Half-Fourier RARE MR Cholangiopancreatography: Experience in 300 Subjects[1]

Ann S. Fulcher, MD
Mary Ann Turner, MD
Gerald W. Capps, MD
Alvin M. Zfass, MD
Kathy M. Baker, RN, MS

Index terms:
Acquired immunodeficiency syndrome (AIDS), 768.2068
Bile duct radiography, 76.1222
Bile ducts, calculi, 76.289
Bile ducts, diseases, 768.288
Bile ducts, MR, 76.12141
Bile ducts, neoplasms, 768.30, 768.33
Bile ducts, stenosis or obstruction, 76.28
Cholecystitis, 762.289
Endoscopic retrograde cholangiopancreatography (ERCP), 76.1222
Pancreatitis, 77.291

Radiology 1998; 207:21–32

Abbreviations:
AIDS = acquired immunodeficiency syndrome
ERCP = endoscopic retrograde cholangiopancreatography
MRCP = MR cholangiopancreatography
RARE = rapid acquisition with relaxation enhancement
SE = spin echo

[1] From the Departments of Radiology (A.S.F., M.A.T., G.W.C., K.M.B.) and Internal Medicine, Division of Gastroenterology (A.M.Z.), Medical College of Virginia of Virginia Commonwealth University, 12th and Marshall Sts, Box 980615, Richmond, VA 23298-0615. Received September 3, 1997; revision requested September 26; revision received November 20; accepted December 8. **Address reprint requests to** A.S.F.

Author contributions:
Guarantor of integrity of entire study, A.S.F.; study concepts, A.S.F.; study design, A.S.F.; definition of intellectual content, A.S.F., M.A.T., A.M.Z.; literature research, A.S.F.; data acquisition, A.S.F., M.A.T., G.W.C.; statistical analysis, K.M.B.; manuscript preparation, A.S.F.; manuscript editing, A.S.F., M.A.T., A.M.Z.

PURPOSE: To determine prospectively the clinical applications and diagnostic accuracy of half-Fourier rapid acquisition with relaxation enhancement (RARE) magnetic resonance (MR) cholangiopancreatography (MRCP) in a large patient population.

MATERIALS AND METHODS: Breath-hold, heavily T2-weighted half-Fourier RARE MRCP was performed in 265 patients with suspected pancreaticobiliary disease and in 35 control patients without symptoms or signs referrable to the biliary tract or pancreatic duct. MRCP findings were correlated with those at direct cholangiography, pathologic examination, cross-sectional imaging, and clinical follow-up.

RESULTS: Diagnostic MRCP examinations were obtained in 299 (99.7%) subjects. MRCP yielded an accuracy of 100% in determining the presence of pancreaticobiliary disease, the presence and level of biliary obstruction, and obstruction due to bile duct calculi. The accuracy of MRCP and MR imaging in determining the presence and level of malignant obstruction was 98.2%. MRCP obviated endoscopic retrograde cholangiopancreatography (ERCP) by excluding choledocholithiasis in patients with acute pancreatitis (n = 13) and nonspecific abdominal pain (n = 82). In patients with sclerosing cholangitis and acquired immunodeficiency syndrome cholangiopathy, MRCP depicted the biliary tract as clearly as did ERCP (n = 9). After failed ERCP, MRCP delineated the pancreaticobiliary tract and helped determine therapeutic options (n = 27).

CONCLUSION: Half-Fourier RARE MRCP enables accurate evaluation of pancreaticobiliary disease and obviates ERCP in some patients.

Since its introduction in 1991 (1), magnetic resonance (MR) cholangiopancreatography (MRCP) has emerged as an accurate, noninvasive alternative to endoscopic retrograde cholangiopancreatography (ERCP) in imaging the biliary tract and pancreatic duct. Several refinements have improved the ability of MRCP to generate high-quality images of the bile ducts and pancreatic duct (2–16). The most recent technical advance, the half-Fourier rapid acquisition with relaxation enhancement (RARE) sequence, permits rapid image acquisition (13 images in an 18–20-second breath hold) and reduces respiratory artifacts as well as susceptibility effects from bowel gas and metallic clips to a negligible level (13–16).

Although ERCP has long been considered the standard of reference for examining the biliary tract and pancreatic duct, the diagnostic accuracy of MRCP is comparable to that of ERCP in the evaluation of choledocholithiasis (3,4,8,12,13,15), malignant obstruction (2,3,11), anatomic variants of the biliary tract and pancreatic duct (5,6,10), and disease of the pancreatic duct (10,11,16). Unlike ERCP, MRCP can be performed in a rapid fashion without instrumentation and avoids the costly complications of ERCP, which include pancreatitis, sepsis, perforation, and hemorrhage.

In previous studies of MRCP, earlier versions of sequences have been used such as two-dimensional fast spin echo (SE) (3,5–7). To our knowledge, published reports of results with half-Fourier RARE MRCP have been limited to small patient populations. To define the usefulness of half-Fourier RARE MRCP in the evaluation of pancreaticobiliary ductal system, we examined 300 subjects. We then sought to determine the influence of this technique on clinical management decisions in a variety of disease processes.

MATERIALS AND METHODS

Study Population

Between March 1996 and July 1997, 300 subjects were examined with the half-Fourier RARE sequence. Investigational review board approval was not necessary because MR imaging was performed as part of the diagnostic evaluation of all subjects included in the study.

Thirty-five control patients (15 men, 20 women) who had no symptoms referrable to the biliary tract or pancreatic duct were examined to establish the ability of the technique to visualize normal-caliber ducts. Of the remaining 265 patients (137 men, 128 women) referred for MRCP, 180 had clinical findings suggestive of biliary or pancreatic ductal disease (abdominal pain, jaundice, elevated liver-associated enzymes consistent with an obstructive profile), nine had biliary or pancreatic ductal dilatation at ultrasonography (US) or computed tomography (CT), and 76 had both clinical and US or CT findings suggestive of biliary or pancreatic ductal disease. These 265 patients ranged in age from 9 to 95 years (mean, 50 years), whereas the 35 control patients without suspected pancreaticobiliary disease ranged in age from 25 to 80 years (mean, 58 years).

