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Research article

The visceral pancreatic neck anterior distance may be an effective parameter to predict post-pancreaticoduodenectomy clinically relevant postoperative pancreatic fistula

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ABSTRACT

Background: The clinically relevant postoperative pancreatic fistula (CR-POPF) is significantly correlated with a high post-pancreaticoduodenectomy (PD) mortality rate. Several studies have reported an association between visceral obesity and CR-POPF. Nevertheless, there are many technical difficulties and controversies in the measurement of visceral fat. The aim of this research was to determine whether the visceral pancreatic neck anterior distance (V-PNAD) was a credible predictor for CR-POPF.
Methods: We retrospectively analyzed the data of 216 patients who underwent PD in our center between January 2016 and August 2021. The correlation of patients' demographic information, imaging variables, and intraoperative data with CR-POPF was assessed. Furthermore, areas under the receiver operating characteristic curves for six distances (abdominal thickness, visceral thickness, abdominal width, visceral width, abdominal PNAD, V-PNAD) were used to identify the best imaging distance to predict POPF.
Results: In the multivariate logistic analysis, V-PNAD ($P < 0.01$) was the most significant risk factor for CR-POPF after PD. Males with a V-PNAD >3.97 cm or females with a V-PNAD >3.66 cm were included into the high-risk group. The high-risk group had a higher prevalence of CR-POPF (6.5% vs. 45.1%, $P < 0.001$), intraperitoneal infection (1.9% vs. 23.9%, $P < 0.001$), pulmonary infection (3.7% vs. 14.1%, $P = 0.012$), pleural effusion (17.8% vs. 33.8%, $P = 0.014$), and ascites (22.4% vs. 40.8%, $P = 0.009$) than the low-risk group.
Conclusion: Of all imaging distances, V-PNAD may be the most effective predictor of CR-POPF. Moreover, high-risk patients (males, V-PNAD >3.97 cm; females, V-PNAD >3.66 cm) have a high incidence of CR-POPF and poor short-term post-PD prognosis. Therefore, surgeons should perform PD carefully and take adequate preventive measures to reduce the incidence of pancreatic fistula when the patient has a high V-PNAD.

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1. Introduction

Pancreaticoduodenectomy (PD), one of the most complicated procedures in pancreatic surgery, is a curative treatment for periampullary malignancies [1,2]. Surgeons pay close attention to PD because of its associated perioperative mortality and postoperative morbidity. However, due to the successful early prediction of high-risk patients and improvement of surgical technique, post-PD mortality has decreased to less than 3% in high-volume centers [3]. A major complication of PD is postoperative pancreatic fistula (POPF), which has a very high mortality [4–6]. Clinically relevant postoperative pancreatic fistula (CR-POPF) is a key area of focus for surgeons according to the standard of the International Study Group of Pancreatic Fistula (ISGPS) [7].

Body mass index (BMI) plays a crucial role in predicting the occurrence of CR-POPF [8,9]; however, it is a not a good measure of abdominal fat. There are additional preoperative measures that can predict POPF, including fatty pancreas and fistula risk scores [10,11]. Further research focuses on visceral obesity, which is defined as a massive accumulation of visceral adipose tissue in the abdominal cavity [12,13]. Surgery in patients with extreme visceral obesity is generally considered to be challenging owing to the restricted surgical space, increased risk of accidental hemorrhage, and the difficulty in placement of drainage tubes [14]. Another significant aspect of visceral obesity is that the pro-inflammatory adipocytokines weaken the immune system and delay wound healing after PD [15]. Therefore, high levels of visceral adipose tissue will increase the risk of postoperative complications, especially POPF. In a previous study in which patients' intra-abdominal fat area was measured by imaging physicians using specialized measurement software, abdominal fat area (AFA) was a useful predictor of CR-POPF and direct factor of PD difficulty [16].

However, few surgeons are able to draw on specific devices and use them to accurately calculate AFA [17]. As a simple alternative, distance measurement using computed tomography (CT), is gradually being recognized by surgeons. In practical terms, the distance between the pancreatic neck and parietal peritoneum, called the visceral pancreatic neck anterior distance (V-PNAD), is important for better comprehension of the surgical difficulty and risk of pancreatic fistula. Compared with intraoperative measurement of the pancreatic texture, V-PNAD is more objective, has better quantitative values, and can be measured preoperatively. Furthermore, the intra-abdominal fat content of the patient can be evaluated by measuring the distance at the level of the third lumbar vertebra (L3), with a possibility of pancreatic fistula development.

This study aimed at assessing whether V-PNAD is a credible predictor for CR-POPF. In addition, we verified whether V-PNAD is the optimal value among several intra-abdominal distance measurements.

