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MRI and CT radiomics for the diagnosis of acute pancreatitis

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ABSTRACT

Purpose: To evaluate the single and combined diagnostic performances of CT and MRI radiomics for diagnosis of acute pancreatitis (AP).

Materials and methods: We prospectively enrolled 78 patients (mean age 55.7 ± 17 years, 48.7 % male) diagnosed with AP between 2020 and 2022. Patients underwent contrast-enhanced CT (CECT) within 48–72 h of symptoms and MRI ≤ 24 h after CECT. The entire pancreas was manually segmented tridimensionally by two operators on portal venous phase (PVP) CECT images, T2-weighted imaging (WI) MR sequence and non-enhanced and PVP T1-WI MR sequences. A matched control group (n = 77) with normal pancreas was used. Dataset was randomly split into training and test, and various machine learning algorithms were compared. Receiver operating curve analysis was performed.

Results: The T2WI model exhibited significantly better diagnostic performance than CECT and non-enhanced and venous T1WI, with sensitivity, specificity and AUC of 73.3 % (95 % CI: 71.5–74.7), 80.1 % (78.2–83.2), and 0.834 (0.819–0.844) for T2WI (p = 0.001), 74.4 % (71.5–76.4), 58.7 % (56.3–61.1), and 0.654 (0.630–0.677) for non-enhanced T1WI, 62.1 % (60.1–64.2), 78.7 % (77.1–81), and 0.787 (0.771–0.810) for venous T1WI, and 66.4 % (64.8–50.9), 48.4 % (46–50.9), and 0.610 (0.586–0.626) for CECT, respectively.

The combination of T2WI with CECT enhanced diagnostic performance compared to T2WI, achieving sensitivity, specificity and AUC of 81.4 % (80–80.3), 78.1 % (75.9–80.2), and 0.911 (0.902–0.920) (p = 0.001).

Conclusion: The MRI radiomics outperformed the CT radiomics model to detect diagnosis of AP and the combination of MRI with CECT showed better performance than single models. The translation of radiomics into clinical practice may improve detection of AP, particularly MRI radiomics.

1. Introduction

Acute pancreatitis (AP) is an acute inflammatory condition of the pancreas resulting from inappropriate intracellular activation of proteolytic pancreatic enzymes, which leads to autodigestive injury of the pancreatic gland [1]. The incidence of this condition has increased over the years and ranges from 20 to 80 per 100 000 per year, varying widely across countries [2]. The two main etiologies of AP are gallstones and alcohol, accounting for 60 %–80 % of all cases [3]. According to the revised Atlanta classification, the diagnosis of AP requires two of the following three findings: (a) abdominal pain consistent with AP (epigastric pain radiating to the back); (b) serum lipase or amylase levels elevated to at least three times the upper limit of normal; and (c) characteristic findings on contrast-enhanced computed tomography (CECT), magnetic resonance imaging (MRI), or transabdominal ultrasonography [4].

Abbreviations: AP, Acute pancreatitis; CECT, contrast-enhanced CT; WI, Weighted imaging; ROC, Receiver operating characteristic; AUC, Area under the curve; US, Ultrasound; CTSI, Computed tomography severity index; GFR, Glomerular filtration rate; DWI, Diffusion-weighted imaging; VOI, Volume of interest.

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The severity of AP is highly variable, ranging from mild to severe. Mild AP generally does not require invasive treatment and is associated with low mortality [5]. Although most patients develop mild pancreatitis, approximately 15–20 % develop severe AP, which is associated with multi-organ failure and requires aggressive treatment and prolonged hospital stay, with mortality rates of up to 30 % [6]. The different clinical outcomes of patients with AP have led to the development of several scoring systems to predict the severity of AP and ultimately to improve patients' clinical outcomes and guide treatments. As rapid, overall available, reproducible, and nearly complete non-invasive tool, CECT is today the most performed imaging modality to confirm or exclude AP. Therefore, the Balthazar computed tomography severity index (CTSI) is the most widely adopted grading system and correlates well with AP severity and length of hospital stay [7]. From a radiological perspective, while severe pancreatitis can be accurately assessed on cross-sectional images, mild forms of AP may be difficult to detect on CECT, with CECT falsely negative in up to 27 % of cases, particularly in the early stages of the disease [8]. The assessment of pancreatitis relies on visual evaluation of the morphological characteristics of the pancreas, including interstitial edema, parenchymal necrosis, peri-pancreatic fat stranding, and collections. These findings, however, may not be sufficiently sensitive for accurately diagnosing mild cases of AP.

