DOI: https://doi.org/10.17816/DD629345

Neuroendocrine tumors of stomach and pancreas: diagnostic potential of radiomics, issues, and solutions

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ABSTRACT

BACKGROUND: Radiomics is currently a promising and prospective tool for diagnosing and treating neuroendocrine neoplasms at various sites. This method is often used for differential diagnosis of gastrointestinal neuroendocrine tumors with other neoplasms at this site.

AIM: The aim of the study was to evaluate the potential of radiomics for differential diagnosis of neuroendocrine tumors of stomach and pancreas.

MATERIALS AND METHODS: The study included data of 12 patients with morphologically proven neoplasms of the stomach (6 with neuroendocrine tumors and 6 with adenocarcinomas) and data of 22 patients with morphologically proven neoplasms of the pancreas (11 with neuroendocrine tumors and 11 with adenocarcinomas). All patients underwent abdominal computed tomography (CT) with intravenous contrast enhancement prior to treatment at the Russian Scientific Center of Roentgenology and Radiology. Radiomics parameters were calculated for the area of gastric and pancreatic tumor manually segmented in the native phase of the CT scan. The results were processed and statistically analyzed using Microsoft Office Excel and R-Studio, a free, open-source software development environment for the R programming language.

RESULTS: CT scan examples demonstrate typical and atypical visual signs of neuroendocrine tumors of stomach and pancreas, contrast enhancement characteristics, location and structure of neoplasms. Fifteen radiomics parameters were identified that were statistically significantly different between gastric neuroendocrine tumor and gastric adenocarcinoma. In pancreas, neuroendocrine tumors differed significantly from adenocarcinomas in 14 radiomics parameters.

CONCLUSION: Neuroendocrine tumors of stomach and pancreas are rare neoplasms that are mostly asymptomatic and difficult to visualize due to their small size and contrast enhancement characteristics. Texture analysis may be a promising approach to differentiate gastrointestinal neuroendocrine tumors from other neoplasms at these sites, especially in the view of the difficulty in obtaining a biopsy.

Keywords: neuroendocrine tumor; neuroendocrine tumor of stomach; neuroendocrine tumor of pancreas; neuroendocrine neoplasia; radiology.

To cite this article:
Nudnov NV, Shakhvalieva ES-A, Karelidze DG, Borisov AA, Ivannikov ME. Neuroendocrine tumors of stomach and pancreas: diagnostic potential of radiomics, issues, and solutions. *Digital Diagnostics.* 2024;5(4):712–724. DOI: https://doi.org/10.17816/DD629345

Received: 22.03.2024 **Accepted:** 22.05.2024 **Published online:** 12.11.2024

DOI: https://doi.org/10.17816/DD629345

Нейроэндокринные опухоли желудка и поджелудочной железы: диагностические возможности радиомики, проблемы и пути их решения

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АННОТАЦИЯ

Обоснование. В настоящее время радиомика является многообещающим и перспективным инструментом в диагностике и лечении нейроэндокринных новообразований различной локализации. Этот метод часто используют для дифференциальной диагностики нейроэндокринных опухолей желудочно-кишечного тракта с другими новообразованиями данной локализации.

Цель — оценить возможности применения радиомики для дифференциальной диагностики нейроэндокринных опухолей желудка и поджелудочной железы.

Материалы и методы. В исследование включены данные 12 пациентов с морфологически верифицированными новообразованиями желудка (6 — с нейроэндокринной опухолью и 6 — с аденокарциномой) и данные 22 пациентов с морфологически верифицированными новообразованиями поджелудочной железы (11 — с нейроэндокринной опухолью и 11 — с аденокарциномой). Всем пациентам до лечения в Российском научном центре рентгенорадиологии выполнено компьютерно-томографическое (КТ) исследование органов брюшной полости с внутривенным контрастированием. Показатели радиомики рассчитаны в области опухоли желудка и поджелудочной железы, которую сегментировали вручную в нативную фазу КТ-исследования. Обработку результатов и статистический анализ проводили с использованием Microsoft Office Excel и свободной среды разработки программного обеспечения с открытым исходным кодом для языка программирования R — R-Studio.

Результаты. На примерах КТ-исследований продемонстрированы типичные и нетипичные визуальные признаки нейроэндокринных опухолей желудка и поджелудочной железы, особенности контрастирования, локализации и структуры новообразований. Выявлено 15 показателей радиомики, которые статистически значимо различаются между нейроэндокринной опухолью желудка и аденокарциномой желудка. В случае поджелудочной железы нейроэндокринные опухоли статистически значимо отличались от аденокарцином по 14 показателям радиомики.

