Optimal Imaging Modalities for the Diagnosis and Staging of Periampullary Masses

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KEYWORDS

• Pancreas • Periampullary • Tumor • Staging • MDCT • MRI • MRCP

KEY POINTS

- High-quality cross-sectional diagnostic imaging has a central pivotal role in evaluation of patients with known or suspected periampullary masses.
- The most commonly used imaging tools include contrast-enhanced multidetector computed tomography and contrast-enhanced MRI with MR cholangiopancreatography.
- The role of imaging is to identify periampullary masses, assess the presence or absence of tumor extension to surrounding vessels and organs, and identify distant metastasis.
- Accurate and complete reporting of relevant imaging findings should be done through the use of template reporting ensuring proper staging and optimal treatment strategies.

INTRODUCTION

Diagnostic imaging is the first step in the evaluation of patients presenting with clinical signs and symptoms referred to the pancreatobiliary system. The most common indications for imaging include painless obstructive jaundice, epigastric pain (suspected of pancreatic or biliary origin), or unexplained pancreatitis in patients older than 40.[1] The most commonly used imaging modalities include transabdominal ultrasound, contrast-enhanced multidetector computed tomography (MDCT), and contrast-enhanced MRI with MR cholangiopancreatography (MRCP).[2] The role of each imaging

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modality varies depending on the clinical presentation and if malignancy is highly suspected or already known from prior imaging.

Transabdominal ultrasound examination can serve as a screening test to detect the presence of biliary dilatation in patient presenting with jaundice and can be helpful in identifying gallbladder stones and/or choledocholithiasis as the cause of the biliary dilatation. However, often the distal common bile duct and pancreatic head region are poorly visualized owing to shadowing from overlying gas limiting the overall sensitivity of ultrasound in screening for pancreatic head or periampullary masses. In patients presenting with painless jaundice, suspected distal common bile duct obstruction, unexplained pancreatitis, or a high suspicion of a pancreatic head mass, the most commonly obtained imaging study is either MDCT or MRI/MRCP. Both examinations provide high contrast and spatial resolutions and can help in assessing the presence of biliary or pancreatic duct dilatation, identifying the level of the biliary or pancreatic duct obstruction, and frequently diagnosing the etiology of the obstruction accurately. A detailed description of these imaging techniques and imaging findings in patients presenting with periampullary masses are discussed.

PERIAMPULLARY MASSES

Masses that can affect the periampullary region can arise either from the pancreatic head, duodenum, Ampulla of Vater or distal common bile duct. These include but are not limited to pancreatic ductal adenocarcinoma (PDA), pancreatic neuroendocrine tumors, cystic pancreatic neoplasms, ampullary adenoma or adenocarcinoma, duodenal adenocarcinoma, and extrahepatic cholangiocarcinoma.[3,4] PDA represent the most common tumor detected on cross-sectional imaging for painless jaundice. It is a very aggressive malignancy with a reported survival rate as low as 4% at 5 years after diagnosis.[5] Despite its low incidence comprising only 3% of the estimated new cases of cancer in the United States, PDA is currently the fourth most common cause of cancer-related death in both males and females.[6] Currently, complete surgical resection without microscopic residual disease or positive margins (R0 resection) offers the best hope of improved survival and potential cure in newly diagnosed patients. Unfortunately, this cannot be achieved in the majority of cases because no more than 15% to 20% of patients have potentially resectable disease at the time of presentation.[7,8] Patients with margin-positive resection at surgery have been shown to have similar survival rates to patients with unresectable disease.[9] Accordingly, these patients would not benefit from the surgical resection and should be spared major surgery with its associated mortality and significant morbidity. Staging of periampullary masses and assessment of the feasibility of complete surgical resection by imaging remains of paramount importance in determining the therapeutic plan. The most relevant determinant of surgical resection in almost all cases is the presence or absence of peripancreatic vessel involvement by the tumor and the absence of distant metastasis.

