Color Doppler Imaging in the Assessment of Vascular Involvement by Pancreatic Carcinoma

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OBJECTIVE. The aim of our study was to assess the accuracy of color Doppler imaging in diagnosing the involvement of peripancreatic vessels by pancreatic carcinoma.

SUBJECTS AND METHODS. We prospectively evaluated the color Doppler images of 61 patients with pancreatic carcinoma. Our evaluations occurred before surgery and focused on vascular involvement. Absence of contact or a short contiguity (≤2 cm) between tumors and peripancreatic vessels was considered to be a sign of resectability on color Doppler imaging; a long contiguity (>2 cm), compression, encasement, or thrombosis was considered to be a sign of unresectability. In all patients, the sonographic diagnosis was compared with the surgical results.

RESULTS. With color Doppler imaging, we detected signs of vascular involvement in 26 of 33 patients in whom vascular involvement was found at surgery. We detected no vascular involvement in 25 of 28 patients in whom no vascular involvement was found at surgery. No false-positive diagnoses occurred when vascular encasement was revealed by color Doppler imaging. For diagnosis of vascular involvement, the sensitivity, specificity, and overall accuracy of color Doppler imaging were 79%, 89%, and 84%, respectively; positive and negative predictive values were 89% and 79%, respectively.

CONCLUSION. Color Doppler imaging is a sensitive and highly specific technique in assessing vascular involvement by pancreatic cancer when absence of contact or vascular encasement is seen. When vascular encasement is detected by color Doppler imaging, a definitive diagnosis of unresectability can be made, and further diagnostic procedures can be avoided. When sonography is used in the initial evaluation of pancreatic cancer, color Doppler imaging can improve the selection of patients for further diagnostic examinations or surgical exploration.

Recent epidemiologic studies show a progressive rise worldwide in the incidence of pancreatic cancer. It is now the fourth most common cause of cancer-related mortality in men [1]. Prognosis is poor, and only about 1% of the patients are still alive 5 years after diagnosis [2].

Surgical resection is the only effective therapy, but because of early involvement of local lymphatics, vessels, and peripancreatic fat tissue and distant metastatic spread, fewer than 20% of patients have surgically resectable tumors at clinical onset of symptoms and diagnosis [3–9].

Survival rates of patients undergoing surgical resection are low (approximately 5–10%); nevertheless, surgery together with intraoperative radiotherapy and chemotherapy may, in selected patients, increase the length of survival and provide a better quality of life [7, 10].

When distant metastases are absent, tumor involvement of the portal vein, mesenteric vessels, and celiac trunk is the major determinant against surgical resection [8, 11, 12]. A standard Whipple's procedure, or duodenopancreatectomy, carries a mortality rate of about 5% [13]. Careful screening of the peripancreatic vessels could avoid unnecessary surgery [14].

Sonography and CT are commonly used imaging techniques in the staging of pancreatic cancer. Both are useful in detecting distant spread but are less effective in evaluating vascular involvement, peritoneal disease, and small liver metastases [12, 15–17].

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Color Doppler imaging allows the simultaneous identification of pancreatic tumors and main peripancreatic vessels [18].

The aim of our study was to assess the accuracy of color Doppler imaging in evaluating local vascular involvement in patients with pancreatic cancer.

Subjects and Methods

Selection of Patients

Patients were selected from a group of 101 patients with pancreatic carcinoma who underwent color Doppler imaging at our institute from June 1991 to June 1995. Because 74 of the 101 patients (73%) were referred from other institutes, gray-scale sonography, CT, or both had already been obtained to rule out distant metastases, invasion of adjacent organs or peripancreatic fat tissue, or obvious vascular involvement, any of which would exclude surgical resectability.

From this group of patients, 31 were rejected for surgery and were excluded from the study because of evidence of advanced disease at the initial diagnostic screening (hepatic or lymph node involvement in 13, ascites in three, obvious vascular involvement in 13, and invasion of adjacent organs in two). Another four patients were excluded because of generally poor health. Five of the remaining 66 patients were not surgical candidates because superimposed bowel gas obscured the sonographic visualization of the pancreas.

In the remaining 61 patients, the color Doppler studies were considered to be technically adequate. All these patients underwent surgery that allowed evaluation of local vascular involvement.

