PET/CT of Cancer Patients: Part I, Pancreatic Neoplasms

OBJECTIVE. Pancreatic cancer continues to have a poor prognosis despite impressive improvements in the outcomes of many other types of cancer, often because most pancreatic neoplasms are found to be unresectable at diagnosis. The purpose of this review is to provide an overview of pancreatic cancer and the role of modern imaging in its diagnosis and management with an emphasis on 18F-FDG PET/CT fusion imaging.

CONCLUSION. Multimodality imaging is critical in the diagnosis and management of pancreatic cancer. PET/CT is increasingly viewed as a useful, accurate, and cost-effective modality in diagnosing and managing pancreatic cancer, but further studies are warranted. Early data suggest that contrast-enhanced PET/CT performed with modern PET/CT scanners yields high-resolution anatomic information for surgical and radiotherapeutic planning and functional information for whole-body staging in the care of patients with this disease.

Pancreatic cancer is the 10th most common cancer in the United States but the fourth leading cause of cancer death [1]. Despite advances in the detection and treatment of other solid malignant tumors, pancreatic cancer continues to have a dismal prognosis—a 5-year survival rate of 6%—because the tumors are difficult to detect and are often diagnosed late in their course. The only cure is resection, but only 20% of patients present with potentially resectable lesions [2]. Even among patients with localized, resectable disease, the survival rate is only 23% [1]. Thus early detection and appropriate selection of surgical candidates are critical to the management of pancreatic cancer.

In addition to aiding selection of surgical candidates, pancreatic cancer imaging helps with characterization of incidentally found lesions, initial staging, surgical and radiotherapeutic planning, assessment of treatment response, and monitoring for disease recurrence. However, the selection of an imaging modality for diagnosing and monitoring pancreatic cancers, particularly adenocarcinoma, is not uniform. CT, transabdominal ultrasound, endoscopic ultrasound [3], ERCP, MRI, MRCP, PET, and PET/CT [4] are all used in the imaging of these cancers. PET/CT is valuable in the diagnosis, staging, therapeutic assessment, and follow-up of many solid tumors in humans [5–13]. This review is an overview of pancreatic neoplasms and of the role of modern imaging in the diagnosis and management of pancreatic cancer with a focus on PET/CT.

Pancreatic Neoplasm Overview

Classification

The major pancreatic neoplasms and their key features are summarized in Table 1. Most pancreatic neoplasms are exocrine, 85% being invasive ductal adenocarcinoma [14]. Pancreatic neuroendocrine tumors, formerly called islet cell tumors, constitute 3–4% of pancreatic neoplasms [14] and are typically benign. Fewer than 2% of malignant pancreatic neoplasms originate from endocrine cells [15]. The other neoplasms are exocrine acinar cell neoplasms, pancreatic cystic neoplasms, and neoplasms of epithelial origin and of mixed differentiation.

Presentation

Pancreatic cancer is often asymptomatic in the early stages. Patients may present with obstructive jaundice, weight loss, abdominal or midback pain, or a combination of these symptoms [16]. Glucose intolerance also can be a sign of pancreatic cancer [17]. Less common presenting symptoms of obstruction include pancreatitis and gastric outlet obstruction [16]. Asymptomatic cancer can be detected incidentally.
on abdominal scans obtained for other reasons. CT scans may depict pancreatic neoplasms several months before symptoms become manifest [18]. Increasing use of imaging has led to increased detection of pancreatic abnormalities, and approximately one third of pancreatic incidentalomas turn out to be malignant [19, 20] (Fig. 1).

Several rare paraneoplastic syndromes associated with pancreatic cancer have been documented. Trouseau syndrome is a well-established paraneoplastic syndrome associated with pancreatic adenocarcinoma that is traditionally defined as migratory thrombophlebitis but has more recently been broadened to include other coagulopathies [21–23]. Pancreatic panniculitis, or subcutaneous areas of nodular fat necrosis, is also associated with pancreatic cancer. Eighty percent of cases of panniculitis related to pancreatic cancer are associated with acinar cell carcinoma. Panniculitis usually involves the lower extremities but also occurs in the buttocks, trunk, and arms [24]. Other interesting paraneoplastic or paraneoplastic-like presenting signs of pancreatic cancer documented at least once include lower leg fasciitis associated with panniculitis [25], eczematous dermatitis [26], fibrous cutaneous hand changes [27], and plantar keratoderma [28].

