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ORIGINAL ARTICLE – PANCREATIC TUMORS

Robotic Pancreatoduodenectomy: Increasing Complexity and Decreasing Complications with Experience: Single-Center Results from 150 Consecutive Patients

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ABSTRACT

Background. This report describes the authors' experience with 150 consecutive robotic pancreatoduodenectomies.

Methods. The study enrolled 150 consecutive patients who underwent robotic pancreatoduodenectomy between 2018 and 2023. Pre- and intraoperative variables such as age, gender, indication, operation time, diagnosis, and tumor size were analyzed. The patients were divided into two groups. Group 1 comprised the first 75 patients, and group 2 comprised the last 75 cases. The median age of the patients was 62.4 years and did not differ between the two groups.

Results. Morbidity was lower in group 2. The mortality rate was 0.7% at 30 days and 1.3% at 90 days, and there was no difference between the groups. There was a significant reduction ($p < 0.05$) in operative time, resection time, reconstruction time, and conversion to open surgery in group 2. Partial resection of the portal vein was performed in 17 patients and more common in group 2 ($p < 0.01$). The number of resected lymph nodes was higher in group 2. The indication for pancreatoduodenectomy did not differ between the two groups. There was no difference in tumor size or clinical characteristics of the patients.

Conclusions. The robotic platform is useful for pancreatoduodenectomy, facilitates adequate lymphadenectomy, and is helpful for digestive tract reconstruction after resection. Robotic pancreatoduodenectomy is safe and feasible for selected patients. It should be performed in specialized centers by surgeons experienced in open and minimally invasive pancreatic surgery.

Pancreatoduodenectomy (PD) is the gold standard technique for the treatment of tumors in the periampullary region.[1] Pancreatoduodenectomy is one of the most problematic procedures due to its technically demanding nature and high postoperative morbidity. Clinically relevant postoperative pancreatic fistula (CR-POPF) is one of the most common and dangerous complications after PD. With the development of the robotic surgical platform, robotic pancreatoduodenectomy (RPD) has established itself as an alternative to laparoscopic and open pancreatoduodenectomy.[2–5] Equipped with three-dimensional (3D) vision and improved dexterity, RPD is theoretically more flexible and stable than conventional open or laparoscopic PD.[3,4] Previous studies have shown that RPD can reduce intraoperative blood loss and postoperative hospital stay compared with open surgery.[6–8] Furthermore, previous studies suggest that minimally invasive pancreaticoduodenectomy (laparoscopic or robotic) is not inferior to open PD in terms of surgical outcomes.[6–9]

The robotic technique has gained acceptance compared with laparoscopy and has been associated with fewer overall complications, fewer serious complications, and a better optimal outcome.[8]

To date, only a few pancreatic centers worldwide have reported 150 cases or more of RPD.[3–5,10–12] The RPD procedures in these studies were performed mostly by multiple surgeons, which may bias the analysis of the results. The current study aimed to evaluate 150 RPD procedures performed by a single surgeon, analyzing two different periods of the learning curve.

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METHODS

Study Design and Setting

This observational study included a cohort of patients treated in an urban reference center for pancreatic diseases in São Paulo, Brazil. All patients undergoing pancreatic resection at our institution are included in a database prospectively maintained by our hepato-pancreato-biliary (HPB) fellows and clinical study nurses and submitted to a multidisciplinary tumor board. This team retrospectively examined 150 consecutive patients who underwent robotic pancreatoduodenectomy for benign or malignant disease between March 2018 and April 2023. During this period, both the da Vinci Si and the da Vinci Xi robots were available, and the choice of one or the other was based on random assignment by the hospital (first come, first served). All the patients were followed up in our surgical clinic with data collection forms. This cohort of patients was divided into two groups for analysis: the first 75 cases were compared with the last 75 cases to examine the effect of the learning curve.

Preoperative Workup

All cases were presented to a multidisciplinary team before surgery was indicated, and workup could vary depending on the preoperative diagnosis. For example, in patients with pancreatic cancer, a biliary stent might be inserted before surgery if the total bilirubin was above 20 mg/dL. Patients with borderline pancreatic cancer underwent endoscopic ultrasound with biopsy and neoadjuvant chemotherapy. Some patients who had pancreatic ductal adenocarcinoma with high CA19-9 levels, enlarged lymph nodes, or other significant signs of advanced disease might undergo PET-CT to rule out distant metastases. Patients with resectable pancreatic cancer were treated with upfront surgery.

Surgical Technique

The surgical technique remained the same throughout the study period, with few changes in the order and execution of some steps. For example, from patient 65 onward, first artery and mesopancreas excision were routinely performed in malignant cases.[13,14] The patient was placed in the supine and 30° inverted Trendelenburg position. Robot-assisted surgery was performed using either the da Vinci Si or Xi robotic platform (Intuitive Surgical Inc., Sunnyvale, CA, USA). This technique includes five trocars (Fig. 1). A pneumoperitoneum was created with an open technique using the infra-umbilical port (Fig. 1). The pneumoperitoneum was created at 14 mmHg. The remaining trocars were inserted under direct vision (Fig. 1).

