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SPECIAL SECTION: PANCREATITIS

Development and validation of a computed tomography index for assessing outcomes in patients with acute pancreatitis: "SMART-CT" index

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Abstract

Purpose The existing CT indices do not allow quantitative prediction of clinical outcomes in acute pancreatitis (AP). The aim of this study was to develop and validate a revised CT index using a nomogram-based approach.

Methods This retrospective study comprised consecutive patients with AP who underwent contrast-enhanced CT between June 2017 and March 2019. 123 CT scans were randomly divided into training ($n=103$) and validation groups ($n=20$). Two radiologists analyzed CT scans for findings described in modified CT severity index and additional exploratory items (13 items). Seven items (pancreatic necrosis, number of collections, size of collections, ascites, pleural effusion, celiac artery involvement, and liver steatosis) found to be statistically significant were used for development of index. Synthetic minority oversampling technique (SMOTE) was employed to balance representation of minority classes and hence this index was named "SMOTE Application for Reading CT in AcuTe Pancreatitis (SMART-CT index)". Binomial logistic regression was used for development of prediction algorithm. Nomograms were then created and validated for each outcome.

Results The new CT index had area under the curve (AUC) of 0.79 [95% CI 0.65–0.93], 0.66 (95% CI 0.54–0.77), 0.75 (95% CI 0.65–0.85), 0.83 (95% CI 0.69–0.96), 0.70 (95% CI 0.60–0.81), and 0.64 (95% CI 0.53–0.75) for mortality, intensive care unit (ICU) stay, length of hospitalization, length of ICU stay, number of admissions, and severity, respectively. The AUC of validation cohort was comparable to the training cohort.

Conclusion The novel nomogram-based index predicts occurrence of clinical outcome with moderate accuracy.

Keywords Acute pancreatitis · Computed tomography · Prognosis · Prediction algorithm · CT index

Introduction

One of the essential issues in managing patients with acute pancreatitis (AP) is the ability to predict clinical outcomes accurately [1]. Patients with mild AP have an excellent prognosis. On the other hand, those with moderately severe and severe AP need substantial in-hospital care and healthcare resources to reduce morbidity and mortality [2, 3]. While contrast-enhanced computed tomography (CT) scan is not required for patients with mild AP, it is used as an important tool for severity assessment in those with moderately severe and severe AP [4]. Balthazar score was the first attempt to predict the severity of AP on CT [4]. However, this score did not have significant correlations with key parameters like the development of organ failure, extrapancreatic parenchymal complications, or peripancreatic vascular complications and was replaced by CT severity index (CTSI) and modified

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CTSI (mCTSI) [5–7]. More recent scores evaluating only the extrapancreatic changes, including extrapancreatic inflammation on CT (EPIC), renal rim grade, and modified renal rim grade, have shown excellent concordance with the severity of AP [7–9]. These scoring systems have performance equivalent to CTSI or mCTSI and have the advantage of higher reproducibility [10]. CTSI, however, underestimates the role of extrapancreatic inflammation [6, 11, 12].

Moreover, none of the scoring systems gives due representation to all the CT parameters in the final score and predicts all the clinically relevant outcomes. The aim of the present study was to utilize a novel approach for the development and validation of a nomogram-based CT index, which can help in the prediction of outcomes in patients with AP.

Methods

Ethical considerations

The Institute Ethics Committee approved the study. As the study involved re-reading of retrospective data, informed written consent was not obtained.

Study population

Consecutive patients with AP between June 2017 and March 2019 were enrolled for this study. The diagnosis of AP was based on the Revised Atlanta classification. Presence of two of the three features viz. abdominal pain suggestive of pancreatitis, serum amylase or lipase level greater than 3 times the upper limit of normal, and characteristics imaging findings led to the diagnosis of AP [13]. Only those contrast-enhanced CT scans which had been acquired within 4–7 days from the onset of pain were included. This is in line with the current recommendations, which suggest that CT should be done at this time in patients with AP [14, 15]. Patients with mild pancreatitis underwent CT scans in the emergency and were managed on outpatient basis. Those with moderate and severe disease at presentation were admitted in the ward or intensive care unit (ICU) based on the need for organ support. 123 CT scans were randomly divided into two groups: training group ($n=103$) and validation group ($n=20$) in a ratio of 5:1 using a computer random number generator. The CT scans (both training and validation group) were analyzed for the purpose of this study by two radiologists who were blinded to the clinical information, including the severity and clinical outcomes, and the previous reports of the scans. The training group was used for development of algorithm. Figure 1 shows the flow of patients.

