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Comparison of the modified Blumgart mattress *vs.* interrupted suture pancreaticojejunostomy in minimally invasive pancreaticoduodenectomy

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Abstract

Aim: The modified Blumgart mattress (BM) and conventional interrupted suture (IS) methods are currently the most widely adopted pancreaticojejunostomy (PJ) techniques utilized during minimally invasive pancreaticoduodenectomy (MIPD). This study aimed to evaluate the postoperative outcomes between the two PJ techniques using robotic and laparoscopic approaches.

Methods: This was a retrospective study involving patients who underwent robotic or laparoscopic pancreaticoduodenectomy (PD) performed by two surgeons from two institutions. Surgical outcomes of the patients were compared according to the PJ techniques of robotic BM (Rob-BM), robotic IS (Rob-IS), and laparoscopic IS (Lap-IS), which were further analyzed among patients who had a soft pancreas and small pancreatic duct, while those with pancreatic ductal adenocarcinoma were excluded from the study.

Results: A total of 230 patients underwent MIPD with 63 Rob-BM, 48 Rob-IS, and 119 Lap-IS for PJ. Within the study population, clinically relevant-postoperative pancreatic fistula (CR-POPF) rates were comparable between Rob-BM and Rob-IS (6.3% *vs.* 10.4%, $P = 0.283$) and between Rob-IS and Lap-IS (10.4% *vs.* 7.6%, $P = 0.661$). Comparing patients with soft pancreas and small pancreatic duct, CR-POPF rates were not statistically different among the groups [16.0% (Rob-BM) *vs.* 10.5% (Rob-IS), $P = 0.055$, and 10.5% (Rob-IS) *vs.* 10.1% (Lap-IS),

P = 0.543]. In the multivariable analysis for risk factors of POPF, soft pancreatic textures and periampullary pathology other than pancreatic cancer were found to be risk factors.

Conclusion: POPF rates after MIPD were not different according to the PJ methods of BM and IS when performed by skilled surgeons.

Keywords: Pancreaticoduodenectomy, pancreatic reconstruction, pancreatic fistula, robot, laparoscopy

INTRODUCTION

Pancreaticoenteric reconstruction is one of the most technically challenging steps of the pancreaticoduodenectomy (PD). Postoperative pancreatic fistula (POPF) is the major driver of postoperative complications after PD. There are multiple contributing factors in the development of POPF, including endogenous, perioperative, and operative factors[1,2]. However, the pancreatectomy-targeted database of the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) has shown that the rate of POPF has improved with time due to international collaborative efforts focusing on standardizing its assessment, mitigation strategies, and management techniques[3,4].

In terms of operative factors, various pancreatic anastomoses have been proposed to handle the remnant pancreas after PD. The debate regarding the best method for pancreatic reconstruction has continued through recent decades, including a comparison of pancreaticogastrostomy versus pancreaticojejunostomy (PJ) and duct-to-mucosa versus invagination. Despite several randomized controlled trials (RCTs), this issue remains open to controversies with conflicting data[5,6], and even meta-analyses of RCTs have failed to show any differences between techniques[7,8]. Meanwhile, Blumgart devised the transpancreatic U-suture technique that combined the concept of duct-to-mucosa anastomosis and the invagination technique covering the cut surface of the remnant pancreas with the jejunal wall[9]. Its modified technique has been introduced in several reports with reduced rates of POPF[10,11].

Recently, minimally invasive PD (MIPD) has attracted worldwide interest and has been increasing in prevalence. In the era of MIPD, the modified Blumgart mattress (BM) suture and interrupted suture (IS) techniques have been widely adopted for pancreatic reconstruction. However, there is a lack of data to compare these two PJ techniques in MIPD. Thus, the present study aimed to compare the perioperative outcomes of patients who underwent laparoscopic (LPD) or robotic PD (RPD) with one of the two pancreatic reconstruction techniques.

METHODS

Study design

This study aimed to investigate the incidence rates of POPF and postoperative complication rates according to a PJ method. It was a retrospective study based on the prospectively collected databases from two institutions. The study included consecutive patients who underwent MIPD for periampullary pathology between March 1, 2014, and March 1, 2022, at the Department of Surgery, Northshore University Health System, Evanston, IL, USA, and CHA Bundang Medical Center, CHA University College of Medicine, Seongnam, Republic of Korea. One institution performed only robotic PD (robotic resection and reconstruction with BM PJ anastomosis), while the other performed laparoscopic PD (laparoscopic resection and reconstruction) and laparoscopic PD with robotic reconstruction based on IS PJ anastomosis. The study cohort underwent PJ reconstruction with one of three methods: robotic BM (Rob-BM), robotic IS (Rob-IS), and laparoscopic IS (Lap-IS). Open conversion cases and patients who underwent other pancreatic reconstruction methods, including invagination PJ anastomosis, were excluded. In Korea, the

selection of robotic or laparoscopic approaches was dependent on the economic status and insurance coverage of the patients who met the same indication criteria for MIPD. The primary aim of this study was to investigate the POPF rates according to the pancreatic reconstruction techniques in MIPD. Therefore, we evaluated the perioperative outcomes according to the PJ methods using two-way comparisons. The first comparison was between Rob-BM and Rob-IS, and the second was between Rob-IS and Lap-IS. These comparisons were further conducted among patients who had a soft pancreas with a small pancreatic duct (less than 3 mm), which was considered as the most potent risk factor of POPF[12]. Patients who converted to open surgery during MIPD and those who underwent other PJ anastomosis methods, such as the invagination method, were excluded.

Patient demographics, operative data, pathologic diagnosis, and perioperative outcomes were collected and analyzed at Northshore University Health System, Evanston Hospital. This study was approved by the institutional review board of each participating institution and was conducted in accordance with the ethical standards of each institutional committee on human experimentation, the Declaration of Helsinki, and the CONSORT statement[13]. The need for patient consent was waived, and anonymized data were collected.

