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Robotic Pancreaticoduodenectomy: Increased Adoption and Improved Outcomes:

Is Laparoscopy Still Justified?

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Abstract

Objective: To compare the rate of postoperative 30-day complications between laparoscopic pancreaticoduodenectomy (LPD) and robotic pancreaticoduodenectomy (RPD).

Background: Previous studies suggest that minimally invasive pancreaticoduodenectomy (MI-PD)—either LPD or RPD—is noninferior to open pancreaticoduodenectomy in terms of operative outcomes. However, a direct comparison of the two minimally invasive approaches has not been rigorously performed.

Methods: Patients who underwent MI-PD were abstracted from the 2014 to 2019 pancreas-targeted American College of Surgeons National Sample Quality Improvement Program (ACS NSQIP) dataset. Optimal outcome was defined as absence of postoperative mortality, serious complication, percutaneous drainage, reoperation, and prolonged length of stay (75th percentile, 11 days) with no readmission. Multivariable logistic regression models were used to compare optimal outcome of RPD and LPD.

Results: A total of 1540 MI-PDs were identified between 2014 and 2019, of which 885 (57%) were RPD and 655 (43%) were LPD. The rate of RPD cases/year significantly increased from 2.4% to 8.4% ($P = 0.008$) from 2014 to 2019, while LPD remained unchanged. Similarly, the rate of optimal outcome for RPD increased during the study period from 48.2% to 57.8% ($P < 0.001$) but significantly decreased for LPD (53.5% to 44.9%, $P < 0.001$). During 2018–2019,

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RPD outcomes surpassed LPD for any complication [odds ratio (OR) = 0.58, $P = 0.004$], serious complications (OR = 0.61, $P = 0.011$), and optimal outcome (OR = 1.78, $P = 0.001$).

Conclusions: RPD adoption increased compared with LPD and was associated with decreased overall complications, serious complications, and increased optimal outcome compared with LPD in 2018–2019.

Keywords

laparoscopic; minimally invasive; optimal outcome; pancreaticoduodenectomy; robotic

Pancreaticoduodenectomy (PD) is the mainstay of surgical therapy for patients with resectable pancreatic ductal adenocarcinoma and other periampullary pathologies.[1] This surgical procedure is technically demanding and has historically been associated with significant morbidity and mortality.[2] The adoption of minimally invasive pancreaticoduodenectomy (MI-PD) has been slow due to the complexity of the surgical dissection, the need to perform several anastomoses and the initial uncertainty about the added benefits offered by the minimally invasive (MI) platforms over the established open approach (OPD).[3] Retrospective series and randomized trials have highlighted some key advantages of MI-PD which include a decrease in intraoperative blood loss, wound complications, and postoperative pain coupled with quicker recovery time and shorter length of stay (LOS) compared with a laparotomy approach.[4–6] However, selection bias typically favors MI approaches. In addition, laparoscopic pancreaticoduodenectomy (LPD) remains a considerable technical challenge, as highlighted by the LEOPARD-2 trial that demonstrated increased 90-day mortality compared with OPD, which ultimately lead to its early termination.[7] Three other randomized controlled trials also have failed to show a clinically meaningful advantage for LPD.[8–10]

Robotic pancreaticoduodenectomy (RPD) is considered by many as a natural evolution of LPD providing surgeons with increased dexterity from endo-wristed instruments, filtration of tremors, 3-dimensional stereoscopic views of the field, and the ability to perform complex dissection, sutures and knots with unprecedented precision and accuracy.[11,12] Recently, multiple conflicting reports have been published on the safety and feasibility of MI-PD, yet the superiority of one MI-platform over the other has not been established.[13,14] Therefore, the primary aim of this study was to compare RPD and LPD with respect to trends over time, 30-day complication rate, and optimal outcome using a large national database.

METHODS

Study Design

The study utilized the 2014–2019 American College of Surgeons National Sample Quality Improvement Program (ACS NSQIP) pancreas-targeted participant user files (PT-PUF) database to perform a retrospective cohort study comparing RPD and LPD trends and outcomes. The ACS NSQIP collects > 150 variables from 700 participating hospitals, including preoperative, intraoperative, and 30-day postoperative mortality and morbidity outcomes.[15] The PT-PUF files benefits from 26 additional variables specific to pancreatectomy in comparison to the general NSQIP database. The ACS NSQIP database is maintained by trained and certified surgical clinical reviewers who collect and verify the accuracy of the data. Due to the nature of the database used, no institutional review board approval was required for this study.