CT acquisition technique

Abdominal CT scans were performed on multidetector-row CT scanners (64-, 128- or 256-detector row scanners, ACT, GE Healthcare; Somatom Definition Flash, Siemens Healthcare; Philips iCT, respectively), 65 s following intravenous injection of 80–100 ml of non-ionic contrast (Omnipaque ® 300 mg/mL, GE Healthcare). The scan parameters were tube current-300 mAs; voltage-120 kVp; pitch-0.993; field of view-350 mm and slice thickness-1 mm. The abdomen

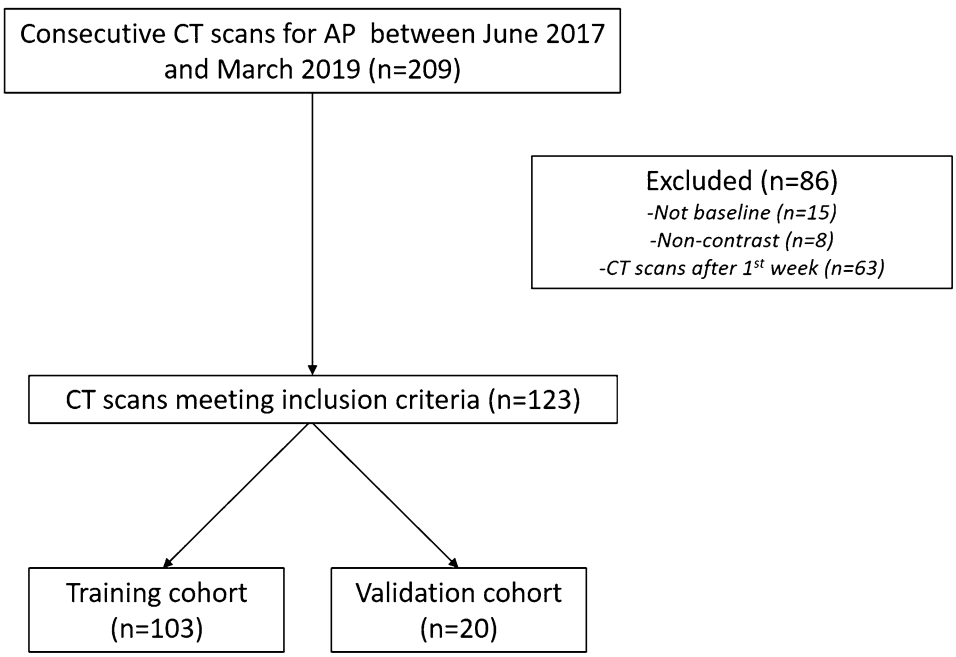

Fig. 1 Flow diagram showing patient recruitment in the study

was scanned from domes of the diaphragm to the pubic symphysis.

CT image analysis

All CT scans were reviewed for image quality and the use of contrast, before consensus assessment by two radiologists with four years (MV) and eight years (PG) of experience in abdominal imaging. Despite the availability of several existing scoring systems for assessing the severity of AP, we utilized items described in mCTSI as this is the most common CT based scoring system and considers both pancreatic and extrapancreatic findings [6, 14, 15]. Also based on the literature review, the study radiologists (MV and PG) proposed exploratory items (Table 1). Modifications were made in some of the mCTSI items (Table 1) based on the recommendations of a multidisciplinary team comprising the gastroenterologists and radiologists (involved in the consensus reading of CT scans). Severity of pancreatitis based on the revised Atlanta classification and clinical outcomes [including length of hospitalization (LOH), length of ICU stay, readmission within 30 days of discharge, surgery, in-hospital mortality) were derived from the record sheets by a gastroenterologist not involved with the reporting of CT scans. The demographic parameters were recorded.

Statistical analysis

Development of a novel index

On a dataset with uneven class distribution (e.g., 90% alive and 10% death) in a binomial predicting variable, if machine learning algorithms are applied directly on the dataset, the algorithm gets inclined toward predicting the majority class. The routine methodology would yield fallacious accuracy by correctly detecting the majority class while leaving away the minor class, while the primary point of interest in developing the predictive algorithm is to identify the minority class. Hence, we employed SMOTE in which there is both over-sampling of minority class and under-sampling of the majority class as a pre-processing step before fitting the data to the model to increase the inclination of the algorithm to detect the minority class [14, 15]. For mortality—minority represents death and majority class represents alive; for surgery—minority represents patient undergoing surgery and majority represents patients managed without surgery; for ICU stay—minority represents stay in ICU and majority represents no ICU stay; in number of hospital admission—minority represents number of hospital admission ≥ 2 and majority represents number of hospital admissions < 2; length of ICU stay—minority represents length of ICU stay of ≥ 2 weeks and majority represents length of ICU stay of < 2 weeks; for Atlanta—minority represents severe disease (1) and majority represents mild and moderately severe disease (0); for organ failure—minority represents presence of organ failure and majority represents absence of organ failure; for multiple organ failure—minority represents number of organ failure ≥ 2 and majority represents number of organ failure < 2. All these nine outcome categories are binomial. SMOTE was utilized for all the categories. All the available variables were first evaluated by univariate analysis keeping a p value < 0.15 against the respective categories. Setting of thresholds of p value < 0.15 for univariate analysis was in line with the evidence that statistical tests perform well in selection of variables after setting a higher significance value in earlier simulation studies and thereby also minimizing the type 2 error [16]. Traditional p values of 0.05 in univariate analysis have shown to miss variables that are important. For the univariate analysis, for continuous variables, independent t test was used for parametric data, and Mann–Whitney U test was employed for the non-parametric data. If the variable is categorical, the Chi square test was used if all the expected values in the contingency table were more than 5, else Fisher exact test was used (provided it is 2*2 contingency table). For those with expected value < 5 and > 2*2 contingency table, Fisher test with Monte Carlo simulation (10,000 replicates) was used. Binomial logistic regression on the pre-processed dataset was used for the development of prediction algorithms. Only the significant variable was kept for the final algorithm at a p value < 0.05. The developed algorithms were then validated by constructing receiver operating characteristic (ROC) curves for its prediction of the respective outcome category in the original dataset. The calibration of the algorithms was also assessed by bootstrapping on 5000 replicates, and apparent as well as bias-corrected values (of actual vs. predictive probability) were determined (Supplementary Fig. 1). The nomograms were then created for each outcome category (Fig. 2). Nomograms help in the easy clinical implementation of the developed model. The combination of nomograms will be henceforth referred to as a master nomogram. Statistical analysis was done using R statistical software version 3.6.1 [17]. The packages which were used other than the base package in R were rms, rmda, ggplot2 [18–20]. Adobe Illustrator was used for creating vector illustrations.

