Cancer Imaging (2010) **10,** S137–S141
DOI: 10.1102/1470-7330.2010.9028

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Staging cancer of the pancreas

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Abstract

Pancreatic carcinoma is the fourth cause of death from cancer in the United States, with a survival rate at 5 years of less than 5%. About 60% of tumors originate at the head of the pancreas, 15% in the body, 5% in the tail; 20% are diffuse within the pancreas. This article discusses the imaging and staging of pancreatic cancer.

Keywords: *Staging; pancreatic cancer.*

Introduction

Pancreatic carcinoma is the fourth cause of death from cancer in the United States, with a survival rate at 5 years of less than 5%[1,2]. About 60% of tumors originate at the head of the pancreas, 15% in the body, 5% in the tail; 20% are diffuse within the pancreas[3]. At the time of diagnosis tumors located in the head are usually smaller (2.5–3 cm) compared with those in the body and tail (5–7 cm), as a result of earlier clinical manifestation because of the close contiguity with the choledochus. Imaging of pancreatic carcinoma has a leading role in assessing the best options for the treatment of pancreatic carcinoma.

Surgical resection is the only curative treatment of pancreatic carcinoma. Unfortunately, at surgical exploration only 5–30% of tumors are amenable to resection[4,5]. Even in expert hands, Whipple's procedure has a mortality of up to 4% and exploratory laparatomy has a morbidity up to 25%[6]. Therefore, the principle goal of preoperative staging is identify all resectable disease to avoid surgical exploration in those patients with unresectable disease.

Multislice computed tomography (MSCT) is the most commonly used technique for staging pancreatic cancer. MSCT has high accuracy with highly accurate isotropic voxel values, which permits multiplanar reconstruction and improves the capacity of the imaging technique to evaluate the relationship between the tumor and the surrounding structures and organs.

Magnetic resonance imaging (MRI) has a leading role in the imaging of the pancreas because of the most recent technical innovations with breath-hold T1- and T2-weighted images and respiratory triggered T2-weighted images, as well as dynamic imaging after injection of contrast material and the use of secretin, allowing greater capacity for non-invasive exploration of the pancreatic ducts and pancreatic parenchyma, and imaging of the pancreatic vessels. With state-of-the-art magnetic resonance equipment, a complete study of a pancreatic lesion can be conducted in about 30–40 min.

[^{18}F]Fluorodeoxyglucose (FDG)-positron emission tomography (PET), especially combined with computed tomography (CT), has an established role in differentiating benign from malignant lesions and in the staging and treatment planning of various tumors. The increased glucose metabolism of most malignant lesions results in significant uptake of FDG in primary malignant tumors and metastases that does not occur in healthy tissues and benign lesions after i.v. injection, allowing a higher conspicuity compared with that of the surrounding tissue[7,8].

Imaging of pancreatic carcinoma

The gross pathologic features of pancreatic carcinoma are represented by a mass with irregular ill-defined contours and a significant fibrous component, and less frequently necrotic changes. Lack of capsule is responsible for early spread of the lesion to the surrounding structures, with special regard to vascular and neural infiltration.

On dynamic imaging after injection of contrast agent, either with CT or MR, the presence of an abundant

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fibrous stroma within the tumor makes the tumor hypovascular, thus appearing hypodense/hypointense to the surrounding parenchyma, but it can be responsible for a delayed enhancement with secondary isointensity of the lesion[9]. Isointensity of the tumor to the surrounding parenchyma as well as coexisting or secondary chronic pancreatitis upstream can make the identification of the tumor as well as differential diagnosis with chronic pancreatitis difficult[10,11]. Some authors suggest that a time–intensity curve of the lesion is useful for the differential diagnosis between pancreatic carcinoma and mass-forming pancreatitis[12]. Hata *et al.*[13] have correlated the enhancement pattern on CT with the vessel density and the amount of fibrous stroma; the results of their study suggest a direct correlation between vessel density and fibrous content and the amount of enhancement. The same results were obtained by Johnson and Outwater[14] with MRI.

