>
<td>60,939 (56,779)</td>
</tr>
<tr>
<td>Follow-up, median (IQR), mo</td>
<td>20 (10-35)</td>
</tr>
<tr>
<td>Vital status</td>
<td>Death due to pancreatic cancer 2020 (72.5), Death due to other cause 247 (8.9), Death due to unknown cause 55 (2.0), Alive 464 (16.7)</td>
</tr>
<tr>
<td>High-volume hospital</td>
<td>1297 (46.6)</td>
</tr>
<tr>
<td>NCI-designated cancer center</td>
<td>1127 (40.5)</td>
</tr>
<tr>
<td>Teaching hospital</td>
<td>1428 (51.3)</td>
</tr>
</tbody>
</table>

Abbreviations: IQR, interquartile range; NCI, National Cancer Institute.

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creatic head tumors (2207 [79.2%]). One thousand thirty-seven patients (37.2%) experienced at least 1 complication, and 565 (20.3%) were readmitted within 30 days of discharge. The median length of stay was 12 days (IQR, 9-18 days). The mean (SD) costs for the index surgical hospitalization and 30-day readmissions were $60,939 ($56,779), with a median of $46,697 (IQR, $32,815-$68,765). Median follow-up time with survival was 20 months (IQR, 10-35 months). Most patients died of pancreatic cancer (2020 of 2731 [74.0%]). Atotal of 1428 patients (51.3%) were treated at a teaching hospital, 1297 (46.6%) were treated at a high-volume pancreatic surgery center, and 1127 (40.5%) were treated at an NCI-designated cancer center.

Median survival for high-volume centers was 23 months (IQR, 11-46 months) compared with 18 months (IQR, 10-35 months) for low-volume centers (P < .001). Patients were more frequently treated with chemotherapy at high-volume vs low-volume centers (879 [67.8%] vs 824 [55.3%]; P < .001) and NCI- vs non-NCI-designated cancer centers (760 [67.4%] vs 943 [56.8%]; P < .001). Among those who underwent chemotherapy with a known regimen (n = 1473), patients who underwent surgery at high-volume centers were more frequently treated with multiagent chemotherapy compared with patients treated at low-volume centers (355 [46.2%] vs 282 [40.1%]; P = .02), whereas there was no difference in the use of multiagent chemotherapy among patients who underwent surgery at NCI- and non-NCI-designated cancer centers (279 [42.3%] vs 358 [44.0%]; P = .50).

Table 2 and Table 3 present univariate analysis of patient demographics and clinicopathologic and treatment differences by survival and cost quintiles. Older age (mean [SD], 69.3 [10.3] years; P < .001), male sex (337 of 615 [54.8%]; P = .03), higher Elixhauser comorbidity index score (mean [SD], 16.7 [10.1]; P < .001), and higher rates of T3 category disease (511 of 615 [83.1%]; P < .001), nodal disease (438 of 615 [71.2%]; P < .001), stage II disease (561 of 615 [91.2%]; P < .001), and poorly differentiated or undifferentiated tumors (278 of 615 [45.2%]; P < .001) were associated with shorter survival. Postoperative chemotherapy (292 of 534 [54.7%]; P < .001), operations performed at high-volume surgical centers (277 of 534 [51.9%]; P < .001), and lower complication (177 of 534 [33.1%]; P < .001) and readmission (99 of 534 [18.5%]; P < .001) rates were associated with longer survival. Similarly, older age (mean [SD], 68.0 [10.0] years; P < .001), higher Elixhauser comorbidity index score (mean [SD], 17.9 [10.9]; P < .001), and higher rates of T3 disease (457 of 557 [82.0%]; P < .001) were associated with higher costs, whereas distal pancreatectomies (197 of 557 [35.4%]; P < .001) were associated with lower costs. In addition, higher rates of complications (416 of 557 [74.7%]; P < .001), readmission (226 of 557 [40.6%]; P < .001), and in-hospital death (63 of 557 [11.3%]; P < .001) were associated with higher costs.

Univariate analysis of patient demographic, clinicopathologic, and treatment differences by value are presented in Table 4. Younger age (mean [SD], 65.7 [11.2] years; P < .001), female sex (284 of 524 [54.2%]; P = .008), lower Elixhauser comorbidity index score (mean [SD], 10.4 [5.9]; P < .001), lower rates of T3 category (331 of 524 [63.2%]; P < .001) and stage II (379 of 524 [72.3%]; P < .001) disease, absence of nodal dis ease (265 of 524 [50.6%]), lower rates of poorly differentiated or undifferentiated tumors (131 of 524 [25.0%]; P < .001), higher rates of distal pancreatectomy (137 of 524 [26.1%]; P < .001), and postoperative chemotherapy (262 of 524 [50.0%]; P < .001) were associated with high-value care. National Cancer Institute–designated cancer centers (247 of 524 [47.1%]; P = .001) and high-volume centers (272 of 524 [51.9%]; P = .02) were also associated with high-value care in this univariate analysis. Longer lengths of stay (median, 19 days [IQR, 14-28 days]; P < .001) and higher rates of complication (372 of 568 [65.5%]; P < .001), readmission (199 of 568 [35.0%]; P < .001), and in-hospital death (82 of 568 [14.4%]; P < .001) were associated with low-value care.

