A Blumgart-Anastomosis Based Half-Invagination Pancreaticoenterostomy With Better Applicability to Laparoscopy and Lower Incidence of Pancreatic Leakage

Qiang Sun

Zhongshan People's Hospital

Peng Peng

Zhongshan People's Hospital

Xueyi Gong

Zhongshan People's Hospital

Jianlong Wu

Zhongshan People's Hospital

Qiao Zhang

Zhongshan People's Hospital

Zhipeng Hu

Zhongshan People's Hospital

Xiaojian Chang

Zhongshan People's Hospital

Zemin Hu (✉ zmhu-zhongshan@outlook.com)

Zhongshan People's Hospital

Research Article

Keywords: Laparoscopy, pancreatoduodenectomy, pancreatojejunostomy, pancreatic leakage, half-invagination

Posted Date: October 13th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-952241/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Background The Blumgart anastomosis has been established as one of the safest anastomoses for pancreas remnant reconstruction, with low rates of postoperative pancreatic fistula (POPF) and postoperative complications. However, how to make laparoscopic pancreaticoenterostomy easier and safer is still a subject to be discussed.

Methods Data of patients undergoing laparoscopic pancreaticoduodenectomy from April 2014 to December 2019 were retrospectively analyzed.

Results 20 cases of half-invagination anastomosis (Group HI) and 26 cases of Cattell-warren anastomosis (Group CW) were included. Intraoperative blood loss, Operative time and Postoperative drainage tube placement time of Group HI was significantly less than those of Group CW. Patients of Clavien-Dindo grade III and above in Group HI was significantly less than Control Group. Group Incidence of POPF in Group HI was significantly lower than that in Group CW. No high-risk group emerged during Fistula risk score analytical phase, and the highest risk of moderate-risk group was pancreatic leakage. Respectively, incidence of pancreatic leakage in Group HI and Group CW was 7.7% and 46.67%, while incidence of Group HI was significantly lower than that in the Group CW.

Conclusions The Blumgart-anastomosis based half-invagination pancreaticoenterostomy with better applicability to laparoscopy can effectively reduce the incidence of postoperative pancreatic leakage.

Introduction

Since the first complete laparoscopic pancreaticoduodenectomy (LPD) was reported by Gagnery et al. in 1994, its development was rapid especially in the past 10 years and had become a regular operation in many large-scale pancreatic centers¹. LPD had obvious advantages in hospital stay and intraoperative blood loss, and its short-term or long-term effects were similar or even better than open pancreaticoduodenectomy (OPD)²⁻⁶. However, there were still a few reports against and skeptical of LPD^{7,8}, this may be relevant to LPD being one of the most complex laparoscopic surgeries and having higher technical requirements on surgeons and a longer learning curve⁹. As with laparotomy, quality of pancreaticointestinal anastomosis is still a key factor in determining postoperative complications and mortality. There were many methods of pancreaticointestinal anastomosis: pancreatic duct to mucous membrane anastomosis, end-to-side anastomosis, strapping pancreaticointestinal anastomosis, interlacing anastomosis, pancreaticogastric anastomosis, etc. However, there was still no universally accepted method could minimize the incidence of pancreatic leakage¹⁰. In 2000, Professor L.H. Blumgart introduced a method of pancreaticointestinal anastomosis with u-shaped suture, which could significantly reduce the occurrence of postoperative pancreatic leakage and was called “Blumgart” anastomosis¹¹. In 2009, Kleespies and Grobmyer reported the detailed methods and effects of this method^{12,13}. Since then, many authors have also reported numerous improved methods. “Blumgart”

anastomosis with a 2.5-20.5% incidence of pancreatic leak was lower than Cattell-warren anastomosis, Kakita anastomosis and pancreatogastric anastomosis¹⁴⁻²².

Despite the rapid development of laparoscopic instruments and surgical techniques, it remained unknown whether laparoscopy can be successfully applied to laparoscopy due to the different operational characteristics of laparoscopy and laparotomy²³. How to make laparoscopic pancreaticointestinal anastomosis easier and safer, which was conducive to the wider and more standardized implementation of LPD, was still a subject to be discussed²³. Present laparoscopic pancreaticoenterostomy mainly adopted pancreatic duct to mucous membrane anastomosis and end-to-side anastomosis, most of which were the same as the laparotomy²³. In addition, some surgeons had improved the characteristics of laparoscopy and achieved promising results²⁴⁻²⁷.

Traditional or modified Blumgart anastomosis was one of pancreatic duct to mucous membrane anastomosis, which was mainly used for laparotomy, while laparoscopic surgery is rarely used^{28,29}. This study reported a Blumgart pancreaticointestinal anastomosis which was improved by laparoscopic characteristics and compared it with laparoscopic cattell-warren pancreaticointestinal anastomosis for the first time.

