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REVIEW ARTICLE

Recent trends in organ-preserving pancreatectomy: Its problems and clinical advantages compared with other standard pancreatectomies

Hiroyuki Kato | Yukio Asano | Masahiro Ito | Satoshi Arakawa | Akihiko Horiguchi

Department of Gastroenterological Surgery, Fujita Health University School of Medicine, Bantane Hospital, Nagoya, Japan

Correspondence
Hiroyuki Kato, Department of Gastroenterological Surgery, Fujita Health University School of Medicine, Bantane Hospital, 3-6-10 Otobashi Nakagawa Ward, Nagoya 454-8509, Aichi Prefecture, Japan.
Email: katohiroyuki510719@gmail.com

Abstract

In this review article, we focus on recent papers on organ-preserving pancreatectomy procedures published since 2010. When comparing central pancreatectomy (CP) and distal pancreatectomy (DP), most studies have concluded that the CP group exhibited significantly lower incidence of new-onset diabetes or diabetes exacerbation than the DP group postoperatively. However, because of increased incidence of morbidities such as pancreatic fistula, the surgeon faces a considerable trade-off between increased short-term morbidity and long-term preservation of endocrine function. When the outcomes of two types of spleen-preserving DP (Kimura and Warshaw procedures) are compared, most studies mentioned the low incidence of postoperative gastric varices and splenic infarction with the Kimura procedure. Although there are several reports regarding the effect of spleen preservation on prevention of postoperative infections, no report on the contribution of spleen preservation to the prevention of overwhelming post-splenectomy infection is seen. The advantages of duodenum-preserving pancreatic head resection (DPPHR) concerning endocrine and exocrine functions continue to be subjects of discussion, mainly due to the limited number of institutions that have adopted this approach; however, DPPHR should be presented as an option for patients due to its low incidence of postoperative cholangitis. Organ-preserving pancreatectomy requires meticulous surgical techniques, and postoperative complications may increase with this surgery compared with standard pancreatectomy, which may be influenced by the surgeon's skill and the surgical facility where the procedure is performed. Nonetheless, this technique has significant long-term advantages in terms of endocrine and exocrine functions and its wider adoption in the future is expected.

KEYWORDS
pancreatectomy, pancreatic fistula, splenectomy, splenic infarction

1 | INTRODUCTION

Organ-preserving pancreatectomy is a surgical procedure that preserves not only the pancreatic parenchyma but also adjacent organs such as the bile ducts, duodenum, and spleen, thus maintaining a favorable long-term postoperative quality of life. For many years, pancreatic surgery for pancreatic head lesions has been performed with excessive resection, as represented by the Whipple procedure (partial gastrectomy, total duodenectomy, and pancreaticoduodenectomy).[1] In contrast, in the late 1970s, pylorus-preserving pancreatoduodenectomy (PPPD), which preserves the stomach and first portion of the duodenum and is the pioneer of organ-preserving pancreatectomy, was developed.[2] The procedure that involves the resection of an inflammatory mass in the pancreatic head while preserving the duodenum is referred to as Beger's operation.[3] Beger's operation was subsequently modified, resulting in the development of duodenum-preserving pancreatic head resection (DPPHR), which is an organ-preserving surgerical approach for managing noninvasive neoplastic lesions.[4] Currently, papillary function can be preserved during DPPHR if blood flow to the lower bile duct is sufficient.[5–7]

In addition to DPPHR, various surgical procedures, including inferior pancreatic head resection[8] and ventral pancreatectomy,[9] that preserve the pancreatic parenchyma as much as possible have been reported.

Distal pancreatectomy (DP) with concomitant splenectomy have been widely performed for lesions located in the pancreatic body and tail, whereas central pancreatectomy (CP) is a procedure for tumors in the pancreatic body that aims to preserve the pancreatic tail and spleen. Dagradi and Serio performed CP for insulinoma in 1982, and this procedure is recognized as the first CP with reconstruction.[10]

The spleen, which is adjacent to the pancreas, is responsible for the prevention of infection caused by enterococci and other bacteria. Spleen-preserving distal pancreatectomy (SPDP) is sometimes employed for low-grade malignant tumors because it may contribute to the reduction of infectious complications.

Organ-preserving pancreatectomy has evolved over the years, and as shown in Figure 1, the number of publications continue to increase every 5 years. However, the procedure's complexity and the lack of clear advantages associated with organ preservation limit its wide use in many institutions.

In this review article, we focus on recent papers published since 2010 on the following points: (1) clinical significance of preserving the pancreatic tail in CP and its related problems; (2) whether spleen preservation contributed to infection prevention in SPDP; and (3) clinical significance of preserving the duodenum in DPPHR and its related problems.

2 | CURRENT TREND OF CP

2.1 | Operative indications and the CP procedure

CP is performed for low-grade malignant or benign tumors localized to the pancreatic body without extrapancreatic invasion. Histologically, pancreatic neuroendocrine tumors, intraductal papillary mucinous tumors, solid pseudo-papillary neoplasm, and other rare tumors (metastatic pancreatic tumor, etc.) are the most common targets of CP. The use of CP for pancreatic adenocarcinoma has not been established and is rarely reported. In one small, single-center, retrospective study, Gao et al.[11] compared the long-term results of CP ($n=9$) and DP ($n=55$) in pancreatic ductal carcinoma (2009–2016). They reported that the prognisis of CP for pancreatic neck carcinoma localized within 2 cm of the pancreas was comparable to that of DP (median postoperative survival: 20.4 months for CP vs. 19.4 months for DP, $p=0.842$). In such cases, it is important to achieve R0 resection intraoperatively using frozen section biopsies of cephalic and caudal pancreatic margins. It is necessary to determine the indication for CP based on tumor location and its progression and to understand the relationship between the tumor and adjacent vessels. For instance, the location of the splenic artery, dorsal pancreatic artery, left gastric vein (LGV), and inferior

