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The laparoscopic approach to pancreatoduodenectomy is cost neutral in very high-volume centers

Emanuel Eguia, MD, MS, MHA[a,*], Paul C. Kuo, MD, MS, MBA[b], Patrick J. Sweigert, MD[a], Marc H. Nelson, MD[a], Gerard V. Aranha, MD[a], Gerard Abood, MD, MS[a], Constantine Godellas, MD[a], Marshall S. Baker, MD, MBA[a]

[a] Department of Surgery, Loyola University Medical Center, Maywood, IL
[b] Department of Surgery, University of South Florida, Tampa, FL

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ABSTRACT

Background: Little is known regarding the impact of minimally invasive approaches to pancreatoduodenectomy on the aggregate costs of care for patients undergoing pancreatoduodenectomy.
Methods: We queried the Healthcare Cost and Utilization Project State Inpatient Database to identify patients undergoing elective laparoscopic or open pancreatoduodenectomy between 2014 and 2016.
Results: In this database, 488 (10%) patients underwent elective laparoscopic; 4,544 (90%) underwent open pancreatoduodenectomy. On adjusted analysis, the risk of perioperative morbidity and overall duration of hospitalization for patients undergoing elective laparoscopic were identical to those for patients undergoing open pancreatoduodenectomy. Patients undergoing elective laparoscopic in low (+$10,399, 95% confidence interval [$3,700, $17,098]) and moderate to high (+$4,505, 95% confidence interval [$528, $8,481]) volume centers had greater costs than those undergoing open pancreatoduodenectomy in the same centers. In very high-volume centers (>127 pancreatoduodenectomies/year), aggregate costs of care for patients undergoing elective laparoscopic were essentially identical to those undergoing open pancreatoduodenectomy in the same centers (+$815, 95% confidence interval [−$1,530, $3,160]).
Conclusion: Rates of morbidity and overall duration of hospitalization for patients undergoing elective laparoscopic are not different than those undergoing open pancreatoduodenectomy. At low to moderate and high-volume centers, elective laparoscopic is associated with greater aggregate costs of care relative to open pancreatoduodenectomy. At very high-volume centers, elective laparoscopic is cost-neutral.

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Introduction

The United States healthcare spending increased by 4% in 2017 alone, reaching $3.5 trillion or $10,739 per person and accounting for 18% of the national gross domestic product.[1] In 2015, 32% of the national healthcare expenditures went toward hospital-based care and 20% toward physician and clinical services.[1] Healthcare providers are under increasing pressure to deliver value to patients by containing costs while continuing to provide a high-quality outcome.

Pancreatiduodenectomy (PD) can be lifesaving but carries a considerable risk of postoperative complications. The index procedure and hospitalization themselves are costly. Complications, related readmissions, and ancillary procedures necessary to manage complications frequently result in substantial increases in the costs of care. Because of the potential to save lives and the high costs of care, PD by nature represents a unique opportunity to improve value for patients.

Previous studies have evaluated the impact of variations in the technical approaches to the PD on perioperative complication rates, rates of readmission, positive margin resection, lymph node count, and duration of hospitalization.[2–7] None of these evaluate the impact of different technical approaches on the costs of care. In the present study, we used the Healthcare Cost and Utilization Project State Inpatient Database (HCUP-SID) to examine differences in aggregate costs of care associated with laparoscopic and open approaches to PD by hospital volume.

Methods

Data source

The HCUP-SID was queried to identify patients undergoing elective laparoscopic (LPD) or open (OPD) PD in Florida, Maryland, Massachusetts, New York, and Washington state between 2012 and 2014. Healthcare Cost and Utilization Project (HCUP) is an administrative dataset composed of a family of health care databases developed through a federal-state-industry partnership sponsored by the Agency for Healthcare Research and Quality.[8,9] Each state inpatient database captures all inpatient discharges at non-federal facilities for the respective state regardless of primary payer.

