Bu et al. European Radiology (2025) 35:7560–7570
https://doi.org/10.1007/s00330-025-11766-z

European Radiology

HEPATOBILIARY-PANCREAS

Contrast-enhanced CT-based prediction models for early intervention efficacy and in-hospital mortality risk in acute necrotizing pancreatitis with persistent organ failure

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Abstract

Objective To develop contrast-enhanced CT-based nomograms for predicting early intervention efficacy and in-hospital mortality in acute necrotizing pancreatitis (ANP) with persistent organ failure (POF).

Materials and methods This retrospective study analyzed 164 ANP patients with POF (110 in the training cohort, 54 in the validation cohort). The Sequential Organ Failure Assessment (SOFA) score was used to evaluate organ dysfunction severity. Contrast-enhanced CT parameters included mean and range CT numbers (HU) of acute necrotic collections (ANC) across anatomical regions, as well as pancreatic necrosis volume (PNV). LASSO regression identified predictors for early intervention efficacy and mortality. Nomograms were assessed using receiver operating characteristic (ROC) curves, calibration curves, and decision curve analysis.

Results Early intervention efficacy predictors included intra-abdominal pressure, cardiovascular hemodynamic changes, and PNV increase. The model demonstrated good predictive performance, with an area under the ROC curve (AUC) of 0.848 (95% CI: 0.769–0.927) in the training cohort and 0.796 (95% CI: 0.644–0.947) in the validation cohort. In-hospital mortality predictors were SOFA score, cardiovascular hemodynamic changes, mean CT number of ANC at the right anterior pararenal space, and CT number range at the left paracolic gutter. The model showed AUCs of 0.918 (training cohort, 95% CI: 0.864–0.971) and 0.860 (validation cohort, 95% CI: 0.801–0.919).

Conclusion ANP patients with intra-abdominal hypertension or significant PNV increase who maintain cardiovascular hemodynamic stability are more likely to benefit from early intervention. An elevated SOFA score, persistent cardiovascular failure, and ANC with poor homogeneity or drainage difficulty are risk factors for in-hospital mortality.

Key Points

Question *The optimal timing for early invasive intervention remains controversial in ANP with POF.*
Findings *Nomogram models integrating organ dysfunction severity and contrast-enhanced CT imaging features can predict treatment response and clinical outcomes in ANP patients with POF.*
Clinical relevance *Our prediction models can identify patients who may benefit from early invasive intervention and assess in-hospital mortality risk for the entire cohort, providing a practical tool to guide clinical decision-making.*

Minchun Bu, Yun Zhang, and Faxi Chen contributed equally to this work.

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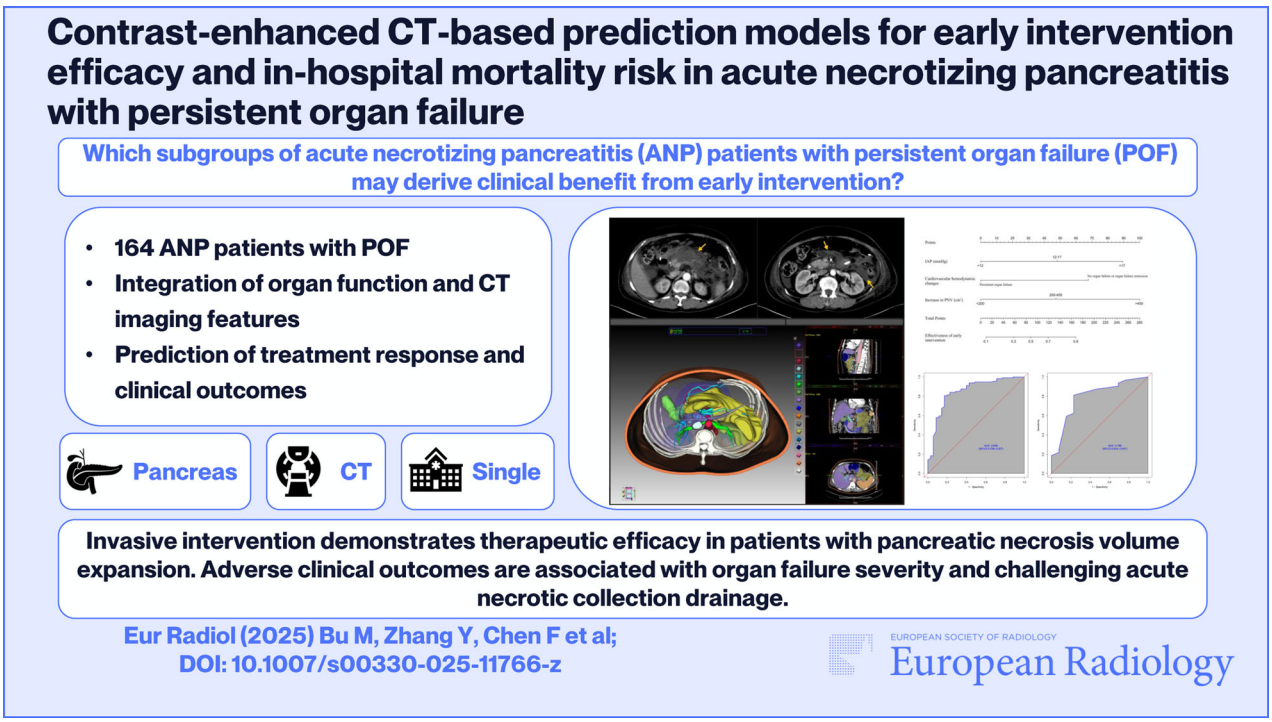
Keywords Acute necrotizing pancreatitis, Persistent organ failure, Early intervention, Predictive model, CT

Graphical Abstract



Introduction

Acute necrotizing pancreatitis (ANP) is a severe digestive system disorder that has been on the rise in recent years [1, 2]. Some patients may develop systemic inflammatory response syndrome in the early stage of ANP, and even organ failure (OF), leading to a high case-fatality rate [3, 4]. Acute necrotic collection (ANC), which contains fluid and solid elements derived from pancreatic parenchyma and/or peripancreatic tissues, represents a significant local complication of ANP and may involve single or multiple anatomical regions [2, 3]. Clinical evidence indicates that ANC and uncontrolled systemic inflammatory reactions are the drivers of OF within the early stage of ANP [5–7]. Consequently, accurate assessment of disease severity and effective treatments for OF are crucial to reducing mortality.

