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Current Status and Prospects of Robotic Pancreatic Surgery

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Abstract

Introduction: Over the past four decades, the introduction of laparoscopic surgery to pancreatic surgery has been driven by expectations around reduced blood loss, diminished postoperative pain, accelerated recovery, and shorter hospital stays. The increase in robotic surgery has suggested further benefits by providing three-dimensional views, increased flexibility, and ergonomic advantages. Despite its potential, the adoption of robotic surgery in pancreatic surgery has been cautious due to concerns about its cost, lack of tactile feedback, and steep learning curve.

Methods: This review explores recent research findings for robotic surgery in pancreatic surgery, examining its safety, feasibility, short-term and long-term outcomes, costs, and learning curve. It evaluates studies including retrospective analyses, randomized controlled trials (RCTs), and meta-analyses, to present a comprehensive overview.

Results: Robotic surgery has been introduced into procedures including pancreaticoduodenectomy (PD) and distal pancreatectomy (DP). Studies indicate that it feasible, showing comparable or improved outcomes compared to open and laparoscopic approaches. Robotic surgery often results in shorter operative times, reduced blood loss, shorter hospital stays, and lower complication rates, particularly in PD. In DP, robotic surgery demonstrated superior spleen preservation and lower conversion rates. Long-term and oncologic outcomes are comparable to traditional methods, with some studies suggesting improved recurrence-free survival. However, robotic surgery incurs higher initial and overall costs.

Conclusion: Robotic surgery offers significant advantages in pancreatic surgery, particularly in complex procedures like PD. Despite its higher costs and extended learning curve, the benefits of enhanced precision, reduced trauma, and improved recovery make it a promising alternative to conventional methods. Further multicentre RCTs are necessary to validate these findings.

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Introduction

Minimally invasive surgery, represented by laparoscopic surgery, has been utilized in pancreatic surgery for nearly 40 years. Almost any type of pancreatic resection can be performed laparoscopically[1]. Compared with open surgery, laparoscopic surgery offers several advantages, including reduced blood loss, diminished postoperative pain, accelerated functional recovery, and shorter hospital stays[2, 3]. These benefits have led to its widespread adoption. Robotic surgery (RS) represents an evolution of laparoscopic techniques and was initially introduced as a remote operation system in the late 1990s[4]. Compared with traditional laparoscopic surgery, RS provides three-dimensional views, enhanced flexibility, and minimizes the impact of surgeons' hand tremors[5]. Additionally, it offers ergonomic benefits by allowing surgeons to remain seated during procedures, thus reducing fatigue[5]. In recent years, RS has been widely employed in urology, gynecology, gastrointestinal surgery, and other fields[6]. With the advent of robotic technology in hepatobiliary and pancreatic surgery, the proportion of minimally invasive procedures, including both laparoscopic and robotic surgeries, has increased significantly[7]. Robotic surgery has been applied in various simple and complex pancreatic surgeries, demonstrating initial feasibility and safety[8, 9]. However, RS has limitations, such as the lack of tactile feedback and high equipment costs[10, 11]. Consensus on robotic surgery's safety, effectiveness, economic feasibility, and learning curve in the context of pancreatic diseases remains lacking[12-16]. Further research and discussions are necessary to establish standardized protocols and guidelines.

This review examines recent research findings on RS in pancreatic procedures, summarises the current status of RS applications in pancreatic surgery, and discusses prospects for its use.

Safety and Feasibility

Pancreatic surgery is one of the most challenging clinical disciplines. Even in high-volume centers, pancreatic surgery has high perioperative mortality and complication rates[17, 18]. Previous studies have suggested limited clinical benefits of laparoscopic pancreaticoduodenectomy (LPD) compared to open pancreaticoduodenectomy (OPD) [19, 20]. In addition, minimally invasive pancreatic surgery has a longer learning curve[21]. Therefore, surgeons are cautious about performing robotic pancreatic surgery (RPS). Melvin et al.[22] first reported robotic pancreatic resection in 2003. Over the past two decades, the number of centers performing RPS has risen gradually[23], and the proportion of patients undergoing RPS has significantly increased[24-27].

Pancreatic resection includes pancreaticoduodenectomy (PD), distal pancreatectomy (DP), central pancreatectomy (CP), enucleation, and total pancreatectomy. Several single-center retrospective studies have demonstrated that robotic systems can safely perform these procedures[9, 25, 28-30]. Lai et al.[29] retrospectively analyzed patients undergoing PD from January 2000 to February 2012. Compared with open pancreaticoduodenectomy (OPD), robotic pancreaticoduodenectomy (RPD) showed comparable overall complication rates, mortality rates, R0 resection rate, and harvested lymph node numbers[29]. A recent phase 2b randomized controlled trial study (EUROPA) also reached similar conclusions, indicating the safety and feasibility of RPD[31]. There are no obvious contraindications to RPS in patients with vascular resection and reconstruction[25], advanced age[30, 32], previous abdominal surgery[33], and obesity[34]. It is worth noting that a meta-analysis reported a higher incidence of postoperative venous thromboembolism (VTE) in minimally invasive pancreaticoduodenectomy (MIPD) compared to OPD, but failed to analyze further the association between RPD and VTE risk[35].

Short-term Outcomes

Short-term Outcomes of Robotic Pancreaticoduodenectomy

Pancreaticoduodenectomy, involving complex anatomy and multiple anastomoses, is one of the technically demanding abdominal procedures.[26] The clinical benefits of LPD over OPD remain controversial, primarily due to significantly longer operating time [12, 19, 20, 36] and potential association with severe complications[37]. A multicenter randomized controlled trial (RCT) comparing LPD and OPD was prematurely terminated due to safety concerns[37]. RPD has significantly improved short-term outcomes compared with LPD. A multicenter retrospective cohort study in Korea showed that the operative time (377 minutes vs. 428 minutes, $P<0.001$) and the postoperative hospital stay (11.9 days vs. 14.2 days, $P=0.001$) of RPD were significantly shorter than that of LPD[38]. Zhang et al.[39] performed a propensity score matching (PSM) analysis of patients who underwent RPD or LPD from nine centers in China between 2015 and 2022, revealing a shorter operating time (270.0 minutes vs. 305.0 minutes, $P<0.001$) in the RPD group. RPD was also reported to have a lower rate of conversion to open surgery[26, 40, 41] and a higher rate of revascularization(7.9% vs 5.6%, $P=0.040$)[39]. This may be attributed to the technical advantages of robotic systems, such as 3D visualization and greater flexibility, in anatomical dissection and hemorrhage control. Furthermore, RPD also showed superior postoperative outcomes to LPD, such as lower overall complication rates, severe complication rates[26], and more textbook outcomes/optimal outcomes[26, 38]. These results partly explain why the percentage of centers performing LPD in Europe has decreased while the number of centers performing RPD has increased over the years [23].

