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A Risk Analysis for Ischemic Necrosis of the Remnant Stomach After Distal Pancreatectomy in Patients With Previous Distal Gastrectomy: A Multicenter Retrospective Survey by the Japanese Society of Pancreatic Surgery

Takashi Kishi[1] | Yoshitsugu Tajima[1] | Hikota Hayashi[1] | Yasunari Kawabata[1] | Kenichiro Uemura[2] | Minako Nagai[3] | Kohei Nishio[4] | Kengo Fukuzawa[5] | Shintaro Yagi[6] | Masaaki Hidaka[1]

[1]Department of General and Digestive Surgery, Shimane University Faculty of Medicine, Izumo, Shimane, Japan | [2]Department of Surgery, Graduate School of Biomedical and Health Science, Hiroshima University, Hiroshima, Japan | [3]Department of Surgery, Nara Medical University, Nara, Japan | [4]Department of Hepatobiliary-Pancreatic Surgery, Graduate School of Medicine, Osaka Metropolitan University, Osaka, Japan | [5]Department of Surgery, Oita Red Cross Hospital, Oita, Japan | [6]Department of Hepato-Biliary-Pancreatic Surgery and Transplantation, Kanazawa University, Kanazawa, Ishikawa, Japan

Correspondence: Takashi Kishi (tk.kishi123@med.shimane-u.ac.jp)

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ABSTRACT

Background/Purpose: The remnant stomach after distal gastrectomy (DG) which receives its blood supply mainly from the splenic artery (SPA), is at high risk for gastric ischemia following distal pancreatectomy (DP). We investigated the risk factors for ischemic necrosis of the remnant stomach (INS) during or after DP in DG patients.

Patients/Methods: We collected 414 patients who underwent DP after DG between July 2009 and December 2019 by distributing questionnaires to members of the Japanese Society of Pancreatic Surgery (JSPS) in 2020, and the risk factors for INS were analyzed in 364 eligible patients.

Results: INS developed in 17 (4.7%) patients. A multivariate logistic regression analysis revealed that dissection of the left inferior phrenic artery (LIPA) during DP (odds ratio [OR] 51.9, $p < 0.001$), current DP for pancreatic cancer (OR 6.19, $p = 0.017$), and previous DG for gastric cancer (OR 6.12, $p = 0.017$) were independent risk factors for INS.

Conclusions: Preservation of the LIPA is necessary to avoid INS when DP is performed in DG patients. Additionally, careful surgical management is required in patients undergoing DP for pancreatic cancer and who have undergone DG for gastric cancer because they are candidates for INS after DP.

1 | Introduction

During distal gastrectomy (DG), the right gastric artery (RGA), left gastric artery (LGA), right gastroepiploic artery (RGEA), and left gastroepiploic artery (LGEA) are typically separated. As a result, arterial blood flow to the remnant stomach after DG relies on the terminal branches of the splenic artery (SPA), such as the short gastric artery (SGA) and the posterior gastric artery (PGA) [1–3]. Recent improvements in survival after DG for both benign and malignant gastric diseases may provide a more significant opportunity for gastrectomized patients to suffer from a pancreatic disorder requiring DP. Although the actual frequency

of patients undergoing DP after DG is unclear because of the uncommon clinical situation, Kimura et al. [4] reported an incidence of 4.0% in a series of 226 patients who underwent DP.

Isabella et al. [5] reviewed 28 cases of ischemic necrosis of the remnant stomach (INS) after DG and noted that the mortality rate reached 70%, with 16 (57%) patients undergoing splenectomy simultaneously with DG. That report highlights the importance of preserving the SPA and its branches for securing a sufficient blood supply to the remnant stomach after DG; therefore, distal pancreatectomy (DP) involving resection of the SPA may lead to ischemic changes in the remnant stomach in patients who have previously undergone DG. However, a recent systematic literature review consisting of 84 DP patients in a propensity score-matched analysis stated that DP could be planned safely even for 14 patients who had undergone DG when the LGA or the left inferior phrenic artery (LIPA) was confirmed on preoperative contrast-enhanced computed tomography (CT), together with a careful observation of possible changes to the blue stomach during DP [6]. Takahashi et al. [7] reported that DP after DG could be performed safely without ischemia of the remnant stomach in cases with a blood supply via an intramural vascular network from the LIPA through the esophagogastric junction. Fujino et al. [8] reported that indocyanine green (ICG) fluorescence imaging ensured perfusion of the remnant stomach during laparoscopic splenectomy in a patient with a history of DG.

However, past studies have consisted of a few subjects or case reports and lacked solid evidence regarding the incidence and risk factors of gastric ischemia and how to secure a sufficient blood supply to the remnant stomach during DP. Therefore, most surgeons remain deeply concerned about the possible ischemic complications of the remnant stomach when performing DP after DG.

This retrospective study investigated the precise incidence and risk factors of INS during or after DP in patients with a history of DG based on questionnaires distributed to the committee members of the Japanese Society of Pancreatic Surgery (JSPS).