A radiologist (A.S.F. or M.A.T.) obtained a medical history for all subjects before MRCP. Study participants were screened for the presence of intracranial surgical clips, cardiac pacemaker, or metallic objects in the orbit. They did not fast before MRCP, and no antiperistaltic agents were administered.

Imaging Techniques

MRCP examinations were performed with a 1.5-T (Magnetom Vision; Siemens, Erlangen, Germany) (n = 20) or a 1.0-T (Magnetom Expert; Siemens) (n = 280) superconducting magnet programmed with the half-Fourier RARE sequence (HASTE; Siemens). A circularly polarized, phased-array body coil was used. Initially, the biliary tract and pancreatic duct were localized with a thick-slab (7-cm) half-Fourier RARE image in coronal-oblique (25°) and axial planes, which necessitated an acquisition time of 7 seconds. These images were then used as guides to evaluate the biliary tract and pancreatic duct with thin-slab (3–5-mm) sections in the coronal-oblique plane parallel to the long axis of the extrahepatic bile duct and pancreatic duct. The thin-slab MRCP acquisitions were obtained at various angles that allowed optimal visualization of the bile and pancreatic ducts; the number of thin-slab acquisitions per patient ranged from three to 15 (mean, seven acquisitions). Both the thick- and thin-slab images were obtained during breath hold.

The half-Fourier RARE parameters for the 1.5-T magnet included repetition time msec/echo time msec (effective) of ∞/95.0; echo train length, 128; flip angle, 150°; section thickness, 3.0 mm with no gap; field of view, 270 × 270 mm; number of signals acquired, one; matrix, 240 × 256; acquisition time, 20 seconds. The half-Fourier RARE parameters for the 1.0-T magnet included ∞/88.0; echo train length, 128; flip angle, 140°; section thickness, 5.0 mm with no gap; field of view, 270 × 270 mm; number of signals acquired, one; matrix, 240 × 256; acquisition time, 18 seconds. Thirteen images were obtained during each 18–20-second acquisition. Fat saturation and shim adjustments were used in all cases. Maximum intensity projection and multiplanar reformatting techniques were applied to the acquired data.

After MRCP, conventional MR imaging of the abdomen was conducted to examine the liver and pancreas. MR imaging sequences included unenhanced T1-weighted breath-hold spoiled gradient echo (148/5; flip angle, 70°; section thickness, 10 mm; gap, 30%), unenhanced and contrast material–enhanced T1-weighted fat suppression (200/4.4; flip angle, 70°; section thickness, 8 mm; gap, 20%), and unenhanced T2-weighted breath-hold fast SE (3,500/138; section thickness, 8 mm; gap, 25%). Gadopentetate dimeglumine (Magnevist; Berlex Laboratories, Wayne, NJ) was administered intravenously in a dose of 0.1 mmol per kilogram of body weight as a bolus followed by a normal-saline flush.

Direct cholangiography was performed in 106 cases (ERCP in 78, percutaneous transhepatic cholangiography in 14, T-tube cholangiography in 14, and intraoperative cholangiography in 10). Multiple cholangiograms were available for 10 patients. The time between performance of MRCP and direct cholangiography was less than 24 hours in 48 cases, 1–7 days in 24 cases, 7–30 days in 20 cases, and more than 30 days in 14 cases. All ERCP examinations were performed by gastroenterologists (A.M.Z. and others), with fluoroscopic monitoring and interpretation by nonstudy radiologists. The radiologist in attendance at ERCP recorded any pertinent endoscopic findings and included the findings in the dictated report. This information was not available to the radiologists who interpreted the MRCP images until the blinded review was complete. Intraoperative cholangiography was performed by surgeons, and results were interpreted by radiologists. Radiologists performed percutaneous transhepatic and T-tube cholangiography and interpreted the results. The radiologists involved in all of these studies were blinded to the MRCP findings.

MR Image Analysis

Two radiologists (A.S.F., M.A.T.) interpreted all MRCP images independently; discrepancies were resolved by consensus. In the control patients, the MRCP images were evaluated for delineation of the extrahepatic and intrahepatic bile ducts; gallbladder; cystic duct; and pancreatic duct in the head, body, and tail of the pancreas. The following grading system was used: excellent (complete delineation), good (nearly complete delineation), fair (partial delineation), poor (nonvisualization).

The same radiologists independently reviewed all MRCP source images and reconstructions for the 265 patients suspected of having pancreaticobiliary disease; diagnostic decisions were made from only the source images. The reviewers were blinded to cholangiographic and pathologic findings. The medical history, laboratory data, and cross-sectional imaging examinations (CT and US) were available to the reviewers at the time of image analysis. The MRCP images were evaluated for the presence, level, and cause of obstruction; this interpretation was conducted in conjunction with analysis of the conventional MR images. Standard cholangiographic criteria were used to differentiate benign and malignant strictures. In all cases, image review was performed both from an interactive workstation and from hard-copy images. Discrepancies were resolved by consensus.

After image analysis, the radiologists correlated the MRCP findings with the direct cholangiographic (n = 106), pathologic (n = 30), and cross-sectional imaging (n = 265) findings. In those patients for whom cholangiographic or pathologic correlation was unavailable, clinical follow-up was conducted by means of chart review and interviewing of the referring physician. The mean duration of clinical follow-up was 9 months (range, 4–14 months).