Because normal pancreas has low glucose utilization, the foci of abnormal FDG uptake can be easily visualized as focal areas of increased activity.

Several authors have reported values for the sensitivity and specificity of FDG-PET in identification of pancreatic malignant lesions that vary in the different studies from 71% to 100% and from 64% to 99%, respectively[15,16]. A tabulated review of published data by Gambhir *et al.*[17] demonstrated that in the 387 patients studied, the weighted average sensitivity and specificity of FDG-PET was 94% and 90% compared with 82% and 75% for CT, respectively. Furthermore, false-negative cases were described because of well-differentiated tumors, small periampullary cancers or in cases of hyperglycemia. In normoglycemic subjects, PET has a sensitivity for tumor identification of 93–98%, although this value decreases to 63% or lower in hyperglycemic patients; a similar trend is found for the negative predictive value, which can decrease from 96% to 38%[17].

Staging of pancreatic carcinoma

Staging of pancreatic carcinoma is based on the TNM classification, that is, on the dimensions and extension of the primary tumor (T), presence or absence of metastatic lymph nodes (N), presence or absence of distant metastases (M)[18,19].

Based on TNM, the most commonly used classification for extension of pancreatic cancer is that of the Union Internationale Contre le Cancer[20], the American Joint Committee Classification[21] and the Japan Pancreas Society (Pancreatic Cancer Registration Committee of the Japan Pancreas Society 2003)[22,23]. According to the different T, N and M stages, pancreatic cancer is classified as locally resectable, locally unresectable and unresectable for distant metastases.

For the T parameter, recent changes in the TNM classification have extended the number of patients amenable to surgical resection, as T4 is now considered the only tumor that infiltrates either the celiac axis or the superior mesenteric artery; limited superior mesenteric vein infiltration is now considered resectable as a result of venous interposition grafts, thus downstaging the tumor to T3[24].

Contrast-enhanced techniques for both CT and MRI, combined with multiplanar reconstruction and maximal intensity projection post-processing, have improved the capability to identify and stage the extent of the tumor and extra-pancreatic involvement[25], especially vascular arterial and venous infiltration, with an accuracy for resectability of about 90% for both CT and MRI in a direct comparison[26,27].

The degree of circumferential vessel involvement by tumor as shown by CT and MRI is useful in predicting which patients will have surgically unresectable tumors. Involvement of vessel in a tumor that exceeds one-half the circumference of the vessel is highly specific for unresectable tumor[28,29], both for arteries and veins. CT and MRI with vascular reconstruction allow a higher degree of recognition than axials alone[30]. However, in a direct comparison of CT and MRI for detection and resectability of pancreatic carcinoma with two independent readers, kappa analysis of interobserver agreement showed a good correlation for CT (0.71) and a moderate correlation of both groups for MRI (0.49)[27].

A specific sign of venous involvement is a reduction in the diameter of the superior mesenteric vein (SMV), the teardrop shape of the SMV[30,31], and dilatation of SMV tributaries[32,33], especially enlargement of the posterosuperior pancreaticoduodenal vein (PDV)[34], and visualization of the inferior PDV[33]; enlargement of the gastro-colic trunk is not conclusive[35].

The location of the tumor in the pancreas determines its route of spread and the nodal groups involved. Lymph node involvement has a significant effect on the survival of patients with pancreatic cancer[36]. However, lymph node involvement in the peripancreatic area does not affect surgical planning, because lymph nodes are removed with the surgical specimen; it is more important to recognize nodal metastases in the celiac node, common hepatic artery node and paraaortic node, because metastases to these nodes preclude patients from surgery, especially for tumors at the head of the pancreas[37]. Nodal involvement in the paraaortic region does not indicate regional invasion but is a statistically independent predictor of early recurrence, and affects survival considerably[38].

