Postprint: Application of Robotic Surgery in Pancreatic Surgery

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Abstract

With the continuous advancement of surgical techniques and the development of laparoscopic and robotic surgical technologies, laparoscopic or robotic surgery is increasingly being employed in patients with pancreatic tumors. Compared with conventional laparoscopy, robotic surgery, albeit more expensive, exhibits significant advantages in anastomosis and reconstruction. The authors have currently conducted a retrospective analysis of the safety and feasibility of robot-assisted treatment for pancreatic tumors, aiming to provide new evidence and insights for the treatment of pancreatic tumors.

Full Text

Preamble

Application of Robotic Surgery in Pancreatic Surgery

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Abstract

With improvements in surgical techniques and the development of laparoscopic and robotic surgery, an increasing number of laparoscopic or robot-assisted procedures are being performed in patients with pancreatic tumors. Compared with conventional laparoscopic surgery, robotic surgery is more expensive but offers clear advantages in anastomosis and reconstruction. This review analyzes the safety and feasibility of robot-assisted surgery for pancreatic tumors, aiming to provide new evidence and insights for the treatment of pancreatic cancer.

Keywords: Pancreatic tumor; Robotic surgery; Minimally invasive surgery

Introduction

Pancreatic cancer is a highly malignant, aggressive tumor with an extremely poor prognosis, representing the fourth leading cause of cancer-related mortality with increasing incidence. Due to the deep location of the pancreas and its proximity to major vessels and vital organs such as the stomach and duodenum, combined with the unique biological behavior of pancreatic cancer that predisposes to early lymph node infiltration and invasion of surrounding organs, arteries, veins, and nerves, pancreatic surgery often involves multiple organs and vessels. This makes it one of the most challenging procedures in hepatobiliary surgery, second only to liver transplantation and hilar cholangiocarcinoma resection. Nevertheless, radical resection remains the only curative approach and the sole method to improve patient survival; however, reported 5-year survival rates rarely exceed 20% even after radical surgery. Surgical approaches vary depending on tumor location: pancreaticoduodenectomy (Whipple procedure) for tumors in the pancreatic head and uncinate process, and distal pancreatectomy (with or without splenectomy) for tumors in the pancreatic body and tail.

With advances in surgical techniques and the development of laparoscopic and robotic surgery, these minimally invasive approaches are increasingly being applied to pancreatic cancer patients. Since Gagner et al. reported the first laparoscopic pancreaticoduodenectomy in 1994 and Cuschieri reported the first laparoscopic distal pancreatectomy in 1996, laparoscopic pancreatic surgery has evolved from being controversial to widely accepted. Large-scale studies on laparoscopic pancreaticoduodenectomy with vascular resection for pancreatic cancer have been reported. Compared with open surgery, laparoscopic surgery offers advantages including reduced trauma, faster recovery, and shorter hospital stays, but is limited by two-dimensional visualization and lack of tactile feedback, making certain delicate operations particularly challenging. In 2003, Melvin et al. reported the first da Vinci robot-assisted radical pancreaticoduodenectomy for pancreatic cancer. The da Vinci robotic system provides magnified three-dimensional visualization and dexterous robotic arms, enabling precise gastrointestinal reconstruction and significantly improving surgical safety and feasibility. This review analyzes the safety and feasibility of robot-assisted surgery for pancreatic tumors to provide new evidence and perspectives for their treatment.

Robotic Pancreaticoduodenectomy

Several large-scale studies have reported on robotic pancreaticoduodenectomy, summarized in Table 1 . Overall, the technique has proven safe and effective. Giulianotti et al. reported 60 cases of robotic pancreaticoduodenectomy in 2010, with 45 cases ultimately diagnosed as adenocarcinoma. The mean operative time was 421 minutes, mean blood loss was 394 mL, pancreatic fistula rate was 31.7%, and 91.7% of patients achieved R0 resection margins.

