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10 year cumulative diagnostic radiation exposure after acute pancreatitis: a retrospective comparison of acute interstitial oedematous and necrotising pancreatitis

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Abstract

Purpose Computed tomography (CT) plays a pivotal role in the diagnosis, severity assessment and recognition of complications in patients with acute pancreatitis (AP). Exposure to cumulative radiation dose increases the risk of malignancy. This study aims to retrospectively investigate imaging utilisation patterns in AP and quantify cumulative effective dose (CED), and identify predictors of high radiation exposure.

Methods Adults admitted with AP between 2012 and 2013 were retrospectively reviewed. All imaging over the subsequent 10 years was analysed, and CED was calculated from dose reports or estimated using diagnostic reference levels where required. High exposure was defined as CED > 100 mSv, a dose associated with an increased lifetime risk of malignancy.

Results One hundred-thirteen patients were included with 3022 imaging studies (92 acute interstitial oedematous pancreatitis (AIOP), 21 necrotising pancreatitis (NP)), CT comprised approximately 18% of examinations but delivered > 85% of radiation. Median (IQR) CED was 19.5 mSv for AIOP and 43.3 mSv for NP ($p = 0.004$). CED exceeded 100 mSv in 4.3% (4/92) of AIOP and 19% (4/21) of NP patients. Overall, 7% (8/113) of the cohort exceeded a CED of 100 mSv. No significant associations were found between CED and aetiology, pseudocyst formation, or mortality.

Conclusion Over a decade of follow-up, 7% of patients with acute pancreatitis exceeded the 100 mSv threshold, with CT accounting for the vast majority of exposure. Necrotising pancreatitis was associated with significantly higher cumulative doses than interstitial disease. Given that up to 30% of patients develop recurrent pancreatitis, strategies to minimize radiation exposure are essential. Optimisation of CT protocols and wider use of non-ionising modalities, including magnetic resonance imaging (MRI) and endoscopic ultrasound where appropriate, may help balance diagnostic accuracy with radiation stewardship.

Keywords Pancreatitis, Necrotizing pancreatitis, Acute interstitial pancreatitis, Effective dose, Radiation exposure

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Introduction

Exposure to ionising radiation from diagnostic imaging carries a cumulative stochastic risk, particularly in patients requiring repeated examinations [1–5]. Acute pancreatitis (AP) is a common inflammatory disorder of the exocrine pancreas [6] with a global annual incidence of 34 cases per 100,000 population and a frequent cause of hospital admission, with a rising incidence worldwide [7, 8]. Up to 30% of patients with AP require repeat imaging due to recurrent episodes, even after identification of the underlying aetiology at initial presentation [9, 10].

Computed tomography (CT) plays a central role in the diagnosis, severity assessment, detection of complications and for guidance of therapeutic interventions [6, 10, 11]. As per the revised Atlanta Classification, AP can be subclassified into acute interstitial oedematous pancreatitis (AIOP) and necrotising pancreatitis (NP) [12]. In comparison to AIOP, NP has a worse prognosis but is much less common, occurring in approximately 10% of patients with acute pancreatitis. While the incidence of complications in higher in NP, both types can result in local complications such as peripancreatic fluid collection, pseudocyst formation, necrosis and systemic complications such as acute respiratory distress syndrome, acute kidney injury and disseminated intravascular coagulation [13–15]. The recurrent nature of AP, as well as its complications often necessitate repeated diagnostic evaluation which can result in a high cumulative dose of radiation [8]. A single multiphasic abdominopelvic CT examination may deliver an effective dose of approximately 16 mSv, substantially exceeding annual background radiation exposure [16–18]. The increasing utilisation of CT imaging coupled with the rising incidence of acute pancreatitis makes this public health issue topical [19].

Despite the frequent use of CT in AP, cumulative radiation exposure in patients with AIOP and NP remains poorly defined. The primary aim of this study was to examine patterns of use of diagnostic imaging in patients with acute pancreatitis and quantify the associated cumulative effective dose (CED) of ionising radiation received by patients with AIOP and NP. Subsequently, this would allow the identification of factors, if any, associated with exposure to greater CED of ionising radiation.