Statistical Analysis

The sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of MRCP in detecting the presence of pancreaticobiliary disease in

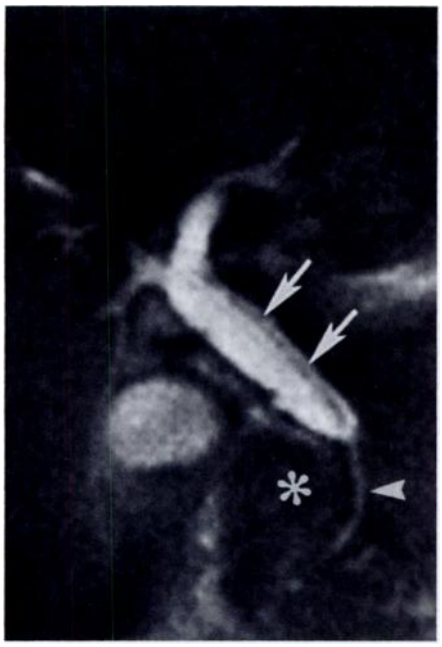


Figure 1. Biliary stent in a 41-year-old man with pancreatic carcinoma. MRCP image shows a stent (arrows) in the dilated extrahepatic bile duct. Fluid fills the stent in the intrapancreatic portion of the bile duct (arrowhead), which is surrounded by the mass of the pancreatic head (*). Note the absence of artifacts associated with the stent.

general were calculated for the patients referred with suspected disease (264 patients [findings at MRCP were nondiagnostic in one patient]). In addition, the sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of MRCP in determining the presence and level of biliary obstruction of all causes were calculated in patients with direct cholangiographic or pathologic correlation or both (n = 106) or only pathologic (n = 11) correlation, as well as in two subtypes of biliary obstruction—bile duct calculi and malignancy. The differences between MRCP and direct cholangiographic findings in those patients who underwent both examinations were tested for statistical significance by using the χ^2 test. The total true-positive findings and the total true-negative findings from the MRCP examinations were used as our actual results. The total true-positive findings and the total true-negative findings from the ERCP examinations were used as our expected results.

RESULTS

Technical Considerations

The biliary tract and pancreatic duct were visualized in 299 MRCP examinations. MRCP findings were not diagnostic in one patient with severe cirrhosis and marked biliary ductal distortion. Surgical clips, biliary and pancreatic duct stents, metallic intrahepatic shunts, arterial embolization coils, large amounts of bowel gas, ascites, and spinal fixation rods were present in 78 (26%) of the 300 subjects but did not affect image quality (Fig 1). In one ventilator-dependent patient, findings were diagnostic at MRCP with complete visualization of the biliary tract and pancreatic duct despite the lack of breath holding. In four patients, the phased-array body coil could not be used owing to obesity, but findings were diagnostic at MRCP.

The mean imaging room time for MRCP was 15 minutes, and the mean imaging time was 2.4 minutes. Because of the short examination time, critically ill and claustrophobic patients could cooperate for the MRCP examination. Fifteen patients gave a history of claustrophobia and initially believed they would not be able to complete the examination. When the short examination time was explained, however, all 15 were willing to attempt entry into the magnet, and the examination was completed in 11. The remaining four patients underwent MRCP after sedation (alprazolam [0.5 mg orally]).

Control Patients

Half-Fourier RARE MRCP permitted visualization of the entire extrahepatic bile duct in all control patients (n = 35) and of the proximal (inner one-half) intrahepatic bile ducts in 31 (89%) (Table 1). Peripheral intrahepatic bile ducts were not visualized. The pancreatic duct in the head and body were completely visualized in 97%, whereas the duct in the tail was completely visualized in 83%.

Patients Suspected of Having Pancreaticobiliary Disease

Of the 300 subjects who underwent half-Fourier RARE MRCP, 265 were referred with clinical or biochemical findings suggestive of obstruction (ie, abdominal pain, jaundice, elevated liver-associated enzymes), biliary or pancreatic duct dilatation, or both at US or CT. Table 2 summarizes the major MRCP findings, which were correlated with direct cholangiographic (n = 106), only pathologic (n = 11), direct cholangiographic and pathologic (n = 19), cross-sectional imaging (n = 265), and clinical follow-up (n = 265) findings. MRCP demonstrated a sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of 100% each in detecting the presence of pancreaticobiliary disease (Table 3).

In those subjects who underwent both MRCP and direct cholangiography (n = 106), the χ^2 test was employed to determine the statistical significance of differences between MRCP and ERCP findings. It was determined that there was no statistical difference between our actual and expected results. Because there was a perfect correlation between both the actual and expected results, our findings were significant at the 99% confidence level ($P < .001$).

Biliary Obstruction—All Causes

Among the 106 patients with direct cholangiographic correlation and 11 with only pathologic correlation (19 patients had both), findings at MRCP were true-positive in 64 for the presence and level of biliary obstruction of all causes and were true-negative in 53 (Table 3).

Calculous Obstruction

Fourteen (5%) of the 265 patients referred for evaluation of suspected obstruction were found to have MRCP evidence of biliary tract stones. Seven of these patients had undergone US and seven, CT; in only two were the biliary calculi detected. Direct cholangiographic correlation was available in all 14: ERCP (n = 9), percutaneous transhepatic cholangiography (n = 3), intraoperative cholangiography (n = 1), or cholecystostomy tube cholangiography (n = 1). The direct cholangiograms confirmed the presence, location, and number of stones (single vs multiple) in 13 of the 14 patients, and no discrepancies were noted between MRCP and ERCP. In one case, a common bile duct calculus was not depicted at diagnostic ERCP; it was detected only after a balloon catheter was passed through the duct.

Nine of the 14 patients had common bile duct stones (six, single stones; three, multiple) (Fig 2). The stones ranged in maximum diameter from 2 to 20 mm (mean, 9 mm), whereas that of the bile ducts ranged from 5 to 25 mm (mean, 14 mm). In three patients, the stones were located in a nondilated duct. The smallest stone detected with MRCP was 2 mm in diameter and was located in a dilated extrahepatic bile duct. The smallest stone detected in a nondilated duct was 3 mm in diameter (Fig 3). None of the nine patients had intrahepatic biliary calculi.

Five of the 14 patients had one (n = 2) or more (n = 3) intrahepatic stones. In four of these patients, the stones occurred

proximal to biliary-enteric anastomotic strictures, whereas in the last patient, the stone was located above a common hepatic duct stricture associated with AIDS cholangiopathy. In one patient, a 1-cm-diameter stone located above an anastomotic stricture was clearly delineated with MRCP but was difficult to detect with percutaneous transhepatic cholangiography. All four patients with stones proximal to anastomotic strictures underwent surgery, at which the presence of the stones and the level and cause of the obstruction was confirmed. None of the five patients with intrahepatic stones had common bile duct stones.