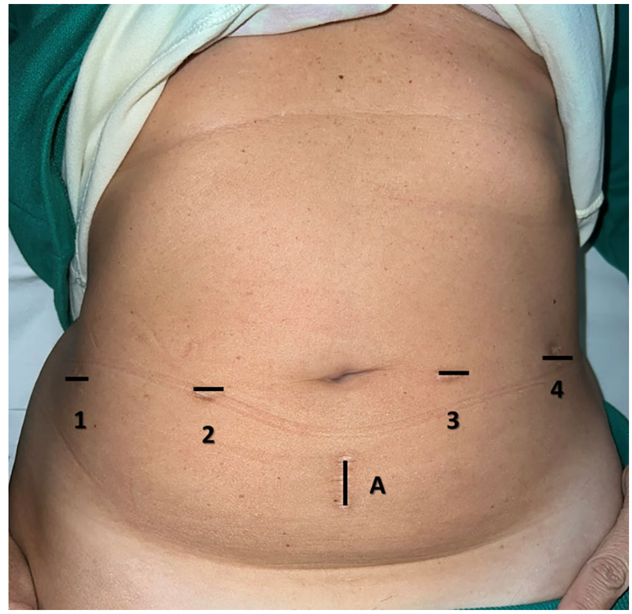

FIG. 1 Trocar disposition. Late postoperative image of the abdominal wall. Four robotic arms are used, as shown. Incision 1 is used for the surgeon's left hand and drainage exteriorization. Incision 2 is used for the camera. Incisions 3 and 4 are for the surgeon's right hand. Incision 4 is used for drainage exteriorization. Incision A is used by the assistant at the bedside

Using this technique, the surgeon sits at the robotic console, and the assistant surgeon stands on the patient's left side. The assistant surgeon performs suction, retraction, clipping, stapling, and changing of the robotic instruments. The most important steps currently for robotic pancreatoduodenectomy can be summarized as follows:

1. The operation begins with opening of the retrocavity and exposure of the pancreas, followed by mobilization of the right colon. A Kocher maneuver is performed with exposure of the inferior vena cava and left renal vein. The superior mesenteric artery (SMA) is identified and dissected along its axis (Fig. 2A).
2. The hilum and gallbladder are dissected. The common hepatic duct is divided and cut below the confluence. The gallbladder is held in its bed and pulled upward to facilitate exposure of the hepatic hilum. The gastroduodenal artery and the right gastric artery are carefully dissected and ligated. The lymphadenectomy is performed with complete skeletonization of the hepatic hilum (Fig. 2B). The right gastroepiploic vessels are divided. The duodenum is transected 2 cm below the pylorus with a stapler (Fig. 2C).
3. The superior mesenteric vein (SMV) and portal vein (PV) are dissected behind the pancreatic neck to create a tunnel (Fig. 2D). An umbilical tape is placed around

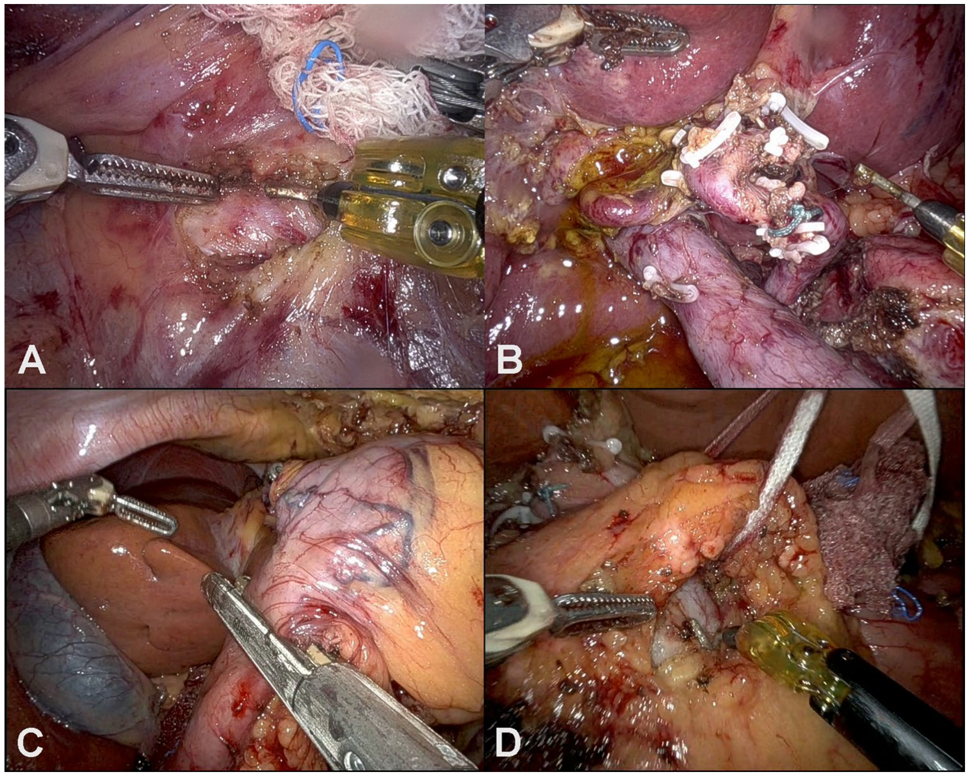

FIG. 2 The main steps of robotic pancreatoduodenectomy. **A** Intraoperative image of the dissection of the superior mesenteric artery. **B** Intraoperative image of the lymphadenectomy. **C** Intraoperative image showing division of the duodenum 2 cm below the pylorus. **D** The intraoperative image shows the portal vein tunnel, which was created behind the pancreatic neck

the pancreatic neck, and the pancreas is divided. The pancreatic margin is sent for frozen-section analysis.