The application of advanced imaging techniques, such as radiomics, may enhance diagnostic accuracy in both mild and severe AP. The analysis of quantitative data extracted from medical images through radiomics can potentially complement radiologists' visual interpretation and may offer the opportunity to obtain additional information that is undetectable by the human eye. Radiomics is defined as the extraction of quantitative features from medical images that are translated into higher-dimensional mineable data for improved decision support [9]. Although these models are mainly used for diagnosing cancer, they are also suitable for non-oncological research [10,11]. Additionally, delta-radiomics allows for noninvasive, longitudinal monitoring of patients without affecting their routine imaging procedures [12]. In the field of pancreatic imaging, a retrospective study in 2020 showed that a radiomics model based on MRI performed well in predicting the severity of AP [13]. A retrospective study conducted in 2023 showed that a radiomics model based on contrast-enhanced CT images could accurately predict AP severity [14]. In the literature, different phases of CT and MRI sequences have been employed individually for radiomics analysis of AP [15]. However, to date, no study has evaluated the combined performances of CT and MRI sequences in the assessment of AP.

This study aimed to investigate the diagnostic performance of multimodal radiomics analysis using CT and MRI for the diagnosis of AP.

2. Materials and methods

2.1. Study design and patient selection

This is a prospective, non-randomized, single-institution, institutional review board-approved study (CER-VD, study ID n°2020–02153).

All in-patients with AP between December 2020 and November 2022 were considered for inclusion in this prospective study. According to the revised Atlanta classification, AP was defined as the presence of two or more of the following three findings: abdominal pain, serum amylase or lipase levels ≥ 3 times the upper limit of normal (>210 U/l et > 180 U/l, respectively) and/or characteristic findings on imaging [4]. Written informed consent was obtained from all participants prior to study inclusion.

Exclusion criteria were as follows: (a) previous diagnosis of chronic pancreatitis; (b) renal failure with estimated glomerular filtration rate less than 30 ml/min/1.73 m2); (c) history of allergic reactions to any contrast media; (d) proven or suspected pregnancy; (e) age under 18 years; (f) general exclusion criteria for MRI (patients with non-MRI compatible metallic or electronic implants, devices or metallic foreign bodies, non-MRI compatible cardiac pacemaker, claustrophobia), and (g) inability to cognitively and/or linguistically understand the patient consent sheet.

According to the clinical routine, each patient underwent clinical assessment, laboratory workup at admission and at 48 h after admission in order to assess the Ranson score [16]. An abdominal CECT was performed within 48–72 h after admission to assess the severity of AP. In addition, a contrast-enhanced pancreatic MRI was performed within 24 h after CECT.

Demographic characteristics, clinical data, laboratory and imaging findings, including etiology of AP, severity index (CTSI), pancreatic necrosis, systemic complications and length of hospital stay, were recorded on a dedicated database. The severity of the AP was rated as the CTSI determined by the consensus of two readers with 2 and 30 years of clinical experience,

respectively. The CTSI was calculated based on a combination of pancreatic inflammation, and degree of pancreatic necrosis as observed on CT, according to the scoring system developed by Balthazar et al. [7].

A control group of subjects without history or diagnosis of pancreatic disease was used to assess the radiomics features of normal pancreatic parenchyma. A list of patients with normal pancreatic findings who underwent abdominal intravenously injected MRI and CECT within a delay of 6 months between November 2019 and October 2022 was retrospectively identified from the local imaging database. The absence of pancreatic abnormality, including inflammatory and post-inflammatory changes, as well as focal and diffuse pancreatic disease, was verified across all four imaging modalities by a radiologist (C.T) with 3 years of experience. MRI and CT of the control group were matched by age and sex with those of the prospective study population. The exclusion criteria for the control group were the same as those for the study population Fig. 1.