Assessment of time taken for reading master nomogram

Six readers (Radiology trainee residents in their 2nd and 3rd year of training, selected by drawing lots) were given hard-copy of a dataset comprising eight different patients. The identification of dataset as well as allotment to an individual resident was randomly done using computer-generated numbers. The readers were initially explained the items included in the master nomogram. Time was recorded (in seconds) while they filled the master nomogram of one patient. The

Table 1 Items evaluated for the development of SMART-CT index

Item	Category	Description
Items included from mCTSI		
Pancreatic necrosis	% necrosis given as an absolute value on a scale on 10% between 0-100%	Pancreatic necrosis was defined as lack of enhancement or enhancement < 30 HU (measured using a region of interest (ROI) of 1 cm^2 in a visibly hypoenhancing area). Based on visible quantification: No involvement was scored 0, while involvement of entire pancreas was scored 100. Involvement of either head or tail of pancreas was given a score of 20% each. If only uncinate process or neck was involved, a score of 10% was given to each. If the body was involved, a score of 40% was given. Scoring in each case was done using this guidance
Pancreatic inflammation	Absent Present	No pancreatic or peripancreatic fluid collection or peripancreatic fat necrosis Presence of fluid collection
Extrapancreatic complications -Pleural effusion -Ascites -Vascular abnormalities		– No pleural effusion <20% of the AP dimension of hemithorax 20-40% of the AP dimension of hemithorax >40% of the AP dimension of hemithorax – No ascites Minimal layering of ascites in the gravity-dependent regions such as pelvis and Morrison's pouch Presence of fluid in the paracolic gutters Sufficient ascites to displace the small bowel loops – Portal vein, splenic vein and superior mesenteric veins were individually assessed for the presence of filling detect, lack of opacification or reduction of caliber. Abnormality for each vein was classified as absent or present. – The entire celiac axis was evaluated for the presence of aneurysms (defined as focal dilatations with caliber more than 1.5 times the adjacent normal segment). Abnormality was classified as absent or present
Exploratory items		
Number of collections (modified from Balthazar [4])	Absolute number of collections	Determined based on the various sites that were involved
Largest dimension of collection (modified from Meyrignac et al. [20] and Çakar et al. [21])	Centimeters	Measured for the largest collection on a coronal image, if a patient had multiple collections
Attenuation of collection (modified from Ke et al. [22] and Hollemans et al. [23])	Hounsfield units (HU)	Measured using ROI of 1 cm^2 placed within the collection excluding gas if present
Gas within collection (modified from Balthazar [4, 5])	Absent Present	Lack of gas within the collection. Presence of gas within the collection

Table 1 (continued)

Item	Category	Description
Liver steatosis	Absent	Normal attenuation of liver.
	Present	Liver steatosis was defined as attenuation of a lobe or most of the liver less than that of spleen measured by four 1 cm^2 ROIs placed on right and left lobe, and spleen. The ROIs over each lobe were averaged and compared with the splenic attenuation [35]
Item	mCTSI	Modifications
Items modified from mCTSI		
Pancreatic necrosis (%)	≤30% and > 30%	Absolute value of pancreatic necrosis in multiples of 10%
Pancreatic inflammation	Pancreatic or peripancreatic fluid collection or peripancreatic fat necrosis	Pancreatic or peripancreatic fluid collection was considered. Peripancreatic fat necrosis was not included
Extrapancreatic complications	Present or absent. No grading. Extrapancreatic complications, whether single or multiple in a patient given a score of 2	Ascites and pleural effusion were graded as mild, moderate and severe. Vascular complications were separated into arterial and venous

readers were required to have a break of 2 min between the filling of master nomogram of each patient. The mean time needed to fill the master nomogram was recorded.