Заключение. Нейроэндокринные опухоли желудка и поджелудочной железы — редкие новообразования, которые в большинстве случаев не проявляют себя клинически и трудно визуализируются из-за малых размеров и особенностей контрастирования. Текстурный анализ может стать перспективным подходом для дифференциальной диагностики нейроэндокринных опухолей желудочно-кишечного тракта с другими новообразованями данной локализации, особенно с учётом сложности взятия биопсии.

Ключевые слова: нейроэндокринная опухоль; нейроэндокринная опухоль желудка; нейроэндокринная опухоль поджелудочной железы; нейроэндокринная неоплазия; лучевая диагностика.

Как цитировать:
Нуднов Н.В., Шахвалиева Э.С.-А., Карелидзе Д.Г., Борисов А.А., Иванников М.Е. Нейроэндокринные опухоли желудка и поджелудочной железы: диагностические возможности радиомики, проблемы и пути их решения // Digital Diagnostics. 2024. Т. 5, № 4. С. 712–724. DOI: https://doi.org/10.17816/DD629345

Рукопись получена: 22.03.2024 **Рукопись одобрена:** 22.05.2024 **Опубликована online:** 12.11.2024

DOI: https://doi.org/10.17816/DD629345

胃和胰腺神经内分泌肿瘤：放射组学的诊断能力、问题及其解决方法

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摘要

论证。目前，放射组学是诊断和治疗各种局部化神经内分泌肿瘤的一种前景广阔的工具。这种方法常用于胃肠道神经内分泌肿瘤与该部位的其他肿瘤的鉴别诊断。

目的 — 评估放射组学在胃和胰腺神经内分泌肿瘤鉴别诊断中的应用可能性。

材料和方法。研究中，包括12名经形态学验证的胃肿瘤患者（6名神经内分泌肿瘤患者和6名腺癌患者）的数据和 22名经形态学验证的胰腺肿瘤患者（11名神经内分泌肿瘤患者和11名腺癌患者）的数据。所有患者在治疗前都在俄罗斯放射学科学中心接受了静脉注射造影剂的腹腔器官计算机断层扫描（CT）检查。计算了胃和胰腺肿瘤区域的放射组学指数，该区域在CT检查的原生相进行了手动分割。使用Microsoft Office Excel和R — R-Studio编程语言的免费开源软件开发环境进行结果处理和统计分析。

结果。通过CT研究实例，展示了胃和胰腺神经内分泌肿瘤的典型和非典型视觉征象、肿瘤的对比度、定位和结构的特征。研究发现，胃神经内分泌瘤和胃腺癌的15项放射组学指标在统计学上存在显著差异。就胰腺而言，神经内分泌肿瘤与腺癌在14项放射组学指标上有明显统计学差异。

结论。胃和胰腺的神经内分泌肿瘤是一种罕见的肿瘤，在大多数情况下临床上并无症状，且由于其体积小、对比度特征而难以成像。纹理分析可能是鉴别胃肠道神经内分泌肿瘤与该部位其他肿瘤的一种很有前途的方法，特别是考虑到活检取样的复杂性。

关键词：神经内分泌肿瘤；胃神经内分泌肿瘤；胰腺神经内分泌肿瘤；神经内分泌瘤；放射诊断。

引用本文：
Nudnov NV, Shakhvalieva ES-A, Karelidze DG, Borisov AA, Ivannikov ME. 胃和胰腺神经内分泌肿瘤：放射组学的诊断能力、问题及其解决方法. *Digital Diagnostics*. 2024;5(4):712–724. DOI: https://doi.org/10.17816/DD629345

收到：22.03.2024 **接受：**22.05.2024 **发布日期：**12.11.2024

BACKGROUND

Neuroendocrine neoplasms (NENs) represent a heterogeneous group of tumors derived from neuroendocrine cells. These tumors encompass a broad spectrum, with the most common types arising in the gastrointestinal tract, lungs, bronchi, thymus, and pancreas [1]. The term *neuroendocrine* refers to cells that exhibit both neural and endocrine characteristics [2]. Under the standardized classification system, all neuroendocrine neoplasms are categorized as *neuroendocrine tumors* (NETs), which include both low-grade NETs and high-grade neuroendocrine carcinomas. Some tumors contain a combination of low- and high-grade histological features and are classified as mixed neuroendocrine–non-neuroendocrine neoplasms, in which the neuroendocrine component constitutes at least 30% of the tumor [1].