Results

In this study, 20 patients in Group HI and 26 patients in Group CW were included, with a total of 46 patients. The clinical and statistical characteristics of the two groups were shown in Table 1. The preoperative clinical and statistical characteristics of the two groups showed no significant difference except in diagnosis. The number of cases of periampullary carcinoma in Group CW seemed to be higher. Intraoperative bleeding (107.00 ± 101.42 VS 107.00 ± 101.42 , $P=0.024$) and operative time (352.5 ± 99.55 VS 426.5 ± 106.47 , $P=0.020$) were significantly lower in Group HI than that in Group CW. Pancreatic texture seen intraoperatively had no significant difference between the two groups. Postoperative drainage tube placement time in Group HI was significantly shorter than that in Group CW (11.55 ± 2.98 VS 15.85 ± 6.77 $P=0.011$). Pancreatic duct diameter in Group HI was significantly lower than that in Group CW (2.96 ± 1.40 VS 4.15 ± 1.64 $P=0.0145$), and the number of pancreatic duct diameter ≤ 3 mm in Group HI was significantly higher than that in Group CW (15 VS 11 $P=0.038$). There was no significant difference in postoperative hospital stay between the two groups.

Table 1
Patient characteristics

	HI group	CW group	P
N	20	26	
Age (years)	58.00±11.32	58.19±10.83	0.954
Sex ratio (M: F)	12:8	11:15	0.373
ASA score	2.35±0.49	2.42±0.50	0.624
Cardiopulmonary disease	5 (25%)	7 (26.9%)	1.000
Diabetes	4 (20%)	4 (15.4%)	1.000
BMI	21.42±3.11	22.38±2.97	0.300
Diagnosis			0.049
Pancreatic cancer	5	5	
Ampullary cancer	3	14	
Bile duct cancer	6	4	
other	6	3	
Preoperative biliary drainage	2	3	1.000
Estimated blood loss (ml)	107.00±101.42	197±147.20	0.024
Transfusion	0	15.38±54.35	0.213
Duration of operation (min)	352.5±99.55	426.5±106.47	0.020
Portal vein resection	1	0	0.435
Duration of PJ drainage tube placement	11.55±2.98	15.85±6.77	0.011
Soft/firm pancreas	11/9	11/15	0.552
Pancreatic duct diameter (mm)	2.96±1.40	4.15±1.64	0.0145
≤ 3 mm (n)	15	11	0.038
Postoperative hospital stays	19.3±11.97	20.96±9.33	0.599
ASA: American society of anesthesiologists.			

Postoperative complications were shown in Table 2. The incidence of postoperative complications in the two groups was similar, but the incidence of patients with Clavien Dindo grade III or above in Group HI was significantly lower than that in the Control group (2 vs 10 P = 0.043). The incidence of POPF in Group HI was 5%, while that in Group CW was 34.6%, which was significantly higher than that in HI group (P=0.028). On the third day after surgery, amylase in the drainage solution was significantly lower in

Group HI than that in Group CW (752.06 ± 1108.63 VS 2641.25 ± 3064.22 , $P=0.020$). One case died in each group. Patient of Group HI died from an unrelated postoperative complication of pulmonary embolism and Group CW died from abdominal bleeding, abdominal infection and multiple organ failure caused leakage. The incidence of pancreatic leakage was found to be different at different stratification levels according to Fistula risk score analysis. Due to the bleeding was significantly reduced after laparoscopic surgery, there were no high-risk patients in this study, and the highest risk of moderate-risk group was pancreatic leakage. Respectively, incidence of pancreatic leakage in the Group HI and Group CW was 1/13(7.7%) and 7/15 46.67%, and incidence of Group HI was significantly lower than that in the Group CW ($P=0.038$).

Table 2
Postoperative complications

	HI group	CW group	P
Total complications (n, %)	10 (50%)	16 (61.5%)	0.111
Clavien I-II	8	6	0.333
Clavien III-IV	1	9	0.028
Clavien V	1	1	1.000
Clavien $\geq$ III	2	10	0.043
Surgery complication			
POPF (B+C)	1 (5%)	9 (34.6%)	0.028
Grade B	1	4	0.369
Grade C	0	5	0.070
Drain AMY level (POD3)	752.06 $\pm$ 1108.63	2641.25 $\pm$ 3064.22	0.020
Biliary leakage	0	0	
Post-pancreaticoduodenectomy hemorrhage (B+C)	0	5	0.059
Delayed gastric emptying (B+C)	3	0	0.075
Acute pancreatitis	1	2	1.000
Intra-abdominal infection	3	10	0.106
Wound infection	0	1	1.000
Reoperation	0	5	0.059
Non-surgical complications			
Respiratory events	1	4	0.369
Cardiac events	0	0	
MODS	1	1	1.000
Mortality 90 Days	1	1	1.000
Fistula risk score (POPF, %)			0.702
Negligible risk (0)	2 (0)	5 (0)	

POPF: postoperative pancreatic fistula; MODS: multiple organ dysfunction syndrome.

	HI group	CW group	P
Low risk (1-2)	5 (0)	6 (2, 33.33%)	0.467
Intermediate risk (3-6)	13 (1, 7.7%)	15 (7, 46.67%)	0.038
High risk (7-10)	0	0	
POPF: postoperative pancreatic fistula; MODS: multiple organ dysfunction syndrome.			

