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ORIGINAL ARTICLE

Robotic versus standard open pancreatectomy: a propensity score-matched analysis comparison

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Abstract

Interest in robotic pancreatectomy has been greatly increasing over the last decade. However, evidence supporting the benefits of robotic over open pancreatectomy is still outstanding. This study aims to assess the safety and efficacy of robotic pancreatectomy compared with the conventional open surgical approach. Propensity score-matched (1:1) was used to balance age, sex, BMI, ASA, tumor size, and malignancy of 17 robotic pancreaticoduodenectomies (PD), 12 pancreatic enucleations (PE), and 28 distal pancreatectomies (DP); and was compared with the open standard approach. Robotic PD was associated with longer operative time (594 vs. 413 min; $p=0.03$) and decreased blood loss (190 vs. 394 ml; $p=0.001$). Robotic PE showed a lower mean length of hospital stay (8.4 vs. 12.8 days; $p=0.04$) and, in addition, robotic DP showed less blood loss (175 vs. 375 ml; $p=0.01$), less severe morbidities (7.14 vs. 17.9%; $p=0.02$), and a reduced mean length of hospital stay (8.9 vs. 15.1; $p=0.001$). Overall, conversion rate was 4 (7%). Robotic pancreatectomy is as safe and effective as the standard open surgical approach with reduced blood loss in PD and DP, length of hospital stay in PE and DP, and severe morbidity in DP.

Keywords Pancreatic resection · Robotic surgery · Case matched

Introduction

There has recently been an increased interest in the minimally invasive surgical approach. A pancreatectomy is among the most complex and challenging of abdominal operations where laparoscopy has important limitations, especially for major pancreatectomies performed in only a few centres [1–3].

Robotic surgical technologies have been introduced with the goal of improving current outcomes from laparoscopic surgery, enhancing a surgeon's dexterity in the surgical field, by means of: first, a magnified three-dimensional view; second, instruments with seven degrees of freedom; and third, intuitive hand-control movements.

However, the role of the robotic approach for pancreatectomies remains controversial and the level of evidence comparing the procedure with the standard open pancreatectomy surgical technique remains low.

Given this background, the aim of this study is to compare the peri-operative outcomes of robotic vs. open pancreatectomies (including pancreaticoduodenectomy, enucleation, and distal pancreatectomy) by applying a propensity score-matching approach.

Materials and methods

This study represents a review of a prospectively collected database of patients undergoing robotic pancreatectomies between October 2010 and March 2017.

Due to the retrospective nature of the study, informed consent was waived. Following approval by the local ethics committee, demographic, clinical, operative, and pathological details were obtained. Before surgery, each patient underwent a radiological study that included abdominal CT scan, MRI, echoendoscopy, and positron emission tomography (PET) as all of them are included in prospective

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oncological studies. All tumors were classified according to the seventh edition of the TNM staging system [4]. The duration of surgery was calculated as skin-to-skin time.

Complications were defined and classified according to the Clavien–Dindo score [5], and severe complication was defined when ≥ III. Pancreatic fistula was defined as grade A, B, or C according to the International Study Group of Pancreatic Fistula (ISGPF) [6].

The main objective was to analyze the two groups in terms of intraoperative outcomes (such as operative time and blood loss; conversion to open is showed only for the robotic group), short-term outcome (such as complications, hospital stay, and reoperation), and pathological data (such as resection margins and retrieved lymph nodes).

Since October 2010, the da Vinci® Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA, USA) has been available at our institution, the Sanchinarro University Hospital, Madrid, Spain. In 2013, the Si version became available at our centre up until 2015 when it was replaced by the latest Xi version.

Patients with tumor size < 4 cm and in the absence of radiological vascular involvement were judged eligible for the robotic approach.

Procedures were, for the most part, carried out by two experienced senior surgeons, with four assistant surgeons with experience in colorectal and esophago-gastric robotic surgery following their completion of a robotics training programme.

In the specimen pathological study, two main borders are studied (resection border and retroperitoneal border); R1 resection was considered if there were tumor cells present < 1 mm of the resection margin.

