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An Update of Clinical CT Imaging of Pancreatic Neoplasm: Tips, Tricks, and Pitfalls

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Abstract The progressive advancement in computed tomography (CT) technology has enabled improved diagnosis and management of pancreatic tumors. Some of these improvements are seen in multidetector CT, dual-energy CT, perfusion CT, and post-processing techniques. Despite the technological improvement, prognosis for tumors such as pancreatic adenocarcinomas remains dismal. This review article will discuss some of the tips, tricks, and pitfalls for optimal utilization of these imaging techniques to characterize, diagnosis, and manage some of the more common pancreatic tumors such as adenocarcinomas, cystic tumors, and neuroendocrine tumors.

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Introduction

Computed tomography (CT) has become an indispensable tool in the medical armamentarium. It has been one of the most rapidly growing imaging modalities and its utilization continues to rise [1]. Computed tomography technology has also advanced significantly in the past several years, enabling more accurate and rapid diagnosis of multiple acute and chronic illnesses. Such advances include multidetector row and rapid thin section imaging CT [2•], perfusion CT, and dual-energy CT (DECT).

Pancreatic tumor imaging is particularly challenging. These challenges include identifying subtle characteristics of cystic lesions that may indicate malignancy, detecting subcentimeter functional pancreatic neuroendocrine tumors for potential resection, and assessing in detail vascular involvement by pancreatic ductal adenocarcinoma to identify potential surgical candidates in this disease for which the prognosis remains dismal [3].

CT, positron emission tomography (PET)–CT, magnetic resonance imaging (MRI), and endoscopic ultrasound (EUS) all play a role in the assessment of pancreatic neoplasms. However, at many institutions, CT imaging is often the preferred imaging modality for pancreatic tumor assessment. The purpose of this review article is to provide an overview of current and recent advances in CT imaging techniques for pancreatic neoplasm imaging, emphasizing tips, tricks, and the pitfalls involved. Common pancreatic tumors such as ductal adenocarcinomas, neuroendocrine tumors, and cystic tumors will be reviewed in regard to how current CT imaging can be optimized for detection and characterization.

CT Protocols

Not all CT protocols are equal and there is no universally applicable protocol. A routine CT protocol of the abdomen obtained only during the portal venous phase will surely miss a small hypervascular neuroendocrine tumor of the pancreas. Therefore, accurate assessment of suspected pancreatic neoplasms necessitates a dedicated CT pancreatic protocol. The evolution of multidetector CT (MDCT) has allowed faster, thinner section, and multiphasic imaging, allowing for optimized pancreatic lesion evaluation. Current CT technology provides for rapid high resolution imaging, enabling detection of pancreatic lesions as small as 2–3 mm, and detailed evaluation of the pancreatic duct which was once only optimally evaluated with endoscopic retrograde cholangiopancreatography (ERCP) or magnetic resonance cholangiopancreatography (MRCP) [4]. As such, the National Comprehensive Cancer Network (NCCN) guidelines has determined that a multiphasic MDCT pancreatic protocol is a recommended imaging modality for staging pancreatic cancer [5••].

Conventional Multiphasic Pancreatic Protocol CT

A typical multiphase pancreatic CT protocol includes three phases: the unenhanced, pancreatic parenchymal, and portal venous phases. An unenhanced phase allows for detection of calcifications in the pancreatic parenchyma, its duct or within lesions. For example, a pancreatic cystic lesion with central scar and calcification would favor a microcystic adenoma/serous cystadenoma and a cystic lesion with peripheral calcification would be concerning for a mucinous cystic neoplasm (MCN) [6]. Calcification that is not associated with a focal lesion may also be indicative of chronic pancreatitis. Hemorrhagic changes from inflammation, trauma, or tumors can often be readily identified on the unenhanced phase. Finally, an unenhanced phase provides baseline attenuation for lesion enhancement measurements if desired [4].

The pancreatic parenchymal phase is typically obtained 40 s after intravenous administration of contrast media at a rate of 3–5 mL/s, which is slightly later than the typical hepatic arterial phase [4, 7, 8]. There is a greater attenuation difference between normal surrounding pancreatic parenchyma and pancreatic lesions at this phase of contrast enhancement, thus enabling better lesion detection, which includes hypodense and hyperdense neoplasms [7] (Fig. 1). It is important to be aware that although the majority of pancreatic adenocarcinomas are hypodense during the pancreatic parenchymal phase, up to 11 % are isoattenuating relative to the surrounding parenchyma, and as such may be challenging to detect based solely on enhancement characteristics [9]. Surrounding arterial vasculature evaluation which is important in staging adenocarcinomas is also optimized during this phase of contrast. The addition of a saline flush in conjunction with a power injector may improve contrast enhancement of the pancreatic parenchyma and vasculature [2•]. Also, because cardiac output of patients is variable, a bolus tracking technique is commonly applied rather than a fixed injection delay for a more accurate pancreatic phase of enhancement [10•].

Finally, the portal venous phase of a multiphasic pancreatic CT protocol is typically obtained at 60–70 s after intravenous administration of contrast media. This allows optimal delineation of the surrounding venous vasculature, including the portal, superior mesenteric, and splenic veins. Venous thrombosis from inflammation or malignancy will be clearly visualized. Assessment for tumor venous involvement is also important during this phase when

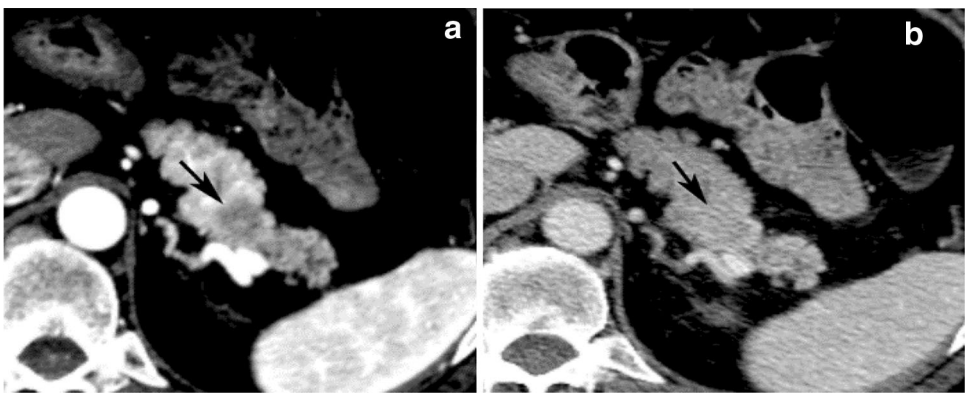

Fig. 1 71-year-old male with pancreatic neuroendocrine tumor. CT of the abdomen pancreatic protocol in the pancreatic parenchymal (**a**) and portal venous phase (**b**). The neuroendocrine tumor seen as a hypodense mass in the pancreatic tail is best visualized in the pancreatic parenchymal phase as compared to the portal venous phase (*arrow*). The hypodense variant of neuroendocrine tumor is uncommon and indicative of poorer prognosis