CROSS-SECTIONAL IMAGING TECHNIQUES

Multidetector Computed Tomography

MDCT is the most commonly used cross-sectional imaging modality in the evaluation and staging of periampullary lesions owing to its widespread availability and high spatial resolution, making it a favorable first choice modality in most institutions. Performance of high-quality MDCT examination in high-volume referral centers specialized in imaging and treating pancreatic diseases has been shown to improve preoperative staging and alter management in a significant proportion of patients.[10] A dedicated pancreatic protocol MDCT includes dual phase acquisition through the upper abdomen including the liver and the pancreas in the pancreatic and the portal venous phases of iodinated intravenous contrast enhancement.[11] The first phase of acquisition (pancreatic phase) is obtained around 40 to 50 seconds after the start of the intravenous contrast administration. This phase provides several important advantages in assessing pancreatic pathologies and the adjacent vasculature. During this phase, there is maximal enhancement of the pancreatic parenchyma, which provides the best visual contrast between hypoattenuating masses and the enhancing pancreatic parenchyma (eg, PDA). Arterially enhancing lesions such as neuroendocrine tumors are better depicted on this phase owing to their early contrast enhancement (**Fig. 1**). A second advantage is the assessment of the peripancreatic vessels, including the common hepatic artery, celiac artery, and superior mesenteric artery. The second phase of acquisition is obtained around 65 to 70 seconds after the start of intravenous contrast administration, which coincides with the portal venous phase. This phase also provides several important advantages including assessment of solid intraabdominal organs for metastasis, most importantly the liver, in addition to evaluation of the peripancreatic venous system including the main portal vein, splenic vein and superior mesenteric vein for possible involvement with tumor.

Thin slice acquisition with subcentimeter slice selection is currently widely available on almost all multidetector CT scanners and should be obtained in every case for optimal evaluation and staging. The thin slices offer significant improvement in the spatial resolution with the acquisition of near isotropic voxels, which offer similar resolution in any plane of image reformation (ie, sagittal, coronal, or oblique)[11,12] (**Fig. 2**). This significant increase in the spatial resolution can help to identify small focal pancreatic lesions and assess the contour of the peripancreatic vessels for possible involvement.

A minimum of 300 mg iodine per milliliter concentration of iodine for the nonionic intravenous contrast medium should be used to improve the contrast to noise ratio profile in assessing the degree of parenchymal organ enhancement and the vascular structures. Reduced scan kilovolts peak setting (<120 KVp) has been shown to lead to increased attenuation of enhancing structures containing high concentration of the iodinated contrast without degrading the diagnostic imaging quality.[13,14] This can potentially help to identify small enhancing structures or lesions such as neuroendocrine tumors and can also potentially help in reducing the amount of intravenous contrast administered.

Fig. 1. Pancreatic neuroendocrine tumor. (*A*) Axial and (*B*) coronal contrast-enhanced multidetector computed tomography images in the pancreatic phase show an enhancing pancreatic tumor in the pancreatic head (*arrow*), which is enhancing more than the background pancreatic parenchyma consistent with a neuroendocrine tumor.