Discussion

In an open surgical environment, the clinical evidence suggested that there were no superior surgical options for reconstruction of the remnant pancreas following PD. It may depend on the surgeons' expertise, experience, the texture of the pancreas, and the patient's condition ^{23,30,31}. To our knowledge, when pancreatic bowel anastomosis, we should pay attention to the following four points: pancreatic juice should be completely drained, blood flow should be maintained in the pancreatic stump, laceration of pancreatic parenchyma should be prevented, and the jejunum wall should be in close contact to the pancreatic cut surface ³². To meet the operation characteristics of laparoscopic Pancreaticenterostomy, the following points should be considered in addition to the above points: (1) Was it simple? (2) Was it technically easy and feasible? (3) Was it secure and safe? (4) Was there any supporting scientific evidence ²³?

In this study, the HI group had more cases with thinner pancreatic duct and diameter ≤ 3 mm, which may be related to the different diagnosis of the two groups. Studies have shown that pancreatic duct diameter ≤ 3 mm is an independent risk factor for pancreatic leakage ³³. Even so, the incidence of pancreatic leakage in Group HI was lower than that in Group CW, and postoperative drainage tube placement time was shorter. There was no significant difference in postoperative hospital stay between the two groups, which may be related to delayed gastric emptying in 3 patients in Group HI, which significantly prolonged the postoperative hospital stay. Callery et al. proposed a Fistula risk score including four factors: Pancreatic texture, diagnosis, pancreatic duct diameter and intraoperative bleeding through analysis ^{34,35}. Based on this, we analyzed the factors of pancreatic leakage analysis, same as above research, it was found that the higher the score, the higher the risk of pancreatic leakage. The highest risk of moderate-risk group was pancreatic leakage, and incidence of Group HI was significantly lower than that in the Group CW. It was worth mentioning that FRS is a risk assessment method for pancreatic leakage based on the analysis of laparotomy, one of which is intraoperative hemorrhage. Previous studies had shown that laparoscopic surgery can significantly reduce intraoperative blood loss, so we believed that FRS did not fully reflect the characteristics of laparoscopic surgery, and adjustments may be necessary.

The methods used in this study had previously been reported by laparotomy ¹⁸. According to the characteristics of laparoscopy, we improved this method and considered it was more suitable for laparoscopy.

Methods of hemostasis in open and laparoscopic pancreas sections were different. During the laparotomy, the small blood vessels and pancreatic ducts can be dissected and ligated carefully, but under laparoscopy, ultrasonic scalpel and electrocoagulation are generally adopted, which was easy to cause bleeding due to eschar detachment or trace pancreatic leakage after operation. U-shaped suture was beneficial to the hemostasis of the pancreatic stump and the reduction of the pancreatic leakage of the small pancreatic duct. Therefore, the Blumgart method based on U-shaped suture should be recommended under laparoscopy. The traditional Blumgart method needs to do 4-6 "U" sutures¹³, too many sutures are not conducive to laparoscopic operation. Compared with the traditional Blumgart method, this method can reduce the number of stitches of "U" suture, facilitated the laparoscopic suture, and reduced the bleeding of the pancreatic stump while preserving the blood supply of the pancreatic stump as much as possible. Scissors were often used to cut off the main pancreatic duct, and blood vessels often existed near the main pancreatic duct. Therefore, the second U-shaped suture was beneficial to reduce the hemorrhage of the pancreatic section and the effusion between the jejunum and the pancreatic section^{32,36}.

In order to make jejunum cover the pancreatic stump better, this method optimized the "U" suture method of the upper and lower margins of the pancreas, so that jejunum can better fit into the pancreatic stump (as shown in the figure). In this study, all cases were placed with pancreatic duct stents, which were not described in the traditional Blugmart method¹². Although there was no definite evidence that stents can reduce pancreatic leakage³⁷, the placement of stent after suturing the posterior wall of pancreatic duct is convenient for anterior wall suturing. In addition, we still believe that the second "U" suture combined with the pancreatic stent tube can reduce the chance of pancreatic fluid leaking through pancreatic duct to mucous membrane anastomosis site.

In this method, all the knots were on the surface of jejunum serous membrane, and the pancreas parenchyma was unknotted, which could bear greater tension, as the pancreas parenchyma had no cutting force, which could reduce the tissue cutting as much as possible even if there was postoperative anastomotic edema. Although laparoscopic suture tension is more difficult to grasp than that of laparotomy, the suture method above can reduce the difficulty of laparoscopic suture, shorten the learning curve, and improve the safety of pancreaticointestinal anastomosis. When the pancreatic duct is located in the posterior margin of the pancreas and anastomotic with Kakita and CW method, the needle eye of the posterior wall of the pancreatic duct to jejunum anastomosis is not easily covered by the jejunum, leading to pancreatic leakage. In this method, all the needles of pancreatic parenchyma were covered by jejunum, reducing the occurrence of such pancreatic leakage. Kim et al. reported the shortcomings of the modified Blumgart method for the first time²¹. They believed that when the jejunum tube diameter was small and the relative pancreatic stump was enlarged or thicker, jejunum insertion was likely to be incomplete, resulting in shear force paralleled to the long axis of the pancreas, leading to the tear of the pancreaticojejunal anastomosis. Our experience in practical application was consistent. Therefore, we believed that the suture of sarcoplasmic layer along the long axis of jejunum^{12,16,18} made jejunum more easily inserted into the pancreatic stump than along the short axis of jejunum^{13,15,32}, and

the stress range was larger, and it was more difficult to cut, especially in cases with thick pancreatic stump or thin jejunum²¹.

