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ORIGINAL ARTICLE

Pancreaticoduodenectomy for benign and premalignant pancreatic and ampullary disease: is robotic surgery the better approach?

Benedetto Mungo[1] · Abdulrahman Hammad[1] · Samer AlMasri[1] · Epameinondas Dogeas[1] · Ibrahim Nassour[2] · Aatur D. Singhi[3] · Herbert J. Zeh III[4] · Melissa E. Hogg[5] · Kenneth K. W. Lee[1] · Amer H. Zureikat[1] · Alessandro Paniccia[1]

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Abstract

Background The robotic platform is increasingly being utilized in pancreatic surgery, yet its overall merits and putative advantages remain to be adjudicated. We hypothesize that the benefits of minimally invasive pancreatic surgery are maximized in pancreatic benign and premalignant disease, in the setting of friable pancreatic tissue and small pancreatic duct.

Methods Retrospective analysis of our prospectively maintained pancreatic database of all consecutive patients who underwent pancreaticoduodenectomy (PD) for benign or premalignant conditions between 2010 and 2020. Peri-operative outcomes and long-term complications were compared between robotic pancreaticoduodenectomy (RPD) and open pancreaticoduodenectomy (OPD).

Results One hundred and eighty eight ($n=188$) patients met our inclusion criteria, of which 68 were OPD and 120 RPD. Malignant histologies were excluded. There were only minor differences in baseline characteristics between the two groups. Post-operative merits of the RPD included lower clinically relevant post-operative pancreatic fistula 10 (8.3%) vs 24 (35.3%), $p<0.001$, fewer surgical site infections; 9 (7.5%) vs 11 (16.2%), $p=0.024$, shorter operative time, greater lymph node yield; 29 (IQR 21, 38) vs 21 (IQR 13, 34), $p=0.001$, and lower 90 days mortality; 1 (0.8%) vs 4 (5.9%), $p=0.039$. Rates of long-term complications were similar, exception made for a higher occurrence of small bowel obstruction (SBO) 2 (1.7%) vs 4 (5.9%), $p=0.031$ and need for surgical intervention for SBO 0 (0.0%) vs 2 (2.9%), $p=0.019$ in the OPD group.

Conclusion Our study suggests that RPD benefits include lower 90-day mortality, shorter LOS, and lower rates of selected complications compared to open pancreaticoduodenectomy.

Keywords Pancreaticoduodenectomy · Robotic surgery · Benign pancreatic disease

Pancreaticoduodenectomy (PD) represents the primary surgical treatment for several malignant and benign pancreatic conditions occurring in the proximal pancreatic gland. While decades of clinical efforts have led to a significant reduction in operative mortality, rates of short- and long-term morbidities remain substantial even in high-volume institutions [1]. In an effort to improve surgical outcomes, select centers around the world have implemented, studied, and popularized the use of minimally invasive pancreatectomy techniques starting from the 1990 decade, when laparoscopic PD (LPD) was first described [2].

LPD was and remains a technically demanding procedure with a steep learning curve which is fraught with the challenging disadvantages brought on by the limited range of motion caused by linear non-articulating instruments, ultimately making complex tissue dissections and fine reconstructions overly complex [3]. Recent randomized data have stressed the technical complexity and challenges in implementation of LPD, to the extreme of questioning the safety of minimally invasive PD (MIPD) altogether [4].

✉ Alessandro Paniccia
paniccia2@upmc.edu

1 Division of GI Surgical Oncology, Department of Surgery, University of Pittsburgh Medical Center, Scaife Hall, Suite A425, 3550 Terrace Street, Pittsburgh, PA 15261, USA

2 Division of Surgical Oncology, Department of Surgery, University of Florida, Gainesville, FL, USA

3 Department of Pathology, University of Pittsburgh Medical Center, Pittsburgh, PA, USA

4 Department of Surgery, UT Southwestern Medical Center, Dallas, TX, USA

5 Department of Surgery, North Shore University, Chicago, IL, USA

Some of the technical limitations of laparoscopy can theoretically be overcome with the use of the Da Vinci robotic platform, which brings to the table tridimensional magnified visualization in high resolution, range of motion that exceeds that of the human wrist and tremor filtration. The results of the largest series of robotic pancreaticoduodenectomies (RPD) have shown that, in experienced hands, RPD is safe and effective without sacrificing post-operative and oncologic outcomes [5]. Over the last decade, robotic pancreas surgery has slowly but steadily expanded to a variety of centers, both in the academic and private setting [6].