Multivariable models for survival, costs, and high-value care are presented in Table 5. Older age (adjusted hazard ratio [aHR], 1.01; 95% CI, 1.01-1.02; P < .001), male sex (aHR, 0.91; 95% CI, 0.83-0.99; P = .02), higher Elixhauser comorbidity index score (aHR, 1.01; 95% CI, 1.01-1.02; P < .001), higher-grade tumors (aHR, 1.84; 95% CI, 1.57-2.16; P < .001), higher T (aHR, 1.45; 95% CI, 1.16-1.80; P < .001), and NCI-designated cancer center status was associated with high-value care. National Cancer Institute–designated cancer centers (aHR, 1.27; 95% CI, 1.02-1.57; P = .03), total pancreatectomy (aHR, 1.47; 95% CI, 1.18-1.82; P < .001), and postoperative complications (aHR, 1.18; 95% CI, 1.07-1.30; P = .001) were associated with shorter survival. Postoperative chemotherapy (aHR, 0.71; 95% CI, 0.64-0.79; P < .001) and high-volume surgical centers (aHR, 0.78; 95% CI, 0.61-0.99; P = .04) were associated with greater survival. Higher Elixhauser comorbidity index score (estimate, 0.006; 95% CI, 0.003-0.008; P < .001), postoperative complications (estimate, 0.22; 95% CI, 0.17-0.27; P < .001), readmissions (estimate, 0.34; 95% CI, 0.29-0.39; P < .001), and longer lengths of stay (estimate, 0.03; 95% CI, 0.03-0.04; P < .001) were associated with higher costs, whereas distal pancreatectomies (estimate, −0.21; 95% CI, −0.26 to −0.17; P < .001) and postoperative chemotherapy (estimate, −0.06; 95% CI, −0.11 to −0.02; P = .006) were associated with lower costs. Operations performed at NCI-designated cancer centers and high-volume centers were not associated with cost differences.

Female sex was associated with higher odds of high-value care (adjusted odds ratio [aOR], 1.10; 95% CI, 1.01-1.19; P = .048), whereas higher Elixhauser comorbidity index score (aOR, 0.97; 95% CI, 0.95-0.98; P < .001), poorly differentiated or undifferentiated tumors (aOR, 0.65; 95% CI, 0.39-0.91; P = .001), T3 category (aOR, 0.71; 95% CI, 0.46-0.95; P = .005), total pancreatectomy (aOR, 0.40; 95% CI, 0.10-0.66; P = .007), postoperative complications (aOR, 0.68; 95% CI, 0.49-0.86; P < .001), readmissions (aOR, 0.64; 95% CI, 0.44-0.84; P < .001), and longer lengths of stay (aOR, 0.82; 95% CI, 0.78-0.85; P < .001) were associated with lower odds of high-value care. National Cancer Institute–designated cancer centers and high-volume centers were not associated with high-value care in multivariable analysis. Because perioperative outcomes (eg, complications, readmissions, and length of stay) were associated with higher costs and decreased survival, we repeated the multivariable survival, cost, and value models after removing these confounding variables; our findings remained unchanged in that neither hospital volume nor NCI-designated cancer center status was associated with high-value care.
Table 2. Patient Demographic, Clinicopathologic, and Treatment Characteristics by Survival Quintile