Of the 265 patients referred for suspected pancreaticobiliary disease, 106 underwent direct cholangiography. In this group of 106, no biliary calculi were detected that were not also detected at MRCP. Half-Fourier RARE MRCP demonstrated a sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of 100% each in the detection of biliary calculi (Table 3).

Thirteen of the 265 patients with pancreaticobiliary symptoms presented with acute pancreatitis of unknown cause, and they underwent MRCP to exclude gallstones as a cause. Of the 13 patients, four had undergone cholecystectomy owing to gallstones. Of the remaining nine patients, both MRCP and US demonstrated gallbladder calculi in six and no gallbladder calculi in three. MRCP demonstrated no evidence of choledocholithiasis in any of the 13 patients. Because of acute pancreatitis, no patient underwent ERCP. The patients were treated medically, and all clinical, biochemical, and cross-sectional imaging findings returned to normal. The cause of pancreatitis was established in only two patients (medication-induced disease in one, and hypertriglyceridemia in the other).

Malignant Obstruction

Thirty-two patients referred for MRCP had malignant biliary or pancreatic ductal obstruction that was confirmed with direct cholangiographic (n = 23), pathologic (n = 15), and/or cross-sectional imaging (n = 32) studies (Table 4). The findings at direct cholangiography (n = 106) and pathologic examination (n = 11) were correlated with the MRCP findings. This correlation revealed a sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of 100%, 97.6%, 98.2%, 94.1%, and 100%, respectively, for the MRCP determination of the presence of a malignant obstruction (Table 3).

TABLE 1
Visualization of the Pancreaticobiliary System with MRCP in 35 Control Patients without Suspected Pancreaticobiliary Disease

Structure Visualized	Visualization			
	Excellent	Good	Fair	Nonvisualization
Bile duct bifurcation	31 (89)	4 (11)	0 (0)	0 (0)
Extrahepatic bile duct	35 (100)	0 (0)	0 (0)	0 (0)
Gallbladder*	31 (100)	0 (0)	0 (0)	0 (0)
Cystic duct	32 (91)	2 (6)	0 (0)	1 (3)
Pancreatic duct				
Head	34 (97)	1 (3)	0 (0)	0 (0)
Body	34 (97)	0 (0)	1 (3)	0 (0)
Tail	29 (83)	6 (17)	0 (0)	0 (0)

Note.—Data are numbers of patients. Data in parentheses are percentages.
* Four patients had undergone cholecystectomy.

The duct proximal and distal to the malignant stricture was visualized in all cases (Fig 4). In determining the level of malignant obstruction, MRCP demonstrated a sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of 100% each. Obstruction was noted in the intrahepatic ducts (n = 1); the proximal extrahepatic bile duct (n = 13); the middle extrahepatic bile duct (n = 3); and the distal extrahepatic bile duct, the pancreatic duct, or both (n = 15).

MRCP enabled correct determination of the type of malignant obstruction in 31 of the 32 patients. One patient had a high-grade stricture of the proximal extrahepatic bile duct and a normal-appearing gallbladder that was diagnosed as cholangiocarcinoma at MRCP. Pathologic examination of the surgical specimen revealed adenocarcinoma of the gallbladder neck with extension to the extrahepatic bile duct; no gallbladder obstruction was present during surgery. This error in determining the type of tumor did not affect patient treatment; the patient was scheduled to undergo surgery owing to the absence of nodal and distant metastases at MR imaging, CT, and US.

MRCP was used in conjunction with unenhanced and contrast-enhanced fat-saturation T1-weighted imaging of the abdomen to determine the cause and extent of the obstructing lesions. MRCP and conventional MR images depicted resectable neoplasms in five (16%) of 32 patients and obviated ERCP and stent placement before surgery. In most instances, conventional MR images helped determine tumor extent without the use of MRCP images. However, in one patient with hilar cholangiocarcinoma in whom conventional MR images showed no evidence of a mass or ductal wall thickening, MRCP demonstrated tumor extending proximally to involve the right and left intrahepatic bile ducts, making the disease unresectable (Fig 5).

TABLE 2
Disease Categories Identified at MRCP in 265 Patients Suspected of Having Pancreaticobiliary Disease

Disease Category	No. of Patients
Biliary calculi	14
Malignant obstruction	32
Chronic pancreatitis	36
Primary sclerosing cholangitis	6
AIDS* cholangiopathy	3
Postoperative biliary anatomy	23
Congenital anomalies	15
Pathologic gallbladder	37
Nonobstructive bile duct dilatation	16
None (normal)	82
Nondiagnostic study	1
Total	265

* AIDS = acquired immunodeficiency syndrome.

In two of the 265 patients suspected of having pancreaticobiliary disease, MRCP showed pancreatic duct dilatation and stricture of the intrapancreatic bile duct in conjunction with a pancreatic head mass that was suggestive of carcinoma. In one patient, subsequent ERCP added no information to findings at MRCP. Both patients underwent correlative imaging (MR imaging, CT, and endoscopic US) that revealed pancreatic head enlargement but did not permit differentiation of a malignant mass from focal pancreatitis. Findings at surgical and cytopathologic analysis revealed no evidence of malignancy in these two patients, but focal pancreatitis was documented.

TABLE 3
Analysis of Findings at MRCP in the Diagnosis of Pancreaticobiliary Disease, Biliary Obstruction, Bile Duct Calculi, and Malignant Obstruction

Disease	True-Positive*	True-Negative*	False-Positive*	False-Negative*	Sensitivity†	Specificity†	Accuracy†	Positive Predictive Value†	Negative Predictive Value†
Pancreaticobiliary disease of all causes									
Presence	182	82	0	0	100	100	100	100	100
Level	182	82	0	0	100	100	100	100	100
Biliary obstruction of all causes									
Presence	64	53	0	0	100	100	100	100	100
Level	64	53	0	0	100	100	100	100	100
Bile duct calculi									
Presence	14	92	0	0	100	100	100	100	100
Level	14	92	0	0	100	100	100	100	100
Malignant obstruction									
Presence	32	83	2	0	100	97.6	98.2	94.1	100
Level	32	85	0	0	100	100	100	100	100

* Data are numbers of cases.
† Data are percentages.