Patient Selection and Definitions

All patients who underwent elective, nonemergent PD were identified using the procedural terminology (CPT) codes of 41850, 48152 (classic PD procedure with and without pancreatojejunostomy, respectively), 48153, and 48154 (pylorus-preserving PD with and without pancreatojejunostomy).

Patients who underwent other procedures performed concomitantly were excluded. The flow diagram for the final cohort included in the study is presented in Supplemental Digital Content 1 (http://links.lww.com/SLA/E192).

Outcomes and Trends

The primary outcomes of this study were measured at 30 days and included: (a) any complication rate, (b) serious complication rate, (c) optimal outcome, and (d) trends of both LPD and RPD. The data were classified into 3 distinct time periods: 2014–2015, 2016–2017, 2018–2019. Serious complication included any of the following events: pneumonia, unplanned intubation, pulmonary embolism, requiring ventilator support for > 48 hours, deep surgical site infection, organ space surgical site infection, wound dehiscence, deep vein thrombosis/thrombophlebitis, cerebrovascular accident, cardiac arrest, myocardial infarction, sepsis/septic shock, or renal failure.[16] Optimal pancreatic surgery outcome was defined as absence of postoperative mortality, serious complication, percutaneous drainage, reoperation, and prolonged LOS (75th percentile, 11 days) with no readmission.[17,18]

Statistical Analysis

Categorical values were shown as counts and proportions, while continuous variables were reported as medians with interquartile ranges. Univariate linear regression for continuous variables and a Pearson χ^2 or Fisher exact tests or univariate logistic regression were performed, when appropriate, for categorical variables. To determine the association of the type of MI approach with complications and optimal outcome, preoperative and intraoperative factors were adjusted using forward multivariable logistic regression. Variables with *P* value <0.2 on univariate analysis were carried on to the multivariate analysis. The significance level was set at <0.05 for all analyses. Statistical analyses were performed using the IBM SPSS statistical package (Version 26; IBM Corp., Armonk, NY).

RESULTS

Baseline Characteristics

A total of 1540 MI-PD cases met inclusion criteria of which 885 (55.5%) were RPD and 655 (44.5%) were LPD. Patients who underwent RPD were older (67 vs 65 years, $P < 0.05$), more likely to be White (82.4% vs 71.6%, $P < 0.001$), have preoperative biliary stenting (55.2% vs 45.8%, $P = 0.013$), receive neoadjuvant chemotherapy (24.5% vs 17.4%, $P < 0.001$), have pancreatic duct size <3 mm (33.3% vs 24.6%, $P < 0.001$), and soft pancreatic gland texture (48.2% vs 31.1%, $P < 0.001$) compared with LPD (Table 1). Nonetheless, neoadjuvant radiotherapy utilization [7.8% (n = 51/655) vs 3.4% (30/885), $P < 0.001$] and vein resection (12.1% vs 6.1%, $P < 0.001$) were recorded with higher frequency in the LPD compared with RPD group, respectively (Table 1). The two cohorts were similar for the remaining examined variables (Table 1, Supplemental Digital Content 2, http://links.lww.com/SLA/E193).

Univariate Outcomes of RPD Versus LPD

For the entire cohort, LPD had significantly more perioperative transfusions (18.6% vs 9.3%, $P < 0.001$), a longer operative time [421 vs 405 (median, minutes), $P = 0.012$], and a higher rate of serious complication (40.2% vs 33.4%, $P = 0.006$), conversion to laparotomy (31.3% vs 13.3%, $P < 0.001$), and pneumonia (4.4% vs 1.8%, $P = 0.003$) compared with RPD. On the other end, RPD had a significantly higher rate of readmission [21.7% (n = 192/885) vs 16.6% (n = 109/665), $P = 0.013$] compared with LPD (Supplemental Digital Content 3, http://links.lww.com/SLA/E194).

In 2014–2015, RPD had a significantly higher rate of any complication (62.9% vs 47.5%, $P = 0.008$), serious complication (46.8% vs 35%, $P = 0.028$), and superficial surgical site infection (10.6% vs 3%, $P = 0.004$) compared with LPD. As a result, the rate of optimal outcome was lower for RPD compared with LPD (48.2% vs 53.5%, $P = 0.518$); however, this difference was not statistically significant. Nonetheless—even in the early years (2014–2015)—the conversion rate was significantly higher in the LPD (26.7% vs 13.5%, $P = 0.003$) compared with RPD (Table 2). In 2018–2019, RPD had a significantly higher rate of optimal outcome (57.8% vs 44.9%, $P = 0.002$) compared with LPD. Moreover, LPD demonstrated a significantly higher rate of conversion (36.4% vs 15%, $P < 0.001$), perioperative transfusion (22.2% vs 9.4%, $P < 0.001$), any complication (61% vs 47.7%, $P = 0.001$), serious complication (45.3% vs 32.3%, $P = 0.001$), pneumonia (7.1% vs 2%, $P = 0.001$), and prolonged LOS (28.7% vs 20.3%, $P = 0.016$) compared with RPD (Table 3).

