Surg Endosc (2017) 31:2380–2386
DOI 10.1007/s00464-016-5238-6

The surgical outcomes of robot-assisted laparoscopic pancreaticoduodenectomy versus laparoscopic pancreaticoduodenectomy for periampullary neoplasms: a comparative study of a single center

Rong Liu[1] · Tao Zhang[1,2] · Zhi-Ming Zhao[1] · Xiang-Long Tan[1] · Guo-Dong Zhao[1] · Xuan Zhang[1] · Yong Xu[1]

Received: 21 May 2016 / Accepted: 16 August 2016 / Published online: 8 September 2016

Abstract
Background Pancreaticoduodenectomy (PD) is a difficult and complex operation. The introduction of robotics has opened up new angles in pancreatic surgery. This study aims to assess the surgical outcomes of robot-assisted laparoscopic pancreaticoduodenectomy relative to its laparoscopic counterpart.
Methods A retrospective study was designed to compare the surgical outcomes of 27 robot-assisted laparoscopic pancreaticoduodenectomy (RPD) and 25 laparoscopic pancreaticoduodenectomy (LPD). Perioperative data, including operating time, complication, morbidity and mortality, estimated blood loss, and postoperative length of stay, were analyzed.
Results The robotic group exhibited significantly shorter operative time (mean 387 vs. 442 min), shorter hospital stay (mean 17 vs. 24 days), and less blood loss (mean 219 vs. 334 ml) than those in the LPD group. No statistical difference was observed between the two groups in terms of complication rate, mortality rate, R0 resection rate, and number of harvested lymph node.
Conclusions RPD is more efficient and secure process than LPD among properly selected patients. RPD is therefore a feasible alternative to the laparoscopic procedure. Further studies are needed to evaluate the cost effectiveness of the robotic approach for PD.

Keywords Periampullary neoplasms · Laparoscopic pancreaticoduodenectomy · Robotic surgery · da Vinci · Comparative study

Rong Liu and Tao Zhang contributed equally to this work and both should be considered first author.

✉ Rong Liu
liurong301@126.com

[1] Department of Hepatobiliary and Pancreatic Surgical Oncology, Chinese PLA General Hospital and Chinese PLA Medical School, 28 Fuxing Road, Haidian District, Beijing 100853, China

[2] Department of General Surgery, 306 Hospital of PLA, Beijing, China

Pancreaticoduodenectomy (PD) was performed by Whipple procedure for the first time for carcinoma of the ampulla of Vater in 1938 [1]. PD is regarded as one of the most difficult operations in pancreatic surgery because of its complexity associated with extensive digestive organ dissection and reconstruction of digestive tract continuity. Currently, PD is performed with the open approach through a long abdominal incision. The application of laparoscopy has been performed with respect to conventional surgery since the 1990s. Since the first report of laparoscopic pancreaticoduodenectomy (LPD) [2], a series of LPD procedures demonstrate feasibility, safety, and adequacy [3–6]. Minimally invasive surgical technique has become popular in surgery because of its improved perioperative period and surgical outcomes [7, 8].

With the development of minimally invasive surgical techniques, surgical robot systems have been gradually applied in the field of pancreatic surgery [9]. These systems exhibit more advantages compared with laparoscopic surgery; such advantages include articulation of instruments with almost 540° of motion, elimination of surgeon tremor, and binocular enhanced three-dimensional vision [10]. The operating time of robot-assisted laparoscopic pancreaticoduodenectomy (RPD) is longer than open approach, but the complication rate is lower. Both LPD and RPD are practical, highly efficient, and safe techniques. Nevertheless, the clinical results of these two minimally invasive approaches of PD have not been directly assessed.

This nonrandomized comparative study aims to evaluate the perioperative outcomes of RPD and LPD.

Materials and methods

Study design

A consecutive series of patients who underwent RPD or LPD for malignant or benign pathologies were selected from the Department of Hepatobiliary and Pancreatic Surgical Oncology, Chinese PLA General Hospital between April 2015 and February 2016. All 27 RPD and 25 LPD cases at the same time period were analyzed in terms of demographic data, operative time, estimated blood loss, postoperative length of stay, morbidity rates, mortality rates, and final pathologic results. This retrospective study was conducted after the approval of the Institutional Review Board.