The majority of available comparative analyses between open pancreaticoduodenectomy (OPD) and RPD focus on groups which mostly consist of pancreatic adenocarcinoma patients, where surgical outcomes are influenced and conditioned by the complex underlying pathology and the need for peri-operative systemic therapy [7, 8]. Patients undergoing neo-adjuvant treatment do experience higher toxicity, although it has recently been reported that not only this does not impact negatively oncologic or surgical outcomes, but it could lead to fewer complications [9]. We hypothesize that the benefits of robotic pancreatic surgery are maximized in pancreatic benign and premalignant disease, in the setting of friable pancreatic tissue and small pancreatic duct. The aim of the current study is to compare peri-operative and long-term outcomes of OPD and RPD in this specific subset of patients.

Methods

The present study is a retrospective cohort analysis of the University of Pittsburgh Medical Center prospectively maintained pancreatic database of all consecutive patients who underwent pancreaticoduodenectomy (PD) for benign or premalignant conditions between 2010 and 2020.

This study was approved by the Institutional Review Board of the University of Pittsburgh (19060135); written consent was waived.

Patient demographics, radiologic, and pathologic data, peri-operative outcomes, and short- and long-term post-operative outcomes were collected.

RPD technique utilized in this study has been standardized across the study period and has been described in detail by our group elsewhere [10]. We deliberately excluded from the current analysis patients belonging to the first 80 RPDs performed at our institution—which constituted our institutional robotic learning curve, in order to remove this as a potential confounder [11]. It is worth mentioning that only 16 patients out of those first 80 RPDs met inclusion criteria for our study based on benign pathology and were therefore excluded from the current analysis.

Peri-operative outcomes and long-term complications (> 90-day post-PD) were compared between RPD and OPD. We analyzed selected post-operative outcomes both individually and as part of groups graded according to the Clavien–Dindo classification [12]. The International Study Group for Pancreatic Fistula definitions was used to classify post-operative pancreatic fistulas (POPF) [13]. Post-operative outcomes were collected for 90 days following the day of surgery. Additionally, information on select complications were collected after the 90^{th} day from the surgery until the most recent day of follow-up for each patient.

Normally distributed continuous data were presented as mean ± standard deviation (SD), and the student's *T* test was applied to compare differences between groups. Non-normally distributed variables were presented as median with interquartile range (IQR) and compared using the Wilcoxon Rank Sum test. Categorical data were compared using the chi-squared test or Fisher's exact probability test as appropriate. Association between different complications and surgical approach were compared using univariate Logistic regression analysis. Variables with a p-value of < 0.2 on univariate analysis were inserted into a multivariable model using a stepwise method to reach a best-fit model. p-values < 0.05 were considered significant and all analyses were performed using STATA 14 (STATA Cop, College Station, Texas).

Results

During the time frame of this study, our institution performed a total of one thousand four hundred ten (1410) PDs. Among these, seven hundred eleven (711) were RPDs.

One hundred eighty eight ($n = 188$) patients met our inclusion criteria, of which 68 were OPD and 120 RPD. Selected histologies included but were not limited to adenoma with dysplasia (any grade), intraepithelial neoplasia, intraductal oncocytic papillary neoplasm, intraductal papillary mucinous neoplasm, pseudopapillary neoplasm, serous cystadenoma, and neuroendocrine tumor with no invasive or metastatic features. Demographics are summarized in Table 1. There were no significant differences in baseline characteristics between the two groups, including age, sex, BMI, and age-adjusted Charlson Comorbidity Index (CCI), with a few exceptions. There was a higher rate of coronary artery disease (24.2% vs 9.2%, $p = 0.005$) in the OPD group and a higher rate of hypertension in the RPD group (39.2% vs 24.2%, $p = 0.040$).

