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Fully robotic total pancreatectomy: technical aspects and outcomes

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Abstract
Robotic total pancreatectomy (RTP) is a novel surgical approach currently performed by a select group of skilled surgeons. As robotic approaches to pancreatic surgery increase worldwide, rates of RTP are expected to increase. However, the standard technique is still evolving and several technical problems still require evaluation. Here, we describe our approach in a stepwise fashion and discuss solutions to overcome technical difficulties.

Keywords Pancreatic cancer · Robotic surgery · Minimally invasive technique

Introduction

The utilization of minimally invasive surgery (MIS) in pancreatic resections is becoming increasingly common [1]. MIS for distal pancreatic resections are associated with decreased blood loss and length of hospitalization [1]. Laparoscopy is now considered by several groups as the preferred surgical approach for distal pancreatic tumors.

Total pancreatectomy (TP) is also being increasingly performed worldwide due to the rising incidence of multifocal intraductal pancreatic mucinous neoplasms (IPMN) [2] and enhanced postoperative care of diabetes mellitus [3]. TP is a more technically demanding procedure as compared to DP, as it includes concurrent pancreaticoduodenectomy with biliary and gastrointestinal reconstruction. Hence, laparoscopic total pancreatectomy (LTP) experience is scarce [1, 4, 5]. The introduction of robotic-assisted TP (RTP) became an attractive option due to three dimensional visualization, higher operative field resolution and increased degrees of freedom to execute complex reconstructions [6]. In addition, the utilization of the Da Vinci(r) surgical system (dVss)

(Intuitive Surgical, Inc., Sunnyvale, CA) robot appears to yield significant higher rates of successful spleen preservation (SP) as compared to conventional laparoscopy [7].

Very few series have been reported assessing the safety, feasibility and outcomes of RTP [8, 9]. The standard technique is still evolving and several technical problems still warrant solutions. We sought to describe the technical aspects of RTP, thereby focusing on details related to adequate robot set-up and SP maneuvers.

Methods

From April 2012 to October 2015, all patients who underwent RTP at The Valley Hospital (Ridgewood, NJ) were included in our prospective collected database. Patient demographics and postoperative courses were described. Intraoperative data including, operative time, surgical technique, spleen preservation, pylorus preservation, complication rates and pathology were reviewed. Further data were gathered by analysing our video database.

This study was approved by the Institutional Review Board (IRB) at The Valley Hospital, Ridgewood, NJ, USA.

Operative procedure

Step 1: Operation room set-up and port placement

The patient is placed supine in reverse Trendelenburg position with both arms tucked along the body. After pneumoperitoneum is established, laparoscopic- and da Vinci-ports

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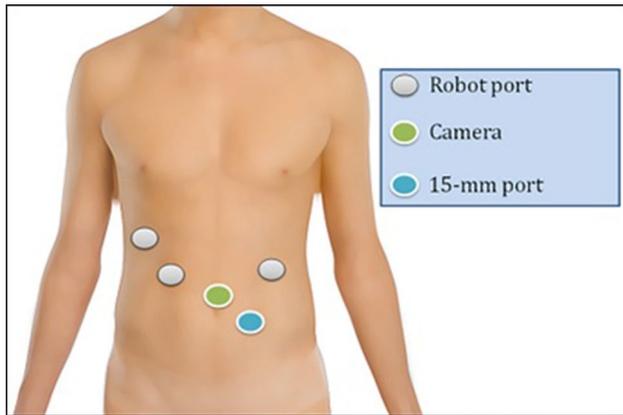3 The Valley Institute of Robotics, Ridgewood, NJ, USA
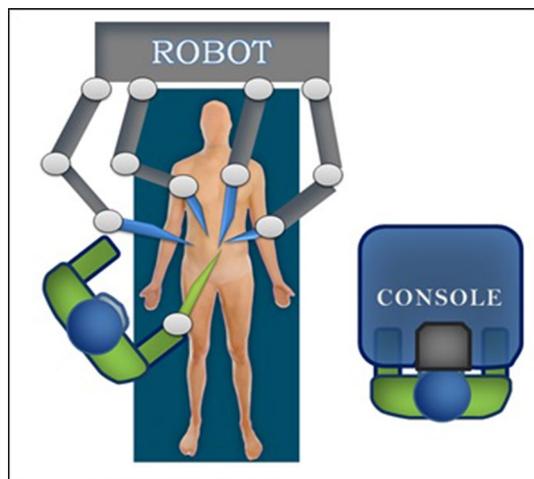
Fig. 1 Trocar placement

Fig. 2 Operative room set-up

are placed as depicted in Fig. 1. Nonetheless, the adequate placement for trocars should be assessed and adjusted according to each case. In addition, due to limited possibilities of tilting the table following robot docking, both 0° scope and 30° angled scope should be available throughout the procedure. The robot is then docked over the head of the patient with arms 2 and 3 at the right lateral side of the table (Fig. 2). The surgeon assumes his position at the robot console and the first assistant stands at the patient's right side.