Pancreatic neuroendocrine tumors present most commonly with abdominal pain; fewer than one half of cases present with endocrine disturbances [29]. Actively secreting neuroendocrine tumors that do cause endocrine disturbances include gastrinoma, which can cause Zollinger-Ellison syndrome; insulinoma, which can cause hypoglycemia; glucagonoma, which can cause diabetes mellitus and is also associated with necrotic migratory erythema; vasoactive intestinal polypeptide tumor (VIPoma), which can cause watery diarrhea and its associated complications; and somatostatinoma, which is associated with an elevated blood glucose concentration and diarrhea [30]. There are case reports of corticotropin-secreting pancreatic neuroendocrine tumors causing Cushin
ging syndrome [31, 32]. More than one half of all neuroendocrine tumors are carcinoid neoplasms [33], but these neoplasms are very rare in the pancreas [34]. The syndrome they cause is notable for diarrhea and flushing [34]. Hypercalcemia related to parathyroid hormone–related peptide (PTHrP) has been reported in a PTHrP-producing neuroendocrine tumor [35], among other extremely rare pancreatic neuroendocrine tumors.

**PET/CT of Pancreatic Neoplasms**

### Role of Multimodality Imaging in Initial Management

The major goals of imaging in the initial management of pancreatic neoplasms are to characterize incidentally found lesions, assist with staging of pancreatic cancer, and assist with surgical and radiotherapeutic planning. CT is the best-validated and most widely available modality for diagnosis and initial management, but MRI, MRCP, transabdominal ultrasound, endoscopic ultrasound, ERCP, PET, and PET/CT have all been used (Table 2). The National Comprehensive Cancer Network (NCCN) provides guidelines for the imaging of pancreatic adenocarcinoma in which CT or MRI is recommended for evaluation of patients in whom pancreatic cancer or ductal dilation is clinically suspected [36]. The NCCN similarly recommends multiphase CT or MRI to evaluate suspected pancreatic neuroendocrine tumors [37]. The American College of Radiology appropriateness criteria for selecting imaging studies are guidelines for imaging of patients with painless jaundice and palpable abdominal masses, again with CT as the most appropriate modality [38, 39]. In numerous studies in recent years, investigators have defined and compared the accuracy of various imaging modalities and techniques and elucidated areas where imaging data are inadequate. This section summarizes current imaging modalities in the initial management of pancreatic neoplasms with a focus on techniques not discussed in detail in the aforementioned established guidelines.

### Triple-Phase Pancreatic PET/CT Protocol

The triple-phase enhanced pancreatic PET/CT protocol (Fig. 2) is performed at our institution. The patient is given an injection of 10 mCi 18F-FDG and waits 60 minutes. Thirty minutes after injection of FDG, the patient drinks 450 mL of oral contrast barium preparation (Volumen, E-Z-EM). The patient is scanned from skull base to mid thigh according to a routine PET/CT protocol with low-dose attenuation-correction CT. CT is then performed in three phases with diagnostic parameters and contrast administration. The first, unenhanced, phase is a deep-inspiration scan of the lower chest and abdomen with the following parameters: 120 kV; automatic tube current, 150–440 mA; slice thickness, 1.25 mm; pitch, 1.375. The second, arterial, phase is a scan of the same area 45 seconds after IV injection of 70 mL of ioversol (Op
tiray, Mallinckrodt Imaging). The third, ve

### Differentiating Benign From Malignant Disease

Multimodality imaging can help characterize lesions as benign or malignant before or, in some benign cases, without tissue diagnosis. The pancreatic CT protocol for evaluation of suspected pancreatic cancer at our institution includes thin-slice MDCT in the unenhanced, arterial, and venous phases (Fig. 2). MRI is an acceptable alternative when patients cannot undergo CT. ERCP, endoscopic ultrasound, and MRCP are useful as adjunct modalities and when CT or MRI reveals ductal stricture but no tumor [36]. The NCCN does not provide specific recommendations regarding PET/CT, except to state that at this time PET/CT is not a substitute for high-quality contrast-enhanced CT because its role is still being established [36]. Although the technology exists for combining diagnostic-quality CT scans and PET images, imaging protocols are still being standardized [4].

