Published in final edited form as:

Ann Surg Oncol. 2011 October ; 18(10): 2764–2771. doi:10.1245/s10434-011-1693-4.

Pancreas-Protocol Imaging at a High-Volume Center Leads to Improved Preoperative Staging of Pancreatic Ductal Adenocarcinoma

Dustin M. Walters, MD¹, Damien J. LaPar, MD¹, Eduard E. de Lange, MD², Marc Sarti, MD², Jayme B. Stokes, MD¹, Reid B. Adams, MD¹, and Todd W. Bauer, MD¹

¹Department of Surgery, The University of Virginia, Charlottesville, VA

²Department of Radiology, The University of Virginia, Charlottesville, VA

Abstract

Background—High-quality preoperative cross-sectional imaging is vital to accurately stage patients with pancreatic ductal adenocarcinoma (PDAC). We hypothesized that imaging performed at a high-volume pancreatic cancer center with pancreatic imaging protocols more accurately stages patients compared with pre-referral imaging.

Methods—We retrospectively reviewed data from all patients with PDAC who presented to the surgical oncology clinic at our institution between June 2005 and August 2009. Detailed preoperative imaging, staging, and operative data were collected for each patient.

Results—A total of 230 patients with PDAC were identified, of which 169 had pre-referral imaging. Patients were selectively reimaged at our institution based on the quality and timing of imaging at the outside facility: 108 (47%) patients were deemed resectable, 54 (23.5%) were deemed borderline-resectable, and 68 (29.5%) were deemed unresectable. Of the resectable patients, 99 opted for resection. Eighty-two of those 99 patients underwent preoperative imaging at our institution, and of these 27% had unresectable disease at the time of surgery compared with 47% of patients who only had pre-referral imaging ($p = 0.14$). Reimaging altered staging and changed management in 56% of patients. Among that group were 55 patients, categorized as resectable on pre-referral imaging, who on repeat imaging were deemed to be borderline resectable ($n = 27$) or unresectable ($n = 28$).

Conclusions—Pancreas-protocol imaging at a high-volume center improves preoperative staging and alters management in a significant proportion of patients with PDAC who undergo pre-referral imaging. Thus, repeat imaging with pancreas protocols and dedicated radiologists is justified at high-volume centers.

Pancreatic ductal adenocarcinoma (PDAC) has the lowest survival rate of any solid malignancy and is the fourth leading cause of cancer death in the United States.¹ Due to the dearth of adequate medical therapy for this disease, long-term survival is only possible for patients who undergo successful pancreatectomy. Unfortunately, only 15–20% of patients diagnosed with PDAC meet resection criteria, which is dependent on local tumor characteristics—particularly involvement of the mesenteric vessels—and presence or absence of distant metastases.² Of those patients deemed resectable preoperatively, 15–40%

have metastatic or locally advanced disease at the time of surgery precluding resection.³⁻⁵ When unresectable disease is found intraoperatively, the patient must recover from surgery before delivery of systemic chemotherapy or radiation. If postoperative complications arise, treatment is further delayed or not delivered at all. To reduce the rate of nontherapeutic laparotomy and minimize delay of appropriate therapy, high-quality preoperative cross-sectional imaging is imperative.

Currently accepted cross-sectional imaging modalities for staging PDAC include computed tomography (CT) and magnetic resonance imaging (MRI).⁶ Numerous studies have compared the diagnostic accuracy of CT to MRI, and the combined results are inconclusive.⁷⁻¹² Both are considered standard of care, and to some extent, choice of imaging is dependent on institutional experience and surgeon preference. Most hospitals in the United States use CT to stage patients preoperatively with PDAC due to lower cost, wider availability, and ease of interpretation. One potential benefit of MRI may be its increased sensitivity in detection of small liver metastases compared with CT.^{13,14}

