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ORIGINAL ARTICLE

National Trends in Robotic Pancreas Surgery

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Abstract

Background Robotic pancreatic surgery is expanding throughout centers across the country. We investigated national trends in the use and outcomes for robotic-assisted pancreaticoduodenectomy (RPD) and distal pancreatectomy (RDP) for primary pancreatic tumors.

Methods The National Cancer Database was queried for RPD and RDP performed during three time periods: 2010–2012, 2013–2014, and 2015–2016. These time periods were compared for patient and center factors as well as surgical outcomes.

Results The use of robotic surgery increased during the study period. Most centers performed a low volume of robotic surgery (RPD, 82% of centers averaged < 1 case/year; RDP, 87% averaged < 1 case/year). From the first to last time period, the proportion of cases performed at academic centers decreased (RPD, 83% to 56%; RDP, 77% to 58%, $p < 0.001$) while patient characteristics remained largely unchanged. For RPD, improvements in mortality (6.7 to 1.8%, $p = 0.013$) and lymphadenectomy (18 to 21 nodes, $p = 0.035$) were observed, with no changes in conversion to open surgery, negative margin resections, or readmissions. For RDP, length of stay decreased (7 to 6 days, $p = 0.048$), but there were no changes in other outcomes. Compared with academic centers, non-academic centers had equivalent rates of conversion to open surgery, negative margins, and 90-day mortality. On multivariate analysis, there was no difference in survival between academic and non-academic centers.

Discussion Robotic pancreas surgery is expanding to a greater variety of centers nationwide with preservation of key surgical outcomes. These findings support the continued rigorous training and proliferation of qualified robotic pancreas surgeons going forward.

Keywords Pancreas · Pancreatic cancer · Robotic surgery · Minimally invasive surgery · Robotic · Pancreaticoduodenectomy · Whipple · Distal pancreatectomy · NCDB

Introduction

Robotic-assisted minimally invasive surgery using the DaVinci platform is being increasingly utilized for various malignancies.[1] The platform is well-suited for complex abdominal surgery due to enhanced visualization, improved instrument dexterity, and surgeon ergonomics. These features facilitate precise dissection and suturing while eliminating tremor and maintaining surgeon comfort. Several reports suggest lower rates of conversion, blood loss, complications, and length of stay compared with standard laparoscopy across several surgical subspecialties.[2–5]

The first robotic pancreaticoduodenectomy (PD) using the DaVinci platform was performed in 2003, but it was not until 2010 that reports of robotic pancreatic surgery began to proliferate. While use of this platform for pancreatic resections may be increasing, it has been limited to specialized, high-volume centers.[6] Several factors may be responsible for this limited dissemination. First, despite the plethora of studies on short-term robotic pancreatic outcomes, few studies have focused on long-term oncologic outcomes. Second, the DaVinci platform is associated with a substantial capital investment and high maintenance fees. Although benefit compared with other approaches has been demonstrated, those studies tend to originate from high-volume pancreatic centers with unique

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resources; this added value may not be attainable in other centers with limited resources.[7] Third, since robotic pancreatic surgery is associated with a long learning curve—and most centers lie below the volume threshold to achieve benchmarked outcomes—surgeons remain skeptical about the morbidity associated with this approach during the early phase of implementation.[8] Finally, formal training in accredited fellowships is currently limited to a few centers, and established criteria for proficiency assessment and credentialing are lacking.[9, 10]

Despite these challenges and due to increased demand from trainees and surgeons, several programs began to incorporate robotic training into their curricula.[11–14] Additionally, several recent institutional and national studies have suggested a benefit to robotic pancreatic surgery over standard laparoscopy and open surgery after the learning curve is surmounted.[15, 16] To date, the impact of those factors on the national utilization of robotic pancreatic surgery has not been examined. In this study, we aimed to examine patterns and trends in the use of robotic surgery for pancreatic tumors in the USA using a national dataset between 2010 and 2016. We sought to identify variations in patient and center demographics, and to compare outcomes across this time period.

Methods

Database and Patient Population

This is a retrospective study using the National Cancer Database (NCDB) from 2010 to 2016. Earlier years were excluded as the variable "robotic surgery" was not recorded before 2010. The NCDB is a national cancer registry that receives information from over 1500 Commission on Cancer–accredited cancer programs in the USA and captures approximately 70% of incident cancer cases in the USA.[17] The study was approved by the University of Pittsburgh Medical Center Internal Review Board.