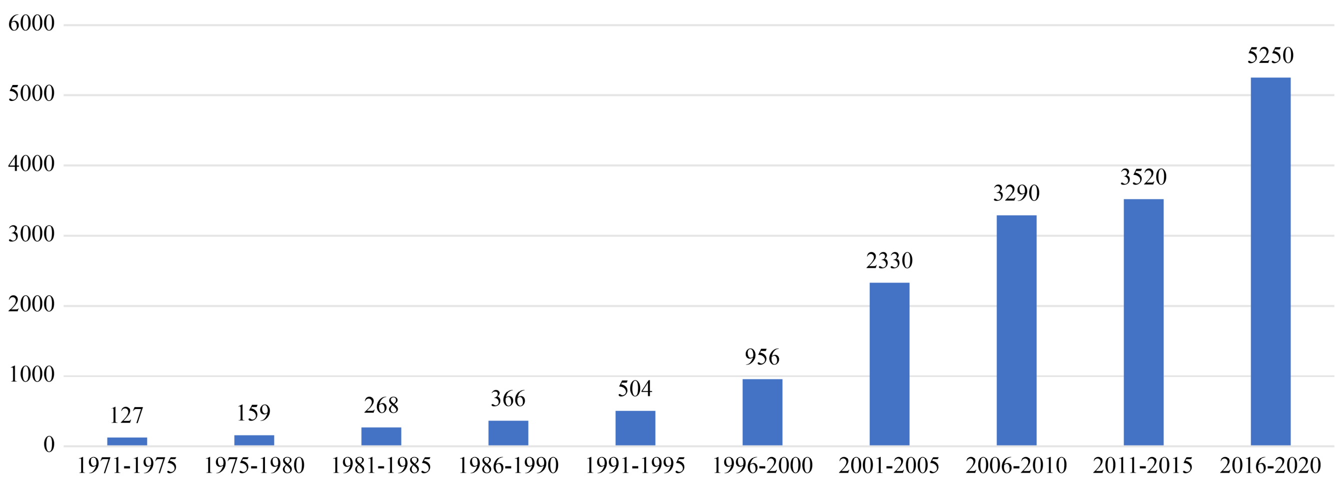

FIGURE 1 Number of articles published on organ-preserving pancreatectomy.

mesenteric vein (IMV) should be carefully confirmed in relation to the mass. The dorsal pancreatic artery often branches from the splenic artery or near the root of the common hepatic artery and is transected in this procedure. In some cases, the dorsal pancreatic artery bifurcates from the superior mesenteric artery.[12] In general, the LGV and IMV can be preserved, but if dissection is difficult due to associated inflammation or other factors, they can be sacrificed. When the right edge of the tumor is beyond the right margin of the portal vein, pancreatic transection and closure are difficult. In such cases, the gastroduodenal artery (GDA) should be sufficiently separated from the pancreatic parenchyma, and pancreatic dissection should be performed on the dorsal side of the GDA. The surgeon should evaluate the morphology of the main pancreatic duct and its branch based on preoperative imaging such as endoscopic retrograde pancreatography or magnetic resonance cholangiopancreatography, ensuring that injury to the inferior branch originating from the main pancreatic and accessory pancreatic ducts is avoided.[13] If these ducts are dissected, pancreatic juice drainage becomes impossible, resulting in intractable pancreatic fistula. Figure 2 shows a typical case in which CP was safely performed for solid pseudopapillary neoplasm located in the pancreatic head. In this case, the location of the pancreatic duct was easily confirmed because the stent tube was inserted from the caudal side as a guide, allowing safe cephalic pancreatic transection.

2.2 | Clinical significance of pancreatic tail preservation in CP

The main purpose of CP is to preserve pancreatic endocrine function by preserving the pancreatic tail and to maintain patient quality of life. Our literature search for articles on the comparison between CP and DP identified several studies published since 2010[14–27] that had compared postoperative endocrine function between CP and DP cases (Table 1). As shown in Table 1, most of the studies presented the results of single-center retrospective studies or meta-analyses aggregating those retrospective studies. Most authors of those studies concluded that the postoperative incidence of new-onset diabetes or exacerbation of diabetes were significantly lower in the CP group than in the DP group. Several meta-analyses revealed the advantage of CP in terms of the incidence of postoperative endocrine insufficiency (relative risk [RR], 0.14–0.22). The only multicenter study that compared CP and DP was by Asano et al.,[24] who demonstrated that glycated hemoglobin (HbA1c) values at 3, 6, 12, 24, and 36 months postoperatively were significantly lower in the CP group than in the DP group. This result could be explained by the distribution of islet cells in the pancreatic parenchyma. Wittingen et al.[28] evaluated the distribution of islet cells in various parts of the pancreas and reported that the islet concentration in the tail was significantly greater than that in the head and body. Thus, pancreatic