Buchs et al. described 44 cases of robotic pancreaticoduodenectomy with a conversion rate of 4.5% (n=2). Compared with the open surgery group, the robotic group had shorter mean operative time (444±93.5 min vs. 559±135 min) and less intraoperative blood loss (387±334 mL vs. 827±439 mL) (P=0.0001). There were no statistically significant differences in overall postoperative complications (36.4% vs. 48.7%) or pancreatic fistula rates (18.2% vs. 20.5%). Three patients had positive resection margins, demonstrating that robotic pancreaticoduodenectomy is safe and effective. Zhou et al. similarly found lower overall complication rates (25% vs. 75%; P=0.05) and pancreatic fistula rates (25% vs. 37.5%) in the robotic group compared with open surgery, with a final R0 resection rate of 87.5%.

Chalikonda et al. in 2012 compared 30 robotic cases with 30 open cases. The robotic group had a longer mean operative time (476 min vs. 366.48 min; P<0.005) and slightly less blood loss (485 mL vs. 775 mL), though this difference was not statistically significant (p=0.13). The robotic group also had shorter hospital stays (9.79 days vs. 13.26 days; P=0.043). Postoperative complications occurred in 9 patients (30%) in the robotic group, including 2 (6.7%) with pancreatic fistula, compared with 13 patients (46%) in the open group, including 5 (16.7%) with pancreatic fistula. Zeh et al. in the same year reported 50 robotic cases, with 37 confirmed malignant on final pathology. Mean hospital stay was 10 days, Clavien III/IV or higher complication rate was 30%, pancreatic fistula rate was 22%, and conversion rate was 16%.

In 2015, Chen et al. reported 60 cases with a mean operative time of 445 minutes, intraoperative blood loss of 500 mL, and mean hospital stay of 20 days. Twenty-one patients developed postoperative complications, including 8 (13.3%) with pancreatic fistula. The R0 resection margin rate was 97.6%. Boone et al. also included 200 patients undergoing robotic pancreaticoduodenectomy, with 120 ultimately diagnosed as malignant. The overall complication rate was 67%, pancreatic fistula occurred in approximately 6.9% of patients, mean hospital stay was 9 days, and 91.7% achieved R0 resection. Polanco et al. in 2016 reported 150 robotic cases with mean operative time of 515.1±106 minutes, mean blood loss of 300 mL, mean hospital stay of 9 days, and 123 patients with malignant tumors. Cunningham et al. and Boggi et al. reported similar findings in the same year, with the former including 96 patients (mean operative time 356.6–363.5 minutes, blood loss 150-225 mL, pancreatic fistula rate 19.7%) and the latter including 83 patients (operative time 527.2±166 minutes, overall complications 73.5%, pancreatic fistula rate 33.8%). These data demonstrate that robotic pancreaticoduodenectomy cases are increasing annually. Compared with open surgery, this approach offers comparable safety with potentially fewer postoperative complications. With increasing experience and surgical proficiency, significant improvements in operative time and blood loss control can be achieved.

Based on the growing body of literature, Kornaropoulos et al. systematically reviewed robotic pancreaticoduodenectomy for pancreatic tumors, analyzing 738 patients from existing studies. The results showed robotic operative times ranging from 356-718 minutes. Boone et al. reported a difference between their first 80 cases and subsequent 120 cases (581 min vs. 417 min). Robotic operative times were significantly longer than open surgery in most studies, while intraoperative blood loss was consistently lower. Conversion rates ranged from 6.5-7.8%, with evidence suggesting that conversion rates are related to technical proficiency. Overall complication rates ranged from 25%-75%. Most studies reported similar pancreatic fistula rates compared with open surgery, though Boggi et al. and Lai et al. found higher rates in robotic patients (33% vs. 16%; 35% vs. 17%). Meta-analyses comparing robotic and open surgery have demonstrated significantly higher R0 resection rates with robotic surgery (OR 0.40; 95% CI 0.20-0.77; P=0.006) and consistently lower blood loss. Robotic surgery was associated with lower wound infection rates (OR 0.18; 95% CI 0.06-0.53; P=0.002) but no significant differences in delayed gastric emptying (OR 0.62; 95% CI 0.26-1.04; P=0.063), reoperation (OR 0.58; 95% CI 0.29-1.13; P=0.11), bile leak (OR 1.20; 95% CI 0.53-2.74; P=0.66), or pancreatic fistula (OR 0.77; 95% CI 0.49-1.22; P=0.27). Additionally, robotic surgery resulted in shorter hospital stays. These findings suggest that robotic surgery improves R0 resection rates, which is a critical prognostic factor. We hypothesize that this may translate to better overall survival compared with open surgery, though this requires confirmation in future studies. With complication rates similar to open surgery and a steep learning curve, many centers are still in the early stages of adoption. We anticipate that more mature robotic techniques will further reduce complications and truly demonstrate the value of minimally invasive surgery.

