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ORIGINAL ARTICLE

Indications, technique, and results of robotic pancreatoduodenectomy

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Abstract Robotic assistance improves surgical dexterity in minimally invasive operations, especially when fine dissection and multiple sutures are required. As such, robotic assistance could be rewarding in the setting of robotic pancreatoduodenectomy (RPD). RPD was implemented at a high volume center with preemptive experience in advanced laparoscopy. Indications, surgical technique, and results of RPD are discussed against the background of current literature. RPD was performed in 112 consecutive patients. Conversion to open surgery was required in three patients, despite nine required segmental resection and reconstruction of the superior mesenteric/portal vein. No patient was converted to laparoscopy. A pancreato-jejunostomy was created in 106 patients (94.6 %), using either a duct-to-mucosa ($n = 82$; 73.2 %) or an invaginating ($n = 24$; 21.4 %) technique. Pancreato-gastrostomy was performed in one patient, the pancreatic duct was occluded in two patients, and a pancreatico-cutaneous fistula was created in three patients. Mean operative time was 526.3 ± 102.4 in the entire cohort and reduced significantly over the course of time. Experience was also associated with reduced rates of delayed gastric emptying and increased proportion of malignant tumor histology. Ninety day mortality was 3.6 %. Postoperative complications occurred in 83 patients (74.1 %) with a median comprehensive complication index of 20.9 (0–30.8). Clinically relevant pancreatic fistula occurred in 19.6 % of the patients. No grade C pancreatic fistula was noted in the last 72 consecutive patients. RPD is safely feasible in selected patients. Implementation of RPD requires sound experience with open pancreatoduodenectomy and advanced laparoscopic procedures, as well as specific training with the robotic platform.

Keywords Robot · da Vinci · Pancreatoduodenectomy · Pancreatectomy · Laparoscopy

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Introduction

First reported in 2003 [1], robotic pancreatoduodenectomy (RPD) is eventually gaining momentum [2]. Laparoscopic pancreatoduodenectomy (LPD) was described some 20 years earlier [3] but, until recently, was employed only in anecdotal cases or in small case series. In a recent European survey, 48 of 203 surgeons (23.6 %) declared to have performed at least one minimally invasive pancreatoduodenectomy (MIPD), but 39 had performed less than 10 procedures and only 4 (2 %) had performed more than 50 MIPDs [4]. Since 50 cases are required to overcome the learning curve of LPD [5], nearly all surgeons performing MIPD in Europe have not completed the learning curve yet. In keeping with these figures, 132 surgeons responding to the questionnaire declared that MIPD is a technical problem [4]. The main reasons for the slow adoption of LPD are quite obvious. Laparoscopy has intrinsic limitations making this technique best suited for procedures that do not require complex digestive reconstructions. Additionally, while many pancreatic surgeons were trained mostly or exclusively in open surgery, there is a lack of agreed standards for training and credentialing for complex laparoscopic operations such as LPD.

The da Vinci surgical system (dVss) (Intuitive Surgical, Sunnyvale, California, USA) is a telemanipulator that faithfully transmits the movements of surgeon's hands to the tip of miniaturized instruments having seven degrees of freedom. Additionally, the dVss provides steady, immersive, stereoscopic, and high-definition view of the operative field. Overall, the dVss is known to restore hand-eye coordination and to improve surgical dexterity. Not surprisingly these properties were found to be particularly rewarding in operations requiring fine dissection in deep spaces and around major vasculature as well as difficult intracorporeal sutures [6]. Since pancreatoduodenectomy includes both these challenges, robotic assistance could improve the outcome of LPD and could make this fantastic operation more easily reproducible on a large scale.

We herein present our experience with RPD focusing on evolution of indications, surgical technique, and results.

Methods

Setting

RPD was implemented at a University teaching hospital serving as Regional Referral Center for pancreatic surgery for the Region of Tuscany (3.8 million inhabitants as of January 1, 2015; http://www.regione.toscana.it) and recruiting patients with pancreatic diseases from all over the country. According to the Programma Nazionale Esiti (http://95.110.213.190/PNEed15/), between January 1, 2009 and December 31, 2014; 635 pancreatic resections for pancreatic tumor were performed at our Institution. The first RPD was performed in April 2008.

Feasibility account

RPD was implemented in the context of a high volume center for pancreatic surgery having preemptive experience on advanced laparoscopic surgery [7–10], including laparoscopic pancreatic resections [11].

Before performing the first RPD the surgeon who started the program (UB) had performed over 700 pancreatic resections and had familiarized with the system in over 50 robotic operations including procedures requiring fine intracorporeal sutures (e.g., repair of visceral aneurysms and pyeloplasty).

All RPDs were performed at an Institutional Center for Robotic Surgery where all robotic procedures are centralized, based on a preset monthly schedule. Given the high annual volume of activity, ranging from pancreatic to gynecologic robotic procedures, this organization model allowed us to have a nurse staff extremely proficient with the dVss but an anesthesia team that was not dedicated to pancreatic surgery [12].

Indications

Selection criteria were progressively modified based on emerging evidence from the literature and increasing personal experience. Exclusion criteria, valid throughout the study period, were: general unsuitability for laparoscopy, previous major surgery in upper abdominal quadrants, locally advanced tumors, patient denial to robotic approach, and lack of timely availability of the da Vinci surgical system (dVss). Patients with high body mass index ($\geq$35 kg/m^2) were initially excluded. As more experience was gained, obese patients were considered eligible on an individual basis but central obesity remained an absolute contraindication.

