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Hyperlipasemia in the immediate postoperative period predicts postoperative pancreatic fistula after pancreatic resections

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ABSTRACT

Background: Postoperative pancreatic fistula is the most common severe complication after pancreatic surgery. It associated with increased morbidity and prolonged hospital stay. Identifying patients at low risk for postoperative pancreatic fistula is essential to enable timely removal of drains and facilitate early discharge. Although postoperative hyperamylasemia is linked to postoperative pancreatic fistula, the role of postoperative hyperlipasemia remains unclear. This study aims to investigate the role of postoperative hyperlipasemia in predicting postoperative pancreatic fistula B/C pancreaticoduodenectomy and distal pancreatectomy.

Material and methods: The study included 471 patients who underwent pancreaticoduodenectomy and distal pancreatectomy at our institution between January 1, 2019, and February 28, 2023. Postoperative hyperamylasemia and postoperative hyperlipasemia were defined as values above the upper limit of normal established at our institution.

Results: In univariate analysis, postoperative hyperlipasemia and postoperative hyperamylasemia on postoperative day 0 demonstrated the strongest association with postoperative pancreatic fistula B/C. Consequently, a subset of 177 patients with available serum lipase and amylase data underwent further investigation. Besides body mass index and high-risk pathology, both postoperative hyperlipasemia and postoperative hyperamylasemia on postoperative day 0 emerged as independent risk factors for postoperative pancreatic fistula B/C in univariate analysis. In multivariate analysis, postoperative hyperlipasemia on postoperative day 0 emerged as a significant predictor of postoperative pancreatic fistula B/C, with body mass index as independent risk factor of postoperative pancreatic fistula B/C.

Conclusion: The absence of postoperative hyperlipasemia on postoperative day 0 could potentially serve as an effective diagnostic tool for identifying patients who are at a low risk of developing postoperative pancreatic fistula B/C after pancreaticoduodenectomy and distal pancreatectomy. Consequently, not only serum amylase, but also serum lipase can be integrated into clinical practice alongside other relevant parameters.

Introduction

Postoperative pancreatic fistula (POPF) is the most common major complication occurring after pancreatic resection.[1] Despite advances in patient selection and perioperative management, POPF B/C remains one of the most challenging and potentially life-threatening complications in pancreatic surgery.[2] The incidence of POPF B/C varies between centers and ranges from 5% to 46%.[3–5]

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The occurrence of POPF B/C has significant clinical implications, including prolonged hospital stay, multiple interventions, reoperation, and intensive care admissions.[6] It is known that POPF B/C can delay or prevent delivery of adjuvant chemotherapy, thereby potentially affecting long-term survival negatively.[7] Conversely, identifying patients at low risk for POPF B/C is crucial to enable timely removal of intraoperatively placed drains and facilitate early discharge for these patients.[8]

For the first time, it has been suggested by Connor[9] that post-pancreatectomy acute pancreatitis (PPAP) is a distinct complication and plays a role in the development of POPF B/C. However, the International Study Group for Pancreatic Surgery (ISGPS) has defined PPAP by clinical and radiologic abnormalities, in contrast to Connor's characterization of PPAP by postoperative hyperamylasemia (POHA).[10] Even though elevated serum amylase levels have been shown to predict PPAP and POPF B/C after pancreatic resections, there is scarcity of data linking postoperative hyperlipasemia (POHL) to POPF.[11–13] As a result, ISGPS has not incorporated serum lipase levels in its new classification of PPAP.[10] In our study, we propose that in addition to POHA, POHL after pancreatic resection could serve as a valuable indicator for predicting POPF B/C. Herein, we aim to determine whether elevated serum lipase levels in the immediate postoperative period can predict POPF B/C in patients following pancreatic resections.

Methods

Study population and inclusion/exclusion criteria

This retrospective cohort study included patients who underwent pancreaticoduodenectomy (PD) or distal pancreatectomy (DP) at our institution between January 1, 2019, and February 28, 2023. The study was conducted with approval of the local ethics committee (reference number: 22-1064). The analysis included patients who were 18 years or older and had undergone elective PD or DP. Patients who underwent enucleation, segment resection, or total pancreatectomy were not part of this study. The exclusion criteria were as follows: individuals who had undergone previous pancreatic surgery, patients for whom drain and serum lipase/amylase levels were not available on any of the first 3 postoperative days, and patients with missing data.