2 | Patients and Methods

2.1 | Study Design

We conducted a questionnaire survey of patients who underwent DP for benign or malignant pancreatic disorders after a history of DG between January 2009 and December 2019 at 175 affiliated institutions that participated in the JSPS in 2020. Additionally, the total number of patients who underwent DP at each institution during the same period was determined. The collected patient data were analyzed for INS occurrence during or after DP. The questionnaire survey was initiated with the approval of the Ethical Committee of Shimane University Hospital (approval number: 20201027-1), and the institutional review boards of other participating hospitals approved this retrospective study.

2.2 | Study Variables

The following preoperative patient characteristics and intraoperative parameters related to DP were reviewed: age, sex, body mass index (BMI), laboratory data such as complete blood count, albumin, glycated hemoglobin (HbA1c), prognostic nutritional index (PNI), controlling nutritional status (CONUT) score, primary gastric disease indicated for DG, reconstruction methods after DG, interval from DG to DP, history of splenectomy, medical history of anticoagulant use, arterial blood flow to the remnant stomach identified on preoperative contrast-enhanced CT, pancreatic pathology indicated for current DP, surgical procedure of DP (conventional DP with splenectomy, splenic vessel-preserving DP (SVPDP), and Warshow's technique), operative time, estimated blood loss, arteries of the remnant stomach divided during DP, combined resection of surrounding organs (e.g., colon and stomach), and a quantitative assessment of blood flow of the remnant stomach during DP. The BMI was calculated by dividing the body weight in kilograms by the square of the height in meters. The PNI was calculated based on the serum albumin concentration and total lymphocyte count (/mL): $10 \times$serum albumin (g/dL)$+0.005 \times$total lymphocyte count (/mL). The CONUT score was also calculated based on the serum albumin concentration, total peripheral lymphocyte count, and total cholesterol concentration.

2.3 | Definition of INS

INS was defined as "unexpected partial or total resection of the remnant stomach required during DP due to ischemic changes of the gastric wall based on the macroscopic discoloration or decreased blood flow on an objective measuring device" and "unexpected reoperation requiring gastrectomy due to gastric ischemia after DP."

2.4 | Study Endpoint

The primary endpoint of this study was to identify risk factors for INS during or after DP in patients with a history of DG. The secondary endpoint was the actual incidence of INS related to DP after DG.

2.5 | Exclusion Criteria

Patients who underwent total remnant gastrectomy during DP for (1) prophylactic planned removal of the remnant stomach in anticipation of postoperative gastric ischemia, (2) necessary remnant gastrectomy for invasive pancreatic cancer or severe adhesions, and (3) remnant gastrectomy for synchronous gastric cancer were excluded from the analysis.

2.6 | Statistical Analyses

Continuous variables are expressed as medians with minimum–maximum (min–max) values. Quantitative data were analyzed using Fisher's exact test and the Mann–Whitney *U* test. Categorical data were analyzed using Pearson's chi-squared test. Significant variables in the univariate analyses were then entered into a multivariable logistic regression analysis to identify independent risk factors for INS. Independent variables are expressed as odds ratios (ORs) with 95% confidence intervals (CIs).

Statistical significance was set at $p < 0.05$. Statistical analyses were performed using the JMP Pro software program ver. 17, for Windows (SAS Institute Inc., Cary, NC, USA).

3 | Results

A questionnaire survey was conducted among 175 affiliated institutions participating in the JSPS, and questionnaire cooperation was obtained from 109 (62.3%) institutions. As a result, 13 866 distal pancreatectomies were performed in the participating institutions during the study period, and 414 DP patients with a previous history of DG were collected. Thus, the incidence of patients requiring DP after DG is 3.0%. Of the 414 DP patients with a history of DG, 50 met the exclusion criteria for concomitant total remnant gastrectomy during DP, including 27 patients who underwent prophylactic scheduled gastrectomy for anticipating postoperative gastric ischemia, 21 with invasive pancreatic cancer, and 2 with synchronous gastric cancer. Consequently, 364 patients, 273 males and 91 females, with a mean age of 72.5 years were eligible for the analysis (Figure 1).

3.1 | INS

Seventeen (4.7%) of the 364 eligible patients developed INS, of whom 15 required gastric resection during DP and 2 underwent reoperation after DP (Figure 1). Among the patients undergoing gastric resection during DP, 14 underwent total remnant gastrectomy and 1 received partial gastrectomy. Although a quantitative decrease in gastric blood flow on ICG fluorescence angiography was confirmed in one of these patients, the need for gastrectomy was determined by macroscopic discoloration of the stomach in all patients. Among the patients who underwent reoperation after DP, one received partial gastrectomy and the other total gastrectomy due to postoperative INS after DP.

In the 347 patients without INS, 19 showed gastric ischemia-related complications after DP, that is, delayed gastric emptying in 11, multiple gastric ulcers in 4, and erosive gastritis in 4. The patient was successfully treated conservatively.

