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Determining Hospital Volume Threshold for the Safety of Minimally Invasive Pancreaticoduodenectomy: A Contemporary Cutpoint Analysis

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Abstract

Background: Guidelines recommend limiting minimally invasive pancreaticoduodenectomy (MIPD) to high-volume centers. However, the definition of high-volume care remains unclear. We aimed to objectively define a minimum number of MIPD performed annually per hospital associated with improved outcomes in a contemporary patient cohort.

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Data Access, Responsibility, and Analysis: Statistical analysis was performed by Dr. Mohamed Adam. Dr. Adam had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Methods: Resectable pancreatic adenocarcinoma patients undergoing MIPD were included from the National Cancer Database (2010–17). Multivariable modeling with restricted cubic splines was employed to identify an MIPD annual hospital volume threshold associated with lower 90-day mortality. Outcomes were compared between patients treated at low- (≤model-identified cutoff) versus high-volume (>cutoff) centers.

Results: Among 3,079 patients, 141 (5%) died within 90 days. Median hospital volume was 6 (range 1–73) cases/year. After adjustment, increasing hospital volume was associated with decreasing 90-day mortality for up to 19 (95% CI 16–25) cases/year, indicating a threshold of 20 cases/year. Most cases (82%) were done at low-volume (<20 cases/year) centers. With adjustment, MIPD at low-volume centers was associated with increased 90-day mortality (OR 2.7; p=0.002). Length of stay, positive surgical margins, 30-day readmission, and overall survival were similar. On analysis of the most recent two years (n=1,031), patients at low-volume centers (78.2%) were younger and had less advanced tumors but had longer length of stay (8 vs. 7 days; p<0.001) and increased 90-day mortality (7% vs. 2%; p=0.009).

Conclusions: The cutpoint analysis identified a threshold of at least 20 MIPD cases/year associated with lower postoperative mortality. This threshold should inform national guidelines and institution-level protocols aimed at facilitating the safe implementation of this complex procedure.

Keywords

Minimally invasive pancreaticoduodenectomy; Hospital volume; National Cancer Database; Restricted cubic splines

INTRODUCTION

Minimally invasive pancreaticoduodenectomy (MIPD), including laparoscopic and robotic approaches, is a potentially attractive option to improve patient outcomes compared to open pancreaticoduodenectomy (PD). Minimally invasive resections of other cancers have the proven benefits of fewer postoperative complications, shorter length of stay, and faster recovery.[1–3] Advocates for MIPD suggest the same benefits may be generalizable. Although single-institution studies from high-volume centers have demonstrated that robotic pancreaticoduodenectomy is associated with less delayed gastric emptying and improved outcomes in sarcopenic patients, the generalizability of these data to low-volume centers has been limited.[4–7]

Several observational studies have demonstrated an association between MIPD and increased postoperative mortality, primarily when performed at low-volume hospitals.[8–10] Perhaps most concerning, a multicenter, randomized controlled trial (LEOPARD-2) comparing laparoscopic versus open PD was terminated early because of a trend towards increased mortality in the laparoscopic group.[10] Because higher hospital volume is associated with improved outcomes, national guidelines recommend limiting MIPD to high-volume centers.[8,11–14] However, the definition of a high-volume pancreatic surgical center is unclear, with prior published thresholds ranging from 10 to 50 cases/year.[9,15] A previous study aiming to objectively define an MIPD hospital volume threshold found that 22 MIPD

cases/year were, on average, associated with fewer postoperative complications.[11] However, this analysis did not account for oncologic variables and focused on MIPD performed between 2000 and 2012 during the early experience with MIPD. There has been a significant increase in MIPD adoption since 2010, with a 74% increase in the number of facilities performing MIPD and a 200% increase in the number of MIPD cases performed between 2010–2015.[16] Given this increase in MIPD deployment with insufficient data to recommend MIPD over open PD, the International Study Group on Minimally Invasive Pancreas Surgery called for clarification of an appropriate MIPD hospital volume threshold for the safe implementation of this complex procedure.[13] As such, a contemporary analysis of the MIPD volume threshold is needed to better define a completed learning curve.