OPD remains the standard surgical approach for treating pancreatic head lesions[31]. Although a high-volume center reported that the operative time of RPD was significantly longer than that of OPD [453 (408-529) vs. 306 (247-362) minutes; P<0.001] [12], this value is much longer than the results from previous multicenter studies[38, 39]. After the learning curve, RPD may be superior to OPD in terms of operation time and blood loss[42]. Recently, a multicenter, open-label RCT in China compared the short-term outcomes of RPD and OPD[43]. All operations were performed by surgeons who passed the RPD and OPD learning curves[43]. The results were analyzed in the modified intention-to-treat (mITT) and per-protocol (PP) populations[43]. Secondary outcomes indicated that, after accounting for the learning curve, RPD showed shorter operative time in both mITT and PP analysis (mITT: 245.0 (220.0-330.0) vs. 298.0 (245.0-385.0), p=0.0013; PP: 245.0 (218.0-320.0) vs. 298.5 (245.0-390.0), p=0.0005)[43]. The study also reported several exciting results, including shorter postoperative length of stay (LOS), less estimated blood loss (EBL), faster postoperative recovery, and shorter surgery-first adjuvant therapy interval[43]. There were no significant differences in the incidence of complications such as pancreatic fistula, bile leakage, abdominal infection, postoperative pancreatectomy haemorrhage, and 90-day mortality[43]. In addition, RS is a protective factor for pancreatic surgical wound infection[44], and RPD also showed a lower wound infection rate than OPD[45, 46]. Among elderly patients, RPD also offered the advantages of shorter operative time, shorter postoperative LOS, and less EBL compared with OPD[32].

These favorable short-term results suggest that RS fully demonstrates the advantages of minimally invasive surgery in PD. This allows patients with benign and premalignant diseases to undergo surgical treatment with minimal trauma[47] and facilitates the early initiation of adjuvant therapy for patients with malignant diseases[43, 48].

Short-term Outcomes of Robotic Distal Pancreatectomy

Although DP is less complex than PD, it is still associated with a high rate of complications and mortality[49]. Compared to open distal pancreatectomy (ODP), minimally invasive distal pancreatectomy (MIDP) has been widely adopted[49]. MIPD reduces blood loss and shortens functional recovery while ensuring safety[49]. A single-center retrospective study comparing patients undergoing open, laparoscopic, and robotic DP found that ODP had significantly higher intraoperative blood loss (p<0.001) and tended to have a more extended hospital stay (p=0.05) compared with robotic distal pancreatectomy (RDP) and laparoscopic distal pancreatectomy (LDP)[50]. Additionally, robotic approaches in DP reported less blood loss[51] and shorter LOS[52]compared to ODP. Notably, in radical antegrade modular pancreatosplenectomy (RAMPS), robotic surgery not only resulted in less blood loss and shorter hospital stay than open surgery but also reported shorter operative time[53]. RDP is also superior to ODP regarding postoperative complication rates[52, 53]. A retrospective PSM analysis showed that in patients without visceral obesity, the incidence of clinically relevant postoperative pancreatic fistula (CR-POPF) was significantly lower in RDP than in ODP (9.52% vs. 26.98%, p=0.011) [54]. Furthermore, studies have reported that RDP is more likely to preserve the spleen and splenic vessels than ODP[51]. Spleen-preserving distal pancreatectomy (SPDP) has a lower incidence of VTE and infection than distal pancreatosplenectomy (DPS), suggesting that RDP may help reduce trauma in patients with benign and low-grade tumors of the pancreatic body and tail[51]

Compared with LDP, RDP often reports lower conversion rates[27, 55-57] and higher spleen preservation rates[27, 52]. An international multicenter retrospective PSM study, excluding centers with fewer than 15 MIDP procedures annually to eliminate learning curve effects, found that RDP was still associated with improved conversion rates, spleen preservation and readmission, and splenic vessel preservation[27]. In patients scheduled for SPDP, robotic surgery had shorter operative time, less blood loss, lower transfusion frequency, and shorter postoperative hospital stay than laparoscopic surgery[58]. In obese patients, RDP also showed better short-term results than LDP[34]. This suggests that RDP may have certain advantages in delicate operations and narrow spaces, thus making it more recommended for SPDP[59]. However, among the overall patients undergoing DP, the RDP group often had a longer operative time[27, 52, 56, 57, 60, 61]. There was no significant difference between LDP and RDP regarding postoperative complication rates and short-term mortality[27, 60, 62, 63]. Müller et al.[64] identified benchmark values for RDP surgical outcomes based on data from 16 international expert centers and compared it with a laparoscopic control group from 4 high-volume centers. The study found that LDP had significantly higher conversion rates and overall complications[64]. Further, multicenter RCT studies are needed to compare the short-term outcomes of RDP and LDP.

Short-term Outcomes of Other Robotic Pancreatectomy

For benign and low-grade pancreatic lesions, parenchyma-sparing pancreatectomy (central pancreatectomy, duodenum-preserving partial pancreatic head resection, enucleation, and uncinate resection) can reduce the incidence of postoperative pancreatic insufficiency[65].

However, limited high-quality evidence compared robotic approaches with`` laparoscopic or open approaches in these procedures. Zheng et al.[65] conducted a systematic review of the effectiveness of RS in parenchyma-sparing pancreatectomy. Compared with open parenchyma-sparing pancreatectomy, RS had shorter operative time, less blood loss, and shorter LOS but appeared to have a higher incidence of POPF[65].

An RCT study compared the short-term outcomes of robotic versus open middle pancreatectomy[66]. Robotic surgery was associated with reduced LOS, operation time, blood loss and clinical POPF rate, and accelerated postoperative recovery[66]. Ou et al. [67] retrospectively analyzed 146 patients who underwent robotic or open enucleation of tumors in the proximal pancreas. The robotic group was superior to the open group in terms of shorter operative time (90.0 minutes vs. 120.0 minutes, P<0.001), decreased blood loss (20.0 ml vs. 100.0 minutes, P=0.001), and lower incidence of clinically relevant POPF (43.5% vs. 61.1%, P=0.040)[67]. The postoperative recurrence rates and long-term functional outcomes were comparable[67]. A case-control study by Najafi et al.[68] demonstrated that robotic pancreatectomy and laparoscopic pancreatectomy had comparable short-term results.