The size threshold for suspicion of nodal involvement is 1 cm in the short axis; however, although with a 1-cm threshold specificity is quite good (85%), its sensitivity is very low (14%), because up to 36% of lymph nodes of 5–10 mm in the short axis have been found to have tumoral involvement, even in lymph nodes less than 5 mm[39], and lymph nodes >10 mm can also be inflammatory[40].

The presence of distant metastases precludes surgical resection and correct identification and characterization are therefore fundamental. Sixty percent of patients who present with pancreatic ductal adenocarcinoma have advanced disease[41]. The liver and peritoneum are the most common sites of distant metastases. To date, no definite decision on the best technique for the staging of abdominal metastases can be given; MRI and laparoscopy are the most commonly used techniques and give similar results[42].

MRI has the best sensitivity for liver metastases, as a result of its high contrast; both T2-weighted (especially fat saturated) and gradient recalled echo T1-weighted images (especially three-dimensional with thin slices after administration of paramagnetic contrast agent) and the use of liver-specific contrast agents have greatly improved the sensitivity of the technique.

Hepatic metastases from pancreatic carcinoma are usually multiple[43] and their size range from a few millimeters to some centimeters[44]. They appear hypointense on T1 images and moderately hyperintense on T2 images and diffusion-weighted imaging (DWI), frequently with a capsular based distribution.

DWI is a promising technique for the identification of small hepatic metastases; respiratory triggering and a *b* value of 50 give a high quality image, with a high signal-to-noise ratio and suppression of signal from vessels, thus allowing easy detection of the lesion from the nearby intrahepatic vessels. According to many authors, lesion detection with DWI is significantly higher than for T2-weighted images, with more significant results for small metastases (<10 mm)[45].

During dynamic imaging after injection of paramagnetic contrast agent, tumors usually appear hypointense with peri-lesional enhancement in more than 50% of patients[44], with either ring peri-lesional enhancement or wedge-shaped peri-lesional enhancement. Occasionally pancreatic liver metastases have been misdiagnosed as pseudolesions because they initially emerged as arterioportal shunts on dynamic CT and MR imaging. The cause of this transient enhancement related to liver metastases from pancreatic cancer is unknown. Gabata *et al.*[43] suggested that the cause of transient hepatic enhancement of liver metastases from pancreatic carcinomas may be correlated with tumor invasion of the portal tract and tumor thrombi of portal venules, which causes decreased portal flow and increased hepatic arterial blood flow. Delayed contrast enhancement of the central portion of the lesion can be observed, as a result of a desmoplastic reaction secondary to the stimulation of hepatic stellate cells[46].

Dynamic imaging after injection of paramagnetic liver-specific contrast agent (MultiHance, Bracco SpA, Milano, Italy; Primovist, Bayer Schering, Berlin, Germany) is superimposable on that obtained with conventional extravascular, extracellular gadolinium-based contrast agents; in the hepatobiliary phase the lesions do not show significant enhancement, as they are not able to uptake the contrast medium[47,48]. After administration of mangafodipir trisodium (Teslascan, GE Health) there is an increase in the liver-to-lesion contrast-to-noise ratio because of the lack of contrast uptake[49]. Metastases do not contain RES cells, thus after super paramagnetic iron oxide injection, the liver metastasis contrast-to-noise ratio is improved with increased lesion conspicuity and detection compared with non-enhanced T2-weighted images[50–52].

Poor spatial resolution of FDG-PET limits the local (T) staging of pancreatic cancer. In nodal staging (N) of disease, both FDG-PET and CT perform poorly. Report sensitivity and specificity for FDG-PET have varied between 46% and 71% and 63% and 100%, respectively[15,53–56]. One possible reason for the apparent low sensitivity of FDG-PET is the close proximity of the peripancreatic lymph node basin to the primary tumor, which can obscure their detection. The major effect of FDG-PET on staging has been in its ability to identify distant metastases (M). The liver is the commonest organ to be affected, followed by the lung and bone marrow. Direct spread into the peritoneum is also not uncommon and is often missed on conventional anatomical imaging. Diederichs *et al.*[15] in a series of 89 patients with pancreatic malignancy, showed the sensitivity and specificity of 70% and 95% for FDG-PET in detecting hepatic metastases, missing just one subcentimeter liver lesion. FDG-PET also detected occult peritoneal metastases in 25% of cases, once again missing poorly localized and microscopic spread. Frohlich *et al.*[57] who looked at the detection of liver metastases with FDG-PET in 168 preoperative patients found FDG-PET to have an overall sensitivity of 68%.