Operative robotic technique

Common step

The abdomen was insufflated with CO_2 using a Veress needle through a 1 mm diameter left hypochondrium incision. Robotic trocars placement is shown in Video 1. An assistant trocar was placed in the right hypochondrium. The gastrocolic ligament was dissected from right to left and adhesions between the pancreas and the posterior surface of the stomach were transected.

Robotic pancreaticoduodenectomy procedure (RPD)

As shown in Video 1, the extended Kocher manoeuvre is completed to expose the inferior cava vein. The gallbladder is removed and the common bile duct is dissected and isolated. The common hepatic artery is identified and dissected, followed by dissection and ligation of the gastroduodenal artery. The common bile duct is then transected. Thus, the pancreas is exposed and the inferior margin of the pancreas is dissected to expose the superior mesenteric vein, and the retropancreatic tunnel is created. If necessary, intraoperative ultrasound is performed to identify tumor location and possible infiltration. Transection of the duodenum or stomach is carried out using a 45 mm endostapler (Ethicon Endo-Surgery). The jejunum is divided distally to the ligament of Treitz using a 45 mm endostapler (blue load). Once this step is completed, the jejunum is retracted to the right, rotating the specimen. When the pancreas is completely dissected, it is divided using the Ultracision (Intuitive Surgical), except for the Wirsung duct that is cut with scissors. Prior to the reconstruction, samples of the pancreatic and common bile duct transection are sent for frozen-section analysis to confirm negative margins. The reconstruction is performed via a single jejunal loop. First, a duct-mucosa pancreatico-jejunos anastomosis is performed with two continuous monofilament sutures, as shown in Video 1, followed by the hepatico-jejuno, and, finally, the gastrojejunostomy anastomosis. A Pfannenstiel incision is used to remove the specimen and place it in an endobag.

Robotic pancreatic enucleation procedure (RPE)

Intraoperative ultrasonography is usually performed to identify the tumor margin and to determine the distance to the main pancreatic duct. Enucleation with an adequate margin is achieved with the use of the Robotic Harmonic® scalpel.

Robotic distal pancreatectomy procedure (RDP)

The lower margin of the pancreas is opened and posterior dissection is continued to mobilize the distal part of the pancreas from the retroperitoneum. The splenic vessels are identified and the pancreas is cut with an endoscopic linear stapler (EndoGIA) or using the Robotic Ultracision (Intuitive Surgical). A spleen-preserving procedure is considered as the first option in patients with benign diseases.

In cases without spleen preservation, the resection is performed en bloc, controlling and ligating the splenic vessels first. The spleen is then dissected from its lateral attachments and ligaments without dissecting the hilum.

Matching process

A 1:1 propensity case-matched study design was used. Comparisons were performed between the patients who underwent robotic pancreatectomy and a matched group extracted from a prospective cohort of patients who underwent surgery in the same centre from 2008 to 2016. Patients were matched by age, gender, body mass index (BMI), American Society of Anesthesiology (ASA) score, malignancy, and tumor size.

Statistical analysis

The distribution of continuous variables is reported as mean and standard deviation. Categorical variables are presented as numbers and percentages. Patients were analyzed according to the *intention-to-treat* principle. The comparison between subgroups was carried out using Student's *t* test or the Mann–Whitney *U* test for continuous variables. Qualitative data were compared using the Chi-square test or the Fischer's exact test when necessary. Disease-free survival (DFS) was defined as the time from surgery to the recurrence of the disease, as specified by the Response Evaluation Criteria in Solid Tumors (RECIST) [7]. Follow-up was updated on April 2017. Survival probability was estimated according to the Kaplan–Meier method, whereas the log-rank test was used for the comparison of survival rates in different subgroups. Patients who had a follow-up period of less than 12 months were excluded from the survival analysis. Statistical analyses were performed in SPSS 16.0 for Windows software (SPSS Inc, Chicago, IL, USA). *p* values were considered significant when less than or equal to 0.05.