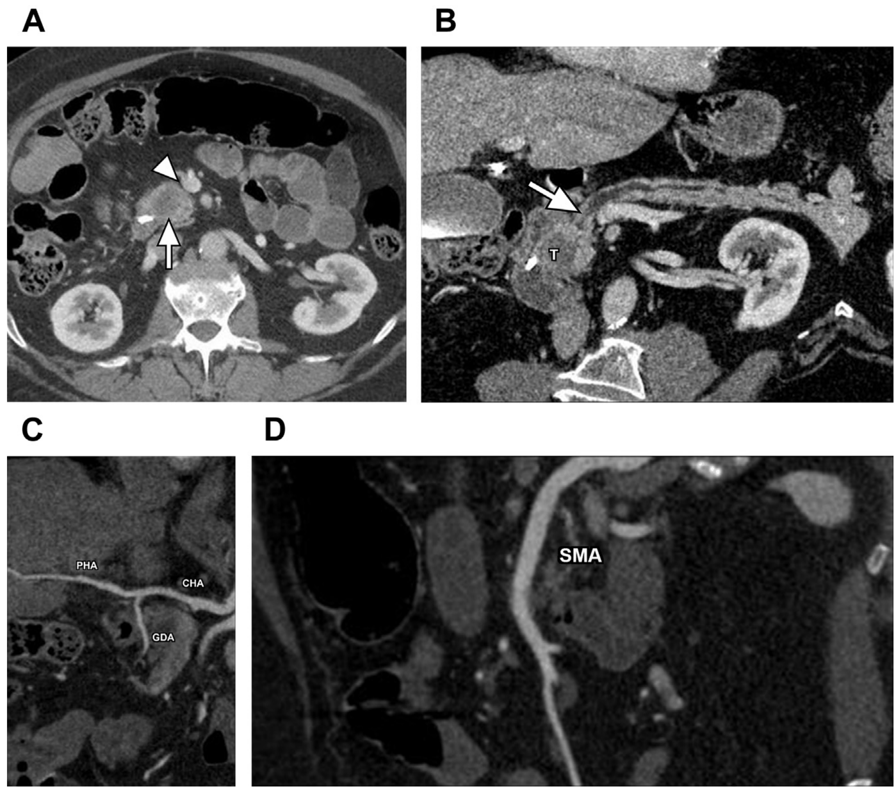

Fig. 2. High-quality dedicated multidetector computed tomography (MDCT) evaluation of pancreatic head adenocarcinoma. (*A*) Axial contrast-enhanced MDCT image through the pancreatic head demonstrate an ill-defined hypodense mass (*arrow*) consistent with pancreatic adenocarcinoma. There is no contact with the adjacent superior mesenteric vein or artery (*arrowhead*), suggesting a resectable tumor. (*B*) Curved reformatted image through the pancreas demonstrate the level of pancreatic duct obstruction (*arrow*) and outlines the edge of the tumor (T). (*C*) High-resolution curved reformatted image through the celiac axis branches improves the assessment of the peripancreatic vessels confirming the lack of tumor contact with the common hepatic artery (CHA), gastroduodenal artery (GDA), and proper hepatic artery (PHA). (*D*) Additional curved reformat through the superior mesenteric artery (SMA) demonstrate lack of tumor contact.

Neutral or low-density oral contrast (such as water or low-density barium suspension) should be used instead of the high attenuation or positive oral contrast used in routine CT examinations. The main role of the neutral or low-density oral contrast is to adequately distend the stomach and duodenum, which helps in assessing local tumor invasion. The neutral contrast agent also avoids streak artifacts associated with the high density positive oral contrast on the 3-dimensional vascular reconstructed images.

MRI

Contrast-enhanced MRI with MRCP has been shown to be of equal accuracy to MDCT for the staging of periampullary masses[15–17] (**Fig. 3**). However, MRI examinations are not commonly obtained as first-line imaging studies in most institutions,

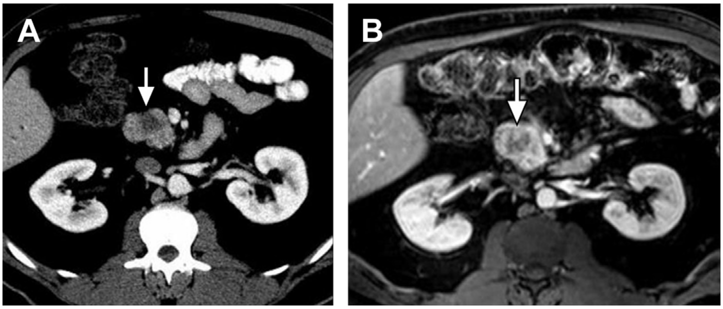

Fig. 3. Pancreatic head mass on multidetector computed tomography (MDCT) and MRI. (*A*) Axial contrast-enhanced MDCT and (*B*) T1-weighted gradient echo with fat suppression images through the pancreatic head demonstrate a focal mass (*arrow*) completely surrounded by pancreatic parenchyma with no extension beyond the contour of the pancreas suggesting a resectable tumor. Both imaging modalities have comparable accuracy for staging pancreatic adenocarcinoma.

mostly owing to their limited availability, higher cost, and the more challenging technical component of performing the examination. Both 1.5- and 3-T magnet systems can be used to obtain high-resolution images of the pancreas and upper abdomen after the administration of gadolinium containing contrast agents (Fig. 4). The main