Conclusion

In daily practice MSCT is the most useful imaging technique for staging of pancreatic cancer. More sophisticated techniques, such as MRI or PET/CT can be used in cases of unequivocal findings at MSCT that suggest the lesion is border-line for resection. In particular, MRI is the best imaging technique to evaluate equivocal focal liver lesions. PET/CT is indicated in cases of suspicious distant spread of the disease.

References

[1] Sahmoun AE, D'Agostino Jr RA, Bell RA, Schwenke DC. International variation in pancreatic cancer mortality for the period 1955–1998. Eur J Epidemiol 2003; 18: 801–16. doi:10.1023/A:1025317410568.

[2] Jemal A, Siegel R, Ward E, *et al.* Cancer statistics, 2006. CA Cancer J Clin 2006; 56: 106–30. doi:10.3322/canjclin.56.2.106. PMid:16514137.

[3] Zamboni G, Capelli P, Pesci A, Beghelli S, Lüttges J, Klöppel G. Pancreatic head mass: what can be done? Classification: the pathological point of view. JOP 2000; 1(3 Suppl): 77–84.

[4] Cooperman AM, Kini S, Snady H, Bruckner H, Chamberlain RS. Current surgical therapy for carcinoma of the pancreas. J Clin Gastroenterol 2000; 31: 107–13. doi:10.1097/00004836-200009000-00004. PMid:10993424.

[5] Wray CJ, Ahmad SA, Matthews JB, Lowy AM. Surgery for pancreatic cancer: recent controversies and current practice. Gastroenterology 2005; 128: 1626–41. doi:10.1053/j.gastro.2005.03.035. PMid:15887155.

[6] Birkmeyer JD, Siewers AE, Finlayson EV, *et al.* Hospital volume and surgical mortality in the United States. N Engl J Med 2002; 346: 1128–37. doi:10.1056/NEJMsa012337. PMid:11948273.

[7] Saisho H, Yamaguchi T. Diagnostic imaging for pancreatic cancer: computed tomography, magnetic resonance imaging, and positron emission tomography. Pancreas 2004; 28: 273–8. doi:10.1097/00006676-200404000-00011. PMid:15084970.

[8] Buchs NC, Chilcott M, Poletti PA, Buhler LH, Morel P. Vascular invasion in pancreatic cancer: Imaging modalities, preoperative diagnosis and surgical management. World J Gastroenterol 2010; 16: 818–31.

[9] Miller FH, Rini NJ, Keppke AL. MRI of adenocarcinoma of the pancreas. AJR Am J Roentgenol 2006; 187: W365–74. doi:10.2214/AJR.05.0875. PMid:16985107.

[10] Birchard KR, Semelka RC, Hyslop WB, *et al.* Suspected pancreatic cancer: evaluation by dynamic gadolinium-enhanced 3D gradient-echo MRI. AJR Am J Roentgenol 2005; 185: 700–3.

[11] Zins M, Petit E, Boulay-Coletta I, Balaton A, Marty O, Berrod JL. Imaging of pancreatic adenocarcinoma. J Radiol 2005; 86: 759–79. doi:10.1016/S0221-0363(05)81443-X.

[12] Tajima Y, Kuroki T, Tsutsumi R, Isomoto I, Uetani M, Kanematsu T. Pancreatic carcinoma coexisting with chronic pancreatitis versus tumor-forming pancreatitis: diagnostic utility of the time-signal intensity curve from dynamic contrast-enhanced MR imaging. World J Gastroenterol 2007; 13: 858–65.