In summary, robotic pancreaticoduodenectomy is gradually moving toward standardization. Compared with open surgery, it offers advantages in hospital stay and blood loss, with comparable complication rates, demonstrating its safety, feasibility, and efficacy. However, most reports originate from large centers and have not achieved widespread adoption, reflecting a substantial learning curve. Current studies are predominantly retrospective, lacking prospective or randomized controlled trials. Furthermore, there is limited reporting on cost analysis, disease-free survival, and long-term outcomes. Few studies have compared robotic surgery with conventional laparoscopic surgery regarding intraoperative and postoperative metrics such as hospital stay, blood loss, complications, and costs. Comparative effectiveness analyses in these areas require strengthening, necessitating further long-term research.

Robotic Distal Pancreatectomy

For distal pancreatectomy, spleen preservation remains a controversial topic. For benign lesions or low-grade malignancies without splenic vessel invasion, spleen preservation is recommended. Increasing evidence demonstrates that the spleen is not a non-functional organ and plays significant roles in immune regulation.

Robotic surgery is gradually being applied to pancreatic body and tail tumors. Overall, given that this procedure remains in the investigative stage and is largely confined to a few major centers, operative times remain longer compared with conventional laparoscopic surgery, though postoperative morbidity is comparable, confirming its safety and feasibility. Kang et al. compared 25 laparoscopic distal pancreatectomies with 20 robotic cases, finding longer operative times in the robotic group (348.7±121.8 min vs. 258.2±118.6 min; P=0.024) and significantly higher costs ($8,304.8±870.0 USD vs. $3,861.7±1,724.3 USD; P<0.001). However, the robotic group had higher spleen preservation rates (95% vs. 64%) with no significant differences in hospital stay (7.1±2.2 days vs. 7.3±3.0 days) or complications (20% vs. 16%).

Daouadi et al. compared 30 robotic cases with 94 laparoscopic cases, with 22 robotic patients ultimately diagnosed as malignant. Compared with conventional laparoscopy, robotic surgery had lower conversion rates (16% vs. 0%) and shorter operative times (372±141 min vs. 293±93 min), with significantly improved R0 resection rates (64% vs. 100%). No differences were observed in postoperative complications (41% vs. 46%), pancreatic fistula (41% vs. 46%), or hospital stay (7.1±4.0 days vs. 6.1±1.7 days). In 2014, Duran et al. compared 16 robotic, 18 laparoscopic, and 13 open cases. The robotic group had significantly shorter hospital stays (8.87 days) compared with both open (20.44 days) and laparoscopic groups (19.16 days), and lower postoperative complications (0% vs. 46% open vs. 44% laparoscopic). All robotic patients achieved R0 resection margins.