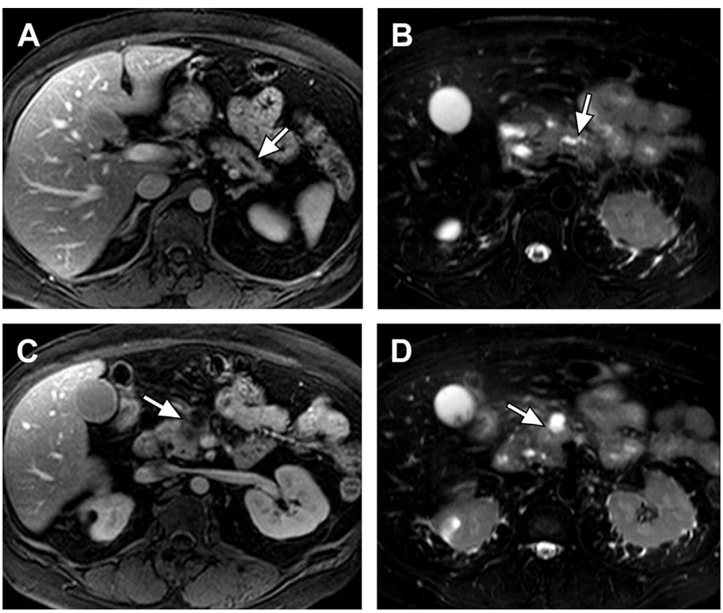

Fig. 4. Pancreatic adenocarcinoma on MRI. (*A*) Contrast-enhanced axial T1-weighted gradient echo with fat suppression and (*B*) axial T2-weighted fast spin echo with fat suppression images through the pancreas demonstrate dilated pancreatic duct in the distal body (*arrow*) concerning for proximal obstructing lesion. (*C, D*) Similar images at a lower level demonstrate a focal mass in the pancreatic head showing low signal intensity on the T1-weighted images (*arrow* in *C*) and high signal intensity on the T2-weighted images (*arrow* in *D*).

advantages of MRI include the higher signal-to-noise ratio compared with the MDCT, which would be most useful in evaluating focal pancreatic masses that are not detected on CT examination and in better evaluation of the biliary or pancreatic duct for assessment of localized stricture. An additional advantage of MRI is the specificity in characterizing indeterminate or suspicious liver lesions identified on the CT examinations to exclude metastasis.

MRI protocol includes the acquisition of the following sequences:

- Axial and coronal T2-weighted single shot fast spin echo images, which are mainly used as localizers to generally assess the location of the pathology and established different planes of acquisition.
- T1-weighted dual echo gradient echo images primarily for assessing lipid and fat-containing lesions (**Fig. 5**).
- T2-weighted fast spin echo with fat saturation to highlight the high signal intensity noted frequently in most periampullary malignant lesions.
- Precontrast and dynamic multiphasic acquisition postcontrast T1-weighted gradient echo with fat saturation after gadolinium administration, which helps to evaluate the enhanced pancreatic parenchyma and hypoenhancing or hyperenhancing focal periampullary lesions. Assessment of the peripancreatic arterial and venous structures can also be assessed during this acquisition.
- MRCP protocol includes the acquisition of heavily T2-weighted 3-dimensional fast recovery fast spin echo images with thin axial or thick slab single shot fast spin echo images. These heavily T2-weighted images highlight the endogenous contrast using the pancreatic and biliary fluid to assess for presence and level of strictures (**Fig. 6**).
- Diffusion-weighted imaging can also be obtained, which can help in the assessment of extrapancreatic metastasis, in particular within the liver.

IMAGING FINDINGS

The role of cross-sectional imaging modalities is to detect the focal periampullary masses, assess for the presence or absence of tumor extension to surrounding vessels and organs, and to identify distant metastasis.

Tumor Detection

PDA typically is seen as a focal low density or signal intensity mass against the background of the enhancing normal pancreatic parenchyma and is best visualized

Fig. 5. Role of MRI in evaluating suspected lesions in the pancreas. (*A*) Axial contrast-enhanced multidetector computed tomography (MDCT) image through the pancreatic head demonstrate an ill-defined hypodense masslike area (*arrow*) concerning for pancreatic adenocarcinoma. Lack of secondary findings such as distal parenchymal atrophy and biliary/pancreatic duct dilatation prompted further evaluation with MRI. (*B*) In-phase and (*C*) out-of-phase T1-weighted gradient echo images demonstrate loss of signal in the same region on the out of phase images (*arrows*) consistent with a benign area of focal fat replacement.

