Review Article

Current Status of Laparoscopic and Robotic Pancreatic Surgery and Its Adoption in Singapore

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Abstract

Despite the potential clinical advantages offered by laparoscopic pancreatic surgery (LPS), the main obstacle to its widespread adoption is the technically demanding nature of the procedure and its steep learning curve. LPS and robotic pancreatic surgery (RPS) have been proven to result in superior short-term perioperative outcomes and equivalent long-term oncological outcomes compared to the conventional open approach, with the caveat that they are performed by expert surgeons who have been trained to perform such procedures. The primary challenge faced by most pancreatic surgeons is the steep learning curve associated with these complex procedures and the need to undergo surgical training, especially with regards to laparoscopic and robotic pancreaticoduodenectomy. Current evidence suggests that RPS may help to shorten the lengthy learning curve required for LPS. More robust evidence—in the form of large randomised controlled trials—is needed to determine whether LPS and RPS can be safely adopted universally.

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Introduction

Pancreatic surgery is considered one of the most complicated and treacherous procedures in the abdominal cavity since it is associated with high morbidity and mortality rates.[1,2] Even with major advancements in surgical technique and perioperative care, the morbidity rate of pancreatic surgery in high-volume expert centres remains high at >50% even as its mortality rate drops to <5%.[1–3] Consequently, despite the "revolution"— minimally invasive surgery (MIS)—in abdominal surgery that took place in the 1990s and early 21st Century, the adoption and practice of MIS in pancreatic surgeries remain limited.

Laparoscopic surgery is associated with several inherent limitations, including diminished haptic feedback, reduced dexterity and decreased natural hand-eye coordination. Any attempt to perform surgery on a patient while observing a 2-dimensional screen is counter-intuitive and compromises hand-eye coordination (fulcrum effect).[4,5] Furthermore, laparoscopic instruments have a limited range of motion, diminished dexterity and may augment physiological tremor. Consequently, robotic surgery was introduced to overcome the limitations posed by laparoscopic surgery.[6,7] Until recently, the only robotic-assisted surgical platform that was widely available

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around the world was the Da Vinci system offered by Intuitive Surgical, Inc. (Sunnyvale, CA, USA) which offered the advantages of a 3-dimensional view (that offsets the loss of hand-eye coordination in laparoscopic surgery), 7 degrees of freedom that replicate human movement with superior dexterity, elimination of physiological tremor and ergonomic comfort.[4,5] In theory, the advantages of this robotic platform would translate into superior fine suturing and dissection that are frequently required in major pancreatic surgery, especially pancreaticoduodenectomy (PD).[8,9]

Although the first laparoscopic pancreatic surgery (LPS) was performed in the early 1990s,[10] the adoption of LPS remained slow; it was only in the past decade that a significant increase in the adoption of LPS by surgeons from around the world was observed.[11] Compared to the open approach, LPS is reported to provide the added benefits of smaller incisions with better cosmetic results, lower level of postoperative pain and estimated blood loss, shorter hospital stay and recovery time with equivalent morbidity and overall mortality rate.[12–18] It is, however, important to emphasise that most of the evidence that supported the use of LPS is limited to retrospective case-control studies,[12–18] and only 4 randomised controlled trials (RCT) had been performed to date.[19–22]

Despite the clinical advantages offered by LPS, the major obstacle to its widespread adoption is the technically demanding nature of the procedure and its steep learning curve.[23] This is attributed to the retroperitoneal location of the organ, its proximity to major vasculature and high propensity for complications such as pancreatic fistula and bleeding. Moreover, major pancreatic surgeries are relatively rare procedures in most tertiary health institutions, making it difficult for many surgeons to obtain sufficient case volume to attain proficiency.

Distal Pancreatectomy

Distal pancreatectomy (DP) is performed for tumours or pathologies that involve the body and tail of the pancreas.[2] For technical reasons, a concomitant splenectomy is also performed since the splenic artery and vein are closely related to the pancreas with many small branches and tributaries that communicate between the pancreas and these vessels. Since DP is technically more simple to perform than PD, laparoscopic distal pancreatectomy (LDP) is therefore more widely performed than laparoscopic pancreaticoduodenectomy (LPD).[5] DP has been proposed as an ideal surgical procedure for MIS as unlike PD, it does not require any complex reconstruction.[5,24]

Nonetheless, as a minimally invasive procedure, LDP remains technically challenging and complex, and has been reported to be associated with an open conversion rate of up to 38% by even reputable high-volume tertiary centres.[25] Studies have shown that LDP offers several advantages over open surgery, especially in short-term perioperative outcomes including less postoperative pain, quicker recovery and decreased blood loss.[12–14,26,27] However, most of these studies were retrospective case-control series. In the only RCT (LEOPARD) that compared minimally invasive DP and open DP by the Dutch Pancreatic Cancer Group, Rooij et al found that the former was significantly associated with decreased blood loss and reduced time to functional recovery at the expense of longer operating time.[21] Similarly, a recent large international cohort study that analysed 1562 minimally invasive DP with 18% open conversion vs 1359 open DP from the American College of Surgeons National Quality Improvement Program demonstrated a risk reduction rate of 11% in composite major morbidity.[27]