Currently, laparoscopic Blumgart pancreaticoenterostomy was rare^{28,29}. Poves et al. first reported the modified Blumgart pancreaticoenterostomy under laparoscopy. In addition, the modified laparotomy Blumgart pancreaticoenterostomy was used to perform paired comparison. In the laparoscopic group, the incidence of postoperative Clavien class III or higher complications and hospital stay were reduced. In implementing this approach, an additional 5-mm trocar was inserted in the epigastrium, just in front of the planned PJ. Through this trocar, the 2-needle polypropylene 2-0 MH 36 mm 1/2 c 90 cm transpancreatic stitches were externalized²⁸. The pancreatic stump was mobilized at least 3 cm from the section margin of the pancreas. The method of this study can shorten the length of suture and facilitated laparoscopic operation. The first suture was fixed by vascular clamp, and the jejunum was close to the pancreatic stump, so that the pancreatic duct to mucous membrane anastomosis could be completed without tension. At the same time, it avoided the need to pull the suture out of the body through another troca, which is convenient for operation.

Peng's banding pancreaticoenterostomy inserted the pancreatic stump into the jejunum, sewed the pancreatic stump and jejunum without penetrating the jejuno-plasmic muscle layer^{38,39}. After the pancreatic stump was inserted into the jejunum cavity, it was bound around the jejunum and the pancreas, and both were tied together to avoid pinholes on the surface of the pancreas, thus significantly reducing the incidence of pancreatic leakage. The essence of Peng's binding pancreaticoenterostomy was a nested method. By banding, the pancreas showed that there is no residual pinhole, thereby reducing pancreatic leakage. In the study by Maggiori et al., a conventional PJ and banding technique had a similar fistula rate, but healing of the fistula took longer in patients with PJ carried out using Peng's technique compared to conventional PJ (29 vs. 9 days)⁴⁰. Incidence of hemorrhage was also higher in the binding technique (6/22 vs. 0/25). The method used in this study, through U-shaped suture and jejunum half invagination, not only achieved the goal of hemostasis to reduce the bleeding of anastomotic mouth, but also achieved the goal of half invagination into the stump of pancreas and jejunum on the needle hole of the pancreas surface, so we called it half-invagination pancreatic duct to mucous membrane anastomosis.

However, it had also been reported that the incidence of pancreatic leakage by using the modified Blumgart method is similar to that by Cattell Warren method and Kakita method^{41,42}. Kawakatsu et al. reported the application in soft pancreas⁴¹. The incidence of pancreatic leakage was 42.7% in the above method and 42.6% in the Kakita method, showing no statistical difference. Lee et al. compared Blumgart method with Cattell Warren method, and the incidence of pancreatic leakage was 13.7% versus 2.3%, $P = 0.110$, respectively⁴². There was no statistical difference, which may need more case verification. Recently, Hirono et al. reported a prospective randomized controlled study for improving Blumgart and Kakita methods³². The incidence of pancreatic leakage in the two groups was 10.3% and 6.8%, respectively. The two groups also had similar complication rates.

The limitations of this study were as follows: this study was a retrospective study with a small number of cases, and the cases in the CW group were completed by two groups of doctors, which may lead to bias in case selection and surgical skills. Nevertheless, we compared the effects of two laparoscopic pancreaticojejunostomy methods for the first time. Moreover, randomized controlled trials should be needed to assess the true value of the laparoscopic approach in PD.

In conclusion, method proposed in this study can effectively reduce the incidence of postoperative pancreatic leakage and serious complications, and is a more convenient, easier, and safer half-invagination pancreatic duct to mucous membrane anastomosis, which is more suitable for laparoscopy.

Materials And Methods

Patients

We reviewed 46 cases of patients who underwent laparoscopic pancreaticoduodenectomy in our hospital from April 2014 to December 2019. All cases were performed by two groups of doctors, one of whom was treated with the modified Blumgart half-invagination anastomosis (Group HI) since May 2017, with a total of 20 patients, and the other 26 with cattell-warren anastomosis (Group CW). Informed consent was obtained from all individual participants included in the study. All procedures in the study were performed at Zhongshan Hospital Affiliated to Sun Yat-Sen University with the approval of the Ethics Committee. All the methods were performed in accordance with all relevant guidelines and regulations.

Surgical procedure

LPD is performed with the patient in supine, with the legs apart and in a slight anti-Trendelenburg position. A holder of the mirror stands between the legs, with an operator and a helper on either side of the patient. A total of 5 trocars were placed. Three trocars of 12mm were located about 5cm below the umbilicus and on the left and right sides of the umbilicus, respectively. Two 5mm trocars were located in the left and right epigastrium. Excepted for 2 cases performed by Olympus 3D laparoscopy, all the other cases were accomplished by 30° 2D laparoscopy.