Fig. 6. Maximum intensity projection (MIP) image from T2-weighted 3-dimensional fast recovery fast spin echo sequence shows focal stricture in the distal common bile duct and proximal pancreatic duct at the same level (*arrow*) consistent with double duct sign, which is a common sign of obstruction secondary to a malignant mass in the pancreatic head.

on the pancreatic phase of acquisition (**Fig. 7**). A small percentage of small PDAs are isoattenuating on CT and cannot be discriminated readily from the surrounding pancreatic parenchyma.[18,19] Indirect signs such as mass effect, contour change, distal pancreatic parenchymal atrophy, and abruptly interrupted main pancreatic duct, despite the lack of visualization of mass, are important indicators for the presence of tumor.[20] These small isoattenuating tumors are best assessed with either MRI examination or endoscopic ultrasonography. Pancreatic neuroendocrine tumors on the other hand typically demonstrate increased enhancement compared

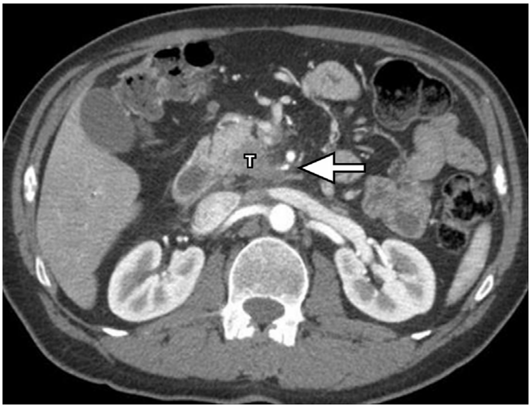

Fig. 7. Pancreatic head adenocarcinoma. Axial contrast-enhanced MDCT image through the pancreatic head demonstrate an ill-defined hypodense mass (T) consistent with pancreatic adenocarcinoma. There is less than 180° tumor contact with the adjacent superior mesenteric artery (*arrow*), suggesting a borderline resectable tumor.

with the background pancreas on the pancreatic phase imaging.[21,22] The pattern of enhancement of pancreatic neuroendocrine tumors can be either homogenous, particularly in small lesions, or heterogeneous with areas of central necrosis, especially in larger lesions. The presence of calcification in these lesions helps in differentiating them from other pancreatic tumors, particularly PDA. Extrahepatic cholangiocarcinomas demonstrate delayed progressive enhancement and are best assessed on MR examinations.[23,24] Ampullary masses are usually difficult to assess on cross-sectional imaging owing to their endoluminal location and are not routinely visualized; however, cross-sectional imaging evaluation remains of value in these cases to assess for extension beyond the ampulla or duodenal wall and to assess vascular involvement as well as the presence of metastasis.[25,26]

Assessment of Tumor Extension

Once a periampullary mass is identified, the next step in the assessment is appropriate staging of the disease and determination of tumor extent to evaluate for potential resectability. This is primarily achieved by assessing whether there is invasion of surrounding vessels including the common hepatic artery, celiac axis, superior mesenteric artery, main portal vein, and superior mesenteric vein, and excluding presence of distant metastasis (**Fig. 8**). Tumor involvement of the adjacent vessels is classified based on the degree of contact between the tumor and the circumference of the involved vessel and is primarily divided into less than or equal to 180° or greater than 180° (**Fig. 9**). Masses with greater than 180° contact with the adjacent vessels indicate high specificity for vascular invasion and consequently tumor unresectability.[27,28] Additional findings of contour deformity and change in the vessel caliber are also considered signs of vascular invasion. Less than 180° contact with the involved vessel would be generally classified as borderline resectable, which have less likelihood of vascular invasion however could benefit from neoadjuvant therapy to decrease tumor size and improve the chances of complete R0 resection at the time of surgery. The NCCN Clinical Practice Guidelines in Oncology (NCCN Guidelines®) provide a classification scheme of resectable, borderline resectable or unresectable tumor depending on the location of the tumor and extent of vascular contact[29] (**Table 1**). Additional advantages of imaging include the identification of vascular anatomic variants that can both affect the staging and the surgical approach to tumor resection (**Fig. 10**).