Although DP is commonly performed with *en bloc* splenectomy, recent studies have recommended spleen preservation since it reduces the risk of postsplenectomy infection and thrombocytosis, haematologic abnormalities and overall morbidity.[28,29] Most pancreatic surgeons concur that the spleen should be preserved as far as possible in benign and borderline malignant neoplasms,[5,22] and 2 techniques have been described for spleen-preserving DP: 1) in the Warshaw technique, the splenic artery and vein are resected, leaving only the short gastric vessels for perfusion of the spleen; and 2) in the Kimura technique, the splenic vessels are spared.[5] Technically, splenic vessel preservation procedures are more demanding since they require meticulous separation of the splenic vessels from the pancreatic parenchyma and ligation of numerous branches of the splenic vessels supplying the pancreas. Consequently, operating time and blood loss tend to be higher. The Warshaw technique, however, is associated with a higher incidence of splenic infarction and left-sided portal hypertension with gastric varices.[24]

Numerous retrospective studies have shown that a major advantage of robotic distal pancreatectomy (RDP) over LDP is that it offers superior spleen preservation rate.[25–34] It is hypothesised that improved dexterity of the robotic system facilitates suturing in

tight spaces and more accurate control of the splenic tributaries, thereby allowing more accurate dissection of splenic vessels from the pancreatic parenchyma.[4,5] These advantages improve the rate of spleen and splenic vessel preservation in DP.

Another advantage of the robotic platform is the lower open conversion rate to open surgery compared to laparoscopic surgery, especially during the learning phase.[35] Conversion to the open procedure is undesirable since it mitigates the advantages of MIS, resulting in increased operating time, intraoperative blood loss and need for blood transfusion, higher complication rates and longer hospital stay.[25,26,36] It is, however, important to emphasise that no RCT has been performed to compare LDP with RDP, and that numerous confounding factors—such as selection bias and learning curve—could have accounted for the findings of these non-randomised studies.

Pancreaticoduodenectomy

Tumours that are located in the periampullary region require formal resection via PD. As a result of the highly complex manipulations that are required during resection and anastomoses thereafter, the minimally invasive surgical approach is only performed by a few pancreatic surgeons in high-volume centres.[37–42] In 1994, Gagner et al[10] reported the first study of LPD; however, the steep learning curve of LPD led to its slow adoption compared to LDP. Even today, the practice of MIS in PD is limited and remains controversial, given the technical complexity of the procedure and lack of perceived advantages over the open approach.

A few large series of LPD[37–9] and robotic pancreaticoduodenectomy (RPD)[40,41] from high-volume centres had reported excellent results associated with MIS. To the best of our knowledge, 3 RCT[19,20,22] had evaluated short-term outcomes of LPD against open PD, but with mixed results. While 2 single-centre RCT from India and Spain[19,20] reported short-term benefits associated with LPD including decreased blood loss and shorter hospital stay at the expense of longer operating time, a multicentre RCT from the Netherlands was forced to cease prematurely over concerns of safety after a high mortality rate was observed in the MIS arm.[22] The findings of these 3 studies suggested that LPD offers advantages over the open approach only when it is performed by experienced surgeons; when LPD is performed by inexperienced surgeons, higher morbidity and even mortality may result.[22] These findings were corroborated by other single-centre retrospective studies that demonstrated the advantages of MIS when it is performed by more experienced centres, and increased morbidity when MIS is undertaken by less experienced centres.[43]

There is growing evidence that robotic pancreatic surgery (RPS) is potentially superior to LPS, especially for more complex procedures such as PD. A recent multicentre study in North America had shown that RPS was associated with a lower open conversion rate than LPS for both DP and PD.[44] Another multicentre study in the United States demonstrated that RPS could be practised safely and yielded similar anastomotic and overall complications rates compared to the open approach even during the initial learning phase.[45] The superior steadiness, precision and dexterity associated with the robotic platform allow fine, accurate dissection and suturing in confined spaces.[4,8,9] These advantages of the robotic platform will potentially shorten the learning curve for the performance of complex anastomoses in minimally invasive pancreaticoduodenectomy (MIPD) such as pancreatoenteric anastomoses and hepaticojejunostomy compared to conventional laparoscopy. This is especially relevant to minimally invasive hepatopancreatobiliary surgeons who practise in countries that have a small population, and who will never acquire the experience and surgical volumes that surgeons in more populous countries such as China and the United States will have.

Learning Curve in LPS and RPS

A major obstacle to the widespread adoption of minimally invasive pancreatic surgery (MIPS)—especially MIPD—is its steep learning curve.[46] In the literature, several authors have addressed the learning curve of LDP. Depending on the outcome measure, it was reported to be as low as from 10–15 procedures[47,48] for open conversion and up to 40 procedures for reduction in operating time.[49] The learning curve of RDP was reported to be shorter than LDP,[50] with 2 studies[51,52] reporting a learning curve of only 5–10 cases for reduction in operating time.