In all cases, partial distal gastric resection was performed without pyloric reservation. Patients with malignant tumors underwent lymph node dissection, including ligaments of duodenum, perihepatic common artery, peripancreatic head, celiac trunk, and left superior mesenteric artery lymph nodes. Concomitant portal vein and/or superior mesenteric vein (PV/SMV) resection is performed in patients with possible or definite tumor invasion. The reconstruction process adopted the "CHILD" method. The upper jejunum segment was lifted through the mesenteric root to the subhepatic portion. In the first step, pancreaticoenterostomy was performed about 5cm from the jejunum rupture end, and in the second step, choledochojejunostomy was performed about 5-15cm from the pancreaticoenterostomy site. When the diameter of the bile duct was ≥ 1.0 cm, 4-0 v-loc was used for bile duct jejunum end-to-end anastomosis; when the diameter of the bile duct was less than 1.0 cm, 4-0 single buckwheat suture was used for intermittent suture and placed internal stents. Finally, the gastrojejunal side to side anastomosis was

performed before the colon. A drainage tube was placed in front of and behind the pancreaticoenterostomy site.

Cattell-Warren pancreaticoenterostomy

The dorsal and jejuno-plasmic muscle layer of the pancreatic stump were sutured with 3-0 prolene suture. A small incision was made at the corresponding jejunum to mesentery for the pancreatic duct to mucous membrane anastomosis. The pancreatic duct was anastomosed was performed by continuous suture using 5-0 prolene suture after placement of a suitable sten. If the diameter of the pancreatic duct ≤ 3 mm, intermittent suture was performed. Finally, the same method was used to complete the anastomosis between the ventral side of the pancreatic stump and jejunum seromuscular layer.

Half-invagination pancreaticoenterostomy

U-shaped suture was performed with 3-0 or 4-0 Prolene according to the thickness of pancreatic stump. Cut the double needle prolene into 15cm and tie the tail knot for standby (3 pieces in total). Step 1: suture A: After suturing the sarcoplasmic muscle layer from top to bottom parallel to the long axis of jejunum, about 1 cm from pancreatic stump, the needle was inserted from paries posterior, and the pancreas parenchyma was full thickness sutured. The other needle was sutured perpendicular to the long axis of jejunum to the sarcoplasmic muscularis, also about 1 cm away from the pancreatic stump, and the full-thickness of the pancreas parenchyma was sutured at the upper edge of the pancreas (Figure 1-a&b). Tightened the suture to make pancreatic stump close to jejunum and fixed the suture with vascular clamp (the suture is not knotted), to facilitate the anastomosis of pancreatic duct to mucosa without tension (Figure 1-c&d). Step 2: suture B: Two needles were parallel to the long axis of jejunum to suture jejunum sarcoplasmic layer, and then were inserted from the head side and tail side of pancreatic duct through paries posterior about 1 cm from the pancreatic stump. The pancreatic parenchyma was sutured in full-thickness without knots (Figure 1-c&d). Step 3 Continuous suture using 5-0 proline was performed of pancreatic duct to the mucosa anastomosis after appropriate pancreatic duct stent tubes were placed. The diameter of the pancreatic duct ≤ 3 mm, then intermittent suture was performed. Step 4: Used suture C to suture symmetrically with the first suture. Henceforth, the jejunum was inserted into the back of the pancreatic stump (Figure 1-e&f). Step 5: From the tail to the head, C, B and A sutures were sequentially (Figure 1-g&h) used to suture the endoplasmic muscle layer in a symmetrical manner with the dorsal side of the pancreatic stump. The suture position is about 1-1.5cm away from the jejunum corresponding to the pancreatic stump, and knot separately (Figure 1-i&j) to complete the insertion of the ventral side of the pancreatic stump (Figure 1-k&l).

Perioperative management and definitions of postoperative complication

If the total bilirubin of patients was > 300 mmol/L before operation, PTCD should be performed for two weeks to reduce jaundice or the total bilirubin reduced to < 51 mmol/L before operation. On the third day after operation, nasogastric tube was removed when flow of nasogastric tube was less than 200 ml/D. On the third day after operation, the drainage fluid from the abdominal drainage tube was collected and

amylase concentration was detected. The drainage tube was removed after the drainage volume was less than 20 ml. On the 5th day after operation, conventional CT scan of the upper abdomen was performed to understand the abscess and effusion in the abdominal cavity. On the third day after operation, patients began to eat liquid food. All patients were treated with somatostatin analogues.

For the definition of postoperative complications (POPF, delayed gastric emptying, postpancreatectomy haemorrhage), the ISGPF classification was applied⁴³⁻⁴⁵, considering POPF grades B and C as clinically relevant. Postoperative bleeding was defined as a postpancreatectomy haemorrhage grade B or C, according to the International Study Group of Pancreatic Surgery⁴⁵. Acute pancreatitis was defined chemically as a raised serum amylase and/or lipase level (at least three-fold above the normal level) for at least 3 consecutive days after postoperative day 3. Acute pancreatitis was confirmed by computed tomography (CT). For the grading postoperative complications, the Clavien-Dindo classification was used⁴⁶. The Fistula Risk Score is a ten-point scale that relies on weighted influence of four variables including gland texture, pathology, pancreatic duct diameter, and intraoperative blood loss^{34,35}. The weighted aggregate of these risk factors was used to calculate individual FRS scores (0-10) for each patient.

Statistical analysis

Continuous data are presented as median $\pm$ SD and were analyzed by means of the Student t test. Categorical variables were compared using Chi square test and Fisher's exact test. All P values were considered statistically significant at 0.05 or less. All statistical analyses were performed using SPSS statistical analysis software package v. 19 (IBM SPSS Statistics, USA).