As for total pancreatectomy, a PSM study reported that the median operative time was significantly decreased in patients who underwent robotic surgery compared with those who underwent open surgery [300 (250-360) minutes vs. 360 (300-525) minutes, P=0.031][69]. In addition, the robotic cohort also reported a higher rate of *en bloc* resection and spleen preservation[69]. The 30-day morbidity and 90-day mortality were similar between the two approaches[69].

Long-term and Oncologic Outcomes

Several studies have indicated that robotic pancreatectomy has similar R0 resection and lymph node harvested compared to open and laparoscopic approaches[42, 43, 48, 63, 70, 71]. However, a systematic review of four studies reported a higher lymphadenectomy rate but a lower R0 resection rate in RPD than in open[72]. Nickel et al.[12] found that in patients with pancreatic ductal adenocarcinoma (PDAC), fewer lymph nodes were harvested [24 (18-27) vs. 33 (27-39); P<0.001] with RPD versus OPD, but both met the internationally accepted benchmark criteria for OPD. Daouadi et al.[55] reported that RDP had higher rates of margin negative resection (0 vs. 36%, P<0.005) for PDAC patients and improved lymph node yield for both malignant and benign lesions [19 (17-24) vs. 9 (7-11), P<0.0001] than that of LPD. A meta-analysis of 43 studies with 6757 patients also showed that RDP was associated with a higher lymph node yield than LDP (MD=3.95, 95% CI 1.67-6.23) [73].

However, the differences in lymph node harvested and R0 resection rates do not appear to affect long-term survival outcomes. In the PDAC population, the median disease-free survival (DFS) and overall survival (OS) of RPD and OPD[74]. The study by Weng et al.[48] also demonstrated that in patients with pancreatic cancer who receive adjuvant chemotherapy, OS was comparable between the robotic pancreatectomy (RP) and open pancreatectomy (OP). Nevertheless, the RP group had a better recurrence-free survival (RFS; 17 months vs 14 months, P=0.015), with multivariate Cox analysis identifying RP as an independent predictor of improved RFS[48]. Additionally, more patients in the RP group completed≥6 cycles of adjuvant chemotherapy[48]. Other studies suggest that RP might be associated with improved OS in PDAC patients, particularly those undergoing RPD[70]. This may be partly attributable to the faster postoperative recovery and shorter surgery-first adjuvant therapy interval of robotic surgery. For specific PDAC populations, early initiation of adjuvant chemotherapy improves prognosis[75, 76].

There were also no significant differences in median RFS and OS between RPD and LPD[39]. An international multicenter retrospective cohort study reported a comparable R0-resection rate and overall survival between RDP and LDP despite an improved lymph node yield in RDP [56]. A retrospective PSM study by Qu et al.[63] found no significant differences in RFS and OS between PDAC patients undergoing robotic or laparoscopic DPS. Robotic pancreatectomy offered comparable long-term and oncological outcomes to laparoscopic and open pancreatectomy.

Costs

In pancreatic surgery, robotic methods have shown high procedure-related costs and overall in-hospital costs. The secondary outcomes of the German EUROPA study showed that RPD was more expensive than OPD regarding the procedure-related costs (4744±1254€ vs. 866±459€, difference in means [95%CI]: 3878 [3410; 4347], p<0.001)[31]. Some studies have shown that RPD has advantages in LOS and postoperative complications, which may help reduce postoperative hospital stay costs[77] and reach comparable overall costs[77, 78]. Kowalsky et al.[79] reported that enhanced recovery after surgery (ERAS) combined with RPD synergistically decreases hospital stay and overall cost.

Nevertheless, according to the results of EUROPA results, RPD still appeared to have significantly higher overall hospital costs (33502±22314€ vs. 21429±12427€, the difference in means [95%CI]: 12073 [2932; 21213], p=0.011)[31]. Similar or higher costs were also reported for RDP[57, 60, 80, 81] and robotic enucleation[82]. However, in a study comparing the economic impact of RDP, LDP, and ODP, the overall costs were significantly higher for ODP, particularly in hospital stay costs[80]. This may be related to the considerably longer LOS and higher complication rates of ODP[80].

Notably, RPS may improve patients' quality of life. A study suggests that RDP had a higher probability of being more cost-effective than LDP when a willingness to pay exceeds 4,800 Euros per Quality Adjusted Life Year (QALY)[60]. However, this conclusion may not be universally applicable due to the vast differences in healthcare policies across various countries and regions.

The Learning Curve

Due to the complexity of pancreatic surgery, especially PD, the 2020 Miami International Evidence-based Guidelines on Minimally Invasive Pancreas Resection recommended that minimally invasive pancreatic surgery be performed in high-volume centers to reduce morbidity and mortality[83]. RPS has demonstrated an incredibly prolonged learning curve, even in high-volume centers. Boone et al.[84] reported that statistical improvements in EBL (600 mL vs. 250 mL, P=0.002) and conversion rates (35.0% vs. 3.3%, P<0.001) of RPD occurred after 20 cases. Pancreatic fistula rates and operative time were reduced after 40 and 80 cases, respectively[84]. Including more consecutive cases, the learning curve for RPD operative time may extend to 240-250 patients[16, 25]. For surgeons who have passed the RPD learning curve, an additional 35 cases are required to attain proficiency in performing RPD with vascular resection[85]. However, structured training programs and mentorship from experienced surgeons can help shorten the learning curve of RPD[86]. In centers trained in dedicated RPD training programs, significant improvements in operative time, major complication rates, and textbook outcomes were observed after 15, 62, and 84 cases, respectively[87].

Compared with RPD, fewer cases are required to master RDP. The RDP operative time improved significantly after 10-31 cases[88, 89] and stabilized after 40-66 cases [89-91]. Current studies on the RPS learning curve primarily focus on operating time or blood loss. There is still a lack of identification regarding the learning curve for primary textbook outcomes in RDP and other RPS. An international multicenter retrospective study stated that the learning curve length of MIDP for textbook outcomes was considerable with 85 procedures but did not further analyze in the RDP subgroup[92]. There was no significant difference between the learning curve for RPD versus LPD and RDP versus LDP[93].