<table>
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<th>Characteristic</th>
<th>Survival Quintile</th>
<th>P Value</th>
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<tbody>
<tr>
<td></td>
<td>Low (n = 615)</td>
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<tr>
<td>Age, mean (SD)</td>
<td>69.3 (10.3)</td>
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<tr>
<td>Male</td>
<td>337 (54.8)</td>
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<tr>
<td>Race</td>
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<td></td>
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<tr>
<td>White</td>
<td>511 (83.1)</td>
<td></td>
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<tr>
<td>Black</td>
<td>35 (5.7)</td>
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<tr>
<td>Asian/Pacific Island</td>
<td>68 (11.1)</td>
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<tr>
<td>Other/unknown</td>
<td>1 (0.2)</td>
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<tr>
<td>Socioeconomic status</td>
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<tr>
<td>Low (first quintile)</td>
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<td>Low to middle (second quintile)</td>
<td>120 (19.5)</td>
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<tr>
<td>Middle (third quintile)</td>
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<td>Middle to high (fourth quintile)</td>
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<td>High (fifth quintile)</td>
<td>124 (20.2)</td>
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<tr>
<td>Elixhauser comorbidity index score, mean (SD)</td>
<td>16.7 (10.1)</td>
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<tr>
<td>T category</td>
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<tr>
<td>T1</td>
<td>24 (3.9)</td>
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<tr>
<td>T2</td>
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<td>T3</td>
<td>511 (83.1)</td>
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<tr>
<td>N category</td>
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</tr>
<tr>
<td>N0</td>
<td>176 (28.6)</td>
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<tr>
<td>N1</td>
<td>438 (71.2)</td>
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<td>NX</td>
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<tr>
<td>Stage</td>
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<tr>
<td>I</td>
<td>54 (8.8)</td>
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<tr>
<td>II</td>
<td>561 (91.2)</td>
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<tr>
<td>Grade</td>
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<tr>
<td>Well differentiated</td>
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<tr>
<td>Moderately differentiated</td>
<td>274 (44.6)</td>
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<tr>
<td>Poorly differentiated or undifferentiated</td>
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<td>Unknown</td>
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<tr>
<td>Pancreatic resection</td>
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<td>Pancreaticoduodenectomy</td>
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<td>Distal pancreatectomy</td>
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<td>None</td>
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<td>Preoperative</td>
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<td>Postoperative</td>
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<td>Radiotherapy</td>
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<td>NCI-designated cancer center</td>
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<td>Teaching hospital</td>
<td>286 (46.5)</td>
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<tr>
<td>High-volume center</td>
<td>244 (39.7)</td>
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<tr>
<td>Costs, mean (SD), $</td>
<td>72 516 (69 025)</td>
<td>&lt;.001</td>
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<tr>
<td>Length of stay, median (IQR), d</td>
<td>15 (10-23)</td>
<td>&lt;.001</td>
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<tr>
<td>Complication within 30 d</td>
<td>324 (52.7)</td>
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<tr>
<td>Readmission within 30 d</td>
<td>162 (26.3)</td>
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</table>

Abbreviations: IQR, interquartile range; NCI, National Cancer Institute.

* Unless otherwise indicated, data are expressed as number (percentage) of patients. Percentages have been rounded and may not total 100. Low indicates 0 to 9 months; low to intermediate, 10 to 15 months; intermediate, 16 to 25 months; intermediate to high, 26 to 41 months; and high, 42 or more months.

b Calculated using analysis of variance.

c Calculated using χ² test.

d Calculated using Fisher exact text.

* Scores range from −11 to 62, with higher scores indicating a greater number of comorbidities.

f Indicates 20 or more cases annually.

g Includes the index surgical hospitalization and readmissions within 30 days.

h Calculated using Kruskal-Wallis test.
Table 3. Patient Demographic, Clinicopathologic, and Treatment Characteristics by Surgical Hospital Cost Quintile

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cost Quintilea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low (n = 557)</td>
</tr>
<tr>
<td>Age, mean (SD), y</td>
<td>65.7 (11.3)</td>
</tr>
<tr>
<td>Male</td>
<td>262 (47.0)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>468 (84.0)</td>
</tr>
<tr>
<td>Black</td>
<td>17 (3.1)</td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>70 (12.6)</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>2 (0.4)</td>
</tr>
<tr>
<td>Socioeconomic status</td>
<td></td>
</tr>
<tr>
<td>Low (first quintile)</td>
<td>84 (15.1)</td>
</tr>
<tr>
<td>Low to middle (second quintile)</td>
<td>79 (14.2)</td>
</tr>
<tr>
<td>Middle (third quintile)</td>
<td>123 (22.1)</td>
</tr>
<tr>
<td>Middle to high (fourth quintile)</td>
<td>112 (20.1)</td>
</tr>
<tr>
<td>High (fifth quintile)</td>
<td>159 (28.5)</td>
</tr>
<tr>
<td>Elixhauser comorbidity index, mean (SD)e</td>
<td>10.5 (6.0)</td>
</tr>
<tr>
<td>T category</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>61 (11.0)</td>
</tr>
<tr>
<td>T2</td>
<td>101 (18.1)</td>
</tr>
<tr>
<td>T3</td>
<td>395 (70.9)</td>
</tr>
<tr>
<td>N category</td>
<td></td>
</tr>
<tr>
<td>N0</td>
<td>236 (42.4)</td>
</tr>
<tr>
<td>N1</td>
<td>319 (57.3)</td>
</tr>
<tr>
<td>NX</td>
<td>2 (0.4)</td>
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<tr>
<td>Stage</td>
<td></td>
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<tr>
<td>I</td>
<td>118 (21.2)</td>
</tr>
<tr>
<td>II</td>
<td>439 (78.8)</td>
</tr>
<tr>
<td>Grade</td>
<td></td>
</tr>
<tr>
<td>Well differentiated</td>
<td>52 (9.3)</td>
</tr>
<tr>
<td>Moderately differentiated</td>
<td>284 (51.0)</td>
</tr>
<tr>
<td>Poorly differentiated or undifferentiated</td>
<td>186 (33.4)</td>
</tr>
<tr>
<td>Unknown</td>
<td>35 (6.3)</td>
</tr>
<tr>
<td>Pancreatic resection</td>
<td></td>
</tr>
<tr>
<td>Pancreatoduodenectomy</td>
<td>310 (55.7)</td>
</tr>
<tr>
<td>Distal pancreatectomy</td>
<td>197 (35.4)</td>
</tr>
<tr>
<td>Total pancreatectomy</td>
<td>17 (3.1)</td>
</tr>
<tr>
<td>Other pancreatectomy</td>
<td>33 (5.9)</td>
</tr>
<tr>
<td>Chemotherapy</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>204 (36.6)</td>
</tr>
<tr>
<td>Preoperative</td>
<td>14 (2.5)</td>
</tr>
<tr>
<td>Postoperative</td>
<td>259 (46.5)</td>
</tr>
<tr>
<td>Sequence unknown/other</td>
<td>80 (14.4)</td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>176 (31.6)</td>
</tr>
<tr>
<td>NCI-designated cancer center</td>
<td>247 (44.3)</td>
</tr>
<tr>
<td>Teaching hospital</td>
<td>250 (44.9)</td>
</tr>
<tr>
<td>High-volume centerr</td>
<td>245 (44.0)</td>
</tr>
<tr>
<td>Survival, median (IQR), mo</td>
<td>26 (12-61)</td>
</tr>
<tr>
<td>Length of stay, median (IQR), d</td>
<td>8 (7-10)</td>
</tr>
<tr>
<td>Complication within 30 d</td>
<td>62 (11.1)</td>
</tr>
</tbody>
</table>

