

Kyuran Ann Choe and Nicholas M. McDonald

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## Introduction

Pancreatic adenocarcinoma has been increasing in incidence [1] and it has been estimated to represent 3 % of new cancer diagnoses and 7 % of cancer deaths in 2014 [2]. Most commonly, the staging of pancreatic carcinoma follows American Joint Committee on Cancer (AJCC) guidelines. In the absence of metastatic disease, there is concurrent classification of tumors into resectable, borderline resectable, and unresectable locally advanced disease for the purposes of clinical management [3–6]. Although there is discussion regarding some of the criteria that define borderline resectable and locally advanced pancreatic cancer, both tumor staging and evaluation of local extent of disease for potential resectability are based on findings seen on cross-sectional imaging, primarily contrast-enhanced multidetector computed tomography (MDCT) and magnetic resonance imaging (MRI).

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## Ultrasound

Transabdominal ultrasound is frequently the initial examination that is performed in a patient with jaundice and it is sensitive for the detection of biliary ductal dilation. However, the etiology of the biliary obstruction can be difficult to elucidate and visualization of the entirety of the pancreas is difficult due to patient body habitus and interference from overlying bowel gas which limits tumor detection. In addition, when a tumor is present, complete assessment of local tumor extension is limited [7]. The finding of biliary and/or pancreatic ductal dilation on ultrasound commonly prompts further imaging evaluation by CT or MRI. The role of endoscopic ultrasound will be discussed in Chaps. 3 and 4.

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## Multidetector Computed Tomography

Optimal imaging of the abdomen and pelvis by CT for the evaluation of patients with pancreatic carcinoma is performed using multidetector scanners which provide thin slices and isotropic data for multiplanar reformatted images and 3D reconstructions. Rapid image acquisition allows for multiple phases of image acquisition with contrast enhancement optimized for tumor detection, vascular assessment, and evaluation for metastatic disease. Initial noncontrast imaging of the

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K.A. Choe, M.D. (✉) • N.M. McDonald, M.D.  
Department of Radiology, University of Cincinnati  
Medical Center, 234 Goodman St. ML 0761,  
Cincinnati, OH 45267, USA  
e-mail: [ann.choe@uc.edu](mailto:ann.choe@uc.edu); [mcdonana@ucmail.uc.edu](mailto:mcdonana@ucmail.uc.edu)