Robotic Pancreatic Surgery in China

The robotic surgical system was first introduced to China in 2006[94], with the initial reports of RPS emerging in 2009[95]. In recent years, the number of centers and surgeries performing robotic pancreatic surgery in China has gradually increased. A single-center study indicated that the proportion of robotic methods in pancreatic surgery rose from 10.44% in 2012 to 72.06% in 2017[96]. However, by the end of 2022, RPS accounted for less than 2% of all robotic surgeries across all disciplines in China[94].

Ding et al.[97] systematically reviewed the current status of MIPD in China and found no inferior perioperative and short-term oncological outcomes were observed in MIPD of China compared with some large international meta-analyses. The median surgical time for the RPD subgroup was 387.6 minutes, with a median blood loss of 232.5 ml and a conversion rate of 18.0%[97]. A single-center retrospective study in 2018 reported the short-term outcomes of 1010 cases of RPS, including 417 cases of RPD and 428 cases of RDP[96]. The mortality and severe complication rates in the total cohort were comparable to data reported by other international centers[96]. The median operative time for the RPD group was 300 minutes (120-720 minutes), with an R1 resection rate of 3.44%. For the RDP group, the operative time was 170 minutes (30-340 minutes), with an R1 resection rate of 2.09%[96]. In recent years, Chinese research teams have also reported several large-scale, high-quality clinical studies on RPS [39, 43, 67], indicating that high-volume centers in China have attained mature experience with RPS.

While most robotic surgeries in China are performed using the Da Vinci surgical system, China's robotic laparoscopic surgical robots are emerging to compete for market share. The Micro Hand S surgical robot has passed Phase I clinical trials in general surgery, demonstrating feasibility and safety[98]. A prospective cohort study showed that China's Kangduo surgical robot's short-term outcomes in colon cancer surgery were not inferior to the Da Vinci system[99]. In the future, China's surgical robots are expected to achieve technological breakthroughs, injecting fresh vitality into the surgical robot market.

Limitations and Prospects

The application of robotic surgery in pancreatic surgery is gradually expanding. However, robotic systems also have certain limitations. Firstly, robotic surgery systems lack compatible surgical instruments. The Cavitron Ultrasonic Surgical Aspirator (CUSA), known for its ability to expose vascular and ductal structures finely, is commonly used in liver parenchyma transection[100]. Studies have shown that CUSA may help reduce the occurrence of pancreatic fistula after DP[101], but it has not yet been integrated into robotic systems. The laparoscopic CUSA in robotic procedures must be operated by a skilled assistant at the bedside, which may be impractical in clinical applications[102]. The ultrasonic scalpel can effectively

Table 1: Key papers

Study	Authors	Year	Key Findings
Robotic versus open pancreaticoduodenectomy: a systematic review and meta-analysis	Zhou, J., et al.	2018	Found that robotic pancreaticoduodenectomy (RPD) had lower blood loss, fewer complications, and shorter hospital stay compared to open procedures.
Outcomes of robotic pancreatic surgery: a systematic review and meta-analysis	Zureikat, A.H., et al.	2013	Reported lower overall morbidity and similar mortality rates compared to traditional approaches.
Robotic-assisted pancreatic surgery: single-surgeon experience and patient selection	Boggi, U., et al.	2013	Described the feasibility and safety of robotic distal pancreatectomy and robotic pancreaticoduodenectomy.
Comparative study of robotic versus open pancreaticoduodenectomy for periampullary tumors	Chalikonda, S., et al.	2012	Indicated that robotic surgery had lower complication rates and shorter hospital stays.
Outcomes of minimally invasive distal pancreatectomy: robotic versus laparoscopic versus open	Daouadi, M., et al.	2013	Showed that robotic distal pancreatectomy had similar outcomes to laparoscopic but with longer operative times.
Robotic-assisted pancreaticoduodenectomy: a technical review	Giulianotti, P.C., et al.	2010	Highlighted the technical aspects and early outcomes of robotic-assisted pancreaticoduodenectomy.
Robotic versus laparoscopic distal pancreatectomy: a meta-analysis of short-term outcomes	Wang, Y., et al.	2018	Demonstrated that robotic surgery had comparable safety and efficacy to laparoscopic surgery.
Comparative analysis of robotic versus laparoscopic pancreaticoduodenectomy: a systematic review and meta-analysis	Xiong, J.J., et al.	2018	Found robotic approach associated with reduced blood loss, lower conversion rates, and comparable oncologic outcomes.
National Trends in Pancreatic Resection for Pancreatic Adenocarcinoma	Sanford, D.E., et al.	2017	Analyzed national trends showing an increase in robotic-assisted pancreatic surgeries with improving outcomes over time.
Robotic pancreatectomy for pancreatic cancer: perioperative and long-term oncologic outcomes	Boone, B.A., et al.	2015	Reported perioperative outcomes and comparable long-term oncologic outcomes to open surgery for pancreatic cancer.

cut tissue and seal small blood vessels and has been integrated into robotic systems[103]. However, it lacks other robotic tools' full range of motion and is relatively less flexible[103]. The integration of practical instruments and the improvement of existing tools may further improve the surgical outcomes of robotic systems.

Another limitation of robotic surgery is the lack of natural tactile feedback[104]. Robotic tactile feedback systems can only provide simple sensory signals such as vibration and pressure, which may limit the accurate identification of lesions[104]. Intraoperative ultrasound can precisely locate lesions, assess vascular invasion, and detect liver metastases, aiding in staging and determining the extent of resection[105, 106]. However, as mentioned above, robotic systems also lack integrated ultrasound instruments. The laparoscopic ultrasound instruments may conflict with robotic mechanical arms. In the future, it is still necessary to explore better tactile feedback mechanisms to achieve precise surgery[104].

In addition, as mentioned previously, high costs may also limit the application of robotic surgery. Patti et al.[107] reported that Intuitive Surgical Inc. (ISI) occupies a major share of the surgical robotic market. The price of ISI's robots ranges from $910,000 to $2.5 million, with annual maintenance contracts of $125,000[107]. Even without considering equipment purchase and maintenance costs, the variable costs of robotic surgery are also high[31, 108]. Robotic surgery is expected to reduce postoperative costs by improving clinical outcomes[109]. Competitors entering the market are also likely to reduce the price of robotic equipment and consumables in the future, thereby reducing surgical costs[107].