Data collection

Data collection comprised demographic information, body mass index (BMI), American Society of Anesthesiologists classification, results of histopathologic examination, neoadjuvant therapy use, postoperative outcomes, and perioperative laboratory parameters such as serum lipase and amylase levels, as well as levels of amylase and lipase in drains. The intraoperative information included operation time, estimated blood loss and vascular resection. High-risk pathology was defined as any other disease condition other than pancreatic ductal adenocarcinoma (PDAC) or chronic pancreatitis.

Measurement of serum and drain lipase/amylase

The first postoperative blood sample (postoperative day 0, or POD0) was obtained 4 hours after the surgery and included mainly red blood cells, electrolytes, liver parameters, etc. Since the predictive value of serum lipase and amylase on POD0 is not well established, these parameters were not measured in all our cases. On subsequent postoperative days, blood analysis was conducted at the start of the day. The upper reference range for serum lipase at our institution was 60 U/L, whereas for serum amylase, the corresponding upper reference range was 109 U/L. Values exceeding our institutional reference range were characterized as POHL and POHA, respectively. The measurement of drain lipase and amylase was conducted mainly on POD2. In very few cases in this cohort, drainage serum lipase and amylase were measured either on the first or third postoperative day.

Summary of standard operative protocol

For patients diagnosed with tumors of the pancreatic head, a PD was performed, whereas DP was undertaken for tumors located within the body to tail. The ISGPS consensus statement was used to determine the standard lymphadenectomy protocol for both PD and DP. To ensure complete resection, vascular resections and reconstructions were performed in cases of malignancies infiltrating the portal vein, superior mesenteric vein, or celiac axis. All patients were administered a single intravenous prophylactic dose of antibiotics before incision. The use of somatostatin analogues was determined by operating surgeon.

The reconstruction after PD was carried out using pancreatojejunostomy. DP was conducted using either an open or minimally invasive approach and using either a stapling device or a scalpel dependent on the thickness of pancreatic parenchyma. In cases in which scalpel transection was used, the pancreatic duct was identified and subsequently closed with monofilament absorbable sutures. Abdominal drains were inserted at the end of the procedure and levels of drain lipase and amylase were measured in accordance with clinic standards. The drains were removed once levels were back to normal. POPF is defined using the latest classification provided by the ISGPS.[14] Specifically, biochemical leak was identified as an elevation in drain amylase levels without any clinical impact. Patients exhibiting prolonged drainage for over 3 weeks due to heightened amylase activity were categorized as POPF grade B. The classification of POPF grade B was also conferred when interventions such as percutaneous, endoscopic, or angiographic procedures became necessary. In cases in which a grade B POPF resulted in organ failure or clinical instability to the extent that reoperation is imperative, the POPF B is upgraded to grade C.

Statistical analysis

Categorical variables were compared using the X^2 test and Fisher exact test, and the Mann-Whitney *U* test and Student *t*-test were used to compare continuous variables as appropriate. Logistic regression analysis was used to obtain odds ratios[10] and 95% confidence intervals and to examine the association between perioperative clinicopathologic factors. Main variables, especially those showing significant results in the univariate analysis ($P < .05$), were subjected to multivariate binary logistic regression analysis. Statistical analysis and graphical illustrations were conducted using GraphPad Prism and SPSS.

Results

Patient demographics

The study population comprised 471 patients who underwent elective PD or DP between January 1, 2019, and February 28, 2023, at our institution. The median age of the patients was 70 (range 18–90) years, and there were 265 men (56%) and 216 women (44%). PD was performed in 295 patients, (63%) and DP in 176 patients (37%). The indications for resections were PDAC (46%), neuroendocrine tumors (16%), cystic pancreatic lesions (15%), chronic pancreatitis (5%), and other pathologies (18%). An American Society

