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Development of Predictive Models for Post-Pancreaticoduodenectomy Pancreatic Fistula: A Preliminary Comparative Study of Internal versus External Drainage Systems

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Abstract

Purpose

This study analyzes risk factors for postoperative pancreatic fistula (POPF) after pancreaticoduodenectomy (PD) across different pancreatic fluid drainage techniques, aiming to inform surgical strategy selection, clinical interventions, and complication prevention.

Methods

A total of 273 patients who underwent PD were included. They were divided into pancreatic fistula and non-fistula groups, and a predictive model for POPF was developed and validated. Patients were then further classified into internal and external drainage groups. Separate POPF prediction models were built for each group to identify group-specific risk factors.

Results

The risk factors associated with POPF in all patients undergoing PD include: a body mass index (BMI) > 25 kg/m², biliary drainage, blood transfusion and invagination pancreaticojejunostomy (IPJ) ($P < 0.05$). Patients in the non-fistula group demonstrated significantly lower postoperative levels of biochemical tests, as well as a reduced duration of abdominal drainage and shorter hospital stays ($P < 0.05$). Furthermore, variables that were significantly associated with POPF among patients in the internal drainage groups included: BMI > 25 kg/m², blood transfusion and IPJ; conversely, for external drainage groups, significant associations were identified with biliary drainage and blood transfusion ($P < 0.05$). The predictive model exhibited acceptable predictive capability as indicated by the Hosmer-Lemeshow (H-L) test results: H-L test = 0.071 and area under the curve (AUC) = 0.684 for internal drainage groups; H-L test = 0.131 and AUC = 0.743 for external drainage groups.

Conclusion

BMI > 25 kg/m², blood transfusion and IPJ are recognized as independent risk factors for POPF. In patients with a BMI > 25kg/m², undergoing internal drainage and invagination pancreaticojejunostomy may elevate the incidence of POPF; conversely, external drainage does not exhibit a significant impact. Therefore, in clinical practice, for obese patients with a BMI > 25kg/m²—particularly those presenting additional risk factors—it is advisable to consider external drainage and to perform pancreaticojejunostomy utilizing a duct-to-mucosa approach. This strategy may contribute to a reduction in the incidence of POPF and facilitate postoperative recovery in these patients.

Introduction

Pancreaticoduodenectomy (PD) is indicated for various tumors located in the head of the pancreas, Vater's ampulla, as well as the descending and horizontal segments of the duodenum, and the distal bile duct[1]. This surgical procedure was first reported by Whipple and colleagues in 1935, gradually gaining widespread recognition and leading to the establishment of a set of standardized clinical surgical norms. The operation involves resection of the distal stomach, duodenum, bile duct, gallbladder, and pancreatic head. Subsequently, pancreaticojejunostomy, choledochojejunostomy, and gastrointestinal anastomosis are performed to reconstruct the digestive tract[2, 3]. Due to complex local anatomy, extensive resection requirements, challenges associated with digestive tract reconstruction post-resection, along with soft tissue characteristics and strong corrosiveness of digestive juices, this surgery is associated with significant complications and mortality rates[4, 5]. Consequently, it remains one of the most challenging procedures within abdominal surgery.

The recent complications observed in patients following PD primarily encompass pancreatic fistula, intra-abdominal hemorrhage, intra-abdominal infection, biliary fistula, and delayed gastric emptying[6–8]. Among these complications, postoperative pancreatic fistula (POPF) is recognized as one of the most formidable challenges associated with PD due to its high mortality rate and its potential to precipitate postoperative hemorrhage, intra-abdominal infection, and gastrointestinal dysfunction. Consequently, POPF has emerged as a significant factor influencing surgical outcomes. Literature indicates that the incidence of POPF following PD varies widely between 0% and 30%[9, 10]. Therefore, effectively predicting the occurrence of POPF after PD and implementing appropriate technical interventions are crucial strategies for enhancing patient prognosis.

Placement of a drainage stent in the main pancreatic duct is a critical intervention aimed at reducing the incidence of POPF and enhancing patient prognosis. The secretion of pancreatic enzymes by the pancreas can be stimulated by intestinal fluid and bile, resulting in erosion at the anastomosis site[11, 12]. Consequently, the insertion of a pancreatic duct stent into the main pancreatic duct can significantly diminish the short-term occurrence of POPF. Based on their drainage mechanisms during PD, pancreatic duct stents can be categorized into two types: internal drainage and external drainage. Internal drainage represents a relatively straightforward approach that facilitates the transport of pancreatic fluid to the distal end of the anastomosis, thereby mitigating its corrosive effects. This method is particularly advantageous for laparoscopic procedures as it has been shown to substantially reduce hospital stays for patients and aligns with enhanced recovery after surgery (ERAS) protocols[13, 14]. In contrast, external drainage entails complete evacuation of all pancreatic fluids from the pancreas. This technique alleviates tension at the anastomosis site, preserves adequate blood supply to this region, and fosters effective healing processes at the anastomosis. However, it is important to acknowledge that external drainage may result in significant loss of bodily fluids and digestive enzymes, potentially leading to gastrointestinal dysfunction and delayed recovery[15, 16].

The efficacy of external drainage of pancreatic duct stents in reducing the incidence of POPF compared to internal drainage remains uncertain. Some studies suggest that external drainage may provide greater

benefits in the prevention and management of POPF than internal drainage[17]. Conversely, other researchers contend that there is no significant difference between these two methods during surgical procedures[15]. In clinical practice, both drainage techniques are frequently utilized, with the choice often influenced by the surgeon's expertise and preferences. Identifying independent risk factors associated with internal and external drainage, as well as determining the optimal conditions for selecting an appropriate drainage method, continues to be a topic worthy of investigation. To address this issue, we aim to compare outcomes related to POPF following PD by evaluating different stent drainage methods. Our objective is to explore effective strategies for minimizing POPF and provide a theoretical foundation for clinicians' decision-making processes.

Patients and Methods

Study Population

This retrospective study gathered clinical data from 273 patients at the Department of Hepatobiliary Surgery, Hunan Provincial People's Hospital (The First Affiliated Hospital of Hunan Normal University), between December 2021 and December 2023. All participants underwent either open or laparoscopic pancreaticoduodenectomy. The research was conducted in accordance with the protocol approved by the Ethics Committee of Hunan Provincial People's Hospital and adhered to the principles outlined in the Declaration of Helsinki.