Multivariate Analysis of Perioperative Outcomes: RPD Versus LPD

For the entire study cohort—between 2014 and 2019—the odds of any complication, serious complication, and optimal outcome were similar between RPD and LPD on multivariate analysis. In 2014–2015, compared with RPD, LPD had significantly lower odds of any complication [odds ratio (OR) = 0.50, $P = 0.008$] and serious complication (OR = 0.53, $P = 0.008$) (Table 4). However, in 2018–2019, LPD had significantly higher odds of any complication (OR = 1.73, $P = 0.004$) and serious complication (OR = 1.62, $P = 0.011$), while it had significantly lower odds of optimal outcome (OR = 0.56, $P = 0.001$) compared with RPD (Table 5).

Trends Over Time

The relative percentage of RPDs—over all PD recorded in the ACS NSQIP database—has significantly increased from 2014–2015 to 2018–2019 (2.4% vs 8.4%, $P = 0.006$), while no substantial change was observed in the relative percentage of LPD cases (Fig. 1). Notably, the rate of optimal outcome significantly increased for RPD (48.2% vs 52.9%, $P < 0.001$) from 2014–2015 to 2018–2019, respectively. Conversely, any complication (47.5%

vs 57.8%, $P < 0.001$) and serious complication (35% vs 45.3%, $P < 0.001$) significantly increased from 2014–2015 to 2018–2019 among LPD cases (Supplemental Digital Content 4, http://links.lww.com/SLA/E195). Not surprisingly, the increase in LPDs complication rate was accompanied by a significant decrease in optimal outcome (53.5% vs 44.9%, $P < 0.001$) from 2014–2015 to 2018–2019 (Fig. 2).

DISCUSSION

The present study utilized the ACS NSQIP pancreatectomy-targeted PUFs to compare 30-day outcomes of MI-PD performed over a 6-year period. Using a large sample size of 1540 patients, this analysis showed a significantly increasing trend in RPD utilization, as well as significantly improving outcomes for the robotic approach. Conversely, LPD utilization has remained relatively unchanged, with a trend toward increased conversion rates and decreasing optimal outcomes. Importantly, this analysis suggests that in recent years (2018–2019) the robotic approach was significantly superior to the laparoscopic approach with respect to any complication, serious complications, and optimal outcome.

To date, pancreaticobiliary surgeons choose freely—within the limits of their training and MI platform availability—between the 2 MI-PD approaches, namely LPD or RPD. The one for LPD is a sound utilitarian argument, suggesting that laparoscopy platforms are readily available within hospital systems and are already integrated into formal surgical training thus making it a natural transition—for trainees and surgeons alike—to learn how to perform a LPD.[19,20] Moreover, a considerable cost-saving opportunity exists in pursuing laparoscopy as the MI-PD platform of choice—which requires minimal capital investment—compared with the acquisition, per-use cost and overall maintenance of a robotic platform.[20,21] In contrast, supporters of the robotic approach note that the improved ergonomic, visual perception, and wider range of motions offered by articulating instruments allows surgeons and trainees to simplify what would have otherwise been complex MI maneuvers, ultimately leading to increased reproducibility and possibly better outcomes.

The robotic platform has been shown to be at least equivalent to laparoscopic approaches for several organ-specific procedures such as colorectal, urological, gastric, gynecological, and distal pancreatic resection.[22–27] However, no large single-institutional comparisons have been performed for RPD and LPD—since only a limited number of institutions perform MI-PD[28]—and, most surgeons who perform MI-PD have adopted one approach over the other, which further hinders direct comparison via clinical trials or even retrospective analyses.[29]

The current study suggests that any complication and serious complication rates have improved significantly over time for RPD, an observation that is in line with recent reports on robotic surgery for other surgical procedures.[30–32] Indeed, the largest published series on RPD outcomes reported on 500 consecutive RPD cases and suggested that the robotic approach was associated with a temporal trend toward improving operating time, perioperative blood loss, conversion, and clinically relevant postoperative pancreatic fistula despite an increasing complexity of cases over time.[33] Similar findings were replicated by Shi et al[34]—who described their experience with 450 consecutive RPD performed at the Shanghai Ruijin Hospital, China—noting progressive improvement of operative and oncologic outcomes. The results obtained at the University of Pittsburgh Medical Center and Ruijin Hospital need to be interpreted with caution, as they represent retrospective analysis of 2 high-volume independent single-center experiences where surgical procedures were performed by a dedicated surgical team beyond the learning curve for RPD, which limits generalizability.