2. Material and methods

2.1. Study design and patients

The patients who underwent PD in The General Hospital of Western Theater Command between January 2016 and August 2021 (Fig. 1) were eligible for this retrospective study. The standard of the ISGPS was used in this study—CR-POPF was defined as POPF Grade B/C [7]. Ethical approval was obtained from our local ethics committee (2021EC3-42), and all procedures of this research complied with the Declaration of Helsinki World Medical Association. The patients provided informed consent for inclusion and the publication of their related images/data.

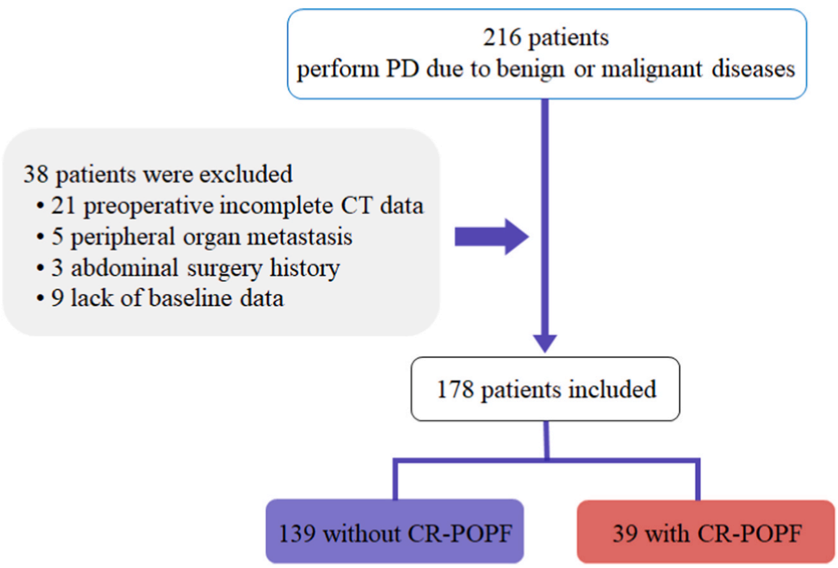


Fig. 1. Distribution of CR-POPF in patients.

2.2. Preoperative characteristics

The patients' demographic information (age and sex), clinical characteristics (weight, height, BMI, smoking and drinking habits, and comorbidities [diabetes or hypertension]), laboratory findings (hemoglobin, total bilirubin, albumin, C-reactive protein [CRP], and tumor marker [i.e., alpha fetoprotein, carcinoembryonic antigen, and cancer antigen 199] levels), and preoperative information (the American Society of Anesthesiologists' grade and abdominal surgery history) were collected.

2.3. Imaging variables

To control bias, two surgeons of the non-surgical team measured the imaging indexes from the patients preoperatively; the average was considered (Supplementary Table 1). Abdominal thickness (AT) referred to the distance between the most convex point of L3 and the abdominal wall. Visceral thickness (VT) referred to the distance between the most convex point of L3 and the parietal peritoneum (Fig. 2a and b). At L3, the gap between the AT and VT was made of subcutaneous fat. Abdominal width (AW) referred to the line perpendicular to AT through the most convex point of L3. VW (visceral width) was part of the AW. Their end point was the parietal peritoneum.

The pancreatic neck was defined as the anterior portion of the portal vein where the superior mesenteric vein meets the splenic vein. The main pancreatic duct (MPD) corresponded to the level of the maximum diameter at this anatomical location. The external surface connecting the pancreatic neck and abdominal wall was the abdominal pancreatic neck anterior distance (A-PNAD), which could reflect the amount of fat from the incision of the skin to the pancreas (Fig. 2c). In addition, the distance between the pancreatic neck and parietal peritoneum was named V-PNAD (visceral pancreatic neck anterior distance) (Fig. 2d). All imaging indexes were measured using Myrian software.

2.4. Surgical procedure

PD was performed by a specific team including three experienced pancreatic surgeons. The standard Whipple operation for choledochojejunostomy, gastrojejunostomy, and pancreaticojejunostomy was performed. After all the anastomoses were completed, the drain was inserted around the pancreaticojejunostomy and choledochojejunostomy. The abdominal drainage tube was not removed until the amylase level of the drainage fluid was normal three consecutive times after PD. Routine antibiotics were administered intraoperatively, while prophylactic somatostatin was administered postoperatively. A consistent postoperative management was used for PD patients. When the patient's gastrointestinal function recovered without CR-POPF, their diet was initiated gradually.