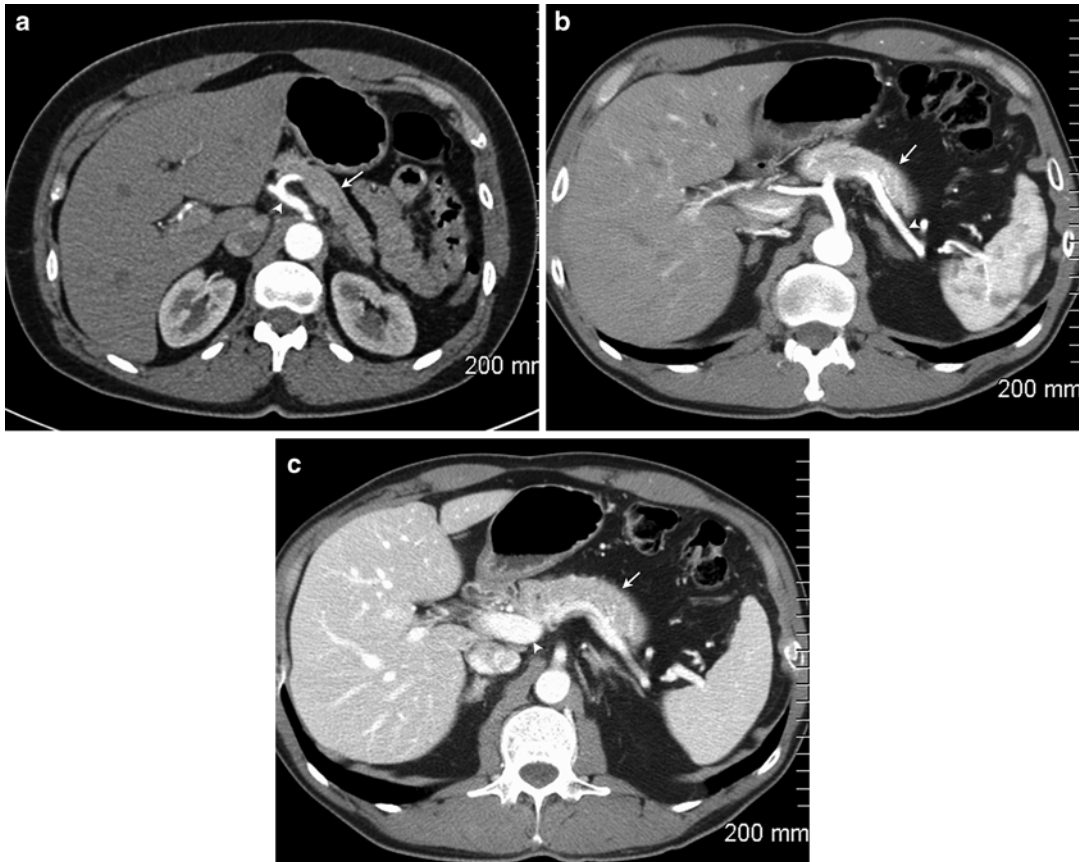


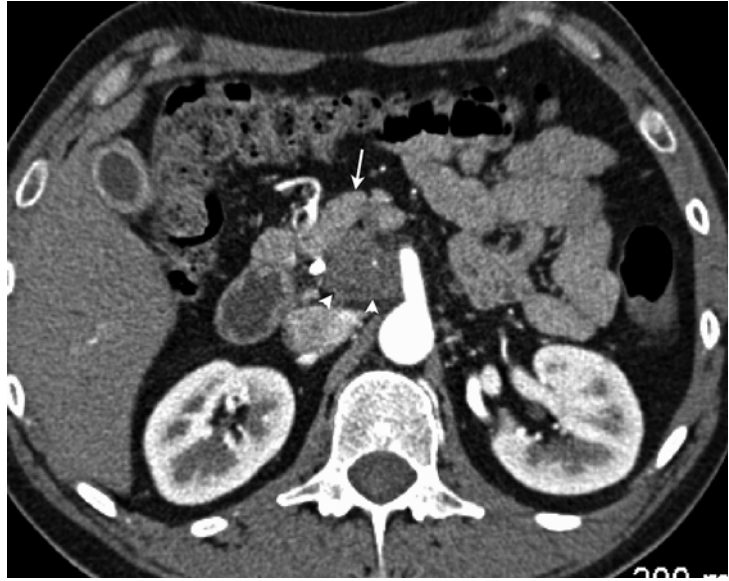
**Fig. 2.1** Normal multiphasic appearance of the pancreas and adjacent structures. The arterial phase image (a) demonstrates dense arterial enhancement of the celiac artery (arrowhead) and mild enhancement of the pancreas (arrow). The pancreatic parenchymal phase (b) shows excellent arterial enhancement of the splenic artery

(arrowhead) with enhancement of the pancreas (arrow). In the portal venous phase (c), there is dense enhancement of the portal vein (arrowhead) with persistent enhancement of the pancreas (arrow). There is parenchymal enhancement of the liver

abdomen is not required but is recommended in the 2012 National Comprehensive Cancer Network (NCCN) guidelines [8]. Negative enteric contrast (usually water) is used to avoid obscuration of the vasculature particularly if 3D reconstructions are utilized [9, 10]. Following intravenous high-iodine ( $>300$  mg I/mL) contrast administration at 3–5 mL/s [11], images may be acquired in the angiographic arterial phase, pancreatic parenchymal phase [12], and portal venous (hepatic) phase (Fig. 2.1). Images are acquired in at least two of these phases, one of which is the portal venous (hepatic) phase for the detection of metastatic disease [13, 14]. At our institution, the portal venous phase extends through the pelvis to

assess for metastatic disease if a recent CT has not been performed. The arterial angiographic phase (Fig. 2.1a) will optimally demonstrate the arteries with less background solid organ enhancement (for 3D volume rendered images), but has less sensitivity for lesion detection due to less image contrast between the tumor and normal parenchyma [13]. Some authors advocate image acquisition in the late arterial/pancreatic parenchymal phase (Fig. 2.1b) to optimize lesion detection and local arterial vascular involvement since the image contrast between the tumor and normal parenchyma is greater in this phase in addition to greater arterial enhancement [13, 15, 16]. The timing of image acquisition is dependent

**Fig. 2.2** Pancreatic adenocarcinoma in the uncinate process (arrowhead) appears hypodense in comparison to the normal parenchyma (arrow)



upon the rate of intravenous contrast administration which is 3–5 mL/s. The arterial phase of enhancement is at 30, 25, and 20 s following the start of peripheral intravenous contrast administration at an injection rate of 3, 4, and 5 mL/s, respectively [13]. Similarly, the normal pancreas demonstrates peak parenchymal enhancement at 50, 45, and 40 s, respectively [13]. Images in the portal venous phase are acquired between 60 and 70 s [13]. Images are typically reconstructed at slice thicknesses of 3 mm or less [3]. The thinner slice data (1.0 mm or less) is used for multiplanar and 3D reconstruction. If the initial examination is not of diagnostic quality to perform adequate tumor and vascular assessment, it should be repeated using a dedicated pancreas cancer protocol [11]. Preferably, imaging is performed prior to biliary stent placement since the stent may cause streak artifact at the level of the pancreatic head limiting evaluation of the local extent of tumor and secondary pancreatitis may obscure the primary lesion and complicate vascular assessment [3, 14].

Pancreatic adenocarcinoma is typically isodense to the normal pancreas on the noncontrast images, limiting their utility for the purposes of staging. Most pancreatic adenocarcinoma tumors enhance less than the normal pancreatic parenchyma and appear hypodense on contrast-

enhanced images (Fig. 2.2). The sensitivity for the detection of tumor is greatest in the pancreatic parenchymal phase in comparison to the arterial and portal venous phases due to maximal differential enhancement and image contrast between tumor and normal parenchyma [13]. Isoattenuating and isoenhancing tumors (Fig. 2.3) comprise a small portion of tumors—5.4 % of pancreatic adenocarcinoma tumors evaluated in a recent study [17] and 11 % in an older study [18]. A higher percentage of smaller (2 cm or less) tumors have been shown to be isoattenuating [19]. These tumors are difficult to detect but may be inferred by secondary signs including mass effect of the tumor on the contour of the pancreas or on adjacent structures or by the level of biliary and/or pancreatic ductal obstruction [17, 18]. When tumors are isoattenuating, evaluation of local extent of disease can be difficult; particularly problematic is the assessment of abutment or encasement of the intrapancreatic portion of the portal vein and superior mesenteric vein in the absence of distortion.