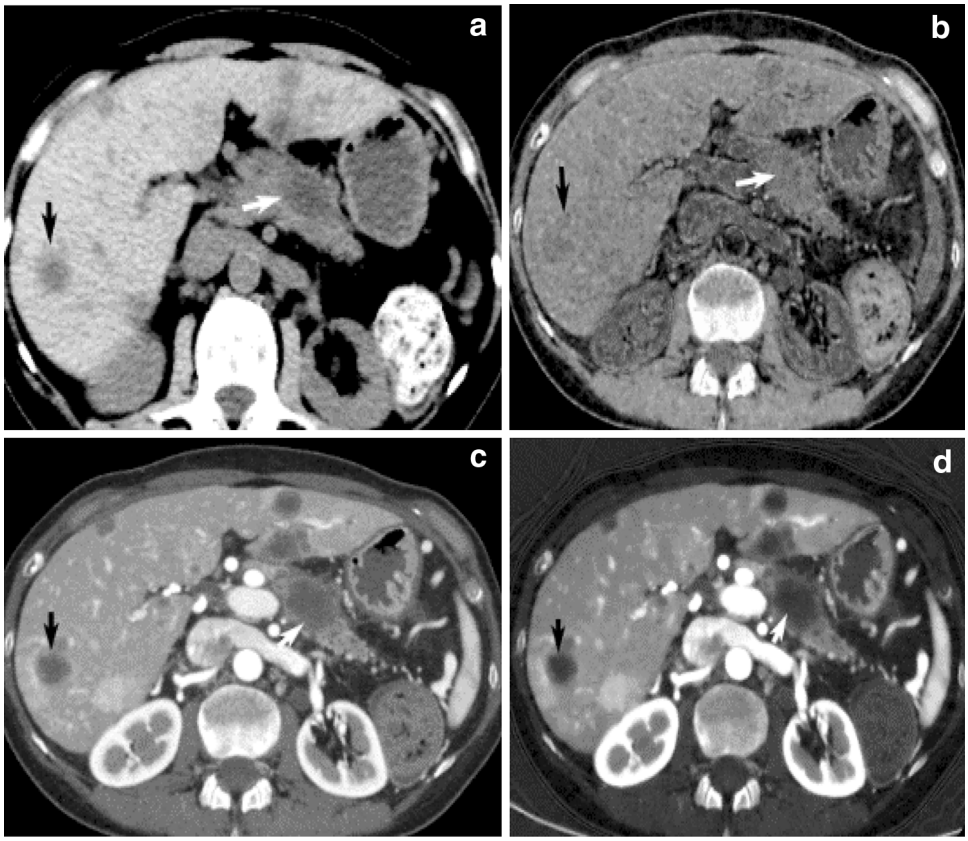

Fig. 2 60-year-old female with pancreatic adenocarcinoma. CT images of the abdomen in the conventional precontrast (**a**), virtual noncontrast enhanced image (VNE) (**b**), and pancreatic parenchymal phase in the conventional (**c**) and with iodine-only image (**d**). Note the difference between the conventional precontrast and VNE images. Contrast is not visualized in the VNE image. The iodine-only image increases the conspicuity of the pancreatic (*white arrow*) and hepatic lesions (*black arrow*)

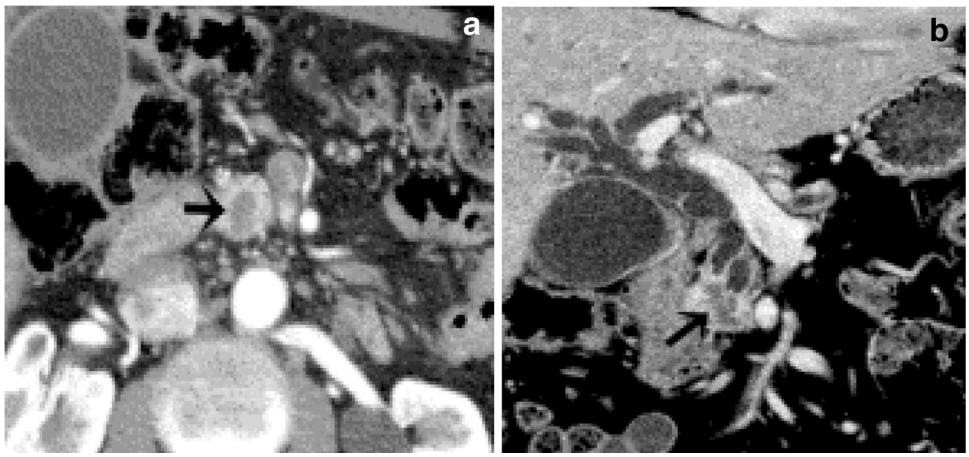

Fig. 3 66-year-old male with pancreatic adenocarcinoma. CT of the abdomen in the axial (**a**) and coronal view (**b**). The primary mass (*arrow*) is hypodense relative to the normal pancreatic parenchyma. The mass causes moderate intrahepatic, extrahepatic, and pancreatic ductal obstruction. The mass also causes pancreatic parenchymal atrophy along the obstructed duct. Note how the coronal image clearly shows the relationship of the mass to the obstructed ducts. This can help in communicating findings to surgeons and gastroenterologists in planning treatment (stent placement or surgery)

evaluating for resectability and reconstruction, particularly for adenocarcinomas [11]. Metastatic disease in the liver will be elucidated during this phase, especially hypoenhancing metastasis from pancreatic adenocarcinomas [4].

The typical dose of intravenous iodine contrast is a fixed 120 mL across a range of patient body weights, which can cause variable pancreatic enhancement. Weight-based contrast media have been suggested to optimize CT

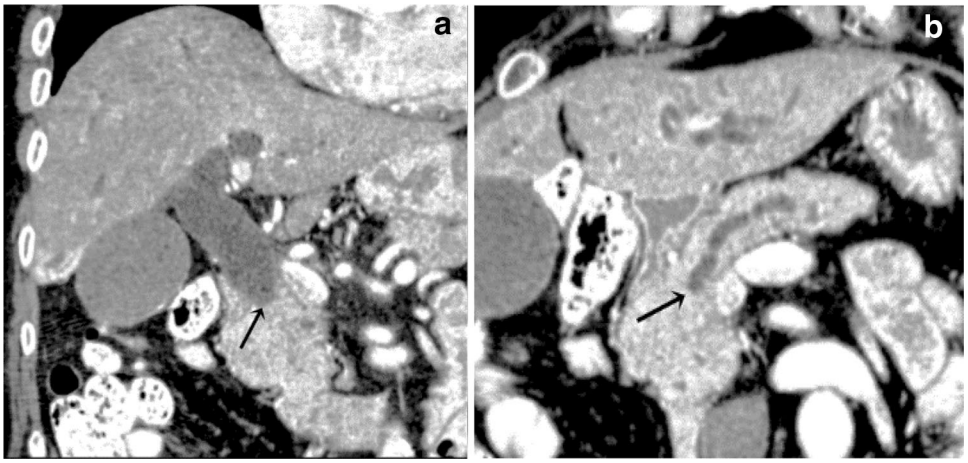

Fig. 4 73-year-old female with pancreatic head adenocarcinoma. Even with good technique in the pancreatic parenchymal phase of CT imaging, the pancreatic head mass is isoattenuating and not seen, which is a pitfall. A tip is to pay close attention to changes in the main pancreatic duct (e.g., duct cutoff). The isoattenuating mass causes intrahepatic, extrahepatic, and pancreatic ductal dilatation (*arrow* in **a**, **b**)