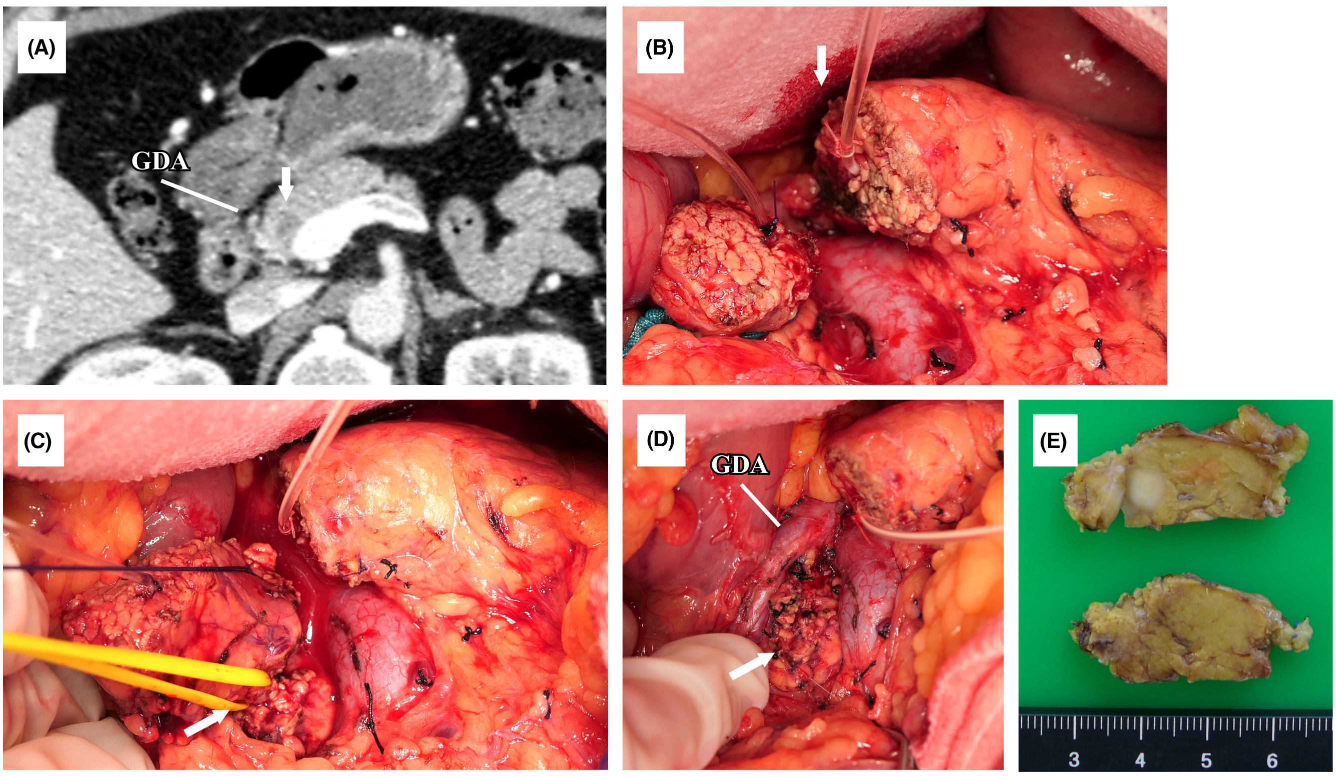

FIGURE 2 A case of solid pseudopapillary neoplasm of the pancreatic head for which middle pancreatectomy was performed. (A) Preoperative computed tomography showing a tumor of the pancreatic head (white arrow). (B) Pancreatic transection line of the pancreatic tail side (white arrow). (C) Pancreatic transection line of the pancreatic head side (white arrow); Yellow tape: the main pancreatic duct. (D) Pancreatic transection line of the pancreatic head side (white arrow); (E) Resected specimen. GDA, gastroduodenal artery.

TABLE 1 Summary of the articles investigating postoperative endocrine functions after central pancreatectomy compared to distal pancreatectomy.

Years	Authors	Type of articles	Duration of study	Main indication	Comparison	Outcomes regarding endcrine function
2010	DiNorcia et al.[14]	Single-center retrospective study	1997–2009	Localized lesion in the neck or proximal body of the pancreas without evidence of high-grade malignancy	CP (n=50) vs. DP (n=50) using propensity score matching	The rate of new-onset and worsening diabetes (CP vs. DP: 14% vs. 46%; p=0.003)
2010	Cataldegirmen et al.[25]	Single-center retrospective study	1992–2007	Focal pancreatic lesions of borderline or benign neuroendocrine neoplasms, cystadenoma, intraductal papillary mucinous neoplasia (IPMN), and secondary metastasis.	Extended CP (n=35) vs. DP (n=35)	Lower incidence of endocrine impairment in the CP group (6% vs. 34%; p<0.05)
2013	Iacono et al.[15]	Systematic review	1988–2010	Benign or low-grade malignant pancreatic tumor	CP (n=359) vs. DP (n=480)	Lower risk of endocrine insufficiency in the CP group (relative risk: 0.22; p<0.001)
2013	Xu et al.[16]	Systematic review	–2012	Various pancreatic tumors	CP (n=202) vs. DP (n=289)	Lower risk of endocrine insufficiency in the CP group (Relative risk: 0.19; p<0.05)
2013	Dumitrascu et al.[20]	Single-center retrospective study	2002–2012	Benign and low-grade malignant lesions of the pancreatic neck or body	CP (n=22) vs. SPDP (n=25)	The rate of new-onset diabetes (CP vs. SPDP: 0% vs. 16%; p=0.111)
2015	Song et al.[30]	Single-center retrospective study	2007–2010	Benign and low-grade malignant lesions in the neck and proximal body of the pancreas	LCP (n=26) vs. LEDP (n=96)	Lower risk of new-onset diabetes LCP than after LEDP (LCP: 11.5% vs. LEDP: 0.8%)
2018	Xiao et al.[16]	Systematic review	1983–2017	Benign and low-grade malignant lesions of the pancreatic neck or body	CP (n=539) vs. DP (n=869)	Lower risk of endocrine insufficiency in the CP group (OR=0.14; p<0.001)
2018	Lv et al.[19]	Single-center retrospective study	2007–2014	Single benign or low-grade malignant tumor confined to the pancreatic neck or proximal body	CP (n=16) vs. DP (n=26)	Comparable incidence of new-onset diabetes mellitus (CP: 0 vs. DP: 8%; p=0.382)
2019	Tan Z et al.[23]	Single-center retrospective study	2007–2016	Benign or low-grade malignant pancreatic lesions	CP (n=39) vs. DP (n=52)	Comparable incidence of new-onset diabetes mellitus (2.6% vs. 13.5%; p=0.223)
2019	Li et al.[27]	Meta analysis	1990–2018	Benign or low-grade malignant pancreatic lesions	CP (n=303) vs. DP (n=491)	Lower risk of endocrine insufficiency in the CP group (odds ratio: 0.17; p<0.05)
2019	Zhang et al.[37]	Single-center retrospective study	2013–2017	Benign and borderline tumors in the pancreatic neck and proximal body	LCP (n=23) vs. LSPDP (n=36)	Similar proportion of postoperative insulin treatment in the LCP group and LSPDP group (0% vs. 3%; p = 1.000).
2020	Lee et al.[17]	Single-center retrospective study	2000–2015	Benign and low-malignant neoplasms	CP (n=55) vs. DP (n=70)	Comparable incidence of new-onset or aggravated diabetes mellitus (15% vs. 16%; p=0.998)
2021	Shi et al.[36]	Single-center retrospective study	2010–2018	Benign or low-grade malignant tumors located in the neck of the pancreas	Robotic CP (n=123) vs. Robotic DP (n=41)	Comparable incidence of endocrine insufficiency (5.3% vs. 10.5%; p=0.671)
2022	Klotz et al.[21]	Single-center retrospective study	2001–2020	Benign or low-grade malignant tumors located in the neck of the pancreas	CP (n=107) vs. DP (n=107)	Comparable incidence of new-onset diabetes (13.3% vs. 36.7%; p=0.056)
2022	Asano et al.[24]	Multicenter retrospective	2013–2017	Benign or low-grade malignant tumors	CP (n=148) vs. DP (n=814)	HbA1c level had been significantly lower in the MP group than in the DP group at 3, 6, 12, 24, 36 months postoperatively.
2023	Jung et al.[34]	Single-center retrospective study	2007–2020	Benign and borderline malignant pancreatic tumors	MICP (n=23) vs. MI-SPDP (n=36)	Lower risk of new onset diabetes mellitus (4.3% vs. 25.0%; p=0.039)

