Original Article

Robotic-assisted versus open total pancreatectomy: a propensity score-matched study

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Background: Total pancreatectomy (TP) is a complex surgical procedure with significant postoperative morbidity. Despite the narrowed range of indications for TP, the introduction of neoadjuvant chemotherapy and the increasing complexity of surgical resections performed in high-volume centers has increased the number of annually performed TPs, especially regarding malignant disease. The introduction of robotic-assisted pancreatic surgery has provided a novel and minimally invasive approach for TP, yet the feasibility of this technique is still unknown. This study assessed the safety and efficacy of robotic-assisted total pancreatectomy (RTP) compared to conventional open total pancreatectomy (OTP).

Methods: All patients who underwent TP between March 2015 and July 2019 in a high-volume institution for pancreatic surgery were included in this retrospective study. Clinical data and perioperative outcomes were derived from the prospectively maintained institutional database. A 1:1 propensity score matching (PSM) method was utilized to compare the RTP and OTP cohorts to minimize bias.

Results: A standardized surgical protocol was utilized for RTP following a learning curve of RPD and RDP. The median operative time for patients who underwent RTP was significantly decreased compared to those who underwent OTP [300 (IQR, 250–360) *vs.* 360 min (IQR, 300–525), P=0.031]. Additionally, *en bloc* resection and spleen-preserving rates were also higher in the RTP cohort. Major 30-day morbidity (Clavien-Dindo > IIIa) and 90-day mortality were similar between the two cohorts. After a median follow-up time of 15 (IQR, 8–24) months, both the RTP and OTP cohorts had a comparable quality of life regarding exocrine and endocrine insufficiency.

Conclusions: RTP appears to be safe and feasible when utilized in high-volume centers for the indicated management of benign and highly selected malignant pancreatic disease. However, further prospective randomized studies are needed to assess the feasibility of this approach.

Keywords: Robotic-assisted total pancreatectomy (RTP); open total pancreatectomy (OTP); propensity score matching (PSM)

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Introduction

Total pancreatectomy (TP) is a technically challenging operation associated with increased perioperative morbidity and mortality (1,2), whereas the resulting endocrine and exocrine insufficiency has a significant impact on patients' quality of life (3). Even though eligibility criteria for TP are strict, this approach is increasingly utilized for a wide range of pancreatic diseases that include multifocal pancreatic neuroendocrine tumors, main duct intraductal papillary mucinous neoplasms (MD-IPMN), pancreatic ductal adenocarcinoma (PDAC), chronic pancreatitis (CP) and even multifocal metastatic pancreatic tumors (4-6). The current optimization of postoperative complication management in pancreatic surgery and improved approaches in the management of postoperative pancreatic endocrine and exocrine insufficiency permit the adoption of TP as an option for the treatment of highly selected patients (7).

In recent years, the prevalence of minimally invasive techniques for pancreatic resections has been significantly increasing. Retrospective studies and recent randomized trials demonstrate that both laparoscopic and robotic-assisted pancreatic surgery is efficacious and safe (8-11). Regarding the latter, an increasing amount of data demonstrates the effectiveness and feasibility of robotic-assisted pancreatic surgery with perioperative and oncological outcomes, which is comparable to open approaches (12-14). However, data on the role of robotic-assisted total pancreatectomy (RTP) are limited; only small retrospective studies have provided an early insight into the potential of this novel approach (15-18). Our department of pancreatic surgery is a high-volume center. In the past 3 years, we have performed 1,000 pancreatectomies annually (year 2017: 1,002; year 2018: 1,089; year 2019: 1,077) including 300 annual robotic pancreatectomies (year 2017: 352; year 2018: 299; year 2019: 271). This study presents a series of patients who underwent RTP, demonstrates their perioperative and long-term outcomes, and compares the results to a cohort of patients who underwent open total pancreatectomy (OTP).

We present the following article in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/hbsn.2020.03.19).

Methods

Patient cohort and data collection

All patients who underwent TP from March 2015 to July 2019 in the Pancreatic Surgery Department of Ruijin Hospital affiliated with Shanghai Jiaotong University School of Medicine were eligible for this retrospective study. The decision to offer a robotic or open approach for TP was decided on an individual basis by the surgical team by considering patient performance status, body habitus, and the status of previous complex abdominal surgeries in combination with patient preference. Patients who underwent completion pancreatectomy for tumor recurrence or as an emergency management of postoperative complications were excluded from the study. Furthermore, patients who underwent near-TP without duodenectomy for any indication or TP for acute necrotizing pancreatitis were also excluded from the cohort.