Nonetheless, when comparing 2 relatively recent technologies it is paramount to evaluate their performance on multiple parameters over a definitive period and, ideally, with data generated from multiple different centers. Although individual metrics of perioperative performance—such as mortality and morbidity—are crucial to understanding surgical quality, they ultimately lack the ability to provide a wholesome understanding of the patient's total experience. Several composite variables have been developed over the years, each with its merits and limitations, yet most recently "optimal outcome" was defined for pancreatic surgery as a compositive variable able to concisely capture the most satisfactory outcome following pancreatic resection.[18] In our cohort, patients undergoing RPD had significantly higher rates of optimal outcome compared with LPD. In addition, the percentage of optimal outcome among RPD cases significantly increased from 2014 to 2019, while no change was noted among the LPD cohort.

Improvements in optimal outcome in robotic pancreas surgery have been previously driven —at least in part—by a reduced postoperative hospital stay and the need for percutaneous drainage.[18,35] Multiple studies have demonstrated a decrease in LOS among robotic-assisted gastrointestinal procedures when compared with laparoscopic ones.[36,37] This difference in LOS remains true even among patients who received enhanced recovery after surgery protocol.[38,39] However, the true driver of improved optimal outcome—within our study cohort—was the decreasing rate of serious complication (46.8%–32.3%). With continued improvement in the RPD technique and the optimization and diffusion of robotic curriculum and training programs, adverse outcomes will likely continue to decrease.

The opposite trend identified among LPD cases, one characterized by lower optimal outcome and higher complication rates and a stalling rate of national utilization certainly raises questions regarding the long-term prospect of the laparoscopic approach. Several reasons might explain these contrasting temporal trends between RPD and LPD. First, validated curricula have been developed for RPD, and are being integrated into both residency and fellowship training programs.[40,41] These curricula might be preferentially steering new adopters of MI-PD toward the robotic platform which is perhaps less technically demanding on surgeons compared with laparoscopy. Moreover, the negative results of the LEOPARD-2 trial and the minimal clinical benefits observed in the recent Chinese randomized controlled trial reported by Wang and colleagues might be also contributing to a general decreasing interest toward LPD.[42,43] In contrast to the LEOPARD-2 trial, which is often criticized for the heterogeneity of the procedural expertise of the participating surgeons—which led to inadequate procedures in 22% of cases based on video review—the surgeons participating in the Wang and colleagues' trial had extensive procedural expertise and yet the benefit of LPD over a classic laparotomy approach were minimal and restricted to 1 day benefit in LOS (16 vs 17).

Previous randomized trials, such as the PADULAP and PLOT, which showed a similar if not superior postoperative morbidity and mortality compared with laparotomy PD were single-institutional analyses often of a single experienced surgeon which makes for difficult generalizability of those results to a wider population of new adopters.[9,10] LPD—when performed by very experienced surgeons in high-volume centers—can achieve remarkable outcomes, as many retrospective studies have shown.[19,44,45] Yet, considering that ~80% of all MI-PDs are still being performed at low volume centers (< 20 MI-PD cases/year) the analysis of a large national database like ACS NSQIP is likely to give a more realistic representation of the national trend again supporting centralization of care for procedures of high complexity.[46,47] Second, the current analysis revealed a significantly lower rate of conversion among RPD as compared with LPD, despite increased utilization. This finding is similar to previous reports, suggesting an increased capacity of the robotic platform to facilitate recovery from intraoperative complications—such as bleeding and difficult dissections—and assist with high-risk anastomoses such as in the setting of soft glands and small pancreatic ducts.[48,49] Conversion from a MI approach to open laparotomy has been linked with increased morbidity. Therefore, that new adopters would gravitate toward a platform perceived to have lower rates of conversion is not surprising.[35,49]

The current study has several limitations. First, the severity of complications as described by the Clavien-Dindo classification could not be determined as this detail is not available in the ACS NSQIP database. However, the classification of complication severity as recorded in the ACS NSQIP represents a valuable surrogate to the Clavien-Dindo classification. Also, procedure-targeted pancreatectomy in NSQIP does define clinically relevant postoperative pancreatic fistulas. Second, the procedure-targeted PUFs do not contain any institutional data; and as such, trends in participating hospitals (volume/surgeon experience) could not be reported. Consequently, this study was unable to determine if the overall increase in RPD volume was a result of established minimally invasive surgery (MIS) surgeons converting to the robotic platform as opposed to new adopting surgeons transitioning part of their volume from OPD to RPD.