2.2. Image acquisition

CT was performed using a 256-detector row Revolution CT scanner (GE Healthcare, Waukesha, WI, USA) with intravenous iodinated contrast medium administration. MRI was performed on a 3 T MR scanner (MAGNETOM Vida, Siemens Healthcare, Erlangen, Germany) with extracellular contrast agent (Dotarem®, Guerbet AG, Zurich, Switzerland). Details of the imaging parameters are provided in the Supplementary Material.

2.3. Pancreas segmentation

Segmentations were performed in consensus by two radiologists (C.T.& M.J) with 10 and 3 years of experience, respectively. Three-dimensional volumes of interest (VOI) of the whole pancreas on CECT and MRI were manually delineated for both populations (patients with AP and healthy control subjects). Observers were aware of the general study objective but unaware of the patient's outcome. The VOI included the entire pancreatic parenchyma, avoiding vessels, necrotic collections, and the Intrapancreatic part of the common bile duct. Radiomics features were extracted from the whole pancreas on CECT images at portal venous phase on 1.25-mm slices and on MRI on axial T2WI HASTE, on axial non-enhanced T1WI and on axial T1WI at portal venous phase in both populations (Figs. 2 and 3). A commercially available software (Mint Lesion™; Mint Medical GmbH, Heidelberg, Germany) was used to segment the pancreas.

2.4. Radiomics feature extraction and predictive modelling

Coded patient images were uploaded to the QuantImage v2 platform (https://medgift.github.io/quantimage-v2-info/), on which radiomics analysis and predictive modelling were performed [17]. First, 107 radiomics features characterizing the shape, intensity distribution, and

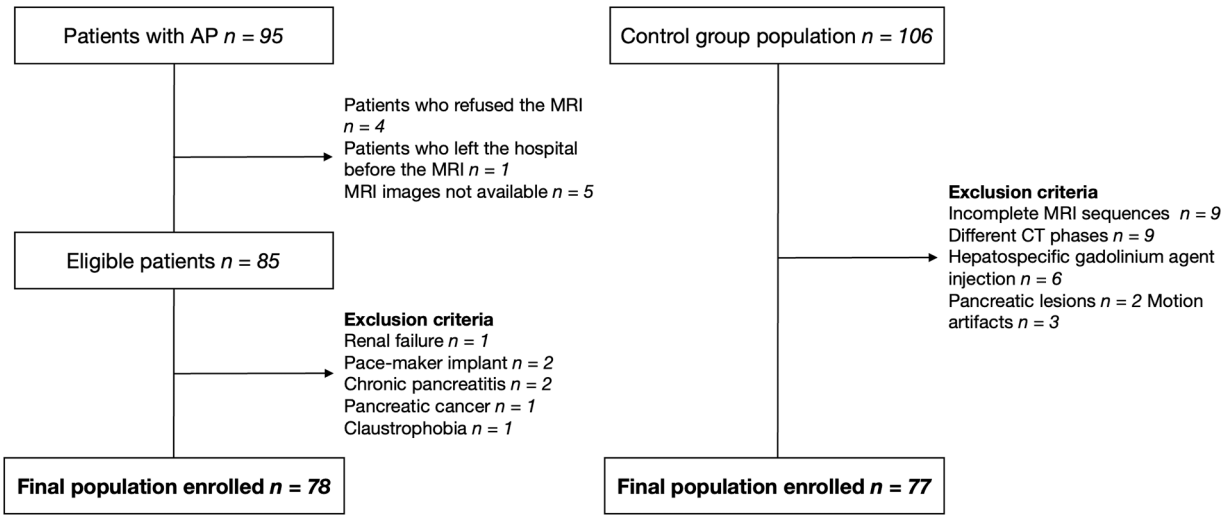

Fig. 1. Flowchart of patient selection.