(continued)
Discussion

In this analysis of patients with early-stage pancreatic cancer in California, pancreatic resections with higher value, defined as high-quality care (ie, longer survival) with low health care costs, were associated with important patient, tumor, and treatment characteristics. However, hospital-level factors, including NCI-designated cancer centers, teaching hospitals, and high-volume centers, were not associated with greater value in multivariable analyses. This finding is surprising in the context of existing literature supporting the association between high-volume centers and improved perioperative outcomes.9-14 These findings suggest that regionalization of pancreatic cancer surgical care may translate into potential improvements in patient long-term survival but not into lower health care costs or, importantly, greater value.

This study expands on previous research27-29 suggesting that patients treated at NCI-designated cancer centers may experience better surgical outcomes for pulmonary, colorectal, and gastric cancer but not necessarily for pancreatic cancer. Similar to this study’s findings, Birkmeyer et al27 found no significant differences in operative mortality or 5-year survival among Medicare patients who underwent pancreatic resection at NCI- and non-NCI-designated cancer centers. Interestingly, these findings contradict the study by Wolfson et al,29 which showed improved survival among Los Angeles County patients who underwent pancreatic resections at NCI-designated comprehensive cancer centers. This may be secondary to the limited population sample in the study by Wolfson et al.29 Regardless, in the present study, using a population-based sample of patients with early-stage pancreatic cancer who underwent surgical resection in 157 California hospitals, we did not find improvements in survival, costs, and, most importantly, the value of care provided at NCI-designated cancer centers.

Our findings suggest a continued need for the identification of value-enhancement measures in pancreatic surgery, especially in high-volume and NCI-designated cancer centers. National Cancer Institute–designated cancer centers and high-volume centers will need to perform surgery for higher-risk patients because higher-risk cancer is their area of expertise. In addition, significant advances in survival of resectable pancreatic cancer are likely to come from more effective chemotherapy rather than improvements in operative management. As such, improvements in value are more likely to be obtained through efforts to reduce cost of health care delivery. At the provider level, all efforts should be made to reduce complications, because complications have been clearly demonstrated to correlate with extended lengths of stay, increased costs, and lower value.15,30,31 From a systems standpoint, implementation of standardized, empirically validated processes of care need to be implemented in an effort to reduce complications, lengths of stay, and readmissions. However, Ho et al32 found that implementation of processes of care in response to complications may increase hospital costs. A counterpoint by Eejaz et al33 noted significant variation among providers with respect to outcomes and cost driven by excess use of resources. Therefore, resource-conscious processes of care designed to reduce cost with consistent adherence by providers is needed in the current health care system.

The implications of our findings on regionalization of pancreatic surgical care, with respect to preferential referrals to high-volume pancreatic surgery centers, are substantial. Consistent with prior research, high-volume centers were associated with improved overall survival but were not associated with significant differences in health care costs.15-17,33 The greater survival associated with high-volume centers is likely multifactorial, because it may be secondary to surgical therapy and more advanced multigent chemotherapy regimens adopted at high-volume centers. Multigent chemotherapy regimens, including gemcitabine hydrochloride–based combination therapies and, more recently, FOLFIRINOX (leucovorin calcium, fluorouracil, irinotecan hydrochloride, and oxaliplatin) have been associated with improved survival compared with single-agent gemcitabine in randomized clinical trials in resectable and metastatic pancreatic cancer.34-38 In the present study, multigent chemotherapy was more frequently used in patients treated at high-volume surgical centers despite such multigent regimens not yet being the standard of care for adjuvant chemotherapy in resectable pancreatic cancer during the time period. Future research is needed to evaluate the differences in multimodality treatment practices at high- and low-volume pancreatic centers and the effect of these treatment practices on patient prognosis as multigent chemotherapy is more commonly used.