Methods

Study design and population

Following institutional ethical board approval, a retrospective analysis of adult patients presenting with AP was performed. The local picture archiving and communication system (PACS) of a tertiary centre was searched electronically with a keyword search function for patients for a report diagnosis of "acute pancreatitis," "pancreatitic inflammation," "AP," "pancreatic inflammation," "interstitial pancreatitis," "necrotising pancreatitis," "peripancreatic fluid collection" from January 2012 to December 2013 inclusive. Patients with a pancreatic malignancy or an equivocal diagnosis i.e. indeterminate imaging features or reports using equivocal terminology (e.g. 'cannot exclude pancreatitis') whereby enzyme and clinical findings did not support the diagnosis were excluded following independent review by 2 investigators. Reviewers were not blinded to pancreatitis subtype or clinical information reflecting the retrospective nature of the study. Indications for imaging included, but were not limited to; initial evaluation of AP on index presentation, for evaluation of suspected recurrent AP, for investigation of AIOP to NP, for evaluation of infected NP, for evolution of NP from acute peripancreatic collection to walled-off necrosis, for planning for interventional procedures and for NP related complications (e.g. bleeding, thrombosis, biliary obstruction and gastric outlet obstruction).

The radiology information system (RIS) was cross referenced to identify the date and type of all imaging procedures these patients underwent including plain radiography, CT, ultrasound, fluoroscopy, nuclear medicine and MRI exams over the following 10-year period. All imaging procedures, including non-abdominal procedures conducted during the 10-year period were collected. Patients' demographics and aetiology were recorded. The accuracy of the capture of all imaging examinations for the population was ensured by the centralised nature of the local radiology service. Due to the centralised nature of the institutional RIS and PACS, all imaging examinations performed within the hospital network during the 10-year follow-up period were captured. Imaging performed outside the hospital network may not have been available and could result in underestimation of cumulative radiation exposure. When study dose reports were not available, a two-step approach was taken to handle the missing data. This approach was adopted due to the retrospective nature of the study and the low proportion of missing dose data per patient. If a patient had previously undergone the same radiological within the study period, that radiation dose was carried forward in a process of simple imputation. In those patients where this was not possible, diagnostic reference level values supplied by the Health Information and Quality Authority (HIQA) in Ireland were used instead.

Medical radiation exposure

To approximate the radiation dose for each diagnostic exam, we obtained the dose length product (DLP) and dose area product (DAP) from the radiation dose information table presented after each examination. The DLP reflects the total integrated absorbed dose for each CT examination and can be calculated by: DLP = the volume computed dose index X scan length, expressed

in mGycm. DAP represents the dose delivered to the patient during radiographic or fluoroscopic procedures and is calculated as dose X irradiated area and expressed as Gy.cm^2. For CT, the length of each body region was measured on the standard posterior- anterior CT radiograph. The effective dose (ED) measures the detrimental biological effect of radiation exposure and is expressed in millisieverts (mSv). It is calculated by weighting the concentrations of energy deposited in each organ with the use of parameters that reflect the type of radiation and the potential for radiation-related mutagenic changes in a reference subject [10]. For CT examinations, ED = K (the tissue conversion factors) X DLP. For radiographic and fluoroscopic procedures, the ED was calculated by multiplying the DAP with the conversion coefficient [20]. A mathematical model was utilised to convert each patient's DLP to an estimated ED [21–23]. When study dose reports were not available, simple imputation or diagnostic reference level values supplied by the Health Information and Quality Authority (HIQA) in Ireland were used instead. After the ED was calculated for each diagnostic imaging study; a CED was calculated for each patient by summating the ED for each imaging study and procedure.

Data analysis

Differences between patients who developed AIOP and NP were analysed with respect to radiation exposure, aetiology, age, the development of pseudocysts/peripancreatic collections and mortality. Normality was determined by Shapiro-Wilk testing while Levene's test was used to determine equal/unequal variances. In evaluation of AIOP and NP, the Mann-Whitney U test was used to compare non-parametric data and chi-square tests were conducted to compare categorical data. Kruskal–Wallis testing was used for non-parametric comparisons across three or more groups. Linear regression was used in determining the relationship between continuous variables such as radiation dose and age. Given the small number of high-exposure events (CED > 100 mSv), multivariable modelling for independent predictors was not performed; univariable analyses are reported. Simple linear regression was performed using Jamovi to assess the association between age and cumulative effective dose (CED). Assumptions for linear regression were assessed by inspection of residual plots, and no major violations were identified.