Lee et al. in the same year compared larger cohorts: robotic (n=37), conventional laparoscopic (n=131), and open (n=637) surgeries. Robotic operative time was slightly longer (213±55.7 min) than laparoscopic (193±45.3 min) and open (85±73.3 min) approaches, but blood loss was lower (P<0.05). No significant differences in complications were observed among the three groups (40% vs. 32% vs. 32%), and both robotic and laparoscopic groups achieved R0 resection. Chen et al. in 2015 reported a large series of spleen-preserving surgeries, with 47 of 69 robotic patients retaining their spleen and 15 ultimately diagnosed as malignant. Robotic surgery showed improvements in blood loss (100 [50-200] mL vs. 290 [200-430] mL), operative time (150 [120-180] min vs. 200 [168-252] min; P<0.001), and hospital stay (11.6±6.6 days vs. 14.7±8.4 days; P=0.023) compared with conventional laparoscopy, with similar overall complications (P=0.808) and pancreatic fistula rates (P=0.376).

Xourafas et al. in 2017 reported a multi-center, prospective analysis from the ACS-NSQIP database (January-December 2014) comparing open (n=921), conventional laparoscopic (n=694), and robotic (n=200) distal pancreatectomies. Compared with open surgery, robotic surgery was associated with lower tumor grade (P=0.0192), longer operative time (P=0.0030), significantly shorter mean hospital stay (P<0.0001), and lower 30-day complication rates (P=0.0476). Compared with conventional laparoscopy, robotic surgery had longer operative times (P<0.0001), lower rates of combined vascular resection (P=0.0487), and lower conversion rates (P=0.0068).

Systematic reviews and meta-analyses comparing robotic and laparoscopic distal pancreatectomy have shown statistically significant differences in operative time (P=0.0001; I^2=86), intraoperative blood loss (P=0.01; I^2=93), spleen preservation rate (P<0.001, I^2=2%), and hospital stay (P=0.01, I^2=49%), but no differences in postoperative complications (P=0.35), conversion rates (P=0.44), resection margins (P=0.1), or number of lymph nodes retrieved (P=0.22).

In summary, robotic distal pancreatectomy is safe and feasible, offering comparable outcomes to conventional laparoscopy in terms of complications, conversion rates, lymph node dissection, and resection margins, with potential advantages in hospital stay and blood loss, and significantly higher spleen preservation rates. Robotic distal pancreatectomy holds considerable promise and value for the future. However, current studies are predominantly retrospective, lacking large-scale prospective multi-center trials. Long-term survival data are also limited, and cost remains a significant concern for both physicians and patients. We anticipate that future reductions in robotic system costs will facilitate broader adoption and application.

Robotic Total Pancreatectomy

For patients with extensive pancreatic involvement, total pancreatectomy may be performed after excluding other contraindications. With improving surgical techniques, complications and mortality rates for total pancreatectomy have decreased significantly. Limited reports of robotic total pancreatectomy exist. Giulianotti et al. in 2011 reported 5 robotic total pancreatectomies with mean operative time of 456 (300-560) minutes, mean blood loss of 310 (50-650) mL, mean hospital stay of 7 days, and postoperative complications in 2 patients. Zureikat et al. in 2013 reported 5 cases, all with postoperative complications and 1 conversion to open surgery, with mean hospital stay of 10 days. In 2015, Boggi et al. compared 11 robotic total pancreatectomies with 11 open cases. The robotic group had no conversions, longer mean operative time (600 vs. 469 min; p=0.014), less blood loss (220 mL vs. 705 mL; p=0.004), with no differences in hospital stay (27 [12-88] days vs. 17 [12-34] days) or postoperative complications (63.6% vs. 45.4%). Given the limited number of robotic total pancreatectomy cases, larger series are needed to validate its feasibility and safety.

Robotic Middle Pancreatectomy

For certain neuroendocrine tumors or low-grade malignancies, middle pancreatectomy may be performed. Limited reports of robotic middle pancreatectomy exist. Zureikat et al. described 13 robotic middle pancreatectomies with 0% mortality but 100% morbidity, mean operative time of 394 minutes, and 2 conversions to open surgery. Chen et al. recently published a randomized controlled trial comparing open (n=50) and robotic (n=50) middle pancreatectomy, demonstrating shorter operative time (160 min vs. 193 min; P=0.002), less blood loss (50 mL vs. 200 mL; P<0.001), and shorter hospital stay (15.6±4.6 days vs. 21.7±12.7 days) in the robotic group, with no differences in postoperative complications or pancreatic fistula rates. Further studies are needed to confirm the safety of robotic middle pancreatectomy given the limited number of cases.