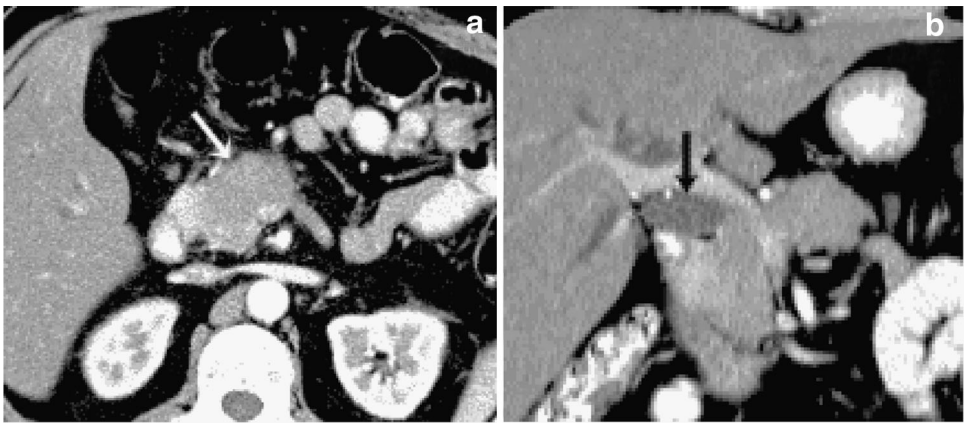

Fig. 5 49-year-old male with autoimmune pancreatitis. The pancreatic head is enlarged, edematous appearing, but without a focal mass identified (*white arrow* in **a**). It causes intrahepatic and extrahepatic biliary obstruction (*black arrow* in **b**). The patient's symptoms and radiographic findings subsequently improved with steroid treatment

enhancement; a dose of 2.0 mL/kg of iohexol 300 (600 mg of iodine per kg body weight) has been found to produce more consistent enhancement across a range of patient body weights [4, 12]. Besides optimizing contrast dose and scan time after intravenous contrast media injection, choice of oral contrast is also important. A negative or neutral oral contrast agent such as water rather than a positive contrast agent such as barium has been recommended. Negative oral contrast agents allow for better visualization of lesions within bowel wall, produce less beam hardening artifacts as can be seen when positive oral contrast pools in the stomach and allows for better 3D reconstructions of vasculature [4, 11].

Current state of the art CTs, typically 64-slice multidetector CT allows for thin section collimation of 0.5–6 mm, which in turns provides isotropic datasets for 3D and multiplanar reconstruction (MPR). These advanced post-processing techniques have helped improved sensitivity and are useful for tumor detection and evaluation [2•, 13, 14]. Thin section imaging of <3 mm, in addition, is recommended for a pancreatic protocol CT [5••]. At our institution, 2.5-mm-thick images are used for primary interpretation and thinner 0.625–1.25 mm axial slices are obtained for multiplanar reconstruction and problem solving.

Dual-Energy CT

Conventional multiphasic MDCT has served as a robust imaging modality for pancreatic tumor evaluation at many

institutions. However, there are issues regarding detection of small and/or isodense appearing pancreatic lesions [15]. Studies have shown that the use of low tube voltage increases the attenuation value of contrast material (iodine) owing to the increased photoelectric effect [16, 17]. This may increase contrast between normal pancreatic parenchyma and pancreatic lesions, thus improving lesion detection. Simply, the normal pancreatic parenchyma enhances avidly during the pancreatic phase and contains more iodine than a pancreatic adenocarcinoma; thus, DECT may improve lesion detection and allow a more accurate measurement of tumor size when compared to a conventional MDCT examination [17, 18].

Recent advances in DECT enable synchronous acquisition of images at two different energy levels, usually obtained at 80–100 and 140 kVp. This technique can be performed with a single source system with two fluctuating photon energies, with a dual-layer detector, or with a dual-source system with two independent X-ray tubes [19]. DECT post-processing software also allows the reconstruction of a range of image types based on the data acquired from dual-energy imaging. The more common of these include virtual noncontrast enhanced (VNE), iodine material density (which enhance the conspicuity of iodine), and mono energetic images. A variety of types of material density images can be created that allow for the identification, semi quantification, or elimination from images of a wide range of materials based on their behavior at low and high energies [16, 18] (Fig. 2). Chu et al. found that 50 % of the cases of iodine-only images added value to pancreatic tumor evaluation and VNE images could replace true non-enhanced images in over 90 % of the cases [16]. Zamboni et al. also demonstrated that a single source lower energy of 80 kV pancreatic phase scanning results in higher conspicuity of pancreatic adenocarcinoma when compared to 120 kV [20].

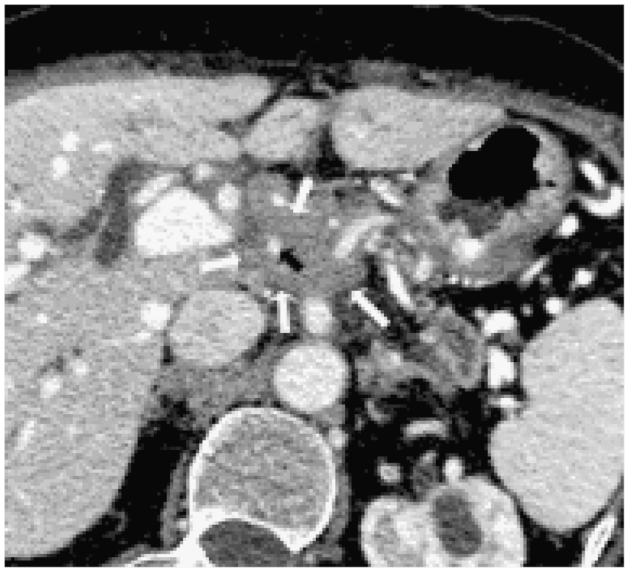

Fig. 6 68-year-old female with unresectable pancreatic adenocarcinoma. The infiltrating pancreatic head mass (*white arrows*) completely encases the common hepatic artery (*black arrow*)