Methods of Sonographic Examination

Three experienced radiologists unaware of the findings of the other imaging tests performed the studies using a color Doppler unit (Esaote Biomedica AU 590; Genoa, Italy) equipped with a 3.5-MHz convex probe. In thin patients with a depth of study less than 5 cm, a 5-MHz microconvex probe was applied.

The preliminary gray-scale sonographic examination documented the location, size, and morphology of the pancreatic mass, which was considered to be present when we identified a focal alteration of the pancreatic echotexture. The gray-scale examination also documented the spatial relationships between the mass and the peripancreatic vessels.

Using the color Doppler method, we evaluated the surgically relevant vessel in different spatial planes. In particular, the portal vein, superior mesenteric vein and artery, celiac trunk, and hepatic artery were examined. In patients with tumors of the pancreatic body or tail, the examinations extended to splenic vessels, although involvement of these vessels did not preclude surgery but required only a modification of surgical approach (total or partial pancreatectomy with splenectomy).

Each vessel was initially examined in the axial and sagittal planes. Oblique scans were then used to position the sonographic beam perpendicular to the plane of contact between the tumor and the vessel itself.

Gain and velocity settings of the color Doppler unit were adjusted to provide good color-filling of the vessel in all the spatial planes while avoiding generation of color artifacts within the tumor.

Next, the radiologist performing the diagnostic procedure prospectively evaluated the spatial relationships between tumors and peripancreatic vessels using both gray-scale and color Doppler imaging.

Absence of contiguity meant that the hyperechoic vascular wall was clearly depicted or that unaffected pancreatic parenchyma was seen between vessels and the hypoechoic pancreatic mass. The length of the tumor–vessel contiguity was measured along the vascular axis. Reduction of vascular lumen was considered to suggest vascular compression. Vascular encasement was indicated when hypoechoic tumoral tissue surrounded more than 50% of the vascular circumference.

Spatial relationships of each examined vessel were graded according to these sonographic criteria: grade 0, absence of contact; grade 1, short contiguity (≤2 cm); grade 2, long contiguity (>2 cm) or vascular compression; grade 3, encasement or thrombosis. The 2-cm cutoff value between sonographic grade 1 and sonographic grade 2 followed a preliminary retrospective study (Angeli et al., presented at the Italian Society of Radiology meeting, November 1992) that found this value to be best at predicting vascular involvement in patients with pancreatic cancer.

The highest grade of vascular involvement given to each patient was then used for data computation. Also, the original interpretation of the radiologist performing each imaging study was used in the assessment and grading of vascular involvement. For the final prediction of resectability, we considered sonographic grades 0 and 1 to be signs of no vascular involvement and sonographic grades 2 and 3 to be signs of positive vascular involvement.

Surgical Procedures

The surgeons were aware of the findings of the sonographic and other imaging tests. Surgical exploration comprised a visual inspection and manual palpation of the liver and omental peritoneum, followed by a careful search for metastatic adenopathy. Vascular involvement was generally studied by means of pancreatic head mobilization and dissection of the portal vein in the hepatoduodenal ligament and of the superior mesenteric vein at the mesenteric root.

The absence of vascular contiguity or minimal contact between the mass and the vessel itself without macroscopic vascular wall invasion was considered a surgical sign of no vascular involvement. Direct vascular invasion, encasement, or thrombosis made the tumors unresectable.

Results

Tumor Identification

In 56 (92%) of 61 patients, sonography identified the pancreatic tumor. Tumor size ranged in diameter from 1.5 to 8 cm (average, 3.7 cm). Of the detected tumors, 43 were in the head or neck of the pancreas and the remaining 13 were in the pancreatic body. All detected tumors were hypoechoic.

In five patients, a focal pancreatic mass was missed at the sonographic study despite good pancreatic visualization. No parenchymal lesion was observed in two of these patients, who were later found to have small tumors of the pancreatic head (<2 cm in maximum diameter). A nonspecific inhomogeneity in the pancreatic parenchyma was observed in the remaining three patients, who had superimposed chronic pancreatitis and pancreatic head tumors (n = 2) or diffuse pancreatic tumor (n = 1).

Vascular Involvement

At surgical exploration, 28 (46%) of 61 patients had resectable tumors, with no involvement of the peripancreatic vessels. Unresectable tumors were found in the remaining 33 patients (54%); liver metastases or peritoneal seeding was found in nine of them.