Step 2: Dissection of the lower border of the pancreas (LBP)

The dissection commences with the opening of the gastrocolic ligament along the gastroepiploic arcade from the pylorus to the level of the short gastric vessels. During this dissection, it is possible to identify the middle colic vessels, right gastroepiploic vessels and gastrocolic trunk. The pancreatogastric fold can also be divided for full pancreas exposure. For this maneuver and throughout most of the

procedure, a dVss(r) bipolar forceps is used at arm 2 and a dVss(r) hook or scissors at arm 1. The stomach is then pulled cranially by its posterior wall with arm 3 to ensure better pancreas exposure. To maximize utilization of the arm 3, the stomach can also be suture-attached to the falciform ligament.

The right gastroepiploic vessels are then dissected down until the gastrocolic trunk is identified and the root of the superior mesenteric vein (SMV) is visualized. The retroperitoneum overlying the lower border of the pancreas (LWB) is then incised and gentle dissection of the loose areolar tissue allows entering the avascular plane behind the pancreas. This dissection progresses from the SMV toward the pancreatic tail.

Step 3: Dissection of the upper border of the pancreas (UBP)

Dissection of the UBP commences by identifying its important anatomic structures: splenic artery (SA), common hepatic artery (CHA), gastroduodenal artery (GDA) and left gastric vein (LGV). Once the vessels surrounding the pancreatic neck (PN) are freed from the pancreatic parenchyma, blunt dissection is performed underneath the PN and an umbilical tape may be passed to encircle the PN at the surgeon's discretion. At this time, it is advisable that the surgeon has already decided upon SP or splenectomy and which preservation technique will be used. This early decision allows the surgeon to carry out important technical steps safely in a stepwise manner, decreasing operative time and blood loss.

Step 4a: Splenic vessel dissection and division

If SP is deemed unsafe or the Warshaw technique (WT) is chosen as the only feasible method for SP, we perform early ligation of the splenic vessels near their origin. Technically, this is accomplished by careful dissection of the splenomesenteric junction at the portal vein (PV) origin. The PN is pulled cranially using an umbilical tape or robot arm 3 and the splenic vein (SV) is then encircled with a vessel loop for further control. The dissection then moves to the UBP, where the SA is dissected free from the pancreatic parenchyma, clipped at its root using Hem-o-lok (r) (Teleflex Medical, Research Triangle Park, North Carolina, USA) or divided using a vascular cartridge linear stapler.

After the division of the SA, the vessel loop used to identify the SV is pulled caudally and the vein is clipped with Hem-o-Lok(r) and subsequently divided. The retroperitoneum is incised along the left lower pancreatic border toward the pancreatic tail. For the splenopancreatectomy technique, the short gastric vessels are cauterized with bipolar and divided. After this point, dissection continues as previously

described for robotic DP [10] until full mobilization of the en-bloc pancreatic body, tail and spleen.

Step 4b: Warshaw technique

Once the SA is divided, the stomach is pulled upward and the left gastric vein is identified. Here, the dissection of the left gastric vein and its careful preservation is an important step to maintain reliable splenic outflow and achieve higher rates of success with WT. After this, the SV can be safely divided as in Step 3a. Dissection towards the pancreatic tail progresses as explained above, except for the splenocolic ligament, which should be kept intact when performing the WT to avoid lower lobe infarction of the spleen. The pancreatic body and tail are dissected free until completely mobile whereas short gastric vessels should be necessarily preserved. At the end of the procedure, 2 mL of indocyanine green (25 mg/Vial, Patheon Italia SpA/HUB Pharmaceuticals LLC) is injected as an IV bolus [11]. The fluorescence imaging system of the dVss(r) is used to assess spleen blood perfusion (Fig. 3).