3.2 | Preoperative Risk Factors for INS

Preoperative patient characteristics and univariate risk analyses for INS related to DP are summarized in Table 1. The mean age was 70.0 years old in the INS group and 73.0 years old in the non-INS group. The INS group comprised 13 males and four females, whereas the non-INS group comprised 260 males and 87 females. There were no significant differences in age, sex, BMI, laboratory data, PNI, or CONUT scores between the two study groups. The primary gastric disorder indicated for DG was gastric cancer in 15 (88.2%) patients and gastroduodenal ulcer in one (5.9%) patient in the INS group. In the non-INS group, 200 (57.7%) patients had gastric cancer, and 136 (39.2%) had gastroduodenal ulcers. The incidence of gastric cancer was significantly higher in the INS group ($p = 0.012$). The intervals between the DG and DP were 176 and 252 months in the INS and non-INS groups, respectively. However, there were no significant differences between the two

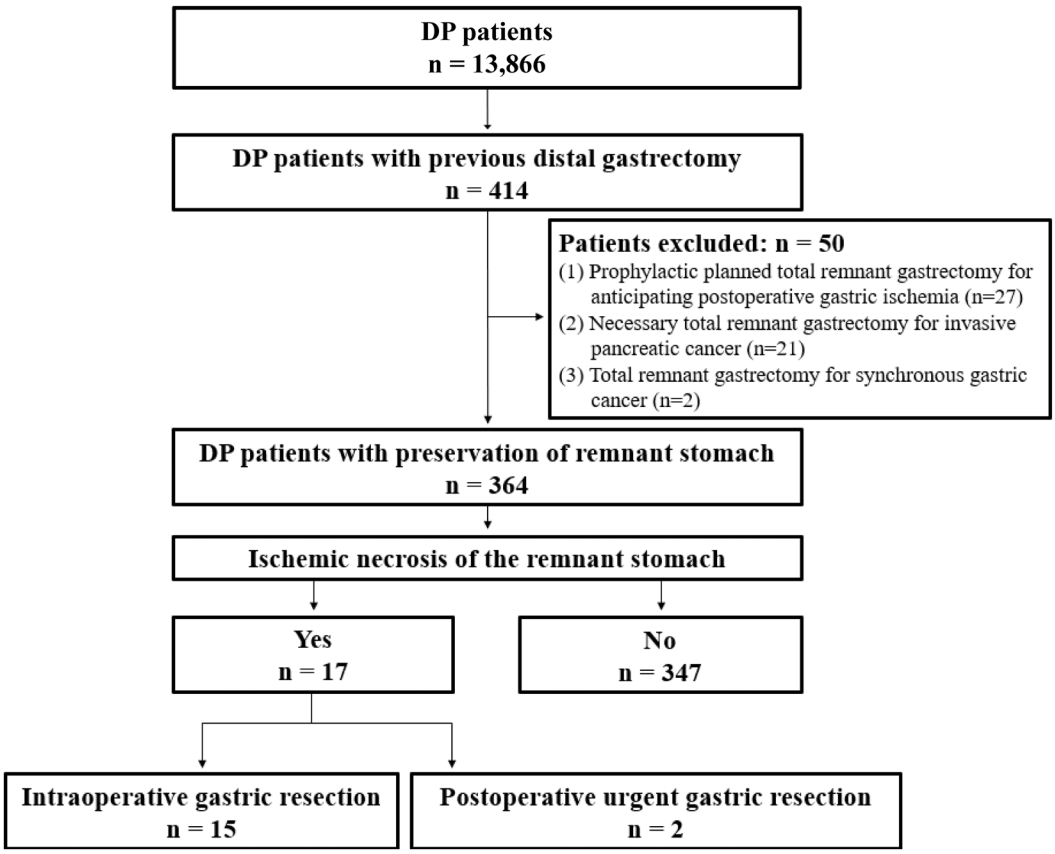

FIGURE 1 | Patient participant CONSORT diagram.

TABLE 1 | Preoperative characteristics of 364 eligible patients and univariate risk analyses for ischemic necrosis of the remnant stomach during or after distal pancreatectomy.