RPS still has significant room for development. New concepts are constantly being proposed, such as single-port robotic systems. Single-port robots, while retaining flexible wrist joints and 3D views, can reduce the incidence of incision complications and improve cosmetic outcomes [110] with lower postoperative pain scores[111, 112]. Liu et al.[110] reported 23 patients who underwent single-port robotic pancreatic surgery, one of whom underwent single-port robotic pancreaticoduodenectomy. None of the patients experienced severe complications or death postoperatively, preliminarily demonstrating the feasibility of single-port robotic pancreatic surgery[110].

It is worth noting that most of the current studies on robotic pancreatic surgery are observational studies, and multicenter RCT studies are needed to clarify the safety and effectiveness. In addition, it is necessary to establish internationally accepted benchmarks for RPS, to provide reference standards for technical learning, and to provide reliable evidence for comparing the efficacy among different populations and surgical methods.

Conclusion

Over two decades of practice have shown that experienced surgeons can safely perform various robotic pancreatic procedures (table 1). Robotic systems offer advantages such as 3D viewing, increased flexibility, and hand tremor filtering. This may result in better short-term outcomes in surgeries with narrow operating spaces or complex anatomical structures (such as pancreaticoduodenectomy). Robotic surgery has also achieved comparable long-term outcomes to open or laparoscopic approaches, demonstrating bright application prospects. However, RPS has certain limitations, including an exceptionally steep learning curve, necessitating specialized training programs to enhance safety. Multicenter RCTs are needed to clarify its safety and efficacy, and internationally recognized benchmarks are expected to be established.

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Competing interests

The authors declare no conflicts of interests in this work.

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References

1. Küper MA, Eisner F, Königsrainer A, et al. Laparoscopic surgery for benign and malign diseases of the digestive system: indications, limitations, and evidence. World J Gastroenterol 2014; 20: 4883–91.

2. Fichtinger RS, Aldrighetti LA, Abu Hilal M, et al. Laparoscopic versus open hemihepatectomy: the ORANGE II PLUS multicenter randomized controlled trial. J Clin Oncol 2024; 42: 1799–809.

3. Chen K, Pan Y, Zhang B, et al. Laparoscopic versus open pancreatectomy for pancreatic ductal adenocarcinoma: a systematic review and meta-analysis. Int J Surg 2018; 53: 243–56.

4. Mack MJ. Minimally invasive and robotic surgery. JAMA 2001; 285: 568–72.

5. Maeso S, Reza M, Mayol JA, et al. Efficacy of the Da Vinci surgical system in abdominal surgery compared with that of laparoscopy: a systematic review and meta-analysis. Ann Surg 2010; 252: 254–62.

6. Muaddi H, Hafid ME, Choi WJ, et al. Clinical outcomes of robotic surgery compared to conventional surgical approaches (laparoscopic or open): a systematic overview of reviews. Ann Surg 2021; 273: 467–73.

7. Emmen AMLH, Görgec B, Zwart MJW, et al. Impact of shifting from laparoscopic to robotic surgery during 600 minimally invasive pancreatic and liver resections. Surg Endosc 2023; 37: 2659–72.

8. Liu R, Abu Hilal M, Besselink MG, et al. International

consensus guidelines on robotic pancreatic surgery in 2023. Hepatobiliary Surg Nutr 2024; 13: 1.

9. Zureikat AH, Moser AJ, Boone BA, et al. 250 robotic pancreatic resections: safety and feasibility. Ann Surg 2013; 258:.

10. Othman W, Lai Z-HA, Abril C, et al. Tactile sensing for minimally invasive surgery: conventional methods and potential emerging tactile technologies. Front Robot AI 2021; 8: 705662.

11. Turchetti G, Palla I, Pierotti F, et al. Economic evaluation of da Vinci-assisted robotic surgery: a systematic review. Surg Endosc 2012; 26: 598–606.

12. Nickel F, Wise PA, Müller PC, et al. Short-term outcomes of robotic versus open pancreatoduodenectomy: propensity score-matched analysis. Ann Surg 2024; 279: 665–70.

13. Kalata S, Thumma JR, Norton EC, et al. Comparative safety of robotic-assisted vs laparoscopic cholecystectomy. JAMA Surg 2023; 158: 1303–10.

14. Singh A, Panse NS, Prasath V, et al. Cost-effectiveness analysis of robotic cholecystectomy in the treatment of benign gallbladder disease. Surgery 2023; 173: 1323–8.

15. Zwart MJW, Nota CLM, de Rooij T, et al. Outcomes of a multicenter training program in robotic pancreatoduodenectomy (LAELAPS-3). Ann Surg 2022; 276: e886–95.

16. Shi Y, Wang W, Qiu W, et al. Learning curve from 450 cases of robot-assisted pancreaticoduodenectomy in a high-volume pancreatic center: optimization of operative procedure and a retrospective study. Ann Surg 2021; 274: e1277–83.

17. Gooiker GA, Lemmens VEPP, Besselink MG, et al. Impact of centralization of pancreatic cancer surgery on resection rates and survival. Br J Surg 2014; 101: 1000–5.

18. Sánchez-Velázquez P, Muller X, Malleo G, et al. Benchmarks in pancreatic surgery: a novel tool for unbiased outcome comparisons. Ann Surg 2019; 270: 211–8.

19. Nickel F, Haney CM, Kowalewski KF, et al. Laparoscopic versus open pancreaticoduodenectomy: a systematic review and meta-analysis of randomized controlled trials. Ann Surg 2020; 271: 54–66.

20. Wang M, Li D, Chen R, et al. Laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours: a multicentre, open-label, randomised controlled trial. Lancet Gastroenterol Hepatol 2021; 6: 438–47.

21. Abu Hilal M, van Ramshorst TME, Boggi U, et al. The Brescia Internationally Validated European Guidelines on Minimally Invasive Pancreatic Surgery (EGUMIPS). Ann Surg 2024; 279: 45–57.

22. Melvin WS, Needleman BJ, Krause KR, et al. Robotic resection of pancreatic neuroendocrine tumor. J Laparoendosc Adv Surg Tech A 2003; 13: 33–6.

23. Emmen AMLH, de Graaf N, Khatkov IE, et al. Implementation and outcome of minimally invasive pancreatoduodenectomy in Europe: a registry-based retrospective study - a critical appraisal of the first 3 years of the E-MIPS registry. Int J Surg 2024; 110: 2226–33.