Cross-sectional imaging of PDAC serves two purposes: evaluation for metastatic disease and assessment of the relationship of the tumor to the mesenteric and portal vessels. Vascular involvement can be difficult to assess. However, it is crucial to distinguish whether there is a clean fat plane between the tumor and the vessels, vascular abutment, or encasement, because this distinction strongly influences tumor resectability and overall treatment plan. Vessel abutment occurs when the tumor involves less than 180° of the vessel circumference, whereas encasement indicates involvement of greater than 180° of the circumference.¹⁵ One cannot overemphasize the importance of preoperative assessment of the mesenteric vessels, underscored by the fact that the mesenteric margin is the most frequent margin harboring residual cancer in R₁ resections.¹⁶

Equally important to high-quality, cross-sectional imaging is accurate interpretation by experienced radiologists. There is evidence that specialized radiologists more accurately interpret images within their specialties.¹⁷ Barry et al. demonstrated significantly improved staging accuracy of patients with gastric cancer by specialist radiologists.¹⁸ Organ-specific imaging protocols are critical for radiologists to accurately assess pathology, particularly for PDAC. One study demonstrated wide variability among different institutions in terms of cross-sectional imaging protocols in PDAC.¹⁹

In light of the complexities of preoperative staging of PDAC, we hypothesized that tumor staging is more accurately performed with imaging at a high-volume pancreatic cancer center with dedicated pancreatic protocols and radiologists than in non-high-volume centers. Accordingly, we sought to determine the accuracy of preoperative staging of PDAC by comparing the rate of finding unresectable disease at the time of surgery for patients deemed to be resectable based on imaging in the pre-referral setting to that in a high-volume referral center. Secondly, we investigated how often repeat imaging at a high-volume pancreatic cancer center altered management of patients with PDAC.

METHODS

This investigation was approved by the Human Investigation Committee of the University of Virginia Institutional Review Board, including a waiver for the need to obtain consent. We performed a retrospective review of all patients with a diagnosis of PDAC who presented to the surgical oncology clinic at the University of Virginia between June 2005 and August 2009. Preoperative imaging data were collected, including study date, modality, and location; site and size of the tumor; vascular involvement; and presence or absence of metastatic disease. For patients who underwent repeat imaging at our institution, we

determined the date and modality of that imaging. Tumors were classified in all cases, based on most recent cross-sectional imaging, by an attending radiologist as resectable, borderline resectable, or unresectable. At our institution, imaging was interpreted by a radiologist with expertise in pancreatic pathology using previously reported definitions,^{15,20} and classification was confirmed during discussion and review at our institution's multidisciplinary gastrointestinal tumor board. For patients who underwent pre-referral imaging, the radiology reports from the referring institution were used and the images were reviewed by the operating surgeon and the multidisciplinary team, which included radiologists. Operative data were collected including date, type of surgery, and whether there was evidence of metastatic or locally advanced disease at the time of surgery, thus precluding resection.

We specifically examined all patients who were deemed resectable based on preoperative imaging and taken to the operating room for planned pancreatectomy. We determined the rate of resectability (i.e., no finding of metastatic or locally advanced disease at the time of operation) for patients who underwent pre-referral imaging only compared to those patients who were imaged preoperatively at our high-volume center. We also analyzed all patients who had pre-referral imaging who were then reimaged at our institution. For this group of patients, we determined how often management changed based on the repeat imaging.

MRI Protocol

At our institution, MRI is utilized as the primary imaging modality for patients with PDAC. Our MRI scanning was performed using Siemens 1.5 T superconducting magnets (Magnetom Sonata, Magnetom Symphony, and Avanto; Siemens Medical Systems) with a four-element torso phased array coil. The following unenhanced breath-hold sequences were performed: axial T1 weighted in-phase and opposed-phase gradient-echo (GRE) imaging; axial T1 weighted magnetization-prepared gradient-echo (MP-GRE); coronal, sagittal, and axial T2 weighted half-Fourier acquisition single shot turbo spin echo (HASTE) imaging; thin section multislice magnetic-resonance cholangiopancreatography (MRCP); thick slab MRCP imaging; and three-dimensional (3D) free breathing MRCP imaging.