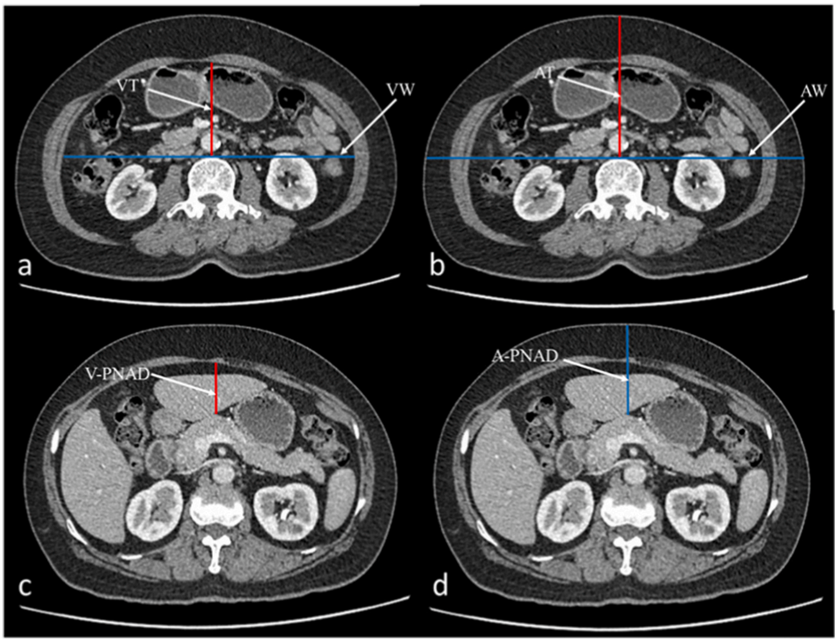


Fig. 2. Measurement of intra-abdominal distance. (a) Measurement of visceral thickness (VT) and visceral width (VW). (b) Measurement of abdominal thickness (AT) and abdominal width (AW). (c) Measurement of visceral pancreatic neck anterior distance (V-PNAD). (d) Measurement of abdominal pancreatic neck anterior distance (A-PNAD). VT, VW, AT and AW could be usually assessed on the same slice (L3). V-PNAD and A-PNAD could be usually assessed on the same slice (pancreatic neck level).

2.5. Statistical analysis

In this study, the categorical variables are expressed as absolute values and percentages. In addition, continuous variables are expressed as average ± standard deviation, while continuous variables with a skewed distribution are presented as median (interquartile range). The receiver operating characteristic (ROC) curves were created for the six distances from the images and CR-POPF. The best predictor was determined by comparing the ROC curves. Univariate logistic regression analysis was performed to identify variables associated specifically with CR-POPF. Indicators that were statistically different in the univariate analysis were included into the multivariate analysis, and independent risk factors were identified using stepwise regression. The ROC curves were drawn for male and female groups separately, and the cut-off PNAD was determined using the maximum Youden index. Finally, the patients were divided into high-risk and low-risk groups. The differences in the frequencies of the categorical variables (complications, perioperative diseases, and readmission) were assessed using the chi-square test by appropriate correction methods. The *t*-test and Mann–Whitney *U* test were performed when appropriate. The level of significance was set at 0.05. Statistical analyses were performed using SPSS software (SPSS 25 Inc. Chicago, IL, USA).

3. Results

3.1. Demographic data and preoperative variables

A total of 216 patients were eligible for the study. Of which, 38 were excluded for having incomplete preoperative CT data (n = 21), peripheral organ metastasis (n = 5), abdominal surgery history (n = 3), and lack of baseline data (n = 9). The remaining patients (n = 178) were then divided into two groups (CR-POPF and no CR-POPF) for analysis of the perioperative factors of CR-POPF (Fig. 1).

A total of 178 patients were included in our study: 139 (78.1%) patients in the no CR-POPF group and 39 (21.9%) patients in the CR-POPF group. The intraclass coefficient (ICC) results suggested that the measurement indexes of the two readers were consistent

Table 1
Characteristics of patients.