Perfusion CT of the Pancreas

Perfusion CT is a functional imaging technique that quantitatively and qualitatively assesses perfusion in an organ based on changes in tissue attenuation after intravenous iodinated contrast material administration. The organ of interest (e.g., pancreas) is repeatedly scanned in quick succession, and density changes are measured from which perfusion parameters such as blood volume (BV),

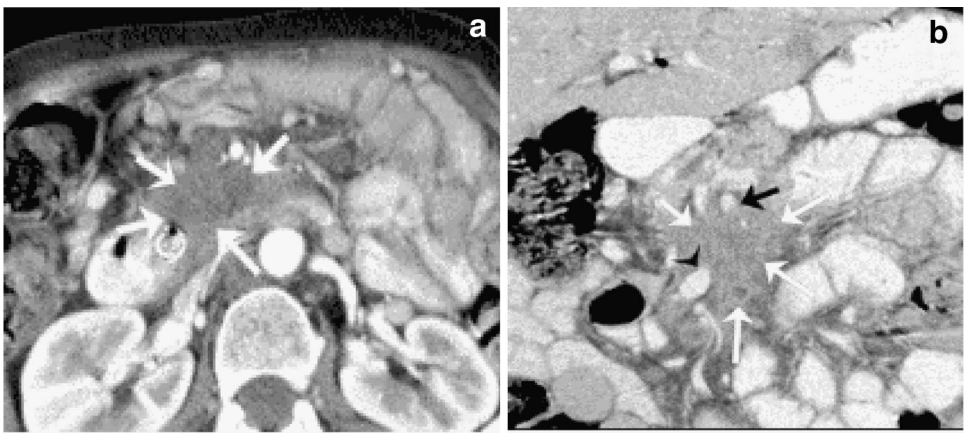

Fig. 7 63-year-old female with pancreatic cancer. The axial view (**a**) reveals an infiltrative mass growing from the pancreatic head (*white arrows* in **a**, **b**). The MPR coronal view (**b**) enables better visualization of the extent of tumor growth along the mesenteric root encasing the SMA (*black arrow*) and SMV (*arrowhead*)

time to peak (TTP), peak enhancement intensity (PEI), and blood flow (BF) can be calculated. Currently, perfusion CT of the pancreas is not widely used, but multiple recent studies have illustrated its potential advantages to conventional CT for select indications including lesion detection, noninvasive differentiation and grading of tumor types, and early prediction of necrosis in severe acute pancreatitis [21].

In regard to pancreatic tumors, perfusion CT has been shown to reliably differentiate between high- and low-grade pancreatic adenocarcinoma using PEI and BV parameters, with 60 % sensitivity and 100 % specificity for identifying high-grade lesions [22]. This could identify patients at high risk of early death following treatment, select patients for confirmatory preoperative fine needle biopsy, and help tailor treatment strategies [22]. Similarly, pancreatic neuroendocrine tumors have been shown to have a strong correlation between blood flow and tumor grade which could help in therapeutic decision making, such as favoring follow-up rather than an aggressive approach in select patients whose tumors show favorable perfusion parameters [23].

Perfusion CT has been shown to reliably identify necrotic pancreatic parenchyma and is useful for predicting the prognosis of severe acute pancreatitis in the early stage, enabling the appropriate selection of patients for prompt, intensive therapy, or surgery [24, 25].

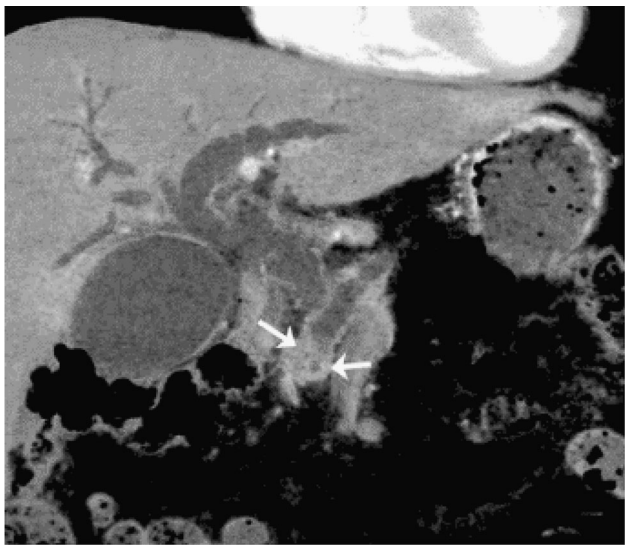

Fig. 8 66-year-old male with pancreatic adenocarcinoma. MinIP image better shows the intrahepatic, extrahepatic, and pancreatic ductal dilatation caused by the primary mass (*white arrows*)

Pancreatic Ductal Adenocarcinomas

Pancreatic ductal adenocarcinoma is the most common of the pancreatic exocrine tumors (approximately 80 %), has a 5-year survival rate of 5 %, and despite investigation of multiple therapies over the past several decades has not shown a decline in mortality rate [8, 10•]. This is in part related to difficulty in identifying early resectable tumors which are often asymptomatic. When symptoms do develop, most tumors at presentation are already advanced and unresectable. Surgical resection remains the only option for cure, and at presentation only 10–20 % of patients are candidates for potential resection [10•]. For patients presenting with suspicion for pancreatic cancer, MDCT has a sensitivity of up to 90 % for detection and 80–90 % for staging [10•].

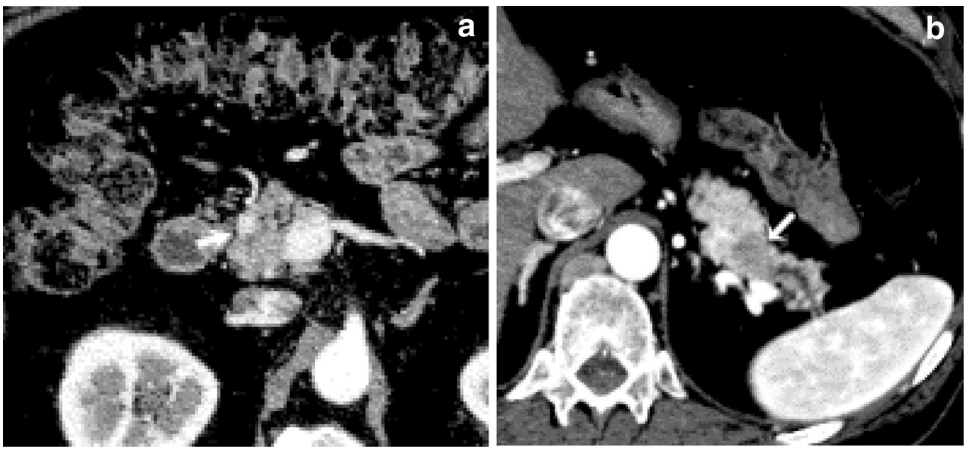

Fig. 9 A typical pancreatic NET tumor manifesting as a small hypervascular lesion in the pancreatic head (*arrow* in **a**). A larger pancreatic NET may not be hypervascular and be hypodense (*arrow* in **b**). Note that the tumor in **b** also causes main pancreatic ductal dilatation, which is a rare occurrences for pancreatic NET