Assessment of interobserver agreement for reading master nomogram

In a separate session, the same six readers involved in time estimation experiment were given a set of eight patients randomly selected using computer-generated scan numbers. The probability of the six outcomes was predicted by each reader using the master nomogram. The inter-reader agreement was assessed by the intraclass correlation coefficient (ICC) using a 2-way random effect analysis of variance model. ICCs of < 0.0, 0.0–0.20, 0.21–0.4, 0.41–0.6, 0.61–0.8, and > 0.81 constituted "poor," "slight," "fair," "moderate," "substantial," and "almost perfect" agreement, respectively.

Validation

Validation was performed by recording the items included in the master nomogram. The probability of clinical outcomes was assessed using the master nomogram and constructing ROC curves.

Results

During the study period, 209 CT scans in patients with AP had been performed. For this study that required re-reading of the scans, 15 scans were excluded as they were found to have a drainage catheter or endoscopic stents and did not represent the baseline scans. Additionally, eight scans were excluded as they were performed without the administration of contrast. Sixty-three scans had been performed after the 1st week of illness as these patients reported after this period to our hospital and these were also excluded. This is based on the recommendations that the initial CT scan in patients with clinically severe disease or those who do not respond to conservative treatment should be performed after 72 h to guide management [14, 15]. Thus, 123 CT scans were finally included in the study.

Patient clinical and demographic data

Mean [standard deviation (SD)] for age was 39.35 years [12.73]. There were 80 (77.7%) males and 23 (22.3%) females in the training cohort. Forty-six (44.7%) patients had moderately severe and 39 (37.9%) patients had severe disease. Organ failure was present in 67 (65%) patients and 10 (9.7%) patients had multiple organ failure. The patient characteristics are detailed in Table 2.

