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Pancreatic Adenocarcinoma: CT versus MR Imaging in the Evaluation of Resectability—Report of the Radiology Diagnostic Oncology Group[1]

PURPOSE: **To compare findings with computed tomography (CT) and magnetic resonance (MR) imaging in pancreatic adenocarcinoma and to determine optimal pulse sequences for MR imaging.**

MATERIALS AND METHODS: **CT scans and MR images were compared of 189 adult patients with known or suspected adenocarcinoma of the pancreas. Levels of confidence were correlated with surgical and pathologic results.**

RESULTS: **The accuracy of CT was 0.73 and of MR imaging was 0.70. The negative predictive value of CT was 0.28 and of MR imaging was 0.23. The positive predictive value of CT was 0.89 and of MR imaging was 0.88. Gradient-echo and T1-weighted spin-echo sequences ranked equally in evaluation of vascular invasion, T1-weighted spin-echo sequences were preferred for assessing lymphadenopathy, and T2-weighted spin-echo sequences were preferred for detecting hepatic metastases.**

CONCLUSIONS: **Cross-sectional imaging modalities are useful in the identification of unresectable pancreatic carcinoma. CT is recommended for initial imaging assessment.**

Index terms: Computed tomography (CT), comparative studies • Magnetic resonance (MR), comparative studies • Pancreas, CT, 770.1211 • Pancreas, MR, 770.1214 • Pancreas, neoplasms, 770.32

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CANCER of the pancreas continues to present a diagnostic and therapeutic challenge. It is the fourth leading cause of cancer-related deaths, ranking second to colorectal carcinoma as a cause of death from malignant gastrointestinal neoplasms. Pancreatic cancer is the least likely neoplasm to be confined to the organ of origin at the time of diagnosis. This factor explains the poor outcome of surgical treatment and the unwillingness of surgeons to perform difficult operations when there is no proved benefit to patient survival. However, early diagnosis is associated with a higher resectability rate (22% versus 14%) and allows more patients to benefit from palliation (40% versus 23%) (1). Imaging has increased surgeons' ability to select appropriate patients for surgical treatment.

Imaging technologies have allowed direct visualization of the pancreas. They also provide the ability to determine whether a neoplasm is localized within the pancreas or has metastasized to the liver or local lymph nodes or invaded surrounding vessels. Such a determination allows a preoperative decision about whether a patient is a candidate for attempted resection or a palliative procedure. Dynamic contrast material–enhanced computed tomography (CT) is most frequently performed to confirm the clinical diagnosis and assess resectability. When CT is performed with protocols directed at optimal imaging of the pancreas, the results can be improved over those obtained with conventional approaches (2).

Magnetic resonance (MR) imaging is beginning to be used in the evaluation of pancreatic disease. Several potential advantages of MR imaging include high tissue contrast (possibly increasing conspicuity of hepatic lesions); the ability to visualize and assess vessel patency without the use of intravenously administered contrast material; and the ability to manipulate pulse sequence parameters, enhancing visualization of structures such as blood vessels and liver. These advantages combine to make MR imaging an alternative in the evaluation of patients with pancreatic adenocarcinoma. Although findings in recent studies suggest a potential superiority of MR imaging over CT in the assessment of pancreatic neoplasms, this superiority has not been realized in the clinical situation (3–6).

The Radiology Diagnostic Oncology Group was formed to evaluate the benefits of competitive imaging procedures. Funded through the National Cancer Institute to conduct comparative imaging trials, the group administers multicenter trials coordinated to provide sufficient numbers of patients from centers with expertise in the diagnosis and treatment of a variety of diseases (7). From September 1990 through November 1992, we collected data to compare findings at CT and MR imaging in the evaluation of pancreatic adenocarcinoma. This initial evaluation was directed at determining the value of CT opposed to MR imaging in predicting the potential resectability of a pancreatic carcinoma. We also compared the ability of the modalities alone and together to depict the radiologic features indicative of vascular invasion,

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Abbreviations: ROC = receiver operating characteristic, STIR = short inversion time inversion recovery.

lymph node disease, and hepatic metastases. We attempted to determine which of the many MR imaging sequences could provide the highest level of confidence in making these observations.