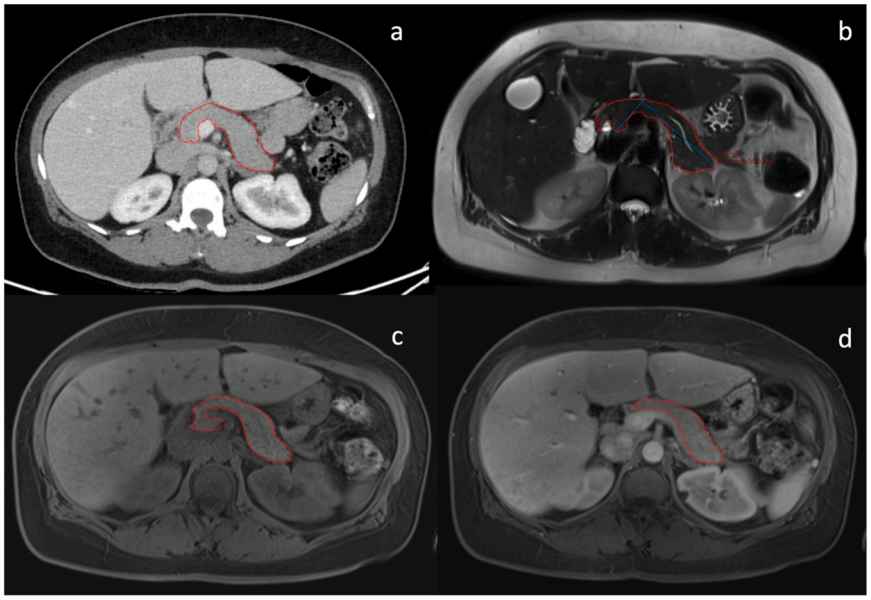

Fig. 2. Example of a single slide of the 3D segmentation of the pancreas performed on contrast-enhanced CT (a), T2 weighted imaging (b), non-enhanced T1 weighted imaging, (c) and portal venous phase T1 weighted imaging (d) allowing radiomics data extraction.

texture of the pancreatic parenchyma were computed for each imaging modality and sequence type using the in-built pyradiomics feature extractor [18]. To ensure comparability of image intensities across patients, MR images were standardized to an intensity mean of 0 and a standard deviation of 1 prior to feature extraction by z-score standardization, using the entire image as a reference. Image intensities were shifted to positive values, and fixed bin widths (0.3 for all MR sequence types and 20 for CT) were used for texture computation.

We developed seven separate models: four models using features derived from one single imaging acquisition (CECT, T2WI MRI, non-enhanced T1WI MRI and PVP T1WI MRI models), and three models combining features from the four different image acquisitions (MRI 3 sequences, CECT + T2WI MRI, CECT + MRI 3 sequences). See Fig. 2.

The dataset was split into training (80 %) and test (20 %) sets and the feature values were standardized based on individual means and standard deviations from the training set. For each model, the set of most relevant features was chosen on the training set, first by removing redundant features (Pearson correlation >0.8) and second by selecting the 20 features with the highest univariate predictive score for AP.

The optimal model and classification algorithm were selected by grid-search with 5-fold stratified cross-validation on the training set. Its generalization performance was evaluated on the test set in terms of the area under the ROC curve (AUC). All models were constructed using the Scikit-learn library used by QuantImage v2 [19]. Feature importance was assessed using the permutation importance index [20].

2.5. Statistical analysis

Confidence intervals (CIs) for average model performance were obtained by bootstrapping (n = 20) from a set of k performance estimates, resulting in n realizations of these k performance estimates. From these, n *mean* performance estimates were computed. The 95 % CI corresponds to values between the 2.5th and 97.5th percentiles of the bootstrap distribution of the mean performance estimates. For cross-validation performance, bootstrapping was applied to $k = 5$ performance estimates resulting from 5-fold cross-validation. For test performance, a set

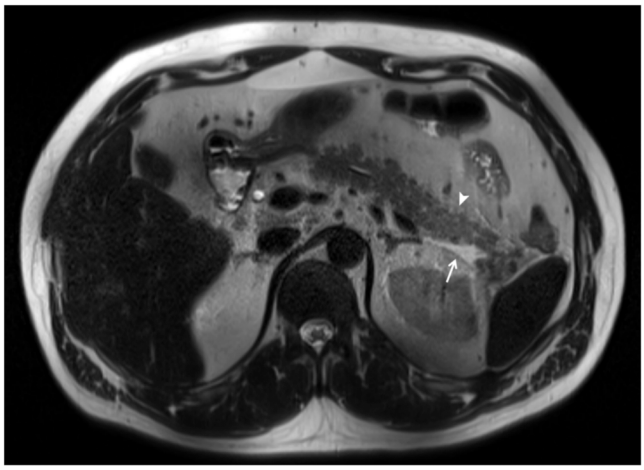

Fig. 3. This axial T2 weighted-imaging MRI image shows mild pancreatic oedema (T2-hyperintensity) (arrowhead) and surrounding peripancreatic inflammation (arrow). The radiomics model confirms the diagnosis of acute pancreatitis.