Abbreviations: CP, central pancreatectomy; DP, distal pancreatectomy; LCP, laparoscopic CP; LEDP, laparoscopic extended DP; MI, minimum invasive; SPDP, spleen preserving DP; LSPDP, laparoscopic SPDP; MI, minimum invasive.

tail preservation significantly contributes to reduced incidence of postoperative endocrine insufficiency.

In recent years, the adoption of minimally invasive surgery (MIS), encompassing laparoscopy or robot-assisted techniques, has become more common in CP.[29–31] The earliest instance of minimally invasive CP was reported in a 2003 case report by Baca and Bokan et al.,[32] detailing a laparoscopic segmental pancreatic resection performed for a pancreatic cystadenoma. Thereafter, the first case series on robot-assisted CP was presented by Giulianotti et al.[33] Their report indicated that among the five cases studied, the mean operative time was 320 minutes, with the mean blood loss amounting to 233 mL. The outcomes revealed no mortality, with only one patient developing a postoperative pancreatic fistula. This complication was conservatively treated. In line with this trend, many studies have compared minimally invasive CP and minimally invasive DP; furthermore, studies comparing CP and SPDP, which is less invasive than conventional DP, have also been published to date.[30,34–37] Particularly, most articles that have compared postoperative endocrine function between CP and DP in only patients with MIS found no significant difference in postoperative endocrine function between the two procedures.[36,37] In 2019, Zhang et al.[38] compared the proportion of postoperative insulin treatment between laparoscopic CP ($n=23$) and laparoscopic SPDP ($n=36$) groups and found no significant difference between the groups (0% vs. 3%, $p=1.000$). Shi et al.[36] compared the incidence of endocrine insufficiency between robot-assisted CP and robot-assisted DP groups and reported that the incidence rate of endocrine insufficiency was similar between the groups (5.3% vs. 10.5%, $p=0.671$). To our knowledge, no studies have focused on how MIS affects endocrine function after pancreatectomy, which is an important topic of focus in the future.

Iacono et al.[15] performed a meta-analysis of studies comparing CP and DP in 2013, and they reported that morbidity and mortality following CP was 45% and 0.8%, respectively. Moreover, the incidence of pancreatic fistula was 41%, indicating a significantly higher risk of postoperative morbidity after CP than after DP. The reason for the high incidence of pancreatic fistula is that suture failure can develop from two sites, including the pancreatic stump and pancratojejunostomy, after CP. Thus, the surgeon always faces a considerable trade-off between increased short-term morbidity and long-term preservation of endocrine function. Thus, several articles have reported the clinical advantage of CP compared with DP in terms of postoperative exocrine function. However, most of the studies employed the necessity of exocrine enzyme replacement as the outcome measure for exocrine insufficiency[18,39] as there is no standard quantitative evaluation method for exocrine dysfunction.

3 | CURRENT TREND OF SPDP

3.1 | Operative indications and the SPDP procedure

SPDP is currently performed worldwide for benign or low-grade pancreatic lesions. There have been many recent reports of laparoscopic procedures regarding SPDP. SPDP can be categorized into two major methods depending on the preservation of splenic blood flow. The Kimura procedure preserves blood flow to the spleen by sparing the splenic artery,[40] and the Warshaw procedure secures blood flow to the spleen by preserving the short gastric artery even after transection of the splenic artery.[41] Hence, performing SPDP requires techniques that are more advanced than those used for standard DP with splenectomy, primarily because the arterial blood flow to the spleen must be preserved. In recent times, the clinical significance of laparoscopic or robot-assisted minimally invasive SPDP procedures has been increasing.[42–44] Notably, the robot-assisted surgical system has undergone considerable advancement to overcome limitations encountered in conventional laparoscopic techniques. The incorporation of a stable three-dimensional visual system, wrist-like movements of surgical instruments, and the absence of tremors has the potential of a finer preservation of splenic blood supply.[44,45]

3.2 | Clinical significance of SPDP in terms of postoperative infection and complications

The Warshaw procedure is technically easier than the Kimura procedure, but there are concerns regarding the risk of postoperative splenic infarction and gastric varices.[46,47] Table 2 summarizes the various meta-analyses and multicenter studies published since 2010 that compared the outcomes of these two types of SPDPs.[43,48–54] Most of the reports mentioned the low incidence of postoperative gastric varices and splenic infarction associated with the Kimura procedure.