MATERIALS AND METHODS

Patient Selection

The following four institutions participated in the study: The Johns Hopkins Medical Institutions, University of Michigan, New York University Medical Center, and Washington University Mallinckrodt Institute of Radiology. Patients were included regardless of age or sex. All patients with suspected adenocarcinoma of the pancreas were recruited in whom surgical exploration was being considered. Patients with pancreatic neoplasms known to be other than adenocarcinoma before attempted accrual were excluded from the study. If a neoplasm eventually proved to be other than adenocarcinoma, the patient was included in the final data analysis. All patients were evaluated for ability to comply with the demands of the protocol. That is, we determined if there were any contraindications to a patient's receiving intravenously administered contrast material or if there were contraindications to MR imaging, such as the presence of cardiac pacemaker.

A total of 189 patients participated in the study: 105 men aged 35–87 years (mean, 64 years) and 84 women aged 35–87 years (mean, 65 years). The data from 28 patients were excluded from analysis. Reasons included misregistration ($n = 1$), prior pancreatic surgery ($n = 2$), history of neoplasm or chemo- or radiation therapy within 5 years of the study ($n = 2$), images were incomplete or unacceptable by quality-control standards or were missing ($n = 4$), resection was not performed within 5 weeks of imaging ($n = 2$), or surgery was canceled ($n = 15$). In the last group, there was no definitive diagnosis of pancreatic cancer ($n = 4$), the patient became too ill to undergo surgery ($n = 1$), pancreatitis developed and the patient could not undergo surgery ($n = 1$), the surgeon and patient decided together to cancel surgery ($n = 2$) or the patient refused surgery ($n = 4$), and no tumor was found ($n = 1$). Surgical data forms were not received for two patients, so the reasons for no surgery were not known.

Among the 161 patients in the study, findings at pathologic examination confirmed that 116 had adenocarcinoma, two had adenocarcinoma of unknown origin (determined at cytologic examination), eight had other malignant neoplasms (adenosquamous carcinoma [$n = 2$], neuroendocrine tumor [$n = 4$], lymphoma [$n = 1$], or poorly differentiated carcinoma [$n = 1$]). Seventeen patients had benign disease; two had normal results at lymph node biopsy. For 11 patients, the surgeon or pathologist recorded "no tumor seen." Histologic data were missing in five patients.

Specific histologic data were not available in eight patients, but imaging data suggested the presence of extensive disease and no further attempts were made to acquire material for pathologic examination. These eight patients were assumed to have pancreatic adenocarcinoma and their data were analyzed with those of the 108 patients with proof of diagnosis. Eighty-seven of the proved adenocarcinomas were confirmed at resection or open pancreatic biopsy, 10 at needle aspiration cytologic examination, six at biopsy of extrapancreatic tissue during laparotomy, and five at liver biopsy.

Scans of patients who had undergone diagnostic CT before entering the study were reviewed by the principal investigators at each site. Those scans were either submitted as part of the study data or were repeated if the investigators determined the submitted scan did not meet protocol guidelines.

CT Protocol

CT was performed with machines capable of high resolution, rapid data acquisition, and dynamic scanning. The scanners were the CT/T 9800 HiLight or HiLight Advantage (GE Medical Systems, Milwaukee, Wis) or DRH or Somatom Plus (Siemens Medical Systems, Iselin, NJ). Spiral CT protocols were not used at any of the institutions. After a scout view was obtained, the pancreas was scanned in contiguous 5-mm-thick sections, and the liver was scanned in 5-mm-thick sections with a 3-mm gap. Scanning began at the inferior portion of the pancreas (at the level of the transverse duodenum), and sections were acquired cephalad. When scanning proceeded craniocaudad, the principal investigator at the site determined scan adequacy on the basis of adequate demonstration of peripancreatic vessels, degree of hepatic attenuation, and appropriate section gap before the patient was registered in the study.

All patients received 150 mL of 60% ionic (or 150 mL of 30% nonionic) intravenously administered contrast material. The agent was administered with a power injector in a 2.0–2.5 mL/sec bolus before scanning, followed immediately with an infusion at 0.8–1.0 mL/sec during the period of data acquisition. The adequacy of vascular and hepatic opacification was estimated on the basis of the attenuation of the main portal vein in the porta hepatis. Attenuation of more than 100 HU over the attenuation of the main portal vein was considered acceptable.