of $k = 100$ model performance estimates were obtained by repeated evaluation of the prediction model on bootstrapped versions of the test dataset.

Differences between model performances were assessed by pairwise permutation tests between the models' performance estimates, applying a value of $p < 0.05$ as significance threshold. Due to the large number of possible permutations, the exact permutation test was approximated by a solution strategy using bootstrapping with 10000 draws.

3. Results

3.1. Patient population

The final study population included 78 patients (mean age 55.7 ± 17 years, 48.7 % male). The control group population included 77 patients (mean age 51 ± 12 years, 51.9 % male). Table 1 summarizes the patient demographics and etiology of pancreatitis.

3.2. Comparison of non-enhanced and venous T1WI-MRI, CECT, and T2WI-MRI

Model metrics, including model type, number of features used, AUC, accuracy, precision, sensitivity, and specificity for models derived from T2WI-MRI, non-enhanced and venous T1WI-MRI, CECT, and combined models, are reported in Table 2.

The non-enhanced T1WI model showed a sensitivity, specificity, and AUC of 74.4 % (71.5–76.4), 58.7 % (56.3–61.1), and 0.654 (0.630–0.677), respectively. Venous T1WI model showed a slightly better performance in distinguishing AP from non-AP, with a sensitivity, specificity, and AUC of 62.1 % (60.1–64.2), 78.7 % (77.1–81), and 0.787 (0.771–0.810), respectively ($p = 0.076$).

The performance of the CECT model was lower than that of the non-enhanced T1WI, venous T1WI, and T2WI models, with a sensitivity, specificity, and AUC of 66.4 % (64.8–50.9), 48.4 % (46–50.9), and 0.610 (0.586–0.626) ($p = 0.007$, $p = 0.001$, and $p = 0.001$, respectively).

The T2WI model exhibited significantly better diagnostic performance compared to non-enhanced and venous T1WI and CECT, with a sensitivity of 73.3 % (95 % CI: 71.5–74.7), specificity of 80.1 % (78.2–83.2), and an AUC of 0.834 (0.819–0.844) ($p = 0.001$ for all three comparisons). While the combined MRI model using all three MR sequences showed a slightly higher performance than T2WI alone, the difference was not statistically significant, with a sensitivity of 81.5 % (95 % CI: 79.7–83.6), specificity of 80.7 % (79.1–82.3), and an AUC of 0.841 (0.856–0.844) ($p = 0.533$).

The combination of T2WI with CECT significantly enhanced diagnostic performance compared to the T2WI model alone, achieving a sensitivity of 81.4 % (80–80.3), specificity of 78.1 % (75.9–80.2), and an AUC of 0.911 (0.902–0.920) ($p = 0.001$). Similarly, combining all three MRI sequences with CECT resulted in a significantly higher diagnostic performance compared to the T2WI model alone, with a sensitivity of 79.1 % (77.2–80.7), specificity of 92.5 % (90.9–93.4), and an AUC of 0.915 (0.906–0.922) ($p = 0.001$). However, there was no statistically significant difference when compared to the T2WI with CECT combination ($p = 0.644$).

The feature list and importances are reported in Supplementary Material for all seven models.

Table 1
General characteristics of the study population.