Patients in the RPD group were more likely to undergo a classic Whipple procedure (88.3% vs 55.9%, $p < 0.001$). Duct size was comparable between the two groups and so was the anatomical distribution of the lesions, the majority of them being pancreatic lesions (85.6%). Pancreatic

Table 1 Baseline characteristics

Characteristic	Whole cohort ($n=188$)	Open group ($n=68$)	Robotic group ($n=120$)	p-value
Age	68 (57, 73)	68 (59, 74)	67 (57, 73)	0.337[a]
Sex				
Female	94 (50.0%)	37 (54.4%)	57 (47.5%)	0.362[b]
BMI	28.36 ± 5.77	27.84 ± 5.4	28.65 ± 5.95	0.356[c]
Comorbidities				
Hypertension	63 (33.9%)	16 (24.2%)	47 (39.2%)	**0.040**[b]
DM	49 (26.3%)	21 (31.8%)	28 (23.3%)	0.209[b]
Coronary artery disease	27 (14.5%)	16 (24.2%)	11 (9.2%)	**0.005**[b]
Prior abdominal surgeries	112 (59.6%)	39 (57.3%)	73 (60.8%)	0.640[b]
Age-adjusted Charlson Comorbidity Index	4 (3,5)	4 (3,5)	4 (3,5)	0.943[a]
ASA class				
2	46 (24.5%	15 (22.1%)	31 (25.8%)	0.363[b]
3	129 (68.6%)	46 (67.7%)	83 (69.2%)	
4	13 (6.9%)	7 (10.3%)	6 (5.0%)	
Pre-op albumin (mg/dl)	3.88 ± 0.74	3.84 ± 0.57	3.91 ± 0.82	0.611[c]
Tumor size on pre-op CT (mm) ($n=126$)	3.20 ± 1.59	3.35 ± 1.74	3.12 ± 1.51	0.457[c]
Lesion size on EUS (mm) ($n=135$)	2.81 ± 1.34	2.91 ± 1.43	2.75 ± 1.30	0.536[c]

Bold values indicate statistically significant difference

Data are mean (SD), median (IQR), or n (%)

[a]Kruskal–Wallis

[b]Chi-squared

[c]*T* test

[d]Fisher exact

Excluded 16 pts from initial learning curve

parenchyma texture was recorded as "soft gland" in a substantial percentage of patients in both groups, yet missing data in more than 30% of the OPD cohort hindered a meaningful comparison with the RPD cohort.

There were no vascular resections in the RPD group compared to only four vascular resections in the OPD group and the conversion rate in RPD cohort was 5%. Of the four vascular resections, one was an arterial resection of an accessory right hepatic artery arising from the superior mesenteric artery, which was inseparable from a large IPMN. There were three vein resections, all of them side bites of the superior mesenteric vein: one for a sizable serous cystadenoma firmly adherent to the vein and two for bulky neuroendocrine tumors tethered to the vein.

Estimated blood loss was significantly less in RPD (200 ml vs 300 ml; $p<0.001$) and operative time was shorter (360.77 ± 83.40 vs 453.79 ± 159.18 min, $p<0.001$) when compared to OPD. The robotic technique also allowed for greater lymph node yield (29 vs 21, $p=0.001$). Table 2 details surgical and histopathological findings.

When comparing post-operative outcomes between both cohorts, RPD patients experienced more biochemical leaks (POPF grade A), 32 (26.7%) vs 12 (17.6%), $p<0.001$), yet they experienced a significantly lower incidence of clinically relevant post-operative pancreatic fistula (CR-POPF grade B and C), 10 (8.3%) vs 24 (35.3%), $p<0.001$), Table 3. Moreover, surgical site infections occurred less frequently in the RPD group, 9 vs 11 (7.5% vs 16.2%, $p=0.024$). Finally, 90-day mortality was significantly lower in the RPD group, when compared to the OPD group 1 vs 4 (0.8% vs 4.9%, $p=0.039$).

For what concerns the 30-day mortality, one mortality in OPD group was due to aspiration and the other one to bleeding from superior mesenteric artery pseudoaneurysm; the only mortality in the RPD group was due to MI. The two additional mortalities in the 90-day window, which both occurred in the open group, were due to CHF exacerbation and to sepsis.

When comparing relevant long-term outcomes, (Table 4), no statistically significant difference existed between RPD and OPD with the exceptions of a higher incidence of small bowel obstruction (SBO) in the OPD cohort (5.9% vs 1.7%, $p=0.031$) and the need for subsequent surgical intervention (2.9% vs 0%, $p=0.019$) after failure of non-operative management.

