Risk factors for postoperative outcomes in laparoscopic pancreaticoduodenectomy: a retrospective cohort study from 2015 to 2023

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Background: Laparoscopic pancreaticoduodenectomy (LPD) is being increasingly performed for pancreatic tumors, offering advantages such as reduced recovery time and trauma. However, currently there is a knowledge gap in risk factors of postoperative complications, intensive care unit (ICU) admission, and prolonged hospital stays. Identifying for these outcomes is essential for improving patient management and surgical results. This retrospective cohort study aimed to explore the important risk factors for postoperative outcomes in LPD.

Methods: This retrospective cohort study included 199 patients who underwent LPD between 2015 and 2023 at a single center. Patients aged 18–85 years with pancreatic tumors were eligible, while those with distant metastases, American Society of Anesthesiologists (ASA) scores >3, or participation in other trials within 6 months prior to the current study were excluded. Data were collected on demographics, preoperative comorbidities, intraoperative variables (e.g., blood loss, transfusion, and revascularization), and postoperative outcomes, including complications, ICU admission, and length of hospital stay. The primary outcomes were postoperative complications and ICU admission, while the secondary outcomes were those factors influencing hospital stay duration. Postoperative complications, such as pancreatic fistula, biliary fistula, abdominal infection, and lung infection were documented as yes or no based on the hospital medical record system or follow-up visits. Besides, pancreatic fistula was further labeled as Grade A, B or C according to the standard of International Study Group on Pancreatic Surgery (ISGPS). The time of measurement was 90 days.

Results: The cohort consisted of 101 males (50.8%) and 98 females (49.2%), with a mean age of 60.3 years [standard deviation (SD) 9.8]. Common complications included delayed gastric emptying (8.54%), biliary fistula (5.03%), and pancreatic fistula (4.52%). At total of 58 (29.15%) patients were admitted to the ICU admission, the median length of hospital stay after surgery is 15 days. Risk factors for complications and ICU admission included a lower preoperative bilirubin level, higher intraoperative blood loss, blood transfusion, revascularization, and chronic pancreatitis. Longer hospital stays were significantly correlated with intraoperative factors such as surgery duration blood transfusion volume, and blood loss (P<0.05).

Conclusions: This study identified several key factors associated with postoperative complications and ICU admission after LPD. Blood loss, blood transfusions, and revascularization were significant predictors of longer hospital stays. Our findings highlight the importance of managing intraoperative variables, and their clinical implications include reducing complications, improving recovery, and refining patient management strategies following LPD for pancreatic tumors.

Keywords: Pancreatic tumor; laparoscopic pancreaticoduodenectomy (LPD); postoperative complications; hospital stay; pancreaticoduodenectomy

Introduction

Study background

Pancreatic tumors are among the most malignant tumors (1,2). Pancreatic cancer (especially pancreatic ductal adenocarcinoma) is associated with the worst prognosis among all the common solid malignancies and is expected to surpass colorectal cancer (second only to lung cancer) as the leading cause of cancer-related death by 2040 (3-5). The preferred treatment option for pancreatic tumors, if conditions allow, is surgical resection. Due to

> **Highlight box**
>
> **Key findings**
> - Significant risk factors for postoperative complications and intensive care unit (ICU) admission after laparoscopic pancreaticoduodenectomy (LPD) included lower preoperative bilirubin level, higher intraoperative blood loss, blood transfusion, revascularization, and chronic pancreatitis.
> - The most common postoperative complications were delayed gastric emptying, biliary fistula, and pancreatic fistula.
> - Intraoperative factors such as surgery duration, blood loss, and transfusion volume were significantly associated with a longer hospital stay.
>
> **What is known and what is new?**
> - LPD is associated with lower morbidity and faster recovery compared to traditional open pancreaticoduodenectomy. However, postoperative complications and prolonged hospital stays remain significant concerns.
> - This study identified certain intraoperative and preoperative factors, including blood loss, transfusions, and revascularization, as key contributors to complications and longer hospital stays, offering new insights into the factors influencing outcomes in patients treated with LPD for pancreatic tumors.
>
> **What is the implication, and what should change now?**
> - Managing intraoperative factors, including minimizing blood loss and transfusion requirements, and optimizing surgical techniques to avoid revascularization may reduce the risk of complications and shorten the length of hospital stays.
> - Future studies should refine predictive models for ICU admission and complications, focusing on improving the accuracy of risk stratification tools. Additionally, surgical teams should prioritize strategies that minimize blood loss and prevent unnecessary transfusions during LPD to enhance patient recovery and reduce postoperative morbidity.