Accurate staging of NETs is essential for determining prognosis and guiding treatment decisions [3]. Gastrointestinal and pancreatic NETs are currently graded into three categories: G1 (low grade), G2 (intermediate grade), and G3 (high grade). According to the 2019 World Health Organization classification and the 2016 guidelines from the European Neuroendocrine Tumor Society (ENETS), grading is based on the mitotic count and the Ki-67 proliferation index (Table 1). These grading criteria are similar for both gastrointestinal and pancreatic NETs [4].

Tumor grade significantly influences survival outcomes. Data from 64,971 patients with NETs in the Surveillance, Epidemiology, and End Results (SEER) database showed median survival times of 16.2 years for G1, 8.3 years for G2, and 10 months for G3 NETs. Survival also varies markedly with disease stage: patients with localized disease had a median survival of over 30 years, those with regional spread had a median of 10 years, and those with distant metastases had a median of 1 year [5].

Gastric NETs represent approximately 11%–12% of newly diagnosed NETs [3]. Pancreatic NETs account for about one-third of gastrointestinal NETs. Among pancreatic NETs, 45%–60% are non-functioning, while 40%–55% are hormone-secreting [6].

In Russia, data on the incidence of NENs are currently unavailable [4]. In contrast, the incidence in the USA was reported at 6.98 cases per 100,000 population in 2012. An independent analysis of the SEER database also indicated an increase in the incidence of gastrointestinal NENs between 1975 and 2008. Although the exact cause of this rise is unclear, improvements in diagnostic techniques and classification may have contributed [1].

To determine the tumor grade, tissue sections were stained using antibodies against pancytokeratin; cytokeratins 7, 14, 18, and 20; as well as synaptophysin (Syn) and chromogranin A (CgA). If one of the neuroendocrine differentiation markers is not expressed, staining with anti-CD56 antibodies is performed, and the expression of somatostatin receptors 2 and 5 (SSTR2 and SSTR5) is assessed as additional markers [4].

The clinical presentation of NETs varies based on the location of the primary tumor, and all NET types are characterized by a high potential for metastasis. A study by Halfdanarson et al. analyzing NET cases in the USA from 1973 to 2000 found that over 60% of patients had distant metastases and more than 20% had regional metastases at the time of diagnosis [7]. Similar results were reported by Loosen et al. in a European cohort, where 84.6% of patients were found to have distant metastases at diagnosis [8].

Diagnosis of gastric and pancreatic neuroendocrine tumors

The clinical symptoms and NENs can vary widely depending on the tumor location. In functioning tumors, symptoms may result from the secretion of biologically active substances.

Most pancreatic NETs are non-functioning, meaning they do not produce clinical signs of hormone overproduction, which makes diagnosis more difficult. In some instances, these tumors are discovered incidentally during evaluations for unrelated conditions [9]. Non-functioning tumors may remain asymptomatic for extended periods or present with nonspecific symptoms. Typical manifestations include diarrhea, hot flashes, and skin flushing, while bronchospasm is observed less frequently. Other symptoms such as intestinal cramping, telangiectasia, edema, cyanosis, joint involvement, muscle pain, and myopathy are rare [4].

Upper endoscopy with biopsy is commonly used for diagnosis, as NETs require confirmation by immunohistochemistry [10]. Abdominal CT is recommended for G1 and G2 NETs larger than 2 cm, as well as for all G3 NETs. In certain cases, abdominal magnetic resonance imaging (MRI), octreotide scintigraphy, and positron emission tomography combined with CT (PET/CT) may also be useful [11].

Table 1. Classification of gastrointestinal and pancreatic neuroendocrine tumors

Grade	Mitotic index (10HPF)	Proliferation index Ki67, %
G1 neuroendocrine tumors	<2	<3
G2 neuroendocrine tumors	2–20	3–20
G3 neuroendocrine tumors	>20	>20
Neuroendocrine carcinomas	>20	>20

Note. G, neuroendocrine tumor grade; HPF, high-power field.

Pancreatic NETs exhibit the greatest contrast enhancement during the early arterial phase (25–35 s), rather than the late arterial phase (35–45 s), which is typically used for pancreatic imaging. This distinction is important because small tumors may be missed during the late arterial phase when the lesion becomes isodense with the surrounding pancreatic tissue [12]. Fig. 1 illustrates characteristic imaging features of pancreatic NETs. Abdominal CT with intravenous contrast revealed a hypervascular lesion in the head of the pancreas, measuring 13 × 9 mm, located near the pancreatic duct and common bile duct, without clear signs of duct compression on CT. The tumor demonstrated marked contrast enhancement during the early arterial phase (10 s) but was poorly visualized in the subsequent contrast phases.