All patients included in this study met the following criteria: (1) underwent PD due to benign or malignant lesions located in the head of the pancreas, the lower segment of the common bile duct, the papilla of the duodenum, or the ampulla of Vater; (2) a pancreatic duct stent was placed at the pancreaticojejunostomy site utilizing either internal or external drainage methods. The choice of drainage approach is determined by the surgeon's preferences and established practices; (3) received routine postoperative administration of proton pump inhibitors and medications that inhibit pancreatic enzyme secretion; (4) provided informed consent personally or through their legal representatives, and signed an informed consent form. Exclusion criteria were as follows: (1) a prior history of pancreatic surgery; (2) concurrent severe cardiovascular or respiratory diseases, or other serious systemic conditions; (3) undergoing total pancreatectomy; (4) incomplete data. Based on these established inclusion and exclusion criteria, a total of 273 patients were enrolled in this study.

Definition and Grading of POPF

According to the diagnostic criteria established by International Pancreatic Fistula Study Group (ISGPF) [18, 19], is classified into three grades: Grade A, Grade B, and Grade C. Since grade A POPF is typically asymptomatic and does not require specific intervention, it was excluded from this study. This study enrolled patients diagnosed with grade B or grade C POPF following PD.

Perioperative management

All cases in this study were performed by senior surgeons from our hospital's hepatobiliary surgery team. Each surgeon possessed extensive experience, having conducted over 100 open and laparoscopic PD. The decision to utilize either laparoscopic surgery (LS) or open PD was made based on the patients' clinical conditions and preoperative imaging data. The digestive tract reconstruction employed the Child procedure, which involved creating a pancreaticojejunostomy between the pancreatic stump and jejunum. In addition, pancreatic ductal stents are utilized to facilitate both internal and external drainage of the pancreatic duct during PD. The choice of drainage method and the technique for pancreaticojejunostomy—whether it be invagination pancreaticojejunostomy (IPJ) or duct-to-mucosa pancreatojejunostomy (DmPJ)—is dependent on the expertise and preferences of each individual surgeon.

Analysis of Indicators

The collected clinical data encompassed demographic information, including the patient's age and gender, body mass index (BMI), underlying medical conditions (such as hypertension, diabetes, and coronary heart disease), preoperative hemoglobin (Hb) levels, liver function parameters (total bilirubin (TBIL), albumin (ALB), alanine aminotransferase (ALT), aspartate aminotransferase (AST)), serum amylase (AMY), and prothrombin time (PT). All blood biochemical test results were recorded as the highest values observed during blood sampling on postoperative days (POD) 1, 3, and 5. The reference value ranges for all categorical variables are established based on authoritative published literature. Preoperatively, the pancreatic duct diameter (PDD) and tumor vascular invasion were assessed using CT/MR imaging data. The methods of preoperative biliary drainage included percutaneous transhepatic cholangial drainage (PTCD), percutaneous transhepatic gallbladder drainage (PTGD), and biliary stent placement. Intraoperative records documented the duration of the operation, estimated hemorrhage, and blood transfusion details. The texture of the pancreatic stump was evaluated by the surgeon through palpation with two classifications: soft pancreatic consistency and hard pancreatic consistency. Tumor characteristics were determined based on routine postoperative pathological reports. Postoperative complications were classified according to the Clavien-Dindo surgical complication grading system[20].

Statistical Analysis

All measurement data were presented as mean ± standard deviation. Differences in measurement data were analyzed using independent sample t-tests or Mann-Whitney U tests, as appropriate. Categorical data were expressed as n (%), and comparisons of categorical variables were conducted using chi-square tests or Fisher's exact tests. All binary variables were classified according to internationally recognized literature classifications and established clinical normal ranges. A univariate logistic regression model was employed to estimate the odds ratio and 95% confidence interval for each variable. Variables that demonstrated statistical significance in the univariate analysis were

subsequently included in the multivariate analysis. The predictive model was derived from this multivariate analysis, with its goodness of fit assessed through the Hosmer-Lemeshow (H-L) test. Statistical analyses were performed using SPSS version 25.0 software, with a *P*-value of less than 0.05 considered statistically significant.

Results

Study Design

Figure 1 illustrates the flowchart outlining the design of this study. A total of 273 patients who underwent PD were included in this investigation. These patients were classified into two groups: the pancreatic fistula group and the non-fistula group, based on whether they developed a POPF. Initially, a predictive model for POPF following PD was established by analyzing both cases with and without POPF, alongside an examination of associated risk factors. This predictive model was subsequently validated internally to assess its effectiveness. Following this, patients were further categorized into internal drainage and external drainage subgroups according to the different methods employed for pancreatic-enteric drainage during their treatment. The postoperative outcomes for these two subgroups were also compared and analyzed. Additionally, separate predictive models for POPF were constructed for each subgroup—with and without POPF—to investigate risk factors specific to both internal drainage and external drainage cohorts. This analysis aims to provide practical insights into optimal pancreatic drainage strategies for patients undergoing PD in clinical practice.

Patients Characteristics

The clinical characteristics of patients who underwent PD in both the pancreatic fistula group and the non-fistula group are summarized in **Table 1**. Among the two cohorts, factors such as age, ALT, AST, AMY, TBIL, ALB, Hb, PT, PDD, gender, hypertension, diabetes, coronary heart disease, abdominal surgery history, surgical methods, pancreatic fluid drainage, pancreatic consistency and tumor type did not exhibit any statistically significant differences between the groups ($P > 0.05$). In contrast, factors including BMI, biliary drainage (BD), blood transfusion (BT) and pancreaticojejunostomy demonstrated statistically significant differences between the two groups ($P < 0.05$).