[13] Hata H, Mori H, Matsumoto S, *et al.* Fibrous stroma and vascularity of pancreatic carcinoma: correlation with enhancement patterns on CT. Abdominal Imaging 2010; 35: 172–80. doi:10.1007/s00261-008-9460-0. PMid:18815826.

[14] Johnson PT, Outwater EK. Pancreatic carcinoma versus chronic pancreatitis: dynamic MR imaging. Radiology 2009; 212: 213–8.

[15] Diederichs CG, Staib L, Vogel J, *et al.* Values and limitations of 18F-fluorodeoxyglucose-positron-emission tomography with preoperative evaluation of patients with pancreatic masses. Pancreas 2000; 20: 109–16. doi:10.1097/00006676-200003000-00001. PMid:10707924.

[16] Delbeke D, Pinson CW. Pancreatic tumors: role of imaging in the diagnosis, staging, and treatment. J Hepatobiliary Pancreat Surg 2004; 11: 4–10. doi:10.1007/s00534-002-0775-x. PMid: 15747028.

[17] Gambhira SS, Czernin J, Schwimmer J, *et al.* A tabulated summary of the FDG PET literature. J Nucl Med 2001; 42(Suppl 5): 1S–93S.

[18] Tamm EP, Silverman PM, Charnsangavej C, Evans DB. Diagnosis, staging, and surveillance of pancreatic cancer. Am J Roentgenol 2003; 180: 1311–23.

[19] Liu RC, Traverso LW. Diagnostic laparoscopy improves staging of pancreatic cancer deemed locally unresectable by computed tomography. Surg Endosc 2005; 19: 638–42. doi:10.1007/s00464-004-8165-x. PMid:15776215.

[20] Sobin LH, Wittekind C. International Union Against Cancer. TNM classification of malignant tumors. 6th ed. New York: Wiley-Liss; 2002.

[21] Greene FL, Page DL, Fleming ID, *et al.* Exocrine pancreas. In: Greene FL, Page DL, Fleming ID, *et al.*, editors. AJCC cancer staging manual. 6th ed. New York: Springer-Verlag; 2002, p. 157–64.

[22] Seiki M, Katsusuke S, Makoto S, Go Vay Liang W. Advancements in pancreatic cancer research in Japan and unfolding prospective. Pancreas 2004; 28: 217–8.

[23] Isaji S, Kawarada Y, Uemoto S. Classification of pancreatic cancer: comparison of Japanese and UICC classifications. Pancreas 2004; 28: 231–4. doi:10.1097/00006676-200404000-00003. PMid:15084962.

[24] Wolff RA, Chiao P, Lenzi R, *et al.* Current approaches and future strategies for pancreatic carcinoma. Invest New Drugs 2000; 18: 43–56. doi:10.1023/A:1006383831045. PMid:10830140.

[25] Brennan DD, Zamboni GA, Raptopoulos VD, Kruskal JB. Comprehensive preoperative assessment of pancreatic adenocarcinoma with 64-section volumetric CT. Radiographics 2007; 27: 1653–66. doi:10.1148/rg.276075034. PMid:18025509.

[26] Arslan A, Buanes T, Geitung JT. Pancreatic carcinoma: MR, MR angiography and dynamic helical CT in the evaluation of vascular invasion? Eur J Radiol 2001; 38: 151–9. doi:10.1016/S0720-048X(00)00280-1.

[27] Grenacher L, Klauss M, Dukic L, *et al.* Diagnosis and staging of pancreatic carcinoma: MRI versus MSCT – a prospective study. Rofo 2004; 176: 1624–33.

[28] O'Malley ME, Boland GW, Wood BJ, Fernandez-del Castillo C, Warshaw AL, Mueller PR. Adenocarcinoma of the head of the pancreas: determination of surgical unresectability with thin-section pancreatic-phase helical CT. AJR Am J Roentgenol 1999; 173: 1513–8.