In addition to anti-infective therapy, nutritional support, and other symptomatic treatments for ANC in ANP patients, surgical intervention may be an effective approach [2–4]. Current guidelines recommend that invasive intervention for ANC should be delayed until at least 4 weeks after disease onset to allow liquefaction and encapsulation of necrotic tissue [2, 5]. Some studies have also indicated that invasive intervention may be considered for organ failure persisting for several weeks if conservative management fails or clinical deterioration occurs, as this may suggest underlying early-stage infection [3, 7]. However, the concept of "several weeks" remains vague, and to date, no clear guidelines exist to define the optimal timing for such interventions in this high-risk subgroup or to clarify which patients would benefit from early drainage [8, 9].

The extent of tissue necrosis caused by the inflammatory process in ANP can be rapidly quantified using computer-assisted imaging analysis [10]. Furthermore, research has demonstrated that pancreatic necrosis volume (PNV), which encompasses both pancreatic parenchyma and peripancreatic tissues, serves as a novel imaging biomarker for predicting the severity of acute pancreatitis (AP). PNV shows stronger correlations with infectious pancreatic necrosis (IPN), multiple organ failure (MOF), open abdominal surgery, intensive care unit (ICU) admission duration, and readmission rates compared to other clinical indicators [11, 12].

Previous study suggests that early intervention in ANP patients with persistent organ failure (POF) may confer

potential clinical benefits, including improved organ function and reduced mortality [8]. In this study, we aimed to develop predictive models assessing the efficacy of early intervention and in-hospital mortality risk by integrating clinical indicators and imaging features of ANP patients with POF.

Materials and methods

Study design

This study was a retrospective cohort study involving patients with AP admitted to the Severe Acute Pancreatitis Center at Jinling Hospital between January 2018 and December 2022. This cohort served as the training dataset. All data were extracted from the AP electronic database with the approval of the Ethics Committee of Jinling Hospital (No. 2019NZKY-003-03). The validation cohort data were derived from a multicenter prospective randomized controlled trial (RCT) investigating whether OF-oriented percutaneous drainage of ANC could improve clinical outcomes in severe acute pancreatitis (SAP) conducted between January 2020 and January 2023 [13]. No patient overlap existed between the RCT and the retrospective cohort. All patients or their family members signed the informed consent document for data collection and academic research on admission. For interventional approaches, the guideline-recommended "step-up" strategy for ANC was adopted, with percutaneous catheter drainage (PCD) serving as the initial step [3, 13].

The inclusion criteria were as follows: meeting the revised Atlanta diagnostic criteria for AP [14]; presence of pancreatic and/or peripancreatic tissue necrosis; presence of POF at day 14 post-onset or prior to intervention; age between 18 and 75 years; undergoing abdominal contrast-enhanced computed tomography (CECT) scan before intervention or within two weeks of onset; undergoing PCD within four weeks of onset.

The exclusion criteria were as follows: history of malignancy; AP in pregnancy, recurrent AP, and chronic pancreatitis; undergoing PCD or endoscopic debridement before admission; and cases with incomplete clinical data.

Clinical data collection and definition of OF

Clinical data collection included gender, age, etiology, C-reactive protein, intra-abdominal pressure (IAP) (measured via bladder manometry), sedative drug types, and analgesic medication doses (doses of opioids including fentanyl, morphine, sufentanil, and remifentanil, were converted to their remifentanil equivalents [15, 16]).

OF was evaluated using the Sequential Organ Failure Assessment (SOFA) score, a standardized tool for assessing six key systems in critically ill patients: respiratory, cardiovascular, hepatic, coagulation, renal, and neurological [17]. OF was defined when an individual organ received a score of ≥ 2; MOF was diagnosed when ≥ 2 organ systems met the OF criteria; POF was defined as OF lasting ≥ 48 h [8, 17]. Since most patients received PCD after two weeks of the disease course, laboratory indicators and organ function status were recorded on day 14 post-onset. For patients requiring intervention within 14 days of onset, clinical data from the day preceding the intervention were collected.

Change in SOFA scores for single-organ system function: patients were classified based on the difference between individual organ SOFA scores on day 7 and day 14 of disease onset (i.e., day 14 SOFA score − day 7 SOFA score). For those undergoing intervention within 14 days of onset, grouping was determined by the difference between pre-intervention and admission SOFA scores. Remission of organ dysfunction: defined as a score difference ≤ −1 (termed "remission"). Persistence of organ dysfunction: defined as a score difference ≥ 0 (termed "persistence"). No organ dysfunction: patients without organ dysfunction were observed between days 7 and 14. For example, in the respiratory system, patients were stratified into three groups: no respiratory failure group, respiratory failure remission group, and persistent respiratory failure group. The same classification criteria were applied to other organ systems (e.g., coagulation, hepatic, and renal).

The primary outcome of this study was the effectiveness of early intervention, defined by the following criteria: a reduction in the total SOFA score by ≥ 2 points at 1-week post-PCD; no increase in any individual organ system SOFA score at the same time. The effective rate was defined as the proportion of patients achieving these predefined clinical benefits. The secondary outcomes were major complications (IPN, intra-abdominal hemorrhage, intestinal fistula, and pancreatic fistula), laparotomy, 30-day mortality, and in-hospital mortality.