Future Perspectives

Despite increasing reports of robotic pancreatic surgery, several challenges remain due to differences in surgical approach and technique from conventional methods. Current applications are largely limited to early-stage tumors, with many patients still unsuitable for robotic approaches. Most reports originate from a few specialized centers, indicating a long learning curve before widespread adoption. Long-term outcome studies are also needed. While robotic surgery appears expensive in developing countries like China, some studies suggest that faster recovery may result in comparable overall costs to open surgery. Future efforts should focus on reducing robotic system costs. Compared with conventional laparoscopy, robotic surgery is more expensive but offers clear advantages in anastomosis and reconstruction rather than resection itself, suggesting that hybrid procedures combining laparoscopic and robotic approaches may be feasible. Mentorship from experienced centers to those in early stages of adoption is crucial, and multi-format robotic pancreatic surgery forums are valuable for sharing experience and promoting collective progress. With the rapid development of minimally invasive surgery, precision surgery concepts, multidisciplinary teams, and enhanced recovery protocols, we anticipate that more centers will adopt robotic pancreatic surgery, and the future of robot-assisted pancreatic tumor surgery will be bright.

Table 1. Literature Review of Large-Scale Robotic Pancreaticoduodenectomy

Study	Operative Time (min)	Blood Loss (mL)	Conversion Rate	Complications	Pancreatic Fistula Rate	R0 Resection	Hospital Stay (days)
Buchs	444±93.5	387±334	4.5%	36.4%	18.2%	93%	16.4±4.1
Chalikonda	476	485	-	30%	6.7%	90%	10.1±5.8
Giulianotti	421	394	-	-	31.7%	91.7%	9 (4–87)
Narula	718±186	153±43	-	-	-	-	17(14–26)
Baker	491.5±94	527.4±87.7	-	-	-	-	25.8 (12–52)
Cunningham	467±152.3	500±200	-	-	19.7%	-	9 (7–14)
Polanco	515.1±106	300	-	-	-	82%	-
Boggi	527.2±166	-	-	73.5%	33.8%	-	-

Study	Operative Time (min)	Blood Loss (mL)	Conversion Rate	Complications	Pancreatic Fistula Rate	R0 Resection	Hospital Stay (days)
Macedo	417±78	-	-	-	-	-	-
Radhid	-	-	-	-	-	-	-
Boone	-	-	16%	67%	6.9%	91.7%	9

*Clavien III/IV

Table 2. Literature Review of Large-Scale Robotic Distal Pancreatectomy

Study	Year	Patients (n)	Operative Time (min)	Blood Loss (mL)	Cost (USD)	Spleen Preservation	R0 Resection	Hospital Stay (days)	Complications
Waters	-	25	258.2±118.6	-	3,861.7±1,724.3	64%	-	7.1±2.2	16%
Kang	-	20	348.7±121.8	-	8,304.8±870.0	95%	-	7.3±3.0	20%
Daouadi	-	30	372±141	315±62	-	-	100%	6.1±1.7	46%
Giulianotti	-	94	293±93	-	-	-	64%	7 (4–28)	41%
Duran	2014	16	265(145–420)	256±93	-	-	100%	8.87	0%
Butturini	-	18	221.4±73.2	-	-	-	100%	19.16	44%
Zureikat	-	37	213±55.7	-	-	-	100%	5 (0–36)	40%
Xourafas	-	131	193±45.3	-	-	-	-	11.4±6.9	32%
Chen	2015	69	150(120–180)	100(50–200)	-	68%	-	11.6±6.6	-

*Clavien II/III/IV

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Note: Figure translations are in progress. See original paper for figures.