Step 4c: Splenic vessel preservation technique (SVPT)

To maintain splenic vessel integrity, the pancreas is pulled upward and splenic vessels are dissected free from the pancreatic parenchyma using the medial-to-lateral approach as previously published [1, 12] until pancreatic body and tail can be fully mobilized to the right hypocondrium. For this step, control of the small venous branches can be secured with dVss(r) bipolar forceps, whereas greater branches are divided between Hem-o-Lok(r) clips.

Step 5: Pancreaticoduodenectomy (PD)

The second stage of the procedure commences by continuing the upper border dissection toward the GDA. The first portion of the duodenum is dissected free and small infra-pyloric branches are coagulated as needed. Upon decision on preserving the pylorus, the duodenum is divided with a linear stapler just above the head of the pancreas. Otherwise, distal gastrectomy is performed with a linear stapler after ligation of right gastric vessels. Once the specimen is no longer attached to the stomach, full exposure of the GDA allows its ligation via the aforementioned techniques.

Next, dissection is continued until complete detachment of the root of the transverse mesocolon from the infra-pancreatic SMV is achieved, followed by the dissection of the right border of the SMV towards the uncinate process. Once the entire mesocolon is detached from the right border of SMV, a complete Kocher maneuver allows the mobilization of the pancreatic head and the duodenum until the proximal jejunum.

The transverse mesocolon is incised left of the middle colic vessels and the proximal jejunum is pulled upward through the created window. This window avoids the necessity of lifting up the mesocolon for jejunual transection and maintains maximal exposure in this robotic approach. After this, the proximal jejunum is divided with a conventional laparoscopic stapler and the first jejunal branches are cauterized using dVss bipolar forceps until the ligament of Treitz is accurately identified and divided. This dissection is carried out until the entire duodenum can be mobilized towards the right hypochondrium. At this point, we routinely attach the proximal jejunal stump and distal stump together by means of a suture. The midjejunum is also stitched to the stapled stomach stump.

Once the duodenum is fully mobilized, detachment of the uncinate process from the SMV and superior mesenteric artery (SMA) can carried out by gentle use of the dVss bipolar forceps. This dissection continues along the PV until the hepatoduodenal ligament is reached and clearly identified from a caudal approach. Following this, the gallbladder is taken down and the common bile duct is divided above the cystic duct level. Finally, the remaining portal branches are coagulated or clipped as needed and the resection is completed.

Step 6: Biliary and gastrointestinal reconstruction

At this time, the stapled distal jejunal stump is already in position due to traction sutures placed before duodenum derotation. These sutures are then removed and a hepaticojejunostomy is fashioned using 5–0 continuous running suture. Reconstruction is then moved to the epigastrium, where the midjejunum is positioned in place via the previous applied

Fig. 3 Identification of spleen perfusion after WT using the Firefly technique. **a** Spleen is clearly visualized after the IV injection of the ICG. **b** Da Vinci camera mode is set to FireFly to identify fluorescent imaging
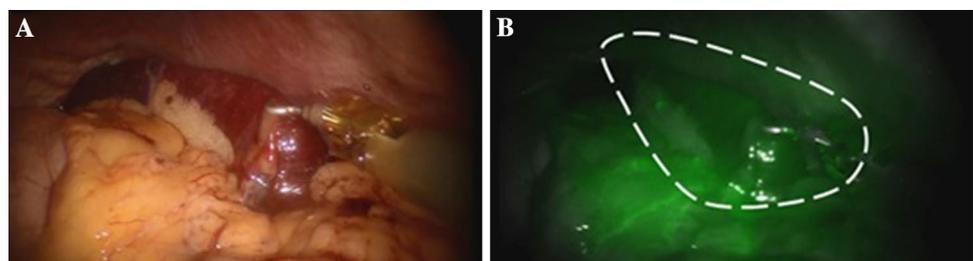
sutures to the posterior gastric wall. After these sutures are removed, duodenojejunostomy (or gastrojejunostomy) is then performed using two layers of 3–0 V-Loc(r) continuous suture. Specimen is extracted through a small supra-pubic incision using a 15-mm ENDO CATCH(r) [Covidien(r), USA].

Limitations

The procedure is technically demanding and requires advanced skill with the robotic approach. A stepwise approach is feasible and efficient for most cases and this systematic method allows the surgeon to carry out the procedure within an adequate operative time. That said, this step-by-step technique has been applied by the author only after achieving extensive experience with distal and robotic pancreaticoduodenectomy.