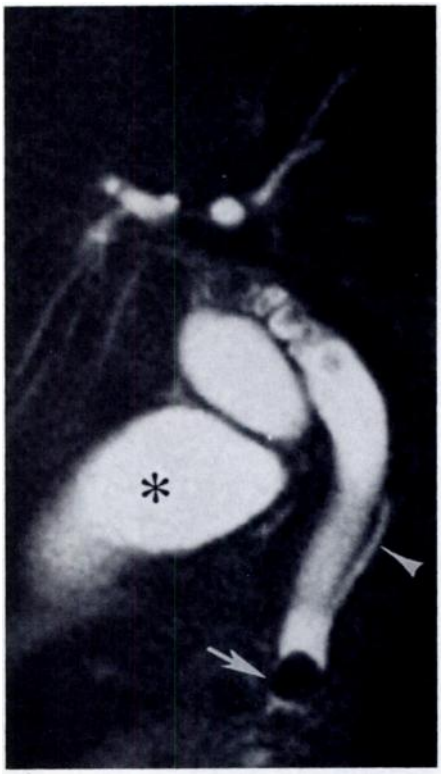


Figure 2. Single common bile duct calculus in a 52-year-old woman who had abdominal pain and nondiagnostic US findings. MRCP image demonstrates a 1.2-cm-diameter calculus (arrow) impacted in the distal common bile duct with extrahepatic and intrahepatic biliary ductal dilatation. The gallbladder (*) and pancreatic duct (arrowhead) are visualized.

Chronic Pancreatitis

In 36 patients, MRCP demonstrated characteristic findings of chronic pancreatitis, including enlargement of the pancreatic duct (>3 mm) and side-branch ectasia (Fig 6). The entire pancreatic duct was visualized in all but one patient in whom the duct in the body and tail of the pancreas was obscured by a 15-cm-diameter pseudocyst.

Among these 36 patients, no discrepancies were noted between MRCP and ERCP findings in 14 patients for whom direct cholangiographic correlation was available. Eight of 22 patients without cholangiographic correlation had experienced a failed or incomplete ERCP examination. The remaining 14 patients were referred for MRCP rather than ERCP to obviate ERCP-induced pancreatitis. In three of the 22 patients without cholangiographic correlation, surgical confirmation of chronic pancreatitis was available. Among the others, findings at US (n = 3), CT (n = 14), or both (n = 2) supported the presence of chronic pancreatitis.

In six patients, MRCP depicted intraductal stones (2–8 mm), which were confirmed at ERCP (n = 3) and CT (n = 3). In two additional patients, MRCP evidence of pancreatic duct strictures was confirmed at ERCP. Seventeen of the 36 patients had biliary duct dilatation secondary to stricture formation (n = 16) or extrinsic compression due to a pseudocyst (n = 1). The two pancreatic duct strictures and the 16 bile duct strictures were correctly identified as benign strictures by the blinded reviewers.

Intrahepatic Bile Duct Disease

Two types of intrahepatic bile duct disease were evaluated with MRCP: primary sclerosing cholangitis (n = 6) and AIDS cholangiopathy (n = 3). Five of the patients with primary sclerosing cholangitis underwent ERCP. MRCP showed the third-order bile ducts in all six patients and permitted more complete visualization of the ducts than did ERCP in four patients. In the ducts visualized at MRCP and ERCP, there were no discrepancies regarding the extent or severity of disease.

In the three patients with AIDS cholangiopathy, MRCP depicted the third-order bile ducts in addition to stenoses (Fig 7). In two patients, ERCP was performed and there was no discrepancy with the MRCP findings. None of the patients with AIDS cholangiopathy had papillary stenosis or polypoid filling defects in the bile ducts.

Postoperative Biliary Anatomy

Twenty-three patients examined with MRCP had surgically altered biliary anatomy: duct-to-duct anastomosis for liver transplantation (n = 11), duct-to-duct anastomosis for penetrating trauma (n = 1), choledochojejunostomy for liver transplantation (n = 2), choledochoduodenostomy for malignant disease (n = 1), choledochojejunostomy for malignant disease (n = 2), and choledochojejunostomy after bile duct injuries related to cholecystectomy and blunt trauma (n = 6).

In the 12 patients with a duct-to-duct anastomosis, the duct proximal and distal to the anastomosis was visualized in addition to the anastomosis itself. In this patient group, MRCP enabled identification of common duct stones (n = 1), ductal irregularity attributed to ischemia (n = 2), recurrent primary sclerosing cholangitis (n = 1), and a plication defect at the anastomosis that mimicked a calculus

(n = 1); these findings were confirmed at direct cholangiography. No disease was detected at MRCP in the remaining eight patients. Five of the eight had cholangiographic correlation, and no discrepancy was noted between the MRCP and direct cholangiographic findings.

Among the 11 patients with biliary-enteric anastomoses, the biliary tract was delineated in all and the anastomosis was visualized in 10. In the one patient in whom the anastomosis was not seen, metastatic pancreatic carcinoma obscured the anastomosis.

Congenital Anomalies

Fifteen patients had congenital anomalies of the pancreaticobiliary system. Nine of the 15 patients had pancreas divisum; cholangiographic correlation was available for six. MRCP depicted ventral pancreatic ducts as small as 1 mm in diameter. The remaining patients had type 1 choledochal cyst (n = 2), aberrant right hepatic duct (n = 1), Caroli disease (n = 1), situs inversus (n = 1), and duodenal duplication and accessory pancreatic lobe (n = 1). Findings in the patients with choledochal cysts and duodenal duplication with an accessory pancreatic lobe were confirmed at both direct cholangiography and surgery. A low and medial insertion of the cystic duct into the bile duct was noted in eight patients.

Gallbladder Disease

Of the 265 patients, 65 had undergone cholecystectomy. Although none of the patients with intact gallbladders fasted before imaging, the gallbladder was visualized at MRCP in all but one patient. In this patient, chronic cholecystitis, which was confirmed surgically, accounted for the inability to visualize the gallbladder. In two patients, the gallbladder was barely detectable owing to marked contraction and multiple low-signal-intensity calculi within it.