its complexity and involvement of multiple anastomoses, pancreaticoduodenectomy (PD) is a challenging form of abdominal surgery and the most difficult procedure for a single tumor among abdominal surgeries (6). Complications after PD pose grave concerns for clinicians and patients alike. At the early stage, abdominal bleeding and gastrointestinal bleeding are frequently observed, and if the bleeding is serious, patients require a second operation (7). In the early to midterm postoperative period, if the anastomosis is poorly performed, digestive fluids leaking into the abdominal cavity may cause corrosion of internal organs, infection, and even rupture of blood vessels, which necessitates reoperation for anastomosis and hemostasis. Pancreatic fistula and biliary fistula are two major types of post-PD leakage complication (8). At a later stage, patients may develop pancreatic dysfunction, diabetes, or dyspepsia due to insufficient pancreatic secretion. Given the various complications and poor outcomes associated with PD, the surgical approach has been improved in recent years. Laparoscopic pancreaticoduodenectomy (LPD) is a laparoscopic surgery for peripelvic tumors and pancreatic tumors. After being refined over the years, LPD can now provide the same postoperative antitumor effect as that of open surgery, with less intraoperative bleeding and better recovery (9). Indeed, it has also been confirmed that LPD is associated with a significant reduction in intraoperative bleeding compared with open PD (OPD) (10-13). Previous studies have tended to focus on the differences in postoperative outcomes between LPD and OPD (13-17). However, the current knowledge gaps are as follows. Within LPD, the preoperative and intraoperative factors that influence postoperative outcomes have not been extensively examined. LPD can still be improved considerably in terms of postoperative complications, reoperation, intensive care unit (ICU) admission, and length of postoperative hospital stay (18,19). Knowledge of how to predict the occurrence of these outcomes is still limited.

Study objective

In this study, we conducted a retrospective analysis of data from patients with pancreatic tumors who underwent LPD at a single center. Our aim was to identify the risk factors for postoperative complications, prolonged postoperative

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hospital stays, and admission to the ICU. Subsequently, we sought to construct prognostic models with satisfactory performance. Our findings included a number of correlations that have not been previously reported. We present this article in accordance with the STROBE reporting checklist (available at https://gs.amegroups.com/article/view/10.21037/gs-2025-63/rc).

Methods

Study design and participants

The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. The ethical approval of this study was obtained from The Second Hospital of Hebei Medical University (ethical approval number: 2025-R013) and informed consent was taken from all the patients.

This retrospective study included 199 patients newly diagnosed with pancreatic tumor who underwent LPD between 2015 and 2023. The inclusion criteria were as follows: (I) age between 18 and 85 years; (II) eligible for partial pancreatectomy via LPD; and (III) informed consent provided prior to surgery. Meanwhile, the exclusion criteria were as follows: (I) presence of distant metastasis; (II) ASA scores >3; and (III) participation in other clinical trials for pancreatic tumors within 6 months. All patients were diagnosed with pancreatic tumors through preoperative computed tomography (CT) imaging or histological analysis. Criteria for surgery were according to the National Comprehensive Cancer Network (NCCN) guidelines.

Variables

We documented baseline variables, intraoperative variables, and postoperative outcome variables. Baseline characteristics included age, gender, height, weight, chief complaints, clinical diagnosis, pre-existing comorbidities (such as hypertension, coronary heart disease, diabetes mellitus, chronic pancreatitis, and hepatitis), history of abdominal surgery, and whether patients received neoadjuvant chemotherapy. Intraoperative variables included surgical approach (pylorus-preserving or not), intraoperative bleeding volume, necessity of blood transfusion and its volume, operation duration, presence of pancreatic-jejunal or pancreatic-gastric anastomosis, biliary anastomosis, and revascularization (if applicable). Postoperative outcomes included complications, length of postoperative hospitalization, requirement for second operation, perioperative mortality, ICU admission, and ICU stay duration.