Table I
Patient characteristics, $n = 471$

Parameter	n (%) or median (IQR)
Age, yr, median (IQR)	70 (61–80)
Sex, n (%)	
Male	265 (56%)
Female	216 (44%)
BMI, kg/m^2, median, (IQR)	24 (22–27)
ASA, n (%)	
1–2	57 (12%)
3–4	414 (88%)
Pathology, n (%)	
PDAC	216 (46%)
NET	75 (16%)
Cystic lesions	70 (15%)
CP	22 (5%)
Others	88 (18%)
Operation, n (%)	
Pancreaticoduodenectomy	295 (63%)
Distal resection	176 (37%)
Vascular resection, n (%)	73 (15%)
Operation time, min, (IQR)	320 (220–370)
EBL, mL, median (IQR)	600 (370–900)
POPF, n (%)	126 (26.5%)
No POPF	188 (40%)
BL	163 (35%)
B	96 (20%)
C	24 (5%)
Length of hospital stay, d	20 (14–26)
30-d mortality, n (%)	10 (2.1%)

ASA, American Society of Anesthesiologists; *BMI*, body mass index; *EBL*, estimated blood loss; *IQR*, interquartile range; *NET*, neuroendocrine tumor; *PDAC*, pancreatic ductal adenocarcinoma; *POPF*, postoperative pancreatic fistula.

of Anesthesiologists classification of 3 or greater was present in 88% of patients. Patient characteristics of the cohort are summarized in Table I.

POHA and POHL after PD and DP

ROC analysis indicated that drain fluid lipase on POD2, when elevated to 3 times the normal institutional value, exhibited the highest sensitivity at 95% and a specificity of 66% (Supplementary Table S1). Among the serum parameters, serum lipase levels on POD 0 and 1 showed the greatest sensitivity and specificity.

In addition, the median serum amylase and lipase levels were notably greater in the POPF B/C group compared with the non-POPF group across all 4 postoperative assessments (Figure, *A* and *B*). Initially, both serum amylase and lipase levels on POD0 and POD1 exceeded the upper limit of the reference range. However, by POD2 and POD3, serum amylase levels returned to normal, whereas serum lipase levels remained elevated on POD2 in the POPF group but normalized by POD3. Notably, the greatest median postoperative levels of both serum amylase ($n = 328$) (Figure, *A*) and lipase ($n = 317$) (Figure, *B*) were observed on POD1.

Association of POHL and POHA with POPF B/C

In the univariate analysis, a statistically significant correlation was observed between BMI exceeding 24 kg/m^2 and the incidence of POPF B/C (Table II). Conversely, female sex and the presence of low-risk pathologies (PDAC and CP) were found to exhibit a significant inverse relationship with the occurrence of POPF B/C. During the postoperative period, hyperlipasemia correlated with POPF B/C across all 3 postoperative days and exhibited an increased odds ratio in relation to POPF B/C, reaching its maximum value on POD0 at 5.20. In contrast, POHA was significantly correlated with POPF B/C only on POD0 and POD1, with its highest odds ratio observed at 3.08 on POD0.

Comparison of POHL and POHA on POD0

Given that POHL and POHA on POD0 demonstrated the highest odds ratios, all 177 patients with both serum lipase and amylase data available were selected for subsequent analysis. A demographic comparison of cohorts with available serum lipase and amylase on POD0 and those with missing data showed no significant differences (Supplementary Table S2).

The rate of POPF B/C was significantly greater in both the POHL and POHA groups (Supplementary Table S3). However, POPF B was observed 3 times more frequently in the POHL group compared with the non-POHL group. In the POHA group, the rate of POPF B was only twice as frequent compared with the non-POHA group. In addition, POPF C was observed in only 1 case (1%) in the non-POHL group, whereas in the non-POHA group, POPF C was observed in 4 cases (3%).

As depicted in Table III, 25% of cases (45 of 177) exhibited concurrent POHL and POHA on POD0 (POHL+/POHA+). Within this subgroup, the incidence of POPF B/C reached 42%. In contrast, patients with normal serum lipase and amylase levels (POHL−/POHA−) constituted nearly 50% of the cohort (86 of 177), with only 8% (7 of 85) developing POPF B/C. Interestingly, cases presenting with POHL alone (POHL+/POHA−) were more frequently observed than those with POHA and normal serum lipase (POHL−/POHA+).

Analysis of risk factors for POPF B/C

In the univariate analysis of perioperative factors, BMI exceeding 24 kg/m^2, and high-risk pathology as well as POHA and POHL on POD0 were significantly associated with POPF B/C (Table IV). These variables were then incorporated into multivariate analysis. After adjustments for these variables in a backward stepwise manner, POHL on POD0 was a significant predictor of POPF B/C and BMI was identified as independent risk factor of POPF B/C in a multivariate analysis (Table IV).