All patients underwent a complete clinical evaluation consisting of physical condition and optimization of comorbidities after hospitalization. All patients received laboratory blood test, serum tumor marker analysis, computerized tomography (CT) scans, magnetic resonance imaging, and positron emission tomography–computed tomography. The inclusion criteria were as follows: tumors confined to the pancreatic head or periampullary region without vascular invasion and complied with the American Society of Anesthesiologists score (ASA) of <3. The exclusion criteria included prior abdominal surgeries, body mass index >40, locally advanced tumors, and inability to withstand prolonged anesthesia. All patients included were well informed of the advantages and disadvantages of RPD and LPD by independent doctors. The principle of free, prior, and informed consent was also referred to. All patients voluntarily gave written informed consents for operation. Moreover, the use of the robotic or laparoscopic approach was at the sole discretion of the patient. The da Vinci®S Surgical System (Intuitive Surgical Inc., Sunnyvale, CA) was used for RPD. All the operations were performed by the same team of experienced surgeons with advanced laparoscopic skills and experience in open pancreatic surgery. Surgeons of the team had overcome the steep initial learning curve of LPD and RPD and completed more than 90 robotic operations per year, which included about 40 pancreatic operations.

Surgical procedures

Patients were placed in supine and reverse Trendelenburg position. The surgeons performed all robot-assisted procedures with da Vinci®S Surgical System (Intuitive Surgical Inc., Sunnyvale, CA). The robotic system was docked over the head of the patient, and the assistant surgeon was positioned between the patient's legs. A 12-mm trocar was placed in the sub-umbilical site for pneumoperitoneum imaging and laparoscopy. After the laparoscopic exploration, the remaining trocars were placed, including one assistant 12-mm trocar in the right hypogastrium and three 5-mm trocars at the right and left subcostal location as well as left hypogastrium (Fig. 1). A camera was placed in the sub-umbilical port. The assistant 12-mm port was used by the assistant surgeon to pass needles and manage the suction irrigator and endostapler. The surgeon performed an extended Kocher maneuver to mobilize the transverse duodenum from the ligament of Treitz beneath the superior mesenteric vessels. The bile duct was freed from the portal vein and hepatic artery. The bile duct was also transected at the hepatic hilar, which was above the cystic duct junction. After the dissection of the hepatic hilum, the gastroduodenal artery was dissected to its origin at the hepatic artery and ligated to expose the portal vein. The portal lymph node was also dissected. The distal stomach was transected with a 75-mm cartridge endostapler (blue load) (Ethicon Endo-Surgery, Cincinnati, OH) (Fig. 2A). The lesser omental bursa was dissected to expose the pancreas, and tissues surrounding the pancreas were freed. The superior mesenteric veins (SMVs) were dissected carefully to create a retropancreatic tunnel between the pancreas and the portal vein (Fig. 2B). The tunneled pancreas was transected from the lateral border of the SMV-portal vein. The pancreatic head was mobilized caudally toward the cephalic direction. The proximal jejunum segment was then identified, retracted into the right upper quadrant below the mesenteric vessels, and transected at the right margin of the superior mesenteric vessels by using a 45-mm cartridge endostapler (blue load)