Variable	Total	No CR-POPF	CR-POPF	*P*
	n = 178	n = 139	n = 39	
Age (years ±SD)	58.2 ± 9.6	58.2 ± 9.8	58.3 ± 8.8	0.17
Gender (n, %)				0.19
Male	107 (60.1)	80 (57.6)	27 (69.2)	
Female	71 (39.9)	59 (42.4)	12 (30.8)	
Height (m, IQR)	1.60 (1.56–1.65)	1.60 (1.56–1.65)	1.61 (1.58–1.65)	0.19
Weight (kg ± SD)	57.4 ± 9.1	56.2 ± 8.8	61.5 ± 9.3	0.91
BMI (kg/m^2, n, %)				**<0.01**
<24	131 (73.6)	110 (79.1)	21 (53.8)	
≥24	47 (26.4)	29 (20.9)	18 (46.2)	
Smoker (n, %)	71 (39.9)	54 (38.8)	17 (43.6)	0.59
Drinker (n, %)	59 (33.1)	49 (35.3)	10 (25.6)	0.26
Comorbidities (n, %)				
Hypertension	33 (18.5)	23 (16.5)	10 ((25.6)	0.20
Diabetes	21(11.8)	16 (11.5)	5 (12.8)	1.00
Laboratory value				
Hemoglobin (g/dL, IQR)	12.8 (11.7–13.9)	12.7 (11.7–13.9)	13.2 (11.6–14.0)	0.57
Total bilirubin(μmol/L, IQR)	144.8 (28.9–231.0)	136.0 (25.9–225.5)	173.9 (41.4–295.6)	0.09
Albumin (g/dL ± SD)	4.07 ± 0.40	4.08 ± 0.41	4.03 ± 0.35	0.41
CRP(mg/L, IQR)	52.4 (12.2–99.0)	44.2 (12.1–89.1)	75.8 (24,8–121.5)	0.07
Tumor markers				
AFP (ng/ml, IQR)	3.3 (2.5–4.3)	3.4 (2.5–4.3)	3.1 (2.1–4.0)	0.11
CEA (ng/ml, IQR)	2.5 (1.6–4.1)	2.6(1.6–4.1)	2.3 (1.6–4.1)	0.72
CA199 (u/ml, IQR)	67.9 (21.5–234.7)	69.8 (21.9–231.0)	58.8 (20.6–251.4)	0.72
ASA classification (n, %)				0.89
1-2	163 (91.6)	128 (92.1)	35 (89.7)	
3-4	15 (8.4)	11 (7.9)	4 (10.3)	
MPD (mm, IQR)	2.84 (2.19–4.24)	3.08 (2.35–4.47)	2.32 (1.55–2.67)	**<0.01**
Image				
AT (cm ± SD)	9.07 ± 2.05	8.77 ± 1.98	10.15 ± 1.94	0.91
VT (cm ± SD)	6.83 ± 1.90	6.53 ± 1.81	7.87 ± 1.90	0.57
AW (cm ± SD)	28.26 ± 3.04	27.83 ± 2.95	29.80 ± 2.91	0.48
VW (cm ± SD)	23.37 ± 2.61	22.92 ± 2.46	24.97 ± 2.50	0.26
A-PNAD (cm, IQR)	5.20 (4.32–6.53)	4.91 (4.05–6.14)	6.52 (5.29–8.41)	**<0.01**
V-PNAD (cm, IQR)	3.54 (2.63–4.65)	3.28 (2.50–3.92)	4.69 (4.02–6.25)	**<0.01**

CR-POPF, clinically relevant postoperative pancreatic fistula. BMI, body mass index; ASA score, American Society of Anesthesiologists score; CRP, C-reactive protein; AFP, alpha-fetoprotein; CEA, carcinoembryonic antigen; MPD, main pancreatic duct. AT, abdominal thickness; VT, visceral thickness; AW, abdominal width; VW, visceral width; A-PNAD, abdominal pancreatic neck anterior distance; V-PNAD, visceral pancreatic neck anterior distance.

(ICC >0.75, $P < 0.05$; in Supplementary Table 1). Of the demographic variables, unlike BMI ($P < 0.01$), the differences in sex, height, weight, and smoking and drinking were not significant between the groups. The difference in CRP level between the two groups was not significant: no CR-POPF group, 69.8 mg/L; CR-POPF group, 58.8 mg/L, $P = 0.07$. The differences between the two groups are shown in Table 1. The patients in the CR-POPF group had a smaller diameter of the main pancreatic duct (3.08 vs. 2.32 mm, $P < 0.01$). The differences in A-PNAD (4.91 vs. 6.52 cm, $P < 0.01$) and V-PNAD (3.28 cm vs. 4.69 cm, $P < 0.01$) between the two groups were also significant.

3.2. Intraoperative data

Comparison of the different surgical variables (operation method: open PD vs. laparoscopic PD, operation time, estimated blood loss, pancreatic texture, vascular resection [yes/no], and blood transfusion) and short-term outcomes between the two groups are shown in Table 2. Although the average operation time was higher in the CR-POPF group, it was not significantly higher than that in the no CR-POPF group (436.2 vs. 447.5 min, $P = 0.22$). Furthermore, there were no significant differences in the implementation rate of vascular resection (portal vein and superior mesenteric vein) and malignancy types between the two groups (Table 2). The average length of stay in the CR-POPF group was five days longer than that in the no CR-POPF group (20 vs. 15 days, $P < 0.01$). The patients with CR-POPF had higher costs, which depicts real-life settings (64208.7 vs. 89095.8 yuan, $P < 0.01$).