Two-second scans with approximately 4–8-second interscan delays were obtained with standard parameters (120 KVp, 140–170 mA) with the minimum field of view to encompass the patient. Scans were obtained at soft-tissue windows (400–500 HU), which allowed assessment of the interfaces between the pancreatic neoplasm and surrounding structures, and at liver windows (125–175 HU) to maximize conspicuity of hepatic lesions. Precise levels were not specified.

MR Imaging Protocol

MR imaging was performed at with one of the following four systems: 1.5-T Signa (GE Medical Systems); 1.5-T Gyroscan (Philips Medical Systems, Shelton, Conn); 1.0- or 1.5-T Magnetom (Siemens Medical Systems). After coronal scout images were obtained, MR imaging was performed with the following four sequences: T1-weighted (repetition time msec/echo time msec = 600/20), T2-weighted multiecho (2,000/50, 100), short inversion time inversion recovery (STIR) (2,000/50 with 150-msec inversion time [2,000/50/150]), and gradient recalled-echo (30/15, with 30° flip angle). Gradient moment nulling was used with the T2-weighted sequence, and presaturation pulses were used with all sequences. No contrast material was administered intravenously or orally. At the beginning of the study not all machines were equipped with respiratory gating, fat suppression, or variable acquisition matrices. Therefore, these features could not be used in the trial.

T1-weighted images were obtained with two signals acquired and a 128 × 128 matrix, and T2-weighted images were obtained with two signals acquired and a 256 × 256 matrix. Contiguous 8–10-mm-thick sections were obtained through the liver and pancreas.

Quality Control

Before the data from an examination were entered into the study, the examinations were evaluated by a quality control committee composed of the study chairman (A.J.M.) and the principle investigators from the four institutions (A.J.M., I.R.F., E.A.Z., D.M.B.). This committee met several times during the period of the study to review all submitted scans and images. The committee had the power to exclude a patient if the MR images did not adhere to protocol standards. When images contained severe artifacts, the patient remained in the trial if the images were obtained according to protocol requirements.

Interpretation of Images

CT scans and MR images were interpreted separately by radiologists at the participating sites. The readers worked independently and did not know the MR imaging findings if they were reading a CT scan or the CT findings if they were reading a MR image. The readers did not know the surgical or pathologic examination findings. Results of other studies (eg, transhepatic cholangiography, selective angiography) were available at the time of the CT and MR imaging readings.

The results of the interpretation were recorded on forms produced for the project. Specific data of the examination (ie, section thickness, rate of injection of contrast material, direction of data acquisition, origin of the image) were recorded for each examination. The readers used a five-point confidence scale to estimate the like-

Table 1
Correlation with Surgical or Pathologic Standard of Reference

Modality	No. of Lesions in Standard of Reference	No. of Positive (Unresectable) Lesions*	No. of Negative (Resectable) Lesions†
		Overall Resectability	
CT alone	143	121 (84.6)	22 (15.4)
MR imaging alone	138	117 (84.8)	21 (15.2)
CT plus MR imaging	126	18 (14)	108 (86)
		Vascular Invasion	
CT alone	118	42 (35.6)	76 (64.4)
MR imaging alone	115	41 (35.6)	74 (64.3)
CT plus MR imaging	103	37 (35.9)	66 (64.0)
		Lymph Node Involvement	
CT alone	108	59 (54.6)	49 (45.4)
MR imaging alone	105	55 (52.4)	50 (47.6)
CT plus MR imaging	95	50 (53)	45 (47)
		Liver Metastases	
CT alone	123	104 (84.6)	19 (15.4)
MR imaging alone	120	101 (84.2)	19 (15.8)
CT plus MR imaging	108	91 (84.2)	17 (15.7)

Note.—Numbers in parentheses are percentages. Percentages do not total 100 because of rounding.
* Surgical specimens were from truly unresectable lesions.
† Surgical specimens were from truly resectable lesions.

lihood that a finding was present: 4, finding definitely present; 3, finding probably present; 2, indeterminate; 1, finding probably absent; and 0, finding not present.