Table 3. Patient Demographic, Clinicopathologic, and Treatment Characteristics by Surgical Hospital Cost Quintile (continued)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cost Quintilea</th>
<th>Low to Intermediate (n = 557)</th>
<th>Intermediate to High (n = 557)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readmission within 30 d</td>
<td></td>
<td>36 (6.5)</td>
<td>103 (18.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>54 (9.7)</td>
<td>146 (26.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>19 (3.4)</td>
<td>63 (11.3)</td>
<td></td>
</tr>
<tr>
<td>in-hospital death</td>
<td></td>
<td>8 (1.4)</td>
<td>7 (1.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 (1.3)</td>
<td>19 (3.4)</td>
<td>&lt;.001f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>63 (11.3)</td>
<td></td>
<td>&lt;.001f</td>
</tr>
</tbody>
</table>

Abbreviations: IQR, interquartile range; NCI, National Cancer Institute.

a Unless otherwise indicated, data are expressed as number (percentage) of patients. Percentages have been rounded and may not total 100. Low indicates less than $30,002; intermediate, $30,002 to $40,674; intermediate, $40,675 to $53,970; intermediate to high, $53,971 to $76,695; and high, greater than $76,995.

b Calculated using analysis of variance.

c Calculated using χ² test.

d Calculated using Fisher exact test.

f Indicates 20 or more cases annually.

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Table 4. Patient Demographic, Clinicopathologic, and Treatment Characteristics by Value