Declarations

Competing interests

The authors declare no competing interests.

Author contributions

Qiang Sun, Peng Peng and Xueyi Gong identified the problem and organized the paper. Jianlong Wu and Qiao Zhang analyzed the data of patients and wrote the main manuscript text. All data are verified by Zhipeng Hu, Xiaojian Chang and Zemin Hu and given comments for further improvements. All authors reviewed the manuscript.

References

1. Gagner, M. & Pomp, A. Laparoscopic pylorus-preserving pancreatoduodenectomy. *Surgical endoscopy*, **8**, 408–410 <https://doi.org/10.1007/bf00642443> (1994).
2. Liu, M. *et al.* Laparoscopic pancreaticoduodenectomy: are the best times coming? *World journal of surgical oncology*, **17**, <https://doi.org/10.1186/s12957-019-1624-6> (2019).

3. Torphy, R. J. *et al.* Comparing Short-term and Oncologic Outcomes of Minimally Invasive Versus Open Pancreaticoduodenectomy Across Low and High Volume Centers. *Annals of surgery*, **270**, 1147–1155 <https://doi.org/10.1097/SLA.0000000000002810> (2019).
4. Sharpe, S. M. *et al.* Early National Experience with Laparoscopic Pancreaticoduodenectomy for Ductal Adenocarcinoma: A Comparison of Laparoscopic Pancreaticoduodenectomy and Open Pancreaticoduodenectomy from the National Cancer Data Base. *Journal of the American College of Surgeons*, **221**, 175–184 <https://doi.org/10.1016/j.jamcollsurg.2015.04.021> (2015).
5. Chen, K., Liu, X. L., Pan, Y., Maher, H. & Wang, X. F. Expanding laparoscopic pancreaticoduodenectomy to pancreatic-head and periampullary malignancy: major findings based on systematic review and meta-analysis. *BMC gastroenterology*, **18**, 102 <https://doi.org/10.1186/s12876-018-0830-y> (2018).
6. Palanivelu, C. *et al.* Randomized clinical trial of laparoscopic versus open pancreatoduodenectomy for periampullary tumours. *The British journal of surgery*, **104**, 1443–1450 <https://doi.org/10.1002/bjs.10662> (2017).
7. van Hilst, J. *et al.* Laparoscopic versus open pancreatoduodenectomy for pancreatic or periampullary tumours (LEOPARD-2): a multicentre, patient-blinded, randomised controlled phase 2/3 trial. *The lancet. Gastroenterology & hepatology*, **4**, 199–207 [https://doi.org/10.1016/S2468-1253\(19\)30004-4](https://doi.org/10.1016/S2468-1253(19)30004-4) (2019).
8. Adam, M. A. *et al.* Minimally Invasive Versus Open Pancreaticoduodenectomy for Cancer: Practice Patterns and Short-term Outcomes Among 7061 Patients. *Annals of surgery*, **262**, 372–377 <https://doi.org/10.1097/SLA.0000000000001055> (2015).
9. Wang, M. *et al.* Practice Patterns and Perioperative Outcomes of Laparoscopic Pancreaticoduodenectomy in China: A Retrospective Multicenter Analysis of 1029 Patients. *Annals of surgery*, <https://doi.org/10.1097/SLA.00000000000003190> (2019).
10. Wang, W. *et al.* The optimal choice for pancreatic anastomosis after pancreaticoduodenectomy: A network meta-analysis of randomized control trials. *International journal of surgery*, **57**, 111–116 <https://doi.org/10.1016/j.ijssu.2018.04.005> (2018).
11. Michael, B. Surgery of the Liver and Biliary Tract. *Mayo Clinic Proceedings* **64**, 270-271.
12. Kleespies, A. *et al.* Blumgart anastomosis for pancreaticojejunostomy minimizes severe complications after pancreatic head resection. *The British journal of surgery*, **96**, 741–750 <https://doi.org/10.1002/bjs.6634> (2009).
13. Grobmyer, S. R., Kooby, D., Blumgart, L. H. & Hochwald, S. N. Novel pancreaticojejunostomy with a low rate of anastomotic failure-related complications. *Journal of the American College of Surgeons*, **210**, 54–59 <https://doi.org/10.1016/j.jamcollsurg.2009.09.020> (2010).
14. Mishra, P. K., Saluja, S. S., Gupta, M., Rajalingam, R. & Pattnaik, P. Blumgart's technique of pancreaticojejunostomy: an appraisal. *Digestive surgery*, **28**, 281–287 <https://doi.org/10.1159/000329584> (2011).