Study population

The analysis cohort included adult patients ≥18 years old were discharged from hospitals within their respective states. Patients who underwent an elective PD for malignant or benign pancreatic pathology by approach were identified based on *International Classification of Diseases, 9th Revision* (ICD-9) codes (157.0 head of pancreas, 157.1 body of pancreas, 157.8 other specified sites of pancreas, 577.1 chronic pancreatitis, 577.2 cyst and pseudocyst of pancreas, 577.8 other specified disease of pancreas, 577.9 unspecified disease of pancreas, 211.7 islets of Langerhans). The operative cohort was determined by a secondary search for patients with a particular diagnosis and operative procedure ICD-9 codes used during their index admission (52.51 proximal pancreatectomy, 52.7 radical PD, 17.4-17.49 robotic-assisted procedures, 54.21 laparoscopy). There were 225 patients who underwent conversion from LPD to OPD. Given limitations of the dataset, we were unable to identify the reason for a conversion from LPD to OPD. We could not identify if a conversion occurred as a part of a plan (diagnostic laparoscopy to rule out carcinomatosis followed by OPD) or as a result of an untoward, intraoperative event. Because of this, we could not perform an intent to treat analysis. To eliminate related bias, we have elected to remove the conversions from the analysis done here.

Study design and statistical analysis

This was a retrospective cohort study of patients undergoing PD between 2012 and 2014. The primary outcome of interest was to examine the association between operative approach (LPD versus OPD) and 90-day aggregate in-hospital costs of care with cases stratified by hospital volume. Our secondary outcome of interest included postoperative outcomes and predictors of being in the fourth quartile (greatest) of the in-hospital 90-day cost of care. Costs included those associated with all readmissions to 90-days after the index operation. Cost data were obtained using HCUP total charges variable multiplied by a hospital-specific, cost-to-charge ratio (CCR). The CCR is developed using standardized information on all-payer inpatient cost and charges reported by hospitals to the Centers for Medicare and Medicaid.

We also evaluated the association between operative approach and rates of postoperative morbidity, readmission, and aggregate postoperative duration of hospitalization, including readmissions to 90 days after the index operation. Operative mortality was defined as death during the index admission. The postoperative morbidities that were captured in HCUP-SID using ICD-9 codes included myocardial infarction, pulmonary embolism, and sepsis. The overall duration of hospitalization included all readmissions up to 90 days post index procedure, and prolonged hospitalizations was defined as a having an overall duration greater than the 75% percentile of the entire PD population.

Statistical analysis

Baseline characteristics were presented as means and standard deviations, medians, and interquartile ranges, or counts and percentages as appropriate based on distribution and type of data. Unadjusted comparisons of ≥2 proportions between LPD and OPD were performed using a chi-squared test, and continuous variables were compared using Student *t* tests or Wilcoxon rank-sum tests as appropriate. Multivariable regression (MVR) was used to evaluate the association between operative approach and rates of the postoperative complications of pulmonary embolism (PE), myocardial infarction (MI), and sepsis, total duration of hospitalization, and aggregate costs of care including all readmissions up to 90 days after the index PD. Candidate variables were determined a priori using best variable subsets and included age, sex, insurance type, race/ethnicity, Charlson comorbidity index (CCI), pathology (benign versus malignant), annual hospital volume of LPD and OPD broken to terciles by case number across the entire cohort, and overall duration of hospitalization. Annual hospital volume for PD included all PD cases done in a given center by either open or laparoscopic approaches in a given year. We were interested in studying the performance of the centers that were high outliers for volume. To do this, we categorized hospital volume by case. The greatest volume tercile included the hospitals performing 33% of the cases in the entire cohort overall years under study. This resulted in a volume categorization as follows: low: ≤17 PD/year; moderate to high: >17 or ≤127 PD/year; and very high volume: >127 PD/year. To be able to compare this analysis to one using a more typical method for categorizing volume, we also performed a sensitivity analysis in which hospitals were categorized based on average number of PDs performed per year in a given center such that the greatest tercile would include the third of the hospitals that had the greatest average PD volume. All analyses were performed using STATA 14 software (StataCorp LLC, College Station, TX). This study was evaluated and approved by the Institutional Review Board at Loyola University Chicago.