Dynamic contrast-enhanced axial T1 weighted 3D volume interpolated breathhold examination GRE imaging was performed with the intravenous administration of 20 cc of gadolinium containing contrast agent [gadodiamide (Omniscan; Amersham Health), gadopentetate dimeglumine (Magnevist; Bayer HealthCare Pharmaceuticals), or gadobenate dimeglumine (MultiHance; Bracco Diagnostics)]. Precontrast acquisition and gadolinium injection occurred simultaneously. Three dynamic contrast-enhanced series were obtained, with a 15-s pause between each acquisition, resulting in pancreatic parenchymal phase (35–55 s after injection), portal venous phase (70–90 s after injection), and delayed phase (100–120 s after injection) images. A single late-phase acquisition was obtained at the end of the study (7–10 min after initial injection).

Subsequently, coronal contrast-enhanced imaging was performed using a fast 3D low-angle shot sequence after the intravenous administration of an additional 20 cc of contrast. The imaging was performed with an initial scan delay of 20 s, and repeated two more times with a 25-s delay between each acquisition. The image parameters were chosen such that isotropic voxels were obtained for multiplanar reconstruction at the time of interpretation.

Statistical Analysis

All group comparisons in this study were unpaired. Categorical variables were compared by using Fischer's exact or Pearson's Chi-square tests. Analysis of variance (ANOVA) was used to compare continuous variables. Categorical variables were expressed as a percentage of

the group of origin, and continuous variables were expressed by mean $\pm$ standard deviation (SD). All p values were two-tailed, and significance was indicated by $p < 0.05$. GraphPad Prism (version 5) software (La Jolla, CA) was used for statistical analyses.

RESULTS

Patient and Imaging Characteristics

General patient characteristics and imaging data based on tumor resectability are detailed in Table 1. A total of 230 patients who presented with PDAC between June 2005 and August 2009 were identified. The mean age of all patients was 66.5 years, and 54.3% were men. At initial visits, 169 patients had undergone pre-referral imaging at another institution. The remaining 61 patients underwent initial imaging at our institution. Of the 169 patients with pre-referral imaging, 124 were reimaged at our institution, which was performed selectively based on quality and timing of pre-referral cross-sectional imaging. Patients were classified as resectable ($n = 108$), borderline resectable ($n = 54$), or unresectable ($n = 68$) based on most recent cross-sectional imaging. Most patients (78.3%) underwent MRI for their immediate preoperative cross-sectional imaging, whereas the remainder (21.7%) were staged using CT.

For those patients reimaged at our institution, the time between pre-referral and repeat imaging was 0.7, 0.9, and 1.2 months for resectable, borderline resectable, and unresectable patients, respectively. Patients with resectable tumors had a mean tumor size of 2.7 cm compared with patients classified as borderline resectable (3.4 cm, $p < 0.05$), and unresectable (4.3 cm, $p < 0.01$). The vast majority of tumors (85.7%) were within the head or uncinate process, whereas 14.3% of tumors were located in the body or tail of the pancreas.

Accuracy of Pre-referral Imaging, Operative Characteristics, and Outcomes

Of the 230 patients who presented with PDAC, 108 patients were resectable based on cross-sectional imaging. Nine of those patients were not scheduled for surgery due to patient refusal ($n = 8$) or significant comorbidities that precluded resection ($n = 1$). Ninety-nine patients consented to pancreatectomy and were taken to the operating room for surgery with curative intent. Of those patients, 69 (69.7%) were resectable and underwent pancreatectomy; 30 were unresectable upon exploration.

Two surgeons (TWB and RBA) performed all pancreatic resections. Pancreaticoduodenectomy (81.2%) was the most commonly performed procedure, followed by distal (15.9%) and total pancreatectomy (2.9%). The 69 patients who were resected were similar to the 30 patients with unresectable disease at the time of surgery in terms of tumor location (head/uncinate vs. body/tail), tumor size, and time from most recent imaging to surgery (Table 2).