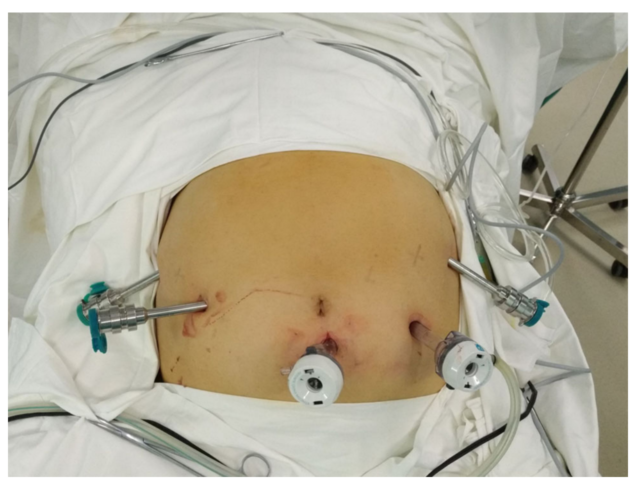

Fig. 1 Laparoscopic port placement in both groups

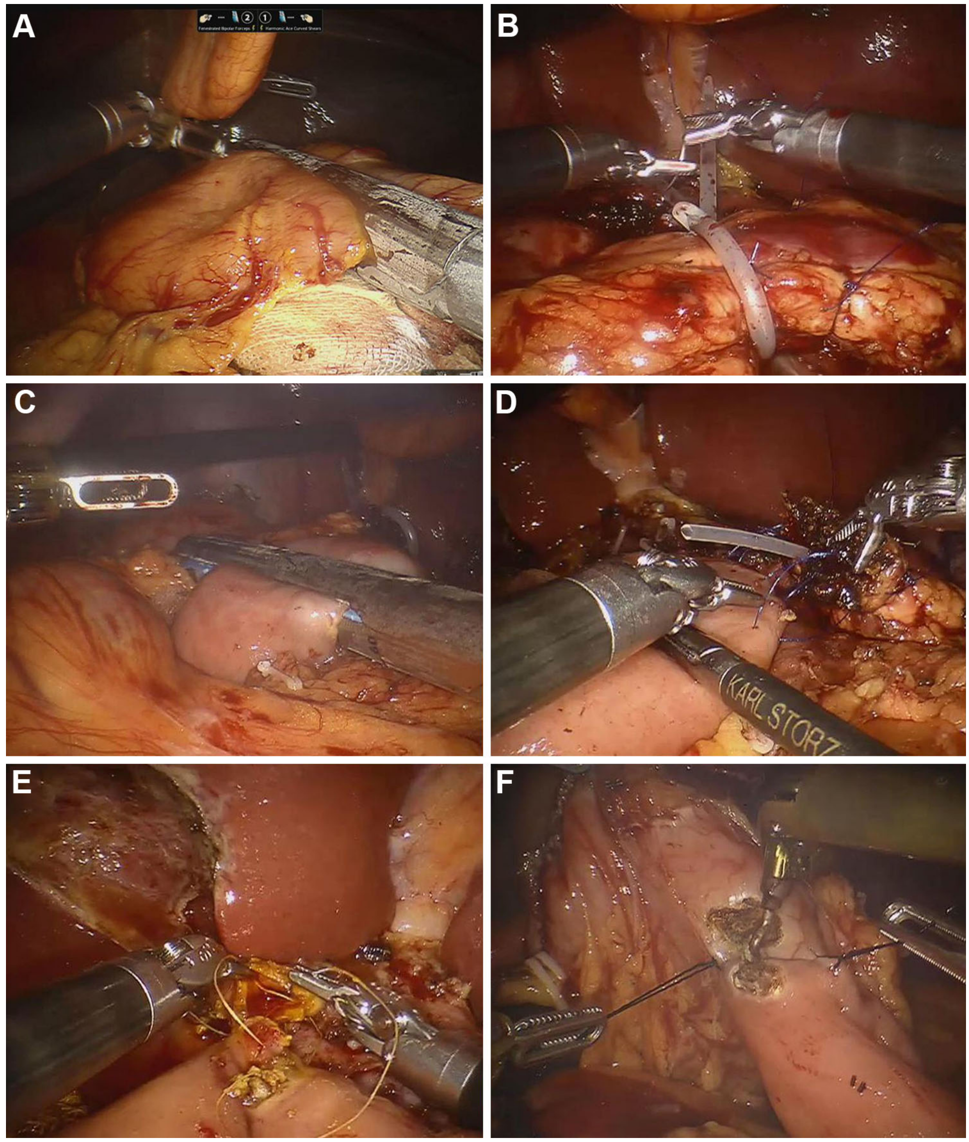

Fig. 2 Representative photographs of the RPD group: **A** Transection of distal stomach. **B** Creation of retropancreatic tunnel. **C** Transection of jejunum. **D** Pancreaticojejunostomy anastomosis. **E** Hepaticojejunostomy anastomosis. **F** Gastrojejunostomy anastomosis