CT scan protocol

Abdominal CECT data of patients on admission (within 7 days of disease onset) and during the second week post-onset or prior to intervention were retrospectively collected and evaluated. For instance, one patient underwent therapeutic intervention on post-onset day 13, with CT scans acquired at days 3 and 12 of the disease course; another patient received treatment at 21 days after onset, with imaging performed on days 7 and 14. Since all patients underwent intervention within four weeks of disease onset, the interval between completion of the second CT scan and finalization of the prediction model typically did not exceed two weeks. All CT scans were performed using a 64-row multi-detector CT scanner (SOMATOM Definition Flash, Siemens Healthineers).

Detailed parameters for image acquisition are provided in Table S1. Following the acquisition of non-contrast images in the supine position, an iodinated contrast agent was administered intravenously through the antecubital vein using a dual-syringe high-pressure injector. A 40-mL saline flush was then administered at the same flow rate.

Image analysis

CECT images were transferred to a dedicated post-processing workstation (Report 3D Viewer, EDDA Technology). All subsequent analyses, including image processing and parameter calculations, were performed using its integrated software modules. Baseline PNV was quantified from the initial CT scan, whereas additional parameters were derived from the second CT scan. The anatomical locations of ANC and associated parameters were independently assessed by two senior abdominal radiologists (X.M. and Q.D., with 15 years and 20 years of experience in abdominal imaging, respectively). The ANCs in different regions were marked (Fig. 1), and the software automatically measured the mean CT number (in Hounsfield units, HU) [18] and the range of CT numbers (i.e., distribution span, defined as the difference between the maximum and minimum CT numbers within the demarcated region). Pancreatic and/or peripancreatic necrotic tissue was manually delineated slice-by-slice using a semi-automatic tool based on tissue density. Subsequently, the software generated a three-dimensional reconstruction of the segmented region, and PNV was automatically calculated in cubic centimeters (Fig. 2). The computed tomography severity index (CTSI) score was evaluated based on the Balthazar grading system [19, 20], which quantifies necrosis of pancreatic parenchyma as the volume fraction of non-enhancing parenchyma on CECT, and necrosis was categorized as: (1) < 30% of total pancreatic volume; (2) 30–50%; (3) > 50%.

According to CECT images, the sites of pancreatic parenchymal necrosis were divided into: (1) pancreatic head; (2) pancreatic neck; (3) pancreatic body; (4) pancreatic tail. The locations of ANC were categorized as: (1) omental bursa; (2) anterior pararenal space (left/right); (3) posterior pararenal space (left/right); (4) paracolic gutter (left/right); (5) pelvic cavity; (6) mesentery and transverse mesocolon; and (7) greater omentum.

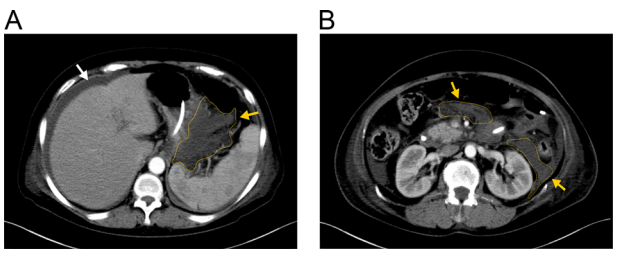


Fig. 1 Labels indicating ANC (yellow arrows) and ascites (white arrows). **A** Omental bursa. **B** Left anterior pararenal space and colonic mesentery. ANC, acute necrotic collection

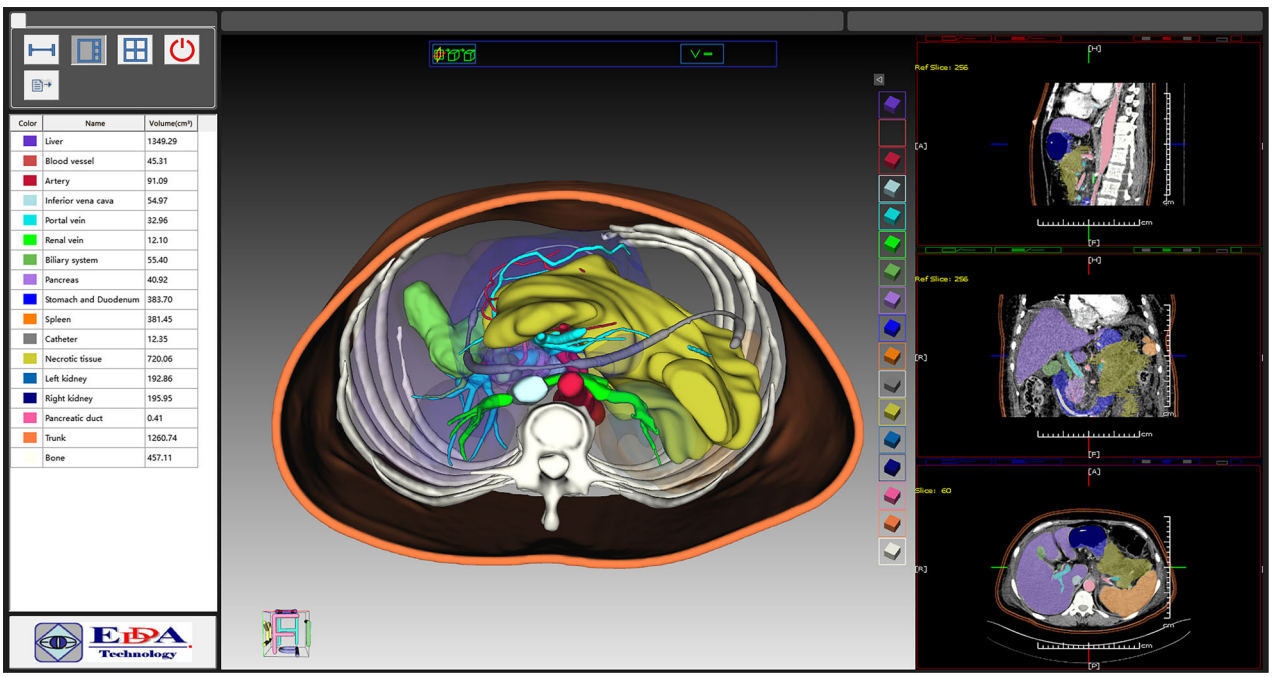


Fig. 2 Delineation and measurement of PNV (marked in yellow). PNV, pancreatic necrosis volume