The results of color Doppler imaging in the different groups of patients are summarized in Figure 1 and are displayed in relation to the final surgical assessment of vessel involvement. In our analysis of the preoperative color Doppler study, we considered the vessels to be uninvolved in 32 patients (19 were grade 0; 13 were grade 1). The remaining 29 patients were classified as positive for vascular involvement (16 were grade 2; 13 were grade 3). Liver metastases and peritoneal seeding were observed in nine of the 13 patients with grade 3 involvement.

Absence of vascular involvement (sonographic grades 0 and 1) was revealed by color Doppler imaging in 25 of the 28 patients who were later found to have uninvolved vessels at surgical exploration (Figs. 2 and 3), yielding a specificity of 89%. All these patients subsequently underwent radical pancreatic resection. Conversely, signs of vascular involvement (sonographic grades 2 and 3) were seen on color Doppler imaging in 26 of 33 patients who later were found to have vascular involvement at surgery (Figs. 4–6), yielding a sensitivity of 79%. In 21 (81%) of these 26 patients with unresectable tumors, both arterial and venous involvement were present; therefore, many of these patients had only palliative biliary and gastric bypass.

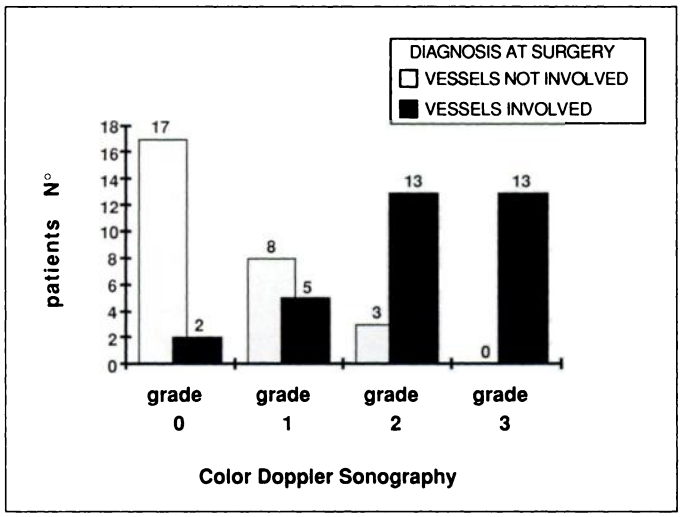

Fig. 1.—Results of color Doppler sonography in evaluation of vascular involvement by pancreatic carcinoma.

Seven patients with sonographic grade 0 (n = 2) or 1 (n = 5) were found to have involved vessels at surgery. Of these cases of false-negative diagnoses, surgery found the superior mesenteric vein to be involved in six, generally at the portal confluence; in four of these six, color Doppler imaging had shown short contiguity between tumor and vessel (sonographic grade 1). A reevaluation of two of these examinations showed a minimal interruption of the hyperechoic venous wall at the site of contact. In the fifth false-negative case, the tumor, which diffusely involved the pancreatic parenchyma, was not clearly distinguished at sonographic examination; consequently, the relationship between the tumor and the adjacent vessels could not be evaluated. The sixth false-negative case occurred at the beginning of our study and was attributed to lack of operator experience. In

Fig. 2.—Axial color Doppler sonogram of 62-year-old man reveals pancreatic head carcinoma separate from mesenteric vessels (sonographic grade 0). Note hyperechoic uninvolved pancreatic tissue between tumor (T) and mesenteric vessels. SMV = superior mesenteric vein, SMA = superior mesenteric artery.

Fig. 3.—Sagittal color Doppler sonogram of 58-year-old man shows short contiguity (sonographic grade 1) between tumor (T) of head of pancreas and superior mesenteric vein (SMV). We measured 18-mm contact length between tumor and vascular wall.

Fig. 4.—Sagittal color Doppler sonogram of 69-year-old woman shows long contiguity (27 mm, sonographic grade 2) between tumor (T) of pancreatic head and superior mesenteric vein (SMV). Vessel is moderately compressed by tumor.

A B

Fig. 5.—Encasement of superior mesenteric vein (SMV) by tumor of pancreatic body (sonographic grade 3) in 55-year-old man.
A, Axial color Doppler sonogram shows encasement of vessel by neoplasm (NPL).
B, Sagittal scan reveals complete longitudinal extension of tumor involvement.