The prospectively maintained institutional database and electronic medical records were primarily utilized for the collection of clinical and demographic data, perioperative surgical outcomes, pathology results, and long-term patient follow-up. Patients were reviewed every 3 months through outpatient clinic appointments that consisted of a physical examination, laboratory tests for endocrine and exocrine insufficiency assessment, updated imaging, and a quality of life evaluation. Intermittent communications via phone were also conducted at shorter time intervals. The Clavien-Dindo classification system was utilized to assess postoperative complications (19).

All of the included patients had previously signed an informed consent and agreed to data collection. This study was approved by the institutional review board of Shanghai Ruijin Hospital (No. 2017-180). The study was performed in accordance with the Declaration of Helsinki (as revised in 2013).

Statistical analysis

SPSS 22.0 (IBM, Chicago, IL, USA) and the R statistical packages (The R Foundation; http://www.r-project.org; version 3.4.3) were utilized for statistical analysis and propensity score matching (PSM). Propensity scores were based on baseline characteristics including age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) status, vascular involvement, position and distribution of the lesion, involvement of adjacent organs, artery variation, and pathology types. The matching was performed in a 1:1 ratio, and a caliper width of 0.2 standard deviations (SDs) was specified. Continuous data were summarized as mean values and SDs or the median values, interquartile intervals and ranges (IQRs) were utilized. Student's *t*-test or the Mann-Whitney U test was used for comparison of continuous variables, and the chi-square

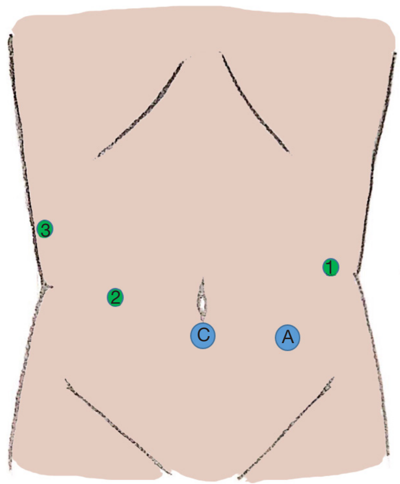

Figure 1 Trocar position.

or Fisher's exact test was used for analysis of categorical variables; categorical variables were expressed as numbers and percentages. A P value of <0.05 was considered statistically significant.

Operative technique for RTP

For all cases, the da Vinci Si Surgical System (Intuitive Surgical Inc. Sunnyvale, CA, USA) was utilized, and a 5-port trocar placement was set up as previously described (20-23) (*Figure 1*). Dissection was performed using harmonic shears, fenestrated bipolar forceps, and Cadiere forceps; the harmonic shears was switched to a needle holder for secure suture and reconstruction. Standard endoscopic staplers were utilized for transection of the jejunum and distal stomach.

A traditional "dividing technique" was employed for solitary benign or borderline tumors of the pancreas with transection of the pancreatic parenchyma at the pancreatic neck and separation of the procedure into two steps: pancreaticoduodenectomy (PD) followed by distal pancreatectomy (DP). When this approach was applied for malignant lesions, assessment of the resection margin was done with a frozen section, and a subsequent TP was performed if the margin was positive and the remnant pancreas was not suitable for anastomosis. In patients with MD-IPMN or selected malignant lesions without vascular involvement, an *en bloc* resection of the pancreatic gland was performed (nondividing technique). For all RTPs, the dissection was initiated by dividing the gastrocolic ligament and continued in an antegrade counterclockwise fashion as demonstrated in *Figure 2*: an extended Kocher maneuver was initially performed for mobilization of the duodenum with identification of the vena cava followed by transection of the jejunal loop approximately 10 cm from the duodenojejunal flexure. Dissection around the SMV/PV/SV was then performed with division of the gastrocolic trunk when indicated. Further mobilization of the distal pancreas and spleen was followed by assessment, dissection, and division of the splenic vessels when a concurrent splenectomy was necessary. In patients where spleen preservation was planned, either the Kimura or Warshaw technique was utilized based on an individual basis (24,25). The next step included dissection of the hepatoduodenal ligament with identification of the common hepatic artery (CHA) and division of the gastroduodenal artery (GDA) and right gastric artery. The common bile duct was divided, and the dissection continued medially with transection of the distal stomach. The whole specimen was shifted towards the right side, and the last step involved resection of the uncinate process with division of the pancreatoduodenal venous branches and the inferior pancreaticoduodenal artery.