Data measurements

Data measurements were obtained through clinical records and laboratory data. Baseline clinical data, including age, gender, weight, preoperative comorbidities, and laboratory markers [e.g., total bilirubin, carbohydrate antigen 19-9 (CA19-9), and carbohydrate antigen 125 (CA125)], were extracted from electronic medical records. Intraoperative details, such as surgical time, bleeding volume, and transfusion volume were recorded from surgical records. Postoperative complications, such as pancreatic fistula, biliary fistula, abdominal infection, and lung infection were documented as yes or no based on the hospital medical record system or follow-up visits. Besides, pancreatic fistula was further labeled as Grade A, B or C according to the standard of International Study Group on Pancreatic Surgery (ISGPS). The time of measurement was 90 days. The length of postoperative hospitalization was calculated from the day of surgery to discharge, with a range from 6 to 87 days and the median is 15 days.

Bias

Selection bias could have arisen due to the single-center, retrospective nature of the study, which might have limited the generalizability of the findings to other populations. Information bias was also possible, as some variation in data recording and follow-up could exist due to differences in how the clinical data and outcomes were documented by different healthcare providers. Recall bias could have affected the self-reported information from patients, especially regarding prior treatments or comorbidities. To minimize these biases, objective clinical data from medical records and imaging were prioritized.

Study size

A total of 199 patients were included in the study. The sample size was based on available patient data from a single institution. Although the sample size was relatively small, it allowed for detailed data collection and provided comprehensive insights into the factors influencing postoperative outcomes.

Statistical methods

The SPSS (V25.0) software was used for statistical analysis. Firstly, descriptive statistics were used to summarize the categorical and continuous variables. Categorical variables,

Table 1 Basic categorical variables among all patients

Features	Frequency	Percent (%)
Gender		
Male	101	50.75
Female	98	49.25
Preoperative biliary drainage		
No	139	69.85
Yes	60	30.15
Biliary drainage method		
PTCD	48	80.00
ENBD	9	15.00
ENBD + PTCD	2	3.33
Cholecystocentesis	1	1.67
Comorbid diseases		
Yes	104	52.26
No	95	47.74
Hypertension		
No	112	56.28
Yes	87	43.72
Coronary heart disease		
No	183	91.96
Yes	16	8.04
Diabetes mellitus		
No	148	74.37
Yes	51	25.63
Chronic pancreatitis		
No	187	93.97
Yes	12	6.03
Hepatitis		
No	195	97.99
Yes	4	2.01
History of abdominal surgery		
No	171	85.93
Yes	28	14.07
Neoadjuvant chemotherapy		
No	195	97.99
Yes	4	2.01

The data in this table do not include censored data. ENBD, endoscopic nasobiliary drainage; PTCD, percutaneous transhepatic cholangial drainage.

such as gender, postoperative complications, and ICU admission, are presented as frequencies and percentages. Continuous variables, such as age, blood loss, and surgical duration, are presented as the mean and SD or as quartiles (the minimum, Q1, median, Q3, and the maximum) when the data distribution was skewed. To compare two groups, t-tests or Mann-Whitney tests were used for continuous variables, while Chi-squared tests were used for categorical data. A P value of less than 0.05 was considered statistically significant. Pearson correlation analysis was used to assess linear relationships between continuous variables. Logistic regression models were used to predict postoperative complications and ICU admission, but none of the models achieved satisfactory performance (accuracy ≥80% for both the actual negative and positive groups). For some dimensions, the total sample size was less than 199 due to missing (blank) data in the hospital records, we use multiple imputation method to process the missing data. Perform multiple imputation using the Mice package in R language, with a set number of 5 imputations. Use predictive mean matching (PMI) method for continuous variables and logistic regression (Logreg) method for categorical variables. After completion of interpolation, by drawing histograms and boxplots of key variables before and after interpolation, the distribution characteristics of the data can be visually compared to preliminarily evaluate that interpolation did not significantly change the data structure.