Diagnostic features included presence of peripancreatic vascular invasion (involvement of any one of the following vessels: celiac, hepatic, splenic, or superior mesenteric arteries or portal, splenic, and superior mesenteric veins); presence or absence of lymphadenopathy; and presence and character of hepatic masses. A global assessment of resectability was performed. For MR studies, the preferred pulse sequences to evaluate a specific parameter were given a subjective rank, and these rankings were compared. That is, the four pulse sequences were ranked in order from most useful (the sequence that provided the highest level of confidence for diagnosis) to least useful. Total room time (time from when the patient entered the scanning suite until he or she left the room) was recorded for both CT and MR imaging.

After the independent readings, CT scans and MR images were re-read together. Again, the readers did not know the surgical or pathologic examination findings. The data from these second readings were analyzed separately to assess the effect of additional imaging information on the performance of a given modality.

Interobserver variability was minimized by the creation of a reference set of images so each participating site had a set of images that displayed clear examples of abnormal findings in each of the categories evaluated. Interinstitutional variability was assessed at two separate combined-reading sessions at which the images and scans from one institution were read by investigators from other institutions.

Surgical Proof

The validity of the imaging findings was correlated directly with findings at laparotomy. The surgeon was aware of the imaging findings at the time of exploration. Surgeons completed data forms that were correlated with the imaging data. Each of the determinants of resectability (vascular invasion, lymphadenopathy, hepatic metastases) was examined. Surgeons indicated a finding as positive or negative on the basis of palpation alone without direct visual inspection or biopsy. Manual palpation of a pancreatic mass fixed to retropancreatic vessels or structures was considered adequate surgical proof of extrapancreatic invasion and of nonresectability. Liver lesions were localized regionally in a scheme identical to that used on the imaging forms. The validity of the imaging findings was determined at biopsy, visual inspection, or palpation. No attempt was made at surgery to visualize every liver lesion indicated on the imaging form. Intraoperative ultrasound was not performed. The dictated surgical report was included with the imaging data forms and filed with the patient's other forms.

Pathologic Analysis

Pathologic evaluation included notation of the size, location, appearance, and histologic features of the mass and associated complications (ie, pancreatitis). Lymph nodes sampled were categorized according to the standard pathologic classification, and the presence or absence of tumor was recorded. Infiltration of the pancreatic capsule was assessed, as was invasion of surgical resection margins. When the mass was not resected, the pathologist indicated the histologic nature of tissue sampled at biopsy. For patients who underwent needle biopsy, cytologic findings were proof of disease, and these findings were recorded on the pathologic examination report form.

Standards of Evidence

In the present study, we asked which imaging test is better in the diagnosis of resectable carcinoma of the pancreas. Resectability, as defined with standard surgical criteria, includes absence of substantial blood-vessel encasement, lymph node involvement, or hepatic metastases. Because of the high prevalence of unresectable pancreatic carcinoma, completely resected lesions and accompanying pathologic specimens were not always available; therefore, the standard of reference had to be varied. If a pancreatic tumor was completely resected, responses on pathologic examination forms were used as the standard of reference. If, at laparotomy, the surgeon believed the tumor could not be removed, the operative findings were used as the standard of reference.

For the purpose of data analysis, surgical specimens that showed vascular invasion, liver metastases, or lymph node metastases at pathologic examination were considered to be from truly unresectable lesions (positive). If none of the three determinants was present, the lesion was considered to be truly resectable (negative). For vascular invasion, lymph node involvement, and liver metastases, the standard of reference was the response on the pathologic examination form (yes or no). If this response was not available, the surgical assessment was used. These data are summarized in Table 1.

Data Analysis

The standardized forms on which clinical data, imaging findings, and surgical and pathologic examination results were recorded and the hard copy of all analyzed images were maintained in a central file at the offices of the American College of Radiology, Philadelphia, Pa. Before data were analyzed, forms were reviewed for completeness and logical consistency. MR images and CT scans were periodically reviewed in Philadelphia by a quality control committee to ensure compliance with the interinstitutional protocol. Final data analysis was performed at the Radiology Diagnostic Oncology Group statistical center, Department of Health Care Policy, Harvard Medical School, Boston, Mass.