Model Built and Validation in All Patients

Table 2 delineates the results derived from both univariate and multivariate regression analyses concerning the risk factors associated with POPF in all patients undergoing PD. The univariate analyses identified several risk factors associated with POPF following PD, including: BMI > 25 kg/m², BD, BT and IPJ ($P < 0.05$). Furthermore, the multivariate analysis revealed that the significantly correlated variables included: BMI > 25 kg/m², BD, BT and IPJ ($P < 0.05$). Multivariate analysis and risk score of POPF following PD in all patients are detailed in **Tables S1.** The multivariate analysis revealed that the variables associated with POPF among all patients undergoing PD include: BMI > 25 kg/m^2 (HR: 2.326, 95%CI: 1.129-4.793), BD (HR: 1.190, 95%CI: 1.005-3.630), BT (HR: 2.910, 95%CI: 1.449-5.843) and IPJ

(HR: 1.955, 95%CI: 1.056-3.768). The POPF prediction model was developed by summing the total points assigned to each of the four independent risk factors, resulting in the following equation: 0.844*BMI+0.647*BD+1.068* BT+0.690*IPJ-2.331.

A predictive nomogram, along with the area under the curve (AUC), calibration curve, and decision curve for POPF, has been developed for all patients undergoing PD and is illustrated in **Figure 2**. It is evident that BD yields a higher score in predicting POPF among all patients following PD, followed by BMI > 25 kg/m², IPJ and BT. The AUC of the prediction model was found to be 0.702 (**Figures 2A and 2B**). The calibration analysis of this POPF prediction model is presented **in Figures 2C**. The calibration curve, coupled with the lack of statistical significance observed in the H-L test (*P* value = 0.074 > 0.05), indicates reliable calibration of the model. Furthermore, the decision curve depicted in **Figure 2D** suggests that if the threshold probability falls within the range of 0.12 to 0.62, utilizing this nomogram can provide greater net benefit to patients compared to either complete intervention or no intervention at all.

Comparison of perioperative data between pancreatic fistula group and non-fistula group

The comparison and analysis of perioperative data between the pancreatic fistula group and the non-fistula group are presented in **Figure 3** and **Table 3**. Compared to the fistula group, patients in the non-fistula group exhibited lower postoperative levels of ALT, AST, AMY, as well as a reduced duration of abdominal drainage and shorter postoperative hospital stays (*P* < 0.05). Additionally, there was a lower incidence of Grade III-IV complications among these patients (*P* < 0.05). However, no statistically significant differences were observed between the two groups regarding operation time, intraoperative hemorrhage, or postoperative levels of WBC, TBIL, ALB, Hb, and PT; nor was there a difference in the occurrence of Grade I-II complications (*P* > 0.05).

Model Built and Validation in internal drainage groups

The univariable and multivariate regression analyses of risk factors for POPF following PD in the internal drainage groups are presented in **Table 4**. The univariate analyses identified several risk factors, including: BMI > 25 kg/m², BT and IPJ (*P* < 0.05). Furthermore, the multivariate analysis indicated that the significantly correlated variables included: BMI > 25 kg/m², BT and IPJ (*P* < 0.05). The multivariate analysis and risk score for POPF following PD in patients within the internal drainage groups are detailed in **Table S2**. The analysis identified several variables significantly associated with POPF among patients undergoing PD in these groups, including: BMI > 25 kg/m² (HR: 2.510, 95% CI: 1.009-6.239), BT (HR: 2.967, 95%CI: 1.181-7.452) and IPJ (HR: 2.274, 95%CI: 1.020-5.070). A predictive model for POPF was developed by aggregating the total points assigned to each of the four independent risk factors, resulting in the following equation: 0.920*BMI+1.088*BT+0.822*IPJ-2.163.

A predictive nomogram, accompanied by the AUC, calibration curve, and decision curve for POPF, has been specifically developed for patients within the internal drainage groups. This is illustrated in **Figure 4**. It is evident that BT demonstrates superior predictive capability for POPF among patients within the

internal drainage groups, followed by BMI > 25 kg/m² and IPJ, and the AUC of the prediction model was found to be 0.684 (**Figures 4A and 4B**). The calibration analysis pertaining to this POPF prediction model is illustrated in **Figure 4C.** The calibration curve, along with the absence of statistical significance observed in the H-L test (*P* value =0.071 > 0.05), indicates a reliable calibration of the model. Furthermore, the decision curve depicted in **Figure 4D** suggests that if the threshold probability ranges between 0.13 and 0.63, employing this nomogram can yield a greater net benefit for patients compared to either complete intervention or no intervention at all.

Model Built and Validation in external drainage groups

The univariable and multivariate regression analyses of risk factors for POPF following PD in the external drainage groups are presented in **Table 5**. The univariate analyses identified several significant risk factors, including: BD and BT (*P* < 0.05). Furthermore, the multivariate analysis indicated that the correlated variables included: BD and BT (*P* < 0.05). The multivariate analysis and risk score for POPF following PD in patients within the external drainage groups are detailed in **Table S3.** The analysis identified several variables significantly associated with POPF among patients undergoing PD in these groups, including: BD (HR: 4.475, 95% CI: 1.523-13.154), and BT (HR: 3.206, 95% CI: 1.061-9.9691). A predictive model for POPF was developed by aggregating the total points assigned to each of the four independent risk factors, resulting in the following equation: 1.499*BD+1.165*BT-2.480.

A predictive nomogram, along with the AUC, calibration curve, and decision curve for POPF, has been specifically developed for patients in the external drainage groups. This is illustrated in **Figure 5**. It is evident that BD demonstrates good predictive capability for POPF among patients within these groups, followed by BT, and the AUC of the prediction model was found to be 0.743 (**Figures 5A and 5B**). The calibration analysis related to this POPF prediction model is presented in **Figure 5C.** The calibration curve, coupled with the lack of statistical significance observed in the H-L test (*P* value = 0.131 > 0.05), indicates reliable calibration of the model. Furthermore, the decision curve depicted in **Figure 5D** suggests that when threshold probabilities range between 0.08 and 0.54, utilizing this nomogram can provide a greater net benefit for patients compared to either complete intervention or no intervention at all.

Comparison of postoperative data between internal drainage group and external drainage group

The comparison and analysis of perioperative data between the pancreatic fistula group and the non-fistula group are presented in **Figure 6** and **Table 6**. In comparison to the internal drainage group, patients in the external drainage group demonstrated a significantly lower postoperative AMY (*P* < 0.05). However, no statistically significant differences were observed between the two groups concerning postoperative levels of ALT, AST, TBIL, Hb, PT, WBC, AMY, ALB; nor were there any differences noted in terms of abdominal drainage duration, length of postoperative hospital stay, or incidence rates of Grade I-II/III-IV complications (*P* > 0.05).