Variables	Ishemic necrosis of the remnant stomach (INS) after DP		*p*
	Yes ($n=17$)	No ($n=347$)	
Age, year, median (min–max)	70.0 (51–86)	73.0 (38–90)	0.575
≥65, *n* (%)	15 (88.2)	288 (83)	
<65, *n* (%)	2 (11.8)	59 (17)	
Gender, male, *n* (%)	13 (76.4)	260 (74.9)	0.886
Body mass index, kg/m^2, median (min–max)	19.5 (11.4–25.2)	19.9 (14.0–30.7)	0.648
≥18.0, *n* (%)	12 (70.6)	263 (75.8)	
<18.0, *n* (%)	5 (29.4)	84 (24.2)	
Hemoglobin, g/dL, median (min–max)	12.5 (9.4–15.0)	12.4 (7.9–14.2)	0.774
≥9.0, *n* (%)	0	17 (100)	
<9.0, *n* (%)	17 (100)	0	
Platelet, $10^3/\mu L$, median (min–max)	18.4 (8.9–36.7)	19.9 (12.4–65.8)	0.768
≥10.0, *n* (%)	16 (94.1)	344 (96.3)	
<10.0, *n* (%)	1 (5.9)	13 (3.7)	
Albumin, g/dL, median (min–max)	4.2 (3.1–4.9)	4.0 (2.2–5.0)	0.418
≥3.5, *n* (%)	0	338 (97.4)	
<3.5, *n* (%)	17 (100)	9 (2.6)	
Hemoglobine A1c, %, median (min–max)	6.8 (5.3–10.0)	6.3 (4.5–13.3)	0.167
≥7.0, *n* (%)	7 (43.8)	78 (27.5)	
<7.0, *n* (%)	9 (56.3)	206 (72.5)	
Nutrition indices, median (min–max)			
PNI	48.3 (34.5–57.7)	46.7 (25.8–62.4)	0.636
≥40, *n* (%)	14 (82.3)	280 (86.4)	
<40, *n* (%)	3 (17.7)	44 (13.6)	
COUNUT score	3.0 (1.0–8.0)	3.0 (1.0–12.0)	0.542
≥5.0, *n* (%)	2 (11.8)	57 (17.5)	
<5.0, *n* (%)	15 (88.2)	268 (82.5)	
Previous distal gastrectomy for gastric cancer, *n* (%)			
Yes	15 (88.2)	200 (57.7)	0.012
No	2 (11.8)	147 (42.3)	
Gastroduodenal ulcer	1 (5.9)	136 (39.2)	
Others	1 (5.9)	11 (3.2)	
Reconstruction methods after distal gastrectomy, *n* (%)			
Billroth-I	12 (70.5)	245 (70.6)	0.998
Billroth-II	3 (17.7)	65 (18.7)	0.911
Roux-en-Y	2 (11.8)	32 (9.3)	0.725
Others	0	5 (1.4)	0.618

(Continues)

TABLE 1 | (Continued)

Variables	Ishemic necrosis of the remnant stomach (INS) after DP		*p*
	Yes ($n=17$)	No ($n=347$)	
History of splenectomy, yes, *n* (%)	0	29 (8.3)	0.205
Anticoagulants, yes, *n* (%)	3 (17.6)	59 (17.0)	0.945
Interval after distal gastrectomy, month, median (min–max)	176 (10.2–516.0)	252 (1.0–870.0)	0.961
≥120, *n* (%)	12 (70.6)	243 (70.0)	
<120, *n* (%)	5 (29.4)	104 (30.0)	
Identification of blood vessels on preoperative CE-CT, *n* (%)			
Esophageal artery (descending branches)	7 (41.2)	181 (52.2)	0.376
Left gastric artery	1 (5.8)	102 (28.0)	0.067
Left gastroepiploic artery	6 (35.2)	144 (39.5)	0.167
Short gastric arteries	14 (82.3)	293 (80.5)	0.100
Posterior gastric artery	8 (47.1)	178 (48.9)	0.773
Left inferior phrenic artery	8 (47.1)	173 (47.5)	0.251
Pancreatic pathology indicated for DP, *n* (%)			
Pancreatic ductal adenocarcinoma	15 (88.2)	199 (57.4)	0.023
IPMN	2 (11.8)	97 (28.0)	0.161
NET	0	11 (3.1)	0.456
Others	0	40 (11.5)	0.137

Abbreviations: CE-CT, contrast-enhanced CT scan; CONUT, controlling nutritional status; DP, distal pancreatectomy; IPMN, intraductal papillary mucinous neoplasm; NET, neuroendocrine tumor; PNI, prognostic nutritional index.

groups. The identification of arterial blood vessels around the remnant stomach was confirmed in the descending branches of the esophageal artery, LGA, LGEA, SGA, PGA, and LIPA using contrast-enhanced CT, but it had no impact on the occurrence of INS. The reconstruction methods after DG, history of splenectomy, and medical history of anticoagulant use showed no marked differences between the INS and non-INS groups. The pancreatic disorders indicated for current DP were pancreatic ductal adenocarcinoma (PDAC, $n=214$), intraductal papillary mucinous neoplasm (IPMN, $n=99$), neuroendocrine tumor (NET, $n=11$), and others ($n=40$). DP was indicated for PDAC in 15 (88.2%) patients in the INS group and 199 (57.4%) patients in the non-INS group, respectively, and the incidence of PDAC was significantly higher in the INS group than in the non-INS group ($p=0.023$).

A multivariable logistic regression analysis of two factors univariately associated with INS identified current DP for PDAC (OR 6.19, 95% CI 1.38–27.7, $p=0.017$) and previous DG for gastric cancer (OR 6.12, 95% CI 1.37–27.4, $p=0.017$) as independent predictors of INS after DP (Table 2).