We selected all patients with non-metastatic pancreatic tumors who underwent robotic pancreaticoduodenectomy (RPD) or robotic distal pancreatectomy (RDP), excluding those coded as either laparoscopic or open. This designation was made by NCDB data abstractors based on operative notes, not billing or administrative information. Patients who underwent enucleation or total pancreatectomy were excluded. We included only primary pancreatic tumors, grouped as pancreatic ductal adenocarcinoma (PDAC: diagnosis codes 8140, 8210, 8211, 8310, 8440, 8450-3, 8470-3, 8470-2, 8480, 8500-3, 8507, 8560-2, 8570-2, 8574-6), neuroendocrine tumors (NET: diagnosis codes 8013, 8150-56, 8246), and a miscellaneous "other" category (i.e. solid pseudopapillary tumor, mucinous adenocarcinoma, and adenosquamous carcinoma). We did not analyze other periampullary malignancies. Patients were grouped into three time periods to facilitate comparisons over time (2010–2012, 2013–2014, and 2015–2016). We examined the percentage of robotic cases performed (out of the total cases) within each time period to compare changes in robotic utilization over time.

Variables, Outcomes, and Definitions

The following patient and center variables were abstracted: patient age, gender, ethnicity, insurance status, median household income of each patient's area of residence, Charlson-Deyo comorbidity score, year of diagnosis, stage, tumor grade, facility type, and location. Facility types were either academic/research programs, integrated network programs, community cancer programs, or comprehensive community cancer programs (the latter two were grouped together for analysis).[18] The following outcomes were analyzed: conversion to open surgery, number of lymph nodes examined, surgical margin status, length-of-hospital stay, 30-day readmission, 90-day mortality, and overall survival. Overall survival data were only available up to the year 2016.

Statistical Analysis

Data are presented as means with standard variations for continuous variables and counts with proportions for categorical ones. The *t* test was used to compare continuous variables and the chi-squared test for categorical variable. Kaplan-Meier curves were used to estimate overall survival for PDAC only, and the curves were compared using the log-rank test. Finally, we developed a Cox proportional hazard model to determine if facility type was independently associated with survival; this model included all preoperative variables as well as tumor histology. In this study, two-sided P values of ≤ 0.05 were considered statistically significant. Analyses were conducted using SPSS version 20.

Results

Temporal Trends in Patient and Center Demographics for Robotic Pancreatic Surgery

During the study period, 799 RPDs and 823 RDPs were performed for primary pancreatic tumors. In the RPD cohort, there were 626 (78.3%) PDAC, 40 (5.0%) NET, and 133 (16.6%) other. In the RDP group, there were 323 (40.3%) PDAC, 139 (16.9%) were NET, and 352 (42.8%) other. Trends in the national utilization of robotic pancreas surgery are depicted in Figs. 1 and 2. For both RPD and RDP, the number of robotic cases performed increased during the study period (2010 to 2016): from 33 to 225 cases for RPD and from

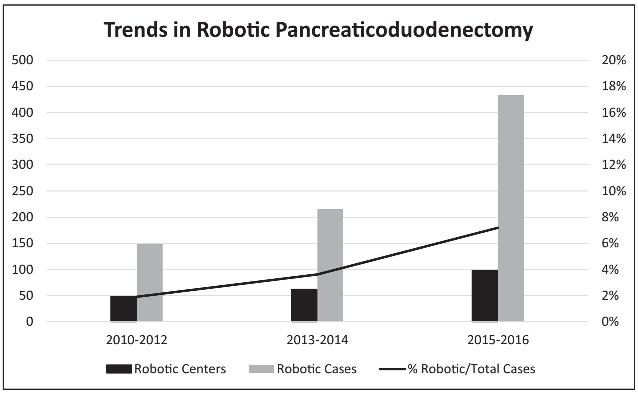

Fig. 1 Graphical representation of the increase in number of robotic pancreaticoduodenectomies being performed, the number of centers performing them, and the proportion of all pancreaticoduodenectomies in the National Cancer Database that were performed robotically. For reference, the total number of pancreaticoduodenectomies performed in each time period were 7794, 5979, and 6036, respectively

18 to 220 cases for RDP ($p < 0.05$). The proportion of cases being performed robotically (compared with other approaches) also increased over this time period: from 2 to 7% for RPD and from 4 to 16% for RDP ($p < 0.05$). The number of centers performing these procedures also increased: 48 and 45 centers performed RPD and RDP in the first time period (2010–2012), respectively, while 98 and 154 centers performed these procedures in the most recent period (2014–2016).