Some pancreatic NETs may appear hypovascular, requiring differentiation from other lesions such as serous cystadenomas, intrapancreatic accessory spleens, renal cell carcinoma metastases, and both cystic and solid masses, including hypovascular adenocarcinomas [13]. Fig. 2 presents a CT image of a pancreatic NET with these features. The lesion, located in the pancreatic body, is round with irregular margins, measuring approximately 2.3 × 2.1 cm, and contains a centrally hypodense area suggestive of necrosis [14]. It appears isodense relative to the pancreatic parenchyma in the venous phase and shows only mild enhancement during the arterial phase. There is no evidence of tumor infiltration into the surrounding fat or vascular structures. In this case, the tumor was identified based on indirect signs, including dilatation of the pancreatic duct, compression of the splenic vein, and moderate enlargement of the pancreatic body. This presentation is atypical for pancreatic NETs. Rare cases have been described in which venous phase enhancement is more pronounced [15].

Gastric NETs are generally hypervascular and typically show increased contrast enhancement during the early arterial phase [16]. G1 and G2 gastric NETs are usually small (<1 cm) and are most often located in the gastric fundus or body [10, 17]. Fig. 3 illustrates typical imaging features of gastric NETs. An exophytic, hypervascular lesion measuring 10 × 9 mm is visible along the greater curvature of the gastric body, with strong arterial phase enhancement.

As with pancreatic NETs, gastric NETs can also show variable contrast enhancement. Fig. 4 illustrates a NET located in the upper wall of the gastric cardia, which displayed increased enhancement during the venous phase and minimal enhancement during the arterial phase.

These cases highlight the diagnostic complexity and variability in imaging features of gastric and pancreatic

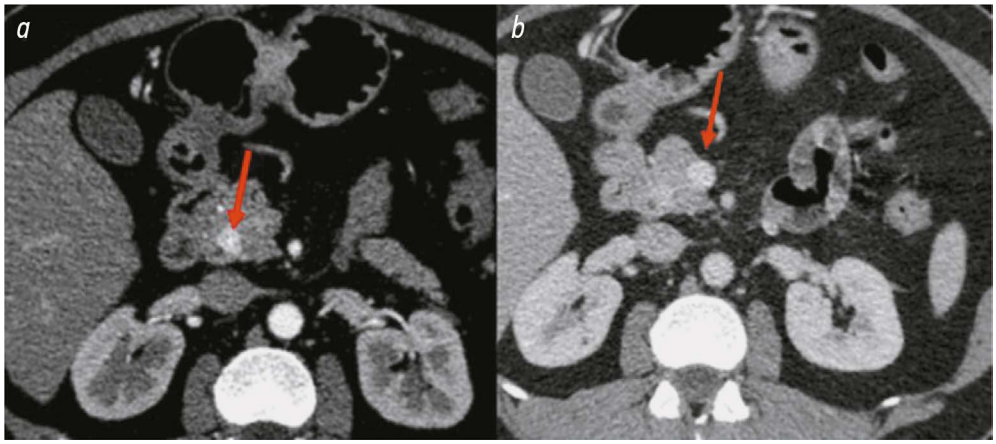

Fig. 1. Abdominal computed tomography with intravenous contrast: *a*, a hypervascular lesion near the common bile duct during the arterial phase (10th second); *b*, venous phase image.

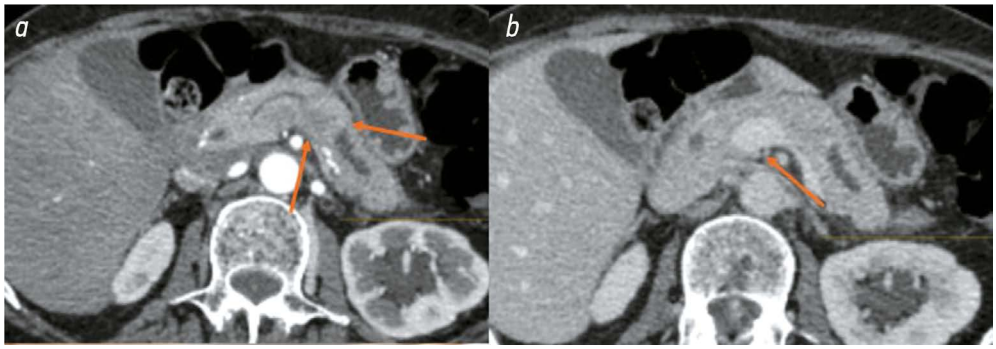

Fig. 2. Computed tomography of a hypovascular pancreatic neuroendocrine tumor: *a*, a moderately hypervascular lesion in the pancreatic body with a hypodense central area and dilatation of the pancreatic duct, arterial phase (10th second); *b*, moderate compression of the splenic vein, venous phase.