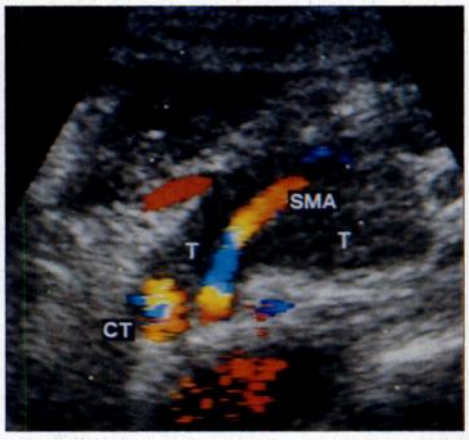

Fig. 6.—Sagittal color Doppler sonogram of 72-year-old woman shows encasement of superior mesenteric artery (SMA) and of origin of celiac trunk (CT) by pancreatic body tumor (T).

the remaining false-negative case, a small area of involvement of the celiac trunk from a tumor of the uncinate process of the pancreatic head was not detected with color Doppler imaging. In all seven of these patients the tumor involved a single vessel. In one patient a radical resection was performed, with a limited resection of the venous wall. A palliative resection of the tumor was performed in the remaining six patients, and the residual perivascular tumor was treated by intraoperative radiotherapy.

Three patients with sonographic grade 2 vessels had false-positive diagnoses. The tumors were not found to involve the vessels at surgery. On color Doppler imaging, tumors of the pancreatic head in these patients showed a long, 3- to 4-cm contact with the mesenteric vein in two cases or the portal vein in one case. At surgery, invasion of the venous wall could not be recognized, and a subtle cleavage was found between tumor and vessel.

No false-positive diagnoses occurred in the sonographic grade 3 group of patients.

For the final diagnosis of vascular involvement, 51 (84%) of the 61 patients were correctly staged by color Doppler imaging. In three patients (5%), vascular involvement was falsely considered to be present (overdiagnoses); in seven patients (11%), vascular involvement was falsely considered to be absent (underdiagnoses).

The positive predictive value of color Doppler imaging in assessing vascular involvement was 89%. The negative predictive value was 79%.

Discussion

Accurate staging before surgery is mandatory for correct therapeutic decisions in patients with pancreatic cancer [17]. In fact, surgical removal of the tumor is the only potentially curative approach in these patients. Correct tumor staging means detection of metastases in the lymph nodes, liver, peritoneum, or lungs and assessment of local tumor resectability. Among the parameters determining the feasibility of surgical resection, involvement of the main peripancreatic vessels is major. For this reason, the purpose of this study was to evaluate the color Doppler imaging technique in assessing this parameter in patients without advanced disease.

Several imaging methods have been used in recent years to assess the vascular involvement of pancreatic cancer. Until a few years ago, angiography was considered the reference technique [19, 20]. CT, which is less invasive and as accurate, later replaced it [11, 21].

Dynamic incremental CT and, more recently, helical CT are now the gold standards for diagnosis and staging of patients suspected of having pancreatic carcinoma [9, 11, 12, 15, 22]. Agreement exists among researchers about signs that are highly specific in predicting nonresectability, such as wall thickening or periarterial soft-tissue cuffing of the celiac axis or mesenteric artery [11, 17, 20, 23, 24]. Fewer researchers agree about CT sensitivity in the detection of vascular involvement: reported diagnostic sensitivity varies between 17% and 100% [11, 23]. One limit of CT technique, the axial acquisition, reduces the detection of vascular involvement along the scanning plane (mostly at the level of the hepatic artery and portal vein).

Some of these problems may be solved by MR imaging, a multiplane technique using fast imaging sequences and bolus infusions of contrast material [18, 22, 25], or MR angiography [26], but limited experiences have been reported.

Several other studies have described the capabilities and limits of sonographic evaluation of pancreatic cancer [17, 27–30]. In previous works, sonographic visualization of pancreatic tumors was considered unsatisfactory in 20–25% of patients because of the deep location of the tumors and a gastrointestinal superimposition [27]. Technologic improvements and operators' increasing skill have reduced the limitations of sonography. In our study population, 92% of the sonographic examinations were considered to be technically adequate, clearly depicting pancreatic masses.