Statistical analysis

All analyses were performed using R software (version 4.2.3). Normally distributed continuous variables were expressed as mean ± standard deviation, with between-group differences analyzed using Student's *t*-test. Non-normally distributed continuous variables were presented as median (interquartile range, IQR) and compared between groups using the Mann–Whitney *U*-test. Categorical variables were presented as frequency (percentage), with intergroup comparisons conducted through the χ^2 test or Fisher's exact test. The intraclass correlation coefficient (ICC) was calculated to evaluate agreement between observers in PNV delineation and quantification. Continuous variables (including SOFA score, IAP, PNV, mean CT number, and range of CT numbers) were stratified into three groups based on IQR thresholds. Least absolute shrinkage and selection operator (LASSO) logistic regression was conducted to select optimal predictive factors. Model fit was assessed with the Hosmer-Lemeshow goodness-of-fit test. The predictive performance of the models was evaluated through receiver operating characteristic (ROC) curve analysis with area under the curve (AUC), calibration curves, and decision curve analysis (DCA). A two-tailed p-value < 0.05 was considered statistically significant.

Results

Baseline clinical characteristics

The flow chart of this study is shown in Fig. 3. In total, 110 ANP patients were assigned to the training cohort, 25 of whom underwent PCD within 14 days of onset. Similarly, 54 ANP patients were assigned to the validation cohort, 20 of whom underwent PCD within 14 days of onset. POF was present in all patients either at day 14 post-onset or before intervention, and there were no significant differences in baseline clinical characteristics between the training and validation cohorts (Tables 1 and S2). Based on the definition of effective early intervention in this study, the effective rate post-intervention was 77.3% (85/110) in the training cohort and 74.1% (40/54) in the validation cohort. There were no significant differences between the two groups in terms of laparotomy ($p = 0.536$), 30-day mortality ($p = 0.722$), or in-hospital mortality ($p = 0.847$), but the training cohort exhibited a higher incidence of IPN.

Imaging characteristics

An excellent inter-observer agreement was observed for evaluating PNV on admission and before intervention, with ICCs of 0.88 (95% CI: 0.82–0.90) and 0.92 (95% CI: 0.87–0.96), respectively. PNV during the second week after onset or prior to intervention increased in both cohorts compared with baseline values on admission, although no significant difference was observed between the two cohorts ($p = 0.457$). The most common site of pancreatic necrosis was the pancreatic body, accounting for 90.9% of patients in the training cohort and 55.6% in the validation cohort. Pancreatic parenchymal necrosis volume exceeding 50% was observed in 44.5% of patients in the training cohort and 29.6% in the validation cohort, but the difference between the groups was not significant ($p = 0.082$). No significant differences were observed in other imaging features (Tables 2 and S3).

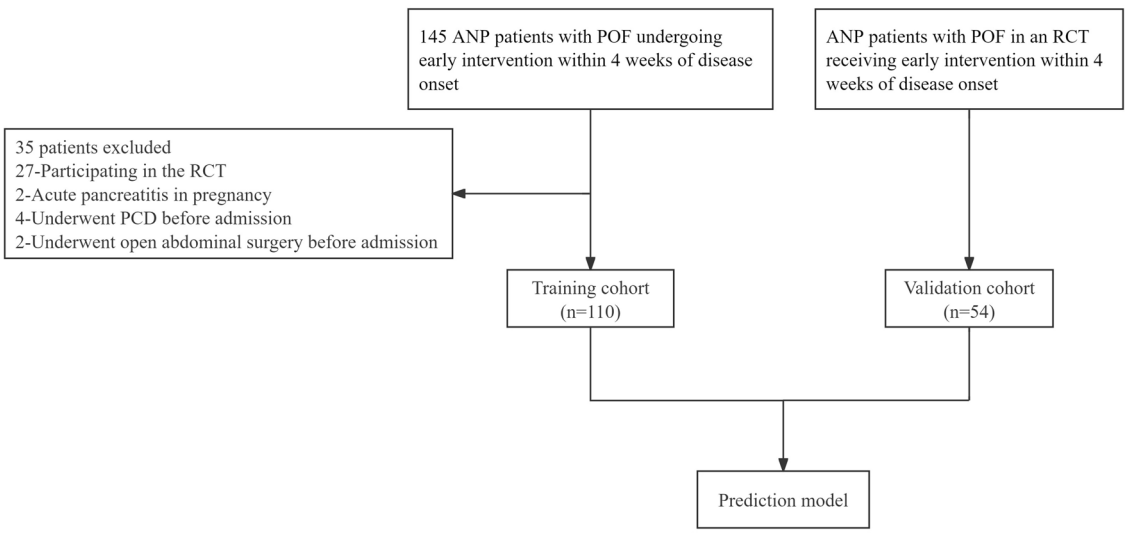


Fig. 3 The flow chart of the study design. ANP, acute necrotizing pancreatitis; POF, persistent organ failure; RCT, randomized controlled trial; PCD, percutaneous catheter drainage