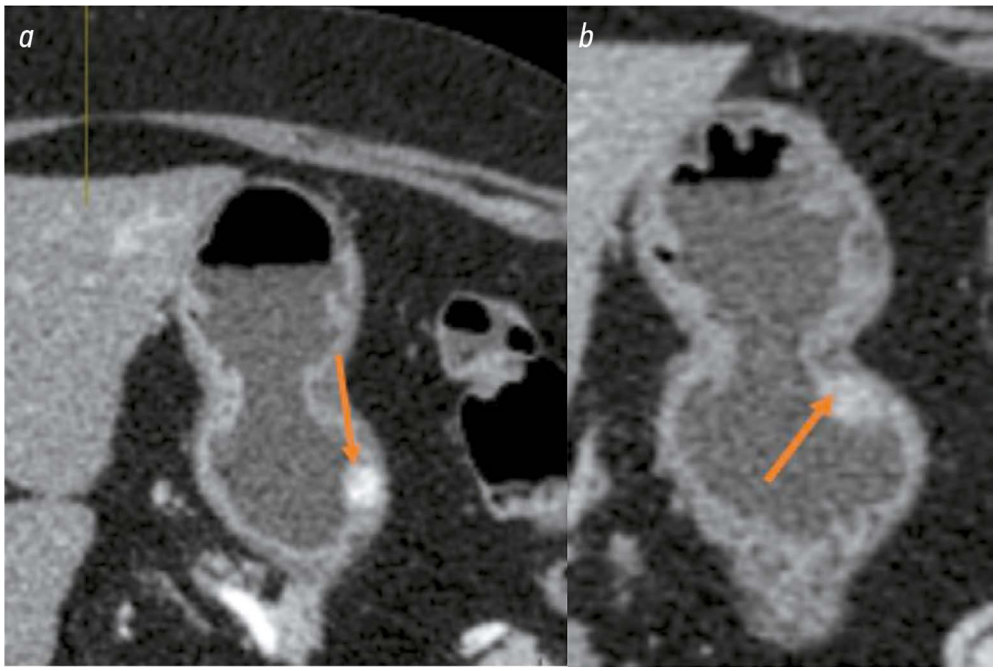

Fig. 3. Gastric neuroendocrine tumor: *a*, tumor tissue showing high contrast uptake, arterial phase; *b*, tumor tissue showing moderate contrast uptake, venous phase.

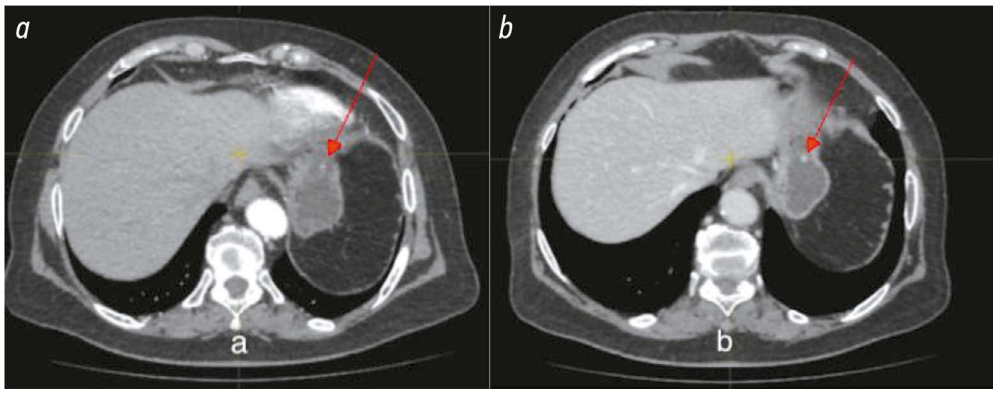

Fig. 4. Gastric neuroendocrine tumor: *a*, low contrast uptake by tumor tissue, arterial phase; *b*, a hyperintense lesion in the upper wall of the gastric cardia (up to 6 mm), venous phase.

NETs. According to recommendations from the European Society for Medical Oncology and the National Comprehensive Cancer Network, pancreatic biopsy is advised only when the tumor is not clearly visualized on three-phase MRI or CT. The sensitivity of cytological and histological evaluation for diagnosing pancreatic cancer does not exceed 90%. In cases where imaging does not provide morphological confirmation of pancreatic cancer, most patients still undergo radical surgical treatment. However, biopsy carries risks, including potential complications and the possibility of tumor cell spread [18].