[29] Lu DS, Reber HA, Krasny RM, Kadell BM, Sayre J. Local staging of pancreatic cancer: criteria for unresectability of major vessels as revealed by pancreatic-phase, thin-section helical CT. AJR Am J Roentgenol 1997; 168: 1439–43.

[30] Lepanto L, Arzoumanian Y, Gianfelice D, *et al.* Helical CT with CT angiography in assessing periampullary neoplasms: identification of vascular invasion. Radiology 2002; 222: 347–52. doi:10.1148/radiol.2222010203. PMid:11818598.

[31] Hough TJ, Raptopoulos V, Siewert B, Matthews JB. Teardrop superior mesenteric vein: CT sign for unresectable carcinoma of the pancreas. AJR Am J Roentgenol 1999; 173: 1509–12.

[32] Hommeyer SC, Freeny PC, Crabo LG. Carcinoma of the head of the pancreas: evaluation of the pancreaticoduodenal veins with dynamic CT – potential for improved accuracy in staging. Radiology 1995; 196: 233–8.

[33] Kanematsu M, Shiratori Y, Hoshi H, Kondo H, Matsuo M, Moriwaki H. Pancreas and peripancreatic vessels: effect of imaging delay on gadolinium enhancement at dynamic gradient-recalled-echo MR imaging. Radiology 2000; 215: 95–102.

[34] Mori H, Miyake H, Aikawa H, *et al.* Dilated posterior superior pancreaticoduodenal vein: recognition with CT and clinical significance in patients with pancreaticobiliary carcinomas. Radiology 1991; 181: 793–800.

[35] Yamada Y, Mori H, Kiyosue H, Matsumoto S, Hori Y, Maeda T. CT assessment of the inferior peripancreatic veins: clinical significance. AJR Am J Roentgenol 2000; 174: 677–84.

[36] Kayahara M, Nagakawa T, Ohta T, *et al.* Analysis of para-aortic lymph node involvement in pancreatic carcinoma. A significant indication for surgery? Cancer 1999; 85: 583–590. doi:10.1002/(SICI)1097-0142(19990201)85:3<583::AID-CNCR8>3.0.CO;2-J.

[37] Maithel SK, Khalili K, Dixon E, *et al.* Impact of regional lymph node evaluation in staging patients with periampullary tumors. Ann Surg Oncol 2007; 14: 202–10. doi:10.1245/s10434-006-9041-9. PMid:17080239.

[38] Sai M, Mori H, Kiyonaga M, Kosen K, Yamada Y, Matsumoto S. Peripancreatic lymphatic invasion by pancreatic carcinoma: evaluation with multi-detector row CT. Abdom Imaging 2010; 35: 154–62. doi:10.1007/s00261-008-9461-z. PMid:18972151.

[39] Roche CJ, Hughes ML, Garvey CJ, *et al.* CT and pathologic assessment of prospective nodal staging in patients with ductal adenocarcinoma of the head of the pancreas. AJR Am J Roentgenol 2003; 180: 475–80.

[40] Doi R, Kami K, Ito D, *et al.* Prognostic implication of para-aortic lymph node metastasis in resectable pancreatic cancer. World J

Surg 2007; 31: 147–54. doi:10.1007/s00268-005-0730-5. PMid: 17171496.

[41] Douglass HJ, Kim S, Meropol N.. Neoplasms of the exocrine pancreas. In: Holland J, Frei EI, Bast RJ, Kufe DW, Morton DL, Weichselbaum RR, editors. Cancer medicine. 4th ed. Baltimore, MD: Williams and Wilkins; 1997, p. 1989–2018.

[42] Schneider AR, Adamek HE, Layer G, Riemann JF, Arnold JC. Staging of abdominal metastases in pancreatic carcinoma by diagnostic laparoscopy and magnetic resonance imaging. Z Gastroenterol 2003; 41: 697–702.