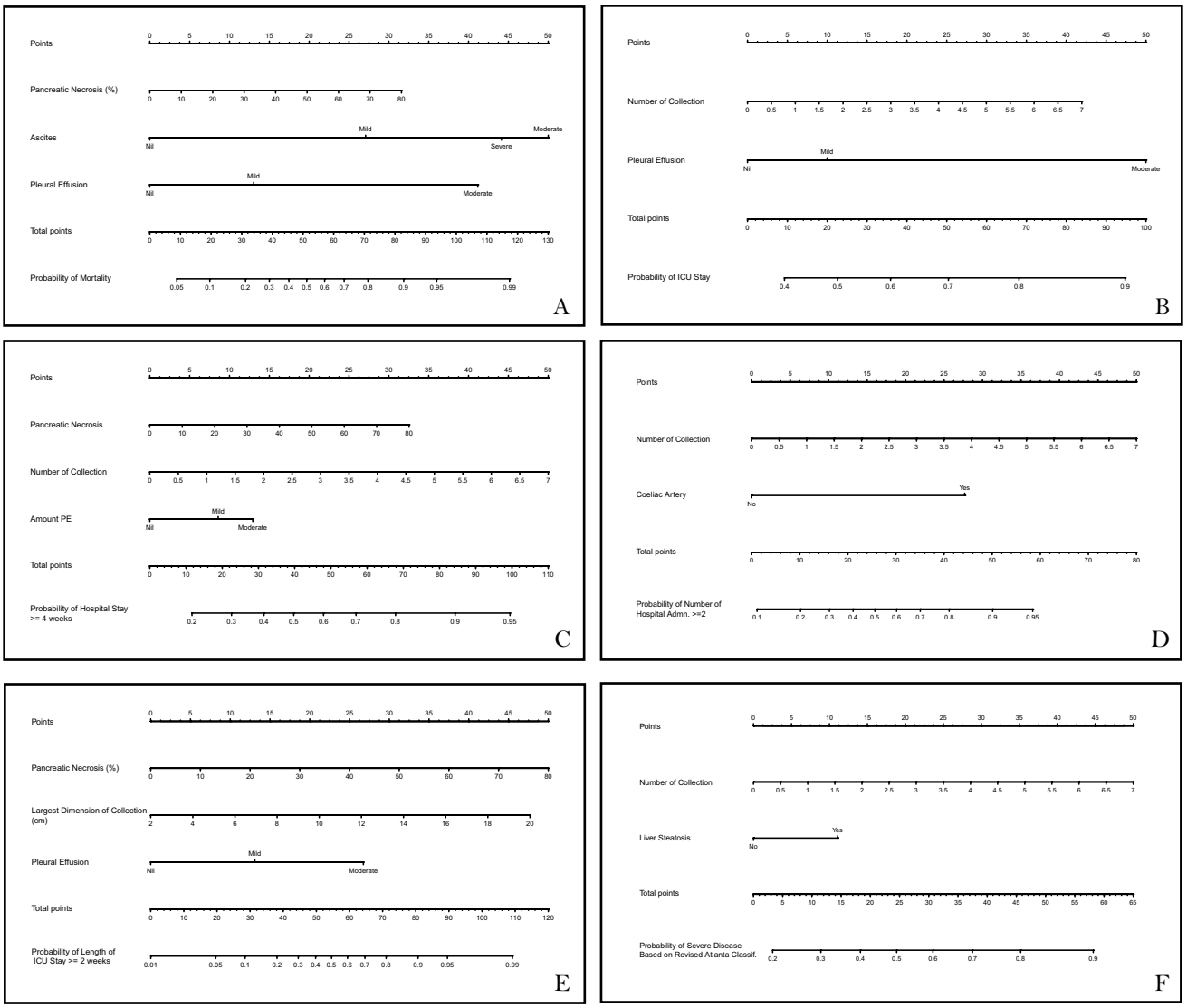

Fig. 2 Nomograms for predicting the probability of clinically significant outcomes. Six outcomes are evaluated. **a** Mortality. **b** Probability of ICU stay. **c** Probability of hospital stay ≥ 4 weeks. **d** Readmission. **e** Probability of ICU stay ≥ 2 weeks, and **f** probability of severe disease. For the nomogram of each outcome, the CT findings mentioned in that nomogram are read and scored. A cumulative score is assigned. The probability of the outcome is assessed based on this score (see Supplementary Fig. 2)

Index development

Univariate analysis of 13 items was performed against each outcome parameter. Out of these, superior mesenteric vein abnormality was excluded as it did not meet the threshold of significance for any of the outcome parameters (Supplementary Table 1). On multivariate analysis, none of the items were found to be significant for the outcome categories: surgery and organ failure. Given the lack of any parameter showing significant association with organ failure, multiple organ failure was not further assessed. Seven parameters (pancreatic necrosis, number of collections, size of collections, ascites, pleural effusion, celiac artery involvement, and liver steatosis) that were found to be significantly associated with the 6 (mortality, ICU stay, LOH ≥ 4 weeks, number of hospital admissions ≥ 2, length of ICU stay ≥ 2 weeks, severe disease) outcome measures were used for construction of nomograms (Table 3, Supplementary Fig. 2). The area under the curve for the outcome is given in Table 4, Fig. 3.

Table 2 Demographic characteristics and clinical outcomes in training group

Parameters	Results
Age (years)	39.53 (SD, 12.73)
Male to female ratio	80/23
Etiology of pancreatitis	
Alcohol	70 (67.9%)
Gallstones	23 (24.4%)
Both alcohol and gallstones	5 (4.9%)
Post-ERCP	3 (2.9%)
Idiopathic	2 (1.9%)
Severity of pancreatitis	
Mild	18 (17.6%)
Moderately severe	46 (44.7%)
Severe	39 (37.9%)
mCTSI	7.48 (SD, 2.30)
Pancreatic necrosis (%)	31.89 (SD, 25.34)
Collections	97 (94.2%)
Number of collections	3.34 (SD, 1.72)
Maximum dimension of collection (cm)	8.72 (SD, 3.57)
Air within collection	12 (11.7%)
Attenuation of collection (HU)	16.63 (SD, 7.60)
Ascites	
Mild	37 (35.5%)
Moderate	13 (12.6%)
Severe	2 (1.9%)
Pleural effusion	
Mild	36 (35%)
Moderate	11 (10.6%)
Severe	0
Liver steatosis	23 (22.3%)
Vascular abnormalities	
Portal vein	11 (10.7%)
Splenic vein	31 (30.1%)
SMV	2 (1.9%)
Celiac axis	4 (3.9%)
Mortality	11 (10.7%)
Surgery	12 (11.7%)
Length of hospitalization (days)	22.9 (SD, 21.56)
Need for ICU admission	38 (36.9%)
Length of ICU stay (days)	3.9 (SD, 7.55)
Number of hospital admissions	
None	17 (16.5%)
One	56 (54.4%)
≥Two	30 (29.1%)

Time taken for reading nomograms and interobserver agreement

The median time required for reading the master nomogram for one patient was 174 s (range 115–180 s) (Supplementary Table 2). There was almost perfect agreement for reading nomogram [ICC, 0.85 (95% CI 0.79–0.91)] (Supplementary Table 3).

Validation

The AUCs in the validation group were comparable with those of the training cohort, except for the prediction of the probability of hospital admissions and length of ICU stay (Table 4 and Fig. 3).