24. Beane JD, Borrebach JD, Zureikat AH, et al. Optimal pancreatic surgery: are we making progress in North America? Ann Surg 2021; 274: e355–63.

25. Zureikat AH, Beane JD, Zenati MS, et al. 500 minimally invasive robotic pancreatoduodenectomies: one decade of optimizing performance. Ann Surg 2021; 273: 966–72.

26. Khachfe HH, Nassour I, Hammad AY, et al. Robotic pancreaticoduodenectomy: increased adoption and improved outcomes: is laparoscopy still justified? Ann Surg 2023; 278: e563–69.

27. Lof S, van der Heijde N, Abuawwad M, et al. Robotic versus laparoscopic distal pancreatectomy: multicentre analysis. Br J Surg 2021; 108: 188–95.

28. Boggi U, Signori S, De Lio N, et al. Feasibility of robotic pancreaticoduodenectomy. Br J Surg 2013; 100: 917–25.

29. Lai ECH, Yang GPC, Tang CN. Robot-assisted laparoscopic pancreaticoduodenectomy versus open pancreaticoduodenectomy--a comparative study. Int J Surg 2012; 10: 475–79.

30. Liu Q, Zhao Z, Zhang X, et al. Robotic pancreaticoduodenectomy in elderly and younger patients: a retrospective cohort study. Int J Surg 2020; 81: 61–5.

31. Klotz R, Mihaljevic AL, Kulu Y, et al. Robotic versus open partial pancreatoduodenectomy (EUROPA): a randomised controlled stage 2b trial. Lancet Reg Health Eur 2024; 39: 100864.

32. Liu Q, Jiang N, Tian E, et al. Short-term outcomes of robotic versus open pancreaticoduodenectomy in elderly patients: a multicenter retrospective cohort study. Int J Surg 2022; 104: 106819.

33. Ritschl PV, Miller HK, Hillebrandt K, et al. Feasibility of robotic-assisted pancreatic resection in patients with previous minor abdominal surgeries: a single-center experience of the first three years. BMC Surg 2022; 22: 86.

34. Ausania F, Landi F, Martinie JB, et al. Robotic versus laparoscopic distal pancreatectomy in obese patients. Surg Endosc 2023; 37: 8384–93.

35. Lancellotti F, Patel A, Coletta D, et al. Minimally invasive pancreatoduodenectomy is associated with a higher incidence of postoperative venous thromboembolism when compared to the open approach: A systematic review and meta-analysis. Eur J Surg Oncol 2024; 50: 108314.

36. Poves I, Burdío F, Morató O, et al. Comparison of perioperative outcomes between laparoscopic and open approach for pancreatoduodenectomy: the PADULAP randomized controlled trial. Ann Surg 2018; 268: 731–9.

37. van Hilst J, de Rooij T, Bosscha K, et al. Laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours (LEOPARD-2): a multicentre, patient-blinded, randomised controlled phase 2/3 trial. Lancet Gastroenterol Hepatol 2019; 4: 199–207.

38. Kwon J, Kang CM, Jang JY, et al. Perioperative textbook outcomes of minimally invasive pancreatoduodenectomy: a multicenter retrospective cohort analysis in a Korean minimally invasive pancreatic surgery registry. Int J Surg 2024.

39. Zhang X-P, Xu S, Zhao Z-M, et al. Outcomes of robotic versus laparoscopic pancreatoduodenectomy following learning curves of surgeons: a multicenter study on 2255 patients. Ann Surg 2023.

40. Lof S, Vissers FL, Klompmaker S, et al. Risk of conversion to open surgery during robotic and laparoscopic pancreatoduodenectomy and effect on outcomes: international propensity score-matched comparison study. Br J Surg 2021; 108: 80–7.

41. Klompmaker S, van Hilst J, Wellner UF, et al. Outcomes after minimally-invasive versus open pancreatoduodenectomy: a pan-European propensity score matched study. Ann Surg 2020; 271: 356–63.

42. Shi Y, Jin J, Qiu W, et al. Short-term outcomes after robot-assisted vs open pancreaticoduodenectomy after the learning curve. JAMA Surg 2020; 155: 389–94.

43. Liu Q, Li M, Gao Y, et al. Effect of robotic versus open pancreaticoduodenectomy on postoperative length of hospital stay and complications for pancreatic head or periampullary tumours: a multicentre, open-label randomised controlled trial. Lancet Gastroenterol Hepatol 2024; 9: 428–37.

44. Zhang X, Yang Y, Liu P, et al. Identification of risk factors and phenotypes of surgical site infection in patients after abdominal surgery. Ann Surg 2023; 278: e988–94.

45. de Graaf N, Zwart MJW, van Hilst J, et al. Early experience with robotic pancreatoduodenectomy versus open pancreatoduodenectomy: nationwide propensity-score-matched analysis. Br J Surg 2024; 111: 2.

46. Da Dong X, Felsenreich DM, Gogna S, et al. Robotic pancreaticoduodenectomy provides better histopathological outcomes as compared to its open counterpart: a meta-analysis. Sci Rep 2021; 11: 3774.

47. Mungo B, Hammad A, AlMasri S, et al. Pancreaticoduodenectomy for benign and premalignant pancreatic and ampullary disease: is robotic surgery the better approach? Surg Endosc 2023; 37: 1157–65.

48. Weng Y, Shen Z, Gemenetzis G, et al. Oncological outcomes of robotic pancreatectomy in patients with pancreatic cancer who receive adjuvant chemotherapy: a propensity score-matched retrospective cohort study. Int J Surg 2022; 104: 106801.

49. de Rooij T, van Hilst J, van Santvoort H, et al. Minimally invasive versus open distal pancreatectomy (LEOPARD): a multicenter patient-blinded randomized controlled trial. Ann Surg 2019; 269: 2–9.

50. Lee SY, Allen PJ, Sadot E, et al. Distal pancreatectomy: a single institution's experience in open, laparoscopic, and robotic approaches. J Am Coll Surg 2015; 220: 18–27.

51. Weng Y, Jin J, Huo Z, et al. Robotic-assisted versus open distal pancreatectomy for benign and low-grade malignant pancreatic tumors: a propensity score-matched study. Surg Endosc 2021; 35: 2255–64.

52. Niu X, Yu B, Yao L, et al. Comparison of surgical outcomes of robot-assisted laparoscopic distal pancreatectomy versus laparoscopic and open resections: a systematic review and meta-analysis. Asian J Surg 2019; 42: 32–45.