Four aims were evaluated. The first was to determine the relative accuracies of CT and MR imaging in a global evaluation of the potential resectability of pancreatic adenocarcinoma. In this analysis, readers were asked to judge whether or not a lesion was unresectable regardless of the criteria met by that lesion. The second aim was to compare CT and MR imaging findings in the evaluation of components of resectability of pancreatic adenocarcinoma, including ability to depict perivas-

Table 2
Comparison of CT and MR Imaging Findings

Modality	Sensitivity	Specificity	Predictive Value		Accuracy
			Positive	Negative	
	Overall Assessment of Resectability*				
CT alone (n = 143)	0.77 (0.77–0.95)	0.50 (0.14–0.16)	0.89 (0.65–0.97)	0.28 (0.09–0.75)	0.73 (0.60–0.85)
MR imaging alone (n = 138)	0.74 (0.64–0.89)	0.43 (0.20–0.67)	0.88 (0.69–0.95)	0.23 (0.14–0.50)	0.70 (0.64–0.75)
	Vascular Invasion				
CT alone (n = 118)	0.47 (0.43–0.60)	0.69 (0.25–0.89)	0.89 (0.65–0.86)	0.28 (0.13–0.73)	0.73 (0.41–0.74)
MR imaging alone (n = 115)	0.47 (0.29–0.88)	0.68 (0.50–0.89)	0.88 (0.64–0.88)	0.23 (0.32–0.80)	0.70 (0.45–0.71)
	Lymph Node Involvement				
CT alone (n = 108)	0.37 (0.26–0.60)	0.60 (0.38–0.84)	0.47 (0.33–0.56)	0.56 (0.33–0.71)	0.53 (0.39–0.59)
MR imaging alone (n = 105)	0.34 (0.23–0.45)	0.76 (0.63–0.88)	0.57 (0.40–0.80)	0.56 (0.50–0.63)	0.56 (0.50–0.60)
	Liver Metastases				
CT alone (n = 123)	0.26 (0.00–1.00)	0.91 (0.71–0.98)	0.36 (0.00–0.50)	0.87 (0.80–1.00)	0.81 (0.74–0.88)
MR imaging alone (n = 120)	0.42 (0.00–1.00)	0.86 (0.64–0.95)	0.36 (0.00–0.67)	0.89 (0.83–1.00)	0.79 (0.69–0.82)

Note.—Numbers in parentheses are ranges.
* Sensitivity is proportion of correctly diagnosed unresectable tumors. Specificity is proportion of correctly diagnosed resectable tumors. Range is among participating institutions.

cular changes indicative of vascular invasion, clinically significant peritumoral or metastatic lymphadenopathy, and presence and characterization of hepatic metastases. The third aim was to determine if there was an increase in the accuracy of either test when both were read in combination. The fourth aim was to determine the most useful MR imaging pulse sequences for determining overall resectability and the three individual determinants of resectability.

Sensitivity was defined as the number (percentage) of correctly diagnosed unresectable lesions (imaging positive). Specificity was defined as the number (percentage) of correctly diagnosed resectable lesions (imaging negative). Sensitivities, specificities, and positive and negative predictive values were calculated to determine the agreement between surgical or pathologic and imaging findings (CT or MR imaging). In computation of sensitivity and specificity, degree-of-suspicion data were classified as follows: 1, normal; 2, probably normal; 3, indeterminate; 4, probably abnormal; and 5, abnormal. Scores of 1 and 2 were negative results; scores of 3–5 were positive results.

For the global assessment of resectability, CT and MR imaging data were compared with the McNemar test. Each of the variables of peripancreatic extension (major vessel invasion, liver metastases, lymph node enlargement) was studied with receiver operating characteristic (ROC) curve analysis (8,9). The curves were fit to CT and MR imaging rating data independently with use of a binormal model and the computer program ROCFIT (10). To compare CT and MR imaging findings, ROC curves for patients with complete CT and MR data sets were constructed with CORROC2 (8). Combined data from the four institutions were evaluated. The range of sensitivity, specificity, and accuracy across the institutions was also reported. To analyze the preferred pulse sequences, readers were asked to provide a subjective ranking of which of the four sequences resulted in images with the best level of confidence for diagnosis. The most highly ranked sequence was compared with the next highest ranked sequence by means of a multinomial test.