Discussion

In this study, we propose a nomogram-based SMART-CT index and its validation in predicting outcomes in AP. Two components that have been used in this scoring are those proposed in the mCTSI and the exploratory items. The items in the mCTSI were revised to allow a greater dynamicity in the developed index: a. scoring of pancreatic necrosis was changed from a 30% threshold to a scale of 0-100% with 10% intervals, b. each extrapancreatic complications was considered separately, c. ascites and pleural effusion were quantified, and d. both venous and arterial complications were explored for their association with outcome. The exploratory items included: a. number of collections, b. largest dimension of collections, c. attenuation of collection, d. gas within collection, and e. liver steatosis. Figure 4 highlights the differences between the proposed index and the previous CT based indices.

The quantification of pancreatic necrosis for nomograms can be done visibly without a need for complicated measurements. The scoring of pancreatic necrosis based on the absolute degree rather than categorization into less than or greater than 30% as proposed in mCTSI may be useful. For example, a patient having 40% necrosis gets a score of 4 (for necrosis) based on mCTSI. The severity based on mCTSI (moderate vs. severe) may not change in another patient having 90% necrosis. However, using nomogram approach, the probability of mortality, length of hospital and ICU stay will change proportional to the percentage of necrosis. Quantification of ascites and pleural effusion may correlate with outcomes as suggested by a recent study in which patients with moderate or severe ascites had worse prognosis [21]. This quantification is also in line with previous scoring systems. The EPIC score proposed by De Waele et al. categorized ascites based on the number of sites involved and pleural effusion based on whether it was unilateral or bilateral [8]. The number of collections was included as both the Balthazar score and CTSI gave more weightage to two or more collections as compared to a single collection [4, 5]. The EPIC score also gave weight to the retroperitoneal inflammation based on its extent [8]. The size of collections was

Table 3 Multivariate regression analysis

	Predictors	Odds Ratios	CI	*p*
Mortality	(Intercept)	0.46	0.14–1.48	0.195
	Pancreatic Necrosis	1.03	1.00–1.05	**0.018**
	Ascites-Moderate	4.91	1.18–20.39	**0.028**
	Ascites-Nil	0.15	0.04–0.58	**0.005**
	Ascites-Severe	3.27	0.27–39.44	0.352
	Pleural Effusion-Moderate	7.05	1.23–40.23	**0.028**
	Pleural Effusion-Nil	0.4	0.13–1.25	0.115
ICU Stay	(Intercept)	0.68	0.40–1.16	0.154
	Number of Collections	1.2	1.04–1.38	**0.01**
	Pleural Effusion-Moderate	3.38	1.45–7.86	**0.005**
	Pleural Effusion-Nil	0.74	0.48–1.13	0.161
Length of Hospital Stay	(Intercept)	0.17	0.03–0.31	**0.021**
	Pancreatic Necrosis	0	0.00–0.01	**<0.001**
	Number of Collections	0.08	0.04–0.11	**<0.001**
	Pleural Effusion-Moderate	0.03	−0.15–0.20	0.764
	Pleural Effusion-Nil	−0.09	−0.20–0.01	0.081
Number of Hospital Admissions	(Intercept)	0.1	0.05–0.20	**<0.001**
	Number of Collections	1.9	1.58–2.28	**<0.001**
	Coeliac Artery Involvement-Yes	11.98	2.65–54.11	**0.001**
Length ICU Stay	(Intercept)	0.02	0.00–0.10	**<0.001**
	Pancreatic Necrosis	1.05	1.03–1.08	**<0.001**
	Size Largest	1.25	1.11–1.41	**<0.001**
	Pleural Effusion-Moderate	3.16	0.88–11.36	0.079
	Pleural Effusion-Nil	0.33	0.13–0.87	**0.025**
Atlanta	(Intercept)	0.2	0.11–0.36	**<0.001**
	Number of Collections	1.59	1.37–1.85	**<0.001**
	Fatty Change-Yes	2.06	1.25–3.41	**0.005**

Table 4 Area under the curve for the various outcome parameters

Outcome parameter	Area under the curve	95% confidence interval
Training cohort ($n=103$)		
Mortality	0.79	0.65–0.93
ICU stay	0.66	0.54–0.77
Hospital stay ≥ 4 weeks	0.75	0.65–0.85
Hospital admissions ≥ 2	0.70	0.60–0.81
ICU stay ≥ 2 weeks	0.83	0.69–0.96
Severe disease	0.64	0.53–0.75
Validation cohort ($n=20$)		
Mortality	0.74	0.42–1
ICU stay	0.70	0.49–0.91
Hospital stay ≥ 4 weeks	0.77	0.56–0.98
Hospital admissions ≥ 2	0.52	0.34–0.70
ICU stay ≥ 2 weeks	0.45	0.06–0.83
Severe disease	0.69	0.49–0.88

considered as recent studies have shown that the volume of extrapancreatic necrosis is an important predictor of the severity of AP [11, 22, 23]. The attenuation of the collection has been shown to be one of the factors predictive of the success of catheter drainage [24–27]. A higher mean CT density suggests greater necrotic debris and as associated with a higher probability of worse outcome with catheter drainage compared to those with lower mean CT density [24–27]. Gas within the collection is an important finding suggesting infection or GI fistulization [28–30]. Infected pancreatic necrosis is known to be associated with an adverse outcome [31]. Liver steatosis is a surrogate marker of visceral adiposity and metabolic syndrome that have been shown to affect the outcome of AP adversely [32–35].