Nonetheless, our personal observation, based on physician-to-physician interaction, participation in national and international meetings, and recently published literature, is that the increase in RPD is mostly driven by new adopters of the MIS platform rather than established LPD surgeons transitioning to the RPD approach. The reasons are likely multifactorial—as shown by the data reported in this manuscript, the LPD volume has remained relatively constant with only a marginal decrease—which potentially suggests that providers who have adopted and mastered the LPD platform continue to utilize this technique. Yet, the significant volume increase in RPD argues for either increasing utilization by a few centers or, most likely, increased adoption throughout North America—which we favor based on our personal experience.

Last, outcomes are followed up for only 30 days instead of 90 days, which is usually recommended for pancreatic surgeries.

However, despite these limitations, the statistically significant analysis demonstrating improved optimal PD using the robotic platform and better outcomes of RPD versus

LPD in recent years is a testament of the ongoing efforts toward optimization and safe implementation of MI robotic-assisted pancreatic surgery.

CONCLUSIONS

Between 2014 and 2019, the utilization of RPD has significantly increased and at a faster pace compared with the laparoscopic approach. Overall morbidity, serious complications, and optimal outcome have significantly improved for robotic cases, while having worsened or stayed the same for laparoscopic procedures. RPD is positioned to become the preferred MI-PD approach as suggested by an increasing adoption rate accompanied by a concomitant improvement in perioperative outcome measures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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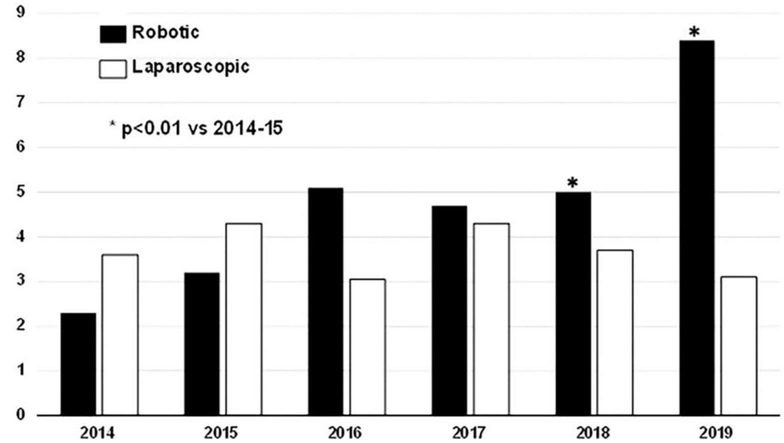

FIGURE 1.

Change in percentage of MI-PD approaches from 2014 to 2019.