Operative procedure

The standard operative procedures of the resection phase during PD were not significantly different between the two institutions. However, the conventional Whipple operation was preferred in one institution, and pylorus-preserving PD was the routine procedure in the other if there was no tumoral involvement around the pylorus or stomach. After completing the resection phase, the retained jejunum was brought in a retrocolic/retromesenteric fashion to the right side of the remnant pancreas. Then, end-to-side PJ anastomosis was performed, followed by hepaticojejunostomy and gastrojejunostomy or duodenojunostomy.

Robotic-modified Blumgart mattress suture pancreaticojejunostomy

The robotic-modified Blumgart mattress suture pancreaticojejunostomy(Rob-BM PJ) was introduced in detail in our previous study[14], and it was performed by an end-to-side and duct-to-mucosa anastomosis [Figure 1]. First, trans-pancreatic horizontal mattress sutures were employed from the anterior to the posterior aspects and straight through the pancreas using 2-0 silk. The suture proceeded through the seromuscular layer of the jejunum from top to bottom of the short vertical axis and was followed by replacement of the transpancreatic mattress suture from posterior to anterior through the pancreas. Three transpancreatic U-sutures were made, and sutures were tied up, keeping the suture tips with robotic instruments for anterior wall suturing. After making a small enterotomy, the pancreatic duct was anastomosed to the jejunal mucosa using ISs with 5-0 PDS (Ethicon, Somerville, NJ, USA). A single pigtail pancreatic stent (Freeman Pancreatic Flexi-Stent; Hobbs Medical, Stafford Springs, CT, USA) was inserted after the posterior stitches but before the anterior stitches were complete. Finally, the retained needle sutures were placed through the anterior layer of the jejunum and were approximated to cover the cut surface of the pancreas [Supplemental Video]. No sealant agent was used, and two closed continuous suction drainage tubes were placed near the pancreatic and biliary anastomosis and pulled through the port site on the right flank.

Robotic and laparoscopic interrupted suture pancreaticojejunostomy

The IS PJ was also created with an end-to-side and duct-to-mucosa anastomosis[15]. The Rob-IS [Figure 2] and Lap-IS [Figure 3] techniques were basically identical, except for the difference in instruments used. The surgeons preferred 5-0 Prolene (Ethicon) for outer layer suturing because larger suture needles induced frequent bleeding and potential risk of POPF from the pancreatic parenchyma. They also used 5-0 PDS (Ethicon) for a duct-to-mucosa anastomosis. The outer layer of sutures started from the posterior wall of

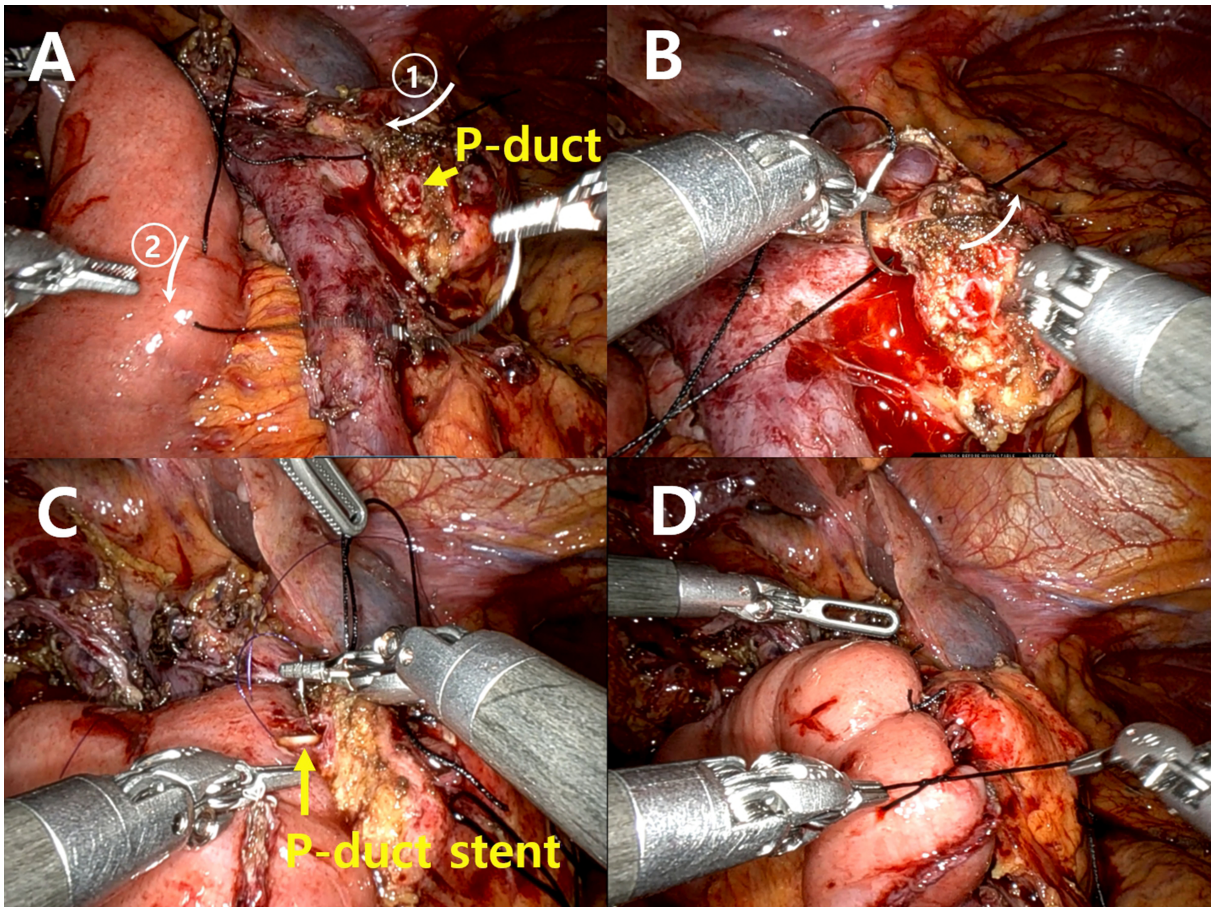

Figure 1. Robotic-modified blumgart pancreaticojejunostomy. (A) Full thickness pancreatic mattress stitch with seromuscular bowel stitch; (B) full thickness pancreatic mattress stitch; (C) duct-to-Mucosa Stitch with pancreatic duct stent; (D) anterior buttress stitches.