One of the earliest uses of pancreatic PET was to differentiate chronic pancreatitis from pancreatic cancer; diffuse versus focal uptake is the differentiating characteristic in this clinical scenario [40] (Figs. 3 and 4). An early tabulated summary of FDG PET literature [41] showed a 50% change in management effect based on 26 patient studies of the use of PET for the diagnosis of pancreatic cancer in all scenarios with a weighted average sensitivity and specificity of 94% and 90% compared with 82% and 75% for CT at that time. In an early use of fusion PET/CT, Lemke et al. [42] found that fusing triple-phase MDCT with PET images improved the sensitivity of differentiating benign and malignant lesions without a significant change in specificity. PET/CT and MRI can be helpful in detecting pancreatic adenocarcinoma in patients with visually isoattenuating lesions at CT [43]. Pancreatic cancer can be differentiated from autoimmune pancreatitis with PET/CT [44, 45], potentially sparing patients unnecessary surgery. Significantly different standardized uptake values at PET/CT have been reported in malignant intraductal papillary mucinous neoplasms compared with benign lesions [46].

In a meta-analysis of 51 studies [47], PET, PET/CT, and endoscopic ultrasound were compared for usefulness in the diagnosis of all pancreatic carcinomas. The investigators found
By differentiating contrast-enhanced and unenhanced PET/CT, the most recent study [51] showed a problem in summarizing the PET/CT literature: Many study reports are unclear about whether contrast material was used uniformly or at all. Contrast-enhanced imaging is expected to improve the CT component of PET/CT, resulting in superior images; however, use of contrast enhancement requires additional expertise by technical staff and by scan readers (Figs. 5–8).

MRI is an accepted modality for imaging of patients with suspected pancreatic cancer, and MRCP is accurate in the diagnosis of biliary stones and strictures. Like ERCP, MRCP is especially useful when a mass is not seen with other imaging modalities but ductal stricture is suspected or known. As a sole technique for diagnosing pancreatic malignancy, MRCP is similar to ERCP with only 84% sensitivity and 94% specificity, according to a 2003 meta-analysis [52]. In a relatively new use, diffusion-weighted MRI (DWI) has been studied as an additional technique to help differentiate benign from malignant disease. Muhi et al. [53] reported that DWI had sensitivity and specificity of 96.2 and 98.6 in the detection of pancreatic carcinoma by three blinded radiologists. Autoimmune pancreatitis can be differentiated from pancreatic cancer with DWI [45], and significant differences in the apparent diffusion coefficients of chronic pancreatitis and pancreatic carcinoma have been found [54].

Cystic Lesions

Incidentally found cystic lesions of the pancreas are a common clinical problem and present a particular challenge in differentiating benign from malignant disease. These cysts are found on approximately 2.3% of CT studies and as many as 19% of MRI studies [55]. Gastroenterology societies, pancreatology groups, and radiology groups all publish guidelines for the management of pancreatic cysts [56–58]. Despite the American College of Radiology consensus publication [58] on the management of incidentally found asymptomatic pancreatic cysts, there remains considerable variability in radiologists’ recommendations for follow-up imaging [59, 60]. This difference may be due in part to the availability of and experience with various imaging modalities not included in the American College of Radiology guidelines. In addition, fewer studies have validated their use, although these alternative imaging modalities and techniques may eventually limit the need for the serial follow-up imaging that is currently recommended [61].
Certain characteristics of cystic lesions help distinguish them as benign versus malignant, such as mural nodules, mural irregularity, peripheral calcifications, and surrounding soft-tissue nonuniformity relative to the rest of the pancreas. PET/CT has been found comparable or superior to PET or CT alone in determining the presence of malignancy in cystic pancreatic lesions [62] (Fig. 9). In one study [63], PET/CT findings led to modification of the initial management strategy for one of five patients with cystic pancreatic neoplasms. False-positive findings, however, have been problematic in the imaging of cystic tumors [64]. DWI also has been used to help characterize cystic lesions of the pancreas. Wang et al. [65] found it difficult to differentiate inflammatory and neoplastic lesions (both solid and cystic) because of an overlap in apparent diffusion coefficients. In contrast, Takakura et al. [66] reported no significant difference in cancer detection between DWI and the recommended MDCT (84% versus 86%) and noted that MRI with MRCP and DWI allows characterization with a single modality without contrast administration.