Conversely, in only a few studies has the ability of sonography to show vascular involvement by pancreatic tumors been reported [28–31]. Sonography is the most frequently used method to initially investigate patients suspected of having pancreatic cancer and can accurately distinguish between obstructing and nonobstructing jaundice, the presenting symptom in most such patients. In a previous study, Kosuge et al. [30] described the sonographic detection of tumoral encasement of peripancreatic arteries as thickening and hyperechogenicity of perivascular fat tissue.

To our knowledge, only two references exist in the literature on the use of the duplex Doppler technique in the study of vascular involvement by pancreatic neoplasms [18, 31] and no studies have described the application of color Doppler imaging to such patients. In our experience, color Doppler imaging permits easy recognition of the peripancreatic vessels that had been barely visible with conventional sonography because of small caliber or deep location. When compared with CT, color Doppler imaging has the advantage of easy multiplanar scanning that permits correct evaluation of spatial relationships between tumors and vessels in the oblique and axial planes.

With our patients, color Doppler imaging allowed us to correctly predict surgical unresectability (presence of vascular involvement) in 79% of patients and surgical resectability (absence of vascular involvement) in 89% of patients. We achieved an overall accuracy of 84% with color Doppler imaging. These results are comparable with (and, at times, more sensitive than) data reported for CT. Major advantages of color Doppler examination over other, more complex staging techniques such as angiography, CT, and MR imaging are its low cost and the independence from contrast material administration.

All false-positive diagnoses occurred in grade 2 patients. No such false-positives occurred in grade 3 patients. Therefore, as already shown for CT, vascular encasement on color Doppler imaging was a specific sign of surgical unresectability.

Six of seven false-negative diagnoses occurred in patients with venous involvement and in four of the six represented understaging of short vascular contacts (sonographic grade 1) at the portal–mesenteric confluence. In some patients, a correct evaluation of spatial relationships between pancreatic cancer and the venous wall at the retropancreatic portion of the portal–mesenteric confluence can be limited by peripancreatic vessels that are deep. Therefore, surgeons must be aware of possible misdiagnoses in this group of patients. Also, according to a recent surgical opinion [9, 32], limited infiltration of the portal venous wall cannot be considered an absolute contraindication to surgical resection. In fact, limited vascular wall resections or complete portal vein resections with vascular graft interposition are now being performed. When limited venous wall involvement is suspected, and when other diagnostic techniques prove inconclusive, we recommend that endovascular sonography be performed, either before surgery (the transhepatic approach) or during surgery. In the preliminary experience of Kaneko et al. [32], this technique achieved 100% sensitivity, specificity, and accuracy in evaluating the portal–mesenteric venous confluence.

A limit of our study may be that surgeons performing the operations were aware of the

preoperative imaging findings and so could potentially be biased by the color Doppler results. Another bias may be introduced by our criteria for patients' selection; many patients (n = 31) with advanced disease at preoperative color Doppler imaging and CT were excluded from our study. Thus, we had a relatively small number of patients in the sonographic grade 3 group, a factor that may have affected the results obtained. Assuming that all patients with obvious vascular involvement (n = 13) had true-positive diagnoses of encasement, then the sensitivity and the positive predictive value of color Doppler imaging would have increased to 85% and 93%, respectively.

In conclusion, when a patient is initially evaluated with sonography and a pancreatic tumor is detected, a careful examination of the peripancreatic vessels using color Doppler imaging is mandatory to determine whether the vessels are involved. Our study found color Doppler imaging to be an accurate technique in predicting—rapidly and noninvasively—vascular involvement in patients with pancreatic cancer. This technique must be considered sufficient and reliable when vascular encasement is evident, because of the high staging specificity of this sign.

If the tumor is considered potentially resectable on the basis of sonographic and color Doppler imaging findings, radical surgery may be assumed to be a feasible solution, although most patients in this situation should continue diagnostic screening with a dynamic CT study or, even better, a helical CT study to look for distant metastases and to evaluate vascular involvement.

Possibly incorrect diagnoses of intermediate conditions such as tumor–vessel contiguity justify the use of other imaging techniques that focus on the vessels, such as MR imaging, angiography, endoscopic sonography, or endovascular sonography. In selected patients, the spatial information provided by color Doppler imaging can guide a more informed planning of such examinations (e.g., special scanning planes for MR imaging). Further studies will be required to understand the real capabilities of these imaging techniques for patients who have limited involvement of the vascular wall.

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