Results

Patient demographics and intraoperative data

A total of 199 patients were enrolled in this study, and the baseline clinical characteristics are summarized in *Tables 1,2*. All cases were pancreatic cancers/tumors, without biliary tumors. Of the 199 patients, 101 (50.75%) were male and 98 (49.25%) were female. The mean age of the cohort was 60.3 (SD 9.8) years. Prior to undergoing surgical intervention, 60 (30.15%) patients received biliary drainage.

Regarding comorbidities, 104 (52.26%) patients had at least one pre-existing condition, with the most common being hypertension (43.72%), diabetes mellitus (25.63%), coronary heart disease (8.04%), and hepatitis (2.01%). A history of abdominal surgery was reported by 28 patients (14.07%). Only 2.01% of patients received neoadjuvant chemotherapy before surgery. The median of carbohydrate antigen 19-9 (CA19-9) (IU/mL) is 149, with a first quartile (Q1) of 0.6 and a third quartile (Q3) of 492.8. The median of carbohydrate antigen 125 (CA125) (IU/mL) is 15.4, Q1

Table 2 Basic continuous variables among all patients (N=199)

Features	Mean	SD	Min	Q1	Median	Q3	Max
Age (years)	60.3	9.8	–	–	–	–	–
Height (m)	1.66	0.079	–	–	–	–	–
Weight (kg)	63.6	11.0	–	–	–	–	–
CA19-9 (IU/mL)	–	–	0.6	46.1	149	492.8	1,001.0
CA125 (IU/mL)	–	–	1.7	10.4	15.4	22.2	275.0
Bilirubin (µmol/L)	–	–	0	12.16	47.4	131.9	369.0

CA125, carbohydrate antigen 125; CA19-9, carbohydrate antigen 19-9; SD, standard deviation.

Table 3 Key factors during surgery

Features	Frequency	Percent (%)
Pylorus preservation		
No	192	96.48
Yes	7	3.52
Intraoperative change of surgical method		
No	187	93.97
Yes	12	6.03
Gastrointestinal anastomosis		
Child	191	95.98
Pancreatic-gastric	8	4.02
Stenting in pancreatic-enteric anastomosis		
Yes	160	80.40
No	39	19.60
Stenting in biliary anastomosis		
No	188	94.47
Yes	11	5.53
Revascularization		
No	171	85.93
Yes	28	14.07

The data in this table do not include censored data.

is 10.4, and Q3 is 22.2. The median preoperative bilirubin (µ mol/L) level was 47.4, Q1 was 12.16, and Q3 was 131.9.

The intraoperative data are presented in *Tables 3,4*. A total of 7 (3.52%) patients underwent LPD with pylorus preservation. Intraoperative conversion occurred in 12 (6.03%) patients. The majority of patients (95.98%) underwent the Child method for gastrointestinal anastomosis,

involving PD with pancreatic-jejunal anastomosis. Only eight patients underwent pancreatic-gastric anastomosis. Additionally, revascularization was performed in 28 (14.07%) patients.

The mean duration of the surgical procedure was 430.8 (SD 120.2) minutes. The median intraoperative blood loss was 500 mL (Q1 =200 mL, Q3 =850 mL). A total of 122 (61.3%) patients received an intraoperative blood transfusion, with a median transfusion volume of 400 mL (Q1 =0 mL, Q3 =600 mL).

Postoperative outcomes

The intraoperative conditions are presented in *Figure 1*, while the postoperative outcomes (30 days after operation) are summarized in *Tables 5,6*. The most common postoperative complications included pancreatic fistula (9/199, 4.52%), biliary fistula (10/199, 5.03%), delayed gastric emptying (17/199, 8.54%), gastrointestinal fistula (2/199, 1.01%), postoperative gastrointestinal bleeding (11/199, 5.53%), abdominal infection (9/199, 4.52%), and lung infection (5/199, 2.51%).

Among these complications, the most concerning postoperative outcomes in terms of frequency were pancreatic fistula, biliary fistula, delayed gastric emptying, and gastrointestinal bleeding. Importantly, no instances of postoperative incision infection, celiac fistula, anastomotic ulcer, intestinal obstruction, renal failure, liver failure, heart failure, myocardial ischemia, acute respiratory distress syndrome, or systemic inflammatory response syndrome, were reported.