4. The Treitz ligament is mobilized, and the jejunum is passed behind the mesenteric vessels. The proximal jejunum is divided with a stapler. Dissection of the SMA is continued and carried out until it is completely separated from the surgical specimen.
5. The uncinate process is separated from the right side of the SMV and PV, and all major branches are carefully ligated until the surgical specimen is freed. The surgical specimen is then placed behind the liver for later removal.
6. Hemostasis is checked, and hemostatic tissues are placed over major vessels such as the PV, SMV, SMA, and hepatic artery (Fig. 3A).
7. Pancreaticojejunostomy (PJ) An end-to-side duct is used in mucosa reconstruction. A 4-0 prolene suture is used for the outer layer, and a 5-0 polydioxanone suture is used for the anastomosis of the main pancreatic duct in a continuous fashion (Fig. 3B). No stent is left in the main pancreatic duct, regardless of its size.
8. Hepaticojejunostomy (HJ). In performing HJ, 5-0 polydioxanone continuous sutures are used. For thick bile ducts,, especially those with long-term biliary prostheses, 4-0 sutures are used (Fig. 3C).
9. Duodenojejunostomy (DJ). As previously described, DJ is performed using the growth factor technique.[15] In brief, the technique consists of a seromuscular running suture with a zigzag stretch stitch. The suture is performed by placing a longitudinal suture through the seromuscular layer of the duodenum 1 cm below the pylorus and another suture along the jejunal axis. This type of suture stretches the jejunum and allows for future growth of the anastomosis. The second step is to open the duodenum and jejunum. The jejunal opening is longer than the duodenal opening. Therefore, some adjustments are necessary. The angles at the edge of the duodenum are cut according to the size of the jejunal opening so that the posterior suture fits. The third step is to perform a full-length posterior layer with a running suture. Then, the anterior layer of the duodenum is removed to match the length of the jejunum. The next step is to perform a full-length anterior layer with a running suture to match the opening of the duodenum to the longer jejunum (growth factor). The anterior seromuscular layer is then performed with interrupted sutures to accommodate the larger opening, and the duodenojejunostomy is complete (Fig. 3D).
10. The surgical specimen is removed in a plastic bag, and the abdominal cavity is drained: a double-lumen drainage tube is placed near the PJ, and a single-lumen positive pressure tube is placed near the HJ. The drains are exteriorized through robotic arm incisions 4 and 1, respectively (Fig. 1).

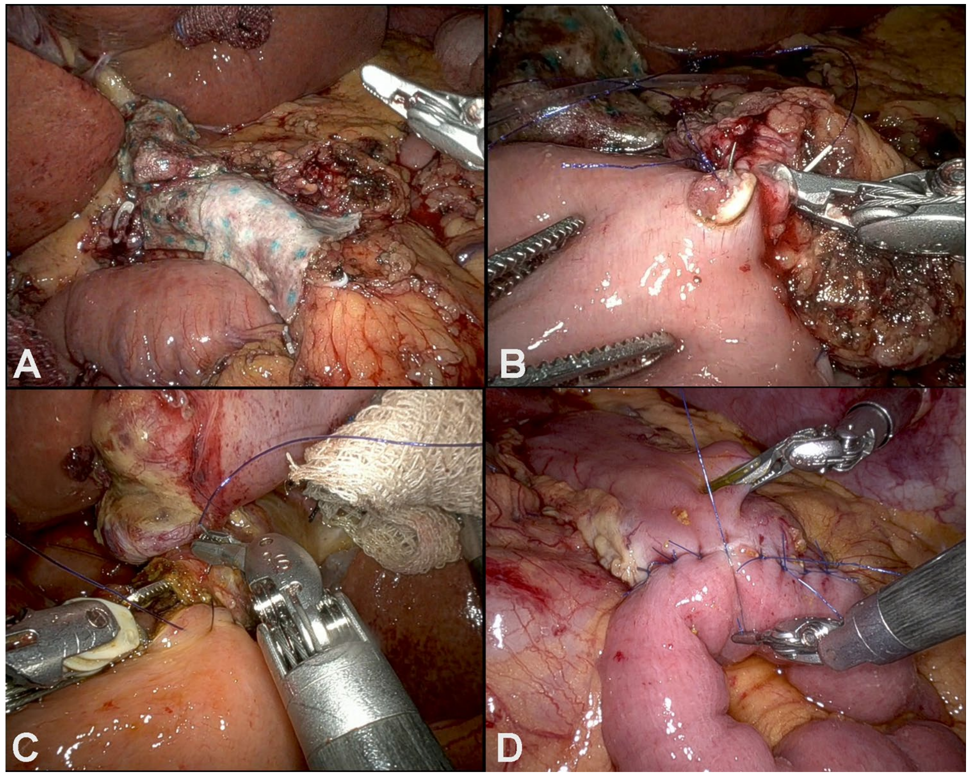

FIG. 3 The main steps of robotic pancreatoduodenectomy. **A** Intraoperative image after resection of the pancreatic head with application of hemostatic tissue to protect the skeletonized vascular structures. **B** Intraoperative image of duct-to-mucosa anastomosis. **C** Intraoperative image of the hepaticojejunostomy. **D** The intraoperative image shows the final aspect of the duodenojejunostomy using the growth factor technique[15]