For instance, Elabbasy et al.[43] reported a lower incidence of splenic infarction (RR = 0.17; 95% CI: 0.09–0.33; $p<0.001$) and gastric varices (RR = 0.16; 95% CI: 0.05–0.51; $p=0.002$) in the Kimura group than in the Warshaw group. Moreover, the rate of intra/postoperative splenectomy was significantly lower in the Kimura group than in the Warshaw group (RR = 0.20; 95% CI: 0.08–0.49; $p<0.001$). However, there was no difference in the incidence of pancreatic fistula between the groups. The difference in the incidence of splenic infarction between the two methods is still being debated. For instance, Korrel et al.[54] conducted a multicenter retrospective study that included 29 high-volume centers (≥15 distal pancreatectomies/year) in eight European countries. They compared 634 Kimura and 244 Warshaw procedures and concluded that the rates of clinically relevant splenic ischemia (0.6% vs. 1.6%, $p=0.127$) and major complications (11.5% vs. 14.4%, $p=0.308$) did not differ significantly between the Kimura and Warshaw procedures.

Although the frequency of gastric varices due to the transection of the splenic vein is clearly higher with the Warshaw procedure, there have been no reports of postoperative bleeding from gastric varices, and the morbid significance of gastric varices after the Warshaw method remains unknown.

The major objective of SPDP is to preserve the spleen because splenectomy increases the risk of infection, particularly

TABLE 2 Summary of the articles comparing short- and long-term outcomes between Kimura's and Warshaw's procedures.

Years	Authors	Type of articles	Duration of study	Comparison	Short-term outcomes	Long-term outcomes
2015	Elabbasy et al.[43]	Meta-analysis	2000–2014	Kimura ($n=652$) vs. Warshaw ($n=291$)	• Lower incidence of splenic infarction (RR = 0.17, $p<0.001$), and intra/postoperative splenectomy (RR = 0.20, $p<0.001$) in the Kimura procedure group • No significant difference in the incidence of pancreatic fistula, length of hospital stay, operative time, or blood loss	Lower incidence of gastric varices (RR = 0.16, $p=0.002$) in the Kimura procedure group
2015	Yu et al.[48]	Meta-analysis	1988–2014	Kimura ($n=440$) vs. Warshaw ($n=259$)	• Shorter operation time in the Warshaw's procedure group ($p<0.0001$) • No difference in blood loss ($p=0.45$) and overall rate of complications ($p=0.1$), including pancreatic fistula rates ($p=0.27$)	Lower incidence of gastric varices ($p<0.01$) in the Kimura procedure group
2017	Yongfei et al.[49]	Meta-analysis	1996–2015	Kimura ($n=644$) vs. Warshaw ($n=301$)	• Higher incidence of postoperative complications including spleen infarction (OR = 9.64, $p<0.001$) in the Warshaw procedure group • Shorter operation time in the Warshaw procedure group ($p<0.001$)	Higher incidence of gastric varices (OR = 11.88, $p<0.001$) in the Warshaw procedure group
2017	Sun N et al.[50]	Meta-analysis	1988–2017	Kimura ($n=476$) vs. Warshaw ($n=279$)	• Lower incidence of splenic infarction (OR = 0.16) in the Kimura group • Lower incidence of intra/postoperative splenectomy (OR = 0.08) in the Kimura procedure group	Lower risk of gastric varices (OR = 0.08, 95%) in the Kimura procedure group
2019	Paiella et al.[51]	Multicenter observtional study	2000–2016	Kimura ($n=109$) vs. Warshaw ($n=55$)	• Lower incidence of delayed gastric emptying (9.1% vs. 1.8%, $p=0.043$) in the Kimura procedure group	No significant difference in the incidence of gastric varices
2019	Song et al.[52]	Meta-analysis	2004–2017	Kimura ($n=679$) vs. Warshaw ($n=360$)	• Lower incidence of clinically relevant postoperative pancreatic fistula ($p=0.03$), splenic infarcts ($p<0\ 0.00001$), and intra- and postoperative splenectomies ($p=0.0009$) in the Kimura procedure group	Lower incidence of gastric varices ($p<0.00001$) in the Kimura group
2022	Hang et al.[53]	Meta-analysis	–2021	Kimura ($n=1467$) vs. Warshaw ($n=706$)	• Lower incidence of splenic infarction (OR: 0.17, $p<0.00001$) in the Kimura procedure group • Shorter hospital stay ($p=0.0008$) in the Kimura procedure group • No significant differences in terms of major complication, postoperative pancreatic fistula (B/C), reoperation, blood loss, or operation time	Lower incidence of gastric varices (OR: 0.19, $p<0.00001$) in the Kimura group
2023	Korrel et al.[54]	Multicenter observational study	2001–2019	MI-Kimura ($n=634$) vs. MI-Warshaw ($n=244$)	• No significant difference in the rates of clinically splenic ischemia (0.6% vs. 1.6%, $p=0.127$) and major complications (11.5% vs. 14.4%, $p=0.308$) • Higher mortality rates after the MI-Warshaw procedure than after the MI-Kimura procedure (0.0% vs. 1.2%, $p=0.023$) • Longer operative time (202 vs. 184 minutes, $p=0.033$) and less blood loss (100 vs. 150 mL, $p<0.001$) in the MI-Kimura procedure group	Not applicable

Abbreviations: MI, minimum invasive; OR, odds ratio; RR, relative risk.