Results

Patient demographics

A total of 113 patients were diagnosed with acute pancreatitis, of which 21 (18.6%) displayed a necrotising variant. In the AIOP population: (55.4% male, 44.6% female) median age was 57 years (IQR 40–74). In the necrotising variant (NP) population: (61.9% male, 38.1% female) median age 49 years (IQR 40–62). Aetiologies of AIOP included gallstones (45.7%), idiopathic (26.1%), alcohol abuse (19.6%), and other (8.7% which included trauma, ERCP induced, post-operative pancreatitis, B-Cell lymphoma, hypertriglyceridemia and a pancreas transplant recipient). In the AIOP group, 6 patients developed pancreatic pseudocysts (6.5%) and 11 patients died (12%). Aetiologies of NP included idiopathic (33.3%), alcohol abuse (38.1%) and gallstones (28.6%). In the NP group 5 patients developed pancreatic pseudocysts (23.8%) and 4 patients died (19%). (Table 1)

Table 1 Baseline characteristics of patients with acute interstitial oedematous pancreatitis (AIOP) and necrotising pancreatitis (NP)

	AIOP (*n* = 92)	NP (*n* = 21)	*P* value
Age (median, IQR)	57 (40–74)	49 (40–62)	0.166
Male gender (*n*, %)	51 (55.4%)	13 (61.9%)	0.589
Aetiology – Alcohol (*n*, %)	18 (19.6%)	8 (38.1%)	0.069
Gallstones (*n*, %)	42 (45.7%)	6 (28.6%)	0.153
Idiopathic (*n*, %)	24 (26.1%)	7 (33.3%)	0.502
Other (*n*, %)	7 (7.6%)	0 (0%)	0.192
Complications			
Pseudocyst formation (*n*, %)	**6 (6.5%)**	**5 (23.8%)**	**0.016**
Death (*n*, %)	11 (12%)	4 (19%)	0.387

Values are shown as median (interquartile range) or *n* (%). Continuous variables were compared using Mann-Whitney U test; categorical variables were compared using contingency table analysis. Boldface indicates values of statistical significance

Table 2 Imaging Studies for the entire population in AIOP vs. NP

Imaging Modality	AIOP (*n* = 92)	NP (*n* = 21)
All modalities	2477	545
CT (*n*, %)	417 (16.8%)	126 (23.1%)
Plain film (*n*, %)	1625 (65.6%)	298 (54.7%)
MRI (*n*, %)	123 (5.0%)	35 (6.4%)
Ultrasound (*n*, %)	233 (9.4%)	57 (10.5%)
Fluoroscopy (*n*, %)	79 (3.2%)	26 (4.8%)
Nuclear medicine (*n*, %)	10 (0.4%)	3 (0.5%)

Imaging utilisation

All patients underwent diagnostic imaging. A total of 3022 imaging studies were performed over the 10-year period (2477 in the AIOP group and 545 in the NP group). The median number of studies performed per patient was 14 (IQR 7–33) for AIOP and 19 (IQR 12–31) for the necrotising variant. Plain radiographs constituted the largest number of imaging procedures followed by CT, ultrasound, MRI, fluoroscopy and nuclear medicine imaging. Patients in the NP group underwent a greater number of CT examinations in comparison to the AIOP group (NP median 5 [IQR 2–6] vs. AIOP median 3 [IQR 1–6], $p = 0.027$). No statistically significant differences were seen in use of other modalities (Tables 2 and 3).

Table 3 Imaging Studies Per Patient Performed in AIOP vs. NP

Imaging Modality	AIOP (*n* = 92)	NP (*n* = 21)	*P* value
All modalities (median, IQR)	14 (7–33)	19 (12–31)	0.203
CT (median, IQR)	**3 (1–6)**	**5 (2–6)**	**0.027**
Plain film (median, IQR)	9 (3–20)	12 (6–18)	0.324
MRI (median, IQR)	1 (0–1)	1 (0–2)	0.305
Ultrasound (median, IQR)	1.5 (1–3)	2 (0–4)	0.916
Fluoroscopy (median, IQR)	0 (0–1)	0 (0–0)	0.475
Nuclear medicine (median, IQR)	0 (0–0)	0 (0–0)	0.360

Boldface indicates values of statistical significance. Mann–Whitney U test was used for comparison

Table 4 Radiation exposure in AIOP vs. NP

	AIOP (*n* = 92)	NP (*n* = 21)	*P* value
Total dose mSv (median, IQR)	19.5 (12.7–53.4)	43.3 (32.9–75.8)	0.004
CT dose *mSv* (median, IQR)	18.5 (11.5–46.8)	42.4 (32.9–69.9)	**0.002**
Total dose > 100 mSv (*n*, %)	4 (4.3%)	4 (19%)	**0.018**