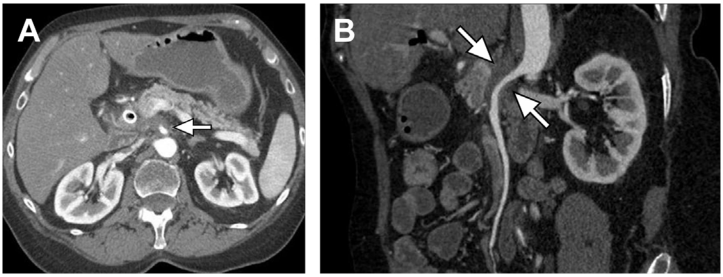

Fig. 8. Superior mesenteric artery (SMA) tumor contact. (*A*) Axial contrast-enhanced multidetector computed tomography (MDCT) image through the pancreatic head demonstrate an ill-defined mass surrounding the SMA (*arrow*) surrounding more than 180° of the vessel circumference. (*B*) Curved reformatted image through the SMA displays the entire length of the vessel and confirms the circumferential contact between the tumor and the vessel (*arrows*) and the mild narrowing in the vessel caliber.

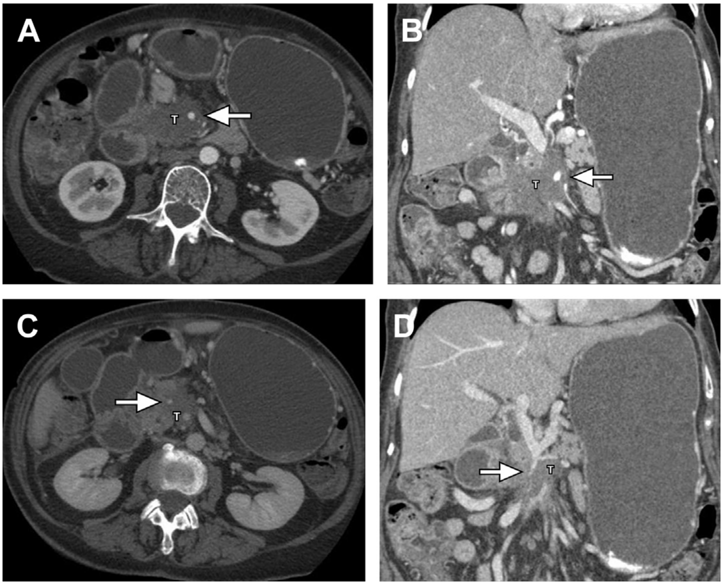

Fig. 9. Unresectable pancreatic head adenocarcinoma. (*A*) Axial and (*B*) coronal contrast-enhanced multidetector computed tomography (MDCT) images in the pancreatic phase through the pancreatic head demonstrate an ill-defined hypodense mass arising from the pancreatic head (T) consistent with pancreatic adenocarcinoma. There is circumferential tumor contact with the adjacent superior mesenteric artery (SMA) (*arrow* in A), which can be seen on both views. There is tumor involvement of the jejunal branches of the SMA (*arrow* in image *B*). (*C*) Axial and (*D*) coronal contrast-enhanced MDCT images in the portal venous demonstrate the circumferential contact of the tumor (T) with the superior mesenteric vein (*arrow*). The coronal view better displays the level of SMV involvement and level of occlusion.

Distant Metastasis

Frequent sites of the metastasis from PDA include peripancreatic lymph nodes, liver, peritoneal cavity and lung. Typically metastatic lesions to the liver seem to be hypodense on MDCT and may demonstrate a targetlike appearance (**Fig. 11**). Metastatic disease can develop in a relatively short time interval and therefore repeat imaging before surgery should be considered if there is a significant interval since the initial staging (**Fig. 12**). Small subcentimeter lesions detected on CT examination are often too small to characterize by CT examination and cannot be characterized accurately as cystic or benign and would be therefore considered indeterminate. These lesions can be further evaluated with MRI examination and/or biopsy for definite characterization and to confirm or exclude metastasis.

For lymph node assessment, generally enlarged lymph nodes measuring more than 1 cm in short axis diameter and with the presence of central necrosis are highly suggestive of metastatic involvement. Regional lymph node involvement at the site of the tumor are not a contraindication to surgery because these lymph nodes can be resected with the primary tumor; however, nonregional lymph node involvement (ie, retroperitoneal lymph nodes) would be considered as metastatic disease and would exclude the patient from curative intent (**Fig. 13**). In the postoperative setting,