The master nomogram proposed in the current study allows the assignment of a percentage probability of clinically significant outcomes. While mortality and ICU stay are outcomes that are commonly reported, we included additional outcomes including the length of hospitalization ≥ 4 weeks, ICU stay ≥ 2 weeks and hospital admissions ≥ 2. The length of hospitalization ≥ 4 weeks and ICU stay ≥ 2 weeks were chosen as the healthcare cost

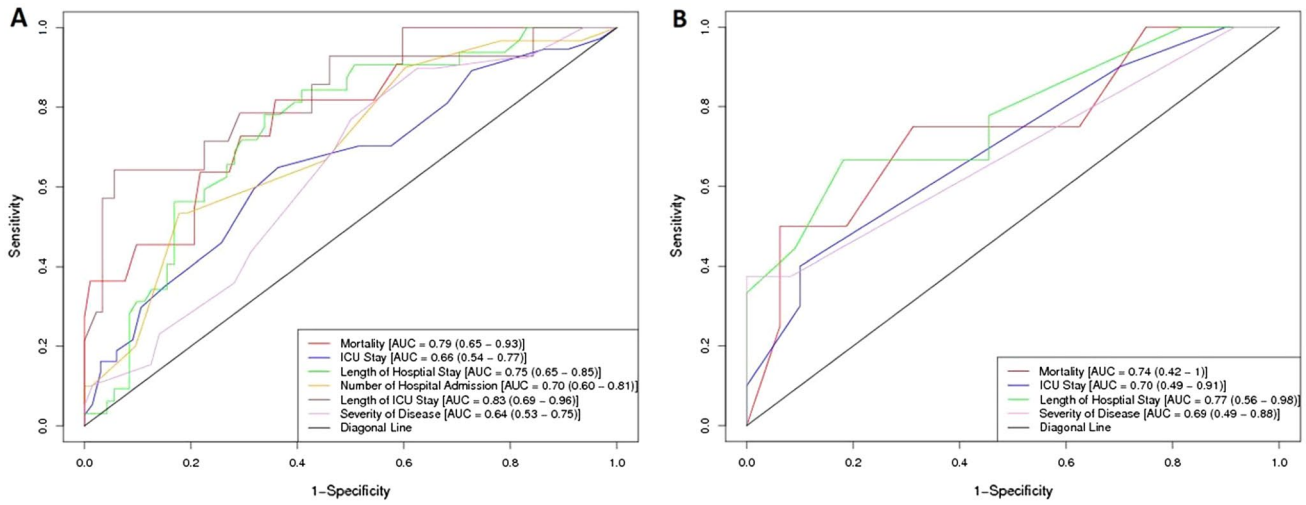

Fig. 3 ROC curves for predicting clinical outcomes in training cohort (**a**) and validation cohort (**b**). The areas under the curve for each outcome are provided as insets in different colors