(Ethicon Endo-Surgery, Cincinnati, OH) (Fig. 2C). About 2 cm of the pancreatic body remnant was mobilized in preparation for pancreaticojejunostomy anastomosis. The dissected segment of the jejunum was retracted toward the right side of the mesentery. Pancreaticojejunostomy, hepaticojejunostomy, and gastrojejunal anastomosis were performed in turn (Figs. 2DEF). A two-layer end-to-side duct-to-mucosal pancreaticojejunostomy anastomotic technique was performed with 4–0 Prolene® sutures. Internal pancreatic ductal stenting was used. The stent was not secured. The reconstruction was completed in each patient by using an end-to-side hepaticojejunostomy and a side-to-side gastrojejunostomy. The specimen was extracted into an endobag through the enlarged umbilical port site. Two peritoneal drains were placed near the pancreaticojejunostomy and hepaticojejunostomy at the end of the procedure.

As in robotic approach, all laparoscopic pancreaticoduodenectomy were performed using the standard procedure (Figs. 3ABCD). The patients were placed in supine and mild reverse Trendelenburg position. Five trocars were required. The surgeon was positioned between the patient's legs, and the assistant surgeon was positioned at both sides of the patient. The operative approach and range of surgical resection were the same with the robotic approach. Pancreaticojejunostomy, hepaticojejunostomy, and gastrojejunal anastomosis were performed as previously described to reconstruct continuity of the gastrointestinal tract. Two channel drains were placed near the pancreaticojejunostomy and hepaticojejunostomy.

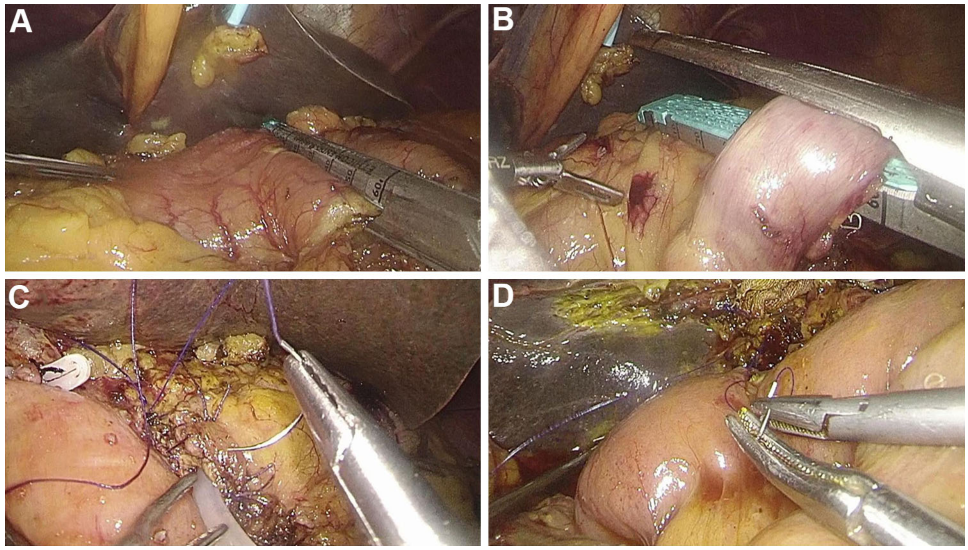

Fig. 3 Representative photographs of the LPD group. **A** Transection of distal stomach. **B** Transection of jejunum. **C** Pancreaticojejunostomy anastomosis. **D** Hepaticojejunostomy anastomosis

Postoperative care

After the operation, the patients were admitted to the Hepatobiliary and Pancreatic Surgical Oncology Unit and received the necessary analgesia. Antibiotics were applied to prevent infection and adjusted in accordance with the blood examination. The nasogastric tube was removed approximately 5 days after the operation. The patients started on a clear liquid diet. Amylase content in peritoneal drainage was measured every 2 days after the operation. The drain was removed in the absence of evident pancreatic fistula. The patients were discharged when they can tolerate soft diet and show negative signs of complications.

Statistical method

SPSS 17.0 statistics software was used. Continuous variables were expressed as mean standard deviation, and Student's *t* test was used to compare data between the two groups. Categorical variables were compared using X^2 test or Fisher's exact test. Differences at $P < 0.05$ were considered statistically significant.