Discussion

PD is situated in a complex anatomical region, involving numerous surrounding organs. This procedure necessitates the resection of a substantial area, and the pancreatic tissue itself is relatively soft. With ongoing developments in surgical methodologies, continuous enhancements in surgical instruments, and refined perioperative nursing protocols, the mortality rate for patients undergoing PD surgery has decreased to below 3%. However, it is important to note that the overall postoperative complication rate remains alarmingly high at approximately 30%[21]. Among these complications, POPF can precipitate further issues such as abdominal hemorrhage, infection, anastomotic leakage, and formation of pancreatic pseudocysts-seriously impacting patient quality of life and presenting significant clinical challenges[22, 23]. In this study, patients in the fistula group experienced a prolonged duration of postoperative abdominal drainage, an extended length of hospital stay, and a higher incidence of grade III-IV complications. These findings indicate that the recovery period for patients within the POPF is significantly longer. These complications impose considerable physical and psychological burdens on patients as well as their families; thus they represent some of the most pressing concerns during the perioperative period following PD.

In recent years, the widespread application of PD in clinical practice, coupled with standardized perioperative management protocols, has led to a significant reduction in postoperative mortality rates. Nevertheless, the incidence of postoperative complications remains high[24, 25]. Medical centers are actively investigating the risk factors associated with POPF following PD and are seeking effective strategies to mitigate these complications[26, 27]. In this study, a total of 273 laparoscopic/open PD procedures were performed, yielding an average operative time of (425.3 ± 111.5) minutes and an average intraoperative hemorrhage of (310.7 ± 227.4) milliliters. Postoperative grade B/C POPF was observed in 54 cases (19.8%). The study encompassed various clinical and pathological variables. Through both univariate and multivariate analyses aimed at identifying risk factors for the development of POPF, it was determined that significant risk factors include a body mass index (BMI) > 25 kg/m², perioperative blood transfusion and IPJ.

BMI is a key objective indicator that reflects the nutritional status of an individual. A BMI > 25 kg/m² is classified as overweight, while a BMI > 30 kg/m² indicates obesity. Existing literature demonstrates that obesity can lead to adverse events during and after surgical procedures[28]. Some researchers suggest that the increased incidence of POPF in patients with elevated BMI may be linked to pancreatic fat infiltration[29]. In obese patients, performing end-to-end suturing on the pancreas poses greater challenges due to factors such as parenchymal fat deposition, which render the pancreas softer yet more brittle; additionally, this condition results in a thinner pancreatic duct. Consequently, during pancreaticojejunostomy, it becomes difficult to maintain tension on the suture thread when stitching and knotting the pancreatic tissue—this difficulty increases the likelihood of damaging both the pancreatic tissue and duct, thereby elevating the risk for POPF. Numerous domestic and international studies indicate that high BMI correlates with an increased occurrence of POPF following PD[30, 31]. The findings of our research align with the majority of existing literature on this topic. In addition, this study identified blood transfusion as an independent risk factor for the development of POPF following PD. This

association may stem from the fact that intraoperative blood transfusions can indirectly impair anastomotic healing by influencing immune regulation or exacerbating inflammatory responses, thereby heightening the risk of POPF. These findings are consistent with those reported in previous studies[32, 33].

Pancreaticojejunostomy is a crucial component in the process of PD. The techniques most commonly utilized for pancreaticojejunostomy in clinical practice primarily include invagination pancreaticojejunostomy (IPJ) and duct-to-mucosa pancreaticojejunostomy (DmPJ)[34]. In IPJ, the distal end of the pancreatic duct is directly inserted into the lumen of the jejunum to a predetermined depth. Subsequently, the outer layer of the pancreatic duct is sutured to either the full thickness or seromuscular layer of the jejunum using absorbable sutures, thereby establishing an effective connection between the pancreatic duct and jejunum. Conversely, DmPJ involves everting the pancreatic duct and then suturing it to the mucosal layer of the jejunum with interrupted sutures. This technique ensures a secure fit and facilitates a reliable anastomosis[35]. It is important to highlight that, in accordance with the findings of this study, the DmPJ procedure aligns more closely with physiological structures. This technique facilitates direct flow of pancreatic juice into the jejunum, thereby enhancing drainage, alleviating pressure within the pancreatic duct, and reducing the incidence of POPF[36]. However, it is essential to note that this surgical operation is relatively complex and imposes higher technical demands on the surgeon; consequently, the duration of the procedure may be extended. Therefore, it is recommended that this operation be performed by experienced pancreatic surgeons.

The placement of pancreatic duct stents can effectively prevent iatrogenic closure of the pancreatic duct during PD, which may otherwise lead to complications such as pancreatic duct obstruction or stenosis[37]. The pancreatic fluid secreted by the pancreas can be directly drained through the stent across the pancreatic anastomosis, thereby reducing both the risk and severity of POPF. Based on their placement methods, pancreatic duct stents can be categorized into two groups: internal drainage and external drainage. The internal drainage of the pancreatic duct following PD may lead to the accumulation of pancreatic fluid at the onset of the jejunum, particularly if gastrointestinal function has not yet recovered. The presence of pancreatic enzymes renders this fluid highly corrosive, which can severely damage both the intestinal wall and anastomosis sites, ultimately leading to the formation of POPF[38]. However, external drainage of the pancreatic duct can effectively remove most of the excess pancreatic fluid from the body. Although some residual fluid may still be discharged from accessory pancreatic ducts or other parts of the pancreas, its overall volume is significantly reduced. Nevertheless, external drainage can lead to substantial loss of both fluid and digestive enzymes, potentially delaying recovery of gastrointestinal function and overall bodily health. Current studies indicate that there is no significant difference in short-term efficacy between these two approaches following surgery[39, 40]. Some research suggests that a definitive conclusion regarding whether to opt for internal or external drainage during PD remains elusive. However, through subgroup analysis utilizing multiple logistic regression, we compared the outcomes associated with internal drainage versus external drainage methods. Our research findings indicated that a BMI > 25 kg/m² and IPJ were identified as risk factors for complications related to internal drainage-associated POPF. Conversely, in patients undergoing

external drainage, an elevated BMI and IPJ did not present similar risks. Therefore, in clinical practice, for patients with a higher BMI, external drainage and DmPJ may prove more effective in mitigating the risk of POPF.