Eighty-two patients who were classified as resectable by imaging underwent preoperative cross-sectional imaging at our institution. Of those patients, 22 (26.8%) were inoperable at the time of surgery due to locally advanced ($n = 11$) or distant abdominal metastatic disease ($n = 11$). Seventeen patients were taken to the operating room with only pre-referral imaging. Of these patients, eight (47.1%) were unresectable at the time of surgery (Table 3), of which two had locally advanced disease and six had distant abdominal metastatic disease. In total, 13 patients were unresectable for locally advanced disease, generally due to vascular involvement. The superior mesenteric artery was involved in four cases, while the common hepatic artery ($n = 3$), superior mesenteric vein ($n = 2$), and inferior vena cava ($n = 1$) also were involved. In three cases, lymph nodes outside the area of resection were identified at the time of surgery. Of the nine patients in the pre-referral imaging only group

who underwent resection, there were eight R₀ resections and one R₁ resection. Of the 60 patients who underwent resection who had imaging at our institution, there were 49 R₀ resections and 11 R₁ resections. The rate of R₀ resection was not significant between groups.

Management Changes

A total of 124 patients with pre-referral imaging underwent repeat imaging at our institution, and overall management was altered for 69 (55.6%) of those patients (Fig. 1). Twenty-eight patients originally classified as resectable based on pre-referral imaging were reclassified as unresectable, 14 of whom had metastatic lesions detected on repeat imaging in the liver ($n = 12$) or lung ($n = 2$), and 14 of whom had T4 lesions due to SMA ($n = 8$) or celiac ($n = 6$) involvement. Twenty-seven patients thought to be resectable on pre-referral imaging were reclassified following repeat imaging as borderline resectable based on vascular involvement. Another 14 patients had management altered in other ways. Seven patients had pre-referral CT scans in which no mass was appreciated; however, reimaging at our institution detected a definable mass. Six patients had indeterminate pre-referral imaging where a pancreas mass was visualized, but resectability could not be determined; all six were classified as resectable on reimaging. One patient was misdiagnosed as having a duodenal fistula on pre-referral imaging. When reimaged at our institution, the patient was found to have a resectable pancreatic head mass.

CONCLUSIONS

This study highlights the importance of high-quality, preoperative, cross-sectional imaging and interpretation in patients with PDAC. There was a trend toward increased accuracy in predicting surgical resectability based on imaging at our high-volume pancreatic center compared with imaging performed in the pre-referral setting (73% vs. 53%, respectively, $p = 0.14$). Our unresectability rate (27%) is similar to previously reported studies.²¹ The role of diagnostic laparoscopy to improve preoperative staging for PDAC was not formally addressed in this study, and although it may improve preoperative staging, its routine use is controversial. At our institution, we routinely perform diagnostic laparoscopy for cancers in the body or tail of the pancreas and use a selective approach for pancreatic head/uncinate cancers. This is supported by Pisters et al.,²¹ who reviewed the role of laparoscopy for staging PDAC and estimated that only 4–13% of patients benefit from routine laparoscopy.

Perhaps the most significant finding of this study was that reimaging patients who had previously undergone pre-referral imaging resulted in management changes in 56% of cases. Twenty-eight patients were reclassified from resectable to unresectable, sparing these patients unnecessary surgery and allowing for potential earlier delivery of systemic chemotherapy and chemoradiation. An additional 27 patients were reclassified from resectable to borderline resectable, allowing for those patients to receive appropriate neoadjuvant therapy followed by restaging and surgery. The reclassification from resectable to unresectable or borderline resectable could potentially be due to interval progression and not necessarily misdiagnosis on pre-referral imaging. However, the mean interval between pre-referral imaging and repeat imaging was less than 1 month, and interval progression unlikely accounts for such a large percent of tumor upstaging. Figures 2 and 3 depict three patients who were classified as resectable based on pre-referral imaging but were reclassified as borderline resectable or unresectable based on repeat imaging at our institution, all performed within 3 weeks. Pawlik et al.²² demonstrated similar findings, reporting that reimaging changed the stage of cancer for 19% of patients and multidisciplinary tumor board review changed management in 24% of patients.