Table 1 Baseline characteristics and clinical outcomes of patients

Indicators	Training cohort ($n = 110$)	Validation cohort ($n = 54$)	p
Age (year)	45.0 (35.0–53.0)	43.5 (35.0–49.0)	0.382
Sex			0.085
Male	71 (64.5)	42 (77.8)	
Female	39 (35.5)	12 (22.2)	
Etiology			0.061
Biliary	45 (40.9)	13 (24.1)	
Hypertriglyceridemia	60 (54.5)	36 (66.7)	
Alcoholic	4 (3.6)	2 (3.7)	
Other causes	1 (0.9)	3 (5.6)	
SOFA score	5.0 (4.0–8.0)	4.5 (4.0–7.0)	0.097
Sedation			0.261
No medication	42 (38.2)	27 (50.0)	
Single medication	39 (35.5)	13 (24.1)	
Combined medication	29 (26.4)	14 (25.9)	
Remifentanil equivalent (mg)	3.0 (2.0–6.0)	3.0 (1.5–6.0)	0.079
IAP (mmHg)	14.5 (12.0–17.0)	15.0 (12.0–18.0)	0.125
CRP (mg/L)	171.2 (107.0–205.5)	153.8 (99.8–201.2)	0.078
Complication			
Infected pancreatic necrosis	96 (87.3)	32 (59.3)	< 0.001
Intestinal fistula	36 (32.7)	10 (18.5)	0.057
Intra-abdominal hemorrhage	47 (42.7)	15 (27.8)	0.064
Pancreatic fistula	38 (34.5)	14 (25.9)	0.265
Laparotomy	25 (22.7)	10 (18.5)	0.536
30-day mortality	16 (14.5)	9 (16.7)	0.722
In-hospital mortality	23 (20.9)	12 (22.2)	0.847

SOFA Sequential Organ Failure Assessment, *IAP* intra-abdominal pressure, *CRP* C-reactive protein

Continuous variables were presented as median (IQR); categorical variables as *n* (%)

Predictive model for the efficacy of early intervention

All candidate variables were included in the LASSO regression analysis, and three potential predictors were screened out (Fig. 4), including IAP, cardiovascular hemodynamic changes occurring within 7–14 days of onset or before intervention, and an increase in PNV. These predictors were incorporated into the nomogram (Fig. 5). The Hosmer-Lemeshow goodness-of-fit test indicated a good model fit ($p = 0.154$). The nomogram demonstrated reliable predictive performance, with AUCs of 0.848 (95% CI: 0.769–0.927) in the training cohort and 0.796 (95% CI: 0.644–0.947) in the validation cohort (Fig. 6A, B). Calibration curves showed that the predicted probabilities were very close to the actual probabilities (Fig. 6C, D). DCA revealed that the model provided a positive net clinical benefit compared to the treat-all and treat-none strategies across threshold probability ranges of 0.13–0.72 in the training cohort and 0.08–0.47 in the validation cohort (Fig. 6E, F).

Predictive model for in-hospital mortality risk

Based on the LASSO regression analysis, four potential predictive factors associated with in-hospital mortality were selected (Fig. S1). These included the SOFA score at day 14 of onset or before intervention, cardiovascular hemodynamic changes occurring during days 7 to 14 after disease onset or before intervention, the mean CT number of ANC at the right anterior pararenal space, and the range of CT numbers of ANC at the left paracolic gutter. A nomogram model was subsequently developed (Fig. S2). The Hosmer-Lemeshow test indicated a good model fit ($p = 0.304$). ROC analysis demonstrated high predictive accuracy, with AUCs of 0.918 (95% CI: 0.864–0.971) in the training cohort and 0.860 (95% CI: 0.801–0.919) in the validation cohort (Fig. S3A, B). Calibration curves showed close alignment between predicted probabilities and actual outcomes (Fig. S3C, D). DCA demonstrated that the nomogram provided significant clinical benefits across a wide threshold probability range, thereby effectively identifying high-risk patients in both cohorts (Fig. S3E, F).

Discussion

By integrating organ functional status and local imaging characteristics, this study developed predictive models for evaluating the efficacy of early intervention and in-hospital mortality risk in ANP patients with POF. The findings suggested that patients with intra-abdominal hypertension (IAH) or a significant increase in PNV who maintain cardiovascular hemodynamic stability are more likely to benefit from early invasive intervention. The mortality risk prediction model demonstrated a strong association between elevated SOFA score and in-hospital mortality. Regarding organ specificity, persistent cardiovascular failure was independently associated with mortality. Among imaging parameters, the mean CT number of ANC in the right anterior pararenal space and the range of CT numbers of ANC in the left paracolic gutter showed significant associations with clinical prognosis.

In ANP, damage-associated molecular patterns released from necrotic tissues exacerbate systemic inflammatory responses by activating macrophages and neutrophils, leading to direct impairment of distal organ function [21]. While hypotension or shock resulting from microcirculatory dysfunction and capillary leakage significantly increases fluid requirements in ANP patients, aggressive early fluid therapy may paradoxically aggravate IAH [22–25]. Al-Bahrani et al reported a correlation between

Table 2 Imaging features based on three-dimensional reconstruction

Indicators	Training cohort ($n = 110$)	Validation cohort ($n = 54$)	*p*
PNV based on the initial CT scan (cm^3)	513.56 (359.54–769.22)	447.85 (337.30–657.25)	0.271
PNV based on the second CT scan (cm^3)	809.56 (519.60–1033.43)	707.33 (437.28–916.17)	0.354
Increase in PNV (cm^3)	217.78 (113.90–348.50)	189.28 (97.27–295.64)	0.457
Extent of pancreatic parenchymal necrosis			0.082
< 30%	20 (18.1)	10 (18.5)	
30–50%	41 (37.3)	28 (51.9)	
> 50%	49 (44.5)	16 (29.6)	
Location of pancreatic necrosis			0.305
Head	60 (54.5)	9 (16.7)	
Neck	89 (80.9)	25 (46.3)	
Body	100 (90.9)	30 (55.6)	
Tail	95 (86.4)	20 (37.0)	
CTSI	8 (8–10)	8 (8–10)	0.075