3.3. Screening imaging data and risk factors

To identify the best imaging distance, the ROC curve was used to calculate the area under the curve (AUC) of the six distances (Fig. 3a–f). The AUC for visceral distance was greater than that for abdominal distance. The best predictor was V-PNAD (AUC = 0.801, $P < 0.01$). Considering the problem of collinearity, instead of other distance indicators, V-PNAD was included in further univariate and multivariate logistic analyses.

To explore the influencing factors of CR-POPF, some demographic, clinical, imaging, and intraoperative data were included into the univariate logistic analysis (Table 3). Total bilirubin and CRP levels seemed to predict CR-POPF but not significantly ($P = 0.07$). In the univariate logistic analysis, dilated MPD ($P < 0.01$) was identified as a protective factor, while soft pancreas ($P < 0.01$), large BMI ($P < 0.01$), and large V-PNAD ($P < 0.01$) were risk factors for CR-POPF after DP. Furthermore, a clear benefit of LPD in the prevention of CR-POPF could not be identified in this analysis ($P = 0.96$). Having screened which factors were related to CR-POPF, multivariate logistic analysis was used to identify independent risk factors. In the final model, soft pancreas (odds ratio, OR = 3.87, $P < 0.01$), small MPD (OR = 0.55, $P = 0.01$), and large V-PNAD (OR = 2.84, $P < 0.01$) were independent risk factors for POPF after PD.

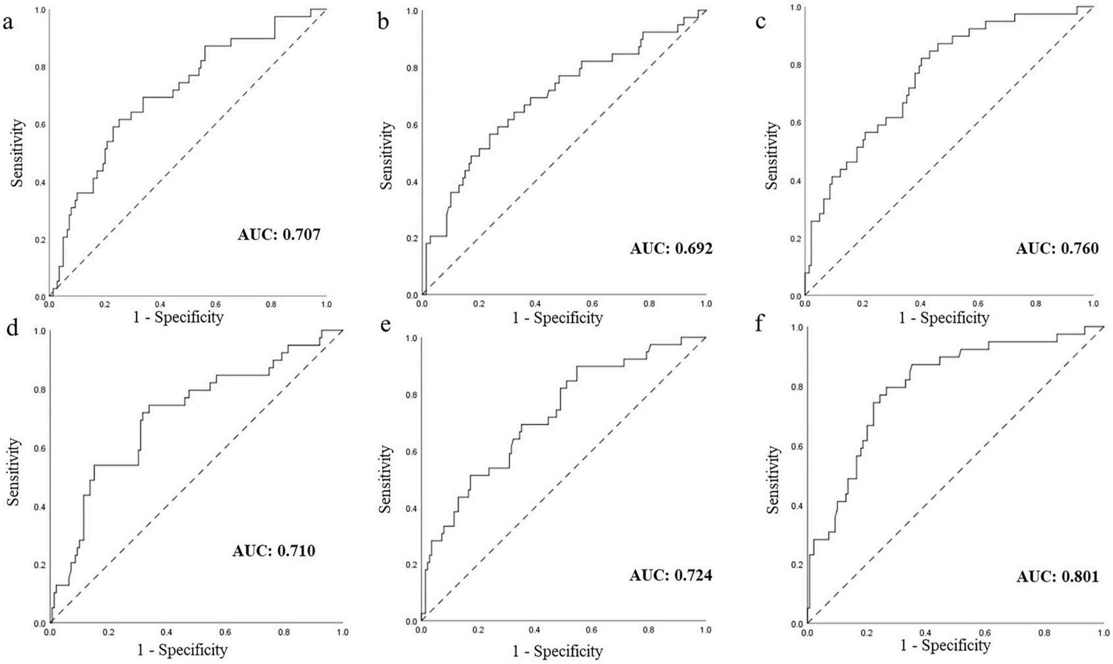
3.4. The impact of V-PNAD on CR-POPF

To evaluate the predictive effect of V-PNAD, we generated ROC curves according to sex due to their different physical characteristics (Fig. 4a and b). The patients were divided into high-risk groups (V-PNAD, male >3.97 cm or female >3.66 cm) and low-risk groups (V-PNAD, male ≤3.97 cm or female ≤3.66 cm) with reference to the cut-off value of the maximum Youden index. Additionally, intraoperative data and short-term prognosis were included in the analysis (Table 4). There were differences in operation time (423 ±

Table 2
Intraoperative and postoperative data.