RESULTS

Overall (Global) Assessment of Resectability

One hundred forty-three patients had complete CT information (CT and pathologic examination or surgical standard-of-reference forms). One hundred thirty-eight patients had complete MR imaging and standard-of-reference forms. One hundred eleven patients had complete CT and MR imaging information. The specificity of CT in predicting resectability was 0.50 (11 of 22 resectable lesions), the sensitivity was 0.77 (93 of 121 unresectable lesions), and the accuracy was 0.73. The specificity of MR imaging in predicting resectability was 0.43 (nine of 21 resectable lesions), the sensitivity was 0.74 (87 of 117 unresectable lesions), and the accuracy was 0.70. The specificity was not significantly different between the two modalities (P = .99) and neither was the sensitivity (P = .84). When these data were converted into predictive values, both CT and MR imaging gave disappointing negative predictive values (0.28 for CT and 0.23 for MR imaging). The positive predictive values were high for both (0.89 for CT and 0.88 for MR imaging) (Table 2). The institutional ranges for CT prediction of nonresectability was 0.71–0.95, and the range for resectability was 0.14–0.86. The institutional range for MR prediction of nonresectability was 0.64–0.89, and the range for resectability was 0.20–0.67. The accuracy of CT ranged from 0.60 to 0.80 and that of MR imaging ranged from 0.64 to 0.75.

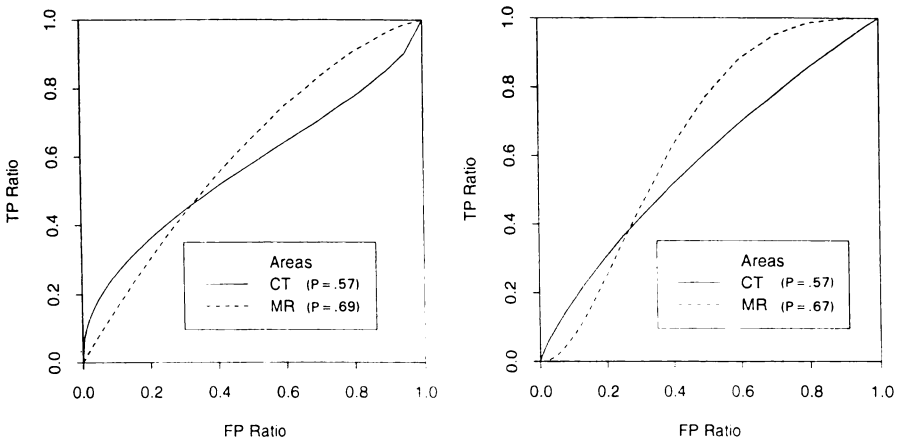
Vascular Invasion

One hundred eighteen patients with suspected vascular invasion had complete standard-of-reference and CT information; 115 had complete standard-of-reference and MR information; and 103 patients had complete CT, MR imaging, and standard-of-reference information. Sixty-four percent of the patients had vascular invasion confirmed at surgery or pathologic examination (Table 1). There was no statistically significant difference in the area (A) under the ROC curves calculated with CORROC (A_{CT} = 0.57 ± .07 [standard deviation], A_{MR} = 0.69 ± .08) for measuring vascular invasion (two-sided P value = .69) (Fig 1). Calculated sensitivities, specificities, accuracies, predictive values, and interinstitutional ranges are shown in Table 2.

The preferred pulse sequence rankings for MR imaging were equally divided among these ranked preferences: gradient-echo first, then T1-weighted followed by T2-weighted and STIR imaging; or T1-weighted first, followed by gradient-echo then T2-weighted and, last, STIR imaging. These sequences were preferred to the next highest ranking by a statistically significant margin (P < .001).

Lymph Node Involvement

Ninety-five patients with suspected lymph node involvement had complete



1. 2.

Figures 1, 2. ROC curves compare performances for (**1**) vascular invasion and (**2**) lymph node involvement. Differences between findings with CT and MR imaging were not statistically significant. *TP* = true-positive, *FP* = false-positive fractions.

Table 3
Results of Combined Modality Readings (n = 111)

Modality	Sensitivity	Specificity	Predictive Value		Accuracy
			Positive	Negative	
CT alone (n = 111)	0.77	0.50	0.90	0.33	0.77
MR imaging alone (n = 111)	0.74	0.43	0.88	0.26	0.73
CT plus MR imaging findings (n = 111)	0.82	0.35	0.88	0.26	0.72
MR imaging plus CT findings (n = 111)	0.83	0.35	0.88	0.27	0.76

Note.—Data are for only those patients who underwent imaging with both modalities to determine resectability.