Results

During the study period time, a total of 57 robotic pancreatectomies were identified (17 RPD, 12 RPE, and 28 RDP) which were matched with 17 open pancreaticoduodenectomies (OPD), 12 open pancreatic enucleations (OPE), and 28 open distal pancreatectomies (ODP).

RPD vs. OPD

The main demographic and pre-operative data comparison of the two groups is summarized in Table 1.

As shown in Table 2, the mean operative time was significantly higher in the RPD group compared to the OPD (595 vs. 413 min; $p=0.03$). Blood loss was significantly lower in the RPD (190 vs. 394 ml; $p=0.001$). Two cases required the conversion to open surgery: the first for pneumoperitoneum intolerance and the other due to a difficult dissection of the common hepatic artery. Overall morbidity as well as severe morbidities and pancreatic fistulas were similar in both groups (Table 2). One case of hepatic-jejunal fistula occurred in the RPD which required reoperation. Other cases of reoperations in both groups are depicted in Table 2.

There were no significant differences in the number of retrieved lymph nodes and margin involvement was found (Table 2). The mean length of hospital stay was similar (RPD: 17.6 days; OPD: 16.5 days; $p>0.5$).

RPE vs. OPE

The baseline characteristics of the two groups are depicted in Table 3.

As shown in Table 4, operative time was similar (RPE: 250 vs. OPE: 222 min; $p>0.5$). No cases required a transfusion, and conversion to open surgery occurred in one case—for the failure of localization of the tumor. Morbidity and pancreatic fistula were similar in both groups (Table 4).

All margins were free from disease. Hospital stay was shorter in the RPE compared to the OPE (8.4 vs. 12.8 days, respectively; $p=0.04$).

RDP vs. ODP

Pre-operative data are shown in Table 5. Operative time of the RDP was similar to the ODP (294 vs. 265 min; $p>0.5$). Conversion occurred in one case due to firm adherences from previous surgery. As shown in Table 6, significant

Table 1 Baseline characteristics of pancreaticoduodenectomy

	Robotic ($n=17$)	Open ($n=17$)	*p* value
Mean age (years)	66.8 ± 9.5	61.4 ± 11.9	> 0.5
Sex ratio (M/F)	8/9	10/7	> 0.5
Mean BMI (kg/m^2)	23.8 ± 4.1	24.6 ± 3.36	> 0.5
ASA score, number (%)			> 0.5
I	3 (17.6)	3 (17.6)	
II	8 (47)	10 (58.8)	
III	6 (35.3)	4 (23.5)	
Mean tumor size (mm)	24.1 ± 5.4	24.8 ± 6.1	> 0.5
Pathology: number (%)			> 0.5
Adenocarcinoma	14 (82.3)	15 (88.2)	
Chronic pancreatitis	2		
Neuroendocrine	1	2	
Neoadjuvant treatment, number (%)	9 (53)	6 (35.3)	> 0.5

Table 2 Surgical and pathological outcomes of pancreaticoduodenectomy

	Robotic ($n=17$)	Open ($n=17$)	p value
Mean operative time (min)	594 ± 66	413 ± 62	0.03
Conversion, number (%)	2 (11.7)[a]	–	–
Mean estimated blood loss (ml)	190 ± 91.6	394 ± 68.4	0.001
Overall morbidity, number (%)	6 (35.3)	7 (41.7)	> 0.5
Severe morbidity (Clavien–Dindo ≥ 3), number (%)	3 (17.6)	3 (17.6)	> 0.5
Pancreatic fistula, number (%)	3 (17.6)	4 (23.5)	> 0.5
A	2	2	
B	1	2	
C	0	0	
Hepatic-jejunal fistula	1 (7.14)	0	> 0.5
Delayed gastric emptying, number (%)	1 (5.9)	2 (11.7)	> 0.5
Wound infection	0	4 (23.5)	0.1
Reoperation, number (%)	3 (17.6)[b]	2 (11.7)[c]	> 0.5
Mean hospital stay, days	17.6 ± 7.91	16.5 ± 8.3	> 0.5
Margin status R1[d], number (%)	1/14 (7.14)	1 (6.6)	> 0.5
Mean number of retrieved nodes	21.5 ± 4.5	22.2 ± 6.2	> 0.5