Results

Demographic data

In this database, 488 (10%) patients underwent LPD, and 4,544 (90%) underwent OPD. On univariate analysis, patients undergoing LPD had a greater CCI (5 [2–6] vs 3 [2–6], *P* < .01), were more likely to have private insurance (40% vs 13%; *P* < .01) and were more likely to have malignant pathology (69% vs 64%; *P* < .01) than those undergoing OPD. LPD was more likely to be done at a very high-volume center than OPD (29% vs 19%, *P* < .01; Table I). We also examined the link between LPD volume and OPD volume and between hospital volume and insurance type. We found that hospitals which had a high volume of LPD were generally high volume OPD centers. Centers that were very high volume for PD had a greater frequency of patients undergoing LPD than moderate to high and low volume centers (14% vs 8% vs 9%). We also noted that proportion of patients who were privately insured was greater in very high-volume centers than it was in low volume centers (52% vs 25%, *P* < .01; Supplemental Table I). There were no differences between the 2 cohorts concerning age, sex, and race or ethnicity.

Postoperative outcomes

We evaluated treatment cohorts to identify differences in postoperative rates of complications and clinical outcomes that might potentially drive differences in 90-day, in-hospital costs. On univariate analysis, patients undergoing LPD in very high-volume

Table I
Demographic and pathologic characteristics of patients undergoing pancreatoduodenectomy*

	Open		Laparoscopic		P value
No. patients, n (%)	4,544	90%	488	10%	
Age, mean (SD)	65	12	65	13	.50
Female sex, n (%)	2,135	47.0%	234	48.0%	.69
CCI, median (IQR)	3	2–6	5	2–6	<.01
Race/ethnicity, n (%)					
White	3,349	73.7%	354	72.5%	.52
Black	398	8.8%	37	7.6%	
Hispanic	354	7.8%	45	9.2%	
Other	445	9.8%	52	10.7%	
Insurance type, n (%)					
Medicare	2,426	53.4%	251	51.4%	<.01
Medicaid	398	8.8%	24	4.9%	
Private	568	12.5%	197	40.4%	
Other	154	3.4%	16	3.3%	
Pathology, n (%)					
Malignant	2,893	63.7%	338	69.3%	.01
Benign	1,651	36.3%	150	30.7%	
Annual hospital PD volume, terciles n (%)					
Low (1–16)	1,213	26.7%	119	24.4%	<.01
Moderate to high (17–127)	2,472	54.4%	225	46.1%	
Very high (>127)	859	18.9%	144	29.5%	

* Data represents 2012 to 2014 for Florida, Maryland, Massachusetts, New York, and Washington.

centers had a shorter index duration of hospitalization (8 [6–11] vs 9 [7–13]) but were more likely to require 90-day readmission (36% vs 27%, P = .03) than those undergoing OPD. There was no difference in rates of in-hospital death during the index admission in low to very-high volume centers by approach. The average unadjusted aggregate costs of care for patients undergoing LPD were less than those undergoing OPD. On univariate analysis in low to moderate-high volume centers, there was no difference in overall morbidity, index duration of hospitalization, 90-day readmissions, and in-hospital death. LPD was, however, more costly in low ($53,748 vs $44,817, P < .01) to moderate-high ($39,803 vs $36,060, P < .01) volume centers than OPD. Costs of care for patients undergoing OPD were greater in low ($44,817 vs $34,133) and moderate-high ($36,060 vs $34,133) volume centers than those for patients undergoing OPD in very high-volume centers (Table II).

On MVR analysis adjusted for age, sex, insurance type, CCI, pathologic diagnosis, and hospital volume, LPD was associated with an increased risk of 90-day readmissions relative to OPD (odds ratio [OR] 1.27, 95% confidence interval [CI] [1.04, 1.55]). The risk of perioperative morbidity (PE, MI, and sepsis) and prolonged duration of hospitalization was not different between groups (Table III).