Patients with acute pancreatitis		Healthy control subjects	
Total patients, n	78	*Total patients, n*	77
Age (years), mean ± SD	55.77 ± 17	Age (years), mean ± SD	51.04 ± 12
Male, n (%)	38 (48.7)	Male, n (%)	40 (51.9)
Etiology of acute pancreatitis, n (%)			
Biliary stone	34 (43)		
Alcohol	12 (15)		
Post-ERCP	11 (14)		
Drugs	3 (4)		
Hypertriglyceridemia	1 (1)		
Iatrogenic	1 (1)		
Unknown	16 (20)		
Computed tomography severity index, n			
CTSI 0–3: mild	62		
CTSI 4–6: moderate	15		
CTSI 7–10: severe	1		

4. Discussion

Our results show that radiomics models based on CT and MRI can effectively contribute to the diagnosis of AP. In particular, the T2WI-MRI model exhibited the best diagnostic performance as single modality compared to non-enhanced and portal venous T1WI-MRI and to CECT. This superior diagnostic performance is likely due to T2WI's ability in detecting parenchymal oedema within the pancreatic gland, a key indicator of AP. Additionally, radiomics models extract quantitative data from these images, revealing subtle patterns and features that remain undetectable to the human eye, thus improving diagnostic accuracy. In fact, pancreatic oedema is characterized by signal hyperintensity on T2WI and may be associated with surrounding peripancreatic inflammation, which is better depicted on T2WI sequences compared to T1WI sequences, although this was not included in the current segmentation. A key finding from our study is that the multi-modality radiomics model, which combines MRI with CECT texture analysis, significantly improved diagnostic performance for the diagnosis of AP. This highlights that integrating different imaging sequences and modalities offers a more comprehensive assessment, ultimately enhancing the ability to detect and diagnose AP with greater precision.

To our knowledge, this is the first multi-modality radiomics aimed at diagnosing AP, making direct comparisons with existing literature challenging. However, our findings align with previous radiomics research focused on single modality. For instance, Zhao et al. showed that a radiomics model based on portal venous phase CT images was effective in the early prediction of AP [14]. Similarly, another study utilizing MRI at late arterial-phase suggested that radiomics could be employed to predict the recurrence of AP [21]. Furthermore, a meta-analysis of multiple pancreatic diseases ranging from pancreatic tumors to autoimmune pancreatitis found that radiomics hold promising diagnostic and prognostic potential for diagnosis of diffuse and focal pancreatic diseases, including AP. Yet, only four of the twenty-four studies in the analysis specifically addressed AP, and the overall levels

Table 2
Model metrics on test datasets for different models tested. The mean and 95 % CI were reported for the area under the curve (AUC), accuracy, precision, sensitivity, and specificity. Abbreviations: CECT: contrast-enhanced CT, WI: Weighted imaging.

Model	Algorithm type	N° of features	AUC	Accuracy	Precision	Sensitivity	Specificity
CECT	Logistic Regression	10	0.610 (0.586–0.626)	0.580 (0.563–0.596)	0.599 (0.585–0.614)	0.664 (0.648–0.687)	0.484 (0.460–0.509)
T2WI	Support Vector Classifier	9	0.834 (0.819–0.844)	0.765 (0.750–0.778)	0.816 (0.800–0.834)	0.733 (0.715–0.747)	0.801 (0.782–0.823)
T1WI non-enhanced	Decision Tree Classifier	9	0.654 (0.630–0.677)	0.666 (0.645–0.679)	0.647 (0.631–0.663)	0.744 (0.715–0.764)	0.587 (0.563–0.616)
T1WI portal venous	Support Vector Classifier	8	0.680 (0.667–0.702)	0.699 (0.687–0.713)	0.774 (0.759–0.793)	0.621 (0.601–0.642)	0.787 (0.771–0.810)
MRI 3 sequences	Logistic Regression	19	0.841 (0.826–0.856)	0.811 (0.795–0.827)	0.812 (0.797–0.828)	0.815 (0.797–0.836)	0.807 (0.791–0.823)
CECT+T2WI	Decision Tree Classifier	16	0.911 (0.902–0.920)	0.799 (0.786–0.812)	0.814 (0.800–0.829)	0.814 (0.800–0.833)	0.781 (0.759–0.802)
CECT+MRI3 sequences	Support Vector Classifier	25	0.915 (0.906–0.922)	0.853 (0.841–0.863)	0.926 (0.911–0.934)	0.791 (0.772–0.807)	0.925 (0.909–0.934)

of evidence were limited [15].