[a]Neumoperitoneum intolerance and difficult vascular dissection

[b]2 Bleeding, 1 hepatic-jejuno anastomotic fistula

[c]2 Bleeding

[d]Percentage according to malignant tumor only

Table 3 Baseline characteristics of pancreatic enucleation

	Robotic ($n=12$)	Open ($n=12$)	p value
Mean age (range), years	61.8 ± 10.9	57.1 ± 8.7	> 0.5
Sex ratio (M/F)	6/6	5/7	> 0.5
Mean BMI	23.5 ± 3.45	24.1 ± 4.30	> 0.5
ASA score, number (%)			> 0.5
I	3 (25)	3 (25)	
II	5 (41.6)	4 (33.4)	
III	4 (33.4)	5 (41.6)	
Mean tumor size (mm)	16 ± 4.2	18 ± 5.1	> 0.5
Pathology: number (%)			> 0.5
IPMN	1	1	
Neuroendocrine	11	10	
Insulinoma	0	1	

IPMN intraductal papillary mucinous neoplasia

Table 4 Surgical and pathological outcomes of pancreatic enucleation

	Robotic ($n=12$)	Open ($n=12$)	p value
Mean operative time (min)	250 ± 31	222 ± 25	> 0.5
Conversion, number (%)	1 (8.3)[a]	–	–
Mean estimated blood loss (ml)	30.7 ± 4.5	31.3 ± 5.8	> 0.5
Overall morbidity, number (%)	2 (16.6)	2 (16.6)	> 0.5
Severe morbidity (Clavien–Dindo ≥ 3), number (%)	2 (16.6)	2 (16.6)	> 0.5
Pancreatic fistula, number (%)	5 (41.6)	5 (41.6)	> 0.5
A	3	2	
B	2	3	
C	0	0	
Wound infection	0	3 (25)	0.1
Reoperation, number (%)	0	0	> 0.5
Mean hospital stay, days	8.4 ± 2.6	12.8 ± 3.1	0.04
Margin status R1, number (%)	0	0	> 0.5

[a]Failure localization of the tumor

differences were found in mean estimated blood loss, severe morbidity, and hospital stay in favor of RDP.

Discussion

The minimally invasive approach for pancreatic tumors is still cautiously considered because of the technical difficulties associated with pancreatic resection and the high risk of post-operative complications [8].

However, in the last decade, more and more minimally invasive pancreatectomies have been reported in the literature, with the main benefits reported in the comparison

Table 5 Baseline characteristics of distal pancreatectomy

	Robotic ($n=28$)	Open ($n=28$)	p value
Mean age (range), years	59.7 ± 10.5	62.5 ± 11.3	> 0.5
Sex ratio (M/F)	16/12	15/13	> 0.5
Mean BMI	24.1 ± 4.5	23.4 ± 4.1	> 0.5
ASA score, number (%)			> 0.5
I	2 (7.14)	3 (10.7)	
II	23 (82.1)	20 (71.4)	
III	3 (10.7)	5 (17.9)	
Mean tumor size (mm)	35.4 ± 5.36	41.3 ± 6.5	> 0.5
Pathology: number (%)			> 0.5
Adenocarcinoma	15 (53.6.)	17 (60.7)	
Chronic pancreatitis	2	3	
Neuroendocrine	6	5	
IPMN	4	2	
Cystic tumor	1	1	
Neoadjuvant treatment, number (%)	8 (28.6)	5 (17.9)	> 0.5