the pancreatic cut surface and extended to the seromuscular layer of the posterior wall of the jejunum. All sutures were immediately tied with this technique. After completing the posterior layer sutures, a small enterostomy was made on the jejunal wall at the contralateral side of the pancreatic duct. Four to six stitches for duct-to-mucosa anastomosis were applied with a short pancreatic duct stent. Then, the anterior wall of the pancreas and jejunal wall were approximated by the same ISs overlapping the pancreatic cut surface with the jejunal wall [Supplemental Video]. A polyglycolic acid sheet (PGA, Neoveil®, Gunze, Japan) and a fibrin glue sealant were routinely used over the pancreatic anastomosis, and bilateral, two-armed, and closed-suction drainage tubes were placed close to the pancreatic and biliary anastomoses.

Postoperative management

The assessment of the drain amylase levels was routinely performed on postoperative days (PODs) 1 and 3, and early (PODs 3-5) drain removal was practiced at the institution that performed the Rob-BM PJ. Drain amylase levels were obtained on PODs 1, 3, and 5, and drains were typically removed on PODs 5 to 7 if there were no complications at the institution that performed the Rob-IS and Lap-IS. There was no change in management for biochemical leak (BL), but medical or interventional management was required for grade B POPF according to the definition provided by the International Study Group of Pancreatic Surgery (ISGPS)[16].

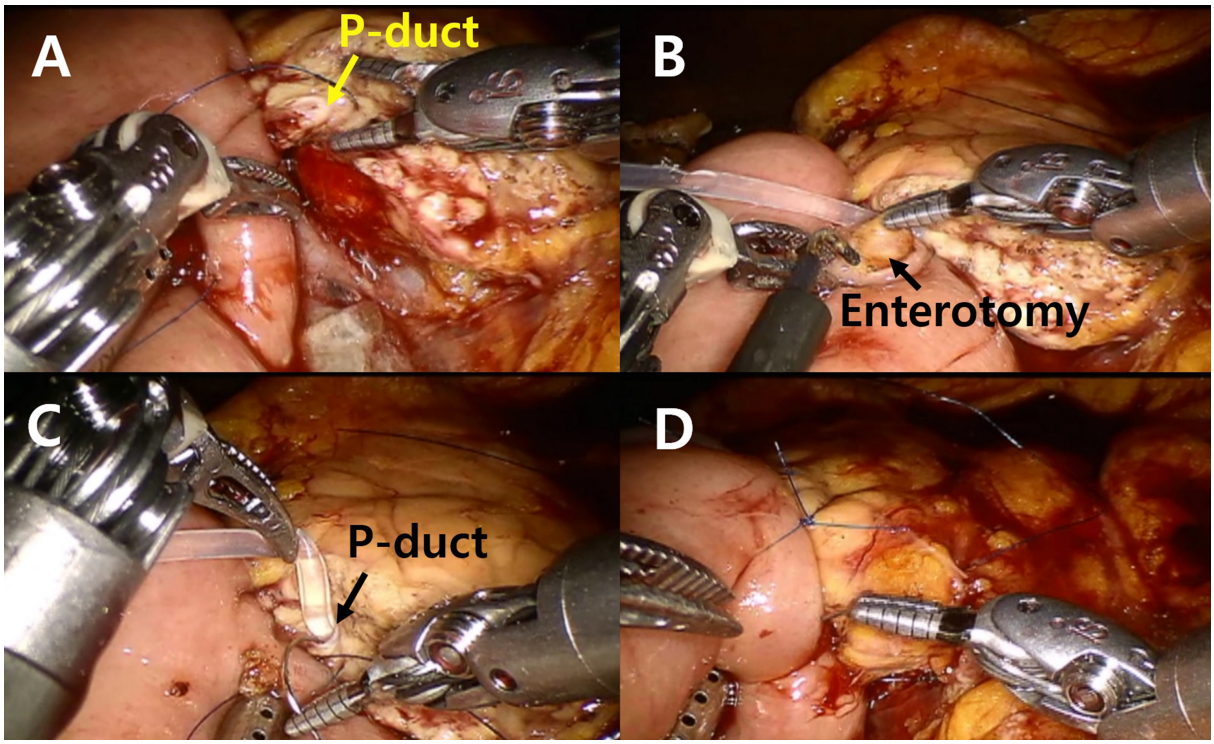

Figure 2. Robotic interrupted pancreaticojejunostomy. (A) Outer layer; (B) enterotomy; (C) pancreatic duct stent and duct-to-mucosa stitch; (D) anterior outer layer.

Definitions

Postoperative complications were graded according to the Clavien-Dindo classification system[17]. POPF and clinically relevant-POPF (CR-POPF)[16], postpancreatectomy hemorrhage (PPH)[18], and delayed gastric emptying (DGE)[19] were defined according to the ISGPS definitions. A postoperative intra-abdominal abscess was defined as a fluid collection with definitive encapsulation, enhanced thick walls, or air bubbles[20]. Bile leakage was defined according to the definition of the International Study Group of Liver Surgery[21]. Cardiovascular and pulmonary (CVP) complications included ischemic heart diseases, deep vein thrombosis, and pulmonary thromboembolism. Pancreatic textures were categorized as either soft (normal and friable) or hard (fibrotic and sclerotic) by the intraoperative assessment of surgeons via visual judgment and instrumental examination[22,23]. The pancreatic duct diameter was measured at the cut surface of the remnant pancreas intraoperatively.