PNV pancreatic necrosis volume, *CTSI* computed tomography severity index
Continuous variables were presented as median (IQR); categorical variables as *n* (%)

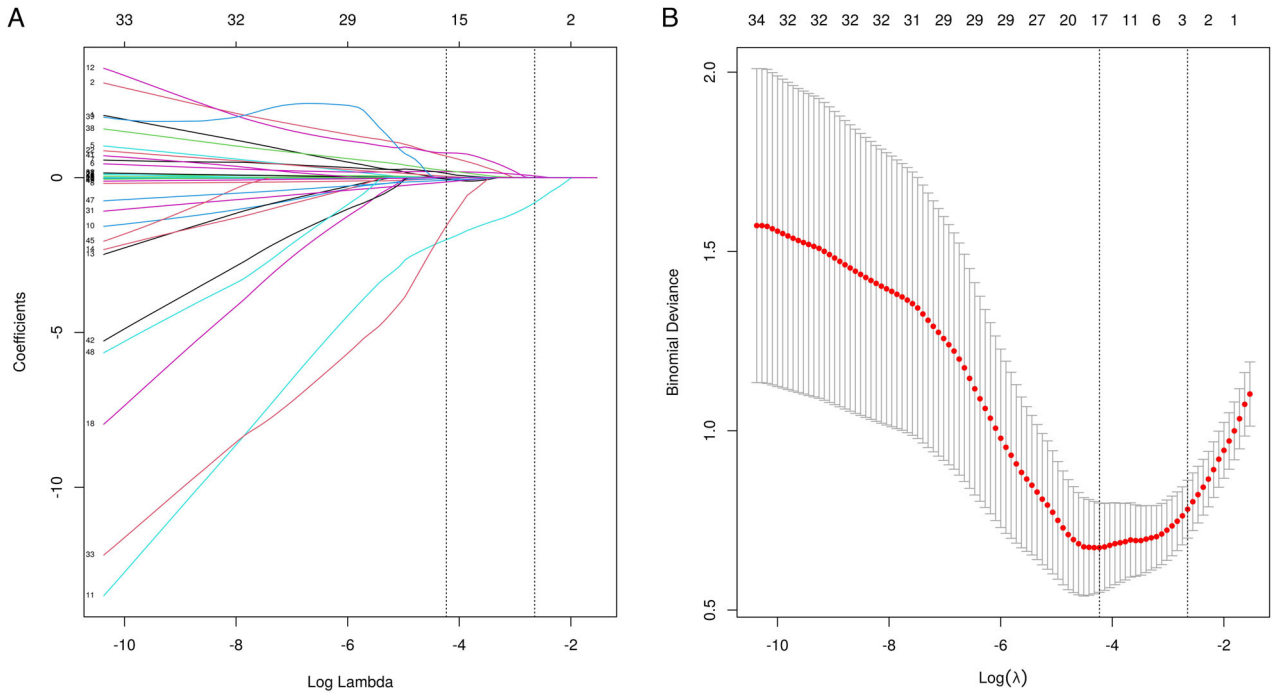


Fig. 4 LASSO regression analysis screening predictive factors for the efficacy of early intervention in ANP patients with POF. **A** LASSO coefficients for all candidate variables. **B** Screening of the optimal penalization coefficient. LASSO, least absolute shrinkage and selection operator; ANP, acute necrotizing pancreatitis; POF, persistent organ failure

elevated IAP, procalcitonin levels, and reduced anti-endotoxin immunoglobulin titers (a biomarker of intestinal barrier dysfunction), which gradually returned to normal with the remission of IAH [26]. Although surgical decompression rapidly alleviates IAH, it carries substantial risks of complications such as enterocutaneous fistula and hemorrhage [24]. Therefore, non-operative management—including nasogastric decompression, prokinetic agents, and PCD—is preferred for SAP patients with IAH [25]. Consistent with prior evidence, our findings indicate that patients with IAH derive greater benefit from early intervention.

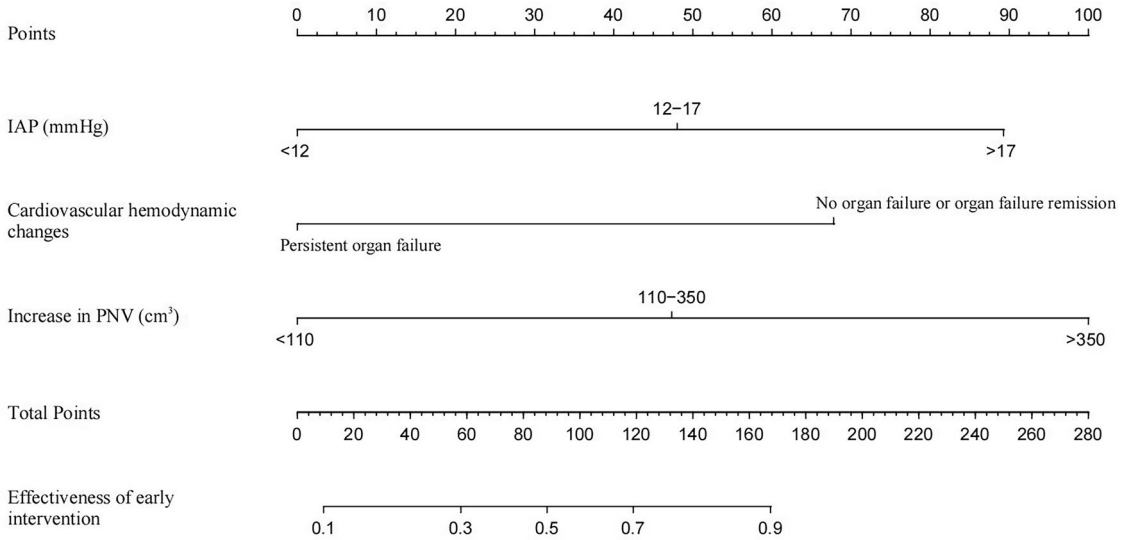


Fig. 5 Nomogram for predicting the efficacy of early intervention in ANP patients with POF. ANP, acute necrotizing pancreatitis; POF, persistent organ failure; IAP, intra-abdominal pressure; PNV, pancreatic necrosis volume