In the present study, we aimed to objectively define a minimum number of MIPD cases performed annually per hospital that is associated with improved outcomes in a contemporary patient cohort. We subsequently aimed to objectively compare outcomes between patients treated at low- versus high-volume centers, with the hypothesis that patients treated at high-volume centers would have improved outcomes.

METHODS

Data Source and Cohort

The National Cancer Database (NCDB) is a joint program of the Commission on Cancer (CoC) of the American College of Surgeons and the American Cancer Society. It contains oncologic outcomes data from >1,500 cancer programs in the United States, capturing approximately 70% of new cancer diagnoses. The most recent NCDB Participant User File (PUF) has approximately 34 million records from 1989–2017 with surgical approach captured since 2010. Data are collected by individual CoC-accredited programs and submitted to the NCDB using standardized coding definitions.[17]

The NCDB PUF was queried to identify all patients with non-metastatic pancreatic ductal adenocarcinoma who underwent MIPD between 2010–2017. Patients who were <18 years, had more than one cancer diagnosis, were treated at multiple hospitals, had unresectable (T4) disease, or had unknown 90-day mortality were excluded. MIPD was defined as robotic or laparoscopic PD. The following variables were extracted: patient age, sex, race, diagnosis year, insurance status, Charlson/Deyo Comorbidity Score, clinical stage (T, N stages), pathologic stage, surgical margin status, tumor grade, number of lymph nodes removed, length of stay, 30-day readmission, 30-day mortality, 90-day mortality, receipt of neoadjuvant/adjuvant therapy, time to adjuvant therapy, and follow-up time. The following hospital-level data were extracted: hospital region and type, including community (100–500 new cancer cases/year), comprehensive community (>500 new cancer cases/year), or academic (>500 new cancer cases/year with post-graduate medical education, research, and clinical trials).[8] Annual hospital volume was calculated for each hospital as the number of all MIPD and open PD performed per hospital per year. Patients who underwent MIPD or open PD but did not meet inclusion criteria were still accounted for when calculating hospital volume. This study was granted an exemption by our Institutional Review Board.

Statistical Analysis

The primary outcome was 90-day mortality. Secondary outcomes included 30-day readmission, 30-day mortality, and length of stay. A multivariable logistic regression model with restricted cubic splines (RCS) was employed to specify and estimate the functional form of annual hospital volume with respect to 90-day mortality. The RCS statistical method provides a flexible model to examine the adjusted effect of a continuous predictor on an outcome and allows for visualization of the relationship without prior knowledge of the association's functional form.[11,18] The following factors were controlled for in this multivariable model: patient age, sex, race, insurance status, Charlson-Deyo Comorbidity Score, diagnosis year, clinical T and N stages, receipt of neoadjuvant therapy, pathologic stage, and hospital type.

The threshold identified from the RCS model was then applied to define low-volume (≤model-identified cutoff) and high-volume (>model-identified cutoff) centers. Descriptive statistics for patients' demographic, clinical, tumor, and hospital characteristics were compared between patients undergoing MIPD at low- versus high-volume centers. The nonparametric Wilcoxon Rank Sum test was used to compare continuous variables, and the chi-squared/Fisher exact tests were used to compare categorical variables.

To review data for the years with the highest MIPD adoption, a subset analysis was performed with patients diagnosed in the most recent two years available in the NCDB, 2015–2016 (no outcomes data are available for patients diagnosed in 2017).

Multivariable logistic regression models controlling for patient age, sex, race, insurance status, comorbidities, clinical T and N stage, neoadjuvant chemotherapy, neoadjuvant radiation, and hospital type were used to analyze outcomes based on hospital volume status.

Internal Validation

A bootstrap simulation incorporating the RCS function was performed to internally validate the functional association between annual hospital volume and 90-day mortality in 1,000 simulation datasets to estimate the point corresponding to the maximum change from this range of annual hospital volumes. The following factors were controlled for in this multivariable model: patient age, sex, race, insurance status, Charlson Comorbidity Score, diagnosis year, clinical T and N stages, receipt of neoadjuvant therapy, pathologic stage, and hospital type.