Statistical analysis

Continuous variables were presented as mean with standard deviation or median with range and analyzed using Student's *t*-test or the Wilcoxon signed-rank test, while categorical parameters were expressed as number and/or percentage of patients and were analyzed using the chi-square test. The multivariable logistic regression analysis was performed to identify risk factors of POPF. A backward selection method with $P < 0.10$ required to remain in the model was used to select variables for the final model. Statistical significance was defined as a two-sided P value of < 0.05. All statistical analyses were performed using IBM SPSS Statistics software Version 28.0 (IBM, Armonk, NY, USA). The description of the analysis was based on the Strengthening the Reporting of Observational Studies in Epidemiology statement[24].

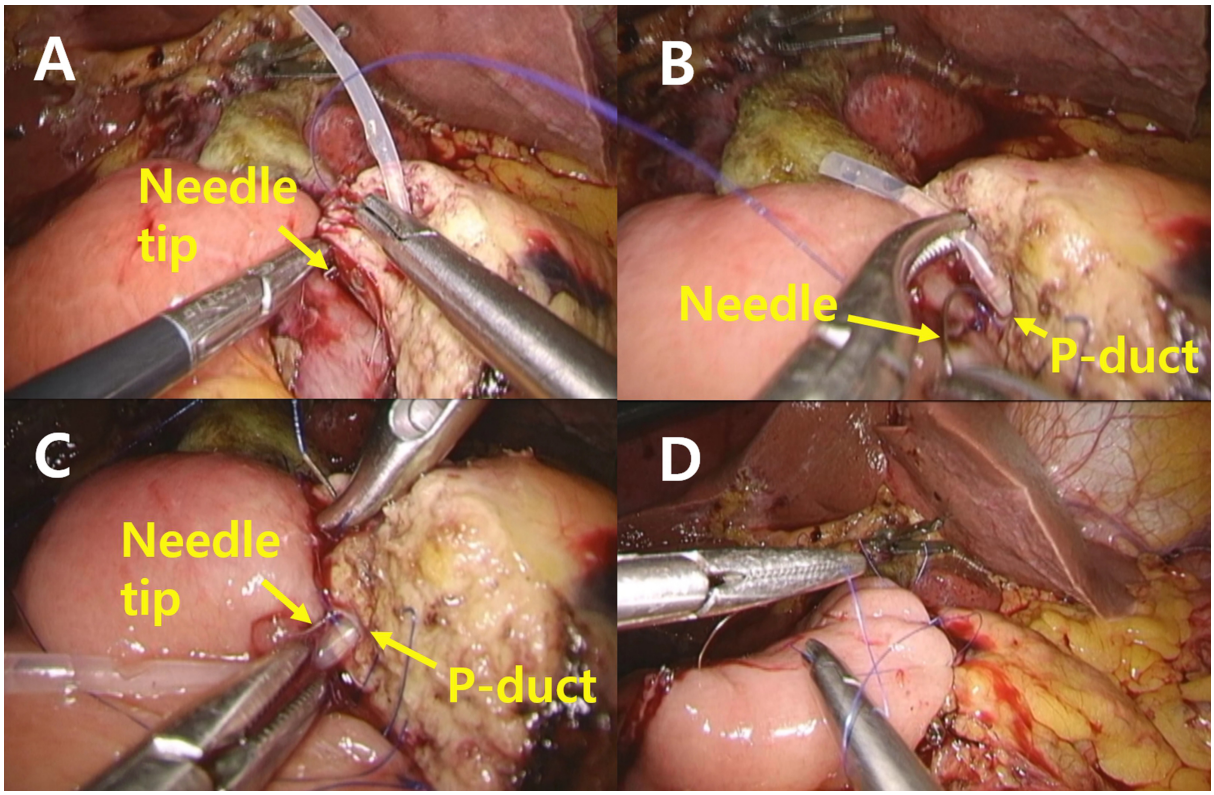

Figure 3. Laparoscopic interrupted pancreaticojejunostomy. (A) Outer layer; (B) pancreatic duct stent; (C) duct-to-mucosa stitch; (D) anterior outer layer.

RESULTS

Baseline characteristics of the entire study population

Sixty-three patients who underwent RPD with Rob-BM PJ, 48 LPD with Rob-IS PJ, and 119 LPD with Lap-IS PJ were included in the current study. Table 1 illustrated the baseline characteristics of patients according to a reconstruction technique. When comparing Rob-BM and Rob-IS groups, the patients in the Rob-BM group were older (68.4 ± 13.5 *vs.* 60.0 ± 14.1, $P < 0.001$), had a higher BMI (26.9 ± 6.4 *vs.* 23.9 ± 3.7, $P = 0.002$), higher rates of ASA scores ≥ 3 (61.9% *vs.* 10.4%, $P < 0.001$), and also had a larger pancreatic duct size (3.4 ± 2.2 *vs.* 2.2 ± 1.2, $P < 0.001$) with a larger proportion of pancreatic cancer (46.0% *vs.* 14.6%, $P < 0.001$). In addition, more patients had a hard pancreas, although the difference was not significant (34.9% *vs.* 18.8%, $P = 0.060$). Compared to patients in the Lap-IS group, patients in the Rob-IS group were younger (60.0 ± 14.1 *vs.* 65.6 ± 11.7, $P = 0.004$) and had more frequently received preoperative chemotherapy (37.5% *vs.* 16.8%, $P = 0.002$).