Eleven (5.53%) patients required a second operation, and there were two perioperative deaths. During the postoperative period, 39 (19.60%) patients were admitted to the ICU, with a median stay of 0 day. The median tumor volume was 17.5 (Q1 =9, Q3 = 33.4) cm^3, and the median longest diameter of 3.5 (Q1 =3,

Table 4 Key surgical continuous variables and characteristics of the excised tumor (N=199)

Features	Mean	SD	Min	Q1	Median	Q3	Max
Duration of surgery (min)	430.8	120.2	–	–	–	–	–
Intraoperative bleeding (mL)	–	–	50	200	500	850	7,000
Total amount of blood transfusion (mL)	–	–	0	0	400	600	3,250

SD, standard deviation.
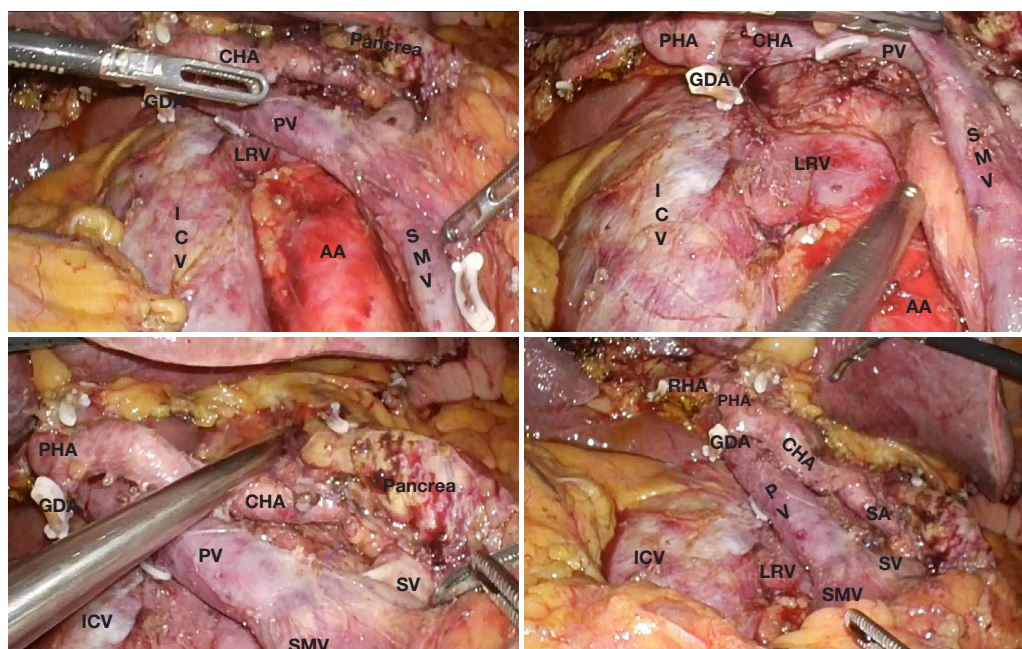
Figure 1 Intraoperative conditions of laparoscopic pancreaticoduodenectomy. AA, aorta abdominalis; CHA, common hepatic artery; GDA, gastroduodenal artery; ICV, inferior caval vein; LRV, left renal vein; PHA, proper hepatic artery; PV, portal vein; RHA, right hepatic artery; SA, splenic artery; SMV, superior mesenteric vein; SV, splenic vein.

Q3 =4) cm. The median length of hospitalization was 15 (Q1 =12, Q3 =21) days.

Risk factors for postoperative complications and ICU admission

First, we focused on preoperative and intraoperative risk factors that could potentially influence postoperative complications (*Table 7*). The analysis revealed that biliary fistula was associated with a lower preoperative bilirubin level (33.7 *vs.* 68.3 µmol/L). Similarly, patients who required a second operation also had lower preoperative bilirubin levels (33.5 *vs.* 68.8 µmol/L).

Additionally, intraoperative bleeding volume was positively correlated with ICU admission (1,000 *vs.* 400 mL). As anticipated, the ICU-admission group also received a significantly higher volume of blood transfusions (600 *vs.* 300 mL). A longer operation time was positively associated with ICU admission (504.71 *vs.* 412.78 minutes) but was negatively correlated with postoperative gastrointestinal bleeding (336.50 *vs.* 435.91 minutes).