For patients with PDAC, delivering optimal treatment—often consisting of combinations of chemotherapy, chemoradiation, and surgery—with appropriate timing is critical. Timing of

each modality ultimately depends on tumor resectability. The current standard of care for patients with resectable tumors who are fit for surgery is initial pancreatectomy, followed by systemic chemotherapy and chemoradiation. Treatment options for unresectable patients include systemic chemotherapy and chemoradiation. Borderline resectable denotes a select patient group with technically resectable tumors but with a high incidence of micrometastatic disease and a margin-positive resection. These patients receive neoadjuvant therapy, are restaged, and undergo surgery if they have no disease progression.

When incorrectly classified, patients do not receive timely, beneficial treatment. For instance, if a patient is misclassified as resectable, undergoes laparotomy, and metastatic disease is found, that patient not only must suffer the pain and potential complications of unnecessary surgery but will have other therapies delayed. There is evidence that as many as 30% of patients do not recover from surgery sufficiently to receive adjuvant therapy²³; thus, some patients may not even receive the only therapy from which they may benefit.

Cross-sectional imaging with CT or MRI is the most accurate method to determine resectability preoperatively and to stratify patients with PDAC into treatment groups. To do so, high-quality imaging and accurate interpretation are absolutely necessary. At our institution, we predominantly use MRI to stage PDAC tumors preoperatively due to the vast expertise of our radiologists with MRI and their implementation of specific MRI protocols optimized for staging PDAC. As we have demonstrated, 78.3% of patients in this study underwent preoperative MRI. In contrast, most institutions primarily use multidetector CT for this purpose. There are benefits to each modality. CT has historically been described as the imaging modality of choice and is less costly than MRI.^{24,25} Generally, CT images are easier to interpret, and interpretation of local spread of disease may be done equally well with both CT and MRI.¹⁴ MRI, although more expensive and more difficult for many surgeons to interpret, may be superior to CT for identifying metastatic liver lesions.^{13,14} This is supported by the present study, in which 12 patients who were reimaged at our institution had liver metastases that were not seen on pre-referral imaging. In 11 of those cases, the pre-referral imaging was by CT and the repeat imaging was performed using MRI. Again, interval disease progression between imaging studies could help explain this phenomenon; however, the short time frame between studies is unlikely to fully explain these results.

This study has notable limitations. It is a retrospective study with inherent selection bias, but prospective trials comparing pre-referral to post-referral imaging would be impossible to perform. Furthermore, the small sample size ($n = 17$) of patients who went to the operating room based on pre-referral imaging alone limits our ability to detect small differences during group comparisons. Cross-sectional imaging varies among institutions and, thus, translation of this study's findings to other institutions is dependent on high-quality imaging and interpretation. The authors recognize that some institutions that do not meet criteria for high-volume PDAC centers likely have excellent quality imaging and radiologic interpretation. However, this study demonstrates that at our high-volume institution, high-quality imaging and interpretation led to increased accuracy of preoperative staging. Notably, repeat imaging altered management in more than half of patients. Finally, as previously mentioned, interval progression of disease between pre-referral and repeat imaging could serve as a potential confounding factor for the results. However, the less than 1-month time interval between imaging studies is unlikely to explain fully the high percentage of patients (56%) with changes in preoperative staging based on repeat imaging.

PDAC is a complex disease and optimal outcomes rely on a multidisciplinary approach,^{22,26} where surgeons and other specialists work in concert to manage each patient on an individual basis. Preoperative staging is paramount to the decision-making process and

cannot be overstated, particularly because effective treatment strategies for PDAC are limited. High-quality preoperative cross-sectional imaging and accurate interpretation allow patients to be treated efficiently with the optimal therapeutic strategy, whereas incorrectly staging patients often leads to suboptimal outcomes. When patients are referred to a high-volume pancreatic cancer center for management of PDAC, repeating cross-sectional imaging is justified.