90-day cost by hospital volume

We then divided the cohorts by hospital volume (terciles) and evaluated the stratified cohorts to identify any association between operative approach and a 90-day aggregate cost of care. We hypothesized that high-volume centers would mitigate costs inherent in applying the laparoscopic approach to PD patients. We performed a MVR adjusted for age, sex, CCI, insurance type, and pathology. We found that patients undergoing LPD in low (+$10,399, 95% CI [$3,700, $17,098]) and moderate to high (+$4,505, 95% CI [$528, $8,481]) volume centers had greater risk-adjusted aggregate costs of care than those undergoing OPD in the same center, whereas, patients undergoing LPD in very high-volume centers (>127 PDs/year) had costs of care that were not different from those patients undergoing OPD in the same hospitals (+$815, 95% CI [−$1,530, $3,160]; Table IV). We also performed a sensitivity analysis in which volume was broken down by hospital volume into terciles. In this analysis, hospitals in the greatest tercile were those

performing 7 to 154 PDs per year, the middle terciles were those performing 3 to 7 PDs per year, and the lowest tercile those performing between 1 and 3 PDs per year. On risk-adjusted comparison using this method to categorize volume, costs of LPD were no different from those for OPD across all terciles. In this way, however, we lose the ability to discriminate a potential performance advantage in the very high-volume centers.

Characteristics of cost outliers

We attempted to identify factors associated with patients becoming high-cost outliers (fourth quartile of cost) after PD. We performed a MVR adjusted for age, sex, CCI, insurance type, and pathology. On our risk-adjusted analysis, the factors associated with being in the greatest quartile for aggregate 90-day costs of care included: male sex (OR 1.17, 95% CI [1.03, 1.33]), CCI score (OR 1.07, 95% CI [1.04, 1.11]), black race (OR 1.40, 95% CI [1.12, 1.76]), Hispanic ethnicity (OR 1.79, 95% CI [1.43, 2.25]), Medicare insurance (OR 1.36, 95% CI [1.13, 1.64]), low (17< PDs per year) hospital PD volume (OR 2.36, 95% CI [1.91, 2.91]), and moderate to high (17–127 PDs per year) hospital PD volume (OR 1.49, 95% CI [1.23, 1.82]). The operative approach was not associated with the risk of being a high-cost outlier (Table V).

Discussion

We aimed to examine the financial impact of the minimally invasive approach to PD on the 90-day in-hospital costs of care for patients undergoing PD. Very few studies to date have evaluated the operative approach and 90-day cost with outcomes stratified by hospital volume. In our current health care environment, evaluating the cost of care is critical to improving patient quality and value-based care. We made several interesting findings in this study. Compared to OPD, patients undergoing LPD had similar rates of postoperative complications, were more likely to require 90-day readmission independent of hospital volume, and were more expensive than OPD in small and moderate volume centers. In contrast, in high volume centers, there was no difference in cost between LPD and OPD.

Table II
Postoperative outcomes of patients undergoing pancreatoduodenectomy by hospital volume

	Low			Moderate-high			Very high		
	Open	Laparoscopic	P value	Open	Laparoscopic	P value	Open	Laparoscopic	P value
Overall morbidity,* n (%)	543 44.8%	55 46.2%	.76	999 40.4%	93 41.3%	.79	314 36.6%	59 41.0%	.31
Index duration of stay, median (IQR)	13 9–21	13 9–22	.55	9 7–14	9 6–14	.20	9 7–13	8 6–11	<.01
90-day readmission, n (%)	395 32.6%	45 37.8%	.24	751 30.4%	73 32.4%	.52	232 27.0%	52 36.1%	.03
In-hospital death, n (%)	60 4.9%	1.7%	.11	62 2.5%	1.8%	.50	9 0.7%	0.0%	.31
90-day hospital cost, median (IQR)	$44,817 $30,217–$69,363	$53,748 $35,128–$87,787	.01	$36,060 $25,454–$56,867	$39,803 $28,542–$57,796	.01	$34,133 $25,999–$50,631	$33,582 $26,635–$50,347	.94

* Overall morbidity includes pulmonary embolism (PE), myocardial infarction (MI), and sepsis.