IPMN intraductal papillary mucinous neoplasia

Table 6 Surgical and pathological outcomes of distal pancreatectomy

	Robotic ($n=28$)	Open ($n=28$)	p value
Mean operative time (min)	294 ± 72	265 ± 69	> 0.5
Conversion, number (%)	1 (3.6)[a]	–	–
Mean estimated blood loss (ml)	175 ± 38.5	375 ± 45	0.01
Spleen-preserving, number (%)	5 (17.9)	3 (10.7)	> 0.5
Overall morbidity, number (%)	6 (21.4)	7 (25)	> 0.5
Severe morbidity (Clavien–Dindo ≥ 3), number (%)	2 (7.14)	5 (17.9)	0.02
Pancreatic fistula, number (%)	3 (10.7)	4 (14.3)	> 0.5
A	2	2	
B	1	2	
C	0	0	
Wound infection	0	4 (14.3)	0.1
Reoperation[b], number (%)	0	2 (7.14)[b]	> 0.5
Mean hospital stay, days	8.9 ± 4.3	15.1 ± 5.6	0.001
Margin status R1, number (%)	0	0	> 0.5
Mean number of retrieved nodes	14.2 ± 5.4	13.6 ± 4.7	> 0.5

[a] Adherences from previous surgery

[b] 2 bleeding

of the laparoscopic vs. the open surgical approach. These are mainly distal pancreatectomies, and very few compare open vs. robotic pancreatectomies [8].

Therefore, available evidence for the comparison of robotic vs. open pancreatectomy—the main objective of our study—is weak.

RPD vs. OPD

To the best of our knowledge, there are only seven studies in the literature (four case-matched) comparing RPD to OPD [9–17]. These studies show that the operative time is always longer for the RPD group, which is consistent with our experience (594 vs. 413 min; $p=0.03$). However, this time decreases with the experience gained in the use of the robotic approach, which includes the first cases of robotic use. Furthermore, the use of the latest da Vinci Xi may has contributed to shortening this time, as the docking manoeuvre is easier and faster.

According to our results, the RPD decreased blood loss (190 vs. 394 ml). These data have been confirmed by all but one study.

In the literature, the rate of conversion ranges from 0 to 16%, with the main cause being the difficult dissection and bleeding [13, 18]. From our experience, there were two conversions to open surgery (11.7%): one case was due to the intolerance of the pneumoperitoneum which occurred in the initial cases where the operative time was longer; and the second case was because of the difficulty of the hepatic artery dissection (Table 2).

Our study showed that hospital stay was similar in both groups. In the literature, the mean length of post-operative stay for RPD ranges from 9 to 23 days resulting in being shorter in three out of six studies [8, 9, 14]. We expect these data to improve with experience.

One of the most important concerns of the minimally invasive approach for PD is the lymphadenectomy. This surgical step is challenging when conducted by laparoscopy. On the other hand, better vision with 3D viewing and stable imaging—along with enhanced instrument control movements provided by the robot—potentially facilitate the lymphadenectomy harvesting a similar number of resected nodes, such as the standard open technique, and as confirmed by our results (21.5 vs. 22.2; $p > 0.5$).

The overall complication rate of RPD described in our study was 35.3%, which is consistent to that described in the literature which ranges from 29 to 68% of patients and is similar to the OPD group [18–21].

Biliary and pancreato anastomosis are critical steps of the pancreatectomy. For this reason, in some laparoscopic series, some authors do not perform the pancreato anastomosis with exclusion of the remnant pancreas. The enhanced dexterity in using the instruments and the vision of the robotic approach make this challenging step easier by the adoption of a minimally invasive approach (see Video 1).

In our series, post-operative pancreatic fistula resulted in being slightly higher in the OPD group (17.6 vs. 23.5%, $p > 0.5$) confirming the safety of this approach. Napoli et al. [17] showed in a matched robotic vs. open approach analysis that, in patients with intermediate risk of developing pancreatic fistula, RPD is associated with higher rate of fistula. However, the overall post-operative morbidity resulted to be equivalent.

Most of groups performed a pancreatico-jejunostomy to restore the pancreatic digestive continuity, except Giulianotti et al. [22] who performed a pancreatico-gastrostomy in their series. Our current practice, as shown in Video 1, is to perform a pancreatico-jejunostomy with two continuous sutures, in the same manner as the OPD.