Acknowledgments

This study was supported in part by Award Number T32HL007849 (DJL) from the National Heart, Lung, and Blood Institute. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Heart, Lung, and Blood Institute or the National Institutes of Health.

REFERENCES

1. Jemal A, Siegel R, Ward E, Hao Y, Xu J, Thun MJ. Cancer statistics. *CA Cancer J Clin*. 2009; 59(4):225–49. [PubMed: 19474385]
2. Li D, Xie K, Wolff R, Abbruzzese JL. Pancreatic cancer. *Lancet*. 2004; 363(9414):1049–57. [PubMed: 15051286]
3. White R, Winston C, Gonen M, et al. Current utility of staging laparoscopy for pancreatic and peripancreatic neoplasms. *J Am Coll Surg*. 2008; 206(3):445–50. [PubMed: 18308214]
4. Borbath I, Van Beers BE, Lonnew M, Schoonbroodt D, Geubel A, Gigot JF, Deprez PH. Preoperative assessment of pancreatic tumors using magnetic resonance imaging, endoscopic ultrasonography, positron emission tomography and laparoscopy. *Pancreatol*. 2005; 5(6):553–61. [PubMed: 16113592]
5. Friess H, Kleef J, Silva JC, Sadowski C, Baer HU, Buchler MW. The role of diagnostic laparoscopy in pancreatic and periampullary malignancies. *J Am Coll Surg*. 1998; 186(6):675–82. [PubMed: 9632157]
6. Spencer JA, Ward J, Guthrie JA, Guillou PJ, Robinson PJ. Assessment of resectability of pancreatic cancer with dynamic contrast-enhanced MR imaging: technique, surgical correlation and patient outcome. *Eur Radiol*. 1998; 8(1):23–9. [PubMed: 9442123]
7. Megibow AJ, Zhou XH, Rotterdam H, et al. Pancreatic adeno-carcinoma: CT versus MR imaging in the evaluation of resectability. Report of the Radiology Diagnostic Oncology Group. *Radiology*. 1995; 195(2):327–32. [PubMed: 7724748]
8. Irie H, Honda H, Kaneko K, Kuroiwa T, Yoshimitsu K, Masuda K. Comparison of helical CT and MR imaging in detecting and staging small pancreatic adenocarcinoma. *Abdom Imaging*. 1997; 22(4):429–33. [PubMed: 9157866]
9. Sheridan MB, Ward J, Guthrie JA, et al. Dynamic contrast-enhanced MR imaging and dual-phase helical CT in the preoperative assessment of suspected pancreatic cancer: a comparative study with receiver operating characteristic analysis. *AJR Am J Roentgenol*. 1999; 173(3):583–90. [PubMed: 10470884]
10. Nishiharu T, Yamashita Y, Abe Y, Mitsuzaki K, Tsuchigame T, Nakayama Y, Takahashi M. Local extension of pancreatic carcinoma: assessment with thin-section helical CT versus with breath-hold fast MR imaging—ROC analysis. *Radiology*. 1999; 212(2):445–52. [PubMed: 10429702]
11. Bluemke DA, Fishman EK. CT and MR evaluation of pancreatic cancer. *Surg Oncol Clin N Am*. 1998; 7(1):103–24. [PubMed: 9443989]
12. 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(7):818–31. [PubMed: 20143460]
13. Trede M, Rumstadt B, Wendl K, et al. Ultrafast magnetic resonance imaging improves the staging of pancreatic tumors. *Ann Surg*. 1997; 226(4):393–405. discussion 405–7. [PubMed: 9351708]
14. Balci NC, Semelka RC. Radiologic diagnosis and staging of pancreatic ductal adenocarcinoma. *Eur J Radiol*. 2001; 38(2):105–12. [PubMed: 11335092]