In patients with potential vascular involvement, thorough preoperative assessment of the reconstruction was performed, and an "artery-first" approach was always utilized (26-28). When a venous resection was deemed intraoperatively necessary, clamping with laparoscopic bulldog clamps was performed prior to the last step of tumor dissection from the PV/SMV confluence. Vascular reconstruction was performed based on the vein deficit, either as a primary closure or an end-to-end anastomosis, both with continuous 5-0 nonabsorbable sutures. Reconstruction of the choledochojejunostomy and gastrojejunostomy was conducted in a standardized single-layer continuous fashion, and a single abdominal drain was routinely placed. Drain removal occurred on postoperative day 5–7, based on the patient's postoperative course, volume of drain fluid, and imaging when available. In all cases, patient-directed oral intake was followed postoperatively, most often with a liquid diet from postoperative day 3. Long-acting insulin was initiated after establishment of adequate oral intake with strict glucose surveillance and a subsequent dose adjustment. Pancreatic enzyme supplementation was also administered at the same time.

When a simultaneous islet-cell autotransplantation (IAT) was planned at the time of RTP, a "dividing technique" was employed with division of the pancreatic neck and performance of a DP as a first step. The distal pancreas and spleen were immediately resected after transection of the splenic vessels for optimal preservation of a viable

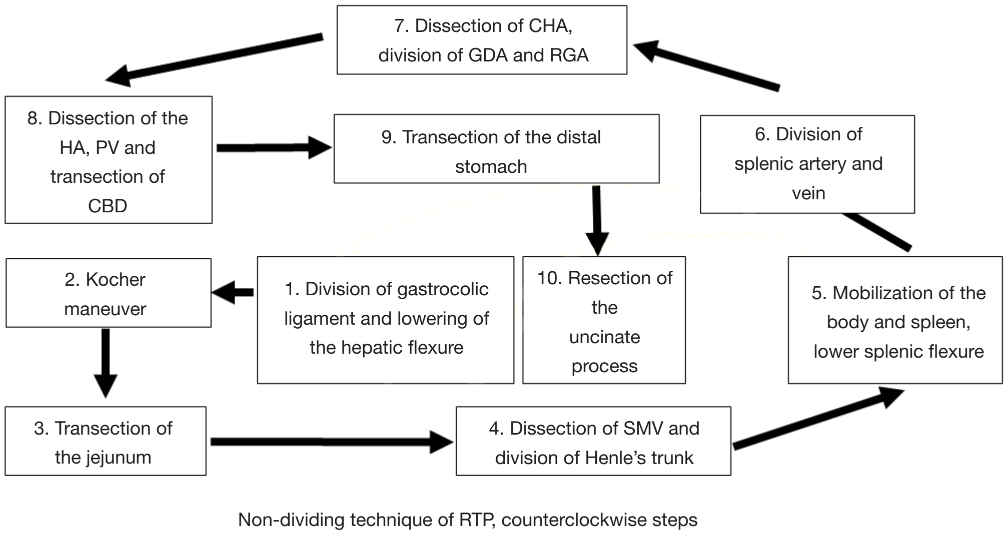

Figure 2 Operative steps of RTP. CHA, common hepatic artery; GDA, gastroduodenal artery; PV, portal vein; RTP, robotic-assisted total pancreatectomy; SMV, superior mesenteric vein.

islet cell population. A PD was then performed, while the distal pancreas was being cleaned and perfused. Prompt extraction of the PD specimen was performed after division of the GDA. Islet cell isolation was performed overnight at the laboratory, and cell pellets were injected into the portal vein (PV) under local anesthesia on postoperative day 1 using ultrasound and confirmed by digital subtraction angiography (DSA) in a hybrid operation room.

Results

Patient cohort

Overall, 117 patients were deemed eligible for inclusion within the studied time period (*Figure 3*). Twenty-four patients were excluded (21%) because they underwent completion pancreatectomy (n=14), duodenum-preserving TP (n=3), or acute necrotizing pancreatitis was the indication for surgery (n=7). Of the remaining 93 patients, 15 underwent an RTP (16%) and 78 an OTP (84%). A comparison of the two groups demonstrated that patients who underwent OTP had significantly lower BMI compared to the ones in the RTP group (P=0.025, *Table 1*). Additionally, OTP patients were found to more often have vascular involvement by the tumor (P=0.026) and aberrant arterial anatomy (P=0.032). Pancreatic adenocarcinoma was the main indication for surgery in the OTP group (82.1%) when compared that of the RTP group where benign lesions were encountered more often (73.3%, P<0.001). No differences were identified in tumor location distribution. After PSM, no differences were identified in patient characteristics between the two cohorts (*Table 1*).