overwhelming post-splenectomy infection (OPSI). OPSI is a syndrome of fulminant sepsis that occurs in asplenic patients, and it results in high mortality and morbidity.[55] Regarding the etiology of OPSI, the spleen plays a pivotal role in the maturation of B cells, which produce opsonized immunoglobulins.[56] Notably, marginal zone B cells, primarily located within the marginal zone of the spleen, rapidly produce specific antibodies against encapsulated bacteria such as *Streptococcus pneumoniae*.[57] Additionally, the spleen functions as a filter against intravascular bacterial contaminants.[58] Consequently, asplenic patients experience impairment in intravascular pathogen filtering and the absence of specific antibody production, which synergistically exacerbate OPSI. In the field of basic scientific research, Nakamura et al.[59] demonstrated the significant protective effect of intravenous immunoglobulin administration in a murine model of OPSI following splenectomy. Moreover, several published reports have explored the contribution of intraperitoneal autotransplantation of splenic cells to the maintenance of post-splenectomy immunity.[60–62] However, the efficacy of this approach is rather limited and has rarely been implemented in clinical settings. Therefore, the preservation of the spleen is crucial to effectively manage postoperative infections, unless doing so compromises the curative potential of tumor resection. To date, no published article has compared OPSI incidence between conventional DP with splenectomy and SPDP. This may be because the most frequent time interval between splenectomy and OPSI has been reported as 10–19 years,[63] which may be too long for the follow-up of patients. Regarding infectious diseases after distal pancreatosplenectomy, Choi et al.[64] reported that common cold or flu episodes were significantly more frequent after laparoscopic pancreatosplenectomy than after SPDP ($p=0.026$), leading to a significantly higher incidence of general fatigue among patients who underwent laparoscopic pancreatosplenectomy ($p=0.014$) and poor health conditions ($p=0.042$). Tang et al. also reported lower incidence of common cold or flu during the follow-up period among SPDP patients than among distal pancreatosplenectomy patients and speculated that the increased frequency of common cold or flu in such patients may indirectly suggest an increased lifetime probability of developing OPSI.[65] Given all these articles, we concluded that it is worthwhile to preserve the spleen during DP, particularly for patients with low-grade malignancy or benign disease. Future multicenter studies that aim to elucidate whether SPDP prevents OPSI when compared with DP accompanied by splenectomy are warranted.

4 | CURRENT TREND OF DPPHR

4.1 | Operative indications and the DPPHR procedure

As mentioned above, DPPHR was initially reported in English by Beger et al.[3] for the treatment of mass-forming chronic pancreatitis.

Beger's procedure is a sub-total resection of the pancreatic head with preservation of the rim of the pancreatic head including the anterior superior pancreatoduodenal artery (ASPDA), limiting the indication of the procedure for benign disease. In 1993, Takada et al.[4] modified this procedure to enable complete resection of the pancreatic head by transection of the ASPDA and gastroepiploic artery, thus extending its indications for low-grade tumors to include intraductal papillary mucinous neoplasm (IPMN) and other premalignant tumors. In this procedure, blood flow to the bile ducts and duodenum is supplied by the posterior superior pancreatoduodenal artery (PSPDA) and posterior inferior pancreatoduodenal artery. Kocher's maneuver is not recommended because it is important to maintain blood flow from the retroperitoneum. In addition, pancreatoduodenal anastomosis is applied to reproduce a more physiological response, although the original method by Beger et al. used a pancreatojejunostomy with Roux-en-Y anastomosis. Regarding the DPPHR technique, Horiguchi et al.[7] emphasized the importance of preserving the blood supply to the bile duct from the PSPDA during the dissection of pancreatic tissue around the bile duct because the PSPDA and its branches closely traverse the region between the bile duct and duodenum. For safe dissection of the parenchyma from the bile duct, groove pancreatic region should be retained to avoid injury of the PSPDA. A typical case of pancreatic head neuroendocrine tumor resected using DPPHR is shown in Figure 3.

In procedures requiring delicate techniques, the first report regarding minimally invasive DPPHR was reported by Peng et al.,[66] and several preliminary reports regarding its safety and usefulness have been published until now.[67–70] Cai et al.[71] performed 24 procedures of laparoscopic DPPHR in a short period in 2019 and reported its safety, and real-time indocyanine green fluorescence imaging was useful in recognizing intraoperative bile duct injury. The authors also reported that real-time indocyanine green fluorescence imaging was useful in identifying intraoperative bile duct injuries. Only one study compared the long- and short-term outcomes between robot-assisted DPPHR and robot-assisted PD. The study reported that the robot-assisted DPPHR group had a shorter surgical duration (188.2 vs. 386.3 min, $p<0.001$) and less blood loss (168.2 vs. 386.3 mL, $p=0.026$) but a higher complication rate (47.1% vs. 32.4%, $p=0.105$) and pancreatic fistula rate (32.4% vs. 17.6%, $p=0.161$) than the robot assisted PD group. Exocrine insufficiency was lower in the robot-assisted DPPHR group than in the robot-assisted PD group (3.0% vs. 24.2%, $p=0.027$). Nevertheless, their findings revealed an elevated hospital mortality rate of 2.9% in the DPPHR group, but failed to elaborate on whether the arterial arcade was properly preserved or not. Consequently, this underscores the necessity of further evolution of surgical techniques in this domain.

4.2 | Clinical advantage of DPPHR compared with pancreaticoduodenectomy

The major advantage of DPPHR is the sustained absorption ability and digestive function, which would be associated with the preservation of the duodenum and function of duodenal papilla. Besides,