A two-sided alpha of 0.05 was used to determine statistical significance. The analysis was performed between October 2020 and February 2021 using SAS version 9.4 (SAS Institute Inc, Cary, NC).

RESULTS

Hospital Volume Threshold

In total, 3,079 patients underwent MIPD between 2010–2017 for pancreatic adenocarcinoma and met inclusion criteria. Of these, 2,499 (81.2%) cases were performed laparoscopically, and 580 (18.8%) were performed robotically. The overall conversion rate from minimally

invasive to open was 24.2% (n=744). Mortality rates were 2.8% (n=71) and 5.5% (n=141) at 30 and 90 days, respectively. Demographic and clinical patient characteristics are summarized in Table 1.

In total, 394 hospitals performed MIPD. The annual MIPD hospital volume ranged from 1 to 73 cases/year, with a median of 6 cases/year (IQR, 3–14). The majority of MIPD cases were performed at academic centers (64.4%). The use of MIPD increased by approximately 150% between 2010–2017, from 206 to 522 cases. The majority of MIPD were performed at low-volume hospitals, with most (67%) performed at hospitals with <10 MIPD performed annually.

The RCS analysis demonstrated that increasing hospital volume was significantly associated with decreasing odds of 90-day mortality for up to 19 (95% CI 16–25) cases/year, indicating a threshold of 20 cases/year (Figure 1). When robotic and laparoscopic PD were analyzed separately, the threshold remained qualitatively similar. Similarly, when the most recent two years (2015–2016) were analyzed separately, the threshold remained qualitatively similar. Low- and high-volume centers were subsequently defined based on the threshold identified by the RCS model. Low-volume centers performed <20 MIPD cases annually, while high-volume centers performed ≥20.

Outcomes by Hospital Volume

The majority of cases (81.5%, n=2,508) were performed at low-volume centers, with a median annual MIPD volume of 5 (IQR, 2–8) compared to 33 cases at high-volume centers (IQR, 23–61). Open PD volume also was higher at high-volume centers, with a median annual open PD volume of 67 (IQR, 51–76), compared to 14 cases (IQR, 7–24).

Patients treated at high-volume centers were more likely to be white (91.2% vs. 85.6%; p<0.001) with clinically higher stage tumors (63.5% vs. 52.5% Stage II; p<0.001) (Table 2). Patients at high-volume centers were more likely to have received neoadjuvant chemotherapy (40.6% vs. 22.0%; p <0.001). Conversion to open was less likely at high-volume centers (20.5% vs. 25.0%; p=0.02). There was no difference in margin positivity between low- and high-volume centers (23.7% vs. 20.2%; p=0.07). More lymph nodes were harvested at high-volume centers, with a median of 25 (IQR, 18–34) compared to 17 nodes at low-volume centers (IQR, 12–24; p<0.001). The median length of stay was shorter by one day at high-volume centers (7 vs. 8 days; p<0.001). There was no difference in 30-day readmissions, receipt of neoadjuvant chemotherapy, or time to adjuvant chemotherapy between centers.

Compared with patients treated at high-volume centers, those who received low-volume care had higher 30-day (3.3% vs. 0.8%; p=0.001) and 90-day mortality (6.3% vs. 2.4%; p<0.001). (Table 2). After adjustment, patients treated at low-volume centers had higher odds of 30-day (OR 4.32; 95% CI 1.50–12.45; p=0.007) and 90-day mortality (OR 2.69; 95% CI 1.42–5.09; p=0.002). There was no difference in length of stay (Table 3).

In the most recent two years available in the NCDB (2015–2016), patients at low-volume centers had higher 30-day (3.0% vs. 0.4%; p=0.03) and 90-day mortality rates (6.6% vs. 2.2%; p=0.009) (Table 4).

DISCUSSION

We objectively determined an MIPD hospital volume threshold that is associated with significantly lower postoperative mortality. Adjusting for patient demographic and clinical characteristics, there was a significant reduction in 90-day mortality with increasing MIPD hospital volume for up to 19 cases/year, after which no further improvement was seen, corresponding to a threshold of 20 cases/year. Patients treated at centers performing <20 MIPD cases/year had more than a two-fold increase in 90-day mortality despite having less advanced disease compared to patients treated at high-volume centers. However, most cases continue to be performed at low-volume centers, which account for the majority of increased MIPD adoption from 2010–2017.