Although we believe that the technique can be expanded and taught to new surgeons, our opinion is that a true learning curve will be difficult to assess due to the complexity of the procedure. Hence, we consider that a major limitation for our RTP approach is the fact it should be reserved for surgeons who are familiar with other standardized robotic pancreatic procedures.

Results

A total of seven consecutive patients underwent a RTP at our institution during the study period. Four (57.1%) patients were female and median age was 67 years (range 49–82 years). Mean BMI was 27.8 kg/m^2 (range 23–44 kg/m^2) and the majority of patients had at least one comorbidity (Table 1).

Five patients underwent RTP due to diagnosis of diffuse IPMN, one patient was referred to surgery due to a complicated chronic pancreatitis and two patients had a multifocal neuroendocrine tumor (NET). One patient had a synchronous pancreatic NET and IPMN.

The resections were distributed as following: one patient underwent classic total pancreatectomy (CTP), defined as removal of the entire pancreas plus the spleen and a distal gastrectomy; four patients underwent SP technique; and five patients had pylorus preserving RTP. Mean operative time was 490 min (range 330–660 min), with a mean estimated blood loss (EBL) of 238 mL (range 50–400 mL). None of patients required intraoperative blood transfusion.

Regarding the technique used for SP, the Warshaw method [13] was performed in three cases, whereas one patient had a splenic vessel preserving dissection. Robot-assisted intraoperative indocyanine green (ICG) green fluorescent imaging [11] was used to assess splenic perfusion in all patients who underwent Warshaw technique (WT).

There were no intraoperative complications such as unpredictable bleeding or visceral injury. One patient had the procedure converted to the open approach after specimen resection due to a difficult reconstruction and operator exhaustion.

Four patients presented with complications postoperatively. One patient had severe peritonitis secondary to gastric perforation, which was successfully repaired laparoscopically. Two patients were readmitted in the first two weeks after discharge due to metabolic complications (Case #4) and vomiting (Case #5). No in-hospital mortality was identified.

Postoperative histopathological reports showed malignant disease in four patients. Definitive diagnosis is summarized in Table 1. Mean tumor size was 2.8-cm (range 2.0- to 4.0-cm). Mean number of dissected lymph nodes was 19 (range 8–27).

Table 1 Patient demographics and case details

Case	Gender	Age	BMI (kg/m^2)	Procedure	OT (min)	EBL (mL)	LOS (days)	Complications
1	M	67	23	CTPS	480	150	10	Ascitis
2	F	65	23	PP–SP	435	240	10	–
3	F	71	26	PP–SP	540	300	7	PE
4	M	49	33	PP–SP	510	330	9	Dehydration—readmission
5	F	82	28	SP	480	200	8	
6	F	52	18	PP-TPS	330	50	10	
7	M	74	44	PP-TPS	660	400	14	Peritonitis

M male, *F* female, *BMI* body mass index, *CTPS* classic total pancreato-splenectomy, *PP–SP* pylorus-preserving spleen-preserving, *SP* spleen-preserving, *PP-TPS* pylorus-preserving total pancreato-splenectomy, *OT* operative time, *EBL* estimate blood loss, *LOS* length of stay

Discussion

Due to improved endocrine and exocrine control with modern insulin regimens and pancreatic enzymes formulations, TP has recently resurged as a safe surgical approach for multifocal IPMN and neuroendocrine tumors. Therefore, there has been an increase in the rates of TP from 9.3% in 1998 to 14.3% in 2004 [2].

Recent small case series have shown the feasibility of laparoscopic TP [4]. However, this approach has a steep learning curve and its technical complexity prevents its widespread use. A robotic approach has been advocated to overcome some of these limitations due to its improved three-dimensional visualization, enhanced ergonomics and less difficult suturing in complex reconstruction.

To our knowledge, there were only four published cases series regarding the use of RTP before this manuscript. Giulianotti et al. [14] reported their initial results after five RTPs, Galvani et al. [15] described six consecutive cases, Zureikat et al. [8] analyzed ten RTPs, and Boggi et al. [9] published their experience after 11 cases (Table 2).