3.3 | Intraoperative Risk Factors for INS

The intraoperative parameters during DP and univariate risk analyses for INS are summarized in Table 3. Conventional DP with splenectomy, SVPDP, and Warshow's technique were performed in 310, 45, and 9 patients, respectively. The surgical procedure had no notable impact on INS occurrence. The operative time was 468 (197–675) min in the INS group and 275 (89–795) min in the non-INS group, with the time being significantly longer in the INS group than in the non-INS group ($p<0.001$). The estimated blood loss was 840 (80–8483) mL and 305 (0–4398) mL in the INS and non-INS groups, respectively, being significantly higher in the INS group than in the non-INS group ($p<0.001$). The SGA, PGA, and LGEA were dissected in many patients during DP, and dissection of these arteries had no marked impact on INS. Dissection of the LIPA significantly affected the occurrence of INS ($p<0.001$). Combined resection of the surrounding organs, such as partial gastrectomy and adrenalectomy along with DP, did not influence INS, but partial colectomy ($p=0.016$) and celiac axis resection ($p=0.004$) showed a significant impact on INS occurrence. An objective evaluation of the gastric blood flow during DP with various measuring devices was performed in 80 (22.0%) patients, including ICG fluorescence angiography in 59, color Doppler ultrasonography in 26, regional oxygen saturation in 26, contrast-enhanced ultrasonography in 15, and others in 21. One patient (5.9%) in the INS group and 17 (4.9%) in the non-INS group had gastric ischemia. However, there was no notable relationship between a decreased gastric blood flow on objective assessment tools and INS occurrence ($p=0.855$).

TABLE 2 | A multivariate logistic regression analysis of preoperative risk factors for ischemic necrosis of the remnant stomach during or after distal pancreatectomy.

Variables	Odds ratio	95% CI	*p* value
Distal pancreatectomy for PDAC	6.19	1.38–27.7	0.017
Previous distal gastrectomy for gastric cancer, yes	6.12	1.37–27.4	0.017

Abbreviations: CI, confidence interval; PDAC, pancreatic ductal adenocarcinoma.

TABLE 3 | Intraoperative parameters during distal pancreatectomy and univariate risk analyses for ischemic necrosis of the remnant stomach during or after distal pancreatectomy.

	Ishemic necrosis of the remnant stomach (INS) after DP		
Variables	**Yes (*n* = 17)**	**No (*n* = 347)**	***p***
Types of pancreatic resection, *n* (%)			
DP	17 (100)	293 (84.4)	0.078
SVPDP	0	45 (13.0)	0.113
Warshow's technique	0	9 (2.6)	0.501
Operative time, min, median (min–max)	468 (197–675)	275 (89–795)	< 0.001
≥ 480, *n* (%)	7 (41.2)	20 (5.8)	
< 480, *n* (%)	10 (58.8)	327 (94.2)	
Blood loss, mL, median (min–max)	840 (80–8483)	305 (0–4398)	< 0.001
≥ 750, *n* (%)	10 (58.8)	70 (20.2)	
< 750, *n* (%)	7 (41.2)	277 (79.8)	
Dissected blood vessels, *n* (%)			
Left gastric artery	2 (11.8)	13 (3.8)	0.151
Left gastroepiploic artery	7 (41.2)	173 (51.6)	0.399
Short gastric arteries	12 (70.6)	270 (79.0)	0.413
Posterior gastric artery	8 (50)	173 (52)	0.761
Left inferior phrenic artery	11 (64)	8 (2.3)	< 0.001
Combined resection of surrounding organs, *n* (%)			
Partial gastrectomy	1 (5.8)	30 (8.6)	0.692
Adrenal gland	1 (5.9)	26 (7.5)	0.805
Colon	6 (6.6)	23 (6.6)	0.016
Celiac axis	2 (11.8)	3 (0.9)	0.004
Common hepatic artery	1 (5.9)	3 (0.9)	0.095
Objective evaluation of gastric blood flow, *n* (%)	2 (11.6)	78 (22.5)	0.298
ICG fluorescence angiography	2 (11.6)	57 (16.4)	0.611
Color doppler ultrasonography	0	26 (7.5)	0.241
Regional oxygen saturation	0	26 (7.5)	0.242
Sonazoid-enhanced ultrasonography	0	15 (4.3)	0.381
Others	0	21 (6.0)	0.296
Gastric ischemia judged by blood flow assessment tools, *n* (%)	1 (5.9)	17 (4.9)	0.855

Abbreviations: DP, distal pancreatectomy; ICG, indocyanine green; SVPDP, splenic vessel-preserving distal pancreatectomy.

A multivariable logistic regression analysis of the five intraoperative factors univariately associated with INS identified dissection of the LIPA (OR 51.9, 95% CI 13.1–205, $p < 0.001$) as the only independent risk factor for INS (Table 4).

No INS-related in-hospital deaths occurred in this study. In the non-INS group, however, two patients (0.5%) died after DP due to postoperative pancreatic fistula (grade C) in one patient and multiple organ failure in the other.