MIPD is a complex and technically demanding procedure with variably-reported outcomes.[6,9,10] Despite single-institution studies demonstrating short-term benefits after MIPD versus open PD, previous analyses of national datasets, which include data from hospitals with a wide range of MIPD volumes, have shown an increased risk of 30-day mortality associated with MIPD.[8,19] Four randomized controlled trials have compared outcomes between laparoscopic and open PD. Palanivelu et al. performed a single-center, randomized controlled, open-label trial where 64 patients were randomized to either open or laparoscopic PD. They demonstrated a shorter length of stay (primary outcome) and fewer surgical site infections after laparoscopic PD, with no differences in mortality.[6] A second single-center, open-label, randomized controlled trial of 66 patients demonstrated shorter length of stay and fewer postoperative complications among patients who underwent laparoscopic versus open PD.[7] Both of these trials were underpowered for their secondary outcomes of postoperative complications and mortality. Subsequently, the multicenter, patient-blinded LEOPARD-2 trial was terminated early after enrollment of 40 patients because of a trend towards higher mortality and postoperative complications in the laparoscopic group.[10] More recently, a multi-center, open-label, randomized controlled trial from China demonstrated a small but statistically significant reduction in length of hospital stay for patients undergoing laparoscopic PD. They found no differences in postoperative complications, 30-day mortality, or 90-day mortality between patients undergoing open versus laparoscopic PD.[20]

A lack of consensus regarding an appropriate MIPD hospital volume threshold complicates the interpretation of existing evidence. It may be possible that the conflicting results of these four trials are influenced by the effects of hospital MIPD volume because each of these trials employed different volume criteria. In the LEOPARD-2 trial, the median annual MIPD case volume was only 11 cases.[10] Furthermore, 22% of graded surgical videos from the trial were deemed below average, raising concerns about the extent to which MIPD was optimally implemented.[10] In contrast, all of the surgeons who participated in the most recent randomized trial had performed at least 104 laparoscopic PDs.[20,21] Additionally, all participating centers in the trial from China had an annual hospital volume of at least 20

MIPD.[20] Considering the results of the present study in conjunction with prior observational studies demonstrating worse outcomes after MIPD performed at low-volume centers, it is reasonable to hypothesize that the compromised outcomes in the LEOPARD-2 trial may have been driven by low hospital and surgeon volume.[8,9,16] As suggested by international consensus guidelines, an objective volume threshold should be integrated into the design of multicenter, randomized controlled trials evaluating MIPD.[13]

Although there is substantial evidence that hospital MIPD volume is an important predictor of postoperative outcomes, reported volume thresholds associated with improved outcomes vary considerably, with estimates ranging from 6–50 cases/year.[9,15,16] A prior analysis of the 2010–2011 NCDB showed an increased risk of 30-day mortality after laparoscopic PD, which became insignificant when restricted to institutions performing >10 laparoscopic PDs annually.[9] This volume threshold, however, was arbitrarily defined. Another group defined high-volume as >6 MIPD cases/year, representing their top 5th percentile hospital volume, while a third group reported a reduction in operative time and blood loss after 50 laparoscopic PD cases.[15,16] Despite statistically significant results, arbitrarily defined cutoffs may provide an inaccurate estimate of the reported threshold because this dichotomization is heavily influenced by the effects of outliers. Defining volume thresholds based on data distribution may lack any meaningful clinical outcomes association and has limited generalizability.[22] In contrast, the RCS analysis we employed considers hospital volume as a continuous outcome and precisely models its relationship with mortality to determine an objective, generalizable threshold. The non-linear assumption in RCS models limits the effects of outliers.

In an RCS analysis of the 2000–2012 National Inpatient Sample files, Adam et al. defined an MIPD threshold of 22 cases/year associated with a significant reduction in postoperative complications, a different primary outcome than the present study.[11] Our current study's findings provide a contemporary update to this threshold in the setting of increased MIPD adoption. The availability of oncologic data in the present analysis allows for a more valid comparison of outcomes across volume groups. As surgeon and center experience with MIPD continues to evolve, these analyses should be periodically updated based on the most contemporary cohorts available.