Univariate logistic regression models examining factors associated with CR-POPF suggested an association between operative time (continuous variable) and higher estimated

Table 2 Surgical and histopathological findings

	Whole cohort ($n=188$)	Open group ($n=68$)	Robotic group ($n=120$)	p-value
Type of pancreatectomy				**< 0.001**[b]
Classic Whipple	144 (76.6%)	38 (55.9%)	106 (88.3%)	
Pylorus-preserving Whipple	44 (23.4%)	30 (44.1%)	14 (11.7%)	
Duct size	3 (2, 6)	3.5 (2, 6)	3 (1, 5)	0.259[a]
Pancreas parenchyma				**< 0.001**[b]
Soft	80 (42.5%)	36 (52.9%)	44 (36.7%)	
Hard	84 (44.7%)	10 (14.7%)	74 (61.7%)	
Unknown	24 (12.8%)	22 (32.4%)	2 (1.7%)	
Vascular resection				**0.027**[b]
None	184 (97.9%)	64 (94.1%)	120 (100%)	
Converted to open	6 (3.2%)	N/a	6 (5%)	N/a
Operative time/min (median/IQR)	366 (303.5, 464.5)	456.5 (305, 566)	353 (303.5, 400)	**0.002**[a]
Estimated blood loss/ml (median/IQR)	200 (100,400)	300 (200,725)	200 (100,300)	**< 0.001**[a]
Site of lesion				0.157[b]
Pancreas	161 (85.6%)	53 (77.9%)	108 (90%)	0.157[2]
Ampulla	9 (4.8%)	4 (5.9%)	5 (4.2%)	
Bile duct	2 (1.1%)	1 (1.5%)	1 (5.2%)	
Duodenum	16 (8.5%)	10 (14.7%)	6 (5.0%)	
Tumor size (pathologic)	3.42 ± 1.83	3.72 ± 1.97	3.59 ± 1.77	0.112[3]
Lymph node removed	27 (19, 38)	21 (13, 34)	29 (21, 38)	**< 0.001**[2]

Bold values indicate statistically significant difference

Data are mean (SD), median (IQR), or n (%)

[a]Kruskal–Wallis

[b]Chi-squared

[c]*T* test

[d]Fisher exact

Excluded 16 pts from initial learning curve

blood loss (continuous variables) with higher odds of a clinically significant pancreatic leak. Older age, history of diabetes mellitus (DM), larger duct size (continuous variable), pancreatic texture (hard), robotic approach, and higher number of lymph nodes resected (continuous variable) were all associated with lower odds of a clinically significant pancreatic leak (Table 5). On multivariable logistic regression model, RPD and larger pancreatic duct size were the only two factors that remained associated with lower odds of a clinically significant pancreatic leak (Table 5).

Discussion

The results of our analysis suggest that robotic pancreaticoduodenectomy has lower 90-day mortality and lower rates of selected peri-operative and long-term complications when compared to open pancreaticoduodenectomy for the treatment of benign and premalignant pancreatic and ampullary disease. Our data also suggest that RPD is associated with a lower incidence of CR-POPF.

As the robotic platform becomes more commonly available, its utilization is steadily increasing and gradually replacing laparoscopy for procedures requiring complex dissection and reconstruction, such as pancreaticoduodenectomy. Thus, the objective clinical impact of the theoretical advantages conferred by robotic-assisted surgical procedures is closely scrutinized and needs validation [14].

Data from meta-analyses have suggested that minimally invasive PD (MIPD) is associated with shorter length of stay, decreased blood loss, and reduced need for transfusion of blood products when compared to OPD [8, 15, 16]. Similarly, in the current study, we observed reduced blood loss in RPD, while LOS did not appear to be significantly different from OPD. One possible explanation is that the enhanced recovery pathway implemented at our institution in the last 5 years might have benefitted both groups equally. A recent systematic review and meta-analysis, focusing specifically on the comparison between RPD and OPD for the management of benign and malignant periampullary disease, suggest that peri-operative and oncologic outcomes are similar