Since the number of centers increased at a faster rate than the overall volume of cases, most centers had a relatively low average annual volume of robotic surgery during the study period. For RPD, 121 centers (82%) performed an average of less than one case per year and only 5 centers (3%) averaged more than three cases per year. For RDP, 175 centers (87%) performed an average of less than one case per year whereas only one center (1%) averaged more than three cases per year.

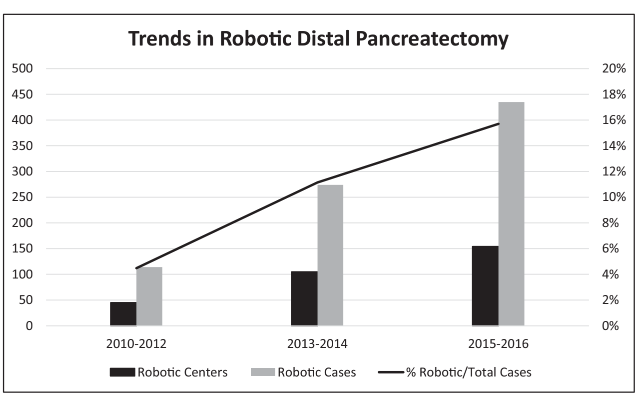

Fig. 2 Graphical representation of the increase over time in the number of robotic distal pancreatectomies being performed, the number of centers performing them, and the proportion of all distal pancreatectomies in the National Cancer Database that were performed robotically. For reference, the total number of distal pancreatectomies performed in each time period were 2547, 2459, and 2770, respectively

There were no clinically significant differences in patient characteristics over time. Patients undergoing RPD and RDP had similar preoperative cancer stage as well as similar burdens of medical comorbidities throughout the study period (Tables 1 and 2). There were, however, changes in the type of facilities performing these procedures. The proportion of robotic cases performed at academic centers decreased over time (RPD, 83 to 56%; RDP, 77 to 58%) with a similar increase in the proportion performed at community programs ($p < 0.001$). There was also a change in the geographic distribution of RPD and RDPs performed throughout the study period. Between 2010 and 2012, 57% of RPDs and 45% of RDPs were performed in the Middle Atlantic region. By 2015–2016, the proportion of cases performed in the Middle Atlantic region decreased to 30% of RPDs and 32% of RDPs with a corresponding increase in the proportion performed in most other regions ($p < 0.001$).

Outcomes of Robotic Pancreas Surgery over Time

Next, we analyzed important surgical outcomes in each of the three time periods (Table 3). Overall, outcomes improved over time. For RPD, there was an increase in the number of lymph nodes examined over time (from 18 to 21, $p = 0.035$) along with a decrease in postoperative mortality (from 6.7 to 1.8%, $p = 0.013$). For RDP, there was a reduction in length of stay over time (from 7 to 6 days, $p = 0.048$) but other outcomes were unchanged. Notably, rates of conversion to open surgery were stable for both procedures, and no surgical outcomes worsened over time. Overall survival for PDAC patients was unchanged across time periods for both RPD (20.9 vs 25.3 vs 20.0 months, $p = 0.217$) and RDP (25.2 vs 37.0 vs median survival months not yet reached) $p = 0.529$).

Outcomes of Robotic Pancreas Surgery by Facility Type

Finally, we compared outcomes between academic and non-academic centers performing robotic pancreas surgery throughout the study period (Table 4). Academic centers examined more lymph nodes for both procedures (RPD, 23 vs 15 nodes; RDP, 14 vs 10 nodes, $p < 0.001$), but non-academic centers had fewer readmissions following RPD (5.1% vs 9.6%, $p = 0.025$). Notably, there were no meaningful differences in other outcomes such as rates of margin negative resections, conversion to open, or postoperative mortality. Additionally, there was no difference in overall survival between academic and non-academic centers for either procedure after adjusting for patient and tumor characteristics (RPD: HR 1.26, $p = 0.093$; RDP: HR 1.12, $p = 0.551$).