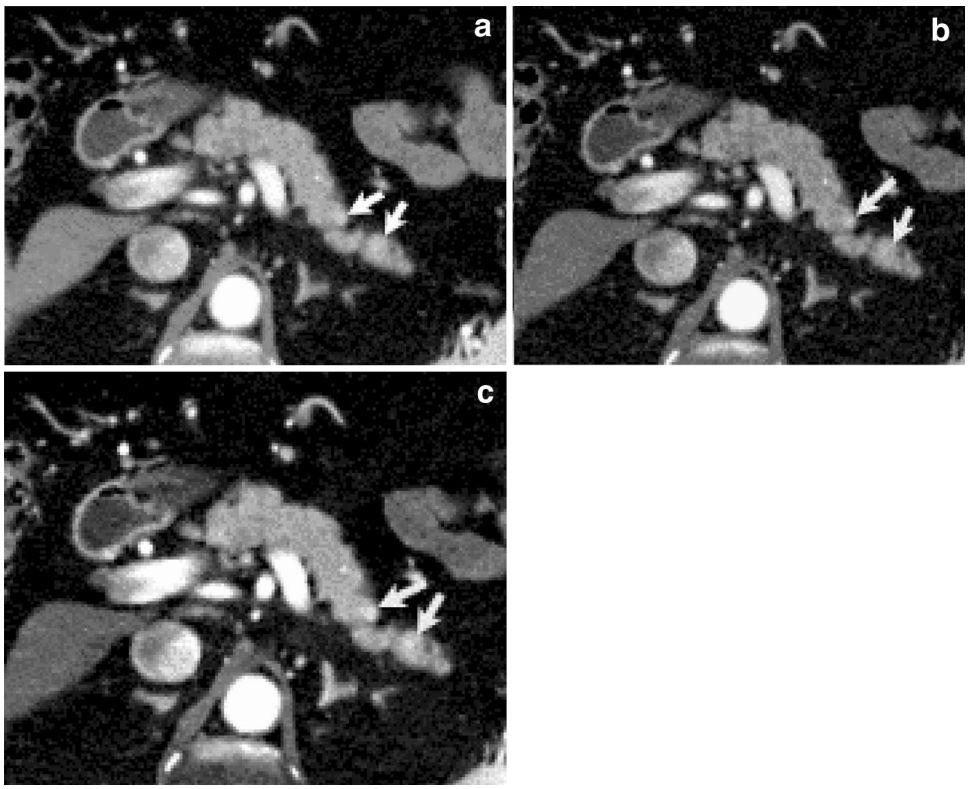

Fig. 10 72-year-old male with pancreatic neuroendocrine tumors. The small hypervascular enhancing neuroendocrine tumors in the pancreatic tail (*white arrows*) are progressively more conspicuous with lower keV and iodine images, ($a = 70$ keV, $b = 50$ keV, $C =$ iodine-only image)

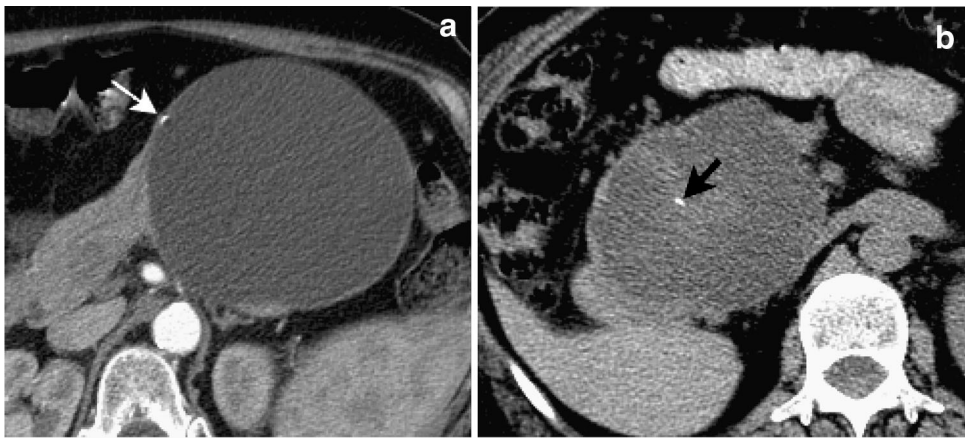

Fig. 11 53-year-old female with mucinous cystic neoplasm with mural calcification (*white arrow* in **a**), compared to 64-year-old female with a serous cystadenoma of the pancreas containing central calcification (*black arrow* in **b**)

On CT, pancreatic ductal adenocarcinomas typically have the appearance of hypoattenuating masses relative to normal parenchyma on the pancreatic parenchymal phase of enhancement due to the desmoplastic nature of the tumor, and are mostly commonly located in the pancreatic head. As noted earlier, 11 % are isoattenuating to normal pancreatic parenchyma, are also typically small (<2 cm), and therefore difficult to visualize [10•]. In these circumstances, indirect signs such as dilatation of the pancreatic or biliary duct, or both (double duct sign), due to stenosis caused by the tumor, should raise suspicion for possible underlying tumor even when a mass is not definitely visualized [8, 10•]. Furthermore, deformity of the pancreatic contour, focal loss of pancreatic parenchymal lobulation, and/or pancreatic atrophy "upstream" to the tumor are other secondary signs [8, 10•] (Fig. 3). Yoon et al. found that most small isoattenuating tumors showed such secondary signs (76 %) [26]. Recent studies have shown that DECT increases the conspicuity between pancreatic adenocarcinoma and normal surrounding pancreatic parenchyma [16, 19, 27•]. These advances in DECT may help improve detection of such small isoattenuating

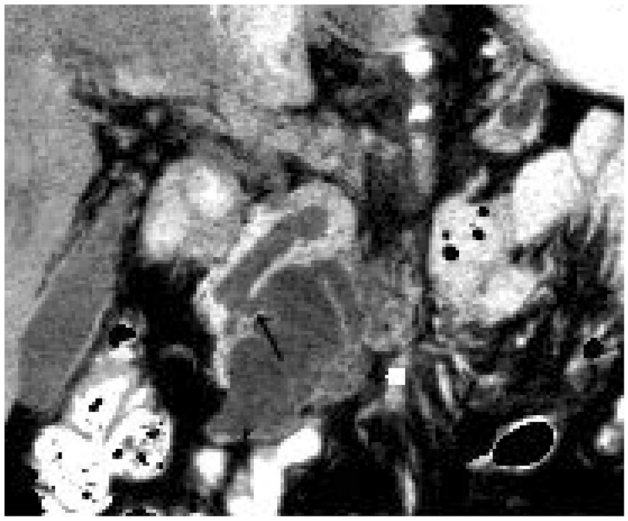

Fig. 12 77-year-old male with combined type IPMN. The MiniP image improves visualization of the side branch communication to the dilated main pancreatic duct (*arrow*)

pancreatic adenocarcinomas. Other studies have suggested that MRI or PET/CT may be useful as subsequent examinations when the patient is suspected of having a lesion on CT based on secondary signs, but a pancreatic mass is not definitely visualized [28]. At our institution, our practice has been that when sufficiently concerning secondary signs are identified on CT in the absence of direct visualization of a mass, that such patients undergo evaluation with endoscopic ultrasound with potential biopsy.