Intraoperative and postoperative outcomes

Intraoperative outcomes were also comparable, but specific key differences were identified (*Table 2*). Operative time was significantly lower in the RTP group (300 *vs.* 360 min, P=0.008), and the difference remained significant after PSM (P=0.031). Additionally, on initial analysis, patients in the RTP cohort were more likely to undergo spleen-preserving resection (P=0.004) and less likely to undergo venous resection and reconstruction (P=0.026). Furthermore, the median postoperative length of stay was lower in the RTP group (18 *vs.* 20 days, P=0.042); in terms of pathology, lymph node resection was more effective in the open approach (17 *vs.* 12 harvested nodes, P=0.018). All aforementioned differences were effectively eliminated after PSM.

One patient in the RTP group underwent a simultaneous IAT. The warm ischemia time was 10 min, and the isolation time was 150 min. The total islet yield was 200,000 islet equivalents (IEQ), which corresponded to a total dose of 4,000 IEQ per kilogram of body weight.

Postoperative complication rates were similar between the two groups. The major 30-day morbidity (Clavien-Dindo > IIIa) was 6.7% (n=1) and 14.1% (n=11) in the RTP and OTP

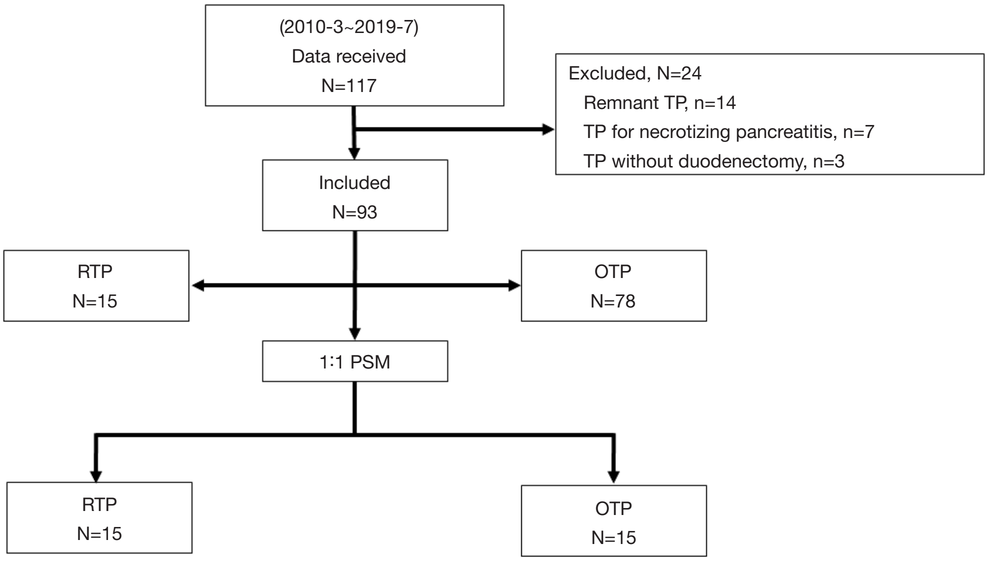

Figure 3 Flow chart. OTP, open total pancreatectomy; RTP, robotic-assisted total pancreatectomy.

group, respectively (P=0.431). No statistical difference was seen after PSM. A detailed presentation of clinical data and outcomes of RTP patients is available in *Table 3*.

Long-term follow-up and oncological outcomes

The median follow-up for all patients was 15 (IQR, 8–24) months. Two patients with severe diarrhea and two patients with diabetic ketoacidosis in the OTP group were readmitted after 3 months. None of the patients in the RTP group presented with severe symptoms from the resulting postoperative endocrine or exocrine insufficiency. In the RTP group, two patients with PDAC presented with disease recurrence at 11 months after the operation, and one of them succumbed to the disease immediately after recurrence. One additional patient died due to a perforation of the digestive tract at 4 months. In the OTP group (after PSM), two patients died because of liver failure caused by a PV thrombosis after PV/SMV reconstruction at 1 and 7 months. One patient had a recurrence 10 months after the surgery and died 3 months later.

Discussion

The main reason for limited utilization of TP is the significant postoperative long-term morbidity (3,29) due to the development of brittle diabetes (Type 3c) and the establishment of exocrine insufficiency that occasionally outweighs the benefits of the operation (regarding patient quality of life or even survival). However, improvements in surgical techniques and optimization of perioperative care of patients who undergo TP have allowed acceptable morbidity and mortality and favorable long-term outcomes in these patients (2,5).