<table>
<thead>
<tr>
<th>Value Level*</th>
<th>Value Levela</th>
<th>Low (n = 568)</th>
<th>Intermediate (n = 1694)</th>
<th>High (n = 524)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>69.4 (10.1)</td>
<td>66.5 (10.6)</td>
<td>65.7 (11.2)</td>
<td>&lt;.001b</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>313 (55.1)</td>
<td>841 (49.6)</td>
<td>240 (45.8)</td>
<td>.008c</td>
<td></td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td>.52d</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>464 (81.7)</td>
<td>1410 (83.2)</td>
<td>434 (82.8)</td>
<td>.52d</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>37 (6.5)</td>
<td>88 (5.2)</td>
<td>27 (5.2)</td>
<td>.52d</td>
<td></td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>67 (11.8)</td>
<td>186 (11.0)</td>
<td>60 (11.5)</td>
<td>.52d</td>
<td></td>
</tr>
<tr>
<td>Other/unknown</td>
<td>0</td>
<td>10 (0.6)</td>
<td>3 (0.6)</td>
<td>.52d</td>
<td></td>
</tr>
<tr>
<td>Socioeconomic status</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (first quintile)</td>
<td>125 (22.0)</td>
<td>331 (19.5)</td>
<td>75 (14.3)</td>
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<td></td>
</tr>
<tr>
<td>Low to middle (second quintile)</td>
<td>119 (21.0)</td>
<td>323 (19.1)</td>
<td>85 (16.2)</td>
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<td></td>
</tr>
<tr>
<td>Middle (third quintile)</td>
<td>111 (19.5)</td>
<td>333 (19.7)</td>
<td>101 (19.3)</td>
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<td></td>
</tr>
<tr>
<td>Middle to high (fourth quintile)</td>
<td>108 (19.0)</td>
<td>323 (19.1)</td>
<td>114 (21.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High (fifth quintile)</td>
<td>105 (18.5)</td>
<td>384 (22.7)</td>
<td>149 (28.4)</td>
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<td></td>
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<tr>
<td>Elixhauser comorbidity index, mean (SD)*</td>
<td>17.7 (10.9)</td>
<td>13.8 (8.5)</td>
<td>10.4 (5.9)</td>
<td>&lt;.001b</td>
<td></td>
</tr>
<tr>
<td>T category</td>
<td>T1</td>
<td>25 (4.4)</td>
<td>111 (6.6)</td>
<td>68 (13.0)</td>
<td>&lt;.001c</td>
</tr>
<tr>
<td>T2</td>
<td>78 (13.7)</td>
<td>232 (13.7)</td>
<td>125 (23.9)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>465 (81.9)</td>
<td>1351 (79.8)</td>
<td>331 (63.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N category</td>
<td>N0</td>
<td>171 (30.1)</td>
<td>618 (36.5)</td>
<td>265 (50.6)</td>
<td>&lt;.001d</td>
</tr>
<tr>
<td>N1</td>
<td>396 (69.7)</td>
<td>1072 (63.3)</td>
<td>257 (49.1)</td>
<td>&lt;.001d</td>
<td></td>
</tr>
<tr>
<td>NX</td>
<td>1 (0.2)</td>
<td>4 (0.2)</td>
<td>2 (0.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage</td>
<td>I</td>
<td>57 (10.0)</td>
<td>197 (11.6)</td>
<td>145 (27.7)</td>
<td>&lt;.001c</td>
</tr>
<tr>
<td>II</td>
<td>511 (90.0)</td>
<td>1497 (88.4)</td>
<td>379 (72.3)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>Well differentiated</td>
<td>41 (7.2)</td>
<td>180 (10.6)</td>
<td>74 (14.1)</td>
<td>&lt;.001c</td>
</tr>
<tr>
<td>Moderately differentiated</td>
<td>275 (48.4)</td>
<td>820 (48.4)</td>
<td>278 (53.1)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>Poorly differentiated or undifferentiated</td>
<td>218 (38.4)</td>
<td>600 (35.4)</td>
<td>131 (25.0)</td>
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<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>34 (6.0)</td>
<td>94 (5.5)</td>
<td>41 (7.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pancreatic resection</td>
<td>Pancreaticoduodenectomy</td>
<td>473 (83.3)</td>
<td>1386 (81.8)</td>
<td>348 (66.4)</td>
<td>&lt;.001c</td>
</tr>
<tr>
<td>Distal pancreatectomy</td>
<td>56 (9.9)</td>
<td>194 (11.5)</td>
<td>137 (26.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total pancreatectomy</td>
<td>29 (5.1)</td>
<td>62 (3.7)</td>
<td>7 (1.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other pancreatectomy</td>
<td>10 (1.8)</td>
<td>52 (3.1)</td>
<td>32 (6.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemotherapy</td>
<td>None</td>
<td>335 (59.0)</td>
<td>570 (33.6)</td>
<td>165 (31.5)</td>
<td>&lt;.001c</td>
</tr>
<tr>
<td>Preoperative</td>
<td>20 (3.5)</td>
<td>53 (3.1)</td>
<td>16 (3.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative</td>
<td>154 (27.1)</td>
<td>822 (48.5)</td>
<td>262 (50.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence unknown/other</td>
<td>59 (10.4)</td>
<td>249 (14.7)</td>
<td>81 (15.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>115 (20.2)</td>
<td>596 (35.2)</td>
<td>163 (31.1)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>NCI-designated cancer center</td>
<td>115 (20.2)</td>
<td>596 (35.2)</td>
<td>163 (31.1)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>Teaching hospital</td>
<td>209 (36.8)</td>
<td>671 (39.6)</td>
<td>247 (47.1)</td>
<td>.001c</td>
<td></td>
</tr>
<tr>
<td>High-volume center</td>
<td>265 (46.7)</td>
<td>760 (44.9)</td>
<td>272 (51.9)</td>
<td>.02d</td>
<td></td>
</tr>
<tr>
<td>Survival, median (IQR), mo</td>
<td>8 (4-11)</td>
<td>20 (12-34)</td>
<td>51 (33-105)</td>
<td>&lt;.001d</td>
<td></td>
</tr>
<tr>
<td>Costs, mean (SD), $h</td>
<td>106 613 (79 238)</td>
<td>55 568 (46 219)</td>
<td>28 792 (73 717)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>Length of stay, median (IQR), d</td>
<td>19 (14-28)</td>
<td>12 (9-17)</td>
<td>9 (8-11)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>Complication within 30 d</td>
<td>372 (65.5)</td>
<td>601 (35.5)</td>
<td>64 (12.2)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>Readmission within 30 d</td>
<td>199 (35.0)</td>
<td>321 (18.9)</td>
<td>45 (8.6)</td>
<td>&lt;.001c</td>
<td></td>
</tr>
<tr>
<td>In-hospital death</td>
<td>82 (14.4)</td>
<td>22 (1.3)</td>
<td>0</td>
<td>&lt;.001c</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: IQR, interquartile range; NCI, National Cancer Institute.

* Unless otherwise indicated, data are expressed as number (percentage) of patients. Percentages have been rounded and may not total 100. High value was defined as the fourth quintile or higher for survival (≥26 months) and second quintile or less for costs ($40 674). Low value was defined as the second quintile or lower for survival (≤15 months) and fourth quintile or higher for costs ($53 971).

b Calculated using analysis of variance.

c Calculated using χ² test.

d Calculated using Fisher exact text.

e Scores range from −11 to 62, with higher scores indicating a greater number of comorbidities.

f Indicates 20 or more cases annually.

g Calculated using Kruskal-Wallis test.

h Includes the index surgical hospitalization and readmissions within 30 days.
Table 5. Multivariable Models for Overall Survival, Surgical Hospitalization Costs, and High Value