Beyond systemic factors, the extent of ANC critically influences ANP severity [11, 27, 28]. A retrospective analysis of 167 ANP patients identified PNV as an independent predictor of hospital readmission and reintervention risk [12]. Lun et al further validated the predictive value of imaging biomarkers in assessing disease severity and guiding therapeutic strategies for ANP, demonstrating that PNV and mean CT attenuation value reliably predict poor outcomes and intervention requirements [29]. Similarly, our findings indicate that dynamic ANC volume changes may have predictive value for early intervention strategies. This appears to be associated with IAH resulting from increased PNV. Notably, the dynamic changes in PNV may bear a potential association with disconnected pancreatic duct syndrome (DPDS), wherein extensive pancreatic necrosis could compromise ductal integrity, resulting in secondary ductal disruption; this rupture subsequently triggers pancreatic juice leakage and enzymatic activation that exacerbates peri-pancreatic necrosis [30, 31]. However, due to the limited sensitivity of early DPDS diagnosis [31], these pathophysiological connections warrant further exploration in future studies.

ANC with POF is a major reason for early mortality in ANP patients, and dynamic clustering of OF progression patterns enables patient stratification and facilitates personalized therapeutic strategies [32]. A multicenter observational cohort study investigating temporal SOFA score trajectories during the initial 14-day ICU admission demonstrated that baseline SOFA scores effectively predict in-hospital mortality among critically ill patients, with the AUC reaching 0.77 [33]. This study establishes the SOFA score as an independent predictor of in-hospital mortality, highlighting that timely interventions to reverse multiple organ dysfunction syndrome are a critical therapeutic strategy. Our medical institution is a comprehensive treatment center mainly focused on surgical therapy. For this specific patient cohort, conservative management—including organ function support and enteral nutrition—is prioritized as the initial approach. In cases where OF persists without improvement, minimally invasive interventions are typically employed. Open abdominal surgery is considered the last resort for patients who exhibit suboptimal response to minimally invasive therapies. From an organ-specific perspective, persistent cardiovascular failure is a significant predictor of adverse clinical outcomes, whereas stable cardiovascular hemodynamics correlate with favorable responses to early treatment. An observational study demonstrated that elevated creatine kinase-MB levels are independently associated with increased mortality and incidence of IPN in AP patients [34]. These findings underscore the critical role of maintaining cardiovascular hemodynamic stability in the multimodal therapeutic strategy for ANP.

In addition, this study identifies regional features of ANC as significant predictors in mortality risk models, consistent with findings by Liu et al [29]. Elevated CT numbers suggest massive necrosis, limiting the efficacy of percutaneous drainage [35, 36]. Concurrently, higher CT numbers may indicate pancreatic hemorrhage; retrospective evidence shows spontaneous hemorrhage in early SAP predicts poor prognosis, with CTSI and serum creatinine levels serving as independent hemorrhage risk