Table III
Risk-adjusted odds of postoperative morbidity, readmission and prolonged duration of hospitalization for laparoscopic relative to open pancreaticoduodenectomy

	OR	95% CI	
Postoperative morbidity			
PE	0.75	0.30	1.89
MI	1.27	0.55	2.92
Sepsis	0.88	0.67	1.16
Severe adverse outcome*	1.10	0.90	1.33
30-day readmission	1.24	1.00	1.54
90-day readmission	1.27	1.04	1.55
Prolonged duration of hospitalization†	0.84	0.64	1.12

* Severe Adverse Outcome includes cases where a patient developed a postoperative pulmonary embolism (PE), myocardial infarction (MI), sepsis.
† Defined as >75% of the overall duration of hospitalization.

The main finding in our study is that the LPD is associated with increased costs of care at low to moderate volume centers and is cost-neutral at very high-volume centers. This result coupled with the finding that complication rates were the same for LPD and OPD would suggest that the LPD from a purely financial standpoint does not add value for patients when performed in low to moderate volume centers. If decisions regarding the provision of care are to be purely value-based (financial) and patients undergoing care in these centers do not have access to greater volume centers, such findings would suggest that the open approach might be preferred for these patients undergoing PD in these low to moderate volume centers. Admittedly, our study is limited to 3 years of experience, involves a small number of states, and admittedly reports the experience of LPD that is early in the use of minimally invasive approaches to PD. It may very well be that over time, with increased national experience, and with better laparoscopic technologies, there will be clear cost-savings or decreased complication rates associated with LPD and that these factors would then support the notion that the LPD adds value for patients. Further study through time are warranted to evaluate for such trends.

We recognize that a small number of institutions have a volume >127 PDs per year. We were interested in understanding how costs vary with volume. More specifically, we were interested in understanding if outlier centers doing a very high volume of cases were able to mitigate costs associated with LPD. Most prior studies break volume by separating hospitals into quartiles based on the average number case done in the hospital in a year: 25% of hospitals do an average of "x" number of procedures per year. We elected instead to categorize volume into quartiles by case. By our method, the greatest quartile is defined as the few hospitals that together performed 25% of the cases in the entire cohort. In our analysis, this resulted in the greatest quartile category being one in which the hospitals in that quartile performed >127 PDs per year. We elected to compare these institutions to all others, primarily because we were interested in understanding whether these high-performing outliers were able to mitigate costs. Other studies have broken volume by hospital, meaning they divided centers into quartiles based on the average number of cases performed at a center. By this method, hospitals would fall into the greatest quartile if their volume was greater than the mean for 75th percentile of annual PDs. In the published literature, this approach seems to correspond typically to >20 to 40 PDs per year. If we had used this method, the very high-performing centers that make up the upper quartile in our study would have been clumped together with centers that are dissimilar to their practice and would be clumped with centers performing a relatively small number of PDs. We would expect in such analyses to lose the ability to study the high performing outliers. We were interested in trying to identify the number of

Table IV
Difference between 90-day inpatient cost for laparoscopic pancreaticoduodenectomy and those for open pancreaticoduodenectomy by hospital volume

	Unadjusted		Adjusted[*]			
	Cost	95% CI		Cost	95% CI	
Hospital volume, terciles						
Low (1–16)	$9,550	−$2,159	$21,259	$10,399	$3,700	$17,098
Moderate to high (17–127)	$3,654	−$3,701	$11,010	$4,505	$528	$8,481
Very high (>127)	−$1,996	−$9,103	$5,112	$815	−$1,530	$3,160

[*] Adjusted for age, sex, malignancy, Charlson comorbidity index, race or ethnicity, insurance type, and procedure type.