Indications to pancreatoduodenectomy were not extended to tumors of uncertain malignant behavior or benign disease because of the possibility of RPD. Similarly, no importance was given to cosmesis.

Pancreatic cancer was seen as a contraindication in the early phase. Subsequently, if clear tumor margins were evident at preoperative imaging, we started to accept patients with pancreatic cancer. Vascular involvement remained a contraindication, but when vein involvement was discovered during surgery the procedure was not converted to open surgery if resection and reconstruction could be safely performed.

Surgical technique

Our technique for RPD was described in detail elsewhere [13] and it is summarized here including the refinements that have occurred since the original description. All RPD were performed using the dVssSiHD.

The patient is placed supine with the legs parted. The assistant surgeon stands between the patient's legs. A total of five ports are used and are placed at least 8 cm aside from each other to minimize the risk of arm collisions. The 11 mm optic port is placed along the right mid-clavicular line at the level of the umbilicus. The 12 mm assistant port is placed immediately below or above the umbilicus, depending on the distance between the xyfoid and the umbilicus. One 8 mm robotic port is placed on the right side along the anterior axillary line 3–4 cm cephalad to the optic port. The other two 8 mm robotic ports are placed specular to the right-sided ports on the left side. Overall, the ports are placed along a smiling line. The patient side cart is docked over the head of the patient (Fig. 1).

As soon as tumor resectability is confirmed, the round ligament of the liver and the fundus of the gallbladder are hanged to the anterior abdominal wall. This maneuver

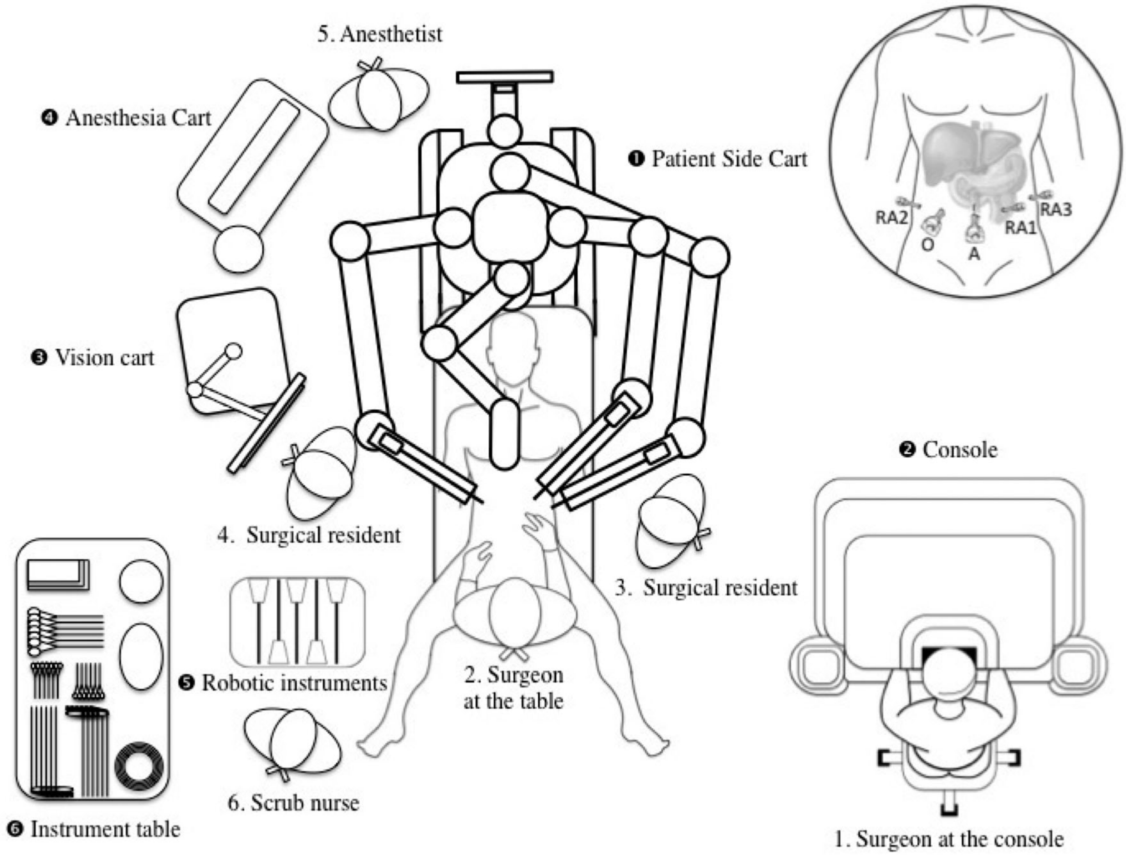

Fig. 1 Operating room setup and port placement (*within circle*) for RPD. *A* assistant port, *O* optic port, *RA* robotic arm

avoids the need for a dedicated liver retractor and/or for the frequent use of a robotic arm to improve exposure.