Although studies have demonstrated that surgeon experience is essential for improved outcomes, a combination of surgeon-level and institution-level factors likely contribute to the lower mortality rates observed at high-volume centers.[23] A systematic review of the safety of MIPD demonstrated the most common causes of mortality after MIPD include sepsis, cardiovascular events, and bleeding.[24] Consequently, structured pathways for postoperative care, high-functioning intensive care units, and resource availability likely contribute to the mortality benefit observed at high-volume hospitals.[25,26] Given this, hospital volume may be able to better account for both surgeon- and hospital-level variables. Furthermore, established structured pathways at centers with high open PD volume likely translate to better MIPD outcomes. Indeed, we found strong correlation between MIPD volume and open PD volume. Given this correlation, we were unable to adjust for one while examining the other as this would create significant collinearity and confound the estimates.

The continued observation that the majority of MIPD cases are performed at low-volume centers and that low-volume centers account for much of the increase in adoption remains concerning. Currently, recommendations for surgeons interested in implementing an MIPD program include participation in dedicated training, continuous quality assessment, and assurance of sufficient case volume.[27] However, given that most MIPD cases are performed at centers with insufficient volumes, it appears that these recommendations are not followed. The drivers of this discrepancy are unclear, and studies to identify successful implementation strategies are needed.[28]

Although our study was not designed to examine disparities in surgical care, we noted racial disparities, with white patients more often undergoing MIPD at high-volume centers as compared to Black patients. This observation raises concerns regarding equitable access to safe implementation of this procedure. Future studies are needed to investigate methods to build capacity in a way that diminishes disparities.

There are limitations to our study. This retrospective analysis is subject to selection bias between low- and high-volume centers. However, we found that high-volume centers treated more complex patients with more comorbidities and higher stage tumors, which could lead to underestimating the observed mortality differences. Vascular resection data are not available, but we used tumor stage for adjustment. There is insufficient granularity in the NCDB coding system to know whether a conversion to open was planned or whether an operation was intended to be performed entirely minimally-invasively. It is possible that there are coding errors in the NCDB. The NCDB does not record operation-specific complications, such as postoperative pancreatic fistula, and lacks information on specific causes of 30- and 90-day mortality. Future studies utilizing other datasets are needed to determine the causes of death that drive the disparity between low- and high-volume centers and identify the specific components of high-volume centers (i.e., surgeon characteristics versus institutional workflow and resources) that confer mortality benefit. This study does not consider trends in hospital volume over time. Future analyses could investigate whether cumulative years of high-volume status are associated with improved mortality.

The NCDB does not include surgeon-level data. Surgeon volume remains important, and there is valid concern that MIPD performed by a low-volume surgeon at a high-volume center may not be safe. Limited studies examining the MIPD learning curve have shown variable results, with a range of 20–104 cases required for proficiency.[21,29] Indeed, surgeon and hospital volume thresholds may not be the same, as evidenced by the LEOPARD-2 trial, where all participating surgeons had performed at least 20 laparoscopic PDs, but median annual laparoscopic PD volume was only 11.[10] As such, the results of our study should not be used in guidelines as blanket permission for any surgeon at a high-volume center to perform MIPD.

Despite its limitations, this study provides valuable and actionable insights into the role of hospital volume in the safe implementation of MIPD. The NCDB offers a broad representation of hospital volume status, and it would not be possible to garner similar information from a single-center study. Based on the well-established literature

demonstrating the superiority of outcomes at high-volume MIPD and open PD centers, it would seem unethical to evaluate this question in a randomized clinical trial.

CONCLUSION

We determined an objective threshold of 20 MIPD cases/year that is associated with improved 90-day mortality in a contemporary NCDB cohort. These findings address the need to clarify an appropriate MIPD hospital volume threshold, as called for in the Miami International Guidelines on Minimally Invasive Pancreas Resection.[13] The threshold determined here may be used to objectively identify centers that have overcome the learning curve to robustly investigate the factors driving improved outcomes in the form of future multicenter, randomized trials. As more surgeons perform MIPD, it is essential to examine methods for capacity building and the safe implementation of this complex procedure.