<table>
<thead>
<tr>
<th>Variable</th>
<th>Survivala</th>
<th>Costsb</th>
<th>High Valuec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>aHR (95% CI)</td>
<td>P Value</td>
<td>Estimate (95% CI)</td>
</tr>
<tr>
<td>Age</td>
<td>1.01 (1.01 to 1.02)</td>
<td>&lt;.001</td>
<td>0.000 (0.001 to 0.001)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.91 (0.83 to 0.99)</td>
<td>.02</td>
<td>−0.02 (−0.04 to 0.01)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>1.01 (0.88 to 1.16)</td>
<td>.88</td>
<td>−0.04 (−0.10 to 0.01)</td>
</tr>
<tr>
<td>Black</td>
<td>1.08 (0.90 to 1.31)</td>
<td>.40</td>
<td>0.02 (0.04 to 0.09)</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>0.84 (0.44 to 1.58)</td>
<td>.58</td>
<td>−0.10 (−0.29 to 0.10)</td>
</tr>
<tr>
<td>Socioeconomic status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>1 [Reference]</td>
<td>NA</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Low to middle</td>
<td>1.01 (0.88 to 1.15)</td>
<td>.90</td>
<td>−0.01 (−0.05 to 0.03)</td>
</tr>
<tr>
<td>Middle</td>
<td>0.95 (0.83 to 1.09)</td>
<td>.46</td>
<td>−0.01 (−0.05 to 0.03)</td>
</tr>
<tr>
<td>Middle to high</td>
<td>0.92 (0.80 to 1.05)</td>
<td>.22</td>
<td>0.02 (0.03 to 0.07)</td>
</tr>
<tr>
<td>High</td>
<td>0.89 (0.77 to 1.02)</td>
<td>.08</td>
<td>−0.02 (−0.08 to 0.03)</td>
</tr>
<tr>
<td>Elixhauser comorbidity index</td>
<td>1.01 (1.01 to 1.02)</td>
<td>&lt;.001</td>
<td>0.006 (0.003 to 0.008)</td>
</tr>
<tr>
<td>Grade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well differentiated</td>
<td>1 [Reference]</td>
<td>NA</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Moderately differentiated</td>
<td>1.49 (1.28 to 1.73)</td>
<td>&lt;.001</td>
<td>−0.03 (−0.09 to 0.03)</td>
</tr>
<tr>
<td>Poorly differentiated or undifferentiated</td>
<td>1.84 (1.57 to 2.16)</td>
<td>&lt;.001</td>
<td>−0.03 (−0.10 to 0.05)</td>
</tr>
<tr>
<td>T category</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>1 [Reference]</td>
<td>NA</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>T2</td>
<td>1.26 (1.03 to 1.55)</td>
<td>.03</td>
<td>0.01 (−0.06 to 0.08)</td>
</tr>
<tr>
<td>T3</td>
<td>1.45 (1.16 to 1.80)</td>
<td>&lt;.001</td>
<td>0.05 (0.04 to 0.15)</td>
</tr>
<tr>
<td>N category</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N0</td>
<td>1 [Reference]</td>
<td>NA</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>N1</td>
<td>1.47 (1.32 to 1.63)</td>
<td>&lt;.001</td>
<td>0.00 (−0.04 to 0.03)</td>
</tr>
<tr>
<td>AJCC stage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>1.27 (1.02 to 1.57)</td>
<td>.03</td>
<td>0.03 (0.05 to 0.11)</td>
</tr>
<tr>
<td>Pancreatic resection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distal pancreatectomy</td>
<td>1.03 (0.91 to 1.18)</td>
<td>.61</td>
<td>−0.21 (−0.26 to −0.17)</td>
</tr>
<tr>
<td>Other pancreatectomy</td>
<td>0.93 (0.73 to 1.18)</td>
<td>.55</td>
<td>−0.13 (−0.23 to −0.02)</td>
</tr>
<tr>
<td>Total pancreatectomy</td>
<td>1.47 (1.18 to 1.82)</td>
<td>&lt;.001</td>
<td>0.05 (−0.04 to 0.15)</td>
</tr>
<tr>
<td>Chemotherapy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1 [Reference]</td>
<td>NA</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Postoperative</td>
<td>0.71 (0.64 to 0.79)</td>
<td>&lt;.001</td>
<td>−0.06 (−0.11 to −0.02)</td>
</tr>
<tr>
<td>Preoperative</td>
<td>0.78 (0.61 to 1.01)</td>
<td>.06</td>
<td>0.07 (−0.01 to 0.15)</td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>0.96 (0.87 to 1.06)</td>
<td>.40</td>
<td>0.00 (−0.04 to 0.04)</td>
</tr>
<tr>
<td>NCI-designated cancer center</td>
<td>1.02 (0.82 to 1.28)</td>
<td>.84</td>
<td>−0.03 (−0.24 to 0.19)</td>
</tr>
<tr>
<td>Teaching hospital</td>
<td>1.06 (0.88 to 1.29)</td>
<td>.55</td>
<td>0.08 (−0.10 to 0.26)</td>
</tr>
<tr>
<td>High-volume centerd (≥20)</td>
<td>0.78 (0.61 to 0.99)</td>
<td>.04</td>
<td>0.11 (0.09 to 0.32)</td>
</tr>
<tr>
<td>Complication within 30 d</td>
<td>1.18 (1.07 to 1.30)</td>
<td>.001</td>
<td>0.22 (0.17 to 0.27)</td>
</tr>
<tr>
<td>Readmission within 30 d</td>
<td>1.01 (0.90 to 1.12)</td>
<td>.93</td>
<td>0.34 (0.29 to 0.39)</td>
</tr>
<tr>
<td>Length of stay</td>
<td>1.00 (1.00 to 1.00)</td>
<td>.94</td>
<td>0.03 (0.03 to 0.04)</td>
</tr>
</tbody>
</table>