15. Varadhachary GR, Tamm EP, Abbruzzese JL, et al. Borderline resectable pancreatic cancer: definitions, management, and role of preoperative therapy. *Ann Surg Oncol*. 2006; 13(8):1035–46. [PubMed: 16865597]
16. Raut CP, Tseng JF, Sun CC, et al. Impact of resection status on pattern of failure and survival after pancreaticoduodenectomy for pancreatic adenocarcinoma. *Ann Surg*. 2007; 246(1):52–60. [PubMed: 17592291]
17. Halligan S. Subspecialist radiology. *Clin Radiol*. 2002; 57(11):982–3. [PubMed: 12409107]
18. Barry JD, Edwards P, Lewis WG, Dhariwal D, Thomas GV. Special interest radiology improves the perceived preoperative stage of gastric cancer. *Clin Radiol*. 2002; 57(11):984–8. [PubMed: 12409108]
19. Callaway MP, Bailey D. Staging computed tomography in upper GI malignancy. A survey of the 5 cancer networks covered by the South West Cancer Intelligence Service. *Clin Radiol*. 2005; 60(7):794–800. [PubMed: 16127832]
20. Katz MH, Pisters PW, Evans DB, et al. Borderline resectable pancreatic cancer: the importance of this emerging stage of disease. *J Am Coll Surg*. 2008; 206(5):833–46. [PubMed: 18471707]
21. Pisters PW, Lee JE, Vauthey JN, Charnsangrevej C, Evans DB. Laparoscopy in the staging of pancreatic cancer. *Br J Surg*. 2001; 88:325–37. [PubMed: 11260096]
22. Pawlik TM, Laheru D, Hruban RH, et al. Evaluating the impact of a single-day multidisciplinary clinic on the management of pancreatic cancer. *Ann Surg Oncol*. 2008; 15(8):2081–8. [PubMed: 18461404]
23. Evans DB. For The Multidisciplinary Pancreatic Cancer Study, Resectable pancreatic cancer: the role for neoadjuvant/preoperative therapy. *HPB (Oxford)*. 2006; 8(5):365–8. [PubMed: 18333089]
24. Bernardino ME, Barnes PA. Imaging the pancreatic neoplasm. *Cancer*. 1982; 50(11 Suppl):2681–8. [PubMed: 7139562]
25. Horton KM, Fishman EK. Adenocarcinoma of the pancreas: CT imaging. *Radiol Clin North Am*. 2002; 40(6):1263–72. [PubMed: 12479710]
26. Hawes RH, Xiong Q, Waxman I, Chang KJ, Evans DB, Abbruzzese JL. A multispecialty approach to the diagnosis and management of pancreatic cancer. *Am J Gastroenterol*. 2000; 95(1):17–31. [PubMed: 10638554]

FIG 1. Management changes based on repeat cross-sectional imaging. *RS* resectable; *BR* borderline resectable; *UR* unresectable

FIG 2.

Example of incorrect assessment of tumor extent at outside institution. **a** Contrast-enhanced CT image obtained at outside institution vaguely shows a mass in the pancreatic head and normal appearance of the SMV and SMA. Involvement of SMA and SMV was not reported at outside institution. **b** Contrast-enhanced MR image at same level obtained 6 days later better demonstrates the mass (dark round tissue indicated by *large arrow*). The tumor can be well-differentiated from the adjacent normal pancreatic parenchyma (bright tissue indicated with 3 *short arrows*). Irregular margins of the SMV indicate vascular involvement and there is abutment of the SMA as well, making this a borderline resectable tumor

FIG 3.