Table 3 Post-operative complications

	Whole cohort ($n=188$)	Open group ($n=68$)	Robotic group ($n=120$)	p-value
Clavien–Dindo grade ≥ III				0.161[b]
III	22 (11.8%)	7 (10.5%)	15 (12.5%)	
IV	22 (11.8%)	10 (14.9%)	12 (10.0%)	
V	5 (2.7%)	4 (6.0%)	1 (0.8%)	
Length of stay (days	6 (5, 10)	6.5 (5, 16)	6 (5, 8)	0.474[c]
Pancreatic fistula				**< 0.001**[b]
Biochemical leak	44 (23.4%)	32 (26.7%)	12 (17.6%)	
Clinically relevant pancreatic fistula	34 (18.1%)	24 (35.3%)	10 (8.3%)`	
Delayed gastric emptying (Yes)	61 (32.5%)	20 (29.4%)	41 (34.2%)	0.503[b]
Pseudoaneurysm	10 (5.3%)	3 (4.4%)	7 (5.8%)	0.676[b]
GDA	2 (20.0%)	1 (33.3%)	1 (14.3%)	
Hepatic/branches	2 (20%)	0 (0%)	2 (28.6%)	
SMA	3 (30.0%)	2 (66.7%)	1 (14.3%)	
Other	3 (30.0%)	0 (0%)	3 (42.9%)	
Pseudoaneurysm treatment				0.167[b]
Embolization	5 (50.0%)	0 (0%)	5 (71.4%)	
Covered stent placement	5 (50.0%)	3 (100%)	2 (28.6%)	
Operative	0 (0%)	0 (0%)	0 (0%)	
Surgical site infection	20 (10.6%)	11 (16.2%)	9 (7.5%)	**0.024**[b]
Re-operation	12 (6.4%)	4 (5.9%)	8 (6.7%)	0.833[b]
Re-admission	68 (36.2%)	28 (41.2%)	40 (33.3%)	0.282[b]
30-day mortality	3 (1.6%)	2 (2.9%)	1 (0.8%)	0.268[b]
90-day mortality	5 (2.7%)	4 (5.9%)	1 (0.8%)	**0.039**[b]

Bold values indicate statistically significant difference

[a]Kruskal–Wallis

[b]Chi-squared

[c]*T* test

[d]Fisher exact

between the two techniques, with few exceptions, such as decreased blood loss and longer operative time in RPD [17].

As part of the oncologic outcomes of the procedure, we observed greater lymph node yield in RPDs (29 vs 21, $p=0.001$); this finding is not novel and has been also described by other groups [18] and across procedures, such as gastrectomy [19].

Yet, definitive benefits in terms of key outcomes such as mortality or development of pancreatic fistula have been elusive and difficult to demonstrate. Of note, data from national databases and multi-institutional studies seem to point toward non-inferiority of RPD rather than superiority over OPD [20, 21].

A rather constant finding in most series comparing OPD with MIPD outcomes is that pancreatic adenocarcinoma represents the most common histologic diagnosis prompting surgical intervention, where surgical outcomes are influenced and conditioned by the complex underlying pathology and the need for peri-operative systemic therapy [7–9]. Therefore, we hypothesized that an ideal population for studying the benefits of RPD would instead consist of patients diagnosed with pancreatic and ampullary benign and premalignant disease. The rationale for this choice rests on the assumption that the improved dexterity and increased visualization granted by the robotic platform would enhance and facilitate surgical reconstruction in the setting of an expected friable pancreatic texture and small pancreatic duct, as often encountered with premalignant and benign periampullary conditions.

The latter two inherent pancreatic gland characteristics are well studied in the literature and known to be among the most important factors leading to the development of clinically relevant post-operative pancreatic fistula formation, which ultimately is associated with morbidity and mortality in PD.

Furthermore, we hypothesize that a lack or limited involvement of perilesional structures, mesenteric or hepatic vasculature, would present a less challenging