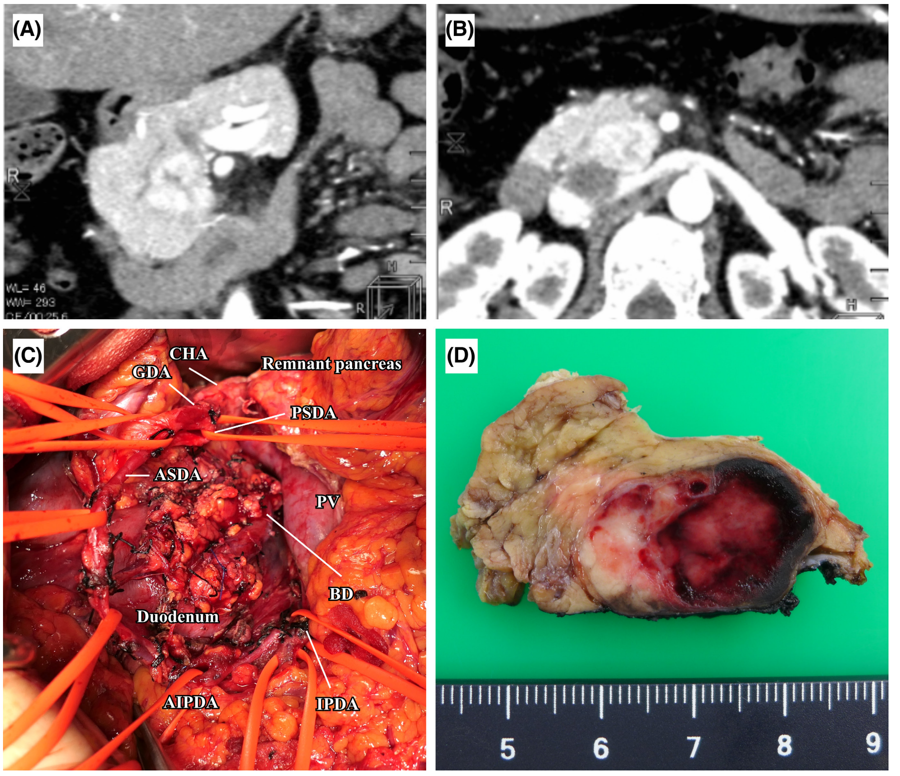

FIGURE 3 A case of neuroendocrine tumor of the pancreatic head for which DPPHR was performed. (A) Coronal section preoperative computed tomography (CT) showing a tumor of the pancreatic head (white arrow). (B) Axial section preoperative CT. (C) Surgical finding of duodenum-preserving pancreatic head resection. (D) Resected specimen of the pancreatic head including the tumor. AIPDA, anterior IPDA; ASPDA, anterior superior pancreaticoduodenal artery; BD, bile duct; CHA, common hepatic artery; GDA, gastroduodenal artery; IPDA, inferior pancreaticoduodenal artery; PIPDA, posterior IPDA; PSPDA, posterior superior pancreaticoduodenal artery; PV, portal vein.

since complex gastrointestinal reconstruction is not required in DPPHR as in PD, the flow of digestive products is more physiologic, resulting in less frequent postoperative anorexia, including delayed gastric empty.[72] In this section, the merit and demerit of DPPHR compared with PD are reviewed according to recently articles published since 2010. Table 3 lists articles published since 2010 that compared postoperative outcomes between DPPHR and PD.[7,73–79]

Regarding the comparison of short-term postoperative complications between DPPHR ($n=21$) and PD ($n=19$), Horiguchi et al.[7] found no significant differences in operative time, blood loss, complications, or hospital stay. Kato et al.[80] also reported no significant difference in the frequency of postoperative complications, including pancreatic fistula, when DPPHR ($n=34$) was compared with subtotal preserving pancreaticoduodenectomy (SSPPD) ($n=41$). Conversely, Pedrazzoli et al. reported significantly higher complication rates (81.5% vs. 40.5%) and pancreatic fistula rates (40.1% vs. 18.9%) with DPPHR ($n=27$) than with PPPD ($n=37$).[76] Thus, it remains controversial whether DPPHR compared with PD is associated with more short-term complications.

To clarify this issue, Beger et al.[79] performed a meta-analysis of studies that compared DPPHR ($n=318$) and PPPD ($n=408$). The meta-analysis reported that lower hospital mortality was observed after DPPHR in 0% of the cases (0/318) compared with 2.2% of the cases (9/404) after PD. The overall odds ratio for mortality (DPPHR vs. PD) was estimated as 0.34 (95% CI: 0.11–1.08). Gong et al. also reported a lower short-term complication rate in the DPPHR group than in the PD group (16.7% vs. 50.0%, $p=0.016$) despite the increased blood loss and longer operative time.

The long-term complications after PD have been reported as nutritional disorder, postoperative cholangitis due to bile duct resection,[81,82] and exocrine[83–85] and endocrine dysfunction,[86] and several studies on the comparisons of such long-term complications between the DPPR and PD groups are reported in Table 3. Horiguchi et al.[7] revealed that both exocrine (evaluated by the ^{13}C-trioctanoin breath test) and endocrine functions (evaluated by HbA1c) were superior in the DPPHR group than in the PPPD group.

Moreover, several reports have demonstrated a decreased incidence of postoperative cholangitis in the DPPHR group compared with the PD group, which could be due to the preservation of duodenal papillary function in the DPPHR group, preventing retrograde cholangitis that can easily occur after PD.[76,78,80]

Since cholangitis after PD significantly deteriorates the patient's postoperative quality of life, lower incidence of postoperative cholangitis in patients treated with DPPHR is a major advantage of DPPHR.

Regarding the long-term nutritional advantage of DPPHR, Sun et al.[77] reported significantly lower incidence of weight loss and pancreatic exocrine insufficiency in patients treated with DPPHR than in those treated with PD. Kato et al.[80] also compared the cumulative incidence of postoperative nonalcoholic fatty liver disease (NAFLD) between patients who underwent DPPHR ($n=34$) and those who underwent SSPPD ($n=41$). NAFLD that develops after PD is different from that which develops due to normal lifestyle-related diseases or overnutrition. With this condition, the body is in a state of starvation due to pancreatic exocrine insufficiency, postoperative diarrhea, and anorexia, resulting in increased fat accumulation in the liver parenchyma, and NAFLD is one of the indicators of malnutrition after pancreatectomy.[83,87]

TABLE 3 Summary of articles comparing short- and long-term outcomes between DPPHR and PD.