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Conflicts of Interest:

JAS is a member of the Data Monitoring Committee of the Medullary Thyroid Cancer Consortium Registry supported by GlaxoSmithKline, Novo Nordisk, Astra Zeneca and Eli Lilly. She receives institutional research funding from Exelixis and Eli Lilly.

All other authors declare no conflicts of interest.

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SYNPOSIS

In this retrospective cohort study, a hospital volume threshold of 20 minimally invasive pancreaticoduodenectomy cases/year was associated with lower postoperative mortality. This volume threshold should inform guidelines and institution-level protocols intended to facilitate the safe implementation of this complex procedure.

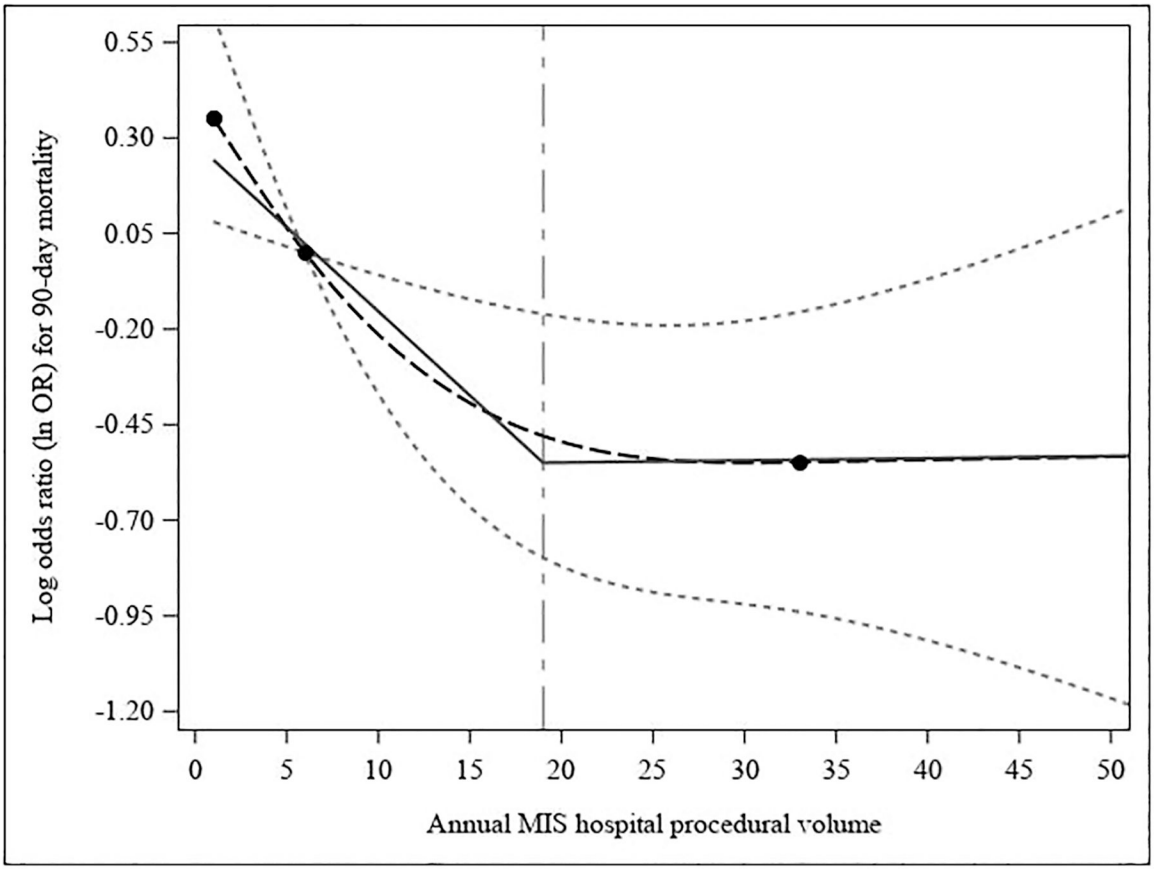

Figure 1. A threshold of at least 20 MIPD cases per year is associated with improved 90-day mortality.