Table 4 Long-term complications

	Whole cohort ($n=188$)	Open group ($n=68$)	Robotic group ($n=120$)	p-value
Any complication (yes)	41 (21.8%)	16 (23.5%)	25 (20.8%)	0.098[b]
Intervention performed				0.117
Percutaneous	11 (5.9%)	4 (5.9%)	7 (5.8%)	
Endoscopic	18 (9.6%)	6 (8.8%)	12 (10.0%)	
Surgical	22 (11.7%)	7 (10.3%)	15 (12.5%)	
Bile duct stricture	20 (10.6%)	6 (8.8%)	14 (11.7%)	0.105[b]
Time to bile duct stricture	315 (164.5, 740)	541 (165, 975)	289.5 (164, 740)	
Intervention–structure				
PTC	11 (5.9%)	4 (5.9%)	7 (5.8%)	0.117[b]
ERCP	14 (7.5%)	3 (4.4%)	11 (9.2%)	0.154[b]
Surgical	2 (1.1%)	0 (0.0%)	2 (1.7%)	0.069[b]
Pancreatitis	16 (8.5%)	7 (10.3%)	9 (7.5%)	0.088[b]
Time to pancreatitis	633 (252.5,925)	666 (552, 1579)	369 (171, 891)	
Small bowel obstruction	7 (3.2%)	4 (5.9%)	2 (1.7%)	**0.031**[b]
Time to SBO	431 (171, 512)	485.5 (431, 560.5)	132.5 (94, 171)	
Surgery for SBO	2 (1.1%)	2 (2.9%)	0 (0.0%)	**0.019**[b]
Incisional hernia	30 (16.0%)	11 (16.2%)	19 (15.8%)	0.115[b]
Time to incisional hernia	403.5 (219, 630)	608 (387, 719)	373 (219, 630)	
Surgery for incisional hernia	18 (9.6%)	5 (7.4%)	13 (10.8%)	0.094[b]
New onset diabetes	5 (2.7%)	0 (0%)	5 (4.2%)	**0.030**[b]
Time to new DM	377 (351, 394)	n/a	377 (351, 394)	
Post-Op pancreatic insufficiency	113 (60.1%)	40 (58.8%)	73 (60.8%)	0.117[b]
GJ Ulcer	3 (1.6%)	2 (2.9%)	1 (0.8%)	0.061[b]
Time to ulcer diagnosis	205 (165, 632)	185 (165, 205)	632 (632, 632)	

Bold values indicate statistically significant difference

[a]Kruskal–Wallis

[b]Chi-squared

[c]*T* test

[d]Fisher exact

Excluded 16 pts from initial learning curve

Table 5 Logistic regression factors associated with POPF grade B/C

Variable	Univariate		Multivariate	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Age	0.97 (0.94–1.00)	0.063		
DM	0.33 (0.11–0.99)	0.49		
Robotic approach	0.40 (0.27–0.61)	< 0.001	0.46 (0.28–0.75)	0.002
EBL/ml	1.0 (0.99–1.00)	0.164		
Duct size/mm	0.79 (0.65–0.97)	0.025	0.75 (0.59–0.95)	0.020
Pancreatic texture (firm)	0.39 (0.15–0.96)	0.041		
Operative time/mins	1.00 (1.00–1.00)	< 0.001	1.00 (0.99–1.00)	0.072
Lymph node harvested	0.93 (0.90–0.97)	0.001		

Combined cohort number of observations = 155, LR $X^2 = 23.02$, $p < 0.001$

surgical dissection and therefore positively impact operative time. This hypothesis was confirmed by our results showing shorter operative time in RPD (360.77 ± 83.40 vs 453.79 ± 159.18 min, $p < 0.001$) when compared to OPD and a conversion rate to laparotomy of only 5%.

The fact that a significant percentage of the RPDs were performed as a two-attending case, and all of them after the learning curve had been achieved, could also have contributed to improve operative time. Most of the patients in this series were two-attending cases at least for portions of the procedure and 59/120 (49.2%) for the entirety of the procedure. Our institution has since largely abandoned that practice, and the percentage of two-attending cases has decreased and has averaged 20% since 2019. We currently reserve two-attending approach to select scenarios, such as in the setting of morbid obesity (BMI > 40), difficult uncinate dissection, sequalae of severe pancreatitis, or need for robotic vein resection.

Our findings on long-term complications match our previously published data for PD for any indication, which suggested that the robotic approach is associated with reduced incidence of SBO when compared to OPD [22]. This is not surprising, considering that open surgery is associated with a more severe inflammatory insult resulting in increased intraabdominal adhesion formation compared to minimally invasive techniques [23].

It is reasonable to hypothesize that the cumulative effect of fewer clinically significant leaks, lesser blood loss, decreased infection rate, and shorter operative time at least in part explains the significant reduction in 90 days mortality observed in our RPD group.

Two randomized trials have shown favorable outcomes of MIPD over OPD [24, 25]. Palanivelu et al. demonstrated shorter LOS and lesser blood loss in MIPD when compared to OPD [24]. The PADULAP trial showed a similar benefit in LOS and, in addition, a reduction in Clavien–Dindo grade ≥ 3 complications [25]. However, the safety of MIPD has been recently questioned by the results of the LEOPARD 2 trial [4].