Dissection and reconstruction both proceed as previously described [13] with minor changes such as the use of 4/0 or 5/0 expanded polytetrafluoroethylene sutures for the external layer of pancreato-jejunostomy and the use of two half running sutures of 3/0 glyconate monofilament for the external layer of duodeno- or gastro-jejunostomy. It is important to note that duodenal hanging, key to expose the posterior margin and the uncinate process of the pancreas, is not prevented by having robotic arm number 3 on the left side of the patient, instead of on the right side (Fig. 2). It is also worth to note that the first jejunal loop does not need to be approached from the left as it can be mobilized from the right side of the mesenteric vessels as shown in Fig. 3. Additionally, the first jejunal loop does not require to be divided before approaching the uncinate margin since after division of the mesentery the intestine becomes very loose and does not reduce the mobility of the specimen. On the other hand, having the intestine intact makes the first jejunal loop immediately available for reconstruction and reduces the risk of torsion.

As regards management of the pancreatic stump, we prefer a pancreatico-jejunostomy using a duct-to-mucosa technique. When the duct is small (<4 mm), we place an internal stent. However, we maintain the same flexibility that we have in open surgery, and employ all commonly used techniques as required in the individual patient. Similarly, we prefer to spare the pylorus but we are open to resect the distal portion of the stomach, when necessary.

The technique for vein resection and reconstruction is unchanged from its original description [13] and respects all the principles described for the open operation, including an artery first approach and an en-bloc segmental vein resection [14].

At the end of the procedure, the round ligament is mobilized to wrap the hepatic artery. Particular attention is paid to avoid direct contact between the stump of the gastroduodenal artery and digestive anastomoses.

The specimen is extracted at the end of the procedure in an endoscopic jar via a small transverse suprapubic incision.

Three 14-Fr pig-tail catheters are placed and left to drain by gravity. One catheter is placed in the Morrison's pouch, behind the hepatico-jejunostomy. The other two catheters are placed in front and behind the pancreato-jejunostomy, respectively (Fig. 4a). The catheter running behind the pancreato-jejunostomy is positioned through a small

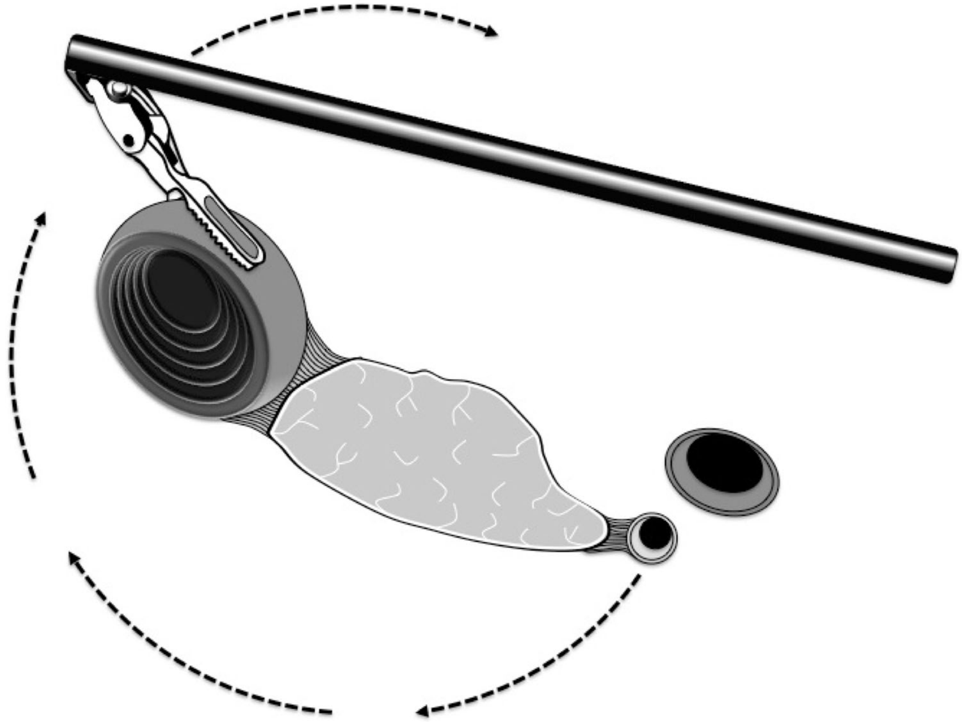

Fig. 2 Duodenal hanging is key in RPD to expose the retroperitoneal margin long the *right* side of the superior mesenteric artery. Robotic arm 3, often designated as the "fourth robotic arm", hangs the duodenum and pulls it to the *right* of the patient thus rotating the pancreatic head off the mesenteric vessels