The diagnosis of gallbladder calculi was made when discrete, low-signal-intensity foci were seen in the gallbladder lumen. Calculi were identified in 34 patients and were confirmed at cross-sectional imaging, surgery, or both. The calculi ranged in diameter from 2 to 25 mm. In three patients, calculi identified at MRCP were not depicted at US (n = 2) or CT (n = 1) but were detected at surgery. In one of the cases in which US failed to depict a calculus, a 1.8-cm-diameter stone located in the gallbladder neck had been obscured by bowel gas. In the second case, the patient's morbid obesity resulted in nondiagnostic US. In the third case, CT failed to depict a completely calculus-filled gallbladder owing to the low attenuation of the stones.

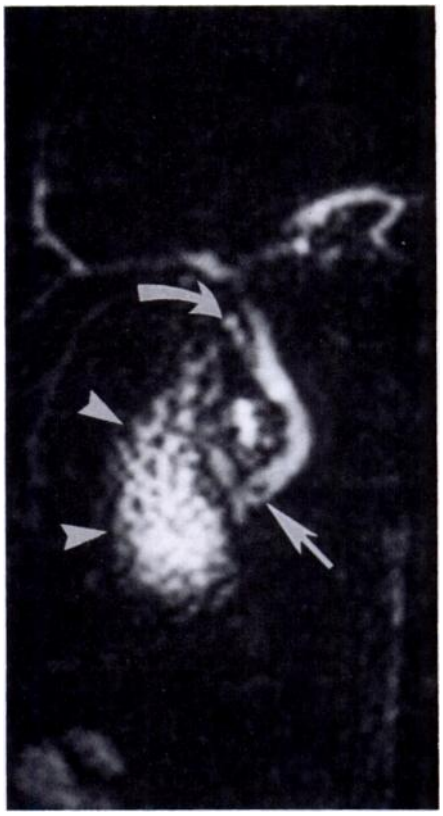


Figure 3. Small distal bile duct calculus in an 18-year-old woman with a 1-year history of recurrent abdominal pain and negative CT findings. **(a)** Scout MRCP image shows a 3-mm-diameter calculus (straight arrow) in the distal bile duct and multiple, small gallbladder calculi (arrowheads). The cystic duct (curved arrow) is noted. **(b)** ERCP image confirms the distal bile duct calculus (arrow) and the multiple gallbladder calculi (arrowheads).

In four patients, low-signal-intensity material was noted in the dependent portion of the gallbladder and was attributed to layering sludge and/or minute calculi. US showed layered material in the gallbladders of three patients.

In five patients, adenomyomatosis was diagnosed at MRCP when minute fluid-filled outpouchings were noted to arise from the gallbladder wall. The adenomyomatosis was fundal in four patients and diffuse in one patient; this diagnosis was confirmed at US in three patients.

Failed or Incomplete ERCP Examinations

In 27 of the patients who were examined with MRCP and ERCP, ERCP failed or was incomplete because the entire biliary tract and pancreatic duct were not opacified. In four patients, congenital and anatomic alterations were responsible. These included a periampullary diverticulum, gastric outlet obstruction due to gastric adenocarcinoma (Fig 8), and duodenal stenosis secondary to radiation-induced fibrosis. One patient experienced failed ERCP due to a Billroth II procedure. In the remaining 23 patients, no anatomic cause for the failed or incomplete cannulation was apparent. For all 27 patients, the referring physicians used information provided at MRCP to determine therapeutic options, which ranged from clinical surveillance to surgical intervention.

Nonobstructive Bile Duct Dilatation

In 16 patients, dilatation of the biliary tract without evidence of an obstructing lesion was demonstrated at MRCP. These patients presented with nonspecific abdominal pain or biliary dilatation incidentally detected at CT or US; all had normal liver-associated enzymes. Five of these patients underwent direct cholangiography, which confirmed both the dilatation and absence of an obstructing lesion. The remaining 11 patients were followed up clinically, did not require further evaluation, and did not show clinical or biochemical evidence of obstruction.

TABLE 4
Malignant Biliary or Pancreatic Ductal Obstruction Diagnosed at MRCP in 32 Patients

Source of Obstruction	No. of Cases
Pancreatic carcinoma (n = 14)	
Head	13
Body	1
Cholangiocarcinoma	7
Nodal metastasis	6
Gallbladder carcinoma	2
Hepatocellular carcinoma	1
Hepatic metastasis	1
Pancreatic metastasis	1
Total	32

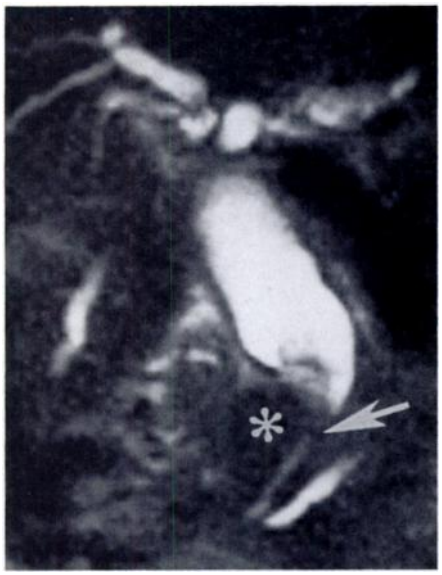


Figure 4. Pancreatic head mass caused bile duct dilatation in a 66-year-old woman. MRCP image demonstrates high-grade stricture of the intrapancreatic bile duct (arrow) with an irregular margin. Note that the strictured duct is visualized within the mass (*).

Normal Bile and Pancreatic Ducts in Symptomatic Patients

Eighty-two patients with right upper quadrant or midabdominal pain, normal or only transient elevation of liver-associated enzymes, and a low clinical suspicion for choledocholithiasis were referred for MRCP. MRCP showed no evidence of choledocholithiasis or other abnormality of the biliary tract, pancreatic duct, or gallbladder in any of the 82 patients. Twenty of these patients underwent ERCP, at which the absence of abnormalities was confirmed. Because the probability of pancreaticobiliary tract disease was too low in the remaining 62 patients to warrant ERCP, this group was followed up clinically and did not require intervention or further radiologic examination. Findings at clinical follow-up of this group conducted 4–14 months after MRCP revealed that a nonpancreaticobiliary source of the abdominal pain was discovered or that the pain resolved spontaneously.