Years	Authors	Type of articles	Duration of study	Main indications	Comparison	Short-term outcomes	Long-term outcomes
2010	Horiguchi et al.[7]	Single-center retrospective study	Unknown	Benign or low grade malignant pancreatic tumor	DPPHR ($n=21$) vs. PPPD ($n=19$)	• No significant difference was found in operative factors; operative time, blood loss, morbidity and hospital stay	• Both exocrine (^{13}C-trioctanoin breath test) and endocrine function (HbA1c) superior in the DPPHR group
2011	Pedrazzoli et al.[76]	Single-center retrospective study	1991–2008	Low-grade malignant pancreatic tumor	DPPHR ($n=27$) vs. PPPD ($n=37$)	• Higher complication rate (81.5 vs. 40.5%) and pancreatic fistula rate (40.1 vs. 18.9%)	• Higher incidence of postoperative cholangitis in the PPPD group ($p<0.0001$) • Higher usage of pancreatic enzymes in the PPPD group ($p=0.003$)
2013	Gong et al.[73]	Single-center retrospective study	1998–2011	Low-grade malignant pancreatic tumor	DPPHR ($n=18$) vs. PD ($n=40$)	• Longer operation time in the DPPHR group (290 min vs. 269 min, $p=0.001$). • Increased blood loss in the DPPHR group (633 mL vs. 495 mL, $p=0.003$) • Lower short-term complication rate in the DPPHR group (16.7% vs. 50.0%, $p=0.016$)	• Lower long-term complication rate in the DPPHR group (11.1% vs. 45.0%, $p=0.012$)
2013	Lü et al.[74]	meta-analysis	1995–2009	Chronic pancreatitis	DPPHR ($n=114$) vs. PD ($n=147$)	• Not applicable	• Equally effective pain relief, exocrine and endocrine function, and similar mortality rates between the groups
2017	Diener et al.[75]	randomized, controlled, double-blind, parallel-group, superiority trial	2009–2013	Chronic pancreatitis	DPPHR ($n=115$) vs. PD ($n=111$)	• No difference in postoperative complications such as blood loss, pancreatic fistula, DGE, wound infection, and length of hospital stay	• No difference in quality of life between the groups within 24 months after surgery ($p=0.284$)
2018	Beger et al.[79]	meta-analysis	1989–2016	Premalignant and low-malignant neoplasms	DPPHR ($n=318$) vs. PPPD ($n=408$)	• In-hospital mortality occurred in zero after DPPHR and in nine (2.2%) after PPPD ($p=0.068$) • Odds ratio of mortality (DPPHR vs. PD): 0.34	• No statistically significant difference in terms of recurrence between the DPPHR and PD groups
2019	Umemoto et al.[78]	Single-center retrospective study	2009–2017	Low-grade malignant lesions in the pancreatic head	DPPHR ($n=13$) vs. PD ($n=14$)	• No significant differences was found in the incidence of postoperative complications • Better nutritional status in the DPPHR group at 3 months post-surgery	• Nutritional marker not significantly different at 6 months and 1-year between DPPHR and PD • None of the patients developing postoperative cholangitis and diabetes
2020	Sun et al.[77]	Single-center retrospective study	2014–2018	Benign or low-grade malignant lesions in the pancreatic head	DPPHR ($n=29$) vs. PD ($n=57$)	• Cumulative (≥3 months after surgery) complications (34.5% vs. 64.9%, $p=0.007$) between the DPPHR and PD groups	• Lower incidence of postoperative pancreatic exocrine insufficiency (6.9% vs. 36.8%, $p=0.007$) and weight change (0.00 vs. 2.00 kg, $p=0.002$) in the DPPHR group than in the PD group

TABLE 3 (Continued)

Years	Authors	Type of articles	Duration of study	Main indications	Comparison	Short-term outcomes	Long-term outcomes
2022	Kato et al.[80]	Single-center retrospective study	2006–2018	Benign or low-grade malignant pancreatic tumor	DPPHR ($n=34$) vs. SSPPD ($n=41$)	• No significant difference in operative factors; operative time, blood loss, rate of pancreatic fistula and Clavien–Dindo ≥ III	• Lower 5-year incidence of NAFLD in the DPPHR group (10% vs. 38%, $p=0.002$) • Higher 5-year cumulative incidence of postoperative cholangitis in the PD group than in the DPPHR group (51% vs. 3%, $p<0.001$)
2022	Asano et al.[24]	Multicenter retrospective study	2013–2017	Benign or low-grade malignant pancreatic tumor	DPPHR ($n=31$) vs. PD ($n=621$)	• Significantly longer operative time in the DPPHR group (546 min vs. 392 min, $p<0.001$) • No significant difference in the incidence of postoperative complications, 30 and 90 days mortality	• No signifivant differences between the groups in terms of postoperative body weight, albumin, total protein and HbA1c at 3, **6**, 12, 24, and 36 months after surgery

Abbreviations: DGE, delayed gastric empty; DPPHR, duodenum preserving pancreatic head resection; HbA1c, glycated hemoglobin; NAFLD, non-alcoholic fatty liver disease; PPPD, pylorus-preserving pancreatoduodenectomy; SSPPD, subtotal stomach-preserving pancreatoduodenectomy.

They elucidated that the 5-year cumulative incidence of NAFLD was significantly lower in the DPPHR group than in the PD group (10% vs. 38%, $p=0.002$). On the other hand, several articles have reported no significant differences in long-term nutritional status when DPPHR was compared with PD.[24,78] The only randomized controlled trial that compared the preservation of long-term quality of life after DPPHR and PD for chronic pancreatitis was designed by Diener et al.,[75] but they reported no significant difference between the two groups. A meta-analysis by Beger et al.[79] that assessed the long-term frequency of tumor recurrence in 318 DPPHR patients compared with 404 PD patients showed no statistically significant difference between the DPPHR and PD groups. This suggests that DPPHR is associated with oncological complete tumor resection in patients with premalignant tumors. Considering all these articles, the advantage of DPPHR is still being discussed; however, DPPHR should be presented as an option for patients with low-grade malignant tumors of the pancreatic head.

In conclusion, organ-preserving pancreatectomy (CP, SPDP, and DPPHR) requires delicate techniques, and postoperative complications may increase with this surgery compared with standard pancreatectomy, which might be dependent on the skill of the surgeon and the facility in which the surgery is performed. On the other hand, organ-preserving pancreatectomy has significant long-term advantages in endocrine and exocrine functions and is expected to become more widely employed in the future as an option for patients with low-grade malignant tumor.

AUTHOR CONTRIBUTIONS

H. K. analyzed and drafted the manuscript. U. A. and A. H. participated in the data collection and assisted with data interpretation. M. I., S. A., and M. S. reviewed and revised the manuscript. All authors read and approved the final manuscript.

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Hiroyuki Kato and Akihiko Horiguchi are editorial board members.

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ORCID

Hiroyuki Kato https://orcid.org/0000-0002-5798-2725
Satoshi Arakawa https://orcid.org/0000-0003-4948-0239
Akihiko Horiguchi https://orcid.org/0000-0002-2187-1396

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