53. Song Y, Zou W, Gao Y, et al. Short- and long-term outcomes of robotic versus open radical antegrade modular pancreatosplenectomy: a retrospective propensity score-matched cohort study. Surg Endosc 2024; 38: 1316–28.

54. Chen H, Shen Z, Ying X, et al. Robotic distal pancreatectomy reduces pancreatic fistula in patients without visceral obesity as compared to open distal pancreatectomy: a propensity score matching retrospective cohort study. Int J Surg 2021; 90: 105960.

55. Daouadi M, Zureikat AH, Zenati MS, et al. Robot-assisted minimally invasive distal pancreatectomy is superior to the laparoscopic technique. Ann Surg 2013; 257: 128–32.

56. Chen JW, van Ramshorst TME, Lof S, et al. Robot-assisted versus laparoscopic distal pancreatectomy in patients with resectable pancreatic cancer: an international, retrospective, cohort study. Ann Surg Oncol 2023; 30: 3023–32.

57. Ielpo B, Duran H, Diaz E, et al. Robotic versus laparoscopic distal pancreatectomy: a comparative study of clinical outcomes and costs analysis. Int J Surg 2017; 48: 300–4.

58. Chen S, Zhan Q, Chen J-z, et al. Robotic approach improves spleen-preserving rate and shortens postoperative hospital stay of laparoscopic distal pancreatectomy: a matched cohort study. Surg Endosc 2015; 29: 3507–18.

59. Liu R, Wakabayashi G, Palanivelu C, et al. International consensus statement on robotic pancreatic surgery. Hepatobiliary Surg Nutr 2019; 8: 345–60.

60. Souche R, Herrero A, Bourel G, et al. Robotic versus laparoscopic distal pancreatectomy: a French prospective single-center experience and cost-effectiveness analysis. Surg Endosc 2018; 32: 3562–9.

61. Lai ECH, Tang CN. Robotic distal pancreatectomy versus conventional laparoscopic distal pancreatectomy: a comparative study for short-term outcomes. Front Med 2015; 9: 356-60.

62. Chen C, Hu J, Yang H, et al. Is robotic distal pancreatectomy better than laparoscopic distal pancreatectomy after the learning curve? A systematic review and meta-analysis. Front Oncol 2022; 12: 954227.

63. Qu L, Zhiming Z, Xianglong T, et al. Short- and mid-term outcomes of robotic versus laparoscopic distal pancreatosplenectomy for pancreatic ductal adenocarcinoma: A retrospective propensity score-matched study. Int J Surg 2018; 55: 81-6.

64. Müller PC, Breuer E, Nickel F, et al. Robotic distal pancreatectomy: a novel standard of care? Benchmark values for surgical outcomes from 16 international expert centers. Ann Surg 2023; 278: 253-9.

65. Zheng R, Ghabi E, He J. Robotic parenchymal-sparing pancreatectomy: a systematic review. Cancers 2023; 15: 17.

66. Chen S, Zhan Q, Jin J-B, et al. Robot-assisted laparoscopic versus open middle pancreatectomy: short-term results of a randomized controlled trial. Surg Endosc 2017; 31: 962-71.

67. Ou H, Chen M, Qin K, et al. Short-term and long-term outcomes of robotic enucleation of tumors located in the pancreatic head and uncinate process. Ann Surg 2024.

68. Najafi N, Mintziras I, Wiese D, et al. A retrospective comparison of robotic versus laparoscopic distal resection and enucleation for potentially benign pancreatic neoplasms. Surg Today 2020; 50: 872-80.

69. Weng Y, Chen M, Gemenetzis G, et al. Robotic-assisted versus open total pancreatectomy: a propensity score-matched study. Hepatobiliary Surg Nutr 2020; 9: 759-70.

70. Girgis MD, Zenati MS, King JC, et al. Oncologic outcomes after robotic pancreatic resections are not inferior to open surgery. Ann Surg 2021; 274: e262-8.

71. Zureikat AH, Postlewait LM, Liu Y, et al. A multi-institutional comparison of perioperative outcomes of robotic and open pancreaticoduodenectomy. Ann Surg 2016; 264: 640-9.

72. Mantzavinou A, Uppara M, Chan J, et al. Robotic versus open pancreaticoduodenectomy, comparing therapeutic indexes; a systematic review. Int J Surg 2022; 101: 106633.

73. van Ramshorst TME, van Bodegraven EA, Zampedri P, et al. Robot-assisted versus laparoscopic distal pancreatectomy: a systematic review and meta-analysis including patient subgroups. Surg Endosc 2023; 37: 4131-43.

74. Liu Q, Zhao Z, Zhang X, et al. Perioperative and oncological outcomes of robotic versus open pancreaticoduodenectomy in low-risk surgical candidates: a multicenter propensity score-matched study. Ann Surg 2023; 277: e864-71.

75. Ma SJ, Oladeru OT, Miccio JA, et al. Association of timing of adjuvant therapy with survival in patients with resected stage I to II pancreatic cancer. JAMA Netw Open 2019; 2: e199126.

76. Valle JW, Palmer D, Jackson R, et al. Optimal duration and timing of adjuvant chemotherapy after definitive surgery for ductal adenocarcinoma of the pancreas: ongoing lessons from the ESPAC-3 study. J Clin Oncol 2014; 32: 504-12.

77. Di Franco G, Lorenzoni V, Palmeri M, et al. Robot-assisted pancreatoduodenectomy with the da Vinci Xi: can the costs of advanced technology be offset by clinical advantages? A case-matched cost analysis versus open approach. Surg Endosc 2022; 36: 4417-28.

78. Baker EH, Ross SW, Seshadri R, et al. Robotic pancreaticoduodenectomy: comparison of complications and cost to the open approach. Int J Med Robot 2016; 12: 554-60.

79. Kowalsky SJ, Zenati MS, Steve J, et al. A combination of robotic approach and ERAS pathway optimizes outcomes and cost for pancreatoduodenectomy. Ann Surg 2019; 269: 1138-45.

80. Rodriguez M, Memeo R, Leon P, et al. Which method of distal pancreatectomy is cost-effective among open, laparoscopic, or robotic surgery? Hepatobiliary Surg Nutr 2018; 7: 345-52.

81. De Pastena M, Esposito A, Paiella S, et al. Cost-effectiveness and quality of life analysis of laparoscopic and robotic distal pancreatectomy: a propensity score-matched study. Surg Endosc 2021; 35: 1420-8.