Several key categorical variables were identified as being associated with postoperative complications or outcomes (*Table 8*). Intraoperative blood transfusion was found to be positively associated with abdominal infection (9/113 *vs.* 0/77). Furthermore, revascularization during surgery was correlated to a higher likelihood of abdominal infection (4/24 *vs.* 5/166). Notably, patients with chronic pancreatitis had a significantly higher incidence of postoperative ICU admission (6/7 *vs.* 33/153). Similarly, there were a greater

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Table 5 Postoperative categorical variables in all patients

Features	Frequency	Percent (%)
Pancreatic fistula		
No	190	95.48
A	2	1.01
B	2	1.01
C	5	2.51
Biliary fistula		
No	189	94.97
Yes	10	5.03
Gastric emptying obstruction		
No	182	91.46
Yes	17	8.54
Gastrointestinal fistula		
No	197	98.99
Yes	2	1.01
Postoperative gastrointestinal bleeding		
No	188	94.47
Yes	11	5.53
Abdominal infection		
No	190	95.48
Yes	9	4.52
Lung infection		
No	194	97.49
Yes	5	2.51
Second operation		
No	188	94.47
Yes	11	5.53
Perioperative death		
No	197	98.99
Yes	2	1.01
ICU admission		
No	160	80.40
Yes	39	19.60

ICU, intensive care unit.

proportion of ICU admissions in patients requiring revascularization (10/18 vs. 29/142).

Regarding the type of gastrointestinal anastomosis, patients who underwent the pancreatic-gastric anastomosis method had a higher incidence of delayed gastric emptying (3/4 vs. 14/178).

Finally, we employed various logistic regression models to predict ICU admission based on the available clinical and surgical factors. Unfortunately, none of the models achieved satisfactory performance, with accuracies below 80% for both the actual negative and positive groups. This suggests that other, yet unidentified factors may play a role in determining ICU admission, warranting further investigation into additional predictors beyond the currently available clinical and surgical data.

Factors associated with length of postoperative hospitalization

Among all continuous and categorical variables, we found that the length of postoperative hospitalization was closely associated with three intraoperative factors (*Table 9*): the duration of surgery (r=0.173; P=0.01), the volume of blood transfusion (r=0.175; P=0.01), and the intraoperative bleeding volume (r=0.148; P=0.04). However, no correlation was found between postoperative stay and other variables.

Discussion

The principal findings of this study are as follows. After LPD, patients with biliary fistula and a second operation had a lower level of preoperative bilirubin. Lung or abdominal infection was associated with a high level of intraoperative bleeding. The risk factors of ICU admission included intraoperative bleeding, amount of blood transfusion, duration of surgery, chronic pancreatitis history, and revascularization. Finally, the length of postoperative hospitalization was correlated with duration of surgery, amount of blood transfusion, and intraoperative bleeding.

In terms of postoperative complications, there is a consensus that LPD has fewer complications (such as lung infection, incision infection, and pancreatic fistula) as compared to OPD (20-22). In comparison with OPD, LPD involves less blood loss, faster recovery of gastrointestinal

Table 6 Postoperative continuous variables among all patients (N=199)

Features	Mean	SD	Min	Q1	Median	Q3	Max
Number of lymph nodes	11.4	6.8	–	–	–	–	–
Number of positive lymph nodes	–	–	0	0.0	0.0	1.0	18.0
Tumor long diameter (cm)	–	–	1	3	3.5	4	13.5
Tumor volume (cm^3)	–	–	0.21	9	17.5	33.4	405.0
ICU stay (days)	–	–	0	0	0	0	24
Postoperative hospital stays (days)	–	–	6	12	15	21	87

ICU, intensive care unit; SD, standard deviation.