The implementation of minimally invasive pancreatic surgery has paved the road for a similar approach in TP (10,30). The first case series was performed with a laparoscopic approach (11,31-34), but robotic-assisted TP reports were soon published (15-17,35,36). Initially, surgeons had to overcome the combination of a learning curve in robotic surgery and the surgical challenges of TP, which explains why most patients in the first series had a diagnosis of CP or benign pancreatic lesions (15,17,36). Nevertheless, the extra degree of freedom with the robotic approach allows more precise dissection of vascular pedicles and accurate manipulation of the tissues (37). Some researchers believe that the more complicated the surgery is, the more robotic surgery should be applied (38). So far, there have been seven publications on RTP ranging from one to eleven patients (*Table 4*). The most comprehensive series is from Boggi *et al.* in 2015 (15), which demonstrated for the first time the feasibility of a robotic approach in TP. However, in this report, we focus on the description of the *en bloc* resection of the pancreas. Furthermore, we compared patient outcomes with a propensity-matched cohort of patients who underwent OTP.

Table 1 Baseline characteristics of the study population

Characteristics	Before PSM			After PSM		
	RTP (n=15)	OTP (n=78)	P value	RTP (n=15)	OTP (n=15)	P value
Age, years	61 [47–68]	65 [57–71]	0.241	61 [47–68]	66 [48–69]	0.771
Sex, n (%)			0.956			1.000
Female	7 (46.7)	37 (47.4)		7 (46.7)	6 (40.0)	
Male	8 (53.3)	41 (52.6)		8 (53.3)	9 (60.0)	
BMI	22.2±4.6	21.6±2.9	0.025	22.2±4.6	22.6±3.9	0.288
ASA, n (%)			1.000			1.000
≤2	11 (73.3)	56 (71.8)		11 (73.3)	12 (80.0)	
>2	4 (26.7)	22 (28.2)		4 (26.7)	3 (20.0)	
CA19-9, n (%)			0.007			0.450
≤35 IU/L	11 (73.3)	28 (35.9)		11 (73.3)	8 (53.3)	
>35 IU/L	4 (26.7)	50 (64.1)		4 (26.7)	7 (46.7)	
PV/SMV involvement, n (%)	3 (20.0)	40 (51.3)	0.026	3 (20.0)	6 (40.00)	0.427
Artery variation, n (%)	0	19 (24.4)	0.032	0	1 (6.7)	1.000
Adjacent organ involvement, n (%)	0	3 (3.9)	0.440	0	0	–
Tumor size	3.5 (2.7–5.5)	4.5 (3.0–6.4)	0.780	3.5 (2.7–5.5)	4.5 (3.4–6.0)	0.955
Pathology, n (%)			<0.001			0.791
PDAC	4 (26.7)	64 (82.1)		4 (26.7)	6 (40.0)	
LGM or RCC	8 (53.3)	12 (15.4)		8 (53.3)	7 (46.7)	
CP or benign tumor	3 (20.0)	2 (2.6)		3 (20.0)	2 (13.3)	
Lesion distribution, n (%)			0.175			1.000
Total pancreas or multifocal	9 (60.0)	32 (41.0)		9 (60.0)	9 (60.0)	
Pancreatic neck	6 (40.0)	46 (59.0)		6 (40.0)	6 (40.0)	

OTP, open total pancreatectomy; RTP, robotic-assisted total pancreatectomy; BMI, body mass index; ASA, American Society of Anesthesiologists; PV/SMV, portal vein/superior mesenteric vein; PDAC, pancreatic ductal adenocarcinoma; LGM or RCC, low-grade malignancy including pNET and IPMN or renal cell carcinoma metastasis; CP, chronic pancreatitis; PSM, propensity score matching.

In the RTP group, there was an equal distribution of patients with benign (CP, cystic lesions or low-grade neuroendocrine tumors) and malignant disease [pancreatic adenocarcinoma or renal cell carcinoma (RCC) metastases] (53% and 47%, respectively). As expected, the proportion of patients with PDAC in the OTP group was higher, which explains the statistical difference in CA19-9 levels, BMI and vascular involvement. All patients with PDAC necessitating a TP were classified as locally advanced or borderline resectable; surgical resection in these patients was associated with longer operative time, increased estimated blood loss (EBL), occurrence of vascular reconstruction, and increased incidence of postoperative complications (2). To reduce bias from confounding variables, we utilized the concept of PSM to optimally compare the two groups: after PSM, the two cohorts had a similar distribution of malignant disease diagnosis and subsequent vascular reconstruction.