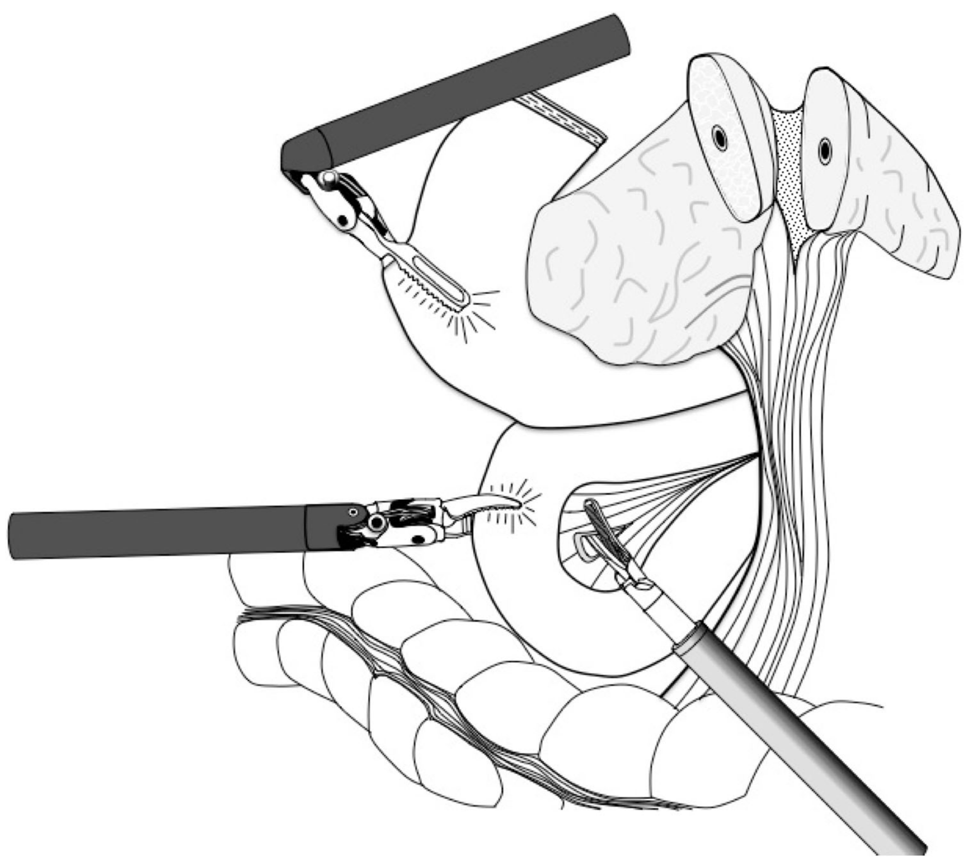

Fig. 3 After extensive Kocher maneuver, duodenal hanging brings the ligament of Treitz behind the superior mesenteric vessels. Incision of the ligament of Treitz exposes the proximal jejunum and allows the division of the mesentery of the proximal jejunum from the *right* side of the mesenteric vessels without additional intestinal mobilization

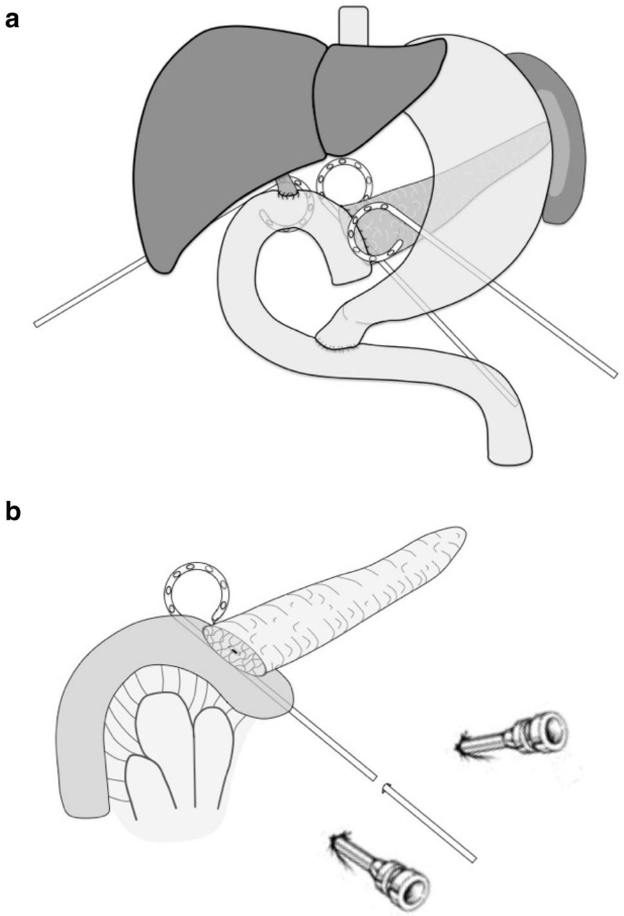

Fig. 4 **a** Final position of surgical drains at the end of the procedure. **b** The drain placed posterior to the pancreato-jejunal anastomosis is placed immediately after completing the external row of the posterior layer of the anastomosis. Placing this drain at this stage is easier and avoids excessive manipulation of the completed anastomosis

dedicated incision, placed between robotic ports 1 and 3 on the left flank. This catheter is placed immediately after completion of the posterior layer of the pancreato-jejunostomy because at this stage it can be easily passed through the tunnel between the anastomosis and the portal/superior mesenteric vein (Fig. 4b).

Data collection and analysis

Data were acquired prospectively and reviewed retrospectively. All perioperative events occurring within 90 days of surgery were considered. Pancreatic fistula [15], delayed gastric emptying [16] and postpancreatectomy hemorrhage [17] were identified and classified using standardized criteria. Postoperative (PO) complications were graded according to the Dindo classification [18]. Complications requiring treatment under general anesthesia or intensive care (grade III and higher) were defined as severe complications [18]. In patients with multiple complications, the highest grade was considered. Further, the comprehensive complication index was calculated for each patient [19].