In addition, our research has certain limitations. As a single-center retrospective study, it lacks multi-center large sample data and is subject to shortcomings such as a small sample size and significant individual variability, which may influence the research outcomes. Looking ahead, we plan to undertake multi-center collaborative research projects that will involve joint investigations into POPF and related complications following both laparoscopic and open PD across various regions and centers. This approach aims to increase the sample size, enhance the reliability of our findings, and provide a comprehensive understanding of the risk factors associated with POPF after PD, ultimately offering more dependable clinical guidance for surgical decision-making in this context.

Conclusion

POPF following PD can result in extended catheterization duration and prolonged hospital stays, significantly hindering patients' postoperative recovery. However, there is no statistically significant difference in the overall incidence of POPF after PD when comparing internal versus external drainage of pancreatic duct. Notably, a blood transfusion and invagination pancreaticojejunostomy are identified as independent risk factors for the development of POPF. In patients with a BMI > 25 kg/m², internal drainage may elevate the risk of developing POPF; conversely, external drainage does not appear to have this effect. Therefore, in clinical practice, for patients with a higher BMI, the implementation of external drainage and duct-to-mucosa pancreaticojejunostomy may demonstrate greater efficacy in reducing the risk of POPF and facilitating an expedited recovery process following surgery.

Abbreviations

BMI
body mass index
PDD
pancreatic duct diameter
LS
laparoscopic surgery
POD
postoperative day
PTCD
percutaneous transhepatic cholangial drainage
PTGD
percutaneous transhepatic gallbladder drainage
BT
blood transfusion

BD
biliary drainage
IPJ
invagination pancreaticojejunostomy
DmPJ
duct-to-mucosa pancreatojejunostomy

Declarations

Disclosures

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Author Contribution

Qi S., Chen K., and Cheng W. were instrumental in the conception of the study. Song Z., Zou C., Liu W., and Liu X. contributed to data collection and auditing processes. Qi S., Song Z., and Huang W. conducted the data analyses and authored the manuscript. Tian B. and Liu C. provided critical reviews of the manuscript. All authors participated in the development of this article and approved its submitted version.

Data Availability Statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics Statement

The studies involving participants were reviewed and approved by the Ethics Committee of Hunan Provincial People's Hospital. The patients/participants provided their written informed consent to

participate in this study.

Tables

Tables 1-6 are available in the Supplementary Files section.

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Figures

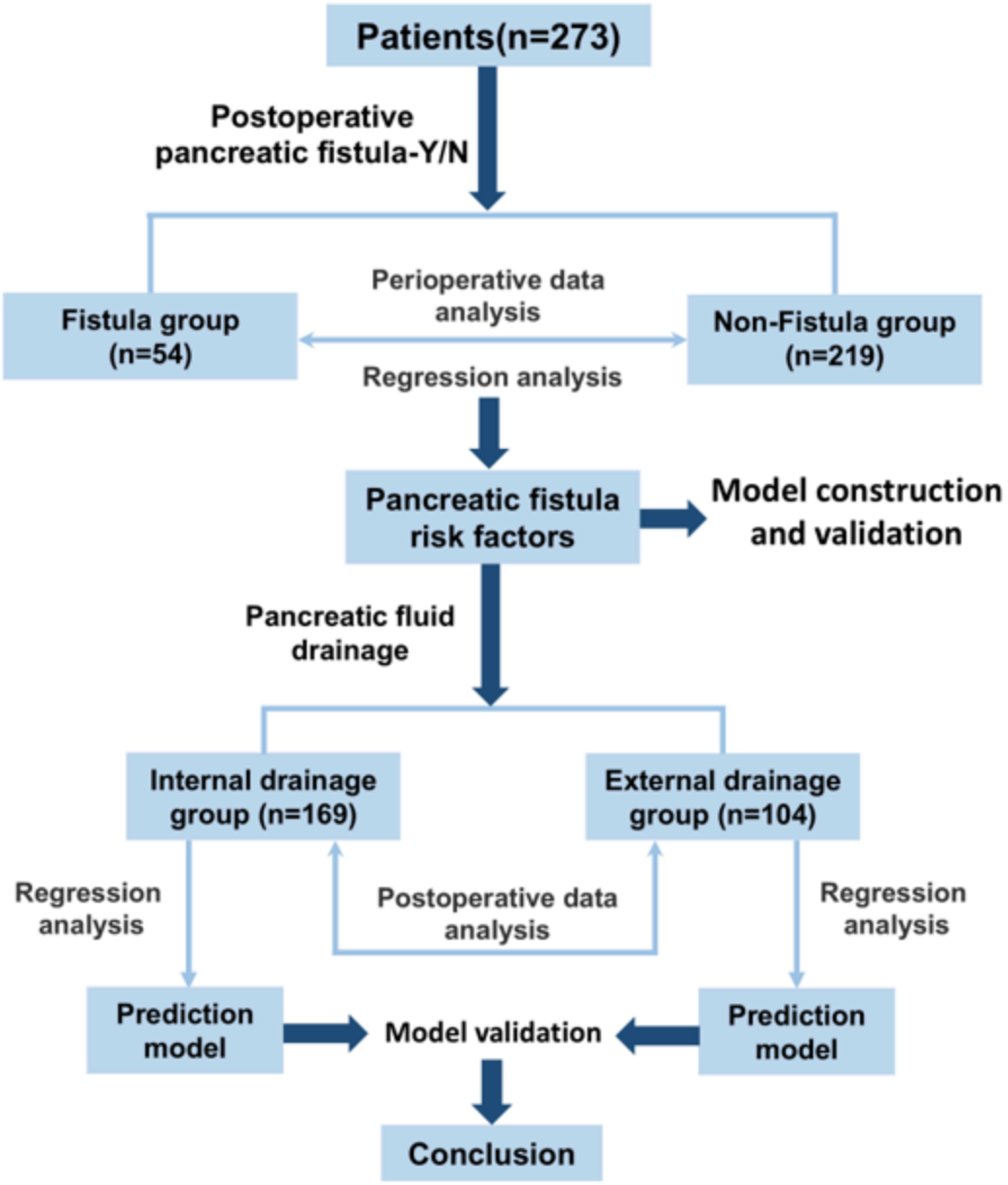


Figure 1

Flowchart of study design.