Furthermore, the operative time in the RTP cohort was significantly lower compared to that in the OTP cohort. These results contradict previous reports that have demonstrated longer operative times for robotic resections (15,38,39). However, recent studies have showed that the operative time in robotic pancreatic surgery can be reduced after a variable learning curve of 20–80 cases

Table 2 Perioperative outcomes of the study population

Outcomes	Before PSM			After PSM		
	RTP (n=15)	OTP (n=78)	P value	RTP (n=15)	OTP (n=15)	P value
Operative time (min), median [IQR]	300 [250–360]	360 [300–450]	0.008	300 [250–360]	360 [300–525]	0.031
EBL (mL)	400 [200–700]	700 [425–1,000]	0.469	400 [200–700]	1,000 [500–1,500]	0.164
R0 resection, n (%)	15 (100.0)	77 (98.7)	1.000	15 (100.0)	15 (100.0)	1.000
En bloc, n (%)	11 (73.3)	36 (46.2)	0.054	11 (73.3)	6 (40.0)	0.139
PV/SMV reconstruction, n (%)	3 (20.0)	40 (51.3)	0.026	3 (20.0)	6 (40.0)	0.427
Spleen-preserving, n (%)	4 (26.7)	2 (2.6)	0.004	4 (26.7)	0	0.099
Biliary leakage, n (%)	0	4 (5.1)	0.840	0	0	–
GJ leakage, n (%)	0	1 (1.3)	1.000	0	0	–
DGE, n (%)	1 (6.7)	3 (3.9)	0.622	1 (6.7)	1 (6.7)	1.000
Abdominal infection, n (%)	2 (13.3)	17 (21.8)	0.457	2 (13.3)	1 (6.7)	1.000
PPH, n (%)	1 (6.7)	3 (3.9)	0.622	1 (6.7)	1 (6.7)	1.000
Chyle leak, n (%)	0	3 (3.9)	1	0	2 (13.3)	0.483
Others, n (%)	2 (13.3)	11 (14.1)	0.937	2 (13.3)	3 (20.0)	1.000
Reoperation, n (%)	0	2 (2.6)	1	0	1 (6.7)	1.000
Major complications, n (%)	1 (6.7)	11 (14.1)	0.431	1 (6.7)	4 (26.7)	0.330
90-day mortality, n (%)	0	5 (6.41)	0.702	0 (0.0)	1 (6.67)	1.000
Readmission, n (%)	3 (20.00)	9 (11.54)	0.371	3 (20.00)	2 (13.33)	1.000
POS (min), median, [IQR]	18 [15–21]	20 [15–28]	0.042	18 [15–21]	21 [16–32]	0.1903
ELN	12 [4–16]	17 [10–24]	0.018	12 [4–16]	16 [11–23]	0.0875
PLN	0 [0–0]	0 [0–2]	0.006	0 [0–0]	0 [0–0]	0.636
ELN (in PDAC)	4 cases: 22 [15–29]	64 cases: 18 [10–24]	0.549	4 cases: 22 [15–29]	6 cases: 11 [7–16]	0.384
PLN (in PDAC)	4 cases: 1 [0–3]	64 cases: 1 [0–3]	0.690	4 cases: 1 [0–3]	6 cases: 1 [0–2]	0.913
Severe diarrhea	0	2	1	0	0	–
Diabetic ketoacidosis	0	2	1	0	0	–

OTP, open total pancreatectomy; RTP, robotic-assisted total pancreatectomy; EBL, estimated blood loss; PV/SMV, portal vein/superior mesenteric vein; GJ leakage, gastrojejunal anastomosis leakage; DGE, delayed gastric emptying; PPH, postpancreatectomy hemorrhage; Others, includes deep vein thrombosis, unconsciousness, pulmonary infection, acute coronary syndrome; Major complications, complication with Clavien-Dindo ≥3; POS, postoperative length of hospitalization; ELN, evaluated lymph nodes; PLN, positive lymph nodes; PDAC, pancreatic ductal adenocarcinoma; PSM, propensity score matching.

(15,20,37,40,41). Our group managed to significantly decrease the operative time by utilizing a systematic modular resection pattern and by standardizing individual roles within the team (42). Previous accumulation of significant experience in robotic PD and DP allowed familiarization with a more complex approach in TP; therefore, our team passed the learning curve for robotic pancreatic resections by performing more than 300 robotic pancreaticoduodenectomies before initiating RTP.

Initially, the "dividing" technique was utilized with a combination of RPD followed by RDP. Yet, since more patients with malignant tumors were offered a