Data are presented as mean ± standard deviation or median and interquartile range as appropriate. p values less than 0.05 were considered significant. To test improvements in operative times, we employed a simple linear regression analysis with analysis of variance (ANOVA). Fisher's exact test and Pearson Chi-Square test were used to compare categorical variables between groups, as appropriate. F ANOVA test was used to compare continuous variables.

Results

The main characteristics of the study population are reported in Table 1.

Three patients (2.7 %) were converted to open surgery, despite nine required segmental resection and reconstruction of the superior mesenteric/portal vein. No patient was converted to laparoscopy. Conversions occurred because of intolerance to pneumoperitoneum ($n = 2$) and vascular injury following port insertion ($n = 1$). No conversion was caused by the inability to complete the operation under robotic assistance.

The pylorus was spared in 103 patients (92 %), and associated procedures were required in 19 patients (15.8 %). These additional procedures included resection and reconstruction of the superior mesenteric/portal vein in 9 patients (8.1 %), hepatic biopsy in 3 patients (2.7 %), atypical liver resection in 2 patients, partial nephrectomy, adrenalectomy, transverse colonic resection, jejunal resection, and repair of incisional hernia in 1 patient each (0.9 %).

A pancreatico-jejunostomy was created in 106 patients (94.6 %), using either a duct-to-mucosa ($n = 82$; 73.2 %) or an invaginating ($n = 24$; 21.4 %) technique. Pancreato-gastrostomy was performed in one patient (0.9 %). In the remaining 5 patients (4.4 %), the pancreatic remnant was thought to be at an exceedingly high risk for severe PO pancreatic fistula and reconstruction was avoided. In two of these patients, with parenchymal atrophy, the duct was ligated while in the remaining three patients a pancreatico-cutaneous fistula was created using a Bracci's catheter of suitable caliber threaded back into the Wirsung duct.

Mean operative time was 526.3 ± 102.4 in the entire cohort. When patients requiring associated procedures were excluded, mean operative time decreased to 506 ± 80.2 ($p < 0.0017$). Operative time progressively reduced over the course of experience (Fig. 5). In particular a significant improvement in operative time was noted when the present series was divided into 5 groups of 20 patients each and a final group of 12 patients. Improvement

Table 1 Baseline characteristics of patients undergoing RPD

Characteristics	*N*, Mean	Percentage, SD
Number of patients	112	
Mean age (years)	60	±14
Sex (number)		
Male	51	46
Female	61	54
Mean body mass index (Kg/m^2)	24.2	±4.4
Prior abdominal surgery	61	54
American society of anesthesiologists score (number)		
I	15	13.4
II	59	52.7
III	38	33.9
IV	0	0
IV	0	0
Age-adjusted Charlson comorbidity index		
0	12	12.7
1–3	52	46.4
4–6	47	41.9
≥7	1	0.7
Histology		
Ductal adenocarcinoma	29	25.8
Ampullary carcinoma	18	16.1
Cystic tumors	10	8.9
Cholangiocarcinoma	10	8.9
Intraductal papillary mucinous carcinoma	4	3.6
Neuroendocrine carcinoma	3	2.7
Adenosquamous carcinoma	3	2.7
Duodenal carcinoma	2	1.7
Other tumor types	33	29.5