15. Neychev, V. K. & Saldinger, P. F. Minimizing shear and compressive stress during pancreaticojejunostomy: rationale of a new technical modification. *JAMA surgery*, **149**, 203–207 <https://doi.org/10.1001/jamasurg.2013.2256> (2014).
16. Fujii, T. *et al.* Modified Blumgart anastomosis for pancreaticojejunostomy: technical improvement in matched historical control study. *Journal of gastrointestinal surgery: official journal of the Society for Surgery of the Alimentary Tract*, **18**, 1108–1115 <https://doi.org/10.1007/s11605-014-2523-3> (2014).
17. Kim, D. J., Paik, K. Y., Kim, W. & Kim, E. K. The effect of modified pancreaticojejunostomy for reducing the pancreatic fistula after pancreaticoduodenectomy. *Hepato-gastroenterology*, **61**, 1421–1425 (2014).
18. Oda, T. *et al.* The Tight Adaptation at Pancreatic Anastomosis Without Parenchymal Laceration: An Institutional Experience in Introducing and Modifying the New Procedure. *World journal of surgery*, **39**, 2014–2022 <https://doi.org/10.1007/s00268-015-3075-8> (2015).
19. Wang, S. E., Chen, S. C., Shyr, B. U. & Shyr, Y. M. Comparison of Modified Blumgart pancreaticojejunostomy and pancreaticogastrostomy after pancreaticoduodenectomy. *HPB: the official journal of the International Hepato Pancreato Biliary Association*, **18**, 229–235 <https://doi.org/10.1016/j.hpb.2015.09.007> (2016).
20. Li, Y. T. *et al.* Effect of Blumgart anastomosis in reducing the incidence rate of pancreatic fistula after pancreatoduodenectomy. *World journal of gastroenterology*, **25**, 2514–2523 <https://doi.org/10.3748/wjg.v25.i20.2514> (2019).
21. Oh, J. S. The Vulnerable Point of Modified Blumgart Pancreaticojejunostomy Regarding Pancreatic Fistula Learned from 50 Consecutive Pancreaticoduodenectomy. *Ann Transl Med* (2018).
22. Kojima, T., Niguma, T., Watanabe, N., Sakata, T. & Mimura, T. Modified Blumgart anastomosis with the "complete packing method" reduces the incidence of pancreatic fistula and complications after resection of the head of the pancreas. *American journal of surgery*, **216**, 941–948 <https://doi.org/10.1016/j.amjsurg.2018.03.024> (2018).
23. Kang, C. M., Lee, S. H., Chung, M. J., Hwang, H. K. & Lee, W. J. Laparoscopic pancreatic reconstruction technique following laparoscopic pancreaticoduodenectomy. *Journal of hepato-biliary-pancreatic sciences*, **22**, 202–210 <https://doi.org/10.1002/jhbp.193> (2015).
24. Cai, Y., Luo, H., Li, Y., Gao, P. & Peng, B. A novel technique of pancreaticojejunostomy for laparoscopic pancreaticoduodenectomy. *Surgical endoscopy*, **33**, 1572–1577 <https://doi.org/10.1007/s00464-018-6446-z> (2019).
25. Wang, M., Xu, S., Zhang, H., Peng, S. & Qin, R. Imbedding pancreaticojejunostomy used in pure laparoscopic pancreaticoduodenectomy for nondilated pancreatic duct. *Surgical endoscopy*, **31**, e433–e433 (2017).
26. Edil, B. H., Cooper, M. A. & Makary, M. A. Laparoscopic pancreaticojejunostomy using a barbed suture: a novel technique. *Journal of laparoendoscopic & advanced surgical techniques. Part A*, **24**, 887–891 <https://doi.org/10.1089/lap.2014.0053> (2014).

27. Cho, A. *et al.* Performing simple and safe dunking pancreaticojejunostomy using mattress sutures in pure laparoscopic pancreaticoduodenectomy. *Surgical endoscopy*, **28**, 315–318 <https://doi.org/10.1007/s00464-013-3156-4> (2014).
28. Poves, I., Morato, O., Burdio, F. & Grande, L. Laparoscopic-adapted Blumgart pancreaticojejunostomy in laparoscopic pancreaticoduodenectomy. *Surgical endoscopy*, **31**, 2837–2845 <https://doi.org/10.1007/s00464-016-5294-y> (2017).
29. De Pastena, M. *et al.* Laparoscopic Pancreatoduodenectomy With Modified Blumgart Pancreaticojejunostomy. *Journal of visualized experiments: JoVE*, <https://doi.org/10.3791/56819> (2018).
30. Kilambi, R. & Singh, A. N. Duct-to-mucosa versus dunking techniques of pancreaticojejunostomy after pancreaticoduodenectomy: Do we need more trials? A systematic review and meta-analysis with trial sequential analysis. *Journal of surgical oncology*, **117**, 928–939 <https://doi.org/10.1002/jso.24986> (2018).
31. Kennedy, E. P. & Yeo, C. J. Dunking pancreaticojejunostomy versus duct-to-mucosa anastomosis. *Journal of hepato-biliary-pancreatic sciences*, **18**, 769–774 <https://doi.org/10.1007/s00534-011-0429-y> (2011).
32. Hirono, S. *et al.* Modified Blumgart Mattress Suture Versus Conventional Interrupted Suture in Pancreaticojejunostomy During Pancreaticoduodenectomy: Randomized Controlled Trial. *Annals of surgery*, **269**, 243–251 <https://doi.org/10.1097/SLA.0000000000002802> (2019).
33. Xingjun, G. *et al.* A score model based on pancreatic steatosis and fibrosis and pancreatic duct diameter to predict postoperative pancreatic fistula after Pancreatoduodenectomy. *BMC surgery*, **19**, 75 <https://doi.org/10.1186/s12893-019-0534-4> (2019).
34. Callery, M. P., Pratt, W. B., Kent, T. S., Chaikof, E. L. & Vollmer, C. M. Jr. A prospectively validated clinical risk score accurately predicts pancreatic fistula after pancreatoduodenectomy. *Journal of the American College of Surgeons*, **216**, 1–14 <https://doi.org/10.1016/j.jamcollsurg.2012.09.002> (2013).
35. Miller, B. C. *et al.* A multi-institutional external validation of the fistula risk score for pancreatoduodenectomy. *Journal of gastrointestinal surgery: official journal of the Society for Surgery of the Alimentary Tract* **18**, 172-179; discussion 179-180, doi:10.1007/s11605-013-2337-8 (2014).
36. Satoi, S. *et al.* Does modified Blumgart anastomosis without intra-pancreatic ductal stenting reduce post-operative pancreatic fistula after pancreaticojejunostomy? *Asian journal of surgery*, **42**, 343–349 <https://doi.org/10.1016/j.asjsur.2018.06.008> (2019).
37. Dong, Z., Xu, J., Wang, Z. & Petrov, M. S. Stents for the prevention of pancreatic fistula following pancreaticoduodenectomy. *The Cochrane database of systematic reviews*, **CD008914**, <https://doi.org/10.1002/14651858.CD008914.pub3> (2016).
38. Peng, S. Y. *et al.* Binding pancreaticojejunostomy: 150 consecutive cases without leakage. *Journal of gastrointestinal surgery: official journal of the Society for Surgery of the Alimentary Tract*, **7**, 898–900 <https://doi.org/10.1007/s11605-003-0036-6> (2003).