Postoperative Workup

Most cases are directed to the intensive care unit after the procedure. Some important routines are worth mentioning, such as amylase fluid level measurement on postoperative days (POD) 1 and 3. The nasogastric tube that is left transanastomotic is tractioned about 10 cm on POD2 to be repositioned inside the stomach. On POD3, if the nasogastric drainage is low, the nasogastric tube is removed. As mentioned earlier, we leave two drains, one near the hepaticojejunostomy and another near the PJ. If the amylase fluid level is inferior to 1000 U/L and declining from the measure on POD1, we remove it on the POD4. The HJ drain is removed after the PJ drain on POD5 or POD6 if drainage is less than 400 mL per day and there is no biliary leakage. If a biochemical fistula occurs, the drain is removed about week 3 postoperatively.

Statistical Analysis

Results are presented as mean and standard deviation for numeric variables (after checking for normal distribution) and as number and percentage for categorical data. Comparison between groups was performed using Student's *t* test for paired data, with equal variance for numeric data (after checking normality of distribution), and using the chi-square test for categorical data. A *p* value lower than 0.05 was considered significant.

Cumulative Sum Analysis of the Learning Curve

The learning curve was constructed based on the results of cumulative sum (CUSUM) analysis. This method has been widely used in determining the learning curve to explore different stages of the learning process. The difference between the total operative time for each patient and the average operative time was calculated by chronological order, with the difference in the first patient then accumulated to the next patient to obtain the CUSUM. The calculation formula was $\text{CUSUM} = \Sigma^{n}{}_{i} = 1\ (xi–\mu)$, where xi represents an individual operative time, and μ represents the mean overall time.

RESULTS

During the study period, 150 patients (82 men and 68 women) underwent robotic pancreatoduodenectomy. The average age was 62.4 years (range, 15–85 years). The demographics and comorbidities of the patients are shown in Table 1. The main indication for surgery was pancreatic ductal adenocarcinoma (PDAC) in 70 patients (46.7%), followed by papilla of Vater adenocarcinoma in 21 patients (14%), intraductal papillary mucinous neoplasms (IPMNs) in 20 patients, neuroendocrine tumors (NETs) in 16 patients, distal bile duct cancer in 8 patients, duodenal cancer in 2 patients, solid pseudopapillary neoplasm (SPN) in 3 patients, chronic pancreatitis in 3 patients, immunoglobulin

TABLE 1 Patient demographics and comorbidities

Demographics and preoperative parameters	Patients 1–75	Patients 76–150	*p* value
Median age: years (range) y	63 (27–82)	64 (15–85)	0.3219
Sex (male:female)	36:39	46:29	0.10097
Jaundice	13	19	0.23175
Weight loss	40	51	0.06597
Albumin < 3.5 g/dL	5	3	0.46738
Weight loss > 10%	3	2	0.64921
Mean BMI (kg/m^2)	25.4 ± 3.5	26.1 ± 3.1	0.09053
Hypertension,	29	31	0.73888
Diabetes	22	17	0.35199
Smoking	27	38	0.06991
Alcohol abuse	6	9	0.41422
Prior abdominal surgery	13	19	0.23175
Preoperative biliary drainage	6	11	0.10694
Malignancy[a] *n* (%)	53 (70.7)	61 (81.3)	0.12616

*adenocarcinoma or high-grade neoplasms

G4 (IGG4)-related disease in 2 patients, mucinous cystadenoma in 2 patients, and serous cystadenoma in 1 patient. Three patients with a preoperative diagnosis of IPMN had high-grade dysplasia at final pathology. The pathology, tumor-node-metastasis (TNM) stage, and tumor characteristics of the patients are listed in Table 2.

Operative variables and outcomes are summarized in Table 3. The mean total operative time was 402.4 ± 94 min. The median hospital stay was 7 days (range, 6–71 days). A blood transfusion was required for 10 patients. The mortality rate was 0.6% after 30 days and 1.6 after 90 days. The morbidity rate was 18.7% (28 patients, some with more than one complication). Among the malignant tumors, the median size of the pancreatic tumor was 3 cm (range, 0.8–8 cm), and 19 (range, 4–77) lymph nodes were removed.

Six of the patients experienced postoperative complications unrelated to pancreatic surgery. Two patients had mild pulmonary symptoms, and one patient had cardiac arrhythmia, one patient had Takotsubo syndrome, one patient had transient cerebrovascular accident, and one patient had anaphylactic shock due to latex. According to the revised 2016 International Study Group (ISGPS) classification[16] for postoperative pancreatic fistula (POPF), 108 patients (72%) had no POPF, 32 patients (21.3%) had