Perioperative outcomes according to the PJ technique in the entire study cohort

Table 2 shows the perioperative outcomes of the entire study population according to a reconstruction technique. The intraoperative outcomes of operative time, estimated blood loss, and intraoperative transfusion were comparable between the three groups. CR-POPF rates were comparable between Rob-BM and Rob-IS (6.3% *vs.* 10.4%, $P = 0.283$), as well as total POPF rates. The major complication rates ≥ grade III (22.2% *vs.* 6.3%, $P = 0.021$) were higher in Rob-BM than Rob-IS with a higher incidence of intra-abdominal abscesses (9.5% *vs.* 0%) and DGE (7.9% *vs.* 2.1%). Total DGE and CVP complications, including complication ≤ grade 2, were also frequent in Rob-BM. Regarding the Rob-IS and Lap-IS groups, the CR-POPF rates were not statistically different (10.4% *vs.* 7.6%, $P = 0.661$). The major complication rate,

Table 1. Baseline characteristics of all patients who underwent Modified Blumgart mattress suture (BM) and Interrupted Suture (IS)

Variables	Rob-BM (*n* = 63)	*P*-value	Rob-IS (*n* = 48)	*P*-value	Lap-IS (*n* = 119)
Age, years (Mean ± SD)	68.4 ± 13.5	< 0.001	60.0 ± 14.1	0.004	65.6 ± 11.7
Sex		0.286		0.148	
Male (%)	29 (46.0)		27 (56.3)		81 (68.1)
Female (%)	34 (64.0)		21 (43.8)		38 (31.9)
Body mass index, kg/m^2 (Mean ± SD)	26.9 ± 6.4	0.002	23.9 ± 3.7	0.234	23.4 ± 4.0
ASA score, No. (%)		< 0.001		0.132	
1-2	24 (38.1)		43 (89.6)		95 (84.1)
3-4	39 (61.9)		5 (10.4)		24 (20.2)
Diabetes, yes, *n* (%)	19 (30.2)	0.268	10 (20.8)	0.794	27 (23.9)
Preoperative biliary drainage, yes, *n* (%)	37 (58.7)	0.531	31 (64.6)	0.743	80 (70.8)
Preoperative chemotherapy, yes, *n* (%)	21 (33.3)	0.649	18 (37.5)	0.002	19 (16.8)
Pancreatic parenchymal texture		0.060		0.317	
Soft	41 (65.1)		39 (81.3)		88 (77.9)
Hard	22 (34.9)		9 (18.8)		31 (27.4)
Pancreatic duct size, mm (Mean ± SD)	3.4 ± 2.2	< 0.001	2.2 ± 1.2	0.090	2.7 ± 2.3
Final pathologic diagnosis, *n*		< 0.001		0.737	
Pancreatic cancer	29 (46.0)		7 (14.6)		20 (17.7)
IPMN	7 (11.1)		1 (2.1)		6 (5.3)
Ampullary cancer	7 (11.1)		16 (33.3)		27 (23.9)
Bile duct cancer	7 (11.1)		17 (35.4)		50 (44.2)
Duodenal cancer	2 (3.2)		2 (4.2)		4 (3.5)
Others	11 (17.5)		5 (10.4)		12 (10.6)
Concomitant vascular resection	1 (1.6)	0.846	1 (2.1)	0.661	4 (3.5)
Pylorus preservation		< 0.001		0.388	
PPPD	2 (3.2)		47 (97.9)		113 (95.0)
Conventional Whipple operation	61 (96.8)		1 (2.1)		6 (5.0)

ASA: American society of anesthesiologists; IPMN: intraductal papillary mucinous neoplasm; Lap-IS: laparoscopic interrupted suture; PPPD: pylorus-preserving pancreaticoduodenectomy; Rob-BM: pobotic modified blumgart; Rob-IS: pobotic interrupted suture; SD: standard deviation.

however, was slightly higher in Lap-IS [6.3% (Rob-IS) *vs.* 18.5% (Lap-IS), $P = 0.045$). Others were comparable between the groups.

Baseline characteristics of patients who had a soft pancreas and small pancreatic duct

The surgical outcomes were compared among patients who had a soft pancreas with a small pancreatic duct and excluding pancreatic ductal adenocarcinoma. The basic demographics of the patients are shown in Table 3. Patients in the Rob-BM group were older (67.5 ± 14.9 *vs.* 60.3 ± 14.6, $P = 0.016$), had a higher BMI (26.7 ± 6.4 *vs.* 23.9 ± 3.8, $P = 0.013$), and had a higher rate of ASA scores ≥ 3 (44.0% *vs.* 10.5%, $P = 0.002$) than the Rob-IS group. However, these variables were similar between the Rob-IS and Lap-IS groups. More patients received preoperative chemotherapy in the Rob-IS than the Rob-BM [31.6% (Rob-IS) *vs.* 1% (Rob-BM), $P = 0.008$] and the Lap-IS [31.6% (Rob-IS) *vs.* 13.9% (Lap-IS), $P = 0.024$]. The disease entity and pylorus-preservation rate were different between the Rob-BM and Rob-IS but similar between the Rob-IS and Lap-IS. Other characteristics were comparable.

Perioperative outcomes according to a reconstruction technique in patients with a soft pancreas and small pancreatic duct

The postoperative outcomes of patients who had a soft pancreas and small pancreatic duct were not

Table 2. Comparison of the perioperative outcomes between Modified Blumgart mattress suture (BM) and Interrupted Suture (IS) pancreaticojejunostomy groups