Table V
Risk-adjusted odds of being a high cost outlier after pancreaticoduodenectomy[*]

	OR	95% CI	
Age, (per year)	1.00	0.99	1.01
Male sex	1.17	1.03	1.33
Charlson comorbidity index	1.07	1.04	1.11
Malignant pathology	0.83	0.68	1.01
Race/ethnicity			
White (reference)			
Black	1.40	1.12	1.76
Hispanic	1.79	1.43	2.25
Other	1.32	1.06	1.64
Insurance type			
Private (reference)			
Medicare	1.36	1.13	1.64
Medicaid	1.19	0.92	1.53
Other	1.27	0.88	1.83
Surgical approach			
Open (reference)			
Laparoscopic	1.01	0.81	1.26
Annual hospital PD volume, (terciles)			
Low (1–16)	2.36	1.91	2.91
Moderate to high (17–127)	1.49	1.23	1.82
Very high (>127) (reference)			

[*] High cost defined as overall 90-day hospital costs greater than the 75th percentile.

procedures needed to be performed in a hospital to create cost-savings or reach a level where there was no difference between the laparoscopic and open approaches with regard to costs. Our study would suggest that at very high-volume centers, LPD provides outcome quality and costs identical to OPD, but that at low to moderate volume centers, the costs of LPD are greater and quality is no different.

The underlying reasons for the increased costs are not clear from this dataset. It may only be that the LPD takes more operative time to complete and requires more expensive instrumentation. Another possibility is that low to moderate volume centers has fistula rates that vary by procedure type with laparoscopic cases having an increased risk of fistula. Management of these fistulas would lead to observed differences in costs between the approach in these centers. A major limitation of our study is that although HCUP provides some information regarding postoperative complication including data on postoperative infection, the HCUP-SID does not track postoperative pancreatic fistulas in particular and does not provide more granular information or where exactly costs are accruing in a particular case. Another possibility is that complication rates do not differ between approaches, but there are inherent costs associated with the LPD (increased OR time and equipment costs), which are mitigated by efficiencies of scale realized by very high-volume centers. Costs data available through HCUP-SID are not granular enough to allow a better understanding of the cause of the cost-differences observed.

Prior studies evaluating drivers of cost in PD have consistently identified increased costs as associated with postoperative complications. One study by Enestvedt et al found that patients with major complications, such as sepsis, pancreatic fistulas, bile leaks, delayed gastric emptying, and pulmonary, renal, and thromboembolic complications contributed to the increased cost after PD.[10] Several other studies have identified postoperative pancreatic fistula as the primary driver of increases in postoperative cost.[10–18] These studies have in general examined cost associated with index hospitalization alone.[19–21] We were able to evaluate that risk over 90 days after PD and found that there were no apparent differences between laparoscopic and open approaches with regard to the complications captured by the data set. Our findings are corroborated in the literature in studies comparing LPD to OPD. Croome et al found that LPD has a lesser duration of hospitalization LOS and faster recovery compared to OPD and allowed patients to recover in a timelier manner and pursue adjuvant treatment options.[22] In a systematic review, Doula et al found that LPD was not associated with any clinically important differences in postoperative outcomes, such as resection margins, rates of postoperative pancreatic fistula, bile leak, delayed gastric emptying, reoperation rates, intraoperative and postoperative mortality, and blood loss compared to OPD.[20] Lastly, a study evaluating the cost in patients undergoing pancreatoduodenectomy in high-volume centers by Tran et al found that patients undergoing an LPD in high-volume centers had les costs ($76,572 vs $106,367, P < .01) of care compared to patients undergoing OPD when comparing clinical outcomes at 30 days post procedure.[23] We found in our results that LPD and OPD had identical rates of postoperative complications and that LPD was cost-neutral in high volume centers but more expensive in low to moderate centers compared to LPD. These findings would suggest that costs associated with the laparoscopic approach are not due to postoperative complications but to other features of the laparoscopic approach, such as operative time and the laparoscopic instrumentation.