Staging and Surgical Planning
CT, MRI, PET, PET/CT, and laparoscopic and open surgery have all been used for staging pancreatic cancer. CT is the best-validated modality and has been the reference standard for assessing locoregional and nodal tumor involvement at or after diagnosis. The pancreatic CT protocol of triphasic cross-sectional imaging and use of thin slices allows assessment of resectability and visualization of important vessels and anatomic relationships (Fig. 10). MRI is an acceptable alternative when patients cannot undergo CT, but it should not be considered an alternative to MDCT, when MDCT is possible, according to NCCN guidelines [36]. A 2009 study [67] comparing gadolinium-enhanced 3D gradient-echo MRCP and MDCT showed similar utility of the two methods in determining resectability.

In terms of the utility of PET, a 2001 analysis of 33 early PET studies [41] showed a combined 36% change in management effect when PET was used for initial staging. Contrast-enhanced PET/CT combines metabolic and anatomic information, and the findings can alter management strategy through prevention of unnecessary laparotomy. In a 2008 study [68], contrast-enhanced PET/CT was significantly superior to PET alone for the preoperative assessment of cancer resectability. PET and PET/CT both had sensitivities of 100%, but PET alone had a specificity of 44%, whereas PET/CT had 56% specificity. Contrast-enhanced PET/CT was superior to unenhanced PET/CT with a sensitivity of 96% and a specificity of 82%. A small number of patients still had unresectable tumors that were missed with all imaging methods and were diagnosed intraoperatively. In a 2009 study [50], the investigators compared PET/CT, MDCT, and MRI/MRCP and found that PET/CT had higher diagnostic accuracy than other methods, was more sensitive in the diagnosis of primary pancreatic malignancy and metastasis, and had findings that changed the management strategy in 10 of 38 cases. However, PET/CT was less sensitive than the other imaging modalities in the diagnosis of lymph node involvement.

Value of FDG PET/CT in the Planning of Radiotherapy for Pancreatic Cancer
Resection is the only curative treatment of pancreatic cancer, and optimal adjuvant and neoadjuvant radiotherapeutic approaches remain controversial [69–72]. Patients with lesions deemed borderline resectable may be able to undergo resection after chemotherapy, radiotherapy, or both [73]. PET/CT has been suggested as potentially useful in delineating the gross tumor volume for radiotherapeutic planning (Fig. 11). Accurately defining gross tumor volume is critical given the risk to normal surrounding tissue (kidney, small bowel, liver, spinal cord, and stomach) during radiotherapy and the potential for missing the tumor in a conformal radiation field. Ford et al. [64] reviewed the role of PET/CT in radiotherapeutic planning and noted improved delineation of tumor margins compared with that achieved with CT alone. Similarly, a single-institution study of CT versus PET/CT in the care of 14 patients undergoing radiation planning for unresectable disease showed that the addition of PET resulted in an average 30% increase in gross tumor volume in five patients owing to the incorporation of additional lymph node metastatic lesions and extension of the primary tumor beyond the volume defined with CT [74]. Although radiotherapy may improve local control and resectability rates for pancreatic cancer and PET/CT has been suggested to be useful in conformal treatment planning, improvements in overall survival with optimized radiation therapy remain to be determined.

Value of FDG PET/CT in Prognosis and Management Strategy
PET and PET/CT findings may play a role in prognosis, assessment of treatment response, and monitoring for cancer recurrence. Schellenberg et al. [75] found that for locally advanced unresectable pancreatic neoplasms, standardized uptake values from pretreatment PET/CT scans were prognostic of overall and progression-free survival even with control for age, presenting CA19-9 result, and single versus combination chemotherapy. Early PET studies showed that PET findings are predictive of histologic response after treatment of pancreatic cancer and that PET shows a decrease in metabolism after intraoperative radiotherapy for unresectable pancreatic cancer earlier than CT does. Thus the tumor response can be evaluated earlier and more accurately with PET than with CT [76–79]. PET may also be more accurate than CT in evaluating treatment response and prognosis [80]. Kuwatani et al.