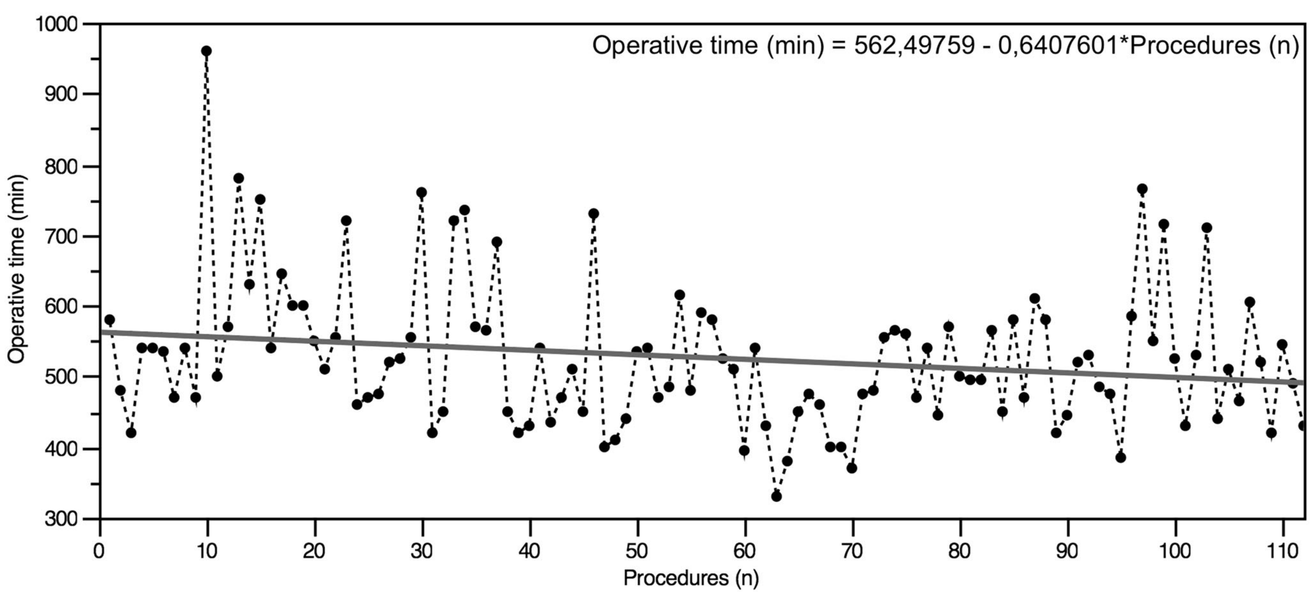

Fig. 5 Operative times showing progressive significant reduction over time

Table 2 Main intra- and post-operative outcome measures for incremental groups of 20 RPD (group 6 is limited to the last 12 cases)

Outcome measure	Group 1 (1–20)	Group 2 (21–40)	Group 3 (41–60)	Group 4 (61–80)	Group 5 (81–100)	Group 6 (101–112)	*p* value
Operative time (min), mean ± SD	563.8 ± 96.7	505.7 ± 80.2	486.9 ± 58.7	473.9 ± 68.8	511.3 ± 65	490.5 ± 90.1	0.018
Vein resection, *n* (%)	0 (0)	4 (20)	2 (10)	1 (5)	1 (5)	1 (8.3)	0.28
Lenght of hospital stay (days), mean ± SD	18.6 ± 2.8	23.9 ± 2.8	25.1 ± 2.8	21.6 ± 2.8	23.4 ± 2.9	18 ± 3.7	0.48
Post-operative complications, *n* (%)	16 (80)	15 (75)	16 (80)	13 (65)	16 (80)	7 (58.3)	0.62
Post-operative pancreatic fistula, *n* (%)	6 (30)	8 (40)	8 (40)	6 (30)	5 (25)	4 (33.3)	0.90
Grade B and C post-operative pancreatic fistula, *n* (%)	3 (15)	5 (25)	6 (30)	4 (20)	3 (15)	1 (8.3)	0.66
Delayed gastric emptying, *n* (%)	14 (70)	12 (60)	12 (60)	7 (35)	6 (30)	2 (16.7)	0.011
Post-pancreatectomy hemorrhage, *n* (%)	3 (15)	4 (20)	4 (20)	1 (5)	2 (10)	0 (0)	0.41
Malignant tumor histology, *n* (%)	9 (45)	15 (75)	14 (70)	11 (55)	15 (75)	12 (100)	0.024
Pancreatic ductal adenocarcinoma, *n* (%)	1 (5)	6 (30)	5 (25)	4 (20)	7 (35)	6 (50)	0.09

was noted also for delayed gastric emptying but not for PO pancreatic fistula, although there were no grade C PO pancreatic fistulae in the last consecutive 72 patients. The prevalence of malignant tumor histology increased over time (Table 2).

Table 3 provides a summary of morbidity and mortality. Overall, 30 and 90-day mortality was 2.7 and 3.6 %. PO complications, of any severity, occurred in 83 patients (74.1 %) in the entire cohort and 69 patients (74.2 %) without associated procedures. Severe PO complications (≥grade III) occurred in 22 patients (19.6 %). Median comprehensive complication index was 20.9 (0–30.8) in the entire cohort, and 20.9 (0–30.8) in patients without associated procedures.

Clinically relevant pancreatic fistula (B and C grades, according to the ISGPF definition) occurred in 19.6 % of the patients.

Overall, 29 patients had a final diagnosis of pancreatic ductal adenocarcinoma (25.9 %). Negative tumor margins, determined by assessing 6 margins and using a 1 mm of clearance, were achieved in 75.8 % of the patients. The mean number of examined lymph nodes was 47.2 ± 12.6, with a mean of 4.9 ± 6.9 positive nodes per patient, and a mean lymph node ratio of 0.11 ± 0.15.

Discussion

We have confirmed the feasibility of RPD. Although our results are not clearly superior to those reported for the open procedure, implementing MIPD without additional morbidity and mortality is an important achievement.

When considering feasibility and safety of RPD, we would like to underscore some important permissive factors. Hospital and surgical volumes are both known to be important for open pancreatoduodenectomy [20, 21]. We believe that this issue is true also for RPD. Large volumes do only spell for competence but also allow judicious selection of patients, especially at the beginning of the experience. RPD is indeed known to be associated with a steep learning curve requiring between 40 and 80 procedures [22, 23]. The volumes required to acquire competence and skills in RPD cannot be identified in 20 annual procedures, including all types of pancreatic resections. Twenty annual procedures were identified as a cut-off for improved outcome in studies based on patients operated in the ‘90s and early 2000s. A more contemporary view of “high volume” in pancreatic surgery includes a larger number of procedures performed yearly, with major centers now perform greater than 200 resections per year. More importantly, we believe that surgeons not dedicated to pancreatic disease and not practicing pancreatic resections frequently should be very prudent when embarking upon RPD. Although gifted surgeons could quickly acquire the technical skills required to complete the operation, we see the risk that an exceedingly enthusiastic approach to this formidable operation could expose the occasional patient to undue risk. A recent population-based study, including all patients undergoing surgery for pancreatic cancer in Italy between 2010 and 2012 demonstrated that not only pancreatic resections are associated with worse in-hospital outcome when performed in low volume hospitals, but also that patients are managed differently based on hospital volume with overuse of palliative/explorative surgery and lower resection rates in low volume hospitals [24]. Open pancreatoduodenectomy should be performed with great caution in low volume hospitals. Probably, MIPD should not be performed in low volume Institutions.