Table 1 Patient and facility characteristics over time for robotic pancreaticoduodenectomy

Patient and facility characteristics	2010–2012	2013–2014	2015–2016	*p* value
N	149	216	434	
Histology				0.625
PDAC	123 (82.6%)	166 (76.9%)	337 (77.6%)	
NET/Other	26 (17.4%)	50 (23.1%)	97 (22.4%)	
Age, mean (SD)	67 (11)	66 (11)	66 (11)	0.770
Male gender	71 (47.7%)	107 (49.5%)	228 (52.5%)	0.535
Charlson-Deyo Score				0.061
0	89 (59.7%)	136 (63.0%)	272 (62.7%)	
1	47 (31.5%)	68 (31.5%)	110 (25.3%)	
2	12 (8.1%)	10 (4.6%)	37 (8.5%)	
3	1 (0.7%)	2 (0.9%)	15 (3.5%)	
Clinical stage				0.199
1	29 (19.5%)	42 (19.4%)	102 (23.5%)	
2	119 (79.9%)	171 (79.2%)	319 (73.5%)	
3	1 (0.6%)	3 (1.4%)	13 (3.0%)	
Facility type				< 0.001
Academic/research	123 (83.1%)	161 (76.3%)	238 (56.0%)	
Integrated network program	6 (4.1%)	28 (13.3%)	77 (18.1%)	
Community cancer program	19 (12.8%)	22 (10.4%)	110 (24.9%)	
Facility location				< 0.001
New England	3 (2.0%)	7 (3.3%)	9 (2.1%)	
Middle Atlantic	85 (57.4%)	77 (36.5%)	129 (30.4%)	
South Atlantic	16 (10.8%)	41 (19.4%)	113 (26.6%)	
East North Central	13 (8.8%)	40 (19.0%)	62 (14.6%)	
East South Central	11 (7.4%)	9 (4.3%)	18 (4.2%)	
West South Central	3 (2.0%)	23 (10.9%)	61 (14.4%)	
West North Central/Mountain/Pacific	17 (11.5%)	14 (6.6%)	33 (7.7%)	

NET, neuroendocrine tumor; *PDAC*, pancreatic ductal adenocarcinoma; *SD*, standard deviation

Discussion

This analysis of the NCDB demonstrates that robotic surgery is being increasingly utilized nationwide to treat patients with PDAC and other pancreatic tumors. We observed an increase in both the number and diversity of centers using this platform, with expansion into non-academic centers. Importantly, despite its dissemination into non-academic and low volume centers, postoperative outcomes remained stable over time and comparable with open surgery benchmarks. Finally, there was a critical improvement in 90-day mortality for robotic pancreatoduodenectomy throughout the course of this study.

Pancreatic surgery is technically challenging and carries a relatively high complication rate. The safety of applying a minimally invasive approach to such complex resections is a valid concern, particularly in view of a recent randomized trial demonstrating laparoscopic pancreatoduodenectomy to be associated with an increased—albeit not statistically significant—mortality rate compared with its open counterpart.[19] Although this trial was terminated early, two other trials from India and Spain suggest a benefit to LPD.[20, 21] Regarding distal pancreatectomy (DP), a recent randomized trial (LEOPARD) of minimally invasive versus open approach suggested improved functional recovery for the minimally invasive approach, while a second pan European propensity matched analysis (DIPLOMA study) for pancreatic cancer demonstrated reduced blood loss and length of stay for the minimally invasive approach.[22, 23]

To date, RPD has not been evaluated in prospective fashion, and the above-referenced DP studies are limited because they combined laparoscopic and robotic approaches together. The robotic approach offers several benefits over laparoscopy, including improved visualization, wristed instruments, increased manual dexterity, and fine motor control; features thought to facilitate complex reconstructions. Several studies have demonstrated a lower proportion of cases being converted to open surgery, particularly for PD.[24–26] Our current study indicates that in recent years, surgeons and hospitals may have realized these advantages and are increasingly incorporating the DaVinci platform in their armamentarium. In the early years of this analysis, robotic pancreas surgery was performed almost exclusively at academic centers and mostly within one

Table 2 Patient and facility characteristics over time for robotic distal pancreatectomy