4 | Discussion

The number of cases of neoplastic tumor of the pancreas, such as PDAC and IPMN, is increasing worldwide [9, 10]. In addition, patients with a history of DG are predisposed to develop pancreatic cancer, along with a prolonged interval after DG [11–13]. As well as a recent improvement in the survival after DG for both benign and malignant gastric diseases, the number of patients with pancreatic cancer after receiving DG has increased [6, 11]. Although the incidence of patients undergoing DP after DG was reported to be 4.0% in a series of 226 DP patients [4], the actual frequency is unclear, as such clinical situations are unusual, and there have been no studies with a sufficient number of patients. The present study, comprising 13 866 DP patients, revealed that the incidence of patients requiring DP after receiving DG was 3.0%.

When performing DP for pancreatic tumors located in the body or tail of the pancreas, especially for PDAC, lymph node dissection around the pancreas and spleen accompanied by splenectomy is essential, involving dissection of the SGA, PGA, and SPA. As the main source of arterial blood supply to the remnant stomach after DG relies on branches from the SPA, the remnant stomach after DG faces a high risk of gastric ischemia during or after DP. Therefore, most gastrointestinal surgeons are concerned about whether the remnant stomach after DG should be removed or if it can be preserved when performing DP. Based on these concerns, 27 (6.5%) of the 414 enrolled patients in this study received prophylactic scheduled total remnant gastrectomy during DP to anticipate postoperative gastric ischemia.

Some authors have claimed that the remnant stomach could be safely preserved when performing DP for patients who had previously undergone DG [4, 6, 7, 14–17]. In the present study, however, 17 (4.7%) of the 364 eligible patients developed INS, including 15 requiring total remnant gastrectomy and 2 undergoing partial gastrectomy during or after DP. Multivariable logistic regression analyses showed that previous DG for gastric cancer (OR 6.12), current DP for PDAC (OR 6.19), and dissection of the LIPA during DP (OR 51.9) were independent risk factors for INS.

TABLE 4 | A multivariate logistic regression analysis of intraoperative risk factors for ischemic necrosis of the remnant stomach during or after distal pancreatectomy.

Variables	Odds ratio	95% CI	*p*
Dissection of the left inferior phrenic artery	51.9	13.1–205	< 0.001
Operative time ≥ 480 min	3.11	0.59–16.1	0.177
Resection of the colon	2.78	0.44–17.3	0.271
Blood loss ≥ 750 mL	1.96	0.45–8.45	0.366
Resection of the celiac axis	1.41	0.12–16.7	0.784

Abbreviation: CI, confidence interval.

The upper part of the stomach is mainly supplied by the LGA, which has abundant connections with SGAs [18–20]. In addition, the collateral blood supply from the LIPA and the descending branches of the esophageal artery also offers a gastric vascular network through the esophagogastric junction [4, 7, 18–20]. Because the remnant stomach after DG relies on its blood supply mainly from the SGA, collateral blood flow from the LIPA or the esophageal artery becomes more critical when performing DP after DG. An increased incidence of necrosis and perforation of the proximal gastric remnants following radical subtotal gastrectomy has been reported in an experimental animal model if the inferior phrenic arteries are cut [21]. The present study showed that preservation of the LIPA plays an essential role in securing a sufficient blood supply to the remnant stomach when performing a DP in patients with a history of DG, as dissection of the LIPA during DP was an independent risk factor for INS. Although Takahashi et al. [7] mentioned that concomitant partial resection of the remnant stomach involves the risk of severe gastric ischemia, partial gastrectomy during DP had no influence on INS occurrence in our study.

In this study, a history of DG for gastric cancer and current DP for PDAC were independent risk factors for INS. DG for malignant gastric disorders involves the thorough dissection of perigastric tissues, including lymph nodes and blood vessels, which may result in a greater reduction of blood flow to the remnant stomach than DG for benign gastric diseases. The same was true for DP in PDAC patients. The LGA is one of the most important vessels that supply the upper part of the stomach and is usually preserved during DG for benign gastric disorders, whereas it is definitely separated in the DG for gastric cancer with the aim of lymph node dissection. Although it remains unclear whether LGA or LIPA has a greater impact on the occurrence of INS after DP in patients with a history of DG, patients with dissection of the LGA in a previous DG would be more susceptible to INS when the LIPA is separated in a current DP. In addition, the LIPA originates from the aorta or celiac artery [22–24], and the LIPA in the latter may be more susceptible than that in the former to damage during DP, especially for PDAC, resulting in remnant gastric ischemia. Although SVPDP and Warshow's technique can preserve SGA and perisplenic blood vessels [25, 26], these procedures were not indicated for PDAC in this study.

Gastroenterological surgeons may expect that the long interval between DG and DP decreases the risk of ischemic complications of the remnant stomach. Takahashi et al. [7] suggested that long periods after a DG may provide an enriched intramural network of the mucosal and submucosal plexuses and stabilize the blood supply to the remnant stomach, leading to a successful DP without ischemia of the remnant stomach in DG patients. However, the interval, that is, a cutoff value of 120 months on a receiver operating characteristic (ROC) curve analysis, did not affect the occurrence of INS in this study. This was the same even when the cutoff value was set at 60, 80, 100, or 240 months (data not shown).