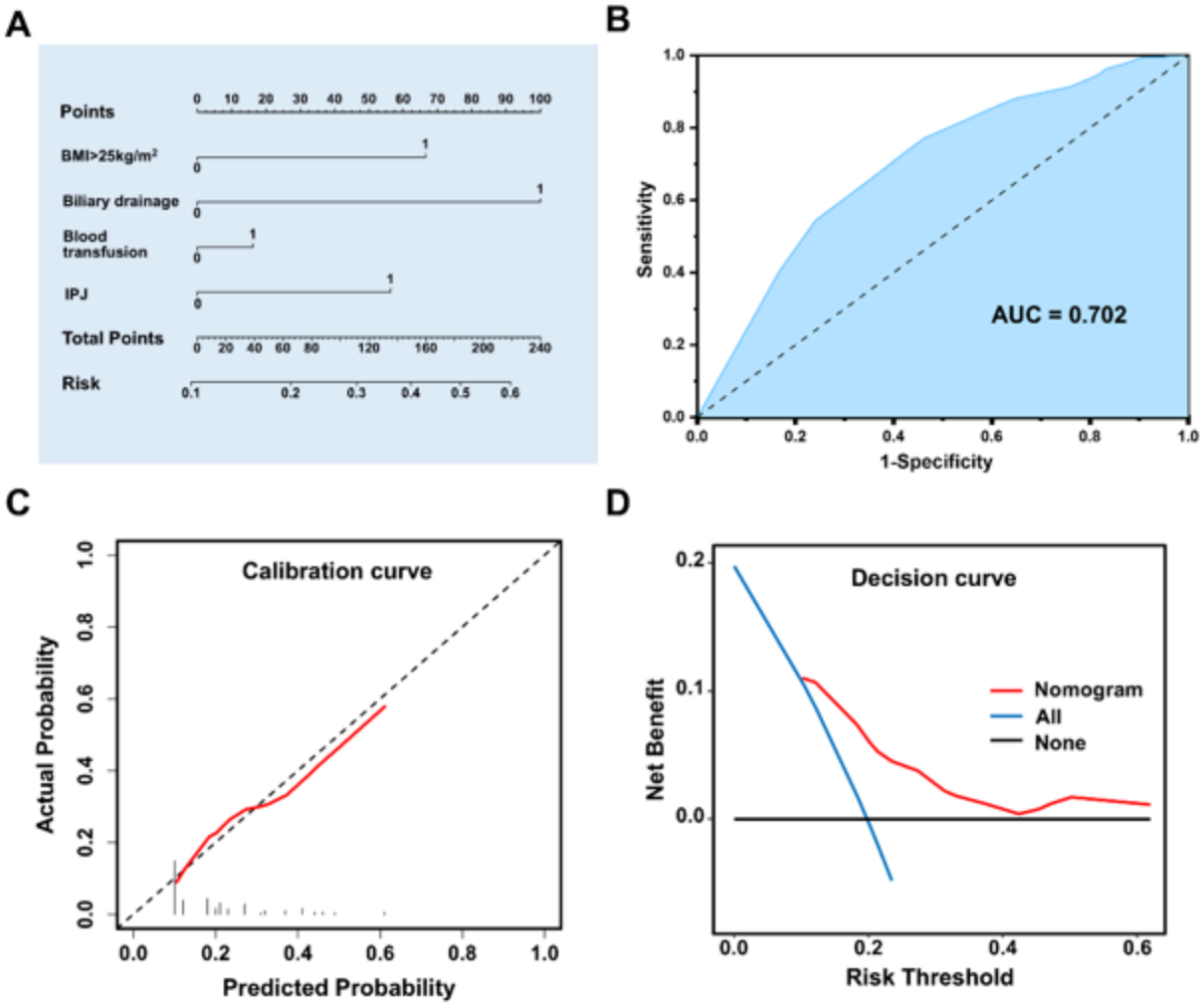


Figure 2

A: A POPF predictive nomogram has been developed for all patients following PD. B: The area under the curve (AUC) of the nomogram. C: Calibration curve of POPF prediction model for all patients. D: This presents the decision curve analysis for all patients.