TABLE 2 Pathology and TNM stage

	Patients 1–75	Patients 76–150	*p* value
Pathology	*n* (%)	*n* (%)	0.23426
Pancreatic adenocarcinoma	30 (40)	40 (53)	0.10171
Ampullary adenocarcinoma	14 (19)	7 (9)	0.09952
IPMN	11 (15)	9 (12)	0.63095
NET	8 (11)	8 (11)	
Distal bile duct/duodenal cancer	6 (8)	5 (7)	
Benign	6 (8)	3 (4)	
SPN	0	3 (4)	
TNM stage[a]			0.48636
0	1 (1.3)	3 (4)	
IA	1 (1.3)	5 (7)	
IB	10 (13)	9 (12)	
IIA	4 (5.3)	1 (1.3)	
IIB	20 (27)	24 (32)	
III	17 (23)	19 (25)	
Tumor features[a]			
Mean size (cm)	3.1 ± 1.2	3.0 ± 1.3	0.32470
Mean no. of lymph nodes harvested	19.1 ± 11.9	24.3 ± 13.1	**0.00705**
Mean no. of positive lymph nodes	2.5 ± 3.9	3.9 ± 6.4	0.11400
Negative margins (*n*)	2	2	0.88611

Bold value indicates statistical significance ($p < 0.05$)

TNM, tumor node metastasis; IPMN, intraductal papillary mucinous neoplasm; NET, neuroendocrine tumor; SPN, solid pseudopapillary neoplasm

[a]Eighth edition of the American Joint Committee on Cancer (AJCC) TNM staging. Patients with benign or low-grade disease were excluded

TABLE 3 Operative variables and complications

Variable	Patients 1–75	Patients 76–150	*p* value
Mean total operative time (min)	441 ± 92	366 ± 81	**< 0.00001**
Resection time	247 ± 74	200 ± 62	**0.00003**
Total reconstruction time	133 ± 30	112 ± 13	**< 0.00001**
Pancreato-jejunal anastomosis time	51 ± 12	40 ± 6	**< 0.00001**
Hepatico-jejunal anastomosis time	21 ± 8	16 ± 4	**< 0.00001**
Duodeno-jejunal anastomosis time	64 ±13	56 ± 9	**0.00007**
Robotic system Si:Xi	36:39	39:36	0.62421
Mean EBL (mL)	291 ± 149	252 ± 100	**0.03234**
PPPD	72	74	0.31077
Previous bariatric	3	1	0.31077
Portal vein resection[a]	3	14	**0.00461**
Conversion	5	0	**0.02295**
Blood transfusion during hospitalization	6	4	0.51269
Mean ICU stay (days)	1.2 ± 0.6	1.1 ± 0.5	0.43917
Mean hospital stay (days)	9.6 ± 5	9.3 ± 8	0.72316
Biochemical leakage	24	18	0.27523
Overall complications	20	10	**0.04123**
Complications ≥IIIA (Clavien-Dindo)	8	5	0.38396
Mean CCI	12.2 ± 13	8.9 ± 14	0.13503
CR-pancreatic fistula	7	2	0.08561
Grade B	6	2	0.14608
Grade C	1	0	0.31569
Wound infections	1	0	0.31569
Delayed gastric emptying	3	2	0.94921
Cardio-pulmonary complications	3	1	0.31077
Bile leak	3	1	0.31077
Post-pancreatectomy bleeding	2	5	0.24551
Reoperation	0	1	0.31569
30-Day mortality	1	0	0.31569
90-Day mortality	0	1	0.31569

Bold values indicate statistical significance ($p < 0.05$)

EBL, estimated blood loss; PPPD, pylorus preserving pancreatoduodenectomy; CCI, comprehensive complications index; ICU, intensive care unit

[a]Those performed after conversion were excluded

a biochemical leak, and 8 patients (5.3%) had a grade B POPF. Grade C POPF was observed in two patients. Biochemical leak was not considered a surgical complication.

Infectious complications occurred in nine patients (6%). Hemorrhagic complications occurred in five patients: two patients with bleeding from a duodenojejunostomy successfully controlled via upper endoscopy and three patients with pseudoaneurysms of the gastroduodenal artery treated via interventional radiology.

Delayed gastric emptying occurred for three patients (2.2%): one grade B patient and two grade C patients. These patients had prolonged hospital stays (18, 34, and 71 days, respectively). The grade B patient was discharged on POD 18. One patient required reoperation for gastric torsion, with the stomach fixed in the abdominal wall, and was discharged on POD71.

All perioperative outcomes, including total operative time, resection time, and reconstruction time, were analyzed. The total operation time (TOT) decreased as the number of cases increased. The same was observed for each stage of surgery including resection, pancreaticojejunostomy, hepaticojejunostomy and duodenojejunostomy.

Based on the learning curve of the CUSUM analysis of the entire operation time, three different phases of the learning process were identified. From the first patient up to patient 30, there was an upward trend, followed by a stabilization of the learning curve after patient 30 and up

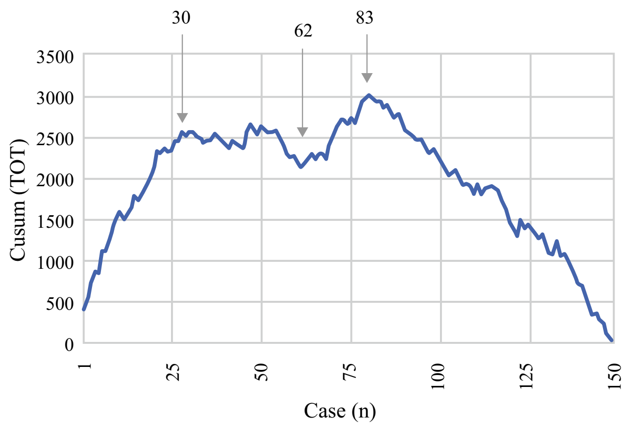

FIG. 4 Cumulative sum (CUSUM) curve of total operating time. From the first case up to patient 30, there was an upward trend, followed by a stabilization of the learning curve after patient number 30 and up to patient 83. From this last patient onward, we observed a downward trend

to patient 83. From this last patient onward, we observed a downward trend (Fig. 4).