Table 3 Patient demographics and case details in RTP

Case	Age	Sex	Procedure	OT (min)	EBL (mL)	POS	Pathology	Complication	Follow-up time	Dose of insulin, IU	Prognosis
1	65	F	Classic	300	100	15	IPMN, pNET	N/A	33	30	Alive
2	81	F	VR	340	300	20	PDAC	N/A	11.9	14	Death from recurrence
3	56	F	*En bloc*, SP	420	600	23	IPMN	N/A	25	16	Alive
4	40	M	*En bloc*, VR	280	300	28	PDAC	N/A	24.8	18	Alive and chemotherapy
5	37	F	*En bloc*	240	100	15	Metastatic RCC and SCN	N/A	24	20	Alive
6	68	M	Classic	360	4,000	20	CP	N/A	24	34	Alive
7	68	M	*En bloc*	360	200	21	IPMN	N/A	23.5	18	Alive
8	59	F	*En bloc*, VR	260	500	11	PDAC	N/A	15.8	18	Alive and chemotherapy
9	76	F	*En bloc*	360	1,500	20	RCC metastasis	N/A	14	22	Alive
10	61	M	*En bloc*	240	1,000	15	CP	DVT	4	10	Death from digestive perforation
11	43	F	*En bloc*, SP	240	200	11	SCN	N/A	12	8	Alive
12	26	M	*En bloc*, SP	200	100	15	pNET	N/A	25	14	Alive
13	77	M	*En bloc*	300	400	18	IPMN	DGE	8	16	Alive
14	67	M	Classic	480	800	37	PDAC	PPH, septic shock	11.4	20	Recurrence and chemotherapy
15	50	M	*En bloc*, SP	350	500	12	pNET	N/A	33	18	Alive

RTP, robotic-assisted total pancreatectomy; OT, operation time; EBL, estimated blood loss; Classic, classic TP using neck-dividing technique; TP, total pancreatectomy; IPMN, intraductal papillary mucinous neoplasm; pNET, pancreatic neuroendocrine tumor; VR, vascular reconstruction; PDAC, pancreatic ductal adenocarcinoma; SP, spleen preserving; RCC, renal cell carcinoma; SCN, serous cystic neoplasm; DVT, deep vein thrombosis; CP, chronic pancreatitis; DGE, delayed gastric emptying; PPH, postpancreatectomy hemorrhage.

robotic resection, we proceeded with a "nondividing" approach. The rationale was to minimize potential tumor dissemination caused by the transection of the pancreatic neck. Interestingly, most patients in the RTP cohort underwent an *en bloc* resection (73%) compared to 46% in the OTP cohort. The advantage of the robotic approach allows a more intricate application of the *en bloc* resection and the ability to clearly visualize the operative field. However, a limited operative surface and width of vision during the robotic procedure necessitated standardization of the operative steps to achieve safe and efficient manipulation. Therefore, an antegrade approach was applied for the *en bloc* RTP in a counterclockwise fashion. A standardized procedure allowed for optimal results: unlike other series (36), our docking of the DaVinci Si system was completed with a 5-port placement, similar to other robotic resections and robotic enucleation of our series with constant instruments and a fixed team (20-23); a 6th or 7th trocar was rarely placed after the beginning of the operation. When difficult exposure or uncontrollable bleeding was intraoperatively encountered, an additional 5-mm trocar was placed between the optical and No. 2 arm for better exposure and use of suction. One of the most challenging aspects of robotic surgery is achieving adequate communication and cooperation between the lead surgeon at the console and the scrubbed assistant, which is a main disadvantage compared to the laparoscopic approach.

Table 4 Outcomes of the Minimally Invasive TP series

Author	Nation	Year	N	Indications	Procedure	VR	SP	OT (min)	EBL (mL)	Conversion	Morbidity	CD ≥3	LOS (day)
Giulianotti *et al.*	US	2011	5	IPMN [1], PDAC [2], CP [1], pNET [1]	RTP	0	2	480	310	0	2	0	7
Galvani *et al.*	US	2014	6	CP [6]	RTP + IAT	0	4	712	630	0	2	0	12.6
Zureikat *et al.*	US	2015	10	IPMN [6], PDAC [1], CP [3]	RTP [9], RTP + IAT [1]	2	2	560	650	1	10	2	10
Boggi *et al.*	Italy	2015	11	IPMN [8], PDAC [2], CP [1]	RTP	2	3	600	220	0	7	2	27
Wang *et al.*	China	2017	3	IPMN [2], pNET [1]	RTP [1], LTP [2]	0	3	490	266	0	2	0	18
Konstantinidis *et al.*	US	2018	1	IPMN [1]	RTP	0	0	NR	0	0	0	0	9
de Mesquita Neto	US	2019	7	IPMN [5], CP [1], pNET [1]	RTP	0	4	490	238	1	4	4	10
Casadei	Italy	2009	1	IPMT [1]	First L then open	0	0	485	1,200	0	0	0	14
Sung Hoon Choi	Korea	2012	5	IPMT [5]	LTP	0	3	450	490	2	0	3	21
Bernard Dallemagne	France	2013	2	IPMN [1], pNET [1]	LTP	0	1	390	400	0	0	0	8
Fan *et al.*	US	2017	23	CP [23]	LTP + IAT [22], LTP [1]	0		493	627.5	2	0	NR	11
Current series	China	2019	15	PDAC [4], IPMN [3], RCC [2], pNET [3], CP [2], CP + SCN [1]	RTP [14], RTP + IAT [1]	3	4	300	400	0	6	1	18