Therefore, research into the potential for achieving morphological confirmation of malignancy through imaging studies is of particular relevance.

Radiomics is currently regarded as a promising approach for the diagnosis and management of NENs at various anatomical sites [19]. It involves the extraction and analysis of numerous quantitative features from medical imaging data, including parameters related to shape, size, texture, intensity, and voxel relationships [20].

Radiomics is applied in research to solve specific clinical tasks. In gastrointestinal NENs, its most common application is in predicting tumor grade [21–23]. Texture analysis has also been used to differentiate gastrointestinal NETs from other gastrointestinal neoplasms. Most studies indicate that models combining radiomics features with clinical and additional diagnostic data yield the highest accuracy. Texture analysis is used less frequently to evaluate treatment response in gastrointestinal NETs. Additionally, some studies have explored the role of radiomics in predicting disease progression and recurrence.

AIM

To assess the potential of radiomics for the differential diagnosis of gastric and pancreatic NETs.

MATERIALS AND METHODS

Study design

This study is an observational, single-center, cross-sectional investigation.

Eligibility criteria

Inclusion criteria: morphologically confirmed gastric or pancreatic neoplasm; abdominal CT with intravenous contrast performed before the initiation of treatment; and documented voluntary informed consent allowing the use of the participant's medical data for research purposes

Non-inclusion criteria: CT scans conducted outside the Russian Scientific Center of Roentgenology and Radiology

Exclusion criteria: absence of CT images of the tumor

Study setting

Data that met the inclusion criteria were collected at the Russian Scientific Center of Roentgenology and Radiology.

Study duration

The study was conducted from December 1, 2023, to March 22, 2024.

Intervention

All participants underwent contrast-enhanced abdominal CT using various scanners, with a slice thickness of 1 mm. CT scans were acquired during the early arterial phase, which is not typically included in standard imaging protocols.

Main study outcome

The primary outcomes were radiomics parameters in patients diagnosed with NETs and adenocarcinoma.

Outcomes registration

CT data from all patients were uploaded into the open-source software 3D Slicer (https://www.slicer.org/), which allows extraction of radiomics parameters from defined regions of interest.

Radiomics features were calculated within the gastric or pancreatic tumor regions. For each patient, the tumor was manually segmented in either the arterial or venous phase, and the resulting contour was aligned with the precontrast phase. Image processing in the precontrast phase is challenging due to the tumor appearing isodense with the surrounding parenchyma. Segmentation in contrast-enhanced phases also presents difficulties, as anatomical mismatches can occur between slices across different CT phases. These factors necessitate an evaluation of segmentation reproducibility, which is a limitation of the study.

A total of 93 radiomics features were extracted for both gastric NETs and adenocarcinomas and for pancreatic NETs and adenocarcinomas. These included first-order statistics and features derived from adjacency and uniformity matrices. Parameters related to the geometry of the region of interest were not analyzed due to challenges in reliably differentiating between healthy and tumor tissues.

The comparison results, including the median, first and third quartiles, and statistical significance of the differences, are presented in the tables.

Subgroup analysis

The study participants' data were categorized into four groups based on tumor site and histologic type:

- Gastric neuroendocrine tumor
- Gastric adenocarcinoma
- Pancreatic neuroendocrine tumor
- Pancreatic adenocarcinoma

Ethics approval

The study was approved by the Independent Ethics Committee of the Russian Scientific Center of Roentgenology and Radiology (Meeting Minutes No. 2, March 1, 2023).

Statistical analysis

The data were processed and analyzed using Microsoft Office Excel and R-Studio, an open-source software development environment for the R programming language. To assess significant differences between medical imaging biomarkers, pairwise intergroup comparisons for each radiomics parameter were conducted using the Mann–Whitney U test. Differences were considered significant if $p < 0.05$.

RESULTS

Participants

The study analyzed data from 12 patients with morphologically confirmed gastric neoplasms (6 with NETs and 6 with adenocarcinomas) and 22 patients with morphologically confirmed pancreatic neoplasms (11 with NETs and 11 with adenocarcinomas). Abdominal CT with intravenous contrast was performed on all patients prior to treatment at the Russian Scientific Center of Roentgenology and Radiology. The neoplasms examined in the study were small (2–3 cm) and varied in grade (G1–G3) and contrast enhancement. Most of the neoplasms included in the study were not initially classified as NETs in prospective CT analysis due to challenges with visual differentiation, requiring further assessment of the CT scans.