RTP demands highly complex operative skills combined with extensive preoperative planning. Although the dVss allows surgeon an undisputed advantage with its range of instrument mobility, it is impossible to neglect the impact of limited exposition after docking. In addition, the most commonly used dVss do not allow surgical table mobility during the procedure. Our first RTP was only performed after 5 years of experience with robotic PD and DP. We noticed that TP could be safely performed in the range of view of the robot without requiring an additional machine, repositioning the patient or laparoscopic dissection prior to docking. Nonetheless, double docking was still used in one morbidly obese patient.

The robotic system allows increased success rates of spleen preservation pancreatic resection. When SP is planned, we recommend a thorough preoperative evaluation analyzing spleen size, hilum position, splenic vessels calcification and their anatomical relationship with the tumor. The benefits of SP in TP still need to be determined. SPDP is associated with fewer infectious complications, less operative blood loss, decreased clinical pancreatic fistula rate and a decrease in overall morbidity rate [7]. SP for RTP has ranged from 20 to 66.6% [15]. Splenic vein preservation has been associated with decreased rates of splenic infarction and secondary splenectomy, although overall morbidity was not significantly different as compared to the Warshaw technique [16]. It is of utmost importance to decide early during the procedure which technique will be applied to decrease operative time and bleeding. Due to the infiltrative nature of the malignancy, we only could preserve the SV in one case, whereas WT was successful in three cases. Based on our previous experience with RDP, [10] we currently use a stepwise approach for the WT: identification and preservation of the left gastric vein, to maintain a reliable venous drainage system for the complex spleen-stomach; careful preservation of the splenocolic ligament maintaining inflow and outflow for the lower pole of the spleen; injection of indocyanine green (ICG) and the utilization of the embedded fluorescent imaging of the dVss Si system [11]. This last step allows us to directly assess remnant splenic perfusion. Prompt removal of a non-viable spleen decreases complications such as postoperative splenic infarction and abscess formation. We believe that the ICG use is an inexpensive, fast and safe method to assess splenic viability after WT and can substitute for other time-consuming methods such as intraoperative ultrasound [17].

Regarding pylorus preservation, there was no difference in total operative time, blood loss or length of stay for the PP-RTP as compared to CRTP. However, we aim to preserve the pylorus whenever possible. After resection, a duodeno-jejuno anastomosis can be fashioned quickly and poses no increased difficulty as compared to gastrojejunal anastomosis.

In conclusion, fully robotic total pancreatectomy is a safe and feasible surgical approach. To maximize the success

Table 2 Robotic total pancreatectomy selected published reports

Author (date)	N	Age	BMI (kg/m²)	Diagnosis	OT (min)	EBL (mL)	LOS (days)	SP/PP
Giulianotti et al. (2011) [14]	5	N/A	N/A	ADK 2; IPMN 1; NET 1; CP 1	480 (300–560)	300 (50–650)	7 (5–10)	2/N/A
Galvani (2014) [15]	6	41 (22–58)	23.2 (18.5–30.1)	CP 6	712 (612–835)	630 (500–800)	12 (11–14)	4/6
Zureikat et al. (2015) [8]	10	58 (20–76)	28.2 (24.5–29.7)	ADK 1; IPMN 6; CP 3	560 (461–592)	650 (400–1000)	10 (7–10)	2/0
Boggi et al. (2015) [9]	11	61 (50–74)	24.8 (18.4–35.0)	ADK 2; IPMN 8; 1 CP	600 (400–800)	220 (100–450)	27 (12–88)	3/10
Current series (The Valley Robotic Institute)	7	67 (49–82)	25 (23–44)	IPMN 4; CP 1; NET 2	480 (330–660)	240 (50–400)	10 (7–14)	4/4

N number of cases, *BMI* body mass index, *OT* operative time, *EBL* estimated blood loss, *LOS* length of stay, *SP* spleen preserving, *PP* pylorus preserving, *N/A* not reported, *ADK* adenocarcinoma, *IPMN* intraductal papillary mucinous neoplasm, *NET* neuroendocrine tumor, *CP* chronic pancreatitis

rates of spleen preservation, vessel preserving technique should be used whenever possible. Further experience is still needed to define long-term outcomes of patients undergoing RTP. As robotic pancreatic resection continues to expand worldwide, its technique will continue to be refined.

Author contribution MNJWB, MFI, LY and PY contributed substantially to the design, implementation of the research, to the analysis of the results and to the writing of the manuscript. Mesquita-Neto J.W.B., MFI, LY and PY also revised all the intellectual content and approved the publication of this final manuscript.

Compliance with ethical standards

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