Patient and facility characteristics	2010–2012	2013–2014	2015–2016	*p* value
N	114	274	435	
Histology				0.978
PDAC	47 (41.2%)	110 (40.1%)	175 (40.2%)	
NET/Other	67 (58.8%)	164 (59.9%)	260 (59.8%)	
Age, mean (SD)	63 (13)	63 (14)	63 (13)	0.831
Male gender	57 (50.0%)	137 (50.0%)	225 (51.7%)	0.885
Charlson-Deyo Score				0.035
00	73 (64.0%)	187 (68.2%)	257 (59.1%)	
01	31 (27.2%)	67 (24.5%)	124 (28.5%)	
02	9 (7.9%)	13 (4.7%)	27 (6.2%)	
03	1 (0.9%)	7 (2.6%)	27 (6.2%)	
Clinical stage				0.277
01	68 (59.6%)	138 (50.4%)	219 (50.3%)	
2	46 (40.4%)	133 (48.5%)	214 (49.2%)	
3	0 (0.0%)	3 (1.1%)	2 (0.5%)	
Facility type				0.012
Academic/research	82 (76.6%)	166 (64.6%)	240 (58.4%)	
Integrated network program	8 (7.8%)	41 (16.0%)	84 (20.4%)	
Community cancer program	17 (15.9%)	50 (19.5%)	87 (21.2%)	
Facility location				0.153
New England	6 (5.6%)	21 (8.2%)	16 (3.9%)	
Middle Atlantic	48 (44.9%)	90 (35.0%)	130 (31.6%)	
South Atlantic	14 (13.1%)	42 (16.3%)	82 (20.0%)	
East North Central	23 (21.5%)	44 (17.1%)	67 (16.3%)	
East South Central	2 (1.9%)	3 (1.2%)	6 (1.5%)	
West South Central	5 (4.7%)	24 (9.3%)	45 (10.9%)	
West North Central/Mountain/Pacific	9 (8.4%)	33 (12.8%)	65 (15.8%)	

NET, neuroendocrine tumor; *PDAC*, pancreatic ductal adenocarcinoma; *SD*, standard deviation

Table 3 Postoperative outcomes over time for patients undergoing robotic pancreaticoduodenectomy and distal pancreatectomy for pancreatic cancer

Postoperative outcomes	2010–2012 *n* (%)	2013–2014 *n* (%)	2015–2016 *n* (%)	*p* value
Pancreaticoduodenectomy				
Converted to open	26 (17.4%)	23 (10.6%)	71 (16.4%)	0.104
Lymph nodes examined, mean (SD)	18 (13)	21 (13)	21 (14)	*0.035*
Negative margin	121 (81.0%)	173 (80.1%)	341 (78.6%)	0.506
Length of stay, days; mean (SD)	11 (8)	10 (7)	9 (8)	0.129
30-day readmission	15 (10.1%)	14 (6.5%)	35 (8.1%)	0.462
90-day mortality	10 (6.7%)	7 (3.2%)	8 (1.8%)	*0.013*
Survival*, months; median (95%CI)	20.9 (18.4–23.4)	25.3 (22.0–28.6)	20.0 (17.5–22.5)	0.217
Distal pancreatectomy				
Converted to open	12 (10.5%)	34 (12.4%)	47 (10.8%)	0.775
Lymph nodes examined, mean (SD)	11 (10)	12 (12)	12 (12)	0.694
Negative margin	102 (89.5%)	245 (89.4%)	385 (88.5%)	0.842
Length of stay, days; mean (SD)	7 (5)	6 (5)	6 (3)	*0.048*
30-day readmission	12 (10.5%)	29 (10.6%)	40 (9.2%)	0.804
90-day mortality	0 (0.0%)	3 (1.1%)	4 (9.0%)	0.550
Survival*7, months; median (95%CI)	25.2 (7.1–43.3)	37.0 (23.5–50.5)	NR	0.529

Italicized values are statisically significant with *P*-value <0.05

CI, confidence interval; *NR*, not reached; *SD*, standard deviation

*Survival analysis includes only pancreatic ductal adenocarcinoma

Table 4 Comparison of outcomes between academic and non-academic centers for patients undergoing robotic pancreaticoduodenectomy and distal pancreatectomy for pancreatic cancer

	Academic *n* (%)	Non-academic* *n* (%)	*p* value
Pancreaticoduodenectomy			
Total number	522 (65.3%)	277 (34.7%)	
Converted to open	79 (15.1%)	41 (14.8%)	0.900
Lymph nodes examined, mean (SD)	23 (14)	15 (10)	< 0.001
Negative margin	417 (79.9%)	218 (78.7%)	0.694
Length of stay, days; mean (SD)	9 (8)	10 (9)	0.366
30-day readmission	50 (9.6%)	14 (5.1%)	0.025
90-day mortality	14 (2.7%)	11 (4.0%)	0.319
Survival probability at non-academic centers (multivariate analysis)	HR: 1.26	95%CI: 0.96–1.64	0.093
Distal pancreatectomy			
Total number	488 (59.3%)	335 (40.7%)	
Converted to open	59 (12.1%)	34 (10.1%)	0.388
Lymph nodes examined mean (SD)	14 (12)	10 (11)	< 0.001
Negative margin	436 (89.3%)	296 (88.4%)	0.251
Length of stay, days; mean (SD)	6 (4)	6 (4)	0.044
30-day readmission	51 (10.5%)	30 (9.0%)	0.479
90-day mortality	4 (0.8%)	3 (0.9%)	0.907
Survival probability at non-academic centers (multivariate analysis)	HR: 1.12	95% CI, 0.78–1.60	0.551