DISCUSSION

Until recently, the noninvasive evaluation of patients suspected of having biliary tract obstruction was limited to US and CT. Whereas these modalities are sensitive in the detection of obstruction, direct cholangiography, particularly ERCP, remains the standard of reference for visualizing the biliary tract and pancreatic duct and for defining the cause of obstruction. However, direct cholangiography is operator dependent and is associated with risks and complications such as pancreatitis. MRCP offers an alternative to ERCP as a noninvasive, easily performed outpatient technique that allows direct visualization of the biliary tract while avoiding the complications of direct cholangiography.

MR cholangiography was introduced in 1991 by Wallner et al (1), who used a two-dimensional, breath-hold, gradient-echo sequence to image the biliary tract. Owing to limitations of this method, two-dimensional fast SE techniques were developed that resulted in improved spatial resolution, reduced sensitivity to motion, and reduced magnetic susceptibility effects (3,5–7). Later, a respiratory-triggered, three-dimensional, fast SE sequence proved to be sensitive and specific for evaluating the biliary tree and pancreatic duct (4,8–10). More recently, a half-Fourier acquisition single-shot turbo SE (half-Fourier RARE) sequence has been shown to be superior to earlier imaging methods, with results that equal the diagnostic capability of direct cholangiography (12–16).

With half-Fourier RARE MRCP, imaging time is dramatically reduced so 13 images are obtained during an 18–20-second breath hold. The breath-hold technique eliminates artifacts arising from respiratory motion. In addition, half-Fourier RARE MRCP is associated with negligible susceptibility effects from bowel gas and metallic foreign bodies (eg, surgical clips) owing to the narrow spacing of the radio-frequency refocusing pulses. Finally, although the half-Fourier RARE sequence was originally limited to a 5-mm section thickness, recent technical advances allow acquisition of sections as thin as 2 mm.

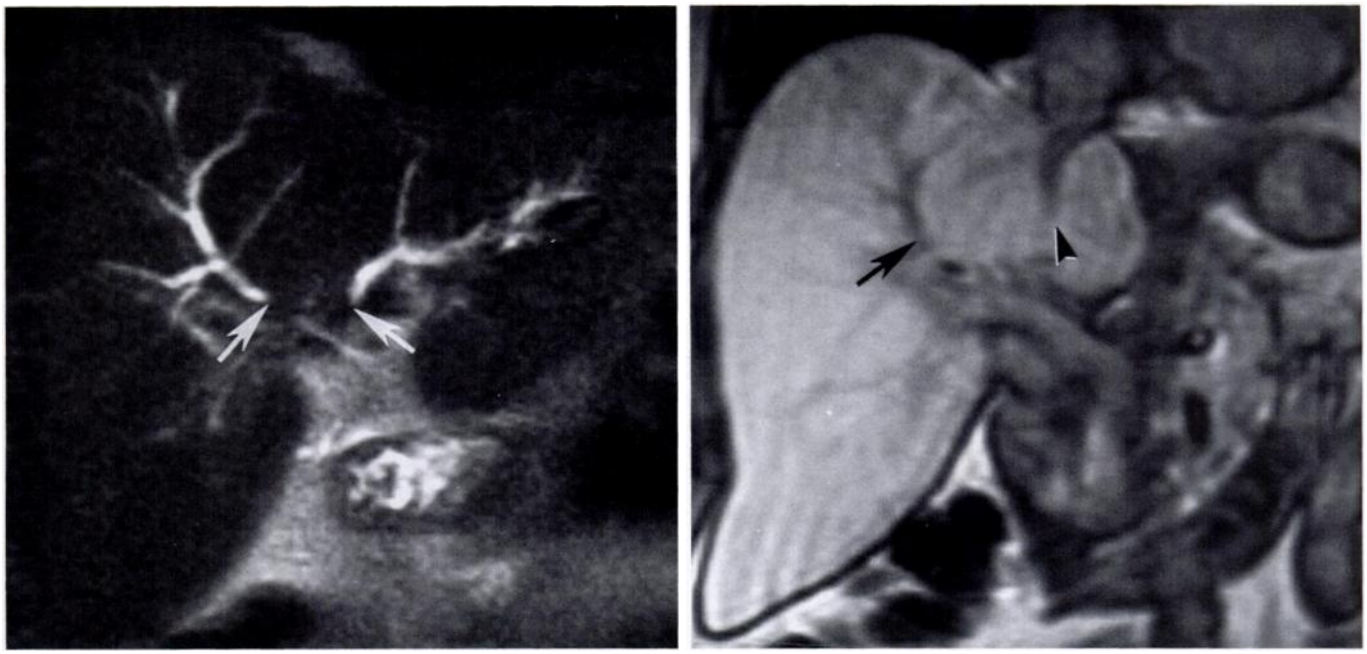
In our study, half-Fourier RARE MRCP clearly imaged the biliary tract and pancreatic duct in 299 of 300 subjects. The biliary tract and pancreatic duct were considered optimally delineated when these structures were displayed along their longitudinal axes in the coronal-oblique plane. Even when patients could not cooperate for the entire breath hold, the images were diagnostic and reproducible owing to the breathing-independent nature of the half-Fourier RARE sequence. Although surgical clips, stents, metallic shunts, or embolization coils were present in 26% of the subjects examined, these did not impair visualization of the biliary tract or pancreatic duct.

The quality of the MRCP examinations was optimized as a result of one or both of the interpreting radiologists being present for the entire examination and prescribing the acquisition angles that optimally delineated the biliary and pancreatic ducts. In our experience, the mean imaging room time for MRCP was 15 minutes and the mean imaging time was 2.4 minutes, which made performance of MRCP possible in pediatric, critically ill, and claustrophobic patients. The mean imaging time of 2.4 minutes represents an important advance compared with times for three- and two-dimensional fast SE studies, in which imaging times were 11.5 and 30 minutes, respectively (10,3).