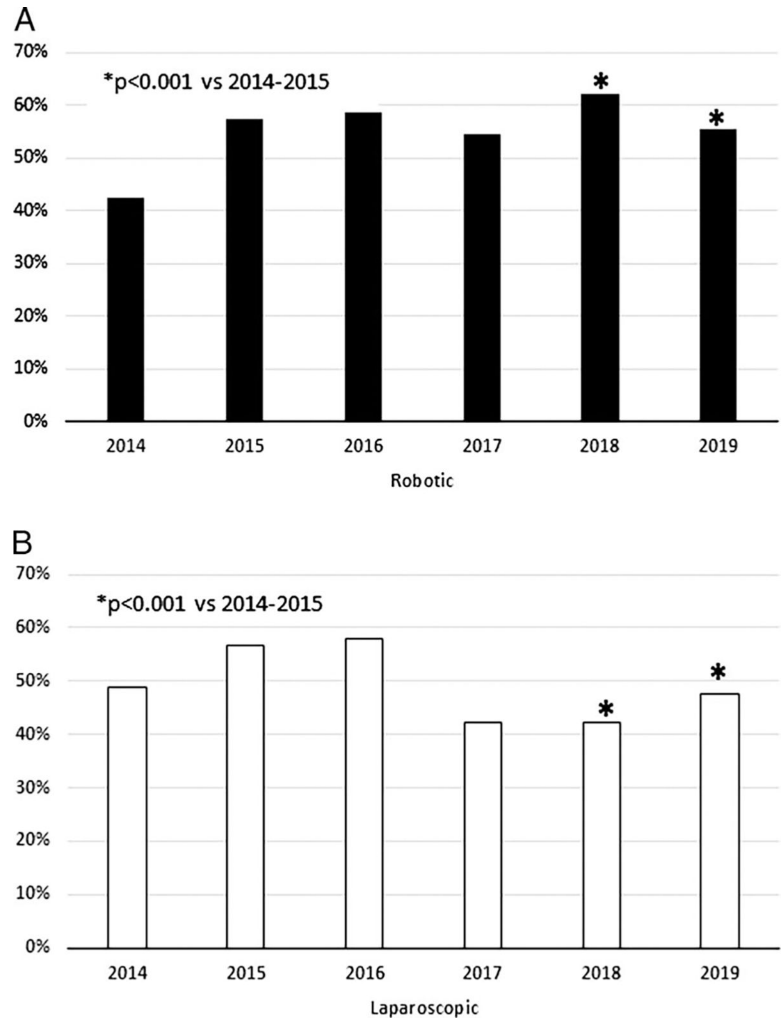

FIGURE 2.

Trends of optimal outcome between RPD (A) and LPD (B).

TABLE 1.

Characteristics of Patients Undergoing MI-PD From 2014 to 2019

	n (%)/Median (IQR)		
	Robotic (N = 885)	**Laparoscopic (N = 655)**	***P***
Age (y)	67 (59, 73)	65 (57, 72)	0.045
Sex			0.764
Male	462 (52.2)	347 (53.0)	
Female	423 (47.8)	308 (47.0)	
Race			< 0.001
White	729 (82.4)	469 (71.6)	
African American	69 (7.8)	57 (8.7)	
Other	87 (9.8)	129 (19.7)	
BMI	27.1 (23.7, 31.1)	26.95 (23.7, 30.4)	0.363
Jaundice	310 (35.0)	237 (36.2)	0.83
Biliary stenting	462 (52.2)	300 (45.8)	0.013
ASA			0.112
I	2 (0.2)	5 (0.8)	
II	211 (23.8)	174 (26.6)	
III	641 (72.4)	445 (67.9)	
IV	31 (3.5)	31 (4.7)	
Neoadjuvant chemotherapy	217 (24.5)	114 (17.4)	0.001
Neoadjuvant radiotherapy	30 (3.4)	51 (7.8)	0.001
Pancreatic duct size			< 0.001
< 3 mm	295 (33.3)	161 (24.6)	
> 3 mm	485 (54.8)	314 (47.9)	
Unknown	105 (11.9)	180 (27.5)	
Pancreatic gland texture			< 0.001
Soft	427 (48.2)	204 (31.1)	
Hard	328 (37.1)	252 (38.5)	
Unknown	130 (14.7)	199 (30.4)	
Vessel resection			< 0.001
None	792 (89.5)	524 (80.0)	
Vein	54 (6.1)	79 (12.1)	
Artery	11 (1.2)	19 (2.9)	
Both	18 (2.0)	19 (2.9)	
Unknown	10 (1.1)	14 (2.1)	
Histology			0.809
Malignant	699 (79.0)	514 (78.5)	
Benign	186 (21.0)	141 (21.5)	
Malignant histology			0.632
PDAC	449 (64.2)	337 (65.6)	

	n (%)/Median (IQR)		
	Robotic (N = 885)	**Laparoscopic (N = 655)**	***P***
Non-PDAC	250 (35.8)	177 (34.4)	

ASA indicates American Society of Anesthesiology; BMI, body mass index; COPD, chronic obstructive pulmonary disease; IQR, interquartile range; PDAC, pancreatic ductal adenocarcinoma.

TABLE 2.