Primary results

The study identified 15 radiomics parameters that showed significant differences between patients with gastric NETs and adenocarcinomas. The comparison results, including the median, first and third quartiles, and the significance of the differences (Mann–Whitney U test), are shown in Table 2.

Table 2. Comparison of radiomics parameters between the two groups of patients with gastric neoplasms

Parameters	Gastric neuroendocrine tumor, Me [Q1; Q3]	Gastric adenocarcinoma, Me [Q1; Q3]	*p*-value
First order Entropy	2.01 [1.88; 2.23]	1.83 [1.62; 1.86]	0.041
First order Interquartile Range	31.50 [27.56; 38.94]	23.50 [19.25; 26.94]	0.026
First order Mean Absolute Deviation	19.19 [17.25; 21.53]	15.54 [12.92; 16.41]	0.041
First order Robust Mean Absolute Deviation	13.36 [12.07; 15.23]	10.04 [8.38; 11.57]	0.026
First order Skewness	-0.25 [-0.43; -0.10]	0.05 [-0.13; 0.24]	0.026
First order Uniformity	0.29 [0.26; 0.31]	0.34 [0.32; 0.40]	0.041
First order Variance	562.42 [479.32; 803.18]	414.40 [311.13; 429.14]	0.041
GLCM Cluster Tendency	2.41 [1.90; 4.08]	1.92 [1.36; 2.02]	0.041
GLCM Joint Entropy	3.83 [3.47; 4.02]	3.48 [2.99; 3.60]	0.041
GLCM Sum Entropy	2.63 [2.44; 2.98]	2.48 [2.22; 2.52]	0.041
GLCM Sum Squares	0.92 [0.78; 1.32]	0.72 [0.57; 0.78]	0.041
GLDM Dependence Non Uniformity Normalized	0.07 [0.06; 0.09]	0.06 [0.06; 0.06]	0.015
GLDM Gray Level Variance	0.97 [0.84; 1.38]	0.76 [0.59; 0.79]	0.041
GLRLM Gray Level Non Uniformity Normalized	0.27 [0.24; 0.29]	0.30 [0.30; 0.35]	0.041
GLRLM Gray Level Variance	1.09 [0.91; 1.56]	0.87 [0.73; 0.98]	0.041

Note. Me, median; Q1, first quartile; Q3, third quartile; GLCM, Gray Level Co-occurrence Matrix; GLDM, Gray Level Dependence Matrix; GLRLM, Gray Level Run Length Matrix.

Table 3. Comparison of radiomics parameters between the two groups of patients with pancreatic neoplasms

Parameters	Pancreatic neuroendocrine tumor, Me [Q1; Q3]	Pancreatic adenocarcinoma, Me [Q1; Q3]	*p*-value
First order Energy	691,524 [580,555; 1,727,135]	2,953,926 [2,318,229; 6,503,888]	0.007
First order Total Energy	1,425,223.71 [284,018.65; 3,100,864.22]	5,091,794.59 [1,502,766.76; 8,727,525.25]	0.047
GLDM Dependence Non Uniformity	28.01 [18.41; 44.78]	116.43 [88.79; 194.84]	0.007
GLDM Gray Level Non Uniformity	219.75 [132.80; 431.55]	868.90 [494.56; 1919.16]	0.001
GLRLM Gray Level Non Uniformity	119.69 [79.75; 161.57]	512.56 [308.03; 731.74]	0.002
GLRLM Run Length Non Uniformity	122.55 [71.16; 271.96]	702.16 [426.47; 1297.70]	0.001
GLSZM Gray Level Non Uniformity	10.52 [4.69; 32.08]	29.51 [19.39; 45.98]	0.034
GLSZM Large Area Emphasis	2826.63 [2243.10; 6732.92]	18,275.14 [7206.26; 42,549.14]	0.007
GLSZM Large Area High Gray Level Emphasis	38 429.22 [20,178.45; 62 109.69]	156,116.40 [102,536.10; 367,510.22]	0.001
GLSZM Low Gray Level Zone Emphasis	0.21 [0.17; 0.27]	0.17 [0.10; 0.23]	0.028
GLSZM Zone Variance	2632.37 [1928.10; 5957.51]	17 305.27 [7058.35; 41,998.41]	0.005
NGTDM Busyness	3.26 [2.01; 5.02]	10.23 [9.13; 26.37]	0.0001
NGTDM Coarseness	0.02 [0.01; 0.03]	0 [0; 0.01]	0.002
NGTDM Strength	0.13 [0.08; 0.26]	0.04 [0.01; 0.06]	0.001

Note. Me, median; Q1, first quartile; Q3, third quartile; GLDM, Gray Level Dependence Matrix; GLRLM, Gray Level Run Length Matrix; GLSZM, Gray Level Size Zone Matrix; NGTDM, Neighboring Gray Tone Difference Matrix.