Boldface indicates values of statistical significance. Doses are displayed in millisieverts (mSv). Mann–Whitney U test was used for comparison

Table 5 Radiation exposure classified by demographics, aetiology and complications

	Entire Cohort (*n* = 113)	Median dose mSv (IQR)	*P* Value
Male Sex (*n*, %)	64 (56.6%)	29.2 (15.6–60.7)	0.101
Aetiology			
Alcohol	26 (23%)	37.4 (19.4–64.0)	0.236
Gallstones	48 (42.5%)	18.9 (12.2–43.7)	0.092
Idiopathic	32 (28.3%)	35.0 (15.6–64.0)	0.620
Other †	7 (6.2%)	19.4 (12.1–49.0)	0.924
Complications			
Pseudocyst (*n*, %)	11 (9.7%)	43.3 (35.6–56.2)	0.151
Death (*n*, %)	15 (13.3%)	32.6 (16.2–55.8)	0.283

Values are presented as median (interquartile range) or *n* (%). Doses are reported in millisieverts (mSv). Between-group comparisons of dose were performed using the Mann–Whitney U test or Kruskal–Wallis test, as appropriate. Age was analysed using linear regression and is therefore not presented as a group comparison

† "Other" aetiology category contained small numbers and should be interpreted with caution

Cumulative effective dose received by patients

Cumulative effective dose represents radiation exposure from all diagnostic imaging during the 10-year follow-up. While many examinations were related to pancreatitis, recurrent disease, or downstream complications, not all imaging could be definitively attributed to pancreatitis in this retrospective study. Median cumulative radiation exposure per patient with AIOP was 19.5 mSv (IQR 12.7–53.4; range 0.1–392 mSv). Cumulative exposures exceeding 100 mSv occurred in 4.3% of patients (4 of 92). In the necrotising variant, median cumulative radiation exposure per patient was 43.3 mSv (IQR 32.9–75.8; range 7.4–379 mSv). Cumulative exposures exceeding 100 mSv occurred in 19% of patients (4 of 21). Computed tomography (CT) accounted for approximately 18% (543/3022) of all diagnostic examinations but contributed up to 88% of the total radiation dose to all patients, with the remaining exposure attributable to fluoroscopy and plain radiography. (Tables 2 and 3) When stratified by subtype, CT comprised approximately 23.1% of all examinations and contributed 87% of the total radiation dose in cases of NP, whereas in AIOP, CT accounted for 16.8% of examinations and 89% of the total radiation dose. (Table 4)

Associations with radiation exposure

Mann Whitney U testing revealed patients with NP were exposed to a higher median radiation dose in comparison to patients with AIOP; 43.3 mSv (IQR 32.9–75.8) versus 19.5 mSv (IQR 12.7–53.4), $p = 0.004$. Cumulative effective dose did not differ significantly across aetiology groups (Table 5). The patients who developed pseudocysts and those who died did not have higher cumulative radiation exposures compared to the others ($p = 0.151$ and $p = 0.283$ respectively). Chi-Square testing revealed a higher risk of pancreatic pseudocysts formation in the NP group of patients ($x^2 = 5.82$, $p = 0.016$), however there were no differences in the risk of death between the two groups ($x^2 = 0.747$, $p = 0.387$). Apart from the development of NP, no aetiological or demographic variables were found to be associated with higher levels of radiation exposure. (Tables 4 and 5). There was no association between age and cumulative effective dose on simple linear regression ($p = 0.994$). Mortality outcomes reflect all-cause death during follow-up; reliable attribution of cause of death specifically to pancreatitis was not possible due to the retrospective design and absence of complete cause-of-death records.

Radiation dose reports were not available for some imaging procedures performed on older scanners at our institution and some externally imported into the institutional PACS system. As described in the methods, this missing data was handled with simple imputation or the use of DRLs where imputation was inappropriate. A median dose of 1.3 mSv (IQR 0.1–7.5 mSv) was imputed/substituted with DRLs for the AIOP cohort when dose data was missing and 3.7mSv (IQR 0.4–12.6 mSv) imputed/substituted with DRLs in the NP cohort. There was no statistically significant difference in this imputation between the two groups ($p = 0.080$).

Per-patient analysis revealed the median imputation percentage to be 5.5% for patients in the AIOP cohort and 4.3% for patients in the NP cohort. Again, there was no statistically significant difference between patients in the two groups ($p = 0.315$).