Patient characteristics and incidence of POPF stratified by POHL on POD0

Among the cohort of 177, 85 patients (48%) experienced POHL, as defined by values above normal serum range. The patients were subsequently segregated into POHL and non-POHL cohorts, as demonstrated in Table V. The POHL group was significantly younger in comparison with the non-POHL cohort. However, no significant differences were observed in terms of hospital stay or 30-day morbidity between the 2 cohorts. The rate of high-risk pathology cases was in the POHL group significantly more in comparison with non-POHL group (63% vs 33%). Notably, patients in the non-POHL group exhibited a 11% rate of POPF B/C. In contrast, patients in the POHL cohort experienced a POPF B/C rate of 39% on POD0. Interestingly, there was no correlation between the degree of lipase elevation and incidence of POPF.

Discussion

Pancreatic resections are complex surgical procedures that carry a high risk of morbidity. Despite the extensive research conducted over the course of several decades, the proper management of POPF continues being a significant challenge for pancreatic surgeons.[15] On the one hand, patients at low risk would benefit from early drain removal, whereas on the other hand, patients at high risk for POPF B/C would benefit from close monitoring.[16]

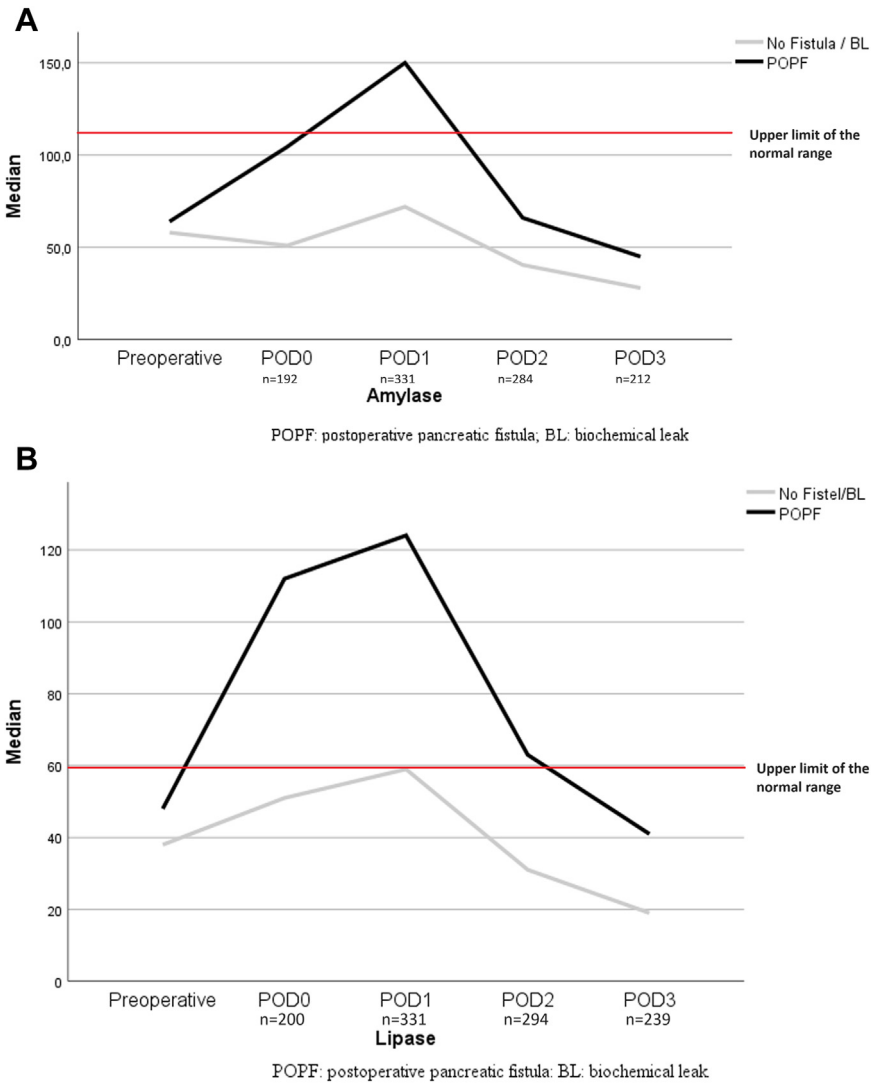

Figure. (A) Postoperative course of serum amylase from POD0 to POD3. (B) Postoperative course of serum lipase from POD0 to POD3. *POD*, postoperative day.