The CUSUM analysis of the resection phase showed that the curve stabilized from patient 23 onward, but then increased from patient 65 to patient 84, probably due to the inclusion of more complex cases requiring PV resection. From patient 84 onward, we achieved good performance even with more complex cases, and the CUSUM analysis showed a downward trend (Fig. 5).

According to the learning curve of the CUSUM analysis, the time for completion of the pancreatojejunostomy decreased after 56 patients. The same was observed for hepaticojejunostomy from patient 51 (Fig. 5).

Based on the learning curve of the CUSUM duodenojejunostomy time analysis, three different phases of the learning process were identified. From the first case up to patient 20, there was an upward trend, followed by a stabilization of the learning curve after patient number 30 and up to patient 79. From this last patient onward, we observed a downward trend (Fig. 5), except for patients 107–120, which was probably due to a change in technique (introduction of the transanastomotic nasogastric tube through the duodenojejunostomy from patient 100 onward).

Comparison of Groups 1 and 2

The cohort of patients with the early experience (group 1: the first 75 patients) was compared with another cohort of patients who had undergone the same surgical procedure in the later period (group 2).

Table 1 shows the demographics and comorbidities of the patients in the two groups. Both groups were comparable in terms of gender distribution, age, body mass index (BMI), American Society Anesthesiology (ASA), symptoms, weight loss, alcohol and tobacco abuse, preoperative biliary drainage, previous abdominal surgery, and comorbidities. The two groups did not differ significantly in terms of age, gender, BMI, presence of jaundice, preoperative biliary drainage, weight loss, hypertension, diabetes, tobacco or alcohol abuse, previous abdominal surgery, or malignant diagnoses.

The indication for surgery did not differ significantly between the first 75 and the last 75 patients. There was a trend toward more patients with malignancies in the second period of our experience (group 2), but this difference was not statistically significant (Table 2). The distribution of TNM stages among malignant patients did not differ between groups 1 and 2 (Table 2). There was no difference in tumor size ($p = 0.32470$). However, the number of lymph nodes harvested was significantly greater in the more recent experience. The number of positive lymph nodes and positive surgical margins did not differ between the two groups (Table 2).

The overall operation time was significantly shorter after the first half of our experience (Table 3). In group 2, the average time was reduced by 75 min ($p < 0.00001$). The resection time also was significantly shorter for the last 75 procedures. The same was true for total reconstruction time, which was significantly shorter in the second period of our experience (Table 3). Estimated blood loss was lower in group 2, but did not affect the need for blood transfusion during hospitalization. Standard surgery included pylorus-preserving pancreaticoduodenectomy, but four patients (three in group 1 and one in group 2) had prior bariatric surgery that precluded pylorus preservation. The number of patients who underwent surgery with the latest model (Xi) of the Da Vinci robotic platform was similar in the two groups ($p = 0.62421$).

In group 2, we observed that more patients underwent PV resection ($n = 14$) and reconstruction ($p = 0.00461$) by the robotic approach. In group 1, only three patients underwent robotic PV resections. Portal vein resection (3 patients) or unintentional damage to the porto-mensenteric axis (2 patients) was the cause of conversion for five patients in group 1. No conversion occurred in group 2 ($p = 0.02295$).

Hospital and intensive care stays did not differ between the two groups. Biochemical leakage was observed in 42 patients (24 in group 1 and 18 in group 2; $p = 0.27523$) and was not considered a complication (Table 3). Fewer complications occurred overall in the second study phase ($p = 0.04123$), but the severity of the complications did not differ between the two groups. The occurrence of clinically relevant postoperative pancreatic fistulas (CR-POPFs) did not differ between the two groups. Grade B CR-POPF occurred for six patients in group 1 and for two patients in group 2. Grade C CR-POPF occurred for one patient in group 1. Other complications such as delayed gastric