Univariate 30-day Outcomes in 2014–2015

	n (%)/Median (IQR)		
	Robotic (N = 141)	**Laparoscopic (N = 202)**	***P***
Operative time (min)	411 (336, 518)	411 (239, 496)	0.239
Conversion	19 (13.5)	54 (26.7)	0.003
Perioperative transfusion	20 (14.2)	29 (14.4)	0.964
Mortality	6 (4.3)	8 (4)	0.892
Any complication	78 (62.9)	87 (47.5)	0.008
Serious complication	66 (46.8)	70 (35)	0.028
Superficial SSI	15 (10.6)	6 (3)	0.004
Deep SSI	4 (2.8)	2 (1)	0.199
Organ space SSI	20 (14.2)	22 (10.9)	0.407
Dehiscence	1 (0.7)	4 (2)	0.334
Pneumonia	1 (0.7)	8 (4)	0.064
Reintubation	9 (6.4)	9 (4.5)	0.431
Failure to wean off ventilator	3 (2.1)	2 (1)	0.387
Pulmonary embolism	4 (2.8)	10 (5)	0.330
Renal insufficiency	0 (0)	1 (0.5)	0.403
Acute renal failure	2 (1.4)	2 (1)	0.716
UTI	8 (5.7)	3 (1.5)	0.030
Cerebrovascular accident	2 (1.4)	0 (0)	0.090
Cardiac arrest	4 (2.8)	5 (2.5)	0.837
Myocardial infarction	2 (1.4)	0 (0)	0.090
Deep vein thrombosis	4 (2.8)	8 (4)	0.577
Sepsis	10 (7.1)	10 (5)	0.405
Septic shock	4 (2.8)	6 (3)	0.942
CR-POPF	27 (19.1)	25 (12.4)	0.085
Delayed gastric emptying	22 (15.6)	32 (15.8)	0.702
Drain POD30	14 (9.9)	15 (7.4)	0.412
Prolonged LOS	34 (24.1)	44 (21.8)	0.612
Readmission	30 (21.3)	34 (16.8)	0.298
Optimal outcome	68 (48.2)	108 (53.5)	0.084

CR-POPF indicates clinically relevant postoperative pancreatic fistula; IQR, interquartile range; POD, postoperative day; SSI, surgical site infection; UTI, urinary tract infection.

TABLE 3.

Univariate 30-day Outcomes in 2018–2019

	n (%)/Median (IQR)		
	Robotic (N = 446)	**Laparoscopic (N = 225)**	***P***
Operative time (min)	404 (342, 491)	431 (365, 515)	0.061
Conversion	67 (15)	82 (36.4)	< 0.001
Perioperative transfusion	42 (9.4)	50 (22.2)	< 0.001
Mortality	7 (1.6)	8 (3.6)	0.100
Any complication	200 (47.7)	133 (61)	0.001
Serious complication	144 (32.3)	101 (45.3)	0.001
Superficial SSI	25 (5.6)	16 (7.1)	0.442
Deep SSI	1 (0.2)	3 (1.3)	0.078
Organ space SSI	70 (15.7)	46 (20.4)	0.125
Dehiscence	0 (0)	2 (0.9)	0.046
Pneumonia	9 (2)	16 (7.1)	0.001
Reintubation	11 (2.5)	9 (4)	0.270
Failure to wean off ventilator	6 (1.3)	4 (1.8)	0.662
Pulmonary embolism	9 (2)	9 (4)	0.134
Renal insufficiency	3 (0.7)	2 (0.9)	0.758
Acute renal failure	4 (0.9)	5 (2.2)	0.159
UTI	4 (0.9)	3 (1.3)	0.599
Cerebrovascular accident	2 (0.4)	0 (0)	0.314
Cardiac arrest	3 (0.7)	3 (1.3)	0.391
Myocardial infarction	2 (0.4)	4 (1.8)	0.084
Deep vein thrombosis	13 (2.9)	10 (4.4)	0.304
Sepsis	28 (6.3)	16 (7.1)	0.681
Septic shock	12 (2.7)	13 (5.8)	0.046
CR-POPF	82 (18.4)	50 (22.2)	0.238
Delayed gastric emptying	78 (17.5)	39 (17.3)	0.453
Drain POD30	38 (8.5)	25 (11.1)	0.277
Prolonged LOS	88 (20.3)	62 (28.7)	0.016
Readmission	93 (20.9)	42 (18.7)	0.505
Optimal outcome	257 (57.8)	101 (44.9)	< 0.001

CR-POPF indicates clinically relevant postoperative pancreatic fistula; IQR, interquartile range; POD, postoperative day; SSI, surgical site infection; UTI, urinary tract infection.

TABLE 4.