It is essential to recognize that this analysis is limited by the fact that HCUP does not track morbidity data in any way that is comprehensive or procedure-specific. HCUP does not include transfusion rates or estimated blood loss and does not track the occurrence of postoperative pancreatic fistulas. With such limitations, it is difficult to conclude that LPD does not add value definitively. There are quality of life issues that are not captured by HCUP that may favor LPD, such as, less postoperative pain and possible lower risk of experiencingl long term complications related to adhesions and incisional hernia. The dataset does, however, capture variables that would be expected to reflect severe morbidity accurately, including readmission, intensive care unit admission, interventional radiologic drainage procedures, and return to the operating room. If there is a potential cost-saving that is occult in the analysis because of a deficiency in the dataset, that savings is likely to be small. These results would suggest that, from a value-based (financial) viewpoint, low to moderate volume centers

should be judicious in performing LPD, and national protocols may need to be developed to accredit institutions in performing laparoscopic procedures in patients with pancreatic pathology.

There are several limitations to this study that have been discussed in detail in prior reports from our group and need to be recognized by the reader.[8,9] This study is a retrospective review of an administrative dataset. We cannot definitively control or adjust for the selection biases that are inherent in these datasets. There is also substantial potential for omitted variable bias. The administrative dataset does not contain detailed, granular clinical information on many physiologic and pathologic measures, which may contribute to patient selection for different interventions, determine outcomes, and affect costs of care. Importantly, the study was limited to 2014, because that data was the latest available from HCUP; experience and advances in techniques have improved markedly in more recent years. More recent rates of utilization were not examined. Our study was limited to a few states and to the hospitals in those states. The findings may or may not be generalizable. Additional studies are needed evaluating the HCUP dataset more broadly to determine if these findings hold across the US population as a whole. Also, our study is only limited to 3 years between 2012 to 2014, therefore, our results probably do not translate to more recent data. Due to data limitations, we were unable to perform an intent-to-treat analysis, therefore, it may add some bias to our postoperative outcomes and cost estimates. By the rules of agreement in the use of HCUP data, we are not allowed to identify the number of hospitals in each tercile because this would allow possible identification of the hospitals involved in the study. Lastly, HCUP CCR cost data does not include professional (physician) fees, post-discharge outpatient fees, and all complication types, and cannot be directly linked to specific clinical activities. Given these limitations, it is difficult to understand the drivers of cost fully. Future studies should explore cost using more granular multi-institutional cost data.

In conclusion, rates of morbidity and overall duration of hospitalization in the 90-day postoperative period for patients undergoing LPD are statistically identical to those undergoing OPD. At low to moderate and high-volume centers, LPD is associated with greater aggregate costs of care relative to OPD, whereas at very high-volume centers, LPD is cost-neutral. This finding suggests that the laparoscopic approach adds very little financial value for patients undergoing PD, but very high-volume centers can develop efficiencies of scale that mitigate costs inherent in the minimally invasive approach to PD.

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Conflict of interest/Disclosure

The authors have no disclosures.