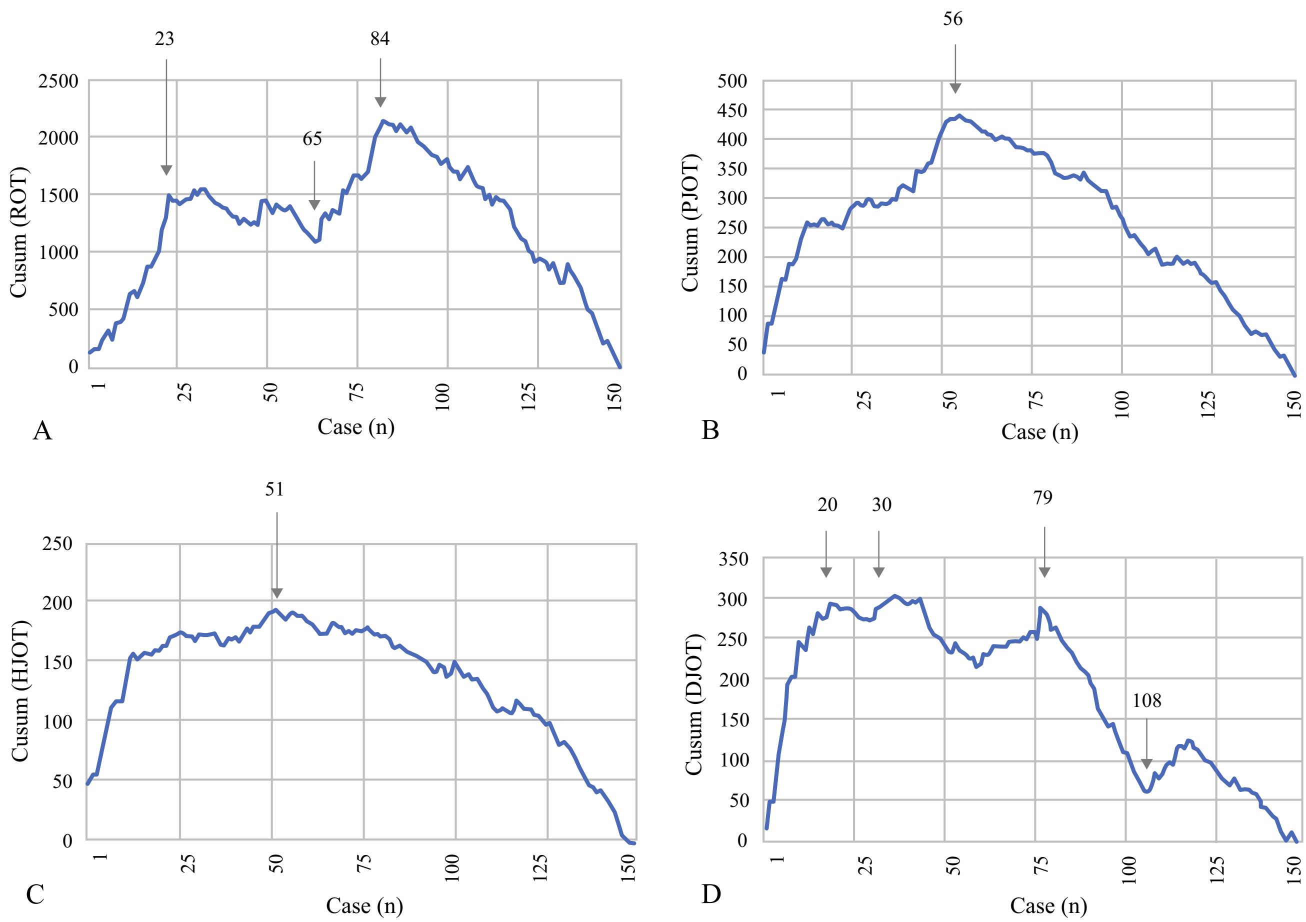

FIG. 5 Cumulative sum (CUSUM) curves of the surgical phases: pancreatic head resection, pancreaticojejunostomy, hepaticojejunostomy, and duodenojejunostomy. **A** The CUSUM curve of the operative time for resection of the pancreatic head (ROT). The curve stabilized from patient 23 onward, but we observed an increase from patient 65 to patient 84, probably due to the inclusion of more complex cases requiring portal vein resection. From patient 84 onward, we achieved good performance even with more complex cases, and the CUSUM analysis showed a downward trend. **B** The CUSUM curve of operative time for pancreatojejunostomy (PJOT). Pancreatojejunostomy completion time decreased after 56 patients. **C** The CUSUM curve of operative time for hepaticojejunostomy (HJOT). The time for hepaticojejunostomy decreased after patient 51. **D** The CUSUM curve of operative time for duodenojejunostomy (DJOT). There was an upward trend from the first case to patient 20, followed by a stabilization of the learning curve after patient number 30 and up to patient 79. From this last patient onward, we observed a downward trend, except for patients 107 to 120, which probably was due to a change in technique

emptying, bile leakage, bleeding, wound infection, and cardiopulmonary complications did not differ between the two groups (Table 3). One patient in group 2 required reoperation due to gastric torsion. One patient in group 1 died before 30 days after surgery, and one patient in group 2 died after 30 days due to postoperative complications.

DISCUSSION

This is the largest series of robot-assisted pancreatoduodenectomies in Brazil and Latin America to date. Despite successful experience with laparoscopic pancreatoduodenectomy, we had difficulties in some cases, especially with patients who had PV invasion, and our conversion rate was high among these patients. In addition, large tumors and anatomic arterial variations were treated with an open approach.

Our initial experience with robotic pancreatic resection in 2008 was limited, and hospital costs were a limiting factor.[17] Since March 2018, a new hospital policy with significant cost reductions for use of the robotic system has prompted us to use the robot systematically in all minimally invasive pancreatic surgery.[18]

In this report, we describe our 5-year experience with robotic pancreatoduodenectomy and discuss our technique and our learning curve. All the patients had their surgery performed by the senior author (M.A.M.). It is important to mention that our team (M.A.M. and F.M.) has a vast experience with laparoscopic liver resections (since 2007) and with laparoscopic pancreatoduodenectomy (since 2012). This previous experience may have affected our learning curve, and the baseline skill of the surgeons may explain the high proportion of PV resections in the current series.