Table 7 Key continuous variables associated with postoperative outcomes

Factors	Complication or outcome	N	Mean	SD	Min	Q1	Median	Q3	Max
Preoperative bilirubin (μmol/L)	Biliary fistula**	10	–	–	29.5	30.4	33.7	40.5	44.7
	No biliary fistula	189	–	–	0	13.1	68.3	136.0	369.0
Preoperative bilirubin (μmol/L)	Second operation**	11	–	–	27.6	28.9	33.5	44.5	53.9
	No second operation	188	–	–	0	13.0	68.8	136.2	369.0
Intraoperative bleeding (mL)	ICU admission**	39	–	–	100	400	1,000	1,750	7,000
	No ICU admission	160	–	–	50	200	400	800	5,000
Total amount of blood transfusion (mL)	ICU admission**	39	–	–	0	400	600	1,200	3,250
	No ICU admission	160	–	–	0	0	300	600	1,680
Duration of surgery (min)	ICU admission**	39	504.71	145.79	–	–	–	–	–
	No ICU admission	160	412.78	108.25	–	–	–	–	–
Duration of surgery (min)	Gastrointestinal bleeding*	10	336.50	117.758	–	–	–	–	–
	No bleeding	189	435.91	120.162	–	–	–	–	–

*, P<0.05; **, P<0.01. ICU, intensive care unit; SD, standard deviation.

function, and shorter recovery time. LPD has less bleeding compared with OPD; the small amount of bleeding under laparoscopy may affect the brightness and clarity of the operative field, and the operator should be particularly careful in maintaining a clear operative field.

Postoperative pancreatic fistula (POPF) remains a critical complication following LPD. Factors such as vascular reconstruction, soft pancreatic texture, pancreatic duct diameter ≤3 mm, low preoperative serum prealbumin levels, and elevated C-reactive protein on postoperative day 7 have been identified as independent risk factors for POPF (23,24). Preoperative biliary drainage (PBD) can significantly increase operative time, hospital stay, and morbidity and should be managed carefully in the perioperative period (25). Laparoscopic approaches tend to have longer operative times, which can be associated with increased complications such as longer length of hospital stay, and higher major morbidity rates as compared to open surgery. However, these drawbacks are often balanced by improved recovery outcomes, such as less blood loss and shorter length of hospital stay (26-28). The learning curve plays a critical role in operative outcomes for LPD. According to a retrospective study in Korea, it was suggested that the LPD technique stabilizes after approximately 44 cases, marking the point at which the surgeon's skills and technique result in more predictable and successful outcomes (29).

Table 8 Key categorical variables associated with postoperative complications or outcomes

Factor	Complication or outcome	No (n)	Yes (n)	Chi-squared	P value
Intraoperative blood transfusion	Abdominal infection			4.364	0.04
No		77	0		
Yes		113	9		
Revascularization	Abdominal infection			4.802	0.03
No		166	5		
Yes		24	4		
Chronic pancreatitis	ICU admission			4.552	0.03
No		153	33		
Yes		7	6		
Revascularization	ICU admission			4.247	0.04
No		142	29		
Yes		18	10		
Gastrointestinal anastomosis	Delayed gastric emptying			6.856	0.009
Child		178	14		
Pancreatic-gastric		4	3		

ICU, intensive care unit.

Table 9 Continuous variables associated with postoperative hospital stay

Features	Pearson R	P value
Duration of surgery (min)	0.173	0.01*
Total volume of blood transfusion (mL)	0.175	0.01*
Intraoperative bleeding volume (mL)	0.148	0.04*
Weight (kg)	0.094	0.19
Tumor volume (cm^3)	−0.07	0.33
Height (m)	−0.069	0.34
CA125 (IU/mL)	−0.061	0.40
Bilirubin (µmol/L)	−0.026	0.71
Age (years)	0.019	0.80
CA19-9 (IU/mL)	0.01	0.89

*, $P<0.05$. CA125, carbohydrate antigen 125; CA19-9, carbohydrate antigen 19-9.

In this study, we found that intraoperative bleeding may increase the risk of lung or abdominal infection. This is not surprising, as increased surgical bleeding can indeed raise the risk of postoperative infection. A previous study has shown a reduction in intraoperative bleeding with LPD compared to OPD and a concomitant reduction in lung infection (30). In addition, those patients with greater blood loss require a greater volume of intraoperative blood transfusion, and we found that those with postoperative infections did indeed have a higher volume of intraoperative blood transfusion. Therefore, the exact cause of postoperative infections, which could be due to both direct blood loss and blood transfusion, needs to be confirmed in subsequent research. Patients admitted to the ICU had greater intraoperative blood loss, which may be explained by the following: (I) a greater amount of intraoperative bleeding in the LPD indicates that the tumor is more complex and thus more difficult to resect, and as a result, there is a higher likelihood of serious postoperative complications; (II) intraoperative blood transfusion is associated with a higher likelihood of postoperative infectious disease and allergies, which may induce a higher inflammatory response; (III) higher intraoperative blood loss is associated with a longer operation duration (our study found that patients with a longer operative time are more likely to be admitted to the ICU postoperatively), which suggests that intraoperative transfusions may cause more intraoperative infections due to the higher operative