Variables	Rob-BM (*n* = 63)	*P*-value	Rob-IS (*n* = 48)	*P*-value	Lap-IS (*n* = 119)
Operative time, min (Mean ± SD)	435.9 ± 91.5	0.243	424.1 ± 84.0	0.310	430.3 ± 67.7
EBL, ml (Mean ± SD)	452.5 ± 1423.2	0.393	394.9 ± 380.5	0.489	393.4 ± 287.9
Intraoperative transfusion, *n* (%)	2 (3.2)	0.120	5 (10.4)	0.424	18 (15.1)
POPF, *n* (%)		0.389		0.801	
BL	11 (17.5)		12 (25.0)		26 (21.8)
B	4 (6.3)		5 (10.4)		7 (5.8)
C	0		0		2 (1.7)
CR-POPF, *n* (%)	4 (6.3)	0.283	5 (10.4)	0.661	9 (7.6)
Major postoperative Cx, *n* (%)	14 (22.2)	0.021	3 (6.3)	0.045	22 (18.5)
IIIA	9 (14.3)		3 (6.3)		14 (11.8)
IIIB	5 (7.9)		0		5 (4.2)
IVA	0		0		1 (0.8)
V	0		0		1 (0.8)
Types of major Cx/ total Cx, *n* (%)		0.048		0.601	
PPH	1 (1.6)		2 (4.2)		3 (2.5)
Intra-abdominal abscess	6 (9.5)		0		5 (4.2)
DGE	5 (7.9)/ 8 (20.6)		0/3 (6.3)		0/ 7 (5.9)
CVP* complications	1 (1.6)/ 8 (12.7)		0		0/ 4 (3.4)
Wound infection or incisional hernia	0		1 (2.1)		6 (5.0)
Others†	1 (1.6)		0		4 (3.4)
Reoperation in 90 days, *n* (%)	6 (9.5)	0.110	1 (2.1)	0.859	2 (1.7)
Readmission in 90 days, *n* (%)	5 (7.9)	0.425	6 (12.6)	0.570	19 (16.0)
Mortality in 90 days, *n* (%)	1 (1.6)	0.381	0	0.524	1 (0.8)
Hospital days, Median (range)	7.0 (5-32)	0.125	9.5 (5-33)	0.052	13.0 (8-70)

BL: biochemical leak; CR-POPF: clinically relevant POPF; Cx: complication; *CVP: cardiovascular and pulmonary complications, which included myocardiac events, deep vein thrombosis, and pulmonary thromboembolism; DGE: delayed gastric emptying; EBL: estimated blood loss; Lap-IS: Laparoscopic interrupted suture; POPF: Postoperative pancreatic fistula; PPH: Postpancreatectomy hemorrhage; Rob-BM: robotic modified blumgart; Rob-IS: robotic interrupted suture; SD: standard deviation; †Others included 1 pneumonia in Rob-BM and 1 pneumonia, 2 gastric ulcers, and 1 acute kidney injury in Lap-IS.

significantly different from those of the entire study population, as illustrated in Table 4. Operation times were comparable between the groups. Estimated blood loss was less in Rob-BM than in Rob-IS (170.0 ± 122.6 *vs.* 339.3 ± 312.9, $P = 0.392$) but similar between Rob-IS and Lap-IS ($P = 0.352$). CR-POPF rates were not statistically different among the groups [16.0% (Rob-BM) *vs.* 10.5% (Rob-IS), $P = 0.055$; 10.4% (Rob-IS) *vs.* 10.1% (Lap-IS), $P = 0.543$]. Similarly, total POPF rates were not statistically different. The major postoperative complication rate was significantly higher in Rob-BM than Rob-IS (32.0% *vs.* 5.3%, $P = 0.004$) and was higher in Lap-IS than Rob-IS (24.1% *vs.* 5.3%, $P = 0.013$). The major complications, including intra-abdominal abscesses (12.0% *vs.* 0%), DGE (8.0% *vs.* 0%), and CVP complications (4.0% *vs.* 0%), were more frequent in Rob-BM than Rob-IS with a higher incidence of total DGE (24.0%) and CVP complications (12.0%) in Rob-BM. Other perioperative outcomes were not different, including postoperative hospital stay, between the groups.

Risk factor analysis of the incidence of POPF following MIPD

During multivariable analysis for risk factors associated with POPF [Table 5], soft pancreatic textures and periampullary pathology rather than pancreatic ductal adenocarcinoma were risk factors for POPF, not technique. Otherwise, multivariable analysis was not powered for risk factors of CR-POPF.

Table 3. Comparison of baseline characteristics of patients with soft pancreas and small pancreatic duct less than 3 mm according to the method of pancreaticojejunostomy

Variables	Rob-BM (*n* = 25)	*P*-value	Rob-IS (*n* = 38)	*P*-value	Lap-IS (*n* = 79)
Age, years (Mean ± SD)	67.5 ± 14.9	0.016	60.3 ± 14.6	0.059	65.0 ± 12.2
Sex		0.236		0.333	
Male (%)	10 (40.0)		21 (55.3)		51 (64.6)
Female (%)	15 (60.0)		17 (44.7)		28 (35.4)
Body mass index, kg/m^2 (Mean ± SD)	26.7 ± 6.4	0.013	23.9 ± 3.8	0.381	23.9 ± 3.5
ASA score, No. (%)		0.002		0.085	
1-2	14 (56.0)		34 (89.5)		60 (75.9)
3-4	11 (44.0)		4 (10.5)		19 (24.1)
Diabetes, yes, n (%)	4 (16.0)	0.617	8 (21.1)	0.792	15 (19.0)
Preoperative biliary drainage, yes, *n* (%)	11 (44.0)	0.087	25 (65.8)	0.692	49 (62.0)
Preoperative chemotherapy, yes, *n* (%)	1 (4.0)	0.008	12 (31.6)	0.024	11 (13.9)
Pancreatic duct size, mm (Mean ± SD)	2.0 ± 0.4	0.117	1.9 ± 0.6	0.383	1.8 ± 0.7
Final pathologic diagnosis, *n*		0.043		0.321	
IPMN	4 (16.0)		0		3 (3.8)
Ampullary cancer	7 (28.0)		15 (39.5)		18 (22.8)
Bile duct cancer	6 (24.0)		16 (42.1)		42 (53.2)
Duodenal cancer	1 (4.0)		2 (5.3)		4 (5.1)
Others	7 (28.0)		5 (13.2)		12 (15.2)
Concomitant vascular resection	0		0		0
Pylorus preservation		< 0.001		0.974	
PPPD	1 (4.0)		37 (97.4)		77 (97.5)
Conventional Whipple operation	24 (96.0)		1 (2.6)		2 (2.5)

ASA: american society of anesthesiologists; IPMN: intraductal papillary mucinous neoplasm; Lap-IS: laparoscopic interrupted suture; PPPD: pylorus-preserving pancreaticoduodenectomy; Rob-BM: robotic modified blumgart; Rob-IS: robotic interrupted suture; SD: standard deviation.