According to Table 2, patients with gastric NETs exhibited significantly higher entropy (indicating greater heterogeneity of gray levels in an image) and variance (representing the distribution of gray level intensity relative to the mean). The GLDM Dependence Non-Uniformity Normalized, where lower values suggest higher tissue uniformity, was also higher in patients with NETs. These results may suggest that NET tissues are more heterogeneous compared to adenocarcinomas.

In patients with pancreatic NETs and adenocarcinomas, 14 radiomics parameters showed significant differences. The results of these comparisons, including the median, first

and third quartiles, and the significance of the differences (Mann–Whitney U test), are presented in Table 3.

The findings in Table 3 show that nearly all parameters were significantly higher in patients with pancreatic adenocarcinoma. The Energy and Total Energy parameters were 76% and 72% higher, respectively, in these patients. The GLSZM Gray Level Non-Uniformity, where lower values indicate higher uniformity in gray level intensity, was also higher in the adenocarcinoma group. Additionally, NGTDM Busyness (reflecting pixel value changes relative to neighboring pixels) was 68% higher in this group, indicating a more heterogeneous texture with sharper intensity variations in pancreatic adenocarcinoma tissues. Therefore, pancreatic adenocarcinoma tissue appears more heterogeneous and denser than NET tissue.

DISCUSSION

The results of this study and the potential application of radiomics in diagnosing gastrointestinal and pancreatic neoplasms are supported by international research. Chiti et al. used texture parameters in the arterial CT phase to differentiate between high-grade (G3) and low-grade (G1/G2) pancreatic NETs, achieving an area under the curve (AUC) of 0.82 [24]. Liang et al. developed a model for distinguishing between carcinoids (G1) and intermediate- to high-grade (G2/G3) pancreatic NETs. This model, which incorporates both radiomics parameters and clinical data, demonstrated a high prognostic value with an AUC of 0.89 [25].

Wang et al. created a prognostic model for differentiating gastric NETs from adenocarcinomas. The best results were obtained by combining radiomics parameters with data on metastasis and tumor margins, yielding an AUC of 0.821 [0.725; 0.895] [26]. Han et al. developed a model using radiomics parameters to distinguish between cystadenomas and pancreatic NETs. Combining machine learning models at various stages of the study produced excellent classification parameters: AUC 0.99, sensitivity 0.98, and specificity 1.0 [27]. Additionally, other studies have addressed the differential diagnosis between NETs and other gastrointestinal malignancies [28–30].

An et al. developed a model to predict relapses of gastrointestinal and pancreatic NETs by combining radiomics parameters with clinical and laboratory data. This model had an AUC of 0.824 [0,751; 0.883], demonstrating strong prognostic value [31]. Similarly, Song et al. predicted tumor relapse in patients with pancreatic NETs following radical resection. The model, which combined radiomics parameters and clinical data, showed the best results with an AUC of 0.83 [32].

Caruso et al. predicted the response to everolimus treatment in patients with NETs from various sites. The prognostic model achieved an AUC of 0.87 [33].

These published studies suggest that radiomics is a promising and effective tool for analyzing medical images of gastrointestinal NETs at different stages of diagnosis and treatment.

CONCLUSION

The clinical cases presented highlight the challenges in diagnosing gastric and pancreatic NETs. Similar density values between NETs and surrounding tissues, small tumor size, and variable contrast uptake can lead to underdiagnosis of these neoplasms. However, texture analysis shows promise as a tool for differentiating gastrointestinal NETs from other gastrointestinal tumors, particularly in the early stages when biopsy is challenging.

We identified biomarkers that significantly differed between NETs and adenocarcinomas of the same location: 15 biomarkers for gastric NETs and 14 biomarkers for pancreatic NETs. These findings suggest that further research is needed, particularly in developing models that combine image texture features with clinical data.

ADDITIONAL INFORMATION

Funding source. This study was not supported by any external sources of funding.

Competing interests. The authors declare that they have no competing interests.

Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. N.V. Nudnov — general concept of research, research design and approval of the final version of the article; E.S-A. Shakhvalieva, D.G. Karelidze, A.A. Borisov — data collection, data analysis, writing the text of the manuscript; M.E. Ivannikov — editing the text of the manuscript.

Consent for publication. Written consent was obtained from patients for publication of relevant medical information and all of accompanying images within the manuscript in Digital Diagnostics journal.

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