CT, MR imaging, and standard-of reference information. Forty-seven percent of the patients had lymph node involvement confirmed at surgery or pathologic examination (Table 2). There was no significant difference in the areas under the individual ROC curves (A_{CT} = .57 ± .08, A_{MR} = .67 ± .09) for measuring lymph node involvement (two-sided P value = .41) (Fig 2, Table 2).

The readers preferred T1-weighted imaging first, followed by T2-weighted, STIR, and gradient-echo imaging, respectively, in assessment of lymph node involvement. T2-weighted images were preferred to the next highest ranking by a statistically significant margin (P < .001).

Liver Metastases

Approximately 15% of patients had liver metastases, limiting our ability to accurately fit ROC curves. CT helped identify liver metastases in five of 19 (26%) patients; MR imaging helped identify metastases in eight of 19 (42%) patients (P = .10) (Table 2). Comparable specificities were 0.91 for CT and 0.86 for MR imaging (P = .32). These values were not considered statistically different.

The readers ranked T2-weighted imaging first, followed by STIR, T1-weighted, and gradient-echo imaging, respectively, in assessment of liver metastases. This rank was not statistically different (P > .05) from the next highest ranking of STIR imaging first, then T2-weighted, T1-weighted, and gradient-echo imaging.

Effect of Knowledge of Findings with Alternative Modality on Interpretation (Combined Readings)

In the global assessment of curative resection, the sensitivity of CT increased when the scans were read with the MR images, but the specificity dropped (Table 3). Similar results were observed for MR imaging. Predictive values did not appreciably change for MR imaging; however, the negative predictive value for CT dropped from 0.33 to 0.26. Only 111 patients had complete imaging data for both primary and joint readings for the question of resectability.

When the data were compared with regard to vascular invasion, the areas under the ROC curves for CT and CT with knowledge of MR findings were essentially the same (0.60 and 0.63 [P = .51]). A similar situation was observed for MR imaging (0.61 and 0.66 [P = 0.40]). For the question of liver involvement, CT alone helped in correct identification of three of 15 instances, whereas CT and MR imaging helped in five of 15 instances. MR imaging alone helped in correct identification of seven of 15 instances, and MR imaging with CT findings helped in eight of 15 instances. When comparable analyses were performed for the detection of lymph node involvement, knowledge of the findings with the other modality had a negative effect on both CT and MR imaging diagnosis. The area under the ROC curve decreased from 0.63 to 0.56 (P = .10) for CT and from 0.67 to 0.54 (P = .10) for MR images when read with CT scans.

Room Time

The mean room time for the performance of CT was 25 minutes ± 13 (n = 136). The mean overall room time for MR imaging was 61 minutes ± 19 (n = 93). The signed rank statistic for comparison of CT and MR imaging room time was 10.6 (P = .0001). The difference was highly significant.

DISCUSSION

Use of imaging tests in the preoperative assessment of pancreatic carcinoma is established and accepted in clinical practice. In the United States, CT is the most frequently used imaging examination. Most literature on the subject has focused on the interplay between angiography and CT. Freeny et al report a series of 159 patients studied over a 6-year period in which CT helped in the correct identification of all unresectable tumors and findings with CT were more accurate than with angiography (11). Other authors corroborated these data, but findings in all series demonstrated the weakness of CT in identifying truly resectable lesions (12,13).

MR imaging provides cross-sectional images and has the potential for improved diagnosis based on inherent increase in tissue contrast. At the time of this study, relatively long imaging times were necessary at MR imaging and image degradation was caused by the inability to suppress biologic motion. Despite these shortcomings, some authors suggest that MR imaging is superior to CT in the diagnosis and prediction of resectability of pancreatic carcinoma (3–6). We devised our study to evaluate these two imaging modalities.

The results of the study did not show significant differences between CT and MR imaging in ability to predict resectability in patients with carcinoma of the pancreas. Furthermore, when the components of resectability are examined separately, neither modality demonstrates superiority over the other. Finally, our data did not show a difference in ability to predict resectability

when the tests were read alone or together.

The CT data were similar to those previously reported (11–13). In these series CT was shown to be excellent in predicting that lesions would be unresectable (positive predictive value, 90%) but failed when there were no CT findings indicative of unresectable disease (positive predictive value, 97%). Our results with CT (positive predictive value for nonresectability, 89%) concurred with those of these previous studies.