Abbreviations: aHR, adjusted hazard ratio; AJCC, American Joint Committee on Cancer, seventh edition; aOR, adjusted odds ratio; NA, not applicable; NCI, National Cancer Institute.

a Based on Cox proportional hazards model, adjusted for within-hospital clustering of patients.

b Includes the index surgical hospitalization and readmissions within 30 days.

c Defined as the fourth quintile for survival (≥26 months) and second quintile or less for costs (≤$40674). Odds ratios based on logistic regression model, adjusted for within-hospital clustering of patients.

d Indicates 20 or more cases annually.

Cost estimates based on generalized linear model with gamma distribution and log link, adjusted for within-hospital clustering of patients.

Defining Value for Pancreatic Surgery in Early-Stage Pancreatic Cancer

Original Investigation Research

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Limitations
This study must be considered in light of its limitations. Because this study uses retrospective observational data, it is subject to the inherent risk of confounding and selection bias. We acknowledge that we are limited by the data provided, and potentially unmeasured confounders, such as functional status, may influence our findings. For example, the finding that adjuvant chemotherapy was associated with lower costs for the surgical hospitalization is potentially secondary to patients receiving adjuvant chemotherapy having better perioperative performance status compared with patients who did not receive adjuvant chemotherapy, and better performance status is associated with lower surgical hospitalization costs. As with most administrative database research, we lack granular clinical detail, including the severity of comorbidities and complications. In addition, because we were only provided with the total costs of each hospitalization from OSHPD, we were not able to perform an analysis of itemized costs (ie, costs of medications, nursing care, operation, imaging, and laboratory studies). Future research should examine itemized costs to determine specific measures that may be used to reduce health care costs for pancreatic surgery. Additionally, because OSHPD does not report data from Kaiser Permanente facilities, we were unable to include these patients in our analysis.

Although value has been consistently described as quality relative to costs, methods of defining and classifying health care value is variable in present research. Soneji and Yang defined value as a ratio of survival relative to costs (ie, value = survival/costs). However, when using this ratio to define high- and low-value care, a patient with poor survival but extremely low hospitalization cost may still be categorized as high value, despite poor survival being inconsistent with high-value care. In contrast, Lawson et al defined high value as requiring high quality and low costs. We defined high- and low-value care consistent with Lawson et al because we preferred to recognize those who met quality (ie, survival) and cost criteria as high or low value.

Conclusions
In this population-based analysis of survival, costs, and value of pancreatic surgery for early-stage cancer, high-value care was associated with important patient, tumor, and treatment characteristics. High-volume pancreatic surgery centers were associated with improved survival; however, high-volume centers and NCI-designated cancer centers were not associated with high-value care. These data suggest that although regionalization of pancreatic cancer surgical care may lead to improvements in patient survival, regionalization is not associated with decreased costs or high value. Therefore, targeted measures to enhance value are needed at high-volume and NCI-designated cancer centers, because these centers already treat a significant fraction of patients with pancreatic cancer and are likely to bear an increasing demand for the care of these patients.

ARTICLE INFORMATION
Accepted for Publication: May 26, 2019.
Published Online: August 21, 2019.

Author Contributions: Drs Bateni and Bold had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Bateni, Bold.

Acquisition, analysis, or interpretation of data: All authors.

Drafting of the manuscript: Bateni, Gingrich, Bold.

Critical revision of the manuscript for important intellectual content: Bateni, Hoch, Canter, Bold.

Statistical analysis: Bateni, Hoch, Bold.

Administrative, technical, or material support: Bateni, Bold.

Supervision: Bold.

Conflict of Interest Disclosures: Dr Bateni reported receiving grants from the Agency for Healthcare Research and Quality outside the submitted work. No other disclosures were reported.

Meeting Presentation: This paper was presented in part at the 90th Annual Meeting of the Pacific Coast Surgical Association; February 16, 2019; Tucson, Arizona.

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