Since Connor first proposed that PPAP may contribute to the development of POPF B/C, numerous studies have been conducted to investigate the potential role of serum lipase and amylase in predicting the occurrence of POPF B/C.[17,18] In the present study, we showed that POHL and POHA occur commonly after pancreatic resections and the greatest median of both serum lipase and amylase was observed on POD1.

At present, the predictive value of biochemical tests in terms of identifying early onset and severity of POPF B/C is being assessed.[19–21] For instance, Murakawa et al[22] demonstrated that PPAP, defined as an elevation of serum amylase levels above the upper limit of normal on POD 1, is an independent risk factor for POPF B/C development after PD. In context of distal pancreatic resections, POHA on POD 1 was also found being correlative with higher rates of POPF B/C and PPAP, as well as prolonged hospital stays.[23] Moreover, a serum amylase level less than 130 U/L 4 hours after surgery was found to have a high negative predictive value (88.8%) for POPF B/C, suggesting that early removal of drainage systems might be possible in patients with serum amylase levels below this threshold.[17]

Despite the numerous studies evaluating the predictive value of serum amylase for POPF B/C, there are relatively few studies that have specifically investigated the potential role of serum lipase as a predictor of POPF B/C.[21,24,25] In a cohort of 85 patients, serum lipase levels on POD1 were found to be significantly elevated in those who developed POPF B/C after PD, as compared with the non-POPF group.[26] Another study conducted on a small cohort of 70 patients found that a combination of serum lipase and interleukin-6 levels on POD3 represented a highly significant early predictor of POPF B/C following pancreatic resections.[27] A combination of serum lipase on POD1 with CRP on POD3 was also demonstrated to be early predictor of POPF.[28]

In contrast to surgical studies, extensive research has been conducted on comparing serum lipase and amylase for predicting the diagnosis and severity of acute pancreatitis.[29] Serum lipase levels begin to increase within 3 to 6 hours of symptom onset, peak within 24 hours, and remain elevated for up to 2 weeks.[30] This extended diagnostic window makes lipase more advantageous compared with amylase. Furthermore, lipase has greater specificity because it is primarily produced by the pancreas.[29]

In comparison with other studies that have examined serum lipase activity after pancreatic resections, the present study represents the largest cohort to compare hyperlipasemia and hyperamylasemia in postoperative setting for predicting the

Table II
Univariate analysis of factors associated with POPF B/C after PD and DP ($n = 471$)

Variable	Univariate analysis				
	n	% POPF	OR	95% CI	*P* value
Age, yr					
≥70	235	23%	0.73	0.5–1.1	.15
<70	236	28%			
Sex					
Female	216	19%	0.55	0.3–0.8	.006
Male	255	31%			
BMI					
≥24	214	34%	2.31	1.5–3.5	<.001
24	257	18%			
Pathology					
Low risk	237	19%	0.49	0.3–0.07	.001
High risk	234	32%			
NAT					
Yes	62	26%	0.74	0.4–0.14	.38
No	409	21%			
Operation					
PD	295	23%	0.75	0.5–1.1	.2
DP	176	29%			
Lipase POD0					
Elevated	97	40%	5.09	2.5–10.5	<.001
Normal	103	12%			
Lipase POD1					
Elevated	193	35%	4.14	2.3–7.5	<.001
Normal	138	11%			
Lipase POD2					
Elevated	107	38%	2.60	1.5–4.4	<.001
Normal	187	19%			
Lipase POD3					
Elevated	54	41%	2.41	1.3–4.6	.007
Normal	185	22%			
Amylase POD0					
Elevated	53	43%	3.3	1.6–6.0	<.001
Normal	139	19%			
Amylase POD1					
Elevated	152	37%	2.9	1.7–4.8	<.001
Normal	179	17%			
Amylase POD2					
Elevated	84	33%	1.5	0.9–2.7	.12
Normal	200	25%			
Amylase POD3					
Elevated	28	32%	1.2	0.5–2.8	.67
Normal	184	28%			

BMI, body mass index; *CI*, confidence interval; *IQR*: interquartile range; *NAT*, neoadjuvant therapy; *OR*, odds ratio; *POD*, postoperative day; *POPF*, postoperative pancreatic fistula.