DISCUSSION

Although various reconstruction techniques for remnant pancreas in PD have been introduced, there are no standard techniques to date. Many surgeons have tried to prove the feasibility and safety of their preferred techniques. In recent years, the BM and conventional IS methods have been gaining popularity as a PJ technique, with an increasing body of literature comparing the two techniques[25]. However, these two PJ techniques have not been compared in the MIPD population. The current study showed that both PJ methods were safe, even in patients with a soft and small duct pancreas, and could be options for PJ in MIPD with appropriately skilled hands. The PJ method itself and other factors did not affect the incidence of overall POPF, but pancreatic characteristics of the parenchymal texture and pancreatic duct size did.

As the basic principle of a reliable pancreaticoenteric anastomosis, mitigating pancreatic leakage is essential. Several prospective RCTs comparing the invagination and the duct-to-mucosa technique have provided conflicting results[6,7]. However, Kilambi *et al.* demonstrated that the techniques were not significantly different in the incidence of POPF and complemented each other, suggesting no need for further studies comparing these two techniques[8]. On the other hand, a recent study tried to explore a different solution to attenuate POPF by comparing single loop and isolated loop techniques for the PJ rather than an anastomosis technique[26]. Another consideration of PJ is maintaining the long-term patency of the pancreatic duct in the remnant pancreas. This would help not only to preserve the pancreatic exocrine function but also to prevent atrophic change to keep pancreatic endocrine function. In particular, a large

Table 4. Perioperative outcomes of patients with soft pancreas and small pancreatic duct less than 3 mm according to the method of pancreaticojejunostomy

Variables	Rob-BM (*n* = 25)	*P*-value	Rob-IS (*n* = 38)	*P*-value	Lap-IS (*n* = 79)
Operation time, min (Mean ± SD)	410.6 ± 99.7	0.392	417.1 ± 84.4	0.352	422.5 ± 64.3
EBL, ml (Mean ± SD)	170.0 ± 122.6	0.008	339.3 ± 312.9	0.186	391.4 ± 284.1
Intraoperative transfusion, *n* (%)	0	0.150	3 (7.9)	0.347	11 (13.9)
POPF, *n* (%)		0.158		0.749	
BL	7 (28.0)		12 (31.6)		21 (26.6)
B	4 (16.0)		4 (10.5)		6 (7.6)
C	0		0		2 (2.5)
CR POPF, *n* (%)	4 (16.0)	0.055	4 (10.5)	0.543	8 (10.1)
Major postoperative Cx, *n* (%)	8 (32.0)	0.004	2 (5.3)	0.013	19 (24.1)
IIIA	6 (24.0)		2 (5.3)		12 (15.2)
IIIB	2 (8.0)		0		4 (5.1)
IVA	0		0		1 (1.3)
V	0				1 (1.3)
Types of major Cx/ total Cx, n (%)		0.049		0.531	
PPH	1 (4.0)		1 (2.6)		2 (2.5)
Intra-abdominal abscess	3 (12.0)		0		4 (5.1)
DGE	2 (8.0)/6 (24.0)		0/3 (7.9)		0/2 (2.5)
CVP* complications	1 (4.0)/3 (12.0)		0		0/2 (2.5)
Wound infection or incisional hernia	0		1 (2.6)		6 (7.6)
Others†	1 (4.0)		0		4 (5.1)
Reoperation in 90 days, *n* (%)	2 (8.0)	0.076	0	0.323	2 (2.5)
Readmission in 90 days, *n* (%)	1 (4.0)	0.145	6 (15.8)	0.933	12 (15.2)
Mortality in 90 days, *n* (%)	1 (4.0)	0.214	0	0.486	1 (1.3)
Hospital days, Median (range)	8.0 (5-32)	0.145	11.0 (8-33)	0.065	13.0 (8-70)

BL: biochemical leak; CR-POPF: clinically relevant POPF; Cx: complication; *CVP: cardiovascular and pulmonary complications, which included myocardiac events, deep vein thrombosis, and pulmonary thromboembolism; DGE: delayed gastric emptying; EBL: estimated blood loss; Lap-IS: laparoscopic interrupted suture; POPF: postoperative pancreatic fistula; PPH: postpancreatectomy hemorrhage; Rob-BM: robotic modified blumgart; Rob-IS: robotic interrupted suture; SD: standard deviation; †Others included 1 pneumonia in Rob-BM and 1 pneumonia, 2 gastric ulcers, and 1 acute kidney injury in Lap-IS.

Table 5. Multivariable analysis of risk factors for Postoperative Pancreatic Fistula

Variable	OR (95% CI)	*P*-value
Soft Pancreatic Texture	3.32 (1.33-8.29)	0.0102
Dx, other than pancreatic cancer	3.36 (1.26-8.96)	0.0157

CI: confidence interval; Dx: diagnosis; OR: odds ratio .

portion of the patients who have a soft pancreas with a small duct might have a good prognosis with a less aggressive disease entity compared to patients with pancreatic ductal adenocarcinoma, which induces a hard pancreas and pancreatic duct dilatation. Green *et al.*[27] and the previous study by the authors[28] demonstrated poor patency rates of the pancreatic duct with the invagination method of PJ in animal experiments. Therefore, duct-to-mucosa PJ seems to be a theoretically appropriate technique.