Pitfalls to consider are that benign focal pancreatic ductal strictures and the focal form of autoimmune pancreatitis may have similar appearances to isoattenuating pancreatic adenocarcinomas [29] (Figs. 4, 5). Likewise, neuroendocrine tumor, metastases to the pancreas, lymphoma, groove pancreatitis, and focal chronic pancreatitis can also mimic the imaging appearance of pancreatic adenocarcinoma [30]. Atypical findings that should suggest a diagnosis other than adenocarcinoma include the absence of significant duct dilatation, incidental detection, hypervascularity, large size (>5 cm), and intralesional cysts [30]. In regard to inflammation, it is not always easy to distinguish pancreatitis from pancreatic adenocarcinoma. Pancreatic cancer can cause pancreatitis in only 5 % of patients, while ductal obstruction is rare in pancreatitis [31].

Once pancreatic adenocarcinoma is detected or suspected, evaluating for surrounding vascular involvement and metastasis to the liver or peritoneum, and suspicious lymphadenopathy is critical for staging and treatment purposes. The role of CT is then to detect any contraindications to surgical resection; CT being found to have a high predictive value for unresectability (90–100 %) [11]. Surgery is usually contraindicated when tumor involves >180° of the circumference of the celiac axis, superior mesenteric artery (SMA), or common hepatic artery (Fig. 6). Tumor involvement of the superior mesenteric (SMV) or portal vein, on the other hand, is not necessarily surgically contraindicated. A consensus report published by the Society of Surgical Oncology defines unresectable, borderline resectable, and resectable pancreatic adenocarcinomas as follows [11]:

- Unresectable: distant metastasis, major venous thrombosis of the portal vein or SMV extending for several centimeter and circumferential encasement of the SMA, celiac axis, or proximal hepatic artery.
- Borderline resectable: no distant metastasis, venous involvement of the SMV/portal vein but without encasement of the nearby arteries, or short segment venous occlusion resulting from either tumor thrombus or encasement but with suitable vessel proximal and distal to the area of vessel involvement, allowing for safe resection and reconstruction, gastroduodenal artery encasement up to the hepatic artery with either short segment encasement or direct abutment of the hepatic artery, without extension to the celiac axis, and tumor abutment of the SMA not to exceed >180° of the circumference of the vessel wall.
- Resectable: no distant metastasis, no radiographic evidence of SMV and portal vein abutment, distortion, tumor thrombus, or venous encasement, clear fat planes around the celiac axis, hepatic artery, and SMA.

It is useful to evaluate vessels on both the pancreatic parenchymal and portal venous phases, with veins being best assessed on the portal venous phase when they are fully opacified and hepatic arterial variants best identified on the pancreatic parenchymal phase. Additionally, when evaluating the relevant vascular anatomy, vascular variants and the relationship of vessels to tumor, multiplanar reconstructions (MPR), created at the scanner, "on-the-fly" using a workstation thin client or on a PACS reading station's built in software are recommended. Studies have shown that 3D imaging of the peripancreatic vasculature was more accurate than axial images alone in assessing resectability [11]. Vargas et al. also found that curved MPR had excellent negative predictive value in assessing tumor invasion of vasculature [32]. MPR, even simple portal venous phase 2–3 mm coronal and sagittal reformations, can allow better depiction of the relationship of tumor to vasculature, which is useful for the referring surgeon and for their discussion with patients (Fig. 7). MPR reconstruction in the oblique or coronal plane along the pancreatic duct is typically helpful. Additional techniques such as minimum intensity projections (MinIP) can help assess

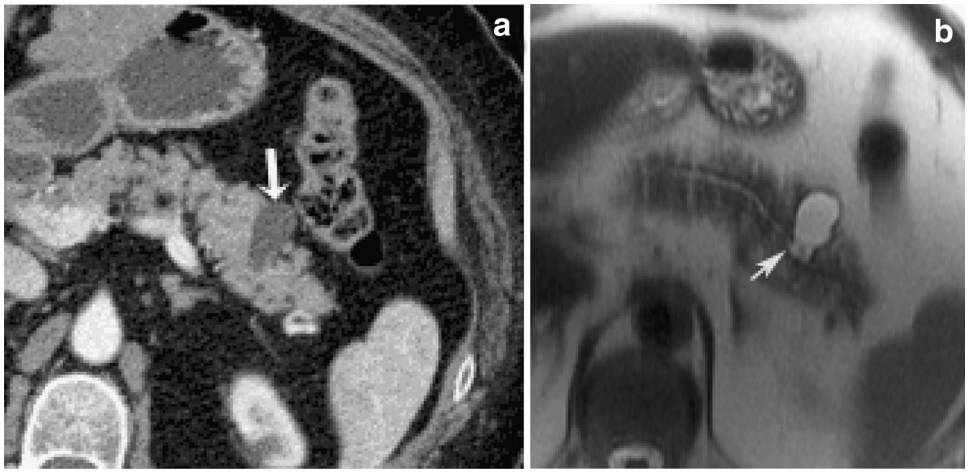

Fig. 13 62-year-old female with side branch IPMN. CT shows a cystic lesion in the pancreatic tail (*arrow* in **a**). Subsequent MRI demonstrates communication of the cyst to the main pancreatic duct (*arrow* in **b**)

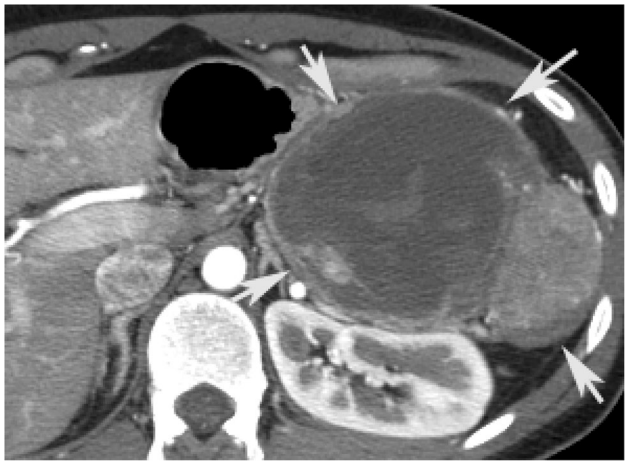

Fig. 14 38-year-old female with SPEN, seen as a large well-demarcated cystic and solid mass (*arrows*) in the pancreatic tail causing mass effect on the left kidney

the low density structures of the bile and pancreatic ducts, while maximum intensity projections (MIP) can assist evaluation of vascular anatomy [10•] (Fig. 8). A pitfall is when tumor is large and there is accompanying pancreatitis, which may result in false positives in predicting vascular involvement [33]. Lee et al. also found that the proximal portal vein and SMV were also difficult to assess with MDCT for tumor involvement due to lack of a clear fat plane in this region and their close proximity to the pancreatic parenchyma [33].