Evaluation of the local extent of the tumor requires careful evaluation of the local vasculature, including the celiac artery and branches, superior mesenteric artery, superior mesenteric vein, and portal vein. Evaluation for aberrant vasculature such as a replaced or accessory right

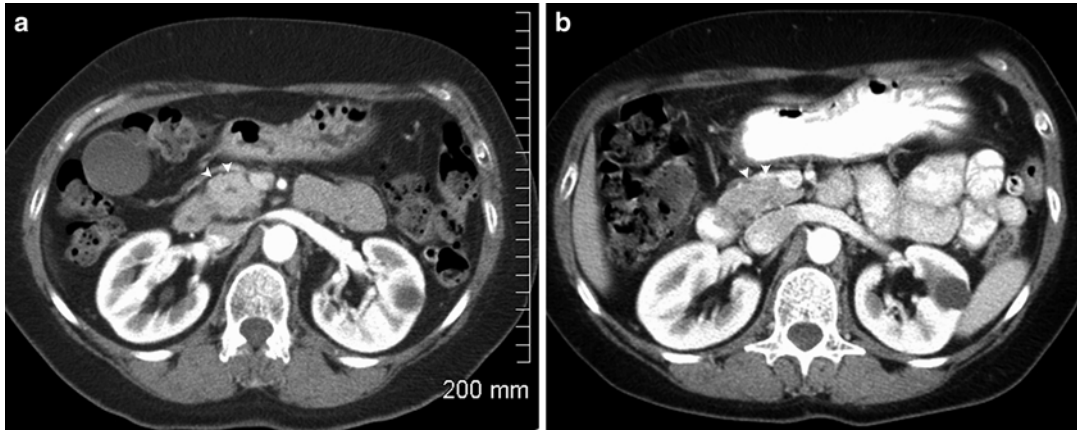


**Fig. 2.3** Isodense pancreatic adenocarcinoma. A pancreatic head mass (*arrowhead, a*) is present causing a contour bulge anteriorly which was not present on a

comparison CT (*b*). The central hypodensity seen in (*a*) is the pancreatic duct

hepatic artery or a replaced common hepatic artery originating from the superior mesenteric artery is also important as the course of these vessels frequently lies between the inferior vena cava and portal vein at the pancreatic head (Fig. 2.4). In the absence of distant metastases, preservation of the fat and soft tissue planes surrounding the adjacent vasculature indicates resectable disease (Fig. 2.5).

The delineation between resectable, borderline resectable, and unresectable locally advanced tumor is based upon the relationship between the tumor and adjacent vasculature [4–6]. Assessment of tumor involvement of the vasculature has been defined relative to the circumference of the vessel [20] without or with distortion of the vessel. An interface between the tumor and vessel of  $180^\circ$  or less has been termed abutment (Fig. 2.6) and greater than  $180^\circ$  has been termed encasement (Fig. 2.7) [11]. Greater than  $180^\circ$  of interface between tumor and vessel (encasement) was demonstrated to be specific for vessel invasion [20]. Irregularity of the vessel contour or narrowing (deformity) is also indicative of vascular invasion (Fig. 2.8) [11, 14]. Multiplanar reformatted images are beneficial for evaluation of the vessels with tumor involvement and assessment of degrees of the interface between the tumor and the vessel (Fig. 2.9) [15, 21, 22]. Vascular tumor obliteration or bland thrombus should also be noted. Since the definition of borderline resectable tumors includes those

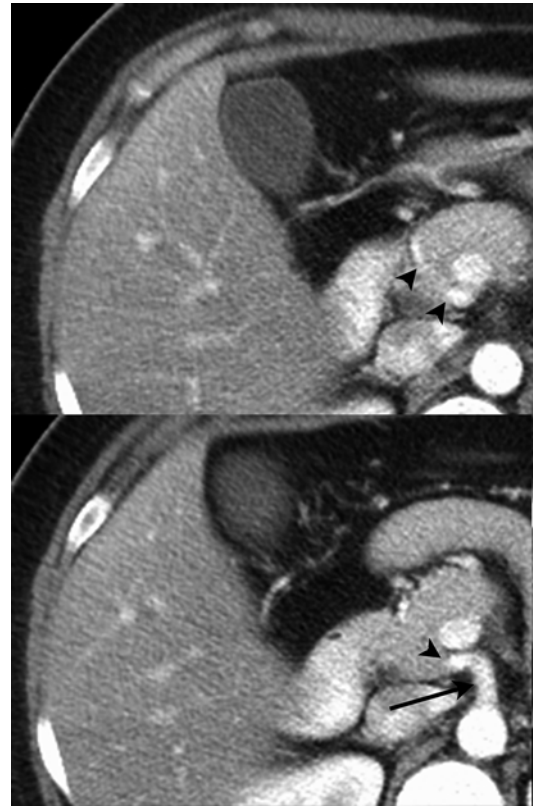


**Fig. 2.4** Two adjacent slices demonstrate a replaced common hepatic artery (*arrowhead*) originating from the superior mesenteric artery (*arrow*)

tumors where arterial or venous resection and reconstruction are being considered, assessment of longitudinal extent of tumor along the portal vein,

**Fig. 2.5** The pancreatic head mass (*arrow*) appears relatively hyperdense due to fatty infiltration of the pancreas. A normal tissue plane is maintained between the tumor and the portal vein (*P*). There is a replaced right hepatic artery (*arrowhead*) seen posterior to the pancreatic head