### TABLE 2: Advantages and Limitations of Pancreatic Cancer Imaging Techniques

<table>
<thead>
<tr>
<th>Modality</th>
<th>Advantages</th>
<th>Limitations</th>
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<tr>
<td>MRI</td>
<td>Depiction of evidence of local extrapancreatic disease</td>
<td>Contraindicated with some metal implants and fragments</td>
</tr>
<tr>
<td>MRCP</td>
<td>Useful for evaluating biliary obstruction</td>
<td>Contraindicated with some metal implants and fragments</td>
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<tr>
<td>CT</td>
<td>Widely available</td>
<td>High cost</td>
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<tr>
<td>PET/CT</td>
<td>Depicts evidence of metastatic disease, Clarification of equivocal CT findings</td>
<td>Radiation and contrast exposure, High cost</td>
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found that PET before and after chemotherapy could be used to estimate chemotherapeutic effect and predict survival. A 2011 review of the role of FDG PET/CT in imaging of recurrent pancreatic carcinoma [82] showed that PET/CT improves evaluation of cancer recurrence in general and that, in particular, it improves evaluation of patients with elevated concentrations of tumor markers (CA19-9) and those with normal or equivocal CT findings (Fig. 12).

Cost-Effectiveness of FDG PET/CT in the Management of Pancreatic Cancer

Cost-effectiveness is a critical factor in determining the optimal imaging modality. In 2006, the most cost-effective and accurate means for diagnosing and staging pancreatic cancer were CT and endoscopic ultrasound [2]. This finding was based on the high cost of MRI, the limited available data on contrast-enhanced PET/CT, and the lack of evidence of the superiority of these modalities to the less expensive CT and endoscopic ultrasound. More recently, however, PET/CT has been recognized as a possible cost-saving imaging modality. Findings at PET and PET/CT for many indications, not only for pancreatic cancer, have been found to change management strategy [83], and although PET/CT has a high initial cost, it has the potential to reduce total imaging costs owing to its superior depiction of distant metastatic lesions, preventing surgery and reducing cancer imaging costs in aggregate.

Heinrich et al. [48] have been one of only a few groups of investigators to examine the cost-effectiveness of PET/CT. They found that for imaging pancreatic adenocarcinoma, PET/CT was more sensitive than conventional CT for detecting distant metastasis and that the findings changed the management plans for 16% of patients with lesions deemed resectable after conventional staging. The cost-benefit analysis included the price of PET/CT, the radiotracer, fine-needle aspiration biopsy, cytologic analysis, ultrasound, CT, thoracoscopic, and pancreatic resection, including physician fees and postoperative stay (based on costs at the authors’ institution for a 15-day postoperative stay based on range of 10–40 days). PET/CT was reported to save an average of $62,912 for all 59 patients included in the study, or $1066 per patient. The authors further determined that limiting PET/CT to patients with lesions deemed resectable at conventional imaging would save $2844 per patient, that limiting the postoperative hospital stay to 10 days led to a savings of $430 per patient, and that using CT-guided fine-needle aspiration rather than ultrasound-guided fine-needle aspiration to confirm each distant metastatic site would still save $341 per patient. The study methods have been criticized, especially with regard to the anatomic field of CT and a lack of preresection laparoscopic exploration cost analysis [84], but the cost analysis was based on an actual standard staging protocol and resultant procedures, not theoretic scenarios, as the authors noted in a reply [85]. In a systematic review of the cost-effectiveness of the use of PET and PET/CT for all diagnoses compared with other imaging techniques and interventions, Langer [86], concurred that PET may be cost-effective and that PET/CT may be more cost-effective than PET, although only four studies analyzing the cost-effectiveness of PET/CT have been published. Future large prospective studies are still warranted, especially with contrast-enhanced PET/CT.

An example of the cost-effectiveness of PET/CT occurred at our institution in 2011. A 59-year-old woman was treated for pancreatic adenocarcinoma. PET/CT found incidentally on a CT scan. Posttreatment PET/CT (Figs. 12A and 12B) showed mild FDG uptake in the soft tissue adjacent to the left kidney that was suspicious for metastatic disease. Two follow-up CT examinations were performed to monitor the lesion and to detect recurrence of disease, but the findings were equivocal. Follow-up PET/CT several months later (Figs. 12C–12G) confirmed the presence of an enlarging perinephric metastatic lesion and new liver lesions. The disease progression in this patient likely would have been confirmed earlier with PET/CT, and the patient would have been saved the expense of two noncontributory interval CT scans.