For LPD, a single-surgeon study[53] that used cumulative sum (CUSUM) chart analysis reported a minimum of 40 procedures before the learning curve—in terms of operating time and blood loss—was completed. Another study from South Korea reported improvements in operating time and postoperative morbidity after approximately 30–60 procedures.[54]

Several studies have analysed the learning curve of RPD. The learning curve of a surgeon—in terms of operating time—was reported to range from between 10–33 procedures.[52,55] For institutions, the learning curve—in terms of blood loss and conversion rate—was shown to improve after 20 procedures, and 20–80 procedures were needed before an improvement in operating time was seen.[56–8]

The varied findings of different studies have highlighted the difficulty in defining the learning curve of a surgical procedure including MIPS. Various factors can affect this "magic number", including the statistical method used (such as CUSUM), outcome measure (such as blood loss, operating time, morbidity and conversion rate), single surgeon vs institutional data, study cohort size and the surgeon's proficiency and experience in MIS and open surgery.[46] Consequently, it is almost impossible to determine the exact number of procedures that are required to complete the learning curve in order to achieve proficiency. It is also very unlikely that the personal learning curves of surgeons will be uniform across indivduals.[46]

The inverse association between institution volume and surgical outcomes is well documented in complex surgeries such as pancreatic surgery.[23,59,60] The volume-outcome effect is seen in MIPS, especially MIPD.[61,62] Current data suggest that MIPD is associated with higher mortality in centres that perform <10 cases a year.[23,46,61,62] This finding is especially relevant to many institutions whose pancreatic centres do not see a high volume of procedures, unlike those in China and the United States. To bridge the wide gulf between the open approach and MIPD, several surgeons have proposed a hybrid technique for the learning curve. This technique is shown to be a safe approach that allows surgeons to make the transition from open PD to MIPD.[63–6]

Limitations of RPS

Despite the theoretical and potential advantages that robotic surgery offers, its widespread use is limited by its high cost that has curtailed accessibility to the robotic platform.[8] Globally, only a few centres[4,15,31] have reported their experiences with RPS. The high cost of acquiring and maintaining this platform has meant that few surgeons from around the world have regular access to this technology for training purposes. This has led to a lack of familiarity and experience with RPS, and few surgeons are willing to attempt complicated robotic procedures such as RPS. It is worthwhile to highlight that with increased adoption and competition, the costs of new technological applications or devices are likely to decrease exponentially with the passage of time.

LPS and RPS in Singapore

In Singapore, the practice of MIPS had grown in the last decade although most pancreatic surgeries are still being performed using the conventional open approach. Earlier studies had reported exclusively on DP but not PD. In 2009, the first study on LPS was published after it reported on 3 patients who underwent spleen-preserving DP.[67] Subsequently, larger series on LDP and RDP were published.[33,68] In 2016, the first study on RPS was published after it reported on 3 cases of spleen-saving, vessel-preserving DP in the Singapore General Hospital (SGH).[29] In a subsequent update in 2018, SGH reported on its experience with 30 RPS: the open conversion rate was only 3.3% and the major (Clavien-Dindo grade >2) morbidity rate was 23.3% with no mortality. [4] These findings established the feasibility and safety of RPS.

In recent years, several case series on LPD and RPD were published. In 2019, SGH reported its first case series of 7 RPD.[66] In a subsequent report of 27 cases of LPD and RPD,[9] it found that the robotic approach allowed surgeons to make the transition from the hybrid approach to the totally MIS approach more quickly in their learning curves. In the same year, Tan et al[65] reported their experience with laparoscopic-assisted pancreaticoduodenectomy (hybrid approach) and described it as a bridge to the totally MIS approach.

Recently, SGH reported its initial experience with 150 MIPS.[69] It found a rapid growth in the practice of MIS in the past 6–7 years and >90% of procedures were performed since 2012. It also noted an increase in the number of complex MIPS that were performed such as LPD and RPD. In their recent study on robotic hepatopancreatobiliary surgery in Singapore, Lee et al[70] reported that as of February 2018, 46 RPS—including 18 RPD—were performed in 2 institutions across Singapore.

Although the number of MIPS is increasing,[69] most procedures—especially LPD and RPD—are routinely performed by a small number of surgeons. In a small country such as Singapore, the primary challenge faced by pancreatic surgeons is the steep learning curve of these complex procedures and their low numbers. Possible solutions may include centralisation of major pancreatic surgeries in a single centre and the adoption of robotic surgery that has been shown to shorten the learning curve, especially in PD.[71] Institutions that

have been performing MIPS should be supported and incentivised to encourage more institutions and pancreatic surgeons to practise MIPS. The introduction of dedicated and structured training programmes and availability of expert proctors are also critical to promote LPS and RPS.[23]

Conclusion

LPS and RPS are rapidly gaining acceptance and practice from around the world and will undoubtedly become the gold standard in pancreatic surgery in the near future, especially in high-volume pancreatic surgery centres. More large and robust RCT are needed to determine whether LPS and RPS can be safely practised globally.

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