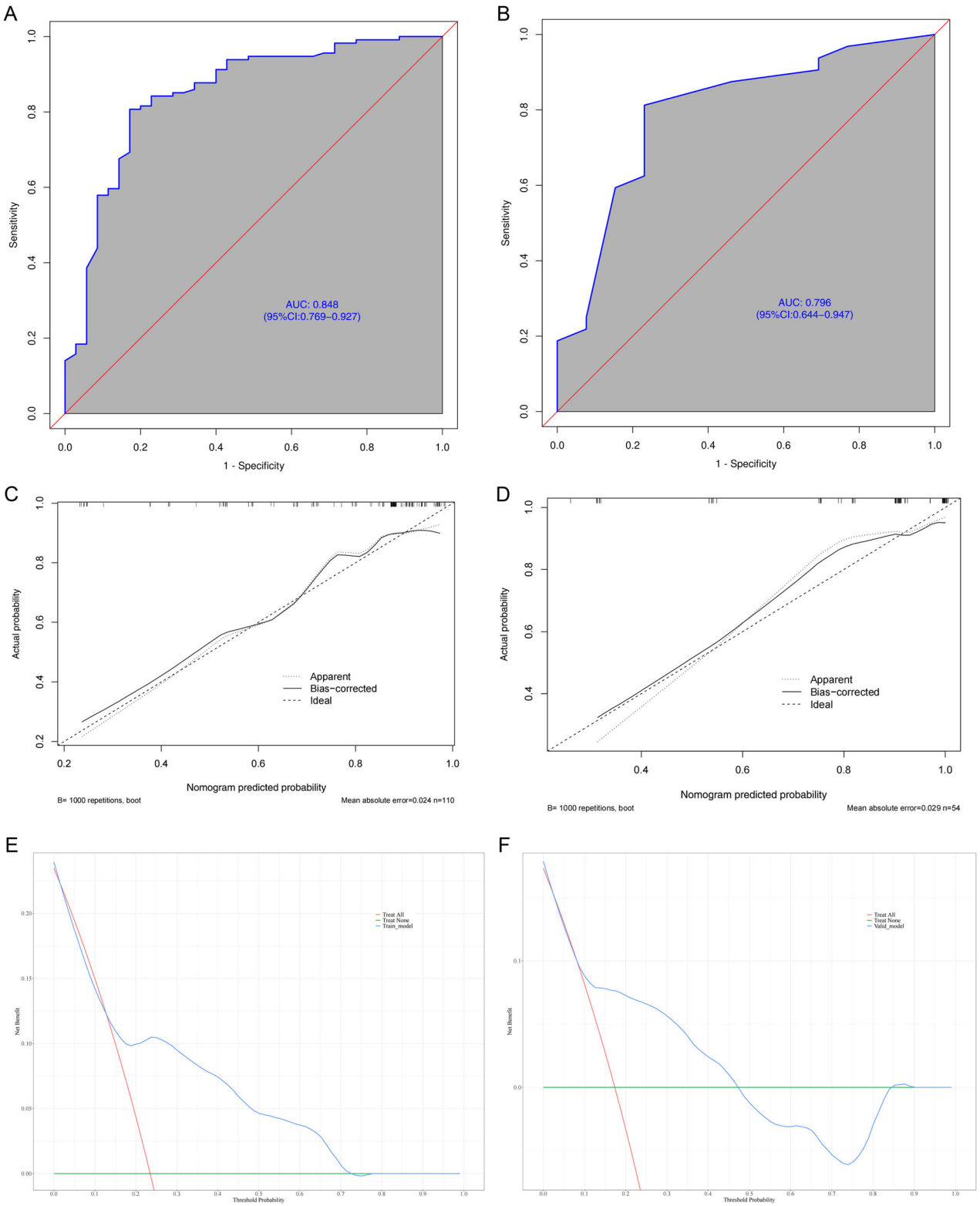


Fig. 6 Performance evaluation of the prediction model for early intervention efficacy. **A** ROC curve and AUC in the training cohort. **B** ROC curve and AUC in the validation cohort. **C** Calibration curve in the training cohort. **D** Calibration curve in the validation cohort. **E** DCA in the training cohort. **F** DCA in the validation cohort. ROC, receiver operating characteristic curve; AUC, area under the curve; DCA, decision curve analysis

factors [37]. The increase in the range of CT numbers indicates higher heterogeneity in local necrosis, which also limits the efficacy of early percutaneous drainage [35, 36]. The ANC located in an anatomically complex region (e.g., paracolic gutter) is considered to have more potential difficulties in drainage [38, 39]. Moreover, the anterior pararenal space ANC correlates with more complications (intestinal fistulae, intraperitoneal hemorrhage), independently predicting in-hospital mortality [39].

This study also has some limitations. First, the single-center design of the training cohort may fail to fully represent the disease characteristics of the target population, and the small sample size of the validation cohort may result in insufficient power to detect overfitting. Second, although two CECT scans were systematically acquired within 14 days of onset, varied examination intervals may introduce temporal bias in necrosis progression characterization. Third, this study employed fixed scan timing for contrast-enhanced phases. While this approach aligns with clinical guidelines and ensures reproducibility, we acknowledge that individual variations in hemodynamics may lead to suboptimal enhancement timing, potentially affecting CT number accuracy. Future studies could integrate bolus-tracking or AI-based timing prediction to further minimize variability. Fourth, CT numbers are inherently influenced by device-specific factors. Although all scans in this study were acquired using a standardized protocol, the generalizability of absolute CT numbers to other imaging systems may be limited. In the next phase, we will design a prospective study to develop detailed CT scanning protocols for validating the model's predictive performance, while placing greater emphasis on long-term outcomes in this patient population, including nutritional status, quality of life, and other relevant clinical indicators.

Conclusions

In summary, invasive intervention demonstrates favorable therapeutic efficacy in patients with IAH or significant PNV expansion when cardiovascular hemodynamic stability is maintained. Risk factors for in-hospital mortality include elevated SOFA score, persistent cardiovascular failure, and ANC with poor homogeneity or difficulty in drainage. These findings contribute to guiding clinical treatment decisions and offer directions for designing more refined studies in the future.

Abbreviations

ANC	Acute necrotic collection
ANP	Acute necrotizing pancreatitis
AP	Acute pancreatitis
AUC	Area under the curve
CECT	Contrast-enhanced computed tomography
CTSI	Computed tomography severity index
DCA	Decision curve analysis
DPDS	Disconnected pancreatic duct syndrome
HU	Hounsfield units
IAH	Intra-abdominal hypertension
IAP	Intra-abdominal pressure
ICC	Intraclass correlation coefficient
ICU	Intensive care unit
IQR	Interquartile range
LASSO	Least absolute shrinkage and selection operator
MOF	Multiple organ failure
OF	Organ failure
PCD	Percutaneous catheter drainage
PNV	Pancreatic necrosis volume
POF	Persistent organ failure
RCT	Randomized controlled trial
ROC	Receiver operating characteristic curve
SAP	Severe acute pancreatitis
SOFA	Sequential Organ Failure Assessment

Supplementary information

The online version contains supplementary material available at https://doi.org/10.1007/s00330-025-11766-z.

Acknowledgements

We thank Xu Meng and Qiang Diao for imaging data curation and analysis, with methodological guidance and critical revisions provided by Lu Ke and Bo Ye.

Funding

We gratefully acknowledge the support from the clinical special research fund of the Affiliated Jinling Hospital of Nanjing University Medical School (Grant no. 22LCYY-QH3).

Compliance with ethical standards

Guarantor

The scientific guarantor of this publication is Gang Li.

Conflict of interest

The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry

No complex statistical methods were necessary for this paper.

Informed consent

Written informed consent was waived by the Institutional Review Board.

Ethical approval

This study was approved by the Research Ethics Review Committee of Jinling Hospital.

Study subjects or cohorts overlap

Not applicable.

Methodology

- Retrospective
- Diagnostic or prognostic study
- Performed at one institution

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Received: 7 January 2025 Revised: 7 May 2025 Accepted: 22 May 2025
Published online: 18 June 2025

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