Discussion

Radiation exposure for patients with AIOP and NP is not well defined within the literature. This study comprehensively assesses diagnostic imaging–associated radiation exposure in patients with AIOP and NP over a 10-year period. We found that approximately 88% of the cumulative radiation dose was attributable to diagnostic CT imaging. Patients received substantial cumulative effective doses (CED), with median values of 19.5 mSv for AIOP and 43.3 mSv for NP. A CED exceeding 100 mSv was observed in 4.3% of patients with AIOP and 19% of patients with NP. In practical terms, patients with AIOP typically accumulated radiation exposure equivalent to approximately one CT examination, whereas patients with NP accumulated exposure equivalent to nearly 3 CT examinations, meaning relatively few additional scans may result in high cumulative exposure of greater than 100mSv. This highlights how quickly patients with necrotising disease can accumulate potentially substantial radiation doses particularly in the setting of recurrent pancreatitis.

Published data on cumulative radiation exposure in pancreatitis is limited. We identified 3 studies that quantified the mean CED in patients with AIOP or NP. One audit from India reported a mean CED of 24 mSv in patients with AIOP and higher doses in more severe disease [23]. Thiruvengadam et al. found that patients with NP in the USA received a mean CED of 274 mSv with 40% of the cumulative radiation dose being from CT imaging and 54% (149 mSv) from therapeutic fluoroscopic procedures [24]. Liu et al. reported a mean CED of 37.5mSv in type 1 autoimmune pancreatitis [25].

Unlike these studies, which focused on specific disease subtypes or shorter follow-up periods, our study evaluates long-term cumulative exposure in both AIOP and NP, providing real-world data from a European tertiary centre. We found that patients with NP receive substantially higher doses of radiation when compared to the AIOP cohort with 19% of patients exceeding a CED of > 100 mSv suggesting a potential increased risk of malignancy [10, 26, 27]. This represents a higher cancer risk than expected when compared to patients with other gastrointestinal disorders e.g. inflammatory bowel disease (IBD) (mean CED 10–36 mSv), cirrhosis (mean CED of 51 mSv), intestinal Behcet disease (41.3 mSv) [28–30].

The biological effects of protracted low levels of radiation have been investigated and debated for years [31]. It has been established that there is an increased risk of malignancy and germline mutation risks associated with protracted low dose radiation [32]. Low dose radiation associated with medical exposure has been linked to the development of solid tumours of colon and bladder [27, 33]. Desmond et al. found malignancies occurred in 7 of 354 patients with Crohn's disease with a mean CED of less than 50 mSv over a 6.7 year period [34]. Another study involving 15 countries found that between 0.6% – 1.8% of all malignancies resulted from diagnostic radiation demonstrating that patients with NP may accumulate relatively high diagnostic radiation exposure, underscoring the importance of dose awareness in this population [35].

CT imaging contributed the majority of radiation exposure in both AIOP and particularly the NP cohorts. The effective dose of radiation from CT is high compared to other diagnostic modalities [16]. Reducing the number of unnecessary CT examinations is paramount to minimizing diagnostic medical radiation. It has been reported that in the USA, up to one third of all CT examinations are repeated unnecessarily or performed when alternative modalities could be utilised with equal diagnostic efficacy [36]. Advances in abdominal CT like low dose acquisitions protocols and iterative reconstruction allow for substantial reductions in dose (30–50%) without compromising imaging quality [37–39]. Additionally, dual energy computed tomography (DE-CT) can create virtual unenhanced images which may replace true unenhanced pancreatic imaging and allow for significant dose reductions [40]. However, further direct comparative studies in the context of acute pancreatitis are needed before low dose or dual energy CT protocols can be definitively recommended.

While the American Association of Physicists in Medicine (AAPM) advise cumulative radiation exposure data should not be used for clinical decision-making; exposure data is valuable in quality improvement and protocol optimisation. Monophasic CT, can reduce radiation exposure by more than 30%, is recommended by the International Association of Pancreatology for follow-up imaging in most cases and may be adequate for many clinical scenarios, including initial diagnosis [41, 42]. A combination of appropriate clinical justification with CT scan protocol optimisation and appropriate use of monophasic imaging would likely reduce the CT- related dose exposure in patients with acute pancreatitis.