Detection of very small liver and peritoneal metastasis, which are the most common cause of distant metastasis, remains a challenge with MDCT [8]; and small liver and peritoneal implants below the resolution of CT may only be seen at surgery. Liver metastasis is best identified on the portal phase of enhancement and is typically hypodense. The application of DECT in aiding detection of liver metastasis is still evolving. A preliminary study by Holmes et al. examined hypervascular liver lesion conspicuity by comparing the weighted average dataset with the pure low-energy (80 kVp) acquisition failed to show improved detection [3, 34]. Such information is not yet available whether dual-energy imaging may improve detection of hypovascular liver metastases on the portal venous phase. Selective staging laparoscopy has been suggested to evaluate for equivocal peritoneal or liver metastasis or low-volume ascites or in the clinical setting of significant weight loss and pain, hypoalbuminemia, and high CA 19–9 levels [11].

Metastatic lymphadenopathy typically occurs in the peripancreatic region. CT sensitivity for detection of metastatic lymphadenopathy is low, and nodes are generally sampled and resected at the time of surgery [31]. Using a short axis of >10 mm as an indicator of lymph node metastases yields a sensitivity of 14 %, specificity of 85 %, positive predictive value of 17 %, and negative predictive value of 82 % [35]. A major limitation for the use of size criteria is that small lymph nodes may contain micrometastasis, while larger lymph nodes may be reactive [35]. A study of morphologic characteristics such as having an ovoid shape, clustering of nodes, and the absence of a fatty hilum were found not to be useful in predicting nodal metastases [35]. Endoscopic ultrasound has been found to be more accurate in assessing lymph node involvement, but has the limitation of being invasive, and being unable to assess comprehensively all relevant nodal stations [36].

Neuroendocrine Tumors

Only 1–5 % of pancreatic tumors are neuroendocrine tumors (NET), which arise from the endocrine pancreas and frequently are incorrectly referred to as "islet cell tumors"

[8]. Neuroendocrine tumors are classified as follows: well-differentiated endocrine tumors, which can be functioning (hormone producing) or nonfunctioning; well-differentiated endocrine carcinoma with low malignant potential; and poorly differentiated endocrine carcinoma which carries a poor prognosis [8]. Functioning neuroendocrine tumors often present with symptoms, may have already been diagnosed biochemically, and in which case the purpose of imaging is to locate the tumor(s).

Neuroendocrine tumors demonstrate characteristic features on CT. Specifically, they tend to be hypervascular and are often best seen, and sometimes only seen on the arterial/late arterial phase of a multiphasic protocol. A pitfall to CT diagnosis is the presence of necrosis and reduced vascularity which may be a feature of large tumors (Fig. 9). NET tumors may also be cystic, but an enhancing, albeit often thin rim, may be helpful in suggesting the diagnosis [37]. Determining whether a pancreatic NET is malignant based solely on imaging in the absence of clear metastases, may be difficult, but is more likely the case in tumors larger than 3 cm, the presence of calcifications, vascular invasion, and/or lymph node enlargement [38].

Insulinomas are the most common type of functioning NET, and 90 % of these tumors are benign. Usually insulinomas are <2 cm in diameter, do not demonstrate a predilection for any particular location within the pancreas, and 94 % are readily detected with dual-phase contrast enhanced CT (even on a two-detector-row scanner) [8]. MDCT with MPR and 3D reconstruction aid in detection and surgical planning.

The second most common functioning NET is gastrinoma; they are usually small, multiple, malignant in up to 60 % and occur in 90 % percent of cases within the "gastrinoma triangle," which represents a region bordered by the descending duodenum, the pancreatic head and neck, and the junction of the common hepatic and cystic ducts [8].

The other forms of pancreatic neuroendocrine tumor are much rarer. These include glucagonoma, VIPoma, somatostatinoma, and nonfunctional NET. They are almost always malignant, present as large masses, demonstrate moderate to strong enhancement, may appear heterogeneous on CT with areas of internal necrosis and cystic degeneration, and on rare occasion cause obstruction of the pancreatic duct [8]. As such, the absence of pancreatic duct obstruction is helpful in distinguishing these tumors from adenocarcinoma. Preoperative assessment of vascular involvement by nonfunctioning NET is reportedly better determined with MDCT than MRI [39].

DECT may improve NET detection. Low-energy (e.g., 50 keV) monochromatic imaging and iodine-only images may increase primary pancreatic lesion conspicuity during the pancreatic parenchymal phase [40, 41] (Fig. 10). This similar technique can also be used to evaluate the typical hypervascular liver metastasis from NET. The use of lower tube voltage settings increases the x-ray absorption of iodine due to increased photoelectric interactions and decreased Compton scattering, thus yielding improved enhancement of iodine-containing vascular and parenchymal organs [40]. Lower energy levels (from 40 to 70 keV) can significantly improve the conspicuity and detection rate of small hypervascular liver lesions [40, 42]. An additional tip is to use negative or neutral oral contrast, since a positive contrast agent may obscure tumor enhancement and detection, particularly when searching for a small gastrinoma in the "gastrinoma triangle."

Pancreatic Cystic Tumors

A variety of cystic lesions in the pancreas are commonly seen, due to the increased use of cross-sectional imaging. The most common cystic pancreatic lesion has reportedly been a pseudocyst (up to 80 %) [8]. However, the use of thinner section imaging is revealing cystic lesions in patient without a history of pancreatitis, and therefore the diagnosis of side branch intraductal papillary mucinous neoplasm is being increasingly considered in the differential of such lesions. Cystic pancreatic lesions include a broad differential such as serous cystadenoma, mucinous cystadenoma/cystadenocarcinoma, and intraductal papillary mucinous tumor.