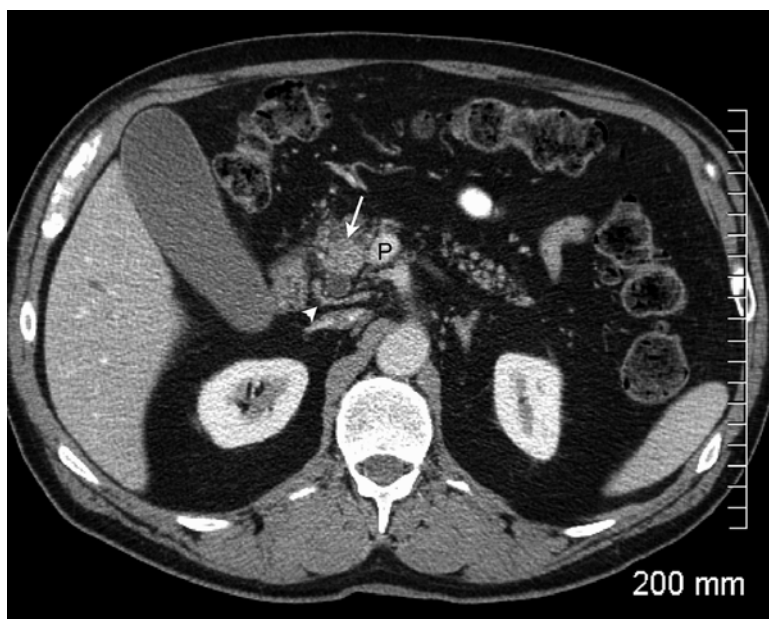


**Fig. 2.6** The pancreatic mass abuts the superior mesenteric artery by about 120° (between *arrowheads*). The soft tissue seen posterior to the superior mesenteric artery is the left renal vein



superior mesenteric vein, and artery and hepatic artery should also be noted [3].

The definition of borderline resectable tumor is under some debate with at least three prevailing definitions, the AHPBA/SSO/SSAT consensus conference [6], the NCCN 2014 guidelines [4], and the Intergroup study [5]. The most recent

2014 NCCN guidelines acknowledge the need for more restrictive definitions of borderline resectable tumors in clinical trials [4].

Pancreatic adenocarcinoma may also directly extend to involve adjacent structures, including adjacent bowel, mesentery, spleen, kidneys, adrenal glands, aorta, and inferior vena cava (Fig. 2.10).

**Fig. 2.7** Pancreatic adenocarcinoma circumferentially encases the superior mesenteric artery (*arrow*)



**Fig. 2.8** Tumor is seen encasing and distorting the superior mesenteric vein (*arrow*). There is greater than 180° of encasement of the superior mesenteric artery (*arrowhead*)



Manifestations of metastatic disease include hepatic metastases, adenopathy beyond the local region, and peritoneal carcinomatosis. Hepatic metastases are typically hypovascular and are best visualized on portal venous phase imaging, appearing hypodense to the enhancing liver (Fig. 2.11). Small liver lesions can be particularly difficult to characterize [14]. Evaluation for adenopathy is based on

size criteria (greater than 1 cm) and enlarged lymph nodes are particularly notable if outside the potential surgical resection bed. Peritoneal tumor may be seen as peritoneal nodularity, omental or serosal thickening or nodularity (Fig. 2.12). However, small volume metastatic deposits on or in the liver and small peritoneal implants are difficult to visualize by imaging [3, 23].

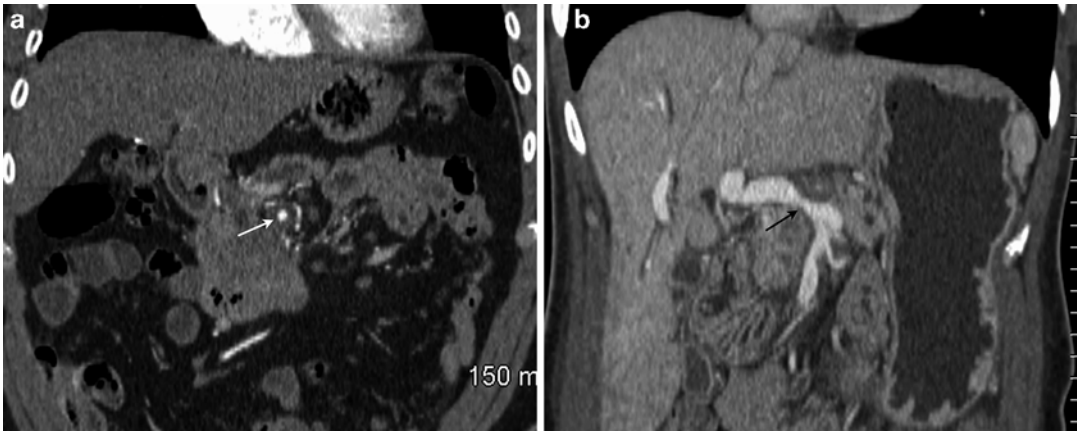


**Fig. 2.9** Coronal multiplanar reformatted images demonstrate encasement of the superior mesenteric artery (**a**, *arrow*) and encasement with narrowing of the portal vein (**b**, *arrow*)

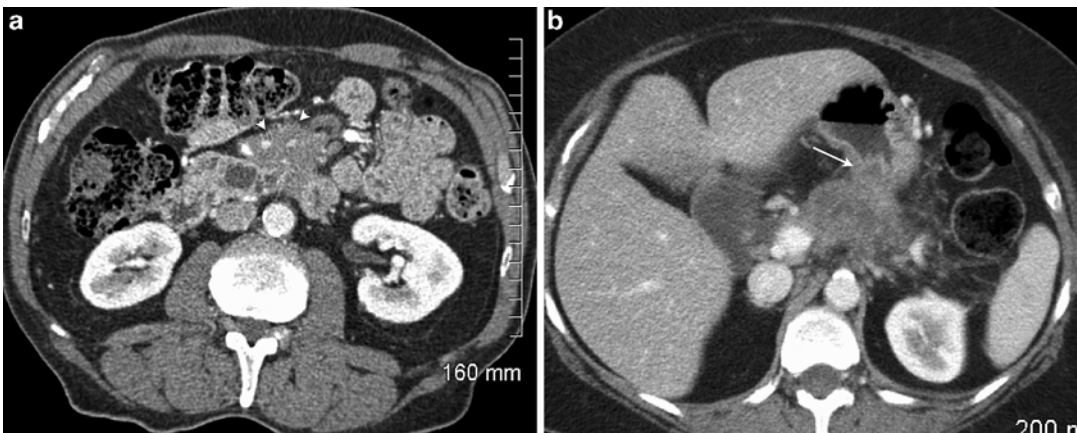


**Fig. 2.10** Pancreatic adenocarcinoma with extension into the small bowel mesentery (**a**, *arrowheads*) and into the posterior gastric wall (**b**, *arrow*)