Magnetic resonance imaging (MRI) represents a non-ionising alternative to CT for selected indications, although longer acquisition times, patient tolerance, and availability may limit its use. However, Liu et al. reported that CT imaging in patients with autoimmune pancreatitis has limited sensitivity (64.1%) in detecting disease relapse when compared to MRI (90.5%) thus restricting its role in monitoring disease recurrence [25]. This is particularly concerning in patients with a high BMI, who have an increased radiation dose with both CT and fluoroscopy imaging and are at a higher risk of developing acute NP. A recent study proposed a simplified MR sequence protocol without dynamic contrast-enhanced

sequences to evaluate inflammatory activity of the pancreas with a reduction in scanning time to 13 min, providing another option for imaging [43]. Ultrasound, including endoscopic ultrasound (EUS), is another non-ionizing option that can address specific clinical questions such as biliary aetiology, interval assessment of peripancreatic collections/pseudocysts and guidance for drainage in selected cases [44–46]. However, it is operator-dependent and may be limited by overlying bowel gas, body habitus and incomplete visualization of deep retroperitoneal collections [46].

Strengths

The extended 10-year follow-up period allows assessment of cumulative diagnostic imaging utilisation and radiation exposure over a clinically meaningful timeframe, capturing long-term patterns that are not apparent in short-term or admission-based analyses. Comparison between acute interstitial oedematous pancreatitis and necrotising pancreatitis provides insight into how disease severity and phenotype influence imaging burden and cumulative effective dose. Imaging data were derived from routine clinical practice, enhancing the real-world relevance and generalisability of the findings. Importantly, the finding that CT accounted for a relatively small proportion of examinations but the majority of radiation exposure identifies a clear and actionable target for radiation stewardship, including careful justification of repeat CT and optimisation of CT protocols.

Limitations

This single-centre retrospective study relied on institutional PACS and RIS searches; while all imaging performed within the hospital network was captured, examinations performed outside the network may not have been available, potentially underestimating cumulative exposure. Radiation dose was estimated using effective dose calculations derived from scanner-reported metrics and diagnostic reference levels, which reflect accepted retrospective methodology but do not fully account for patient size, imaging technique, or scanner-specific factors; individual absorbed doses may therefore vary. Imaging performed during follow-up may have been unrelated to the index episode of acute pancreatitis, such that cumulative effective dose reflects total diagnostic imaging exposure rather than pancreatitis-attributable dose for every examination. Accordingly, cumulative effective dose reflects overall diagnostic imaging exposure in patients with acute pancreatitis rather than pancreatitis-specific imaging alone, despite efforts to review imaging indications where available. The necrotising pancreatitis subgroup was small, limiting power for subgroup analyses, and imaging practices evolved over the 10-year follow-up, which may affect generalisability to current practice. The retrospective design also precluded reliable assessment of how individual imaging examinations influenced clinical management or therapeutic decision-making, as imaging indications, findings, and downstream management actions could not be consistently extracted. The low number of patients with cumulative effective dose > 100 mSv limited multivariable analysis. Long-term outcomes such as incident malignancy were not assessed, as the study was not designed or powered to evaluate cancer outcomes and comprehensive malignancy data were not available in this retrospective cohort. Accordingly, any discussion of cancer risk relates to established population-based radiation risk models rather than observed malignancy outcomes and should be interpreted with caution. Despite these limitations, the study demonstrates a substantial cumulative radiation burden associated with acute pancreatitis and highlights opportunities for radiation stewardship.

Conclusion

Patients with acute pancreatitis, particularly those with necrotising disease, are exposed to substantial cumulative radiation doses, with a notable proportion exceeding 100 mSv over long-term follow-up. Given that up to 30% of patients develop acute recurrent pancreatitis, clinicians need to consider cumulative radiation exposure, particularly from repeated CT imaging. Most of this burden arises from CT, underlining the importance of correlating imaging requests with clinical and laboratory findings to ensure appropriate use. Adoption of dose-optimised CT protocols and consideration of MRI as a follow-up modality may help reduce long term radiation exposure. These findings highlight the need to balance diagnostic accuracy with radiation stewardship and to develop follow-up strategies that minimise unnecessary imaging while maintaining safety.

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Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by SS, NNC and EOB. The first draft of the manuscript was written by NNC and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.Conceptualization: NNC, Methodology: NNC; Formal analysis and investigation: NNC; Writing - original draft preparation: NNC; Writing - review and editing: SS, RL, EOB, LDK, EK, DJR, MM. Funding acquisition: n/a; Supervision: MM.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Clinical Research Ethics Committee (CREC) of the Cork teaching hospitals. Adult participant consent was not required because it was waived by the Clinical Research Ethics Committee due to retrospective design.

Consent for publication
Not applicable. No identifying images or personal clinical details of participants are included in this manuscript.

Competing interests
The authors declare no competing interests.

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