Variable	Total	No CR-POPF	CR-POPF	*P*
	n = 178	n = 139	n = 39	
Operation (n, %)				0.91
Open	111 (62.4)	87 (62.6)	24 (61.5)	
Laparoscope	67 (37.6)	52 (37.4)	15 (38.5)	
Operation time (min ±SD)	438.7 ± 114.7	436.2 ± 120.3	447.5 ± 92.6	0.22
Blood loss (ml, IQR)	400 (300–550)	400 (300–550)	400 (300–600)	0.22
Vascular resection				
Portal vein (n, %)	13 (7.3)	8 (5.8)	5 (12.8)	0.25
Superior mesenteric vein (n, %)	2 (1.1)	2 (1.4)	0	0.32
Pancreatic texture (n, %)				**<0.01**
Soft	61 (34.3)	38 (27.3)	23 (59.0)	
Hard	117 (65.7)	101 (72.7)	16 (41.0)	
Blood transfusion (n, %)	67 (37.6)	50 (36.0)	17 (43.6)	0.39
Length of stay (d, IQR)	15 (12–21)	15 (11–19)	20 (26–29)	**<0.01**
Cost(¥, IQR)	69388.5 (56028.8–85839.3)	64208.7 (55124.7–80306.5)	89095.8 (78137.1–115398.2)	**<0.01**
Disease (n, %)				0.15
Pancreatic tumor	47 (26.4)	41 (29.5)	6 (15.4)	
Duodenal cancer	60 (33.7)	43 (30.9)	17 (43.6)	
Bile duct cancer	71 (39.9)	55 (39.6)	16 (41.0)	
Reoperation	4 (2.2)	2 (1.4)	2 (5.1)	0.21
Mortality	5 (2.8)	2 (1.4)	3 (7.7)	0.12

CR-POPF, clinically relevant postoperative pancreatic fistula. Reoperation and mortality were calculated within 30 days after operation.



(a) The ROC of abdominal thickness (AT). (b) The ROC of abdominal width (AW). (c) The ROC of abdominal pancreatic neck anterior distance(A-PNAD).
(d) The ROC of visceral thickness (VT). (e) The ROC of visceral width (VW). (f) The ROC of visceral pancreatic neck anterior distance(V-PNAD).

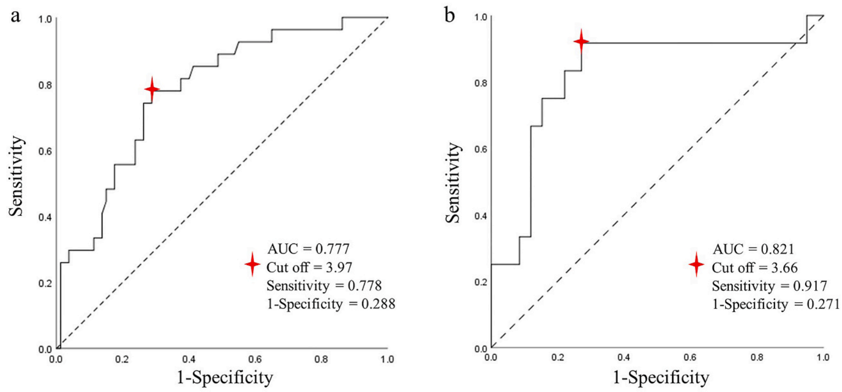
Fig. 3. AUC at different distances. (a) The ROC of abdominal thickness (AT). (b) The ROC of abdominal width (AW). (c) The ROC of abdominal pancreatic neck anterior distance (A-PNAD). (d).The ROC of visceral thickness (VT). (e) The ROC of visceral width (VW). (f) The ROC of visceral pancreatic neck anterior distance (V-PNAD).

Table 3
Univariate and multivariate analyses for CR-POPF.

Pre-operative variable	Univariate analysis			Multivariate analysis		
	OR	95% CI	*P*-value	OR	95% CI	*P*-value
Age (years)	1.00	0.96–1.04	0.96			
Comorbidities						
Hypertension	0.58	0.25–1.34	0.20			
Diabetes	0.86	0.30–2.58	0.82			
Laboratory value						
Hemoglobin (g/dL)	1.04	0.87–1.25	0.65			
Total bilirubin(μmol/L)	1.00	1.00–1.01	0.07			
Albumin (g/dL)	0.73	0.31–1.76	0.49			
CRP(mg/L)	1.01	1.00–1.01	0.07			
Soft pancreas	3.82	1.82–8.00	**<0.01**	3.87	1.53–9.79	**<0.01**
MPD (mm)	0.42	0.27–0.65	**<0.01**	0.55	0.36–0.84	**0.01**
BMI (kg/m^2)	1.22	1.08–1.38	**<0.01**	0.86	0.69–1.07	0.17
V-PNAD (cm)	2.31	1.70–3.14	**<0.01**	2.84	1,68–4.79	**<0.01**
Operation (OPD/LPD)	0.96	0.46–1.99	0.91			
Operation time	1.00	0.99–1.01	0.59			
Blood loss	1.00	0.99–1.01	0.78			

CR-POPF, clinically relevant postoperative pancreatic fistula. BMI, body mass index. CRP, C-reactive protein. MPD, main pancreatic duct. V-PNAD, visceral pancreatic neck anterior distance.