Table III
Incidence of POPF B/C after PD and DP stratified by presence of POHL and POHA

POPF		POHL+/ POHA+	POHL+/ POHA−	POHL−/ POHA+	POHL−/ POHA−	*P* value
No POPF		8 (18%)	10 (25%)	0 (0%)	63 (73%)	<.001
BL		18 (40%)	16 (40%)	3 (50%)	16 (19%)	
B		15 (33%)	11 (27.5%)	3 (50%)	6 (7.0%)	
C		4 (9%)	3 (7.5%)	0 (0%)	1 (1.2%)	
Total	177	45 (25%)	40 (22.5%)	6 (3%)	86 (48%)	

DP, distal pancreatectomy; *PD*, pancreaticoduodenectomy; *POHA*, postoperative hyperamylasemia; *POHL*, postoperative hyperlipasemia; *POPF*, postoperative pancreatic fistula.

development of POPF B/C. Furthermore, this is the first study to show POHL on POD0 as independent predictor for POPF B/C.

In our investigation, POHL and POHA emerged as a frequent biochemical occurrence after PD and DP. Notably, irrespective of whether patients developed POPF B/C, the median of serum lipase and amylase was the greatest on POD1, followed by a gradual decrease beginning on POD2. Consequently, the kinetics of

Table IV
Uni- and multivariate analysis of factors associated with POPF B/C after PD and DP ($n = 177$)

	Univariate analysis			Multivariate analysis		
	OR	95%CI	*P* value	OR	95%CI	*P* value
Age						
≥70	0.64	0.3–1.2	.2			
Sex						
Female	0.85	0.4–1.7	.6			
BMI						
≥24	3.16	1.5–6.5	.001	2.7	1.2–5.8	.01
Pathology						
High risk	3.2	1.6–6.7	.001			
NAT						
Yes	1.1	0.4–3.0	.8			
Operation						
PD	0.52	0.2–1.0	.07			
POHL POD0						
Elevated	5.20	2.4–11.4	<.001	4.3	1.8–9.7	<.001
POHA POD0						
Elevated	3.08	1.5–6.3	.002			

BMI, body mass index; *CI*, confidence interval; *DP*, distal pancreatectomy; *NAT*, neoadjuvant therapy; *NAT*, neoadjuvant therapy; *OR*, odds ratio; *PD*, pancreaticoduodenectomy; *POD*, postoperative day; *POHA*, postoperative hyperamylasemia; *POHL*, postoperative hyperlipasemia; *POPF*, postoperative pancreatic fistula.

postoperative serum lipase and amylase seem to be inadequate for predicting occurrence of POPF B/C. However, an elevation of these enzymes in the serum such as POHA over 130 U/L and POHL over 44.5 U/L has been reported to be a reliable predictor of POPF B/C. As a result, identifying patients who exhibit low-risk characteristics for POPF B/C on the basis of early biochemical markers could be valuable in facilitating the timely removal of drains. In our study population, patients with normal serum lipase on POD0 exhibited a 10% incidence of POPF grade B, with only 1 (1%) patient experiencing grade C. Conversely, among the same cohort of 177 patients, those with normal serum amylase levels had a 15% incidence (19/121) of POPF grade B and a 3.0% incidence (4/121) of POPF grade C. Therefore, these findings strengthen the potential of POHL on POD0 as an appealing biochemical marker for the identification of patients with a reduced risk of POPF B/C. Thus, these patients could undergo early drain removal and subsequent early hospital discharge in alignment with the Enhanced Recovery After Surgery guidelines.