Supplementary materials

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References

1. NHE-Fact-Sheet 2018. https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/nhe-fact-sheet.html. Accessed July 12, 2018.
2. Sharpe SM, Talamonti MS, Wang CE, et al. Early national experience with laparoscopic pancreaticoduodenectomy for ductal adenocarcinoma: A comparison of laparoscopic pancreaticoduodenectomy and open pancreaticoduodenectomy from the National Cancer Data Base. J Am Coll Surg. 2015;221:175–184.
3. Kantor O, Talamonti MS, Sharpe S, et al. Laparoscopic pancreaticoduodenectomy for adenocarcinoma provides short-term oncologic outcomes and long-term overall survival rates similar to those for open pancreaticoduodenectomy. Am J Surg. 2017;213:512–515.
4. De Rooij T, Klompmaker S, Hilal MA, Kendrick ML, Busch OR, Besselink MG. Laparoscopic pancreatic surgery for benign and malignant disease. Nat Rev Gastroenterol Hepatol. 2016;13:227.
5. Abdelgadir Adam M, Choudhury K, et al. Minimally invasive versus open pancreaticoduodenectomy for cancer. Ann Surg. 2015;262:372–377.
6. Mendoza III AS, Han HS, Yoon YS, Cho JY, Choi Y. Laparoscopy-assisted pancreaticoduodenectomy as minimally invasive surgery for periampullary tumors: A comparison of short-term clinical outcomes of laparoscopy-assisted pancreaticoduodenectomy and open pancreaticoduodenectomy. J Hepatobiliary Pancreat Sci. 2015;22:819–824.
7. Poves I, Burdío F, Morató O, et al. Comparison of perioperative outcomes between laparoscopic and open approach for pancreatoduodenectomy: The PADULAP randomized controlled trial. Ann Surg. 2018;268:731–739.
8. Eguia E, Cobb AN, Kirshenbaum EJ, Afshar M, Kuo PC. Racial and ethnic postoperative outcomes after surgery: The Hispanic paradox. J Surg Res. 2018;232:88–93.
9. Eguia E, Cobb AN, Kothari AN, et al. Impact of the Affordable Care Act (ACA) Medicaid expansion on cancer admissions and surgeries. Ann Surg. 2018;268:584–590.
10. Enestvedt CK, Diggs BS, Cassera MA, Hammill C, Hansen PD, Wolf RF. Complications nearly double the cost of care after pancreaticoduodenectomy. Am J Surg. 2012;204:332–338.
11. Wang J, Ma R, Churilov L, et al. The cost of perioperative complications following pancreaticoduodenectomy: A systematic review. Pancreatology. 2018;18:208–220.
12. Vanounou T, Pratt W, Fischer JE, Vollmer Jr CM, Callery MP. Deviation-based cost modeling: A novel model to evaluate the clinical and economic impact of clinical pathways. J Am Coll Surg. 2007;204:570–579.
13. Vanounou T, Pratt WB, Callery MP, Vollmer Jr CM. Selective administration of prophylactic octreotide during pancreaticoduodenectomy: A clinical and cost-benefit analysis in low-and high-risk glands. J Am Coll Surg. 2007;205:546–557.
14. Brown EG, Yang A, Canter RJ, Bold RJ. Outcomes of pancreaticoduodenectomy: Where should we focus our efforts on improving outcomes? JAMA Surg. 2014;149:694–699.
15. Eisenberg JD, Rosato EL, Lavu H, Yeo CJ, Winter JM. Delayed gastric emptying after pancreaticoduodenectomy: An analysis of risk factors and cost. J Gastrointest Surg. 2015;19:1572–1580.
16. Knechtle WS, Perez SD, Medbery RL, et al. The association between hospital finances and complications after complex abdominal surgery. Ann Surg. 2015;262:273–279.
17. Langan RC, Huang C-C, Mao WR, et al. Pancreaticoduodenectomy hospital resource utilization in octogenarians. Am J Surg. 2016;211:70–75.
18. Ghafeari AA, Birkmeyer JD, Dimick JB. Variation in hospital mortality associated with inpatient surgery. N Engl J Med. 2009;361:1368–1375.
19. Gerber MH, Delitto D, Crippen CJ, et al. Analysis of the cost effectiveness of laparoscopic pancreatoduodenectomy. J Gastrointest Surg. 2017;21:1404–1410.
20. Doula C, Kostakis ID, Damaskos C, et al. Comparison between minimally invasive and open pancreatoduodenectomy: A systematic review. Surg Laparosc Endosc Percutan Tech. 2016;26:6–16.
21. Tran TB, Dua MM, Worhunsky DJ, Poultsides GA, Norton JA, Visser BC. An economic analysis of pancreaticoduodenectomy: Should costs drive consumer decisions? Am J Surg. 2016;211:991–997.e1.
22. Croome KP, Farnell MB, Que FG, et al. Pancreaticoduodenectomy with major vascular resection: A comparison of laparoscopic versus open approaches. J Gastrointest Surg. 2015;19:189–194.
23. Tran TB, Dua MM, Worhunsky DJ, Poultsides GA, Norton JA, Visser BC. The first decade of laparoscopic pancreaticoduodenectomy in the United States: Costs and outcomes using the nationwide inpatient sample. Surg Endosc. 2016;30:1778–1783.