Conclusion

Numerous imaging modalities are used for the diagnosis and management of pancreatic cancer. The best-validated uses of PET and PET/CT are initial staging and treatment planning. Given the poor prognosis and limited treatment options for pancreatic cancer, the greatest potential benefit is gained during this time frame. Data on the usefulness of PET and PET/CT in surgical and radiotherapeutic planning, for monitoring for treatment response and recurrent disease, and on cost-effectiveness are somewhat more limited and require further study. Multimodality imaging is critical in the diagnosis and management of pancreatic cancer. As the spatial resolution of PET/CT continues to improve with the development of 16- and 64-MDCT PET/CT systems and the increasing use of contrast material, contrast-enhanced PET/CT may become the imaging test of choice in the management of pancreatic cancer, and as such continued prospective evaluation is warranted.

References


Table 3: Prospective Studies of PET/CT in the Diagnosis of Pancreatic Cancer

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<tr>
<th>Author</th>
<th>Year</th>
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<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
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<td>55.6</td>
<td>87.9</td>
<td>55.6</td>
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PET/CT of Pancreatic Neoplasms


Fig. 1—77-year-old man with incidental finding of pancreatic lesion at routine 2-year imaging follow-up of laryngeal cancer. A and B, Coronal maximum-intensity-projection (A) and axial (B) PET images show increased uptake in area of pancreas (arrow, B). C and D, Axial CT (C) and corresponding PET/CT (D) images show 2-cm poorly marginated low-attenuation mass at junction of body and tail of pancreas with moderate FDG uptake (arrow, D). Distal pancreas and spleen resection yielded pancreatic ductal carcinoma and multiple negative peripancreatic lymph nodes.
Fig. 2—55-year-old man with pancreatic adenocarcinoma. A–F, Unenhanced (A), arterial (C), and venous (E) phase CT images and corresponding fused FDG PET/CT (B, D, and F) images show appearance during triple-phase contrast-enhanced pancreatic PET/CT protocol.
PET/CT of Pancreatic Neoplasms

Fig. 3—67-year-old man with jaundice and vague abdominal pain due to autoimmune pancreatitis. ERCP revealed diffuse irregular narrowing of main pancreatic duct. 

A and B, Coronal maximum-intensity-projection (A) and axial PET (B) images show moderate diffuse increased FDG accumulation in pancreas (percutaneous drainage tube is present in common bile duct and passes to outside drainage bag).

C, Axial CT image shows diffusely enlarged pancreas and mild prominence in pancreatic head with distinct mass formation.

D, Fused axial PET/CT image shows relatively homogeneous increased activity throughout pancreas (maximum standardized uptake value, 5.1). Serum assays revealed elevated antinuclear antibody, rheumatoid factor, and antilactoferrin antibody levels. Treatment with corticosteroids produced prompt remission.
Fig. 4—62-year-old man undergoing chemotherapy for metastatic lung cancer with idiopathic pancreatitis causing severe upper abdominal pain that radiates to back. ERCP showed diffuse irregular narrowing of main pancreatic duct without site of obstruction. Metastatic nodes were present adjacent to pancreatic head. A and B, Coronal maximum-intensity-projection (A) and axial PET (B) images show moderate diffuse increased FDG accumulation in pancreas. C, Axial CT scan shows diffusely enlarged pancreas. D, Axial fused PET/CT scan shows moderate diffuse increased FDG accumulation and enlarged pancreas. Symptoms resolved with supportive treatment.
PET/CT of Pancreatic Neoplasms

Fig. 5—52-year-old woman with hypoglycemic episodes and increasing back pain and history glucagon-secreting pancreatic neuroendocrine tumor treated with resection of primary tumor and left hepatic lobe.

A–C, Coronal maximum-intensity-projection (A), axial PET (B), and fused axial PET/CT (C) images show 2.5-cm mass in head of pancreas with mild FDG uptake (arrow, C).

D, Axial CT scan shows hypoenhancing pancreatic head lesion.

E, T1-weighted fat-suppressed MR image shows lesion.

F, Octreotide SPECT/CT scan shows intense 111In-octreotide accumulation in pancreatic head mass (arrow).

Fig. 6—64-year-old woman with pancreatic adenocarcinoma, acholic stools, and jaundice.
A, T2-weighted selective partial inversion recovery MR image shows pancreatic head mass (arrow) with obstruction.
B, Axial contrast-enhanced CT image shows heterogeneously enhancing necrotic solid mass (arrow) in pancreatic head.
C, Axial contrast-enhanced fused PET/CT image shows intense hypermetabolic activity (arrow) corresponding to mass in B.