Previous study evidenced that textural analysis shows an overall better performance compared to standard image evaluation of AP performed by radiologists [22]. Our findings are consistent with the existing literature, showing improved specificity and a comparable area under the curve (AUC) to radiologists' diagnostic performance, although a slightly lower sensitivity [23]. Although imaging plays an important role in confirming or excluding the diagnosis of AP, especially in unclear clinical situations, early-stage and mild forms of pancreatitis can be challenging to identify on CECT and MRI. In fact, CECT has been reported to have false-negative results in up to 27 % of cases during the first days of illness or in cases of mild pancreatitis, primarily due to its low sensitivity in detecting parenchymal subtle changes and peri-pancreatic inflammation [8]. Given the challenging management of AP, especially in the severe forms associated with high mortality, the prompt identification of early cases of AP may improve patient outcomes and guide clinical decision-making. The application of radiomics analysis to CECT, which is routinely performed for patients with suspected AP, may provide additional information at minimal cost, without the need for further imaging or laboratory tests. Given its non-invasive nature, radiomics analysis holds promise for aiding in the early detection of AP. Therefore, we recommend incorporating this technique into clinical practice, as it can significantly enhance diagnostic precision and improve patient outcomes.

Our study has several limitations. First, although our study is prospective, it was conducted at a single center, which may introduce patient selection bias. Our findings should be independently validated using external datasets. Additionally, future research is needed to assess the diagnostic performance of radiomics models in larger and more diverse patient populations. Another limitation is manual segmentation of the pancreatic gland, performed in consensus by two radiologists, which ensured high inter-rater reliability, but made the task time-consuming and dependent on expert knowledge of pancreatic imaging. To improve efficiency, particularly in the emergency setting, future studies should explore automatic segmentation techniques. Another limitation of this study is the exclusive use of the venous phase for segmentation, as the arterial phase was not available in all patients due to variability in imaging protocols. While the arterial phase typically offers superior contrast for pancreatic tissue, the venous phase was consistently available and sufficient for the analysis. Future studies could explore the inclusion of the arterial phase to potentially enhance tissue characterization. Lastly, while all MRI examinations in our study were obtained at a single institution using standardized protocols and equipment from one vendor, two patients had CT scans performed externally. Variations in image acquisition and reconstruction algorithms may introduce variability in the extracted radiomics data, potentially impacting the model's performance. However, these data reflect real-world clinical practice, where patients with suspected acute pancreatitis may undergo imaging at different institutions.

The findings of this study encourage investigating the role of radiomics analysis in the early diagnosis of AP within 24 h after the initiation of symptoms. Additionally, since prognosis is often difficult to predict, based on radiologists' assessments or clinical scoring systems alone, textural analysis could be employed to predict patient prognosis, leading to early identification of patients at the highest risk of developing clinically severe AP, who may require intensive therapy. Furthermore, integrating radiomics models with other biomarkers or clinical data could pave the way for personalized prediction models, enhancing the ability to identify severe cases of pancreatitis at admission or in the early stages of the disease.

5. Conclusion

The MRI radiomics model outperformed the CT radiomics model to predict the diagnosis of AP and the combination of MRI with CECT showed a better performance than the single radiomics models. Integration of radiomics models into routine clinical and radiological workflows has the potential to improve the detection of AP, especially in early-stage and mild forms of pancreatitis. Future research should explore their application in predicting the severity and complications of AP to further aid clinical decision making.

Ethical approval

Institutional Review Board approval was obtained.

Informed consent

Written informed consent was waived by the Institutional Review Board.

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CRediT authorship contribution statement

Abler Daniel: Formal analysis, Data curation. **Schmidt Sabine:** Supervision, Conceptualization. **Porões Fabio:** Methodology, Data curation. **Tartari Caterina:** Writing – original draft, Investigation. **Dromain Clarisse:** Supervision, Conceptualization. **Depeursinge Adrien:** Software, Investigation. **Jreige Mario:** Supervision, Investigation. **Vietti Violi Naïk:** Supervision, Investigation. **Vetterli Thomas:**

Software.

Declaration of Competing 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.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ejro.2025.100636.

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