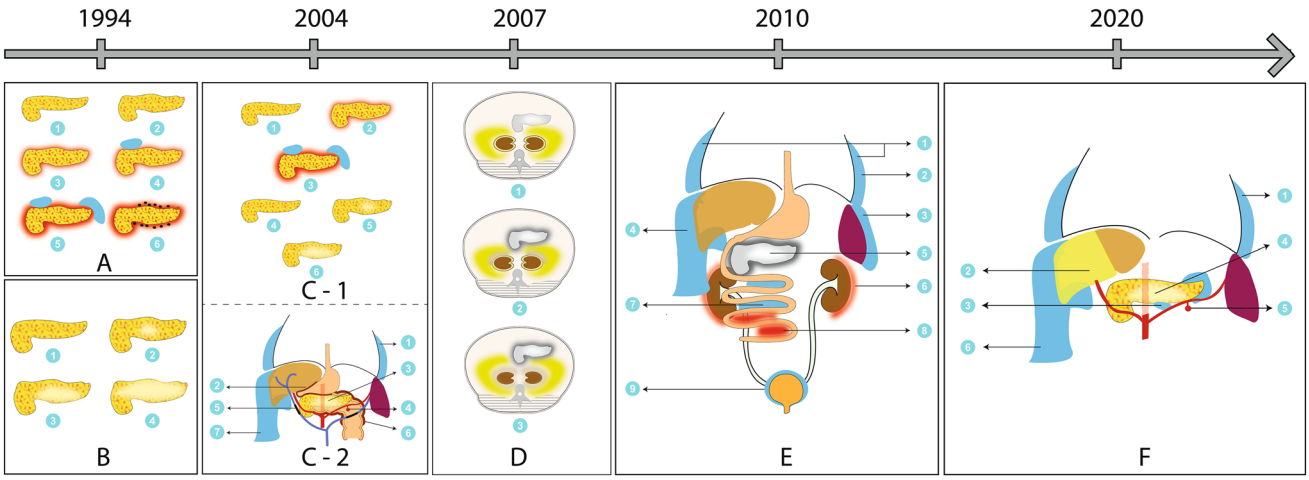

Fig. 4 Various scoring systems in acute pancreatitis. **a** Balthazar score (1-normal pancreas, 2-increase in bulk of pancreas, 3-peripancreatic inflammation, 4-single peripancreatic collection, 5-two peripancreatic collections, 6-retroperitoneal air [black dots]). 1, 2, 3, 4, 5 + 6 correspond to grade A, B, C, D and E, respectively; **b** grading of pancreatic necrosis (1-no necrosis, 2- < 30%, 3-30-50%, 4- > 50%), **a** + **b** CT severity index (CTSI), **c** modified CTSI (C1-peripancreatic changes and pancreatic necrosis [1-normal, 2-peripancreatic inflammation, 3-peripancreatic fluid collections, 4-no pancreatic necrosis, 5-necrosis < 30%, 6-necrosis > 30%) and C2-extrapancreatic changes (1-pleural effusion, 2, 6-gastrointestinal involvement, 3-pancreatic necrosis, 4-arterial pseudoaneurysm, 5-venous thrombosis, 7-ascites), **d** renal rim grade (1-no perirenal/pararenal fat inflammation, 2-pararenal fat inflammation, 2-involvement of both pararenal and perirenal fat), 3-, **e** extrapancreatic inflammation in CT (EPIC) score (1-unilateral pleural effusion, 2-bilateral pleural effusion, 3-perisplenic ascites, 4-perihepatic ascites, 5-pancreas [pancreatic changes are not considered in this score], 6-unilateral retroperitoneal inflammation, 7-bilateral retroperitoneal inflammation, 8-interbowel fluid, 9-pelvic fluid), **f** Proposed SMART-CT index (1-pleural effusion, 2-liver steatosis, 3-collection [includes number as well as largest dimension], 4-pancreatic necrosis [percentage on a scale of 0-100% with increments of 10%], 5-celiac artery involvement, 6-ascites)

implications are substantial [36]. Our study is the first study in the literature to propose a nomogram-based approach for CT features in AP. Compared to CTSI/mCTSI or any other existing scoring system, present CT index allows assignment of the probability of occurrence to each clinically significant outcome by the use of nomograms in a time-efficient manner. The prediction of outcomes using baseline CT may help stratify the level of care needed by the patient and more efficient utilization of healthcare resources.

We could not develop nomograms for predicting the probability of surgery and organ failure as none of the included items were found to be statistically significant on

multivariate analysis for these outcomes. The decision to perform surgery in AP is guided by multiple factors [37]. The failure to predict the probability of organ failure based on imaging in the current study is in line with a few other studies showing a lack of significant association between CTSI and the development of organ failure [38, 39].

We validated the nomograms. The AUC of the validation cohort was comparable except for ICU stay ≥ 2 weeks and hospital admissions ≥ 2. This may be related to the smaller number of patients in the validation cohort. The time taken to read the nomogram was assessed using multiple readers. The time to read master nomogram for one patient was 174 s (range 115–180 s). The inter-reader agreement was almost perfect. This implies that proposed nomogram-based scoring system can be effectively incorporated into the clinical practice.

The strengths of the present study are the use of SMOTE for adequate representation of minority classes. We evaluated all the CT abnormalities to adequately represent them in the scoring. Validation of the algorithm was done. There was homogeneity of CT scans as we included only those patients who underwent CT scan in the first week. Nomograms allow the easy clinical implementation of the developed model. Nomogram-based approach is being increasingly incorporated in the management of other diseases also [40, 41].

The limitations of the study are relatively small validation cohort and the inability to develop a model for surgery. We had a small number of patients with mild disease. This is due to the referral bias and limited indications of CT in this group. However, patients with mild AP have a very low probability of clinical outcomes. As we utilized only contrast-enhanced CT, patients who underwent non-contrast CT due to presence of acute kidney injury were excluded. We did not use the Hounsfield units for evaluating relative attenuation of liver and spleen for diagnosis of hepatic steatosis. The diagnosis of hepatic steatosis was rather based on the visual assessment. Objective criteria for liver steatosis are best defined on non-contrast CT. However, the routine acquisition of non-contrast CT is associated with additional radiation exposure and is not recommended [42]. Finally, we did not incorporate abdominal fat in the scoring system. There is evolving data to suggest that visceral adipose tissue may affect the severity of AP [43].

In conclusion, we developed a new CT index for assessing outcomes in acute pancreatitis. We adopted a novel approach based on nomograms for easy clinical implementation of the proposed index. This index allows the assessment of the probability of each clinically significant outcome. However, this index needs external validation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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