Conversely, patients presenting with POHL on POD0 exhibited a 4-fold greater risk of developing clinically significant POPF grade B/C. Interestingly, the rate of POPF C was in this subgroup 8% in contrast to 1% in the non-POHL group. It is well-established that patients who develop POPF B/C face a mortality rate greater than 10%.[31] POPF B/C also can lead to additional complications, including intra-abdominal abscess formation and postoperative hemorrhage, owing to the aggressive nature of pancreatic enzymes.[32] Consequently, patients experiencing postoperative hemorrhage often require urgent radiologic intervention or revision surgery and treatment in the intensive care unit . Patients identified as high risk for developing POPF B/C could benefit from prolonged abdominal drain therapy, facilitating the drainage of abdominal fluids and enabling prompt diagnosis and intervention in cases of postoperative hemorrhage. Specifically, in patients without intraoperative drain insertion, POHL on POD0 could detect patients at high risk.

Study limitations

Despite being the largest investigation of its kind exploring the predictive utility of serum lipase levels in postoperative setting for

Table V
Patient characteristics and postoperative outcome stratified by POHL on POD0 (n = 177)

Variable	Non-POHL (n = 92) (52%)	POHL (n = 85) (48%)	P value
Sex			
Male	58 (63%)	48 (56%)	.3
Female	48 (37%)	52 (44%)	
Median age, yr (IQR)	74 (64–82)	69 (58–78)	.01
Median BMI, kg/m^2, (IQR)	20 (14–26)	25 (23–28)	.1
ASA			
I/II	12 (13%)	10 (12%)	.7
III/IV	79 (87%)	75 (88%)	
NAT			
Yes	15 (16%)	8 (9%)	.1
No	77 (84%)	77 (91%)	
Pathology			
PDAC/CP	62 (67%)	34 (40%)	<.001
Others	30 (33%)	51 (60%)	
EBL, mL (IQR)	600 (400–1,000)	600 (400–900)	.3
POPF, n (%)			
No POPF	63 (68%)	18 (21%)	<.001
BL	19 (21%)	34 (40%)	
POPF B	9 (10%)	26 (31%)	
POPF C	1 (1%)	7 (8%)	
Operation			
PD	59 (64%)	60 (70%)	.3
DP	33 (36%)	25 (30%)	
Operation time, min	330 (260–390)	330 (250–370)	.5
Vascular resection, n (%)			.01
Yes	23 (25%)	9 (11%)	
No	69 (75%)	76 (89%)	
Hospital stay, d (IQR)	20 (14–26)	21 (15–29)	.1
30-d mortality, n (%)	3 (3%)	2 (2%)	.7

ASA, American Society of Anesthesiologists; *BMI*, body mass index; *CP*, chronic pancreatitis; *DP*, distal pancreatectomy; *EBL*, estimated blood loss; *IQR*, interquartile range; *NAT*, neoadjuvant therapy; *PD*, pancreaticoduodenectomy; *PDAC*, pancreatic ductal adenocarcinoma; *POD*, postoperative day; *POHA*, postoperative hyperamylasemia; *POHL*, postoperative hyperlipasemia; *POPF*, postoperative pancreatic fistula.

the incidence of POPF B/C, the present study is not without limitations. This study is limited by its reliance on a single-center cohort and its retrospective, non-randomized design. In conclusion, our study highlights the potential of serum lipase on POD0 as a significant biochemical tool for identifying patients at a low or high risk of POPF B/C after pancreatic resection. Therefore, we propose that serum lipase, as it effectively indicates pancreatic damage, can be integrated into clinical practice alongside other relevant parameters.

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Conflicts of interest/Disclosure

The authors have indicated that they have no conflicts of interest regarding the content of this article.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, UA used ChatGPT 4 to refine language usage, correct grammar and punctuation errors to improve overall writing quality. After using ChatGPT 4, the authors (U.A., B.R., J.W.) reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Ughur Aghamaliyev: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Ganildo Cepele:** Data curation, Formal analysis, Methodology, Writing – review & editing. **Felix O. Hofmann:** Data curation, Writing – review & editing. **Mathilda Knoblauch:** Data curation, Writing – review & editing. **Claudius Kessler:** Data curation, Formal analysis, Writing – review & editing. **Alexander Crispin:** Formal analysis, Investigation, Methodology, Software, Validation, Writing – review & editing. **Maximilian Weniger:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Joachim Andrassy:** Conceptualization, Writing – review & editing. **Bernhard W. Renz:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. **Jens Werner:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [https://doi.org/10.1016/j.surg.2024.09.005].

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