Serous cystadenoma predominantly affects women in the 6th to 7th decade ("grandmother tumor") and is generally benign. The typical CT appearance is of a lesion comprised multiple (>6) small cysts each measuring <2 cm in diameter, and without communication with the pancreatic duct. The larger serous cystadenomas may have a sponge-like appearance with central, punctate, or globular calcifications [8]. Rarely, serous cystadenoma may present as a unilocular cystic tumor, similar to a mucinous cystadenoma/cystadenocarcinoma. Endoscopic ultrasound (EUS) with biopsy may help in these cases.

Mucinous cystic neoplasm (MCN) usually occurs in women in the 4th to 5th decade and is, therefore, known as the "mother tumor." Its histology ranges from that of the benign adenoma, borderline tumor to non-invasive and invasive carcinoma. CT imaging findings include a unilocular or multilocular macrocystic lesion. The presence of thick enhancing septae, solid mural papillary projections, or a partially solid appearance is indicative of potentially malignant histology [8]. Mucinous cystic neoplasm may have cyst wall calcification, which is helpful in distinguishing these tumors from serous cystadenomas, which characteristically demonstrate central calcification (Fig. 11). The lack of a pancreatic main or side branch

communication distinguishes it from an intraductal papillary mucinous neoplasm (IPMN).

IPMN tumors, in contrast, are associated with a slight male predominance, tends to occur in patients in their 6th or 7th decade, and arise from the main pancreatic duct or side branch pancreatic duct epithelium. On histologic examination, their appearance can range from benign dysplasia, borderline malignancy, to infiltrative carcinomas [8]. IPMNs are classified into main duct, side branch duct, or combined. Signs on CT described as predictive of malignancy include main pancreatic duct dilatation >10 mm, diffuse or multifocal involvement, calcified intraluminal content, a bulging papilla, and solid contrast enhancing papillary proliferations [8]. The incidence of malignancy is higher in the main duct forms than in the side branch varieties. Guidelines such as those from the American College of Radiology or those published by Tanaka et al. show a growing trend towards observing those lesions without stigmata of malignancy given the high likelihood that many of these are benign [43••]. Studies have shown that side branch IPMN measuring greater 3 cm or growth of more than 2 mm/year is associated with increased risk of malignancy (12 and 45.5 %, respectively) [44]. The appearance of main duct IPMN may overlap with that of chronic pancreatitis particularly with regard to dilatation of the main pancreatic duct and atrophy of the pancreatic parenchyma. However, chronic pancreatitis will not have bulging of the papilla, will not show enhancing nodules within the duct, but may show ductal stones [8].

Other tips to help distinguish and evaluate pancreatic cystic lesions include measuring the density/Hounsfield unit (HU) of the lesion. Chalian et al. reported that higher attenuation cysts (>14.5 HU, accuracy of 73.5 %) are more associated with pseudocysts than unilocular mucin-containing cysts [45]. A lobulated shape, thin wall, and smooth internal surface were more common in benign cysts; conversely, a round, oval, or complex shape with a thick wall and irregular internal surface was found more frequently in premalignant and malignant cystic lesions [46]. EUS-guided cyst fluid aspiration may be helpful in cyst characterization since mucinous tumors typically demonstrate elevated carcinoembryonic antigen (CEA) or carbohydrate antigen 19–9 (CA 19–9) and increased fluid viscosity [47].

In evaluating pancreatic cystic lesions, it is also important to utilize thin section imaging and post-processing techniques to optimally characterize the findings, especially when determining whether there is ductal communication. Some studies have suggested that MPR and curved MPR (cMPR), alone or in combination with axial images obtained oblique to the pancreatic head, body, and tail as superior to axial images alone in evaluating the pancreatic duct [48–50]. MinIP images may also enhance the detection of cystic lesions, their internal characteristics, and their communication to pancreatic ducts [50] (Fig. 12).

Pancreatic cysts are typically incidental findings discovered on a CT performed for other reasons. When found, they can be further evaluated with a dedicated pancreatic protocol multiphasic CT study, MRI/MRCP, or EUS. MRI has better sensitivity and specificity than CT in differentiating IPMN from other cystic pancreatic lesions (96.8 vs. 80.6 % sensitivity and 90.8 vs. 86.4 % specificity, respectively) [44] (Fig. 13).

With regard to management, lesions with CT features consistent with a serous cystadenoma are not surgically resected unless symptomatic or 4 cm or more in size [51]. Cystic lesions with pathognomonic findings for MCN are resected in suitable candidates, regardless of the size due to their malignant potential [44]. For lesions suggestive of side branch IPMN that are <3 cm and simple in appearance (without stigmata of malignancy as noted previously or dilatation of the main pancreatic duct) imaging follow-up is usually indicated. According to the 2012 international consensus guidelines from the International Association of Pancreatology in Fukuoka, Japan, a 2–3 year follow-up for lesions <10 mm, yearly for lesions 10–20 mm, and 3–6 months for lesions 20–30 mm [43••]. Finally, resection is recommended for all patients with CT findings suggestive of a main duct IPMN with duct dilatation >10 mm [43••].

Other Lesions

Besides the above describe pancreatic lesions of ductal adenocarcinoma, NET, and cystic lesions, there are other entities that can be found in the pancreas which are not covered in depth in this review article. For example, there are solid pseudopapillary tumors (SPEN), acinar cell carcinoma, metastasis, lymphoma, sarcoma, etc. SPEN has been referred to as the "daughter tumor," since it predominantly affects young women. These tumors are often of low-grade malignancy, and on imaging are typically large, well demarcated, and encapsulated [44] (Fig. 14). Metastasis to the pancreas is generally rare; however, primary tumors known to commonly metastasize to the pancreas include renal cell cancer, malignant melanoma, lung cancer, and breast cancer; involvement may manifest as single or multiple lesions [8]. The appearance of the metastatic lesions depends on the nature of the primary tumor. Renal cell carcinoma and melanoma metastases are typically hypervascular, similar to NET, while lung and GI primaries will cause typically hypodense metastases that can have an appearance similar to primary pancreatic adenocarcinoma [8].

Conclusion

CT technology continues to advance, seen with progressive achievement in MDCT, DECT, perfusion CT, and advanced post-processing techniques. Pancreatic adenocarcinoma prognosis remains dismal due to the inability for early detection. It is of utmost importance to perform a dedicated multiphasic MDCT pancreatic protocol for optimal detection and accurate staging of this deadly disease. Additionally, DECT utilizing low monochromatic energies and iodine-only images may help detect small and isoattenuating tumors and metastasis. Similar imaging techniques are also beneficial for evaluation of NET. Finally, advanced post-processing techniques are recommended in the evaluation of pancreatic cystic tumors, in helping to differentiate benign from malignant lesions.

Compliance with Ethics Guidelines

Conflict of Interest Ott Le, Eric P. Tamm, Nicolaus Wagner-Bartak, Priya Bhosale, Madhavi Patnana, Raghu Vikram, and Aliya Qayyum each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

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