Smoothed restricted cubic splines plot shows increasing hospital volume was associated with decreasing 90-day mortality for up to 19 cases/year, indicating a threshold of 20 cases/year.

Dashed black line: Estimated regression line identified by the model.

Dotted grey lines: 95% CIs

Black dots: 3 knots

Dashed grey line: Cutoff identified at 19 cases/year, with adjustment for the effects of patient age, sex, race, insurance status, comorbidities, year of diagnosis, hospital type, clinical T and N stages, receipt of neoadjuvant therapy, and pathologic stage.

Table 1:

Demographic, Clinical, and Hospital Characteristics of Patients Undergoing MIPD at Low- (<20 cases/year) versus High-Volume (≥20 cases/year) Centers

	No. (%)			
	Volume			
	Low (n = 2508)	High (n = 571)	All Patients (n = 3079)	*P* value
Patient age, median (IQR), years	67 (60–74)	68 (60–75)	67 (60–74)	0.14
Female	1242 (49.5)	263 (46.1)	1505 (48.9)	0.14
Race				
White	2146 (85.6)	521 (91.2)	2667 (86.6)	<0.001
Black	235 (9.4)	24 (4.2)	259 (8.4)	
Other	127 (5.1)	26 (4.6)	153 (5.0)	
Insurance status				
Insured	2446 (98.3)	564 (100.0)	3010 (98.6)	<0.001
Uninsured	42 (1.7)	0 (0.0)	42 (1.4)	
Charlson Comorbidity Score				
0	1590 (63.4)	336 (58.8)	1926 (62.6)	0.008
1	654 (26.1)	185 (32.4)	839 (27.2)	
≥2	264 (10.5)	50 (8.8)	314 (10.2)	
Clinical Stage				
I	1170 (47.5)	204 (36.5)	1374 (45.5)	<0.001
II	1293 (52.5)	355 (63.5)	1648 (54.5)	
Neoadjuvant Chemotherapy	548 (22.0)	232 (40.6)	780 (25.5)	<0.001
Neoadjuvant Radiation	206 (8.3)	47 (8.2)	253 (8.3)	>0.99
Pathologic Stage				
I	277 (11.0)	41 (7.2)	318 (10.3)	0.006
II	2231 (89.0)	530 (92.8)	2761 (89.7)	
T Stage				
T1	393 (15.7)	68 (11.9)	461 (15.0)	<0.001
T2	986 (39.3)	195 (34.2)	1181 (38.4)	
T3	1129 (45.0)	308 (53.9)	1437 (46.7)	
N Stage				
N0	1910 (76.2)	398 (69.7)	2308 (75.0)	0.002
N1	598 (23.8)	173 (30.3)	771 (25.0)	
Tumor grade				
1	219 (9.8)	17 (4.1)	236 (8.9)	<0.001
2	1242 (55.3)	235 (56.2)	1477 (55.5)	
3	783 (34.9)	166 (39.7)	949 (35.6)	
Approach				

	No. (%)			
	Volume			
	Low (n = 2508)	High (n = 571)	All Patients (n = 3079)	*P* value
Laparoscopic	2151 (85.8)	348 (60.9)	2499 (81.2)	<0.001
Robotic	357 (14.2)	223 (39.1)	580 (18.8)	
Hospital location				
Northeast	557 (22.4)	317 (55.8)	874 (28.6)	<0.001
South	935 (37.6)	102 (18.0)	1037 (33.9)	
Midwest	639 (25.7)	132 (23.2)	771 (25.2)	
West	357 (14.3)	17 (3.0)	374 (12.2)	
Hospital type				
Academic	1411 (56.7)	556 (97.9)	1967 (64.4)	<0.001
Community	47 (1.9)	0	47 (1.5)	
Comprehensive community	1030 (41.4)	12 (2.1)	1042 (34.1)	
Annual MIPD hospital volume, median (IQR), cases	5 (2–8)	33 (23–61)	6 (3–14)	<0.001
Annual OPD hospital volume, median (IQR), cases	14 (7–24)	67 (51–76)	18 (8–40)	<0.001

Abbreviations: **MIPD**: minimally invasive pancreaticoduodenectomy; **IQR**: interquartile range.