Multivariate Analysis for Any Complication, Serious Complication, and Optimal Outcome in 2014–2015

	Any Complication				Serious Complication				Optimal Outcome			
		95% of OR				95% of OR				95% of OR		
2014–2015	**OR**	**Lower**	**Upper**	***P***	**OR**	**Lower**	**Upper**	***P***	**OR**	**Lower**	**Upper**	***P***
Sex (female)					0.659	0.416	1.042	0.075				
Race												
White	Reference								Reference			
African American	2.404	0.921	6.276	0.073					0.458	0.195	1.074	0.072
Other	0.937	0.425	2.063	0.871					1.318	0.596	2.913	0.495
BMI					1.024	0.989	1.061	0.188				
Diabetes												
None	Reference			0.291								
Non–insulin dependent	1.949	0.844	4.496	0.118								
Insulin dependent	1.044	0.458	2.381	0.919								
History of smoking									0.700	0.388	1.265	0.238
History of COPD	1.361	0.383	4.834	0.634					0.313	0.096	1.025	0.055
History of hypertension	1.494	0.892	2.501	0.127					0.567	0.362	0.887	0.013
Weight loss > 10%	2.605	1.036	6.549	0.042	1.837	0.852	3.959	0.121				
History of bleeding disorder					2.237	0.568	8.810	0.250				
History of obstructive jaundice	0.648	0.393	1.069	0.089	0.596	0.370	0.960	0.033				
Vessel involvement												
None	Reference			0.145	Reference			0.064	Reference			
Vein	1.925	0.868	4.269	0.107	2.170	1.076	4.375	0.030	0.605	0.302	1.212	0.156
Artery	2.600	0.634	10.669	0.185	3.410	0.955	12.169	0.059	0.658	0.174	2.483	0.537
Both	0.459	0.128	1.641	0.231	0.536	0.138	2.085	0.368	0.286	0.075	1.093	0.067
Approach												
Robotic	Reference				Reference							
Laparoscopic	0.506	0.306	0.836	0.008	0.535	0.336	0.851	0.008				

BMI indicates body mass index; COPD, chronic obstructive pulmonary disease.

TABLE 5.

Multivariate Analysis for Any Complication, Serious Complication, and Optimal Outcome in 2018–2019

	Any Complication				Serious Complication				Optimal Outcome			
	Multivariate				Multivariate				Multivariate			
		95% of OR				95% of OR				95% of OR		
2018–2019	**OR**	**Lower**	**Upper**	***P***	**OR**	**Lower**	**Upper**	***P***	**OR**	**Lower**	**Upper**	***P***
Age	1.02	1.01	1.04	0.024	1.01	0.99	1.02	0.506				
Sex (female)									1.24	0.90	1.71	0.176
Race												
White	Reference				Reference							
African American	1.04	0.57	1.91	0.898	1.24	0.68	2.28	0.468				
Other	1.46	0.91	2.34	0.117	1.43	0.91	2.24	0.119				
BMI	1.04	1.08	1.07	0.015								
Diabetes												
None	Reference								Reference			
Non–insulin dependent	0.75	0.45	1.23	0.250					0.86	0.54	1.38	0.551
Insulin dependent	1.65	0.97	2.83	0.067					0.63	0.38	1.05	0.078
History of dyspnea	3.17	1.17	8.54	0.023	2.76	1.12	6.82	0.027				
History of COPD					1.83	0.72	4.65	0.204	0.53	0.20	1.37	0.193
History of hypertension	1.01	0.69	1.45	0.995	1.18	0.82	1.68	0.357	0.88	0.63	1.23	0.474
History of biliary stenting	0.76	0.54	1.07	0.117	0.76	0.54	1.07	0.125	1.99	1.36	2.92	0.000
Neoadjuvant chemotherapy					0.78	0.51	1.21	0.280				
Neoadjuvant radiotherapy									0.63	0.28	1.43	0.276
Duct size > 3 mm	0.48	0.32	0.72	0.000	0.46	0.31	0.69	0.000	1.99	1.36	2.92	0.000
Hard gland texture	0.83	0.55	1.25	0.367	0.76	0.49	1.17	0.215	1.64	0.95	2.82	0.075
Vessel involvement												
None	Reference				Reference							
Vein	1.35	0.77	2.37	0.294	1.68	0.95	2.96	0.074				
Artery	2.89	0.69	12.01	0.145	6.01	1.49	24.14	0.011				
Both	16.70	2.07	135.07	0.008	4.12	1.39	12.23	0.011				
Approach												

2018–2019	Any Complication				Serious Complication				Optimal Outcome			
	Multivariate				Multivariate				Multivariate			
		95% of OR				95% of OR				95% of OR		
	OR	**Lower**	**Upper**	***P***	**OR**	**Lower**	**Upper**	***P***	**OR**	**Lower**	**Upper**	***P***
Robotic	Reference				Reference				Reference			
Laparoscopic	1.74	1.19	2.53	0.004	1.62	1.11	2.36	0.011	0.56	0.39	0.78	0.001

BMI indicates body mass index; COPD, chronic obstructive pulmonary disease.