Table 1
Criteria for classification of tumors resectability status

Resectability Stage	Arterial Contact	Venous Contact
Resectable	No arterial tumor contact present	No tumor contact of the SMV or PV or solid tumor contact of $\leq$180° without vein irregularity
Borderline	• Pancreatic head: ◦ Solid tumor contact with CHA without extension to celiac axis or hepatic artery bifurcation allowing for safe and complete resection and reconstruction ◦ Solid tumor contact with the SMA of $\leq$180° ◦ Presence of variant arterial anatomy with tumor contact (eg, accessory RHA, replaced RHA, replaced CHA and the origin of replaced or accessory artery) • Pancreatic body/tail: ◦ Solid tumor contact with the CA of $\leq$180° ◦ Solid tumor contact with the CA of >180° without involvement of the aorta and with intact and uninvolved GDA	• Solid tumor contact >180° with the SMV or PV • Solid tumor contact $\leq$180° with contour irregularity of the vein and or thrombosis but with suitable vessel proximal and distal to the site of involvement allowing for safe and complete resection and vein replacement • Solid tumor contact with the IVC
Unresectable	Distant metastasis (including nonregional lymph node metastasis) • Pancreatic head: ◦ Solid tumor contact with SMA >180° ◦ Solid tumor contact with the CA >180° ◦ Solid tumor contact with the first SMA branch • Pancreatic body/tail: ◦ Solid tumor contact of >180° with the SMA or CA ◦ Solid tumor contact with the CA and aortic involvement	• Pancreatic head: ◦ Unreconstructable SMV/PV tumor involvement or occlusion (can be owing to tumor or bland thrombus) ◦ Solid tumor contact with the most proximal draining jejunal vein into SMV • Pancreatic body/tail: ◦ Unreconstructable SMV/PV tumor involvement or occlusion (can be owing to tumor or bland thrombus)

Abbreviations: CA, celiac axis; CHA, common hepatic artery; GDA, gastroduodenal artery; IVC, inferior vena cava; PV, portal vein; RHA, right hepatic artery; SMA, superior mesenteric artery; SMV, superior mesenteric vein.

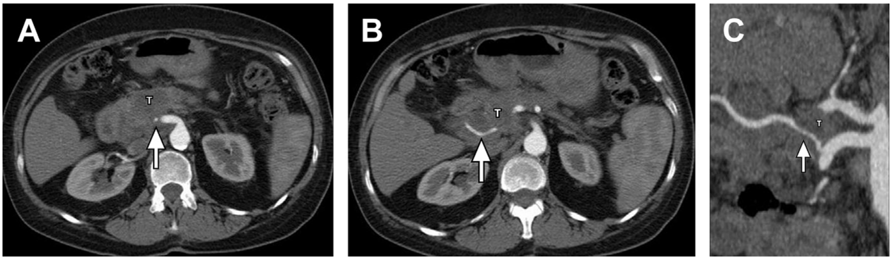

Fig. 10. Arterial variant and tumor contact. (*A*, *B*) Axial contrast-enhanced (MDCT) images through the pancreatic head demonstrate an ill-defined mass (T) consistent with pancreatic adenocarcinoma. There is a replaced right hepatic artery arising from the superior mesenteric artery (*arrow*) coursing through the tumor. (*C*) Curved reformatted image displays the replaced artery (*arrow*) contact with the adjacent tumor (T) to a better advantage and confirm vessel involvement through the demonstration of focal narrowing in the vessel caliber.

cross-sectional imaging is also helpful in evaluating for tumor recurrence locally or in the pancreatic remnant (Fig. 14).

STRUCTURED REPORTING

Using a structured report, instead of freestyle dictations, ensures an accurate, detailed, and comprehensive radiology report to optimize patient care and thus outcome.[30,31] This can be achieved through the use of reporting templates, which requires the entry of imaging findings into defined fields pertaining to all the information that is needed in the staging of tumor. An additional advantage of the structured report is facilitating the use of standardized lexicon that is mutually accepted, understood, and used by the various medical specialties involved in the care of these

Fig. 11. Metastasis from pancreatic adenocarcinoma at presentation. Axial contrast-enhanced multidetector computed tomography (MDCT) image at the level of the liver obtained at the time of diagnosis demonstrate focal mass in the pancreatic body (*arrow*) corresponding to the primary pancreatic tumor. Multiple hypodense masses with enhancing rim are present in the liver (*arrowheads*) corresponding with metastatic deposits.