Our experience confirms that RPD is associated with long operative times. Although we have noted shorter operative times in the most recent period, we barely see

Table 3 Main intra- and post-operative outcome measures

Outcome measure		
Operative time (min) (mean ± SD)	526.3	±102.4
Operative time RPD, without associated procedures (min) (mean ± SD)	506.0	±80.2
Conversion to open	3	2.6 %
Intraoperative blood transfusions (U)	6	5.4 %
Perioperative blood transfusions (U)	32	28.5 %
Post-operative complications	83	74.1 %
Grade I	9	8.0 %
Grade II	52	46.4 %
Grade III	18	16.0 %
IIIa	10	8.9 %
IIIb	8	7.1 %
Grade IV	0	0 %
IVa	0	0 %
IVb	0	0 %
Grade V	4	3.5 %
Comprehensive complication index (median–IQR)	20.9	0–30.8
Post-operative pancreatic fistula	37	33.0 %
Grade A	15	13.3 %
Grade B	20	17.8 %
Grade C	2	1.7 %
Delayed gastric emptying	53	47.3 %
Grade A	3	2.6 %
Grade B	32	28.5 %
Grade C	18	16.0 %
Post-pancreatectomy hemorrhage	15	13.4 %
Intraluminal	4	3.5 %
Extraluminal	11	9.8 %
Intra- and extraluminal	1	0.9 %
Grade A	1	0.9 %
Grade B	4	3.5 %
Grade C	10	8.9 %
Interventional radiology procedures	11	9.8 %
Percutaneous catheter drainage	10	8.9 %
Endovascular procedures	1	0.9 %
Reoperation	13	11.6 %
Length of hospital stay (days) (mean ± SD)	22	±12.7
Readmission (90-day)	10	8.9 %

how operative time could be dramatically reduced in a procedure that relies more on precision than on speed. As discussed in the recent consensus statement on the use of robotics in general surgery by the European Association of Endoscopic Surgeons, precision in surgery is inversely related to speed, while complex tasks in endoscopic surgery are performed better and faster with robotics [25]. These statements match well with the impressively low rate of intraoperative blood transfusions achieved in the present series of RPD. In open pancreatoduodenectomy intraoperative blood transfusions are required between 28 and 42 % of the patients [26, 27].

About the quality of the results following RPD vs open pancreatoduodenectomy specific considerations apply. Open pancreatoduodenectomy is a well-established procedure, although yet imperfect in terms of morbidity and mortality. Variations in surgical technique and PO management exist but each high volume center has standardized surgical techniques and recovery protocols. On the contrary RPD is still under development with major experience (≥100 cases) gained at just a handful of Institutions worldwide. Techniques for RPD mimic open procedures but are yet immature. Despite the obvious limitations when comparing well-established and newly developed procedures, especially regarding parameters related to safety, length of hospital stay is often used to define the efficacy of RPD versus open pancreatoduodenectomy. This outcome measure is used as a surrogate marker of faster recovery and is scrutinized by stakeholders because of its implications on costs. The combination of these factors could even create undue pressure on surgeons, favoring early hospital discharge, to demonstrate the advantages of MIPD and show its economic sustainability. However, reduction in length of hospital stay is of limited interest to patients [28, 29]. Patients often do not recover fully and are still symptomatic on discharge after major surgery. Timing of hospital discharge is influenced by cultural and organizational factors [2] and may not correlate with long term recovery. A more objective evaluation of PO recovery divides this process into three phases: early (0–24 h or 0–7 days), intermediate (first 28 or 60 days), and late (first 6 weeks of 3 months) [30]. Speed and quality of recovery in the first phase is influenced mostly by pain, nausea, perioperative medications and delirium. As such the early phase, for a major procedure such as pancreatoduodenectomy, does not reflect only the surgical trauma but rather, and perhaps even more accurately, the quality of intraoperative and early PO care. The intermediate phase is again influenced by pain but also by anxiety, depression, physical impairment and cognitive dysfunction, especially when surgery was performed for cancer [31]. The late phase is characterized by persistence of symptoms that afflict the early and the intermediate period.

When we have decided to implement our program for RPD we have identified safety as the main priority. In Italy patients cannot be discharged to intermediate care facilities and must be self-sufficient when leaving the hospital. As a consequence, in keeping with the results from other Italian series [32], our length of hospital stay is longer than wished. Another important consideration regards the fact that, at least so far, we have been the only Italian high volume center pursuing MIPD and that at the beginning of this experience there was little evidence in the literature supporting this approach. Admittedly, our length of hospital stay could also reflect an overprotective policy and could not represent the true potential of RPD. The implementation of a protocol for enhanced recovery after surgery [33] is expected to reduce the length of hospital stay.