TP, total pancreatectomy; IPMN, intraductal papillary mucinous neoplasm; PDAC, pancreatic ductal adenocarcinoma; CP, chronic pancreatitis; pNET, pancreatic neuroendocrine tumor; RCC, renal cell carcinoma; SCN, serous cystic neoplasm; RTP, robotic-assisted total pancreatectomy; LTP, laparoscopic pancreatectomy; IAT, islet-cell autotransplantation; CD, major complications with Clavien-Dindo ≥3; LOS, length of stay.

In the RTP cohort, three patients with PDAC underwent a vein resection, and in two cases, it was performed when the "nondividing" *en bloc* technique was applied. Vein resection in pancreatic surgery has significantly increased and is mainly due to the establishment of neoadjuvant treatment (43). Previous reports have demonstrated the feasibility of vein resection in robotic pancreatic surgery with acceptable morbidity and mortality (44); however, the experience in RTP is very limited (27,45). In this study, all three patients underwent a segmental vein resection and reconstruction with an end-to-end anastomosis without the use of vein graft or patch. We believe that there is still a debate regarding the role of arterial resections in pancreatic surgery (46), more so in the setting of minimally invasive TP. Yet, it is an interesting field to explore since reports in open pancreatic surgery are promising (47). Spleen preservation was also achieved in 50% of patients with benign diagnoses who underwent RTP. Previous studies have demonstrated increased spleen preservation rates in patients who underwent robotic compared to laparoscopic DP (48,49), and our results on RTP show similar outcomes. Furthermore, no patients in the RTP group were converted to an open procedure. A recent study showed that conversion rates in minimally invasive pancreatic surgery are improving and appear to be significantly lower in robotic cases (50). It appears that precision in instrument movement and tissue manipulation achieved with the robot is crucial in that aspect.

A borderline increased postoperative stay (POS) was also identified in the RTP group; however, the median POS of all patients is significantly higher compared to a series from Europe and the United States (11,36). In western countries, increased healthcare costs and a developed network of patient care in the community facilitate earlier patient discharge; yet in China, patients remain in the hospital until fully recovered. This difference in hospitalization strategy may account for the increased POS in this study (51). Additionally, the RTP and OTP groups had comparable 30-day morbidity and 90-day mortality. In TP, there are no pancreatic fistula-associated complications with the absence of pancreatic anastomosis. However, the challenge of postoperative management remains in terms of endocrine and exocrine function regulation. The establishment of an apancreatic state and the consequent intestinal malabsorption and brittle diabetes have a significant impact on a patient's quality of life. Especially regarding diabetes, the high frequency of alternating hypoglycemic and hyperglycemic events is not tolerable by many patients, and therefore, case selection is critical (3,29). One of the surgical modalities used to address postoperative endocrine insufficiency is IAT. In this study, we report the first successful RTP with IAT performed in China. This is a previously described procedure with multiple surgical variations (11,16) and increasing utilization (52). The potential advantage of the robotic approach is late blood supply preservation and optimization of the isolated islet cell population.

There are several limitations in this study. First, it is a retrospective case series and therefore subject to selection bias. Additionally, even though our team has significant experience in robotic pancreatic resections, the authors acknowledge that the results of the first 15 RTP procedures are somehow biased by a procedure-specific learning curve. This is also evident from the fact that most patients with PDAC were assigned to undergo an OTP. Furthermore, the RTP cohort is relatively small in comparison, even after PSM, which could explain in part the absence of significant differences between the two groups. Additionally, there is significant heterogeneity regarding the indications for TP and the patient's background. Lastly, the follow-up time for the studied patients was relatively limited, and long-term outcomes of RTP will be further evaluated. However, this study demonstrates the feasibility of robotic-assisted TP in a selected cohort of patients when performed in high-volume centers with extended robotic experience and adds more information to the small pool of existing data indicating the necessity for prospective studies.

Conclusions

In this retrospective study, the application of RTP in a selected cohort of patients appears to be safe and feasible in the management of both benign and malignant pancreatic lesions. A "nondividing" *en bloc* technique in a counterclockwise fashion allows for optimal surgical results with comparable mortality and morbidity compared to an open approach. A standardized surgical protocol can decrease operative time without affecting patient outcomes. Further multicenter prospective studies are necessary to better identify candidate patients for RTP.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All of the included patients had previously signed an informed consent and agreed to data collection. This study was approved by the institutional review board of Shanghai Ruijin Hospital (No. 2017-180).

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