An 88% positive predictive value was established for MR imaging in our study. Fifteen patients considered to have unresectable tumors at CT or MR imaging underwent laparotomy and surgical resection for cure. Pathologic analysis corroborated the imaging findings by confirming the lesions to have been truly unresectable in 13 patients. These results emphasized the positive predictive value for nonresectability. However, cross-sectional imaging is poor in predicting that a tumor will be truly resectable (negative predictive value of 28% for CT and 23% for MR imaging).

Values for the individual components of resectability did not show statistically significant differences. The standards of reference are less than the total sample size for these components because a definitive answer (at either surgery or pathologic examination) was required to assess truth. Thus in a patient in whom there was, for example, a peritoneal implant, and the surgeon did not explore or palpate the pancreas, standard-of-reference information concerning vascular encasement or liver metastases may not have been obtained.

These data must be interpreted in the context of a multiple-institution effort. Whereas on one hand, the combination of data generates a large study population, inherent error is introduced because of the variety of readers. The ranges of responses over the participating institutions are shown in the Tables, and the great degree of variability is impressive. This phenomenon can limit the usefulness of multiple-institution readings. Data from multiple Radiology Diagnostic Oncology Group studies are being evaluated to determine the impact of varying expertise among radiologists. It is premature to derive any conclusions.

The MR image readers' preferential ranking of the pulse sequences was consistent. The differences between the pooled preferences was statistically significantly higher than the next series of possible choices. For overall evaluation of resectability, the readers preferred images obtained with T1-weighted sequences over those obtained with T2-weighted sequences. For vascular encasement, images obtained with gradient-echo sequences rated equally with those obtained with T1-weighted sequences. For lymphadenopathy, T1- and T2-weighted sequences were preferred; for liver metastases, T2-weighted and STIR were the preferred sequences. Therefore, with use of the available technology, the readers could have garnered sufficient information with T1- and T2-weighted spin-echo sequences. Although the gradient-echo and STIR sequences were useful for detecting vascular invasion and liver metastases, the readers did not feel compelled to choose them as exclusively necessary for answering a specific question.

We did not test each sequence independently; the rankings were based on the readers' subjective assessments after evaluating images obtained with all sequences. Thus it is not clear that, for example, findings for resectability on images obtained with a STIR sequence did not influence decisions about images obtained with a T1-weighted (the preferred) sequence. The number of MR sequences used is important because the room times for the examinations were significantly different, MR imaging taking slightly more than twice the time of CT.

The current study was designed to incorporate state-of-the-art pulse sequences, but these sequences are not state-of-the-art today. Mitchell et al gave details of the pancreatic anatomy with use of techniques such as fast spin-echo and fat-suppressed MR imaging (5). Recent articles (5,6) describe the use of fast MR imaging techniques coupled with enhancement with intravenously administered contrast material for evaluation of the pancreas. These sequences were not available at all sites during the period of the trial, nor had intravenous administration of gadopentetate dimeglumine been approved by the U.S. Food and Drug Administration for evaluation of pancreatic disease during the period of patient accrual. Recent results with manganese (II) *N,N'*–dipyridoxylethylenediamine-*N,N'*–diacetate 5,5'–bis-(phosphate) in the evaluation of pancreatic carcinoma are promising, but this agent has not yet begun phase III testing in the United States (14). Most MR imaging practices routinely use conventional spin-echo imaging as described in this study, although use of the fast techniques is rapidly spreading. Nonetheless, our data can be extrapolated to current general MR imaging practice.

Most clinicians consider the value of cross-sectional imaging in pancreatic cancer to be the ability to depict obviously unresectable disease. Findings with CT and MR imaging have been shown to be comparable in this group of patients. Because of the increased cost and room time associated with MR imaging and the inability to show improved performance when both CT scans and MR images are read together, CT should continue to be the procedure of first choice. Performance of MR imaging can be reserved for patients allergic to intravenously administered contrast material. According to reader preference, MR pulse sequences can be tailored, and images obtained with conventional spin-echo sequences can be relied on for diagnosis. We acknowledge that our results cannot take into account results with helical (spiral) CT or newer, faster, and less artifact-ridden MR imaging pulse sequences or the benefits of intravenously administered paramagnetic contrast media. ■

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