Results

During the study period, 52 operations were performed. Twenty-seven patients underwent RPD, and 25 patients underwent LPD. The mean patient age was 57.16 years in the RPD group and 60.54 years in the LPD group ($P = 0.39$). Malignant cases accounted for 81.4 % of patients in the RPD group and 92 % of patients in the LPD group. No significant difference was observed in the gender distribution between the two groups. The ASA classification included 15 (55.6 %) ASA I and 12 (44.4 %) ASA II in the RPD group as well as 10 (40 %) ASA I and 15 (60 %) ASA II in the LPD ($P = 0.26$). The two groups were well matched for age, gender, tumor size, and final pathologies (Table 1). All patients in both groups had no vascular invasion during the surgery.

The main operative and postoperative outcomes are summarized in Table 2. The LPD group showed significantly longer operative time (mean, 387 vs. 442 min) and longer hospital stay (mean 24 vs. 17 days) than those in the RPD group ($P < 0.05$). The estimated blood loss during the operation in the RPD group was less than that in the laparoscopic group ($P < 0.05$). One patient required conversion to open surgery because of severe peritoneal adhesion in the LPD group. No significant difference was observed between the two groups in terms of overall complication rates (29.6 vs. 44 %) and mortality rates (3.7 vs. 0 %). Postoperative complications in the RPD group included four pancreatic fistula, representing 14.8 %, and five patients (20 %) developed pancreatic fistula in the LPD group. All these patients did not require further surgical treatment. The patients were managed conservatively with octreotide and antibiotics. The drains of these patients were kept in place, and the output was measured. The drains were removed when the output was minimal and amylase content in peritoneal drainage was within the normal range. Only one patient in the LPD group required reoperation because of intraperitoneal hemorrhage. Exploratory laparotomy was performed to determine hemorrhagic spots. Hemostasis by ligation was also carried out. One postoperative death occurred in the RPD group. The patient suffered from pulmonary embolism leading to respiratory failure.

Table 1 Details of patients and pathology

Variables (*n*)	RPD ($n = 27$)	LPD ($n = 25$)	*P* value
Age	57.16 ± 8.56	60.54 ± 18.25	0.39
Gender (male/female)	14/13	12/13	0.78
ASA score			0.26
1	15	10	
2	12	15	
3	0	0	
Pathologic parameters and outcomes			0.46
Ca pancreas	7	5	
Cholangiocarcinoma	4	9	
Ca ampulla	10	8	
Neuroendocrine tumor	1	1	
Solid pseudopapillary neoplasm	2	0	
IPMN	3	2	
Tumor size (cm)	2.24 ± 1.60	1.90 ± 1.29	0.40
Mean lymph node harvested	8 ± 5	6 ± 3	0.09
Positive margin	0	0	

Table 2 Intraoperative and postoperative outcome

Variables (*n*)	RPD ($n = 27$)	LPD ($n = 25$)	*P* value
Operating time (min)	387 ± 58	442 ± 96	0.015
Estimated blood loss (ml)	219 ± 126	334 ± 175	0.01
Open conversion	0	1	0.96
Number of patients with complication	8	11	0.28
Overall complication			
Pancreatic fistula	4	5	0.89
Bile leakage	3	5	0.61
Postoperative hemorrhage	1	2	0.94
Intraabdominal collection/abscess	0	1	0.96
Delayed gastric emptying	2	3	0.92
Wound infection	0	1	0.96
Reoperation rate	0	1	0.96
Postoperative death	1	0	0.98
Mean postoperative hospital stay (days)	17 ± 5	24 ± 13	0.012

Discussion

PD remains one of the most difficult and complex operations in pancreatic surgery. All of the PD procedures involve extensive digestive organ dissection and multiple anastomoses to reconstruct digestive tract continuity, such as pancreaticojejunostomy, hepaticojejunostomy, and gastrojejunal anastomosis. Although Gagner and Pomp reported the feasibility of LPD for the first time in 1994 [2], this technique has not been recommended yet as the standard therapeutic approach of periampullary neoplasms not only because of technical limitations of laparoscopy but also of insufficient training method for laparoscopic techniques. The robotic surgery system was initially invented for military use, especially for operations wherein surgeons cannot arrive on time. Currently, the robotic surgery platform has been introduced into minimally invasive surgery [11, 12]. The da Vinci surgical system consists of four robotic arms, and the surgeon sits at a separate console during the operation.