An intraoperative quantitative assessment of gastric blood flow is expected to predict ischemic complications in the remnant stomach [27–29]. In the present study, various assessment tools, such as ICG fluorescence angiography and color Doppler ultrasonography, were applied in 80 (22.0%) patients, and 1 patient in the INS group and 17 patients in the non-INS group were assessed as having gastric ischemia. However, these assessments had no impact on INS occurrence. In the INS group, two patients underwent ICG fluorescence angiography during DP; one patient showed an ischemic change of the gastric wall on both the macroscopic and ICG fluorescence examinations and then promptly underwent remnant gastrectomy, while the other showed sufficient gastric blood flow on both evaluations and developed INS after DP. Gastric blood flow assessment during surgery is currently in the trial stage, and no definitive criteria for determining the need for additional gastric resection have been established. Indeed, the results of the objective evaluation of gastric blood flow were not used as a basis for deciding the indication for gastrectomy, and the utility of blood flow assessment was undetermined in this study.

The sample size of this study, consisting of 364 patients, was much larger than that of previous studies [4, 6, 7, 14–17, 26, 28–29]. However, the present study has some potential limitations. First, it was a retrospective study based on questionnaires from the committee members of the JSPS. This could have resulted in missing data or inevitable bias in the analysis. Second [27], patients who underwent prophylactic planned total remnant gastrectomy were excluded from the analysis, which may have led to an incorrect incidence of ischemic complications of the remnant stomach after DP in patients with a history of DG. Third, we were unable to identify the utility of the quantitative assessment of gastric blood flow during DP to predict the occurrence of INS. Further investigation is required.

In conclusion, DP following DG has a potential risk of serious ischemic complications of the remnant stomach, and the LIPA should be preserved during DP to avoid INS. In addition, more careful surgical management is required in performing DP, especially in patients undergoing DP for PDAC and patients who have undergone DG for gastric cancer because they are candidates for INS after DP. Therefore, the development of more reliable intraoperative quantitative assessment tools for gastric blood flow is required.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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Appendix A

Participating Institutions

Department of Surgery, Graduate School of Biomedical and Health Science, Hiroshima University; Department of Surgery, Nara Medical University; Department of Hepato-Biliary-Pancreatic Surgery, Osaka Metropolitan University Graduate School of Medicine; Department of Surgery, Oita Red Cross Hospital; Department of Surgery, Division of Hepato-Biliary-Pancreatic Surgery, Kobe University Graduate School of Medicine; Department of Surgery, Graduate School of Medicine, Tohoku University; Department of Surgery and Oncology, Graduate School of Medical Sciences, Kyushu University; Department of Surgery, Institute of Gastroenterology Tokyo Women's Medical University; Department of Gastroenterological Surgery, Okayama University Graduate School of Medicine; Department of Hepatobiliary Pancreatic Surgery, Chiba Cancer Center; Department of Surgery, Kochi Health Sciences Center; Department of Surgery, Kansai Medical University; Department of Surgery, Kinki University Faculty of Medicine; Department of Gastroenterological Surgery, Graduate School of Medicine Sciences, Kumamoto University; Department of Hepato-Biliary-Pancreatic Surgery, Dokkyo Medical University; Department of Gastroenterological Surgery, Hyogo College of Medicine; Department of Gastroenterological Surgery, Nippon Medical School; Department of surgery, Kobe City Medical Center General Hospital; Department of Hepato-Biliary-Pancreatic surgery, Kyoto First Red Cross Hospital; Department of Gastroenterological, Breast and Endocrine Surgery, Yamaguchi University Graduate School of Medicine; Department of Surgery, Nagasaki University Graduate School of Biomedical Sciences; Department of Surgery, Kitakyusyu Municipal Medical Center; Department of Surgery, Fukuyama City Hospital; Department of Surgery, Surgical Oncology and Science, Sapporo Medical University; Department of Gastroenterological Surgery, Yokohama City University; Department of General Surgery, Chiba University Graduate School of Medicine; Department of Surgery, Nagoya central Hospital; Department of Surgical Oncology, Gifu University School of Medicine; Department of Gastroenterological Surgery, Faculty of Medicine, Fukuoka University; Department of Gastroenterological Surgery, Osaka International Cancer Institute; Department of Surgery, Hachioji Digestive Disease Hospital; Department of Hepato-Biliary-Pancreatic Surgery, Tokyo Medical and Dental University; Department of Hepatobiliary and Pancreatic Surgery, National Cancer Center Hospital East; Department of Surgery, Division of Surgical Oncology, Tottori University Faculty of Medicine; Department of Gastrointestinal and General Surgery, St. Marianna University School of Medicine; Department of Hepato-Biliary-Pancreatic Surgery, Osaka City General Hospital; Department of Gastrointestinal and Hepatobiliary–Pancreatic Surgery, Faculty of Medicine, University of Tsukuba; Department of Surgery, Kure Medical Center and Chugoku Cancer Center; First Department of Surgery, Faculty of Medicine, University of Fukui; Department of Gastroenterological Surgery, Takamatsu Red Cross Hospital; Second Department of Surgery, Wakayama Medical University; Division of Digestive Surgery, Department of Surgery, Kyoto Prefectural University of Medicine; Department of Gastroenterological Surgery, Aichi Cancer Center Hospital; Department of Hepato-Biliary Pancreatic Surgery and Transplantation, Kyoto University Hospital; Department of Gastroenterological Surgery, Hirosaki University Graduate School of Medicine; Department of Surgery, Yamagata University Graduate School of Medical Science; Department of Surgery, Funabashi Municipal Medical Center; Gastroenterological Surgery and Oncology, Tazuke Kofukai Medical Research Institute, Kitano Hospital; Department of Surgery, Yamagata Prefectural Central Hospital; Department of Hepatobiliary Pancreatic and Transplant Surgery, Mie University Graduate School of Medicine; Department of Gastroenterological Surgery II, Hokkaido University Faculty of Medicine, Department of Gastroenterological Surgery, Nagoya City University Graduate School of Medical Sciences; Department of Surgery, Sapporo Kosei General Hospital; Department of Digestive Surgery, Kawasaki Medical School; Department of General Surgery, Kurashiki Central Hospital; Department of Surgery, The Jikei University School of Medicine; Department of Surgery, National Defense Medical College; Department of Gastroenterological Surgery, Kagawa University Hospital; Division of Surgical Oncology, Department of Surgery, Nagoya University Graduate School of Medicine; Department of Surgery, Saitama Medical Center, Jichi Medical University; Department of Surgery, National Hospital Organization Nagasaki Medical Center; Department of Surgery, Kimitsu Chuo Hospital; Department of Surgery, Osaka Saiseikai Nakatsu Hospital; Department of Hepato-Biliary-Pancreatic Surgery, Kyorin University Hospital; Department of Digestive Surgery, Saku Central Hospital; Department of Surgery, Fujita