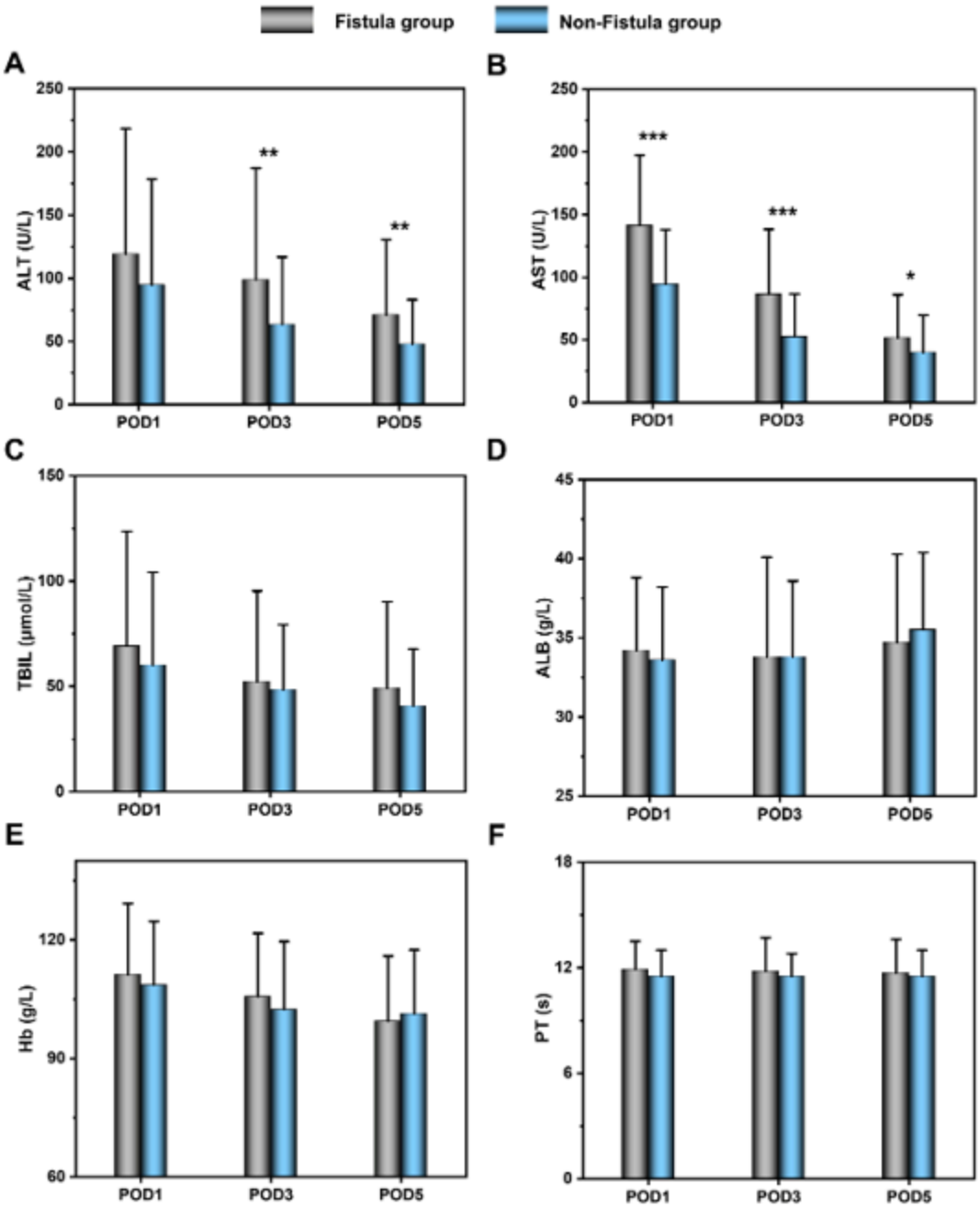


Figure 3

Comparison of postoperative laboratory indexes between pancreatic fistula group and non-fistula group, including POD1, POD3, POD5 value of ALT (A), AST (B), TBIL (C), ALB(D), Hb(E) and PT(F).

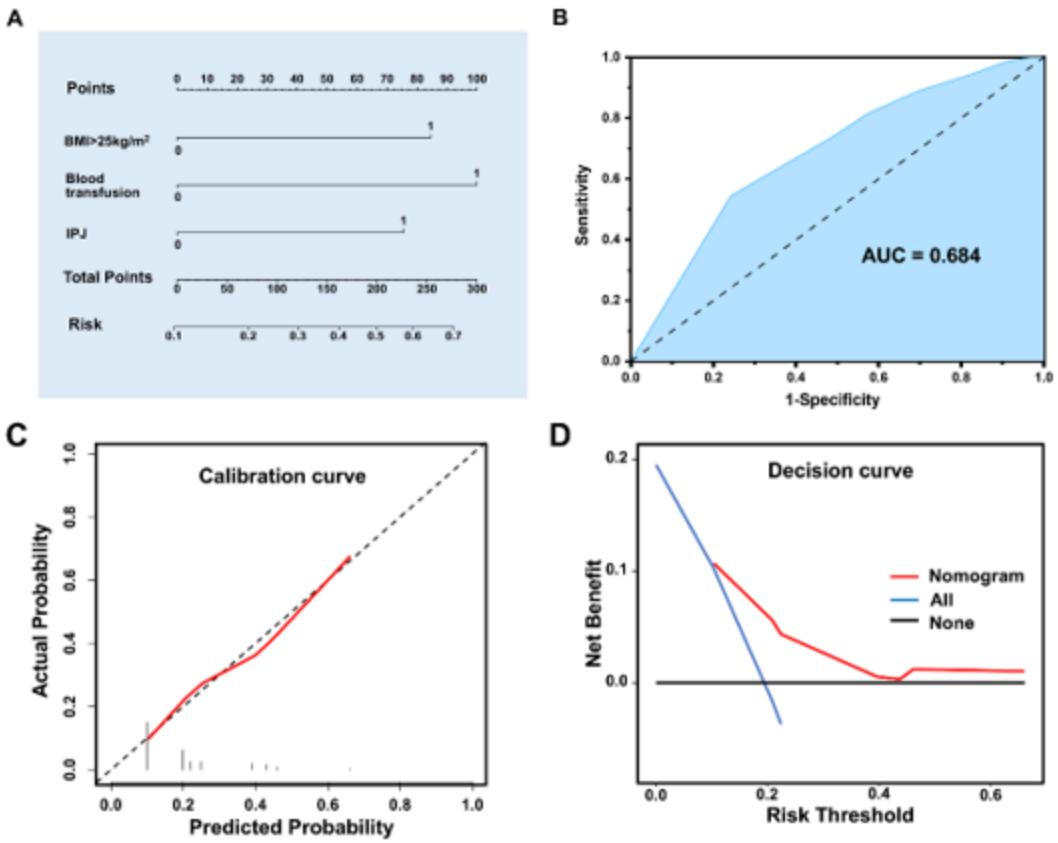


Figure 4

A: The pancreatic fistula predictive nomogram has been developed for patients in the internal drainage group following PD. B: The AUC of the nomogram. C: Calibration curve illustrating the performance of the POPF prediction model for patients in the internal drainage group. D: Presentation of the decision curve analysis for patients in the internal drainage group.