Fig. 7—72-year-old man with pancreatic lymphoma, epigastric discomfort, and fatigue. Upper gastrointestinal endoscopic findings were normal.
A–C, Coronal maximum-intensity-projection (A) and axial PET (B and C) images show intense FDG uptake in pancreas.
D and E, Axial CT images show 2.5-cm hypoenhancing pancreatic mass (arrow, D) and spleen for PET/CT comparison.
F and G, Axial fused PET/CT images show 2.5-cm uncinate mass with intense FDG uptake (maximum standardized uptake value, 8.9) and moderate diffuse activity in spleen (arrow, G) that suggested lymphoma. Fine-needle aspiration of pancreatic mass and bone marrow biopsy yielded follicular non-Hodgkin lymphoma.
Fig. 8—70-year-old man with history of hairy cell leukemia initially diagnosed 4 years earlier and treated with splenectomy and chemotherapy. Follow-up CT showed 3.2 × 2.7 cm mass in body of pancreas. A, Coronal maximum-intensity-projection image shows moderate diffuse activity in bone marrow of axial and proximal appendicular skeleton. B, Axial PET image shows increased uptake in pancreatic head (arrow). C and D, Axial CT (C) and corresponding PET/CT (D) images show 3.2-cm mass (arrow, D) in head of pancreas with moderate FDG uptake (maximum standardized uptake value, 5.0). Pancreatic mass and bone marrow biopsies confirmed diagnosis of recurrent hairy cell leukemia.
Fig. 9—46-year-old man with abdominal pain due to pancreatic adenocarcinoma. A–D, Coronal maximum-intensity-projection (A), coronal contrast-enhanced fused PET/CT (B), and axial contrast-enhanced fused PET/CT (C and D) images show hypermetabolic activity and mass (arrow, C and D) in head and neck of pancreas without evidence of metastatic disease. Biliary stent is in place. E and F, Axial contrast-enhanced CT images show cystic lesion (arrow, F). Cystic areas are likely pseudocysts.

Fig. 10—58-year-old man with 6 weeks of painless jaundice; ultrasound showed pancreatic abnormality. A and B, Coronal arterial (A) and venous (B) phase CT images show heterogeneously enhancing mass (blue arrow, A) in head of pancreas encasing hepatic artery and dilatation of common bile (yellow arrow, A) and pancreatic (red arrow, A) ducts.

Fig. 11—62-year-old man with known inoperable T2N0M0 adenocarcinoma of the pancreas undergoing staging scanning for radiotherapeutic planning. A, Axial CT image shows head of pancreas with indwelling stent. B, Same axial slice as A fused with FDG PET scan obtained for staging. PET enables radiation oncologist to more easily discern gross tumor volume (inner outline), for which 50 Gy in 25 daily fractions is prescribed, whereas clinical target volume (outer outline) encompassing locoregional nodal basins receives 45 Gy in 25 fractions through dose painted intensity-modulated technique.
PET/CT of Pancreatic Neoplasms

Fig. 12—59-year-old woman with history of pancreatic adenocarcinoma found incidentally on CT scan.

A and B, Contrast-enhanced axial CT (A) and contrast-enhanced axial fused PET/CT (B) images obtained immediately after therapy show mild FDG uptake in soft tissue adjacent to left kidney (arrow, B) that was suspicious for metastatic disease.

C–G, Follow-up coronal maximum-intensity-projection (C), axial contrast-enhanced CT (D and E), and axial contrast-enhanced fused PET/CT images (F and G) scans obtained several months after A and B confirm presence of enlarging perinephric metastatic lesion and new liver lesion (arrows, F and G). Two interval CT scans between the PET/CT scans were noncontributory.

FOR YOUR INFORMATION

This article is part of a self-assessment module (SAM). Please also refer to “PET/CT of Cancer Patients: Part 2, Deformable Registration Imaging Before and After Chemotherapy for Radiation Treatment Planning in Head and Neck Cancer,” which can be found on page 968.

Each SAM is composed of two journal articles along with questions, solutions, and references, which can be found online. You can access the two articles at www.ajronline.org, and the questions and solutions that comprise the Self-Assessment Module by logging on to www.arrs.org, clicking on AJR (in the blue Publications box), clicking on the article name, and adding the article to the cart and proceeding through the checkout process.

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