Table 2:

Unadjusted Outcomes of Patients Undergoing MIPD at Low- (<20 cases/year) versus High-Volume (≥20 cases/year) Centers

	No. (%)			
	Volume			
	Low (n = 2508)	High (n = 571)	All Patients (n = 3079)	*P* value
Conversion to Open	627 (25.0)	117 (20.5)	744 (24.2)	0.02
Positive Surgical Margin	504 (20.2)	135 (23.7)	639 (20.9)	0.07
Lymph Nodes, median (IQR), No.	17 (12–24)	25 (18–34)	19 (13–26)	<0.001
Length of stay, median (IQR), days	8 (6–12)	7 (6–11)	8 (6–12)	<0.001
30-day Readmission	202 (8.1)	56 (9.8)	258 (8.4)	0.18
30-day Mortality	67 (3.3)	4 (0.8)	71 (2.8)	0.001
90-day Mortality	129 (6.3)	12 (2.4)	141 (5.5)	<0.001
Adjuvant Chemotherapy	1448 (59.7)	361 (63.2)	1849 (60.3)	0.13
Time to Adjuvant Chemotherapy, median (IQR), days	55 (42–70)	57 (45–71)	55 (42–70)	0.05
Follow up, median (IQR), months	21.4 (11.5–34.9)	23.7 (14.2–37.1)	22 (11.9–35.4)	0.006

Abbreviations: **MIPD**: minimally invasive pancreaticoduodenectomy; **IQR**: interquartile range.

Table 3:

Adjusted Outcomes of Patients Undergoing MIPD at Low- (<20 cases/year) versus High-Volume (≥20 cases/year) Centers

Outcome	Odds Ratio (95% CI)	Increase (95% CI)	*P* value
30-day Mortality	4.32 (1.50 – 12.45)	NA	0.007
90-day Mortality	2.69 (1.42 – 5.09)	NA	0.002
30-day Readmission	0.80 (0.57 – 1.14)	NA	0.22
Length of stay, days	NA	0.26 (−0.77 to 1.30)	0.62

Abbreviations: **NA**: Not applicable.

Table 4:

Unadjusted Outcomes of Patients Undergoing MIPD at Low- (<20 cases/year) versus High-Volume (≥20 cases/year) Centers for the Most Recent Years (2015–2016)

	No. (%)			
	Volume			
	Low (n = 806)	High (n = 225)	All Patients (n = 1031)	*P* value
Clinical Stage				
I	390 (49.1)	79 (36.4)	469 (46.3)	<0.001
II	405 (50.9)	138 (63.6)	543 (53.7)	
Approach				
Laparoscopic	662 (82.1)	116 (51.6)	778 (75.5)	<0.001
Robotic	144 (17.9)	109 (48.4)	253 (24.5)	
Conversion to Open	196 (24.3)	61 (27.1)	257 (24.9)	0.39
Positive Surgical Margin	170 (21.2)	52 (23.2)	222 (21.6)	0.52
Lymph Nodes, median (IQR), No.	18 (12–25)	27 (21–36)	20 (13–27)	<0.001
Length of stay, median (IQR), days	8 (6–12)	7 (5–10)	8 (6–11)	<0.001
30-day Readmission	57 (7.1)	23 (10.2)	80 (7.8)	0.16
30-day Mortality	24 (3.0)	1 (0.4)	25 (2.4)	0.03
90-day Mortality	53 (6.6)	5 (2.2)	58 (5.6)	0.009
Adjuvant Chemotherapy	499 (62.1)	142 (63.1)	641 (62.4)	0.82
Time to Adjuvant Chemotherapy, median (IQR), days	53 (41–68)	59 (48–69)	55 (42–68)	0.07

Abbreviations: **MIPD**: minimally invasive pancreaticoduodenectomy; **IQR**: interquartile range.