The robotic platform exhibits enormous advantages over traditional laparoscopy. Traditional laparoscopy only has monocular vision and limited degrees of freedom. Surgeons manipulate the system by using pivot and fulcrum. Suturing and knot tying is quite difficult. By contrast, the robotic surgical system features a three-dimensional stereoscopic view of the operating field and improved hand–eye coordination. Moreover, the movement of endoscopic wrist instrument in the system shows seven degrees of freedom and could filter hand tremor. Finally, the robotic surgical system demonstrates ease of suturing and tying intracorporeal knots with robotic arms [13].

Current developments in surgical technologies allow surgeon to perform all pancreatic operations, including PD, in minimally invasive manner. Both LPD and RPD are considered safe and feasible in appropriately selected patients [14, 15]. Several studies have compared the laparoscopic approach and the open approach for PD [16]. Croome et al. compared 108 LPD and 214 open PD (OPD) cases, well matched for pathologic parameters; results showed shorter length of hospital stay in the former group as well as similar perioperative outcomes, including leakages in both groups [17]. Moreover, the LPD group showed earlier start of adjuvant therapy and longer progression-free survival, although the overall survival rate was similar between the two groups. In several comparative studies on RPD and OPD, the RPD group demonstrated significantly longer operative time, reduced blood loss, and shorter hospital stay compared with the open group [18–20]. No significant difference was observed between the two groups in terms of overall complication rates, mortality rates, R0 resection rate, and harvested lymph node numbers. Thus, minimally invasive approach for PD is safe and feasible in appropriately selected patients. However, the differences between these minimally invasive methods have not been systematically studied yet.

In this study, we performed a retrospective comparative study of LPD and RPD. Results show that the RPD group exhibited significantly shorter operative time, hospital stay, and less blood loss during the operation compared with those in the laparoscopic group. Interestingly, robotic surgical systems require additional docking time relative to that in the laparoscopic group. Moreover, the convenience of suture and knot tying in the robotic surgical system shortened the entire operation time. All these outcomes may be interpreted partly because of the advantages of robot-assisted surgery over traditional laparoscopic surgery; these advantages include improved operative field, filtration of tremor, and freedom in movement. All of these features can contribute to precise gland dissection with minimized risk of tissue and vascular injuries as well as reduce the time for restoration of digestive continuity. Robotic surgery is more advantageous than traditional laparoscopic surgery in terms of the complexity of operations, especially in fine anastomosis procedures. Several studies demonstrate the same views in other areas such as cardiac surgery and gastrointestinal surgery [21–24]. The reduction in postoperative recovery time in hospital could be related to the short operation time. In addition, no significant difference was observed between the two groups in terms of overall complication rates, mortality rates, and number of lymph nodes harvested. The robotic surgical systems show improved outcomes during the perioperative period. In addition, RPD is associated with a faster learning curve than LPD because the robotics offers surgeons faster and easier learning of anastomotic technical skills. The operation time of RPD decreased after the first 33 operations and was associated with reduced rate of complication; a minimum of 40 cases are required for surgeons with a certain level of laparoscopic experience to attain technical competence for performing LPD [25, 26]. However, both robotic and laparoscopic operative times decrease rapidly with practice. Simultaneous development of these two minimally invasive approaches is considered safe and feasible, with acceptable health-related costs. This medical equipment must be further popularized in most hospitals in China. At present, most hospitals can carry out LPD, which requires the surgeon to have several open PD experience and patience.

In conclusion, RPD is a more feasible and safer procedure than LPD in appropriately selected patients. RPD could be a viable alternative to the standard laparoscopic procedure. Moreover, the robotic surgical system facilitates a shorter learning curve than laparoscopic surgery. The robotic-assisted technique should be considered as a valuable tool to reduce the learning time for beginners. However, robotic surgery is expensive. Hence, further studies are required to evaluate the cost effectiveness of the robotic approach for PD in comparison with laparoscopic techniques. With the development of endoscopic technology, the robotic operating cost will be reduced to a reasonable level in the near future.

Compliance with ethical standards

Disclosures Drs. Rong Liu, Tao Zhang, Zhi-Ming Zhao, Xiang-Long Tan, Guo-Dong Zhao, Xuan Zhang and Yong Xu declare no conflicts of interest or financial ties to disclose.

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