The conventional IS proposed as the Cattel-Warren anastomosis[29] and the transpancreatic mattress suture as in the Blumgart anastomosis[30] are the two representative duct-to-mucosa PJ anastomosis techniques. The conventional IS duct-to-mucosa PJ was designed to allow for close adherence between the pancreatic

stump and jejunal wall, maintaining pancreatic ductal patency[31]. However, there were concerns about possible dead space in the interspace at the PJ, resulting in retention of effusion from the pancreatic cut surface, easy laceration of the pancreatic parenchyma during suturing, and development of tangential shear forces during tightening of the knots in multiple ISs[32,33]. Therefore, the BM technique was devised, intending to eliminate tangential tension and shear forces between the jejunum and pancreatic cut surface[30]. Hirono *et al.* conducted an RCT to compare the incidence of CR-POPF between the IS and BM groups in open surgery. In their study, there was no significant difference of CR-POPF between the two groups [6.8% (IS) *vs.* 10.3% (BM), $P = 0.367$] or in overall postoperative complication rates[32]. They also measured fluid collection in the interspace of the pancreatic stump and jejunal wall at PJ by computed tomography on the fourth POD between the two groups. The maximal area of interspace at PJ observed was smaller in the BM group, implying that this technique might create a tighter junction and closer contact between the pancreatic cut surface and intestinal wall. A recent meta-analysis by Cao *et al.*, which analyzed five retrospective studies and one RCT, demonstrated that the BM method was associated with a lower incidence of CR-POPF [OR 95%CI, 0.32 (0.12-0.84); $P = 0.02$] compared to IS anastomosis but comparable overall severe complication rates[34]. On the other hand, Kawakatsu *et al.* investigated the POPF rates of the two PJ anastomoses in patients with a soft pancreas, and the results demonstrated no difference in CR-POPF rates (42.7% *vs.* 42.6%, $P = 0.985$)[35]. In the current study, the PJ anastomosis techniques were not associated with the POPF rate, even in the population that underwent MIPD, suggesting that both PJ methods are safe when performed by skilled hands. It has been suggested that technical skills contribute to risks of POPF in robotic PJ[36], but this is the first study comparing PJ anastomotic techniques in an entirely minimally invasive cohort.

Despite comparable POPF rates among the PJ techniques, overall and major postoperative complications were higher in the Rob-BM group than the Rob-IS group in both the entire cohort and the cohort of patients who had a soft pancreas and a small pancreatic duct. CVP complications were frequent in the Rob-BM group. These complications were not directly related to the outcomes of PJ anastomoses but instead to patient comorbidity. The patients in the Rob-BM group were older and had higher BMI and ASA scores, which might influence the higher major complication rates, such as CVP complications. Age, obesity, functional status, and the presence of a comorbidity were well-known risk factors for the morbidity rate after PD[37,38]. Chang *et al.* demonstrated that obesity increased wound infections, return to the operating room, septic shock, renal insufficiency, and pulmonary embolism after PD in their nation-wide observational study using the 2010-2015 ACS NSQIP[39]. Interestingly, the Lap-IS group showed higher major postoperative complication rates than the Rob-IS group, even though they underwent the same laparoscopic resection and PJ anastomosis techniques. Robotic surgery costs more than twice conventional laparoscopic surgery in South Korea[40]. Therefore, patient selection would be stricter for robotic surgery, which might have influenced the higher complication rates in Lap-IS.

DGE is one of the most common procedure-specific complications, occurring in 16%-57% of patients following PD[41-43]. In this study, the DGE rates were exceptionally higher in the Rob-BM group, which underwent a conventional Whipple operation in 96.8% of the patients. Pylorus-preserving PD has been suggested as a risk factor for the development of DGE[44,45], whereas other studies found that pylorus preservation was not associated with a higher incidence of DGE[19,46,47]. The causes of DGE are not fully understood and are suspected to be multifactorial. Functional factors include decreased plasma motilin concentration, denervation, or devascularization, as well as postoperative complications such as POPF, PPH, or infection[47]. Our study also did not reveal a clear cause of DGE. Nevertheless, we speculated that the prevalence of DGE in the Rob-BM group might be related to the higher incidence of overall postoperative complications, older ages, higher BMIs, and higher ASA scores. A difference in gastrojejunal

and duodenal-jejunal anastomoses could also be a contributing factor.

There were several limitations to the current study. First, BM and IS PJ techniques were performed by different surgeons at different institutions, impeding homogenous comparison. Second, even though both participant centers were high-volume centers performing more than 20 MIPD per year[48], the sample size was not eligible for a matching analysis. However, this study focused on CR-POPF rates between the Rob-BM and Rob-IS PJ anastomosis. In addition, the Rob-IS and Lap-IS were compared to assess CR-POPF rates following the same PJ technique by different modalities. To the best of our knowledge, this is the first study that compared the BM and IS techniques for PJ in MIPD.

In conclusion, CR-POPF rates of Rob-BS, Rob-IS, and Lap-IS were not different when performed by skilled and experienced surgeons, even in patients with a high-risk pancreas with soft textures and a small pancreatic duct. Further large-volume studies are necessary to establish a standard PJ anastomosis technique in MIPD with consideration of training aspect, learning curves, and safety.

DECLARATIONS

Authors' contributions

Study conception and design: Choi SH, Hogg ME
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Manuscript review: Choi SH, Kuchta K, Rojas AE, Paterakos P, Mehdi SA, Talamonti MS, Hogg ME

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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None.

Conflicts of interest

MEH has received funding from Intuitive Surgical, which goes to her institution for services, including proctorship, host observation sites, and teaching courses (< $6,000 annually). All other authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

The current study was done in accordance with the ethical standards of each institutional committee on human experimentation, the Declaration of Helsinki, and the CONSORT statement. The need for patient consent was waived. This study was approved by the institutional review board of each participating institution (EH23-110).

Consent for publication

Not applicable.

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