## Magnetic Resonance Imaging

Although most centers use MDCT as the primary examination for staging pancreatic cancer, MRI is a useful alternate imaging modality for both detection and staging, particularly when contrast-enhanced MDCT is contraindicated [14]. MR is equivalent to MDCT for detection and assessment of local disease [24–26]. On T1 weighted images, the normal pancreas is relatively hyperintense due to the higher content of protein in the pancreatic acini [10]. This is more conspicuous on T1 weighted images with fat suppression (Fig. 2.13). Tumors are hypointense to isointense to the

normal pancreas on T1 weighted images [27]. On T2 weighted images, tumors are usually hyperintense to isointense (Fig. 2.14) [27]. Heavily T2 weighted images acquired for MR cholangiopancreatography (MRCP) will demonstrate the level of biliary or pancreatic ductal obstruction if present (Fig. 2.15) [28]. The atrophic parenchyma in the region of upstream pancreatic ductal dilation may demonstrate decreased signal on the T1 weighted images [10]. With gadolinium-based intravenous contrast administration, images are acquired using fast T1 weighted fat-suppressed 3D gradient echo sequences, also allowing for multiphase acquisitions [29] similar to MDCT (Fig. 2.16). The enhancement characteristics of

**Fig. 2.11** Hypodense liver lesions (arrowheads) representing metastatic disease

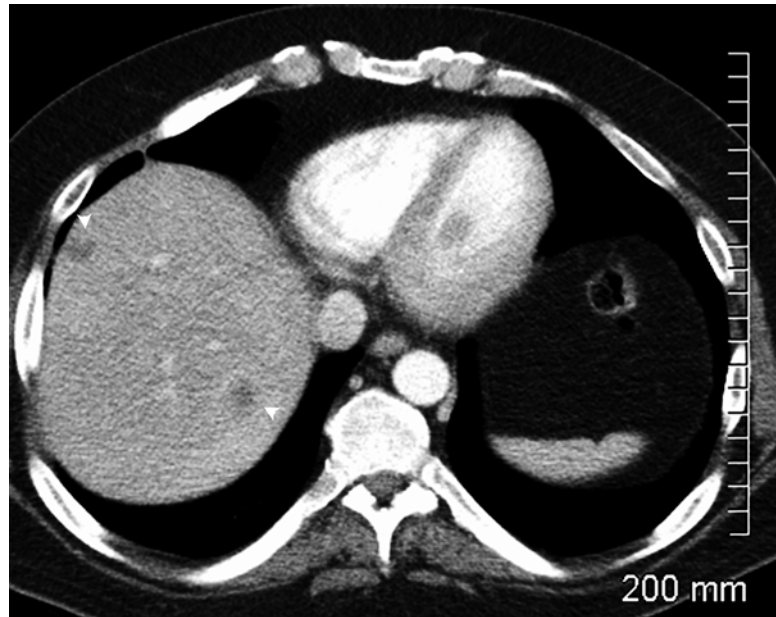
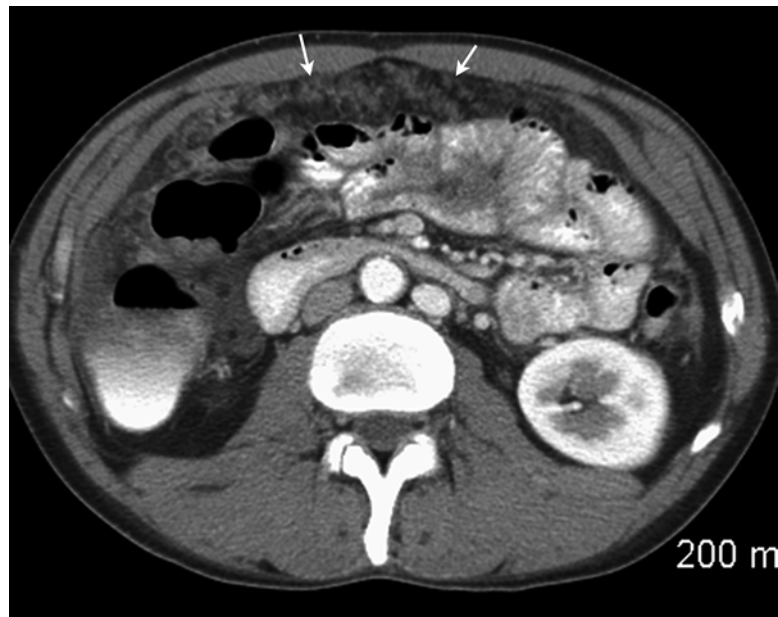


**Fig. 2.12** Omental nodules (arrows) are consistent with peritoneal carcinomatosis. A small amount of free fluid is also present



normal pancreatic parenchyma and tumor are similar to CT, with pancreatic adenocarcinoma enhancing less than normal parenchyma in the arterial and portal venous phases. Lesion conspicuity is greatest on the arterial phase images (Fig. 2.17) [29]. On diffusion weighted images, pancreatic carcinoma tends to have restricted diffusion [10], but these images are less sensitive

than the contrast-enhanced images for tumor detection [29]. In addition, diffusion weighted images are unable to differentiate between pancreatic adenocarcinoma and mass forming chronic pancreatitis [30, 31]. Assessment of vascular involvement may also be performed by MR with equivalent performance to MDCT for determination of resectability [32]. Preservation of the fat