112 vs. 462 ± 115 min, $P = 0.03$) and surgical methods ($P = 0.05$) between the two groups. The higher complication rate was observed in the CR-POPF group (6.5% vs. 45.1%, $P < 0.01$). The differences in other complications such as intraperitoneal infection (1.9% vs. 23.9%, $P < 0.01$), pulmonary infection (3.7% vs. 14.1%, $P = 0.01$), pleural effusion (17.8% vs. 33.8%, $P = 0.01$), and ascites (22.4% vs. 40.8%, $P = 0.01$) were also significant. Postoperative hospital stay (14 [11–20] vs. 17 [14–28] days, $P < 0.01$), intensive care unit length of stay (4 [3–5] days vs. 4 [4,5] days, $P < 0.01$), and cost (64209 [55542–80773] yuan vs. 79600 [60452–94393] yuan, $P < 0.01$) were higher in the high-risk group due to the high incidence of complications.



(a) The cut-off value of male in V-PNAD (b) The cut-off value of female in V-PNAD

Fig. 4. Selection of cutoff values for different genders. (a) The cut-off value of male in V-PNAD. (b) The cut-off value of female in V-PNAD.

4. Discussion

The aim of this research was to determine whether the V-PNAD was a credible predictor for CR-POPF. Of all imaging distances, V-PNAD may be the most effective predictor of CR-POPF. Moreover, high-risk patients (males, V-PNAD >3.97 cm; females, V-PNAD >3.66 cm) have a high incidence of CR-POPF and poor short-term post-PD prognosis.

Previous studies have reported that CR-POPF occurred in 21.9% of patients after PD [18,19]. The MPD is often observed by surgeons using preoperative CT and has been proven to be closely related to CR-POPF, which is consistent with our study findings. In the multivariate logistic analysis, small MPD (OR = 0.52, $P < 0.01$) was a risk factor for CR-POPF. However, BMI did not show a strong predictive effect in our model; this is contrary to a previous study wherein high BMI was a crucial predictor of POPF Grade B/C [20]. Contrarily, Shimizu [21] et al. observed no significant difference in the incidence of CR-POPF between overweight, obese, and normal-weight patients. Given that the predictive effect of BMI on CR-POPF remains controversial, some scholars have suggested that intra-abdominal fat area may be a better surrogate index [22]. In our study, soft pancreas was an independent risk factor for CR-POPF (OR = 3.87, $P < 0.01$), which is consistent with previous studies [14,15]. Considering that pancreatic texture is assessed intra-operatively by the leading physician on palpation, V-PNAD has three advantages. First, it can be measured preoperatively using imaging metrics. Second, imaging data are objective. Third, while pancreatic texture is a dichotomous variable (soft or hard), V-PNAD

Table 4
Comparison of perioperative outcomes between two groups stratified.

Variable	Low risk group (107)	High risk group (71)	*P*-value
	Male ≤3.97 or Female ≤3.66	Male >3.97 or female >3.66	
Gender			0.68
Male (n, %)	63 (58.9)	44 (41.1)	
Female (n, %)	44 (62.0)	27 (38.0)	
Operation			**0.05**
Open (n, %)	73 (65.8)	38 (34.2)	
Laparoscope (n, %)	34 (50.7)	33 (49.3)	
Operation time (min ±SD)	423 ± 112	462 ± 115	**0.03**
Blood loss (ml, IQR)	400 (300–600)	400 (300–500)	0.64
CR-POPF, n (%)	7 (6.5)	32 (45.1)	**<0.01**
Other complications (n, %)			
Biliary leak	0	3 (4.2)	0.12
Chyle leak	5 (4.7)	5 (7.0)	0.75
Intraperitoneal infection	2 (1.9)	17 (23.9)	**<0.01**
Delayed gastric emptying	7 (6.5)	9 (12.7)	0.16
Pulmonary infection	4 (3.7)	10 (14.1)	**0.01**
Incision dehiscence	0	0	1
Pleural effusion	19 (17.8)	24 (33.8)	**0.01**
Ascites	24 (22.4)	29 (40.8)	**0.01**
ICU stay (d, IQR)	4 (3–5)	4 (4–5)	**<0.01**
Length of stay (days, IQR)	14 (11–20)	17 (14–28)	**<0.01**
Reoperation	3 (2.8)	1 (1.4)	0.92
Cost(¥, IQR)	64209 (55542–80773)	79600 (60452–94393)	**<0.01**
Mortality	2 (1.9)	3 (4.2)	0.64

CR-POPF, clinically relevant postoperative pancreatic fistula. ICU stay, postoperative ICU length of stay. Length of stay, postoperative hospital stay. Reoperation and mortality were calculated within 30 days after operation.

is a metered variable that quantifies the risk of POPF. The prediction of POPF has been explored by previous studies, and the most concerned are the fatty pancreas and fistula risk scores (FRS). An increasing number of surgeons are committed to judging the fat content of the pancreas through preoperative imaging. In addition, the FRS system is widely used in clinical practice. However, as a component of the FRS, pancreatic texture has been discussed in detail above, lacking more objective imaging measurement standards.