difficulty and longer operative times, ultimately leading to deterioration in the postoperative period (12).

Another interesting finding was that a low bilirubin level was associated with a higher risk of biliary fistula and second operation, which has rarely been reported. One study found preoperative total bilirubin >200 μmol/L to be an independent risk factor for perioperative calculation of blood loss (31). However, in general, percutaneous transhepatic biliary drainage should be performed preoperatively in patients with serum bilirubin above 200 μmol/L (30). In our study, bilirubin levels were 33.7 and 68.3 μmol/L in biliary fistula and non-biliary fistula groups, respectively, both of which were considerably lower than 200 μmol/L. Normally, bilirubin levels are elevated in patients with pancreatic tumors. A 2023 study reported a 6.4% incidence of biliary fistula after PD, and one of the risk factors included a higher preoperative bilirubin level (8). For the first time, we found a positive correlation between low preoperative bilirubin and postoperative biliary fistulae in PD, but this result needs to be validated in a larger sample of data. Moreover, the preoperative bilirubin was lower in the second-operation group, but again, this should be confirmed is future research due to the small sample size. However, this also suggests that if preoperative bilirubin is low, it should also be monitored closely in the postoperative period, and all potential factors related to secondary surgery should be considered.

Furthermore, we examined the features influencing the length of postoperative hospitalization, and three key factors were identified: duration of surgery, amount of blood transfusion, and intraoperative bleeding. Often, typical postoperative complications (e.g., pancreatic and biliary fistulas) prolong the postoperative hospital length of stay (8,32-34). Previously, it has been reported that the mean length of hospital stay is prolonged in older adult patients (9). Our results do not support the effect of age on the duration of postoperative hospitalization. Rather, age was associated with three highly correlated intraoperative factors (duration of surgery is naturally correlated with the volume of blood transfusion and intraoperative bleeding). This intriguing result suggests that it is possible to shorten the length of postoperative hospital length of stay simply by optimizing the LPD procedure, with this being less related to the patients' clinical characteristics. Conversely, patients should be expected to require a longer hospital stay if they lose a large amount of blood intraoperatively and if the duration of surgery is particularly long.

It should be noted that a shortcoming of this study is that our dataset underperformed both in predicting ICU admission by classification and postoperative length of stay by regression, and there is a need to add other preoperative/intraoperative dimensions and increase the number of patient samples. In addition, many common complications did not occur (or the positive samples were very few) because the sample size was small. In particular, intraoperative bleeding was associated with an increased risk of infection, ICU admission, and prolonged hospital stay. The novel results that low preoperative bilirubin levels may predict biliary fistula and a need for second operations require further validation. However, the study's small sample size, retrospective design, and inclusion of only a single center limit its ability to establish causality or offer generalizability. Although the identified risk factors are likely applicable to other high-risk surgeries, their impact may vary across different settings or patient populations. The novel associations, especially those regarding bilirubin levels, need to be replicated in larger, multicenter studies before they can be applied more broadly. Thus, caution is needed in translating these findings to other institutions or clinical contexts.

Conclusions

For patients with a high volume of intraoperative bleeding and blood transfusion in LPD, preventative measures against lung and abdominal infections should be enacted well in advance. Moreover, early warning measures for ICU admission are necessary in the postoperative period, especially for patients with chronic pancreatitis, those with a high volume of intraoperative bleeding or intraoperative blood transfusion, and those who have a long duration of surgery who are expected endure longer postoperative hospitalization.

Acknowledgments

Footnote

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. The ethical approval of this study was obtained from The Second Hospital of Hebei Medical University (ethical approval number: 2025-R013). All participants signed the informed consent prior to recruitment.

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