[43] Gabata T, Matsui O, Terayama N, Kobayashi S, Sanada J. Imaging diagnosis of hepatic metastases of pancreatic carcinomas: significance of transient wedge-shaped contrast enhancement mimicking arterioportal shunt. Abdom Imaging 2008; 33: 437–43. doi:10.1007/s00261-007-9280-7. PMid:17610105.

[44] Danet IM, Semelka RC, Nagase LL, Woosely JT, Leonardou P, Armao D. Liver metastases from pancreatic adenocarcinoma: MR imaging characteristics. J Magn Reson Imaging 2003; 18: 181–8. doi:10.1002/jmri.10337. PMid:12884330.

[45] Bruegel M, Rummeny EJ. Hepatic metastases: use of diffusion-weighted echo-planar imaging. Abdom Imaging 2010; 35: 454–61. doi:10.1007/s00261-009-9541-8. PMid:19471997.

[46] Tien YW, Wu YM, Lin WC, Lee HS, Lee PH. Pancreatic carcinoma cells stimulate proliferation and matrix synthesis of hepatic stellate cells. Hepatology 2009; 51: 307–14.

[47] Petersein J, Spinazzi A, Giovagnoni A, *et al.* Focal liver lesions: evaluation of the efficacy of gadobenate dimeglumine in MR imaging – a multicenter phase III clinical study. Radiology 2000; 215: 727–36.

[48] Reimer P, Rummeny EJ, Daldrup HE, *et al.* Enhancement characteristics of liver metastases, hepatocellular carcinomas, and hemangiomas with Gd-EOB-DTPA: preliminary results with dynamic MR imaging. Eur Radiol 1997; 7: 275–80. doi:10.1007/s003300050150. PMid:9038130.

[49] Schima W, Függer R, Schober E, *et al.* Diagnosis and staging of pancreatic cancer: comparison of mangafodipir trisodium-enhanced MR imaging and contrast-enhanced helical hydro-CT. AJR Am J Roentgenol 2002; 179: 717–24.

[50] Seneterre E, Taourel P, Bouvier Y, *et al.* Detection of hepatic metastases: ferumoxides-enhanced MR imaging versus unenhanced MR imaging and CT during arterial portography. Radiology 1996; 200: 785–92.

[51] Ward J, Naik KS, Guthrie JA, Wilson D, Robinson PJ. Hepatic lesion detection: comparison of MR imaging after the administration of superparamagnetic iron oxide with dual-phase CT by using alternative-free response receiver operating characteristic analysis. Radiology 1999; 210: 459–66.

[52] Oudkerk M, van den Heuvel AG, Wielopolski PA, Schmitz PI, Borel Rinkes IH, Wiggers T. Hepatic lesions: detection with ferumoxide-enhanced T1-weighted MR imaging. Radiology 1997; 203: 449–56.

[53] Buchs NC, Chilcott M, Poletti PA, Buhler LH, Morel P. Vascular invasion in pancreatic cancer: imaging modalities, preoperative diagnosis and surgical management. World J Gastroenterol 2010; 16: 818–31.

[54] Takhar AS, Palaniappan P, Dhingsa R, Lobo DN. Recent developments in diagnosis of pancreatic cancer. BMJ 2004; 329: 668–73. doi:10.1136/bmj.329.7467.668. PMid:15374918.

[55] Heinrich S, Goerres GW, Schafer M, *et al.* Positron emission tomography/computed tomography influences on the management of resectable pancreatic cancer and its cost-effectiveness. Ann Surg 2005; 242: 235–43. doi:10.1097/01.sla.0000172095.97787.84. PMid:16041214.

[56] Bares R, Dohmen BM, Cremerius U, *et al.* Results of positron emission tomography with fluorine-18 labeled fluorodeoxyglucose in differential diagnosis and staging of pancreatic carcinoma. Radiologe 1996; 36: 435–40. doi:10.1007/s001170050093. PMid:8778929.

[57] Frohlich A, Diederichs CG, Staib L, *et al.* Detection of liver metastases from pancreatic cancer using FDG PET. J Nucl Med 1999; 40: 250–5.