**Fig. 2.13** Fat-suppressed T1 weighted spoiled gradient echo image demonstrates bright T1 signal intensity of the normal pancreas (*arrows*)

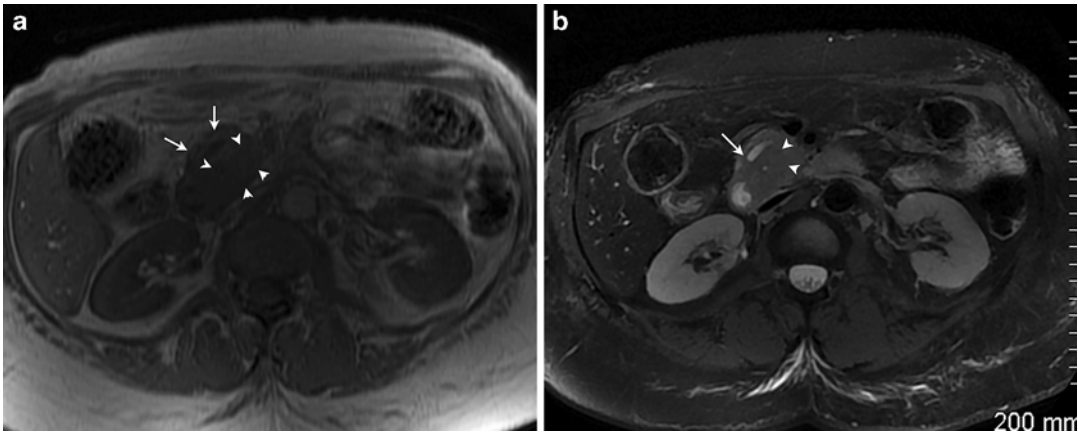
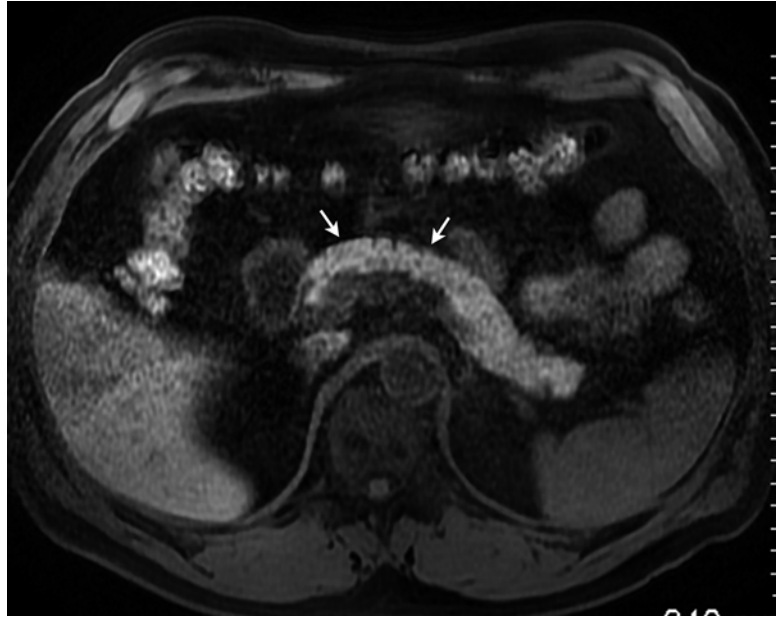


**Fig. 2.14** Tumor (*arrowheads*) is hypointense to the pancreas (*arrow*) on the T1 weighted image. (a) On the fat-suppressed T2 weighted image (b), the mass (*arrowhead*)

is isointense to slightly hypointense to the pancreas. A dilated pancreatic duct (*arrow*) is seen

plane between tumor and vessel is seen as a persistent high T1 signal fat surrounding the vessel on non-fat suppressed T1 weighted images.

MRI can be useful in detecting tumors that are isoattenuating on CT (Fig. 2.18) [27], with a reported sensitivity of 79.2 % of this group of tumors [17]. MRI may also have a benefit in the imaging of small tumors (less than 2 cm) [10].

Evaluation for metastatic disease is well documented by MRI. MR evaluation of the liver is

better than MDCT at characterizing small lesions [10, 33] since cysts and hemangiomas are high signal on T2 weighted images and contrast enhancement patterns are characteristic (Fig. 2.19). MR evaluation with agents that are taken up by normal hepatocytes on delayed imaging (gadoxetic acid) is more sensitive for the detection of hepatic metastases but also allows for the detection of tumor and evaluation of local extent of disease [34].