In the study by Pecorelli et al. wherein 202 patients who underwent pancreatic resection were included, visceral obesity was an independent predictor of POPF [23]. Body morphometric imaging has advanced considerably, and there is a growing body of literature that recognizes the importance of CT/magnetic resonance imaging in assessing the area of intra-abdominal fat [24]. Radiologists propose that AFA should be measured by setting the density at a threshold of −190 to −30 HU at L3 on CT [16,25]. Through the multivariate logistic analysis of imaging data of 103 patients who underwent PD, Tranchart et al. calculated the cut-off value (84 cm^2) and found that a visceral fat area (VFA) greater than the cut-off value was the only independent predictive factor of CR-POPF [26].

Unfortunately, the determination of AFA is technically challenging for surgeons. The measurement of AFA requires special imaging software and is a time-consuming process. As an alternative, some researchers have suggested that calculation of distances at L3, such as the portal vein distance and abdominal depth, may serve as predictors for the occurrence of a pancreatic fistula [17,27]. Four imaging indexes (AT, VT, AW, and VW) measured at L3 were included into this study; their effectiveness in predicting CR-POPF was compared. Visceral fat was more important than abdominal fat (AUC: 0.710 and 0.724 vs. 0.707 and 0.692). However, previous distance measurements at L3 were estimated based on the fat distribution throughout the abdomen rather than the pancreatic level. Of note, the PNAD has not been described previously. According to the AUC of PNAD, we can infer that V-PNAD may be a better predictor of CR-POPF (AUC = 0.801). The environment between the peritoneum and pancreas directly affects the difficulty of pancreatic exploration and pancreatojejunostomy in both LPD and OPD [28–30]. In previous studies, the fat level at L3 was calculated using AFA only; these variables are unsatisfactory because they do not consider the surgical entrance to the neck of the pancreas, which is the most important area of the surgery. Of note, V-PNAD represents the fat content from the pancreatic neck to the abdominal wall, and it has a higher value in patients with visceral obesity.

Men and women have varying physical indicators [31,32]. Sex is an important criterion as supported by the different VFA between male and female patients in a prior study [33]. However, most similar studies have ignored this difference [17,27]. We observed that male patients with a V-PNAD above 3.97 cm and female with a V-PNAD above 3.66 cm were high-risk patients. The comparison of two groups indicated that patients with higher V-PNAD had a longer duration of surgery. The high-risk group had a higher incidence of CR-POPF, longer postoperative hospital stay, and higher cost than the low-risk group. Therefore, surgeons should perform PD carefully and take adequate preventive measures to reduce the incidence of pancreatic fistula when the patient has a high V-PNAD.

This study has some limitations. Its single-center and retrospective nature may limit our study's generalizability; therefore, our results should be confirmed in a large, randomized clinical trial. Furthermore, our study included only Chinese patients; these findings may differ according to race. Although recent prospective studies demonstrate that there is no significant difference in postoperative complications between LPD and OPD, the subjectiveness of the surgical procedure might affect the results. Lastly, the major endpoint (CR-POPF) and other complications were considered 30 days after the operation because of the difficulty of follow-up.

In summary, V-PNAD calculated preoperatively using CT data is important in identifying high-risk patients. Of all the imaging distances for the level of intra-abdominal fat, V-PNAD may be the most effective predictor of CR-POPF. Male patients with a V-PNAD above 3.97 cm and female patients with a V-PNAD above 3.66 cm comprise the high-risk group with a high incidence of POPF and poor short-term prognosis. Surgeons should pay close attention to them and prevent the occurrence of CR-POPF during the perioperative period in a timely manner.

Ethics approval and consent to participate

The study was approved by the ethics committee of General Hospital of Western Theater Command. The ethical approval number is 2021EC3-42.

Patient consent for publication

All authors have read the article and agreed to publish it.

Author contribution statement

Zhirong Zhao: Conceived and designed the experiments; Analysed and interpreted the data; Wrote the paper. Lichen Zhou: Analyzed and interpreted the data; Contributed analysis tools and data; Wrote the paper. Li Han: Analyzed and interpreted the data; Wrote the paper. Shibo Zhou: Contributed analysis tools and data; Wrote the paper. Zhen Tan: Analyzed and interpreted the data; Wrote the paper. Ruiwu Dai: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare no competing interests.

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Not applicable' for that section.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e13660.

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