This randomized controlled trial, comparing OPD with laparoscopic PD, was interrupted early due to increased (but not significant) complication-related 90-day mortality in the MIPD arm. Yet it must be mentioned that institutions only had to perform 20 or more pancreatoduodenectomies annually and surgeons had to have done 20 or more laparoscopic pancreatoduodenectomies before trial participation.

It is worth stressing that MIPD is a highly challenging procedure, with a taxing learning curve. Previously, our group reported on how a formal-structured complex robotic training leads to increased proficiency with MIPD, with the ultimate scope being maximization of surgical quality and patient safety [26, 27]. A recent report suggests that fellowship-trained hepatobiliary surgeons may be able to perform equally OPD and MIPD with good outcomes from the very beginning of their practice [28]. As such, according to our experience, it is reasonable to speculate that the outcomes of RPD are better judged when analyzed in a high-volume setting with dedicated training. Moreover, the volume–outcome relation is well described and has been stressed in the Miami international evidence-based guidelines on minimally invasive pancreas resection [29].

Indeed, we must acknowledge that this manuscript's intent was not to evaluate the learning curve associated with robotic pancreaticoduodenectomy performed in the setting of high-risk pancreatic glands. Yet, we have extensively evaluated our institutional learning curve, which was previously reported at approximately 40 cases, where a significant decrease in the rate of POPF was appreciated (from 27.5 to 14.4%). Still, those initial 40 cases were part of our developmental platform phase, where resection and reconstruction techniques underwent adaptation and optimization [11].

The introduction of formal robotic training curricula and their adoption by trainees and practicing surgeons are impacting the rate at which proficiency in robotic surgery is achieved.

In order to provide some guidance on the learning curve associated with robotic pancreaticoduodenectomy performed in the setting of high-risk pancreatic glands, we analyzed the initial 50 cases experience of one of the authors–who completed a formal robotic training curriculum during fellowship.

Within the initial 50 RPD cases (comprehensive of all histology treated) the rate of grade-B POPF was 12% (six of 50) of which four occurred within the first 20 cases (initial 7 months) and two occurred in the subsequent 30 cases (grade-B POPF 6.6%); no grade-C POPF occurred. Benign and premalignant periampullary lesions (as defined within this manuscript) accounted for 16 out of the initial 50 cases. The rate of grade-B POPF for the first 16 cases of RPD performed in the setting of benign and premalignant periampullary lesions was 12.5% (two of 15). Based on the authors' experience and after reviewing our institutional data, we recommend accumulating an experience of at least 20 cases performing pancreatico-jejunal anastomosis in low- to intermediate-risk pancreatic glands before engaging in the reconstruction of high-risk pancreatic glands.

Our study has several strengths: First, the use of our prospectively populated pancreatic database provides granular information for patient's baseline, tumor, treatment, and outcomes characteristics. Secondarily the highly standardized RPD approach at our institution and the exclusion of learning curve cases minimized deviations in outcomes driven by interpersonal variation in technique or expertise.

The major limitation of our study lies in its retrospective nature. Even though pre-operative patients' and diseases' characteristics had minimal differences between the two groups, selection bias cannot be completely excluded.

These findings are timely and relevant and support the safety of use of RPD in patients with benign and premalignant pancreatic and ampullary disease. This is particularly important when considering that indications for PD in this patient population are oftentimes less compelling than those for malignancy. The occurrence and perhaps the patient's perception of a poor outcome in this setting could be exacerbated by the lack of an absolute indication, such as the presence of definitive malignancy. It is therefore imperative to tailor efforts toward offering this group of patients the safest and least burdensome procedure available.

While randomized data are needed to strengthen our conclusions, our results make a compelling argument in support of increased utilization of the robotic platform in the surgical treatment of benign and premalignant pancreatic diseases, in the appropriate patient population.

Declarations

Disclosures Drs. Benedetto Mungo, Abdulrahman Hammad, Samer AlMasri, Epameinondas Dogeas, Ibrahim Nassour, Aatur D. Singhi, Herbert J. Zeh III, Melissa E. Hogg, Kenneth K. W. Lee, Amer H. Zureikat and Alessandro Paniccia have no conflicts of interest or financial ties to disclose

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