We divided our experience into two groups of 75 cases each. Analysis of the two groups showed no difference in patient demographics and preoperative parameters (Table 1). There also was no difference in pathology or TNM stage (if applicable) (Table 2). However, in the more recent period (group 2), we observed a greater number of lymph nodes harvested from patients with malignant tumors (Table 2). The main reason for this was systematic mesopancreas resection in the second group.[14]

In the more recent period, we observed a significant reduction in total operative time, resection time, and total reconstruction time (Table 3). In our last 75 cases, we reached a plateau in mean operative time (366 ± 81 min). This result was comparable with the last 100 cases (373 ± 76 min) from a larger series that included 500 patients.[4]

The time for each type of anastomosis (pancreatic, biliary, and duodenal) also was significantly reduced in group 2. Several reasons certainly can be given for this reduction. First, the learning curve itself played a major role in this result. However, if we analyze our series, we can see other technical changes that contributed to the better results in the later period (group 2). Systematizing the technique was important to improve the results. Routine fixation of the liver, mobilization of the right colon, and a systematic artery-first approach were important steps to achieve such a reduction.

Another important outcome was a decrease in overall complications (Table 3). The blood loss and conversion rate were significantly lower in group 2 than in group 1 despite the expansion of the selection criteria, including borderline resections. In fact, the number of patients with robotic PV resection was significantly higher in group 2 than in the earlier period.

The learning curve had no effect on the incidence of pancreatic fistulas (Table 3), as found in another series.[2–4] These results may be related to previous experience with open and laparoscopic pancreaticojejunostomy. Several authors reported a decrease in clinically relevant postoperative pancreatic fistulas with increasing experience.[5,11] We believe that the lack of an established skill in performing this anastomosis may pose a high risk for clinically relevant postoperative pancreatic fistula at the beginning of a surgeon's robotic pancreatoduodenectomy experience without prior experience or training in minimally invasive pancreatojejunostomy.[19] However, robotic pancreatoduodenectomy may reduce the number of clinically relevant pancreatic fistulas compared with the open approach, as shown in a propensity-matched analysis.[20]

In our series, we found no difference in delayed gastric emptying between the two groups. However, because we use a modified technique for duodenojejunostomy,[15] our rate of this complication was lower than in other studies (Table 3).[4,19,21,22]

The CUSUM learning curve based on total operative time showed a steady increase until case number 30 and a stabilization of total operative time until case number 62, when we started to operate on more complex patients with the robotic approach, which initiated a steep upward curve until patient 83. This means that the learning curve is 83 cases for more complex cases, including PV invasion, and 30 cases for a simple pancreatoduodenectomy (Fig. 4). However, the learning curves can be better understood if we examine the individual curves.

The individual CUSUM learning curves for the resection phase, pancreatojejunostomy, hepaticojejunostomy, and duodenojejunostomy also were analyzed. We found that the learning curve for the resection phase can be less than 23 cases. However, as we started to include more complex cases, we possibly needed 80 to 85 cases to overcome the learning phase and master robotic pancreatoduodenectomy, which includes resection and reconstruction of the portomesenteric axis.[23–27] Analysis of the CUSUM learning curve for pancreatojejunostomy showed that after 56 cases, we could perform any type of pancreatojejunostomy regardless of the size of the duct and texture of the pancreas. Analysis of the CUSUM learning curve for hepatojejunostomy showed that the learning curve was 51 cases. This anastomosis seems to be easier to perform, but we encountered very small ducts, thick bile ducts, bile ducts damaged by the insertion of a metal prosthesis, and even an accessory right posterior duct, which increased the time to perform the anastomosis. Finally, CUSUM analysis of duodenojejunostomy showed a learning curve of 20 to 30 cases and difficulty reducing the time until patient 79. However, from patient 100 onward, after experiencing gastric torsion in one patient during the immediate postoperative period, we decided to place a nasogastric tube through the duodenojejunostomy to avoid torsion. This led to a further prolongation of the duodenojejunostomy confection time (Fig. 5).

Our previous experience with laparoscopic pancreatoduodenectomy was important in shortening our learning curve.[25] However, the similarity of the robotic approach to pancreatoduodenectomy with the open procedure is much greater than with the laparoscopic counterpart. If the surgeon has experience with open pancreatoduodenectomy and knowledge of laparoscopic surgery, it is not essential to have experience with laparoscopic pancreatoduodenectomy before attempting a robotic Whipple procedure. We also have found that a much higher proportion of patients are suitable for robotic Whipple surgery than for a laparoscopic approach.

The increasing adoption of robotic pancreatoduodenectomy, with improved clinical and oncologic outcomes, may challenge the use of the laparoscopic approach.[28,29] In the Netherlands, after a randomized controlled trial comparing open and laparoscopic pancreatoduodenectomies, which were discontinued due to increased mortality in the laparoscopic group,[30] the number of laparoscopic pancreatoduodenectomies in that country decreased to zero.[19] Conversely, since 2018, we have replaced all minimally invasive pancreatic procedures with the robotic approach. Since our first robotic pancreatoduodenectomy, we have realized that this technique is superior to laparoscopy, and we have abandoned laparoscopic pancreatoduodenectomy despite good initial results.[27]

CONCLUSIONS

The robotic platform is useful for pancreatoduodenectomy, facilitates appropriate lymphadenectomy, and is helpful in reconstruction of the digestive tract after resection. Robotic pancreatoduodenectomy is safe and feasible for selected patients. It should be performed in specialized centers by surgeons experienced in pancreatic surgery. It could replace laparoscopic pancreatoduodenectomy in the near future.

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