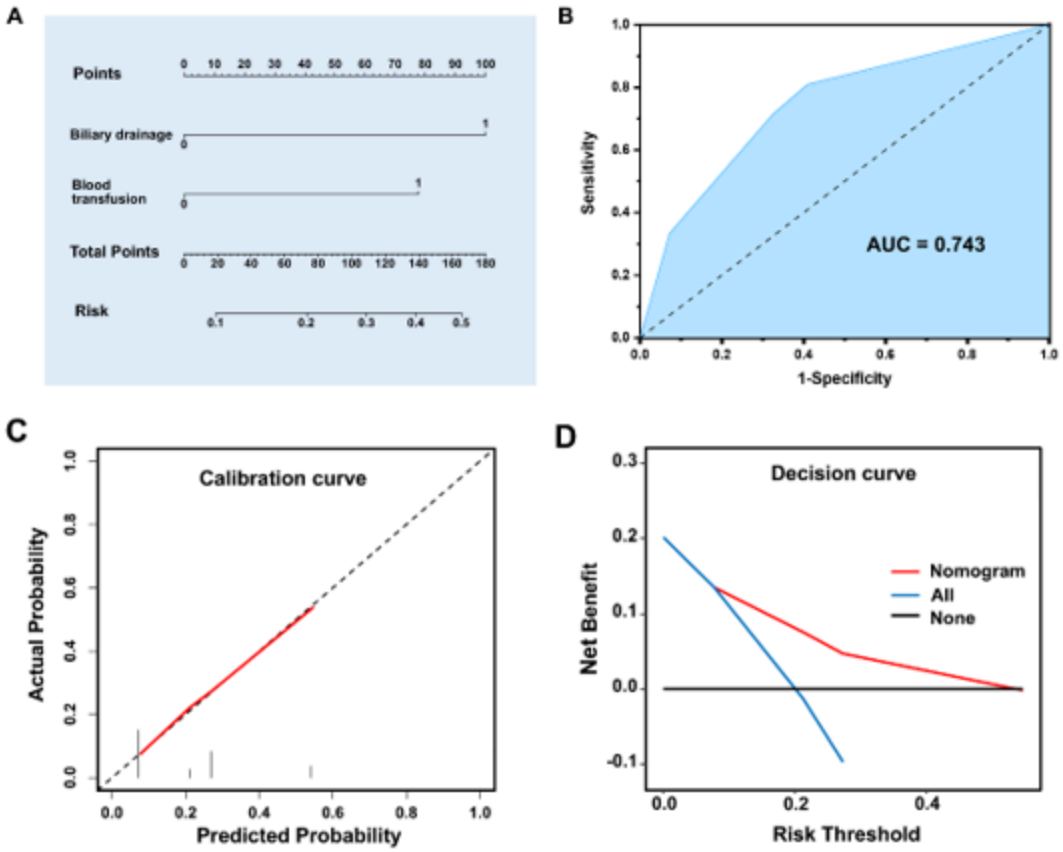


Figure 5

A: The pancreatic fistula predictive nomogram has been developed for patients in the external drainage group following PD. B: The AUC of the nomogram. C: Calibration curve illustrating the performance of the POPF prediction model for patients in the external drainage group. D: Presentation of the decision curve analysis for patients in the external drainage group.

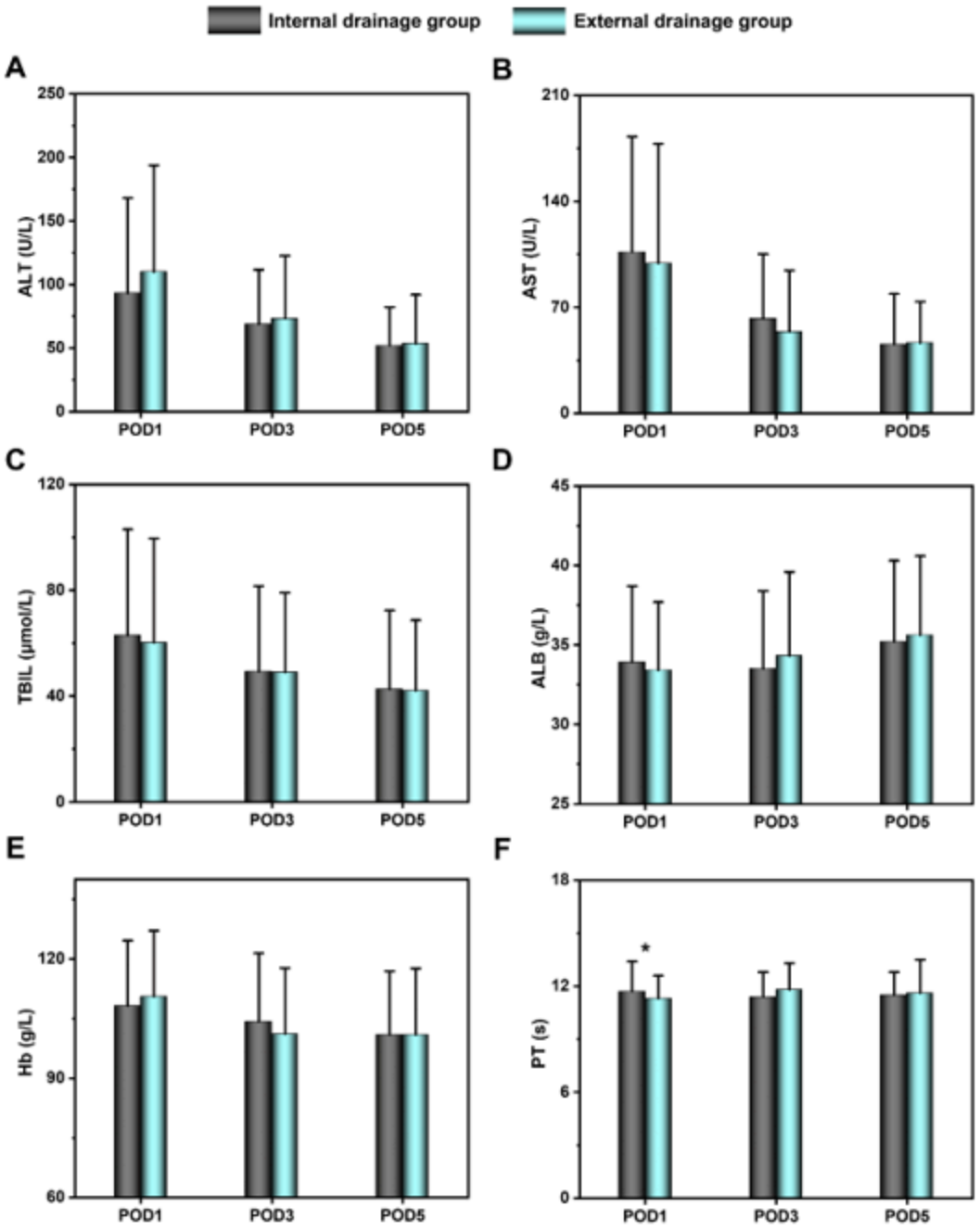


Figure 6

Comparison of postoperative laboratory indexes between internal drainage group and external drainage group, including POD1, POD3, POD5 value of ALT (A), AST (B), TBIL (C), ALB(D), Hb(E) and PT(F).

Supplementary Files

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- Tables.docx
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