**Fig. 2.15** 3D MRCP image demonstrates the level of biliary and pancreatic ductal dilation (*arrows*)

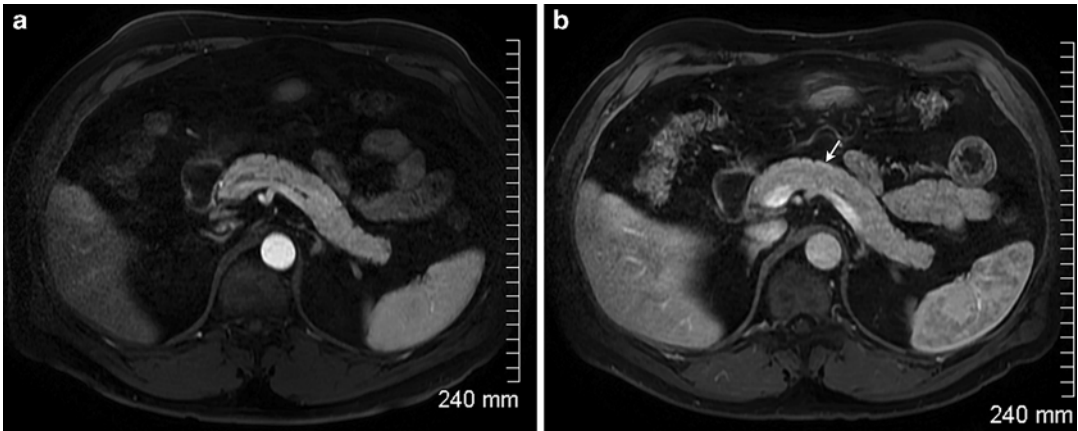


**Fig. 2.16** Arterial phase (a) and portal venous phase (b) images of a normal pancreas with homogeneous enhancement

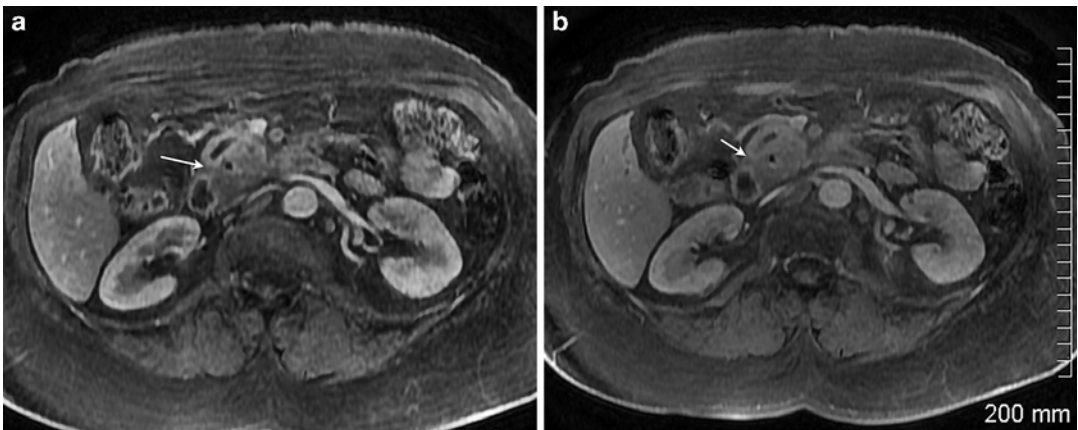


**Fig. 2.17** Arterial phase (a) and portal venous phase (b) images demonstrate greater signal intensity difference between the tumor and the pancreas (*arrow*) on the arterial phase study (a)

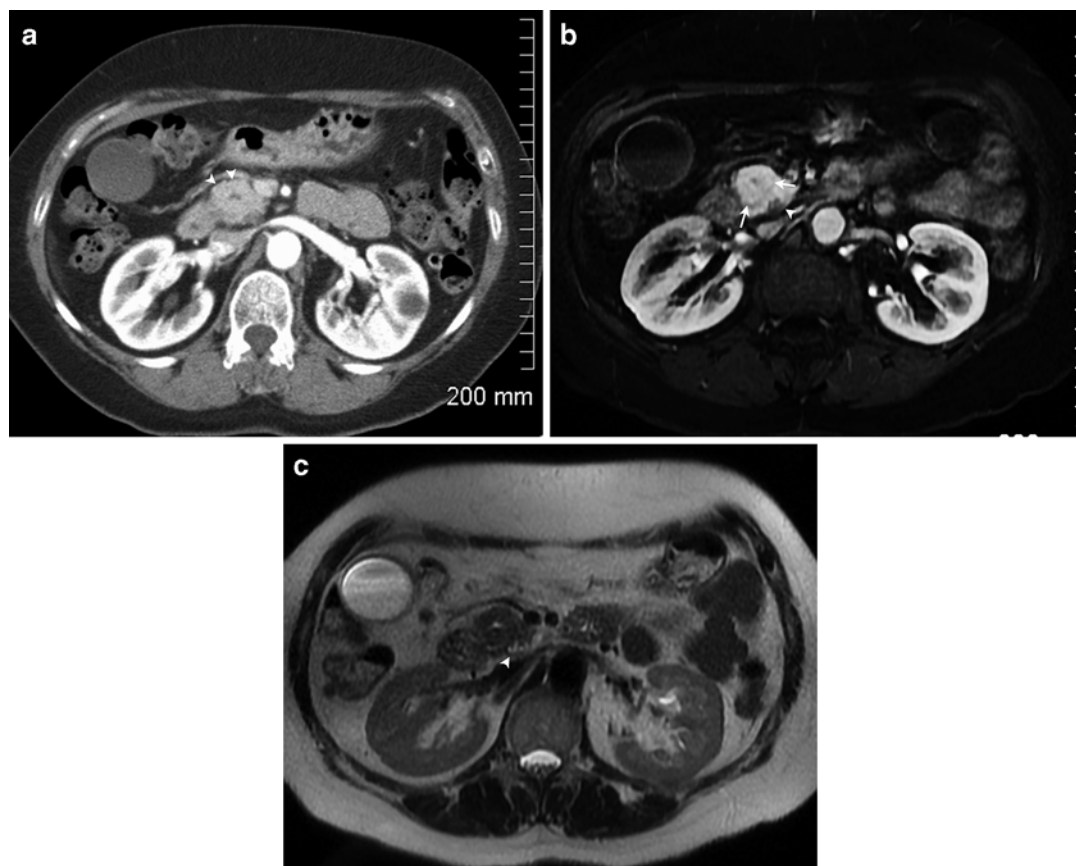


**Fig. 2.18** In the same patient as seen in Fig. 2.3 (a), the tumor is now visible on the contrast-enhanced study (b, arrows). The small hypointense focus (arrowhead) seen

posterior to the tumor is shown to represent a dilated pancreatic ductal sidebranch on the T2 weighted image (c)