*Non-academic includes integrated network programs, community cancer programs, and comprehensive community cancer programs

CI, confidence interval; *SD*, standard deviation

or two regions of the country. The volume of cases appears to not only increase over time but also disperse from a few regional academic centers to community centers nationwide. Those findings likely reflect two phenomena—the proliferation of recent graduates from programs incorporating robotic pancreas surgery into their curricula, and the increased exposure and retraining of established pancreatic surgeons in the robotic technique.[11, 14]

Training programs, such as the one developed at the authors' institution, and an increased engagement of surgical societies in robotic training are in part attributable to this safe dissemination.[12, 27, 28] The Center for Advanced Robotic Training (CART) at the University of Pittsburgh has helped train and proctor a large number of academic and community surgeons around the country based on a mastery curriculum, similar to that employed in the training of our fellows.[12, 28] Coupled with adequate training, surgeons must utilize safe and appropriate patient selection when developing a robotic program at their institution. As with any new procedure or technology, early success is vital before expanding to more difficult cases or higher risk patients.

Importantly, surgical outcomes appear not to be compromised in this transition. In fact, our study indicates that mortality following RPD, which has been a major concern in light of the Dutch trial, has decreased over time. There were fewer lymph nodes examined at non-academic centers, but it is unclear from this analysis how attributable this observation is to surgical retrieval or pathologic examination.

Another interesting finding is that most centers performing RPD and RDP fell within the "low volume" cutoff, with most centers performing an average of less than one case per year (RPD or RDP). A commonly accepted "high volume" cutoff for pancreatic surgery is 20 cases/year.[29, 30] In this analysis, only 5% and 2% of centers performed 20+ RPDs and RDPs, respectively, over the entire study period. It should be emphasized however that this study focused on PDAC and pancreatic NETs, and these "low volumes" do not include pancreatectomies performed for benign disease or other types of periampullary cancer. Interestingly, despite this relatively low volume, surgical outcomes were stable over time and comparable to recently published open benchmarks.[31, 32] This indicates an inherent limitation in arbitrarily assigning procedural volume thresholds for complex procedures such as PD. Many surgeons gain experience and comfort with robotic surgery by performing less complicated procedures before embarking on pancreatectomies. Additionally, overall experience with pancreatic surgery appears to predict outcomes following minimally invasive pancreas surgery according to one study.[6] Thus, while higher hospital volumes certainly predicts improved outcomes for pancreas surgery, the use of arbitrary volume standards has been questioned[29] and may not adequately assess surgeon experience and ability.

There are several limitations to this study. First, our analysis and conclusions are based on the retrospective analysis of blinded data, from which we can only derive statistically significant correlations. Despite this limitation, the NCDB provides a large sample size derived from a combination of low- and high-volume academic and community centers and is a reasonable representation of most cancer-related outcomes nationwide. Second, we were unable to account for individual surgeon experience and training; factors known to influence outcomes. Third, our study focused on primary pancreatic tumors and excluded pancreatectomies performed for periampullary malignancies of the bile duct, ampulla and duodenum, benign disease, and cystic neoplasms. This limited our ability to assess overall hospital and surgeon robotic experience and its impact on outcomes. It would be fair to assume that the findings in this are applicable to RPD and RDP performed for other indications nationwide. Finally, since the NDCB does not provide data on complications, we used length of hospital stay as a surrogate for postoperative complications.

Conclusion

This study suggests that robotic pancreas surgery is being successfully adopted by an increasing number of surgeons and hospitals with acceptable outcomes nationwide. Although this dissemination does not seem to be limited by established volume thresholds for open pancreatic surgery, outcomes are comparable with open surgery benchmarks. These findings support the continued assessment and growth of robotic pancreatic surgery and the need to ensure appropriate training and credentialing of surgeons moving forward.

Compliance with Ethical Standards

The study was approved by the University of Pittsburgh Medical Center Internal Review Board.

Conflict of Interest The authors declare that they have no conflict of interest.

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