Health University; Second Department of Surgery, Hamamatsu University School of Medicine; Division of Digestive Surgery, Ehime Prefectural Central Hospital; Department of Surgery, Nakagami Hospital; Department of Surgery, Ibaraki Prefectural Central Hospital and Cancer Center; Department of Gastrointestinal Surgery Tenri Hospital; Department of Surgical Oncology and Regulation of Organ Function, Miyazaki University School of Medicine; Department of Surgery, Tochigi Cancer Center; Department of Surgery, Nippon Medical School, Chiba Hokusoh Hospital; Department of Gastroenterological Surgery, Fujita Health University Bantane Hospital; Division of Gastroenterology and Hepatology, Toho University Omori Medical Center; Department of Gastrointestinal Surgery, Sasebo City General Hospital; Department of Gastroenterological Surgery, Ibaraki Medical Center, Tokyo Medical University; Department of Surgery Saiseikai Utsunomiya Hospital; Department of Surgery, School of Medicine, Kitasato University; Department of Hepato-Biliary-Pancreatic Surgery and Pediatric Surgery, Saitama Medical Center, Saitama Medical University; Department of Surgery, Tokyo Dental College, Ichikawa General Hospital; Department of Surgery, Fussa hospital; Department of Gastrointestinal Surgery, Konan Medical Center; Department of Surgery, Saiseikai Toyama Hospital; Department of Surgery and Science, Graduate School of Medicine and Pharmaceutical Sciences, University of Toyama; Department of Surgery, Kyouaikai Tobata Kyouritsu Hospital; Department of Surgery, Obihiro Kosei Hospital; Department of surgery、Saga university Faculty of Medicine; Department of Surgery, Meiwa Hospital; Department of Gastrointestinal and Breast Surgery, National Hospital Organization Disaster Medical Center; Department of Surgery, Toho University Ohashi Medical Center; Department of Surgery, Shiga University of Medical Science; Department of Surgery, Matsusaka Central General Hospital; Department of Hepato-Biliary-Pancreatic Surgery, Tokyo Medical and Dental University; Department of Surgery, National Hospital Organization Nagoya Medical Center; Division of Gastroenterological, Hepato-Biliary-Pancreatic, Transplantation and Pediatric Surgery, Department of Surgery, Shinshu University School of Medicine; Department of Surgery, Kawasaki Municipal Hospital; Department of Surgery, Niigata Prefectural Center Hospital; Department of Surgery, Osaka Rosai Hospital; Department of Surgery, Teikyo University Chiba Medical Center; Department of Gastroenterology, Hokkaido Gastroenterology Hospital; Department of Surgical Oncology, Kagoshima University Graduate School; Department of Surgery, Kurume University School of Medicine; Department of Surgery, Saitama City Hospital; Department of Digestive Surgery, Saitama Medical University International Medical Center; Department of Gastroenterological Surgery, Aichi Medical University; Department of Surgery, Maeda hospital; Department of Surgery, Matsusaka City Hospital; Department of Surgery, Sakai City Hospital.