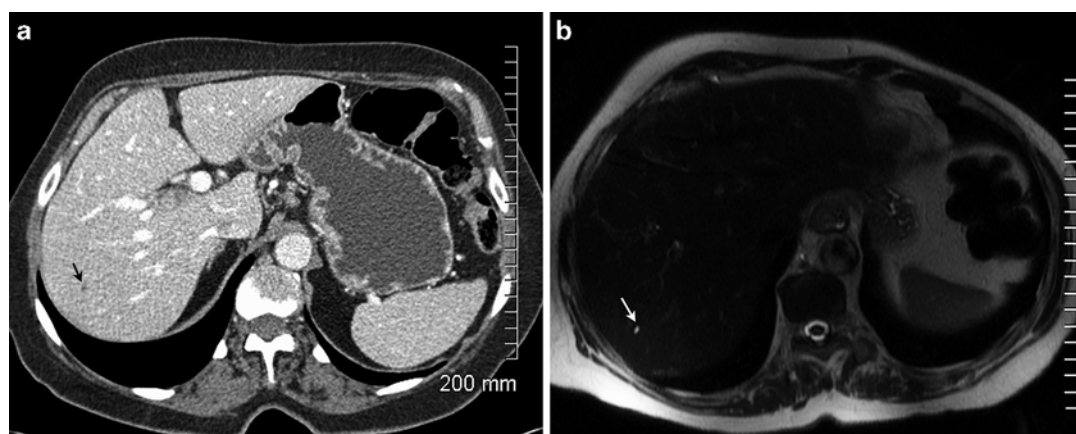


**Fig. 2.19** A tiny low attenuation lesion (arrow) is seen on CT (a). On T2 weighted MR (b), the lesion is well circumscribed and high in signal intensity consistent with a cyst

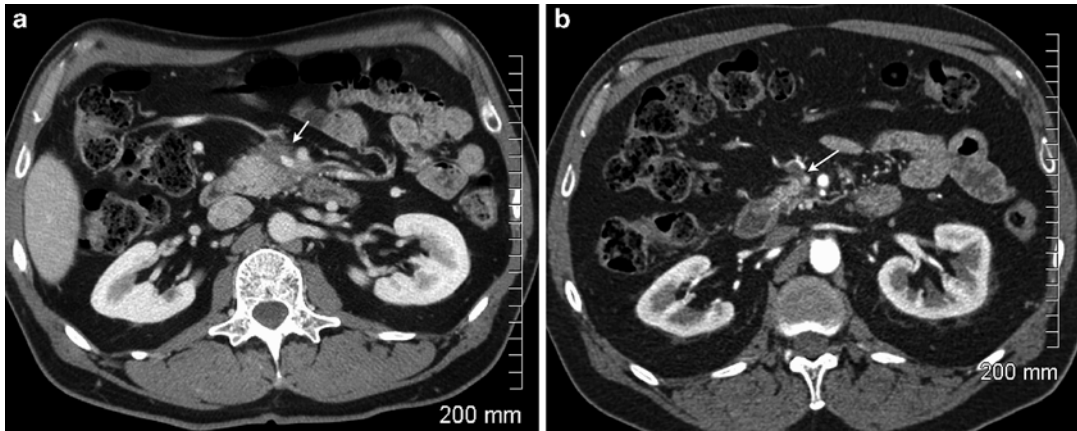


**Fig. 2.20** Tumor (*arrow*) is seen deforming the superior mesenteric vein prior to therapy (**a**). Following neoadjuvant therapy (**b**), there is residual, but less extensive soft tissue (*arrow*)

### Positron Emission Tomography/ Computed Tomography

At this time,  $^{18}\text{F}$ fluorodeoxyglucose (FDG) PET/CT has no role in the assessment of the local extent of pancreatic carcinoma [35]. The limited CT images are performed for attenuation correction and are routinely performed without intravenous contrast which is not adequate for evaluation for local vascular involvement [36].  $^{18}\text{F}$ FDG uptake by the tumor limits also evaluation of the local tissues [10, 37]. The role of  $^{18}\text{F}$ FDG PET/CT in detection and evaluation of metastatic and recurrent disease is evolving [38, 39].

### Imaging Following Therapy

Following neoadjuvant therapy for borderline resectable and unresectable locally advanced tumor, MDCT is less sensitive for prediction of potential resectability [40, 41]. This may be due to the inability to differentiate residual soft tissue at the tumor bed as either residual tumor or fibrosis (Fig. 2.20) [41]. Following therapy, the degree of vascular involvement may also be overestimated [40]. In a recent study, decreasing contact between tumor and the superior mesenteric vein or portal vein and decreasing contact with the superior mesenteric artery were associated

with an R0 resection. However, decreasing tumor size was not significantly associated with an R0 resection [42].

### Reporting

A multidisciplinary expert group sponsored by the Society of Abdominal Radiology and the American Pancreatic Association recently provided a consensus statement and reporting template for pancreatic ductal adenocarcinoma to facilitate complete reporting of the imaging findings [11, 43]. This document provides guidelines for comprehensive description of the primary tumor with characterization of the interface between tumor and adjacent vasculature and evaluation of extrapancreatic disease. Documentation of pertinent vascular variants is also included. Utilization of a structured reporting template is favored to provide consistent image interpretation and reproducible reports.

### Summary

In summary, the clinical staging of pancreatic carcinoma is dependent upon optimal cross-sectional imaging, either MDCT or MRI. With both imaging modalities, multiphase imaging is needed to detect the tumor, to evaluate the relationship of the tumor to adjacent vasculature for potential

resectability, and to evaluate for metastatic disease. MDCT is more commonly used, but MRI is an alternative modality. MRI can be beneficial in detecting tumors that are isodense on CT and is better at characterizing small liver lesions.

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