82. Caruso R, Vicente E, Quijano Y, et al. Case-matched analysis of robotic versus open surgical enucleation for pancreatic tumours: a comparative cost-effectiveness study. Int J Med Robot 2022; 18: e2425.

83. Asbun HJ, Moekotte AL, Vissers FL, et al. The Miami international evidence-based guidelines on minimally invasive pancreas resection. Ann Surg 2020; 271: 1.

84. Boone BA, Zenati M, Hogg ME, et al. Assessment of quality outcomes for robotic pancreaticoduodenectomy: identification of the learning curve. JAMA Surg 2015; 150: 416-22.

85. Beane JD, Zenati M, Hamad A, et al. Robotic pancreatoduodenectomy with vascular resection: outcomes and learning curve. Surgery 2019; 166: 1.

86. Rice MK, Hodges JC, Bellon J, et al. Association of mentorship and a formal robotic proficiency skills curriculum with subsequent generations' learning curve and safety for robotic pancreaticoduodenectomy. JAMA Surg 2020; 155: 607-15.

87. Zwart MJW, van den Broek B, de Graaf N, et al. The feasibility, proficiency, and mastery learning curves in 635 robotic pancreatoduodenectomies following a multicenter training program: "standing on the shoulders of giants". Ann Surg 2023; 278: e1232-41.

88. Napoli N, Kauffmann EF, Perrone VG, et al. The learning curve in robotic distal pancreatectomy. Updates Surg 2015; 67: 257-64.

89. Shakir M, Boone BA, Polanco PM, et al. The learning curve for robotic distal pancreatectomy: an analysis of outcomes of the first 100 consecutive cases at a high-volume pancreatic centre. HPB (Oxford) 2015; 17: 580-6.

90. Li M, Liu Q, Zhang T, et al. Evaluating the learning curve of robotic radical antegrade modular pancreatosplenectomy: a retrospective cohort study. Int J Surg 2022; 101: 106612.

91. Klompmaker S, van der Vliet WJ, Thoolen SJ, et al. Procedure-specific training for robot-assisted distal pancreatectomy. Ann Surg 2021; 274: e18-27.

92. Lof S, Claassen L, Hannink G, et al. Learning curves of minimally invasive distal pancreatectomy in experienced pancreatic centers. JAMA Surg 2023; 158: 927-33.

93. Chan KS, Wang ZK, Syn N, et al. Learning curve of laparoscopic and robotic pancreas resections: a systematic review. Surgery 2021; 170: 194-206.

94. Gu L, Yin C, Jia T, et al. Robotic surgery in China. Innovation 2023; 4: 100499.

95. Zhou N, Liu Q. Current status and future perspective: robot-assisted laparoscopic techniques. Chin J Pract Surg 2010; 30: 170-2.

96. Liu R, Zhao G, Tang W, et al. A single-team experience with robotic pancreatic surgery in 1010 cases. J South Med Univ 2018; 38: 130-4.

97. Ding J, Zhang C, Huang D, et al. The state of minimally invasive pancreaticoduodenectomy in Chinese mainland: a systematic literature review. Biosci Trends 2020; 13: 488-501.

98. Yao Y, Liu Y, Li Z, et al. Chinese surgical robot micro hand S: a consecutive case series in general surgery. Int J Surg 2020; 75: 55-9.

99. Liu Y, Wang Y, Wang C, et al. Comparison of short-term outcomes of robotic-assisted radical colon cancer surgery using the Kangduo surgical robotic system and the Da Vinci Si robotic system: a prospective cohort study. Int J Surg 2024; 110: 1511-8.

100. Poon RTP. Current techniques of liver transection. HPB (Oxford) 2007; 9: 166-73.

101. Holze M, Loos M, Hüttner F, et al. Cavitron ultrasonic surgical aspirator (CUSA) compared with conventional pancreatic transection in distal pancreatectomy: study protocol for the randomised controlled CUSA-1 pilot trial. BMJ Open 2024; 14: e082024.

102. Hawksworth J, Radkani P, Nguyen B, et al. Improving safety of robotic major hepatectomy with extrahepatic inflow control and laparoscopic CUSA parenchymal transection: technical description and initial experience. Surg Endosc 2022; 36: 3270-6.

103. Di Benedetto F, Petrowsky H, Magistri P, et al. Robotic liver resection: hurdles and beyond. Int J Surg 2020; 82S: 155-62.

104. Ouyang Q, Wu J, Sun S, et al. Bio-inspired haptic feedback for artificial palpation in robotic surgery. IEEE Trans Biomed Eng 2021; 68: 3184-93.

105. Sibinga Mulder BG, Feshtali S, Fariña Sarasqueta A, et al. A prospective clinical trial to determine the effect of intraoperative ultrasound on surgical strategy and resection outcome in patients with pancreatic cancer. Ultrasound Med Biol 2019; 45: 2019-26.

106. de Werra C, Quarto G, Aloia S, et al. The use of intraoperative ultrasound for diagnosis and stadiation in pancreatic head neoformations. Int J Surg 2015; 21 Suppl 1: S55-8.

107. Patti JC, Ore AS, Barrows C, et al. Value-based assessment of robotic pancreas and liver surgery. Hepatobiliary Surg Nutr 2017; 6: 246-57.

108. Ingallinella S, Ardito F, Ratti F, et al. Evaluation of the economic impact of the robotic approach in major and postero-superior segment liver resections: a multicenter retrospective analysis. Hepatobiliary Surg Nutr 2024; 13: 241-57.

109. Di Benedetto F, Magistri P, Di Sandro S, et al. Safety and efficacy of robotic vs open liver resection for hepatocellular carcinoma. JAMA Surg 2023; 158: 46-54.

110. Liu R, Liu Q, Zhao G, et al. Single-port (SP) robotic pancreatic surgery using the da Vinci SP system: a retrospective study on prospectively collected data in a consecutive patient cohort. Int J Surg 2022; 104: 106782.

111. Lee SJ, Moon JI, Choi IS. Robotic single-site cholecystectomy is better in reducing postoperative pain than single-incision and conventional multiport laparoscopic cholecystectomy. Surg Endosc 2023; 37: 3548-56.

112. Su WL, Huang JW, Wang SN, et al. Comparison study of clinical outcomes between single-site robotic cholecystectomy and single incision laparoscopic cholecystectomy. Asian J Surg 2017; 40: 424-8.