39. Peng, S., Mou, Y., Cai, X. & Peng, C. Binding pancreaticojejunostomy is a new technique to minimize leakage. *American journal of surgery*, **183**, 283–285 [https://doi.org/10.1016/s0002-9610\(02\)00792-4](https://doi.org/10.1016/s0002-9610(02)00792-4) (2002).
40. Maggiori, L. *et al.* Binding versus conventional pancreaticojejunostomy after pancreaticoduodenectomy: a case-matched study. *Journal of gastrointestinal surgery: official journal of the Society for Surgery of the Alimentary Tract*, **14**, 1395–1400 <https://doi.org/10.1007/s11605-010-1212-0> (2010).
41. Kawakatsu, S. *et al.* Comparison of pancreatojejunostomy techniques in patients with a soft pancreas: Kakita anastomosis and Blumgart anastomosis. *BMC surgery*, **18**, 88 <https://doi.org/10.1186/s12893-018-0420-5> (2018).
42. Lee, Y. N. & Kim, W. Y. Comparison of Blumgart versus conventional duct-to-mucosa anastomosis for pancreaticojejunostomy after pancreaticoduodenectomy. *Annals of hepato-biliary-pancreatic surgery*, **22**, 253–260 <https://doi.org/10.14701/ahbps.2018.22.3.253> (2018).
43. Bassi, C. *et al.* The 2016 update of the International Study Group (ISGPS) definition and grading of postoperative pancreatic fistula: 11 Years After. *Surgery*, **161**, 584–591 <https://doi.org/10.1016/j.surg.2016.11.014> (2017).
44. Wente, M. N. *et al.* Delayed gastric emptying (DGE) after pancreatic surgery: a suggested definition by the International Study Group of Pancreatic Surgery (ISGPS). *Surgery*, **142**, 761–768 <https://doi.org/10.1016/j.surg.2007.05.005> (2007).
45. Wente, M. N. *et al.* Postpancreatectomy hemorrhage (PPH): an International Study Group of Pancreatic Surgery (ISGPS) definition. *Surgery*, **142**, 20–25 <https://doi.org/10.1016/j.surg.2007.02.001> (2007).
46. Dindo, D., Demartines, N. & Clavien, P. A. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Annals of surgery*, **240**, 205–213 <https://doi.org/10.1097/01.sla.0000133083.54934.ae> (2004).

Figures

Figure 1

Half-invagination pancreaticoenterostomy. (a&b) Suture A: The two needles were sutured perpendicular to the long axis of jejunum to the sarcoplasmic muscularis, about 1 cm away from the pancreatic stump, and the full-thickness of the pancreas parenchyma. (c&d) Fixed the suture A with vascular clamp (the suture is not knotted), so as to facilitate the anastomosis of pancreatic duct to mucosa without tension; suture B: Two needles were parallel to the long axis of jejunum to suture jejunum sarcoplasmic layer, and

then were inserted from the head side and tail side of pancreatic duct through paries posterior about 1 cm from the pancreatic stump. The pancreatic parenchyma was sutured in full-thickness without knots. (e&f) Pancreatic duct to the mucosa anastomosis was performed after appropriate pancreatic duct stent tubes were placed. Used suture C to suture symmetrically with the suture A. (g&h) From the tail to the head, C, B and A sutures were sequentially used to suture the jejuno-plasmic muscle layer in a symmetrical manner with the dorsal side of the pancreatic stump and knot separately. (i&j) Completed the insertion of the ventral side of the pancreatic stump. (k) Side view post suture. (l) Dorsal side of the pancreaticointestinal anastomosis, the jejunal serosal layer was inserted into the pancreatic stump.