Example of liver metastases not detected at outside institution due to inadequate imaging protocol. **a** Axial T2-weighted MR image obtained at outside institution vaguely shows a small focus of increased signal at the margin of segment 6 (*arrow*) consistent with metastasis. This lesion was not reported at the outside institution. Other images of the same study also poorly showed the lesion but no contrast enhancement images were obtained, which would have improved lesion depiction. Repeat MR imaging at our institution performed 18 days later shows the same lesion on **(b)** T2-weighted image and it is more clearly depicted with **(c)** gadolinium contrast-enhanced imaging. **d** Contrast-enhanced CT image of the liver obtained at outside institution in patient with mass in the pancreatic tail shows normal liver with no evidence of metastases. **e** Contrast-enhanced T1-weighted MR image obtained at our institution 13 days later clearly shows several small metastases (*arrows*), making the tumor unresectable

TABLE 1

Patient and imaging characteristics by resectability as determined by cross-sectional imaging

	RS (n = 108)	BR (n = 54)	UR (n = 68)	Total (N = 230)
Age (year), mean $\pm$ SD	67 $\pm$ 10.3	65.1 $\pm$ 9.5	66.7 $\pm$ 9.8	66.5 $\pm$ 10
Sex				
Male (% column)	55 (50.9)	31 (57.4)	39 (57.4)	125 (54.3)
Female (% column)	53 (49.1)	23 (42.6)	29 (42.6)	105 (45.7)
Image location and timing				
No pre-referral imaging (% column)	37 (34.3)	15 (27.8)	9 (13.2)	61 (26.5)
Pre-referral imaging (% column)	71 (65.7)	39 (72.2)	59 (86.8)	169 (73.5)
Re-imaged at our institution (% pre-referral)	51 (71.8)	36 (92.3)	37 (62.7)	124 (73.4)
Time from pre-referral to repeat imaging in months, mean $\pm$ SD [*]	0.7 $\pm$ 0.6	0.9 $\pm$ 0.7	1.2 $\pm$ 0.8	0.9 $\pm$ 0.8
Type of imaging				
MRI (% column)	84 (77.8)	48 (88.9)	48 (70.6)	180 (78.3)
CT (% column)	24 (22.2)	6 (11.1)	20 (29.4)	50 (21.7)
Size of tumor on imaging (cm), mean $\pm$ SD	2.7 $\pm$ 1	3.4 $\pm$ 1.6 ^{**}	4.3 $\pm$ 2.1 [‡]	3.34 $\pm$ 1.7
Location of tumor on imaging				
Head/uncinate (% column)	90 (83.3)	50 (92.6)	57 (83.8)	197 (85.7)
Body/tail (% column)	18 (16.7)	4 (7.4)	11 (16.2)	33 (14.3)

RS resectable; BR borderline-resectable; UR unresectable; MRI magnetic resonance imaging; CT computed tomography

^{*} *p* value not statistically significant^{**} *p* < 0.05 compared with RS[‡] *p* < 0.01 compared with RS

TABLE 2

Patients initially deemed resectable based on cross-sectional imaging who were taken to the operating room for pancreatectomy ($n = 99$)

	Resectable in OR ($n = 69$)	Unresectable in OR ($n = 30$)
Location of tumor		
Head/uncinate (%)	57 (82.6)	24 (80)
Body/tail (%)	12 (17.4)	6 (20)
Size of tumor (cm $\pm$ SD)	2.6 $\pm$ 1	2.9 $\pm$ 1.1
Time from last imaging to surgery (months), mean $\pm$ SD	1.1 $\pm$ 0.9	1.2 $\pm$ 0.7

TABLE 3

Resectability of patients based on preoperative imaging

	Pre-referral imaging only (<i>n</i> = 17)	Imaging at high-volume center (<i>n</i> = 82)
Resectable in OR (%)	9 (52.9)	60 (73.2)
Unresectable in OR (%) *	8 (47.1)	22 (26.8)
Abdominal metastases	6 (35.3)	11 (13.4)
Locally advanced	2 (11.8)	11 (13.4)
R ₀ resection (%)	8 (47.1)	49 (59.8)
R ₁ resection (%)	1 (5.9)	11 (13.4)

*
 $p = 0.14$ by Fisher's exact test