The hepato-jejunal fistula we had in the RDPC occurred in our second case at 5 days from surgery, and was successfully managed operatively using the open surgical approach with a re-anastomosis. After this case, no more anastomosis complications occurred. Again, gaining experience is paramount to be able to improve results. Napoli et al. [24] focused their study in the learning curve, showing that operative time dropped after 33 RPD procedures. Considering these data, our experience with only 17 cases should be considered inside the learning curve. Unlike studies the open approach, this study commenced from the time the first patients were operated on after the acquisition of the da Vinci system. This aspect may have influenced data in favor of the open group.

Our current practice is to consider tumor size greater than 4 cm, vascular involvement, and invasion of an adjacent organ as a contraindication for the minimally invasive approach, which is in agreement with most of the teams who perform RPD [10, 23, 25].

However, with increasing experience and the results of learning through each procedure, we believe that vascular resection can be considered as an indication for RDCP, as showed by Kauffmann et al. [26].

EP

Currently, given the advances in pre-operative studies, an increasing number of pancreatic benign and borderline tumors are being detected [27]. For this reason, pancreatic enucleation is increasingly performed as it is parenchyma-sparing and a less invasive procedure compared to the conventional pancreatectomy, also reducing the risk of exocrine and endocrine insufficiency.

Robotic pancreatic enucleations are infrequently described in the literature, and we found only two studies comparing it with the conventional open technique (Shi, Tian) [28, 29].

Our results show the following: that this procedure is as safe as the open surgical technique; that it did not increase pancreatic fistula or major complication rates; and that it showed a shorter hospital stay (8.4 vs. 12.8 days, $p = 0.04$). Operative time resulted in being only slightly higher in the REP group (250 vs. 222 min; $p > 0.5$). On the contrary, the study from Tian et al. [28], which matched 60 cases of REP for neuroendocrine tumors with 60 OEP, showed a significantly shorter operative time for the robotic group (150 vs. 117 min; $p < 0.01$).

DP

Contrary to DCP and in the same way as REP, the mean operative time of DP was similar in both groups (294 vs. 265 min; $p > 0.5$), and these data are in line with that reported by Røsok et al. [30] who identified only three observational studies comparing a total of 70 RDP vs. 672 ODP (251 vs. 247 min). Furthermore, concomitant with the same study [30] where blood loss was the lowest in the RDP group (median 236 ml), our case-matched study showed a lower blood loss (175 vs. 375 ml, $p = 0.01$) and a shorter hospital stay (8.9 vs. 15.1 days, $p = 0.001$) in the RDP compared to ODP.

Conversion occurred in only one patient due to difficulties in the vascular dissection, which is the most frequent cause of conversion reported in the literature, with a mean rate of 26% of cases.

In 17.9% of cases of the RDP, the spleen was preserved in a similar manner to the open approach (10.7%). In our practice, we perform a splenic preservation whenever it is possible on benignant lesions and neuroendocrine tumours smaller than 2 cm in size. To preserve the spleen, it is recommendable preserve its vessels, which can be very difficult when using the minimally invasive approach. However, robotics may better facilitate this manoeuvre as confirmed by Chen et al. [13] who compared 69 RDP with 50 laparoscopic DP performed over the last 10 years and concluded that RPD could achieve a higher rate of spleen preservation.

Other factors of post-operative morbidity and mortality were comparable between the groups.

This study has some limitations due to its retrospective nature. However, there are no prospective randomized clinical trials comparing robotic vs. the open surgical technique. The unicentric nature of our study guarantees the homogeneity of the surgical procedures performed in both robotic and open groups.

Furthermore, there are some factors which are difficult to compare with the open technique, such as the ergonomic position of the surgeon, which is especially useful for more complex and long-lasting procedures such as those in the pancreatic field.

Conclusions

The results of our study are promising, showing that robotic pancreatectomy is a safe and effective approach compared with the conventional open surgical technique. Data from our initial experience need to be further studied in larger series and clinical trials.

Compliance with ethical standards

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

Research involving human participants and/or animals The study was approved by the institutional ethical committee of the HM Hospitals group.

Informed consent All patients included were informed about the treatment and written informed consent was obtained before all surgeries.

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