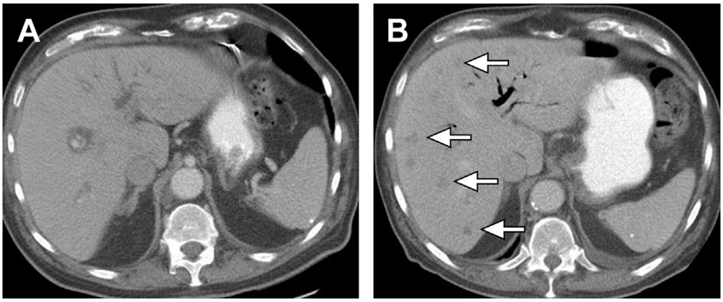

Fig. 12. Metastasis from pancreatic adenocarcinoma. (*A*) Axial contrast-enhanced multidetector computed tomography (MDCT) image at the level of the liver obtained at the time of pancreatic adenocarcinoma diagnosis (tumor not shown) demonstrates no focal hepatic lesions. (*B*) Follow-up examination after 4 weeks demonstrates multiple hypodense lesions with enhancing rim in the liver (*arrows*) corresponding with interval development of metastatic deposit.

patients. Structured reporting in patients with PDA has been shown to provide superior evaluation of the tumor and facilitate surgical planning.[32] Several professional organizations such as the Society of Abdominal Radiology, American Pancreatic Association, American College of Radiology, and Radiological Society of North America have introduced several standardized structured templates for reporting into radiology practice. One of these templates developed by the Society of Abdominal Radiology and American Pancreatic Association, which was adopted by the National Comprehensive Cancer Network, has been published recently.[33] The template includes all pertinent imaging findings including tumor characteristics (ie, size, location, biliary or pancreatic ductal dilatation, and presence of calcifications), vascular contact with the peripancreatic arteries and veins (including description of vascular variants) and whether there are pathologic lymph nodes (regional or nonregional), surrounding organ involvement or metastasis.

Fig. 13. Metastatic pancreatic adenocarcinoma to lymph nodes outside the operative field. (*A*, *B*) Axial contrast-enhanced multidetector computed tomography (MDCT) images in the portal venous phase demonstrates a hypodense lesion (T) in the pancreatic tail consistent with pancreatic adenocarcinoma. Enlarged porta hepatis and portocaval lymph nodes are seen (*arrows*). The primary pancreatic would have been classified as resectable, but the presence of the metastatic lymph nodes outside the operative field (distal pancreatectomy) changes the classification to metastatic disease.

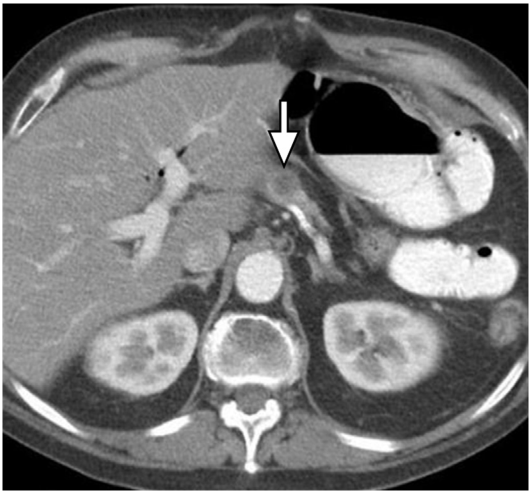

Fig. 14. Tumor recurrence after resection. Axial contrast-enhanced multidetector computed tomography (MDCT) image through the pancreatic body after a Whipple procedure and resection of previously diagnosed pancreatic adenocarcinoma in the pancreatic head demonstrate a new focal ill-defined hypodense mass (*arrow*) in the proximal remaining portion of the pancreas consistent with recurrent tumor.

SUMMARY

Cross-sectional diagnostic imaging including MDCT and MRI/MRCP play an essential role in the evaluation of patients with known or suspected periampullary masses. Both imaging modalities can accurately identify and localize the focal periampullary masses establishing the diagnosis. Moreover, these imaging modalities play a critical role in the assessment of the patient for treatment allocation based on the local staging of the tumor and excluding the presence of distant metastasis. MDCT is the most frequently obtained modality owing to widespread availability and familiarity of most radiologists with the technique and imaging findings. MRI with MRCP can be used interchangeably with CT where access and expertise is available.

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