The rate and type of complications in our series of RPD are quite similar to the figures reported for the open procedure, with two major exceptions: a higher rate of delayed gastric emptying and the absence of pseudoaneurysms from large visceral arteries. It is also worth of note that no grade C PO pancreatic fistula was noted in the last consecutive 72 patients, despite many of them were at high risk for this complication because of the relatively low percentage of pancreatic cancer, and the consequent high prevalence of soft pancreas with small ducts.

Regarding delayed gastric emptying our results could be influenced by our choice to spare the pylorus, that is based on our historical experience with open pancreatoduodenectomy, with the first pylorus preserving procedures performed as early as 1982 [34]. Pylorus preservation is known to be associated with higher rates of delayed gastric emptying when compared with the classical Whipple procedure [35]. Additionally, in our most recent open experience we prefer to place the duodeno-jejunal anastomosis in an antecolic location, while in our RPD we still perform all digestive anastomosis on the same jejunal loop passed behind the mesenteric vessels in the former duodenal bed. Antecolic reconstruction is known to improve delayed gastric emptying after pylorus-preserving pancreatoduodenectomy [36]. Modifications in our policy for pylorus preservation and route for digestive reconstruction could improve the rate and severity of delayed gastric emptying in RPD. Improvement in delayed gastric emptying was noted in the most recent part of this experience.

We have not noted visceral pseudoaneurysms in this consecutive series of 112 RPD. The only patient who had major post-pancreatectomy hemorrhage from a large visceral artery (superior mesenteric artery) had no evidence of pseudoaneurysm on either contrast-enhanced computed tomography or repeat surgery. This case was described in detail previously [12]. No visceral pseudoaneurysm was also noted in 18 additional patients undergoing robotic total pancreatectomy in the same period of time making a total of 130 resections of the pancreatic head without visceral pseudoaneurysms. Visceral pseudoaneurysms are a well known complication of open pancreatoduodenectomy and were reported to occur between 5 and 6 % of the patients after RPD [37, 38]. We do not have a clear explanation for this result. We speculate that careful surgical technique, selective ligatures of all arterial branches, coverage of the stump of the gastroduodenal artery with the falciform ligament, could have played a role. Further experience will clarify whether RPD is associated with fewer visceral pseudoaneurysms.

Management of the pancreatic remnant is clearly the Achille's hell of pancreatoduodenectomy. Any significant reduction in morbidity after pancreatoduodenectomy relies on improvement of pancreatic anastomosis. Robotic assistance permits all types of pancreatic reconstructions. High definition, magnified, stereoscopic vision and use of endowrist® instruments allow impressive suturing precision, especially when dealing with small ducts. Despite these technology advantages we have not shown an improvement in the rate of PO pancreatic fistula. This result could be at least in part related to the fact that many of our patients were at high risk for PO pancreatic fistula, because of the initial selection favoring patients without pancreatic cancer. In this group of patients with soft pancreas and small ducts there are few individuals in whom any pancreatic anastomosis is thought to be at an exceedingly high risk of major complications. To address this issue Balzano and Co-authors have proposed elective total pancreatectomy followed by islet autotransplantation [39]. In these circumstances we prefer to avoid the pancreatic anastomosis and to drain the pancreatic juice externally. The rationale for this approach is to create a controlled external pancreatic fistula that has a benign course. Of course external duct drainage produces, by definition early morbidity and abolishes exocrine pancreatic function. As a consequence it is rarely used, and it is considered an option only in frail patients at high risk for PO pancreatic fistula. It is worth to note that none of our patients having external duct drainage was reoperated either to address early complications or to provide internal drainage. Reoperation to provide internal drainage remains an option, but typically the amount of exocrine secretion progressively decreases so that the catheter can be eventually withdrawn without consequences.

In this series all RPD were performed by a single surgeon. Implementation of a program for RPD is a serious undertaking making safety the first and key objective to pursue. This is the main reason for which we decided to invest on a single, very high volume, surgeon having performed hundreds of open PD. Reproducibility of RPD by other surgeons, within and outside our institution, is one of our major future objectives. While we are currently working on a formal training curriculum, including simulation, dry-lab exercises, and possibly animal models, we believe that RPD should be learned stepwise and that proficiency should be gained on each individual step before moving to the next. Training for RPD should occur under appropriate operative conditions including frequent accessibility to the robotic platform, high volume of pancreatic procedures, and expert surgeon supervision. Considering that the two most crucial steps of RPD are dissection of the posterior margin and drainage of the residual pancreatic stump, lean patients with periampullary tumors are recommended to learn dissecting the posterior margin and patients with ductal adenocarcinoma (i.e., with a hard pancreas and a dilated duct) are suggested to learn performing pancreatic anastomosis. Additionally, when one member of the team is learning, all the other teammates should be very expert.

In conclusions, we have reported one of the largest world experiences on RPD showing that this procedure is safely feasible in selected patients. This program was developed by dedicated pancreatic surgeons at a high volume center. Refinements in surgical technique and PO management protocols are likely to occur and could improve the results, eventually making RPD an attractive alternative to open pancreatoduodenectomy in a larger proportion of patients.

Compliance with ethical standards

Conflict of interest The authors do not have any conflict of interest to disclose.

Ethical approval All procedures analyzed in this study were conducted in accordance with the ethical standards of our Institution, and with the 1964 Helsinki declaration and its later amendments.

Informed consent All participanting individuals provided informed consent.

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