Until the advent of MRCP, the noninvasive evaluation of choledocholithiasis was limited to US and CT, neither of which is consistently sensitive in this application (17–22). The US diagnosis is particularly difficult in subjects who have no associated dilatation of the bile duct, yet this group accounts for up to one-third of all patients with choledocholithiasis (18,20). The sensitivity of US in the detection of biliary calculi is lowered by gas or debris in the duodenum, pancreatic head calcifications, and adjacent surgical clips, but half-Fourier RARE MRCP is not affected by these factors.

For years, ERCP has been regarded as the standard of reference for the diagnosis of choledocholithiasis. Frey et al (23) demonstrated a sensitivity of 90.4%, a specificity of 98%, and an accuracy of 95.8% for ERCP in the detection of choledocholithiasis. However, complications occur in as many as 5% of patients (24,25), with the most common ERCP-induced complication being pancreatitis, which occurs in 3.6%–5.1% of diagnostic ERCP examinations (24,26,27).

In our study, biliary calculi were diag-



a. b.

Figure 5. Unresectable hilar cholangiocarcinoma in a 67-year-old man with painless jaundice. **(a)** MRCP image shows proximal extension of hilar cholangiocarcinoma to involve the right and left hepatic ducts (arrows), which made the disease unresectable. **(b)** Gadolinium-enhanced coronal T1-weighted gradient-echo image shows the dilated right hepatic duct (arrow) and a portion of the left hepatic duct (arrowhead) but no evidence of hepatic extension of tumor.

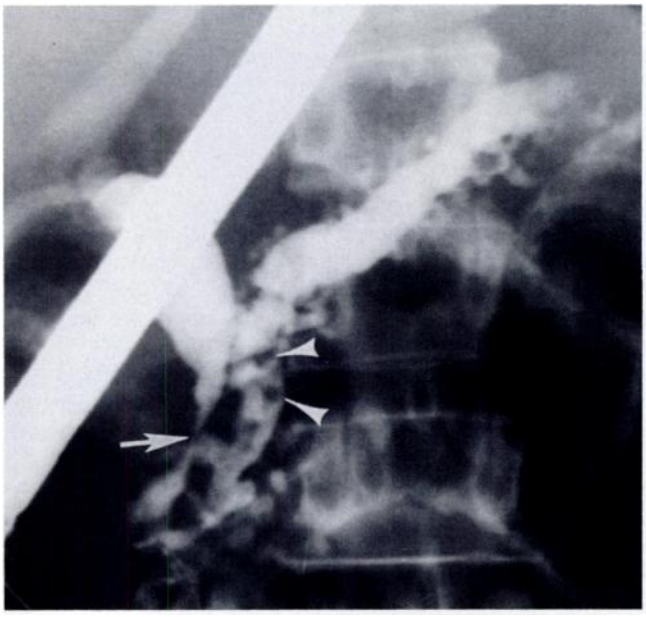
nosed at MRCP in 14 of the 265 patients referred for evaluation of pancreaticobiliary disease and were confirmed at direct cholangiography in all 14. In nine of the 14 patients, the calculi were located in the extrahepatic bile duct. In the 106 patients for whom direct cholangiograms were also available, no false-positive or false-negative diagnoses of biliary calculi were made at MRCP. The improved spatial resolution afforded by the half-Fourier RARE sequence enabled detection of calculi as small as 2 mm in diameter in a dilated duct and 3 mm in a nondilated duct. Three of the nine cases of common duct stones were detected in nondilated ducts. These findings are similar to those in an earlier, smaller study of half-Fourier RARE MRCP (13). However, our results represent an improvement in the sensitivity of 81% noted by Guibaud et al (3) in the diagnosis of choledocholithiasis with a two-dimensional fast SE sequence. Findings in our study also represent an improvement over those in a recent half-Fourier RARE MRCP study, which showed a sensitivity and specificity of 93% and 89%, respectively (15).

Although half-Fourier RARE MRCP is sensitive and specific in the evaluation of biliary calculi, air in the biliary tract may be confused with biliary calculi, because both appear as filling defects in the high-signal-intensity bile. However, differentiation is usually possible as biliary air is located in nondependent portions of the bile duct, whereas calculi tend to be located in dependent portions. In addition, a history of recent biliary intervention or biliary-enteric anastomosis is helpful. In other cases, calculi may be missed owing to ductal tortuosity (15), which underscores the need for tailoring of the MRCP examination by a radiologist. The major disadvantage of MRCP is that it is purely diagnostic, whereas ERCP is both diagnostic and therapeutic. Nevertheless, the high positive and negative predictive values of half-Fourier RARE MRCP make it well suited as a noninvasive means of screening for biliary calculi. The high negative predictive value may obviate ERCP in many cases. In fact, the major advantage of MRCP in the setting of suspected calculous disease may lie not in the detection of biliary calculi but in their exclusion. Therefore, MRCP may lessen the need for ERCP, particularly when the probability of stones is low. In our study, 82 patients were referred for MRCP because of abdominal pain and a low clinical suspicion for biliary calculi. In this group, no patient was found to have common duct stones.

The role of MRCP in patients with suspected gallstone pancreatitis is emerging. Because of the pancreatitis, physicians are sometimes reluctant to request ERCP to exclude stones as a cause. MRCP enables reliable exclusion of common duct stones in this group of patients in whom ERCP may pose added risks. In our study, performance of MRCP obviated diagnostic ERCP in all 13 patients suspected of having gallstone pancreatitis. Performance of additional prospective trials with larger numbers of patients is necessary to clarify the role of MRCP in this setting.

The usefulness of MR imaging in the detection of malignant abdominal neoplasms, particularly pancreatic carcinoma, is well established (28,29). MRCP offers an important advantage in the setting of malignant obstruction in that it provides noninvasive depiction of the biliary tract and pancreatic duct and can be used as an adjunct to conventional MR imaging in determining resectability and in planning for surgical and percutaneous interventions (30). Additional benefits of MRCP in the setting of malignant obstruction include no instrumentation and, therefore, no chance of inducing sepsis secondary to injection or overinjection of an obstructed system; visualization of the obstruction without the risk of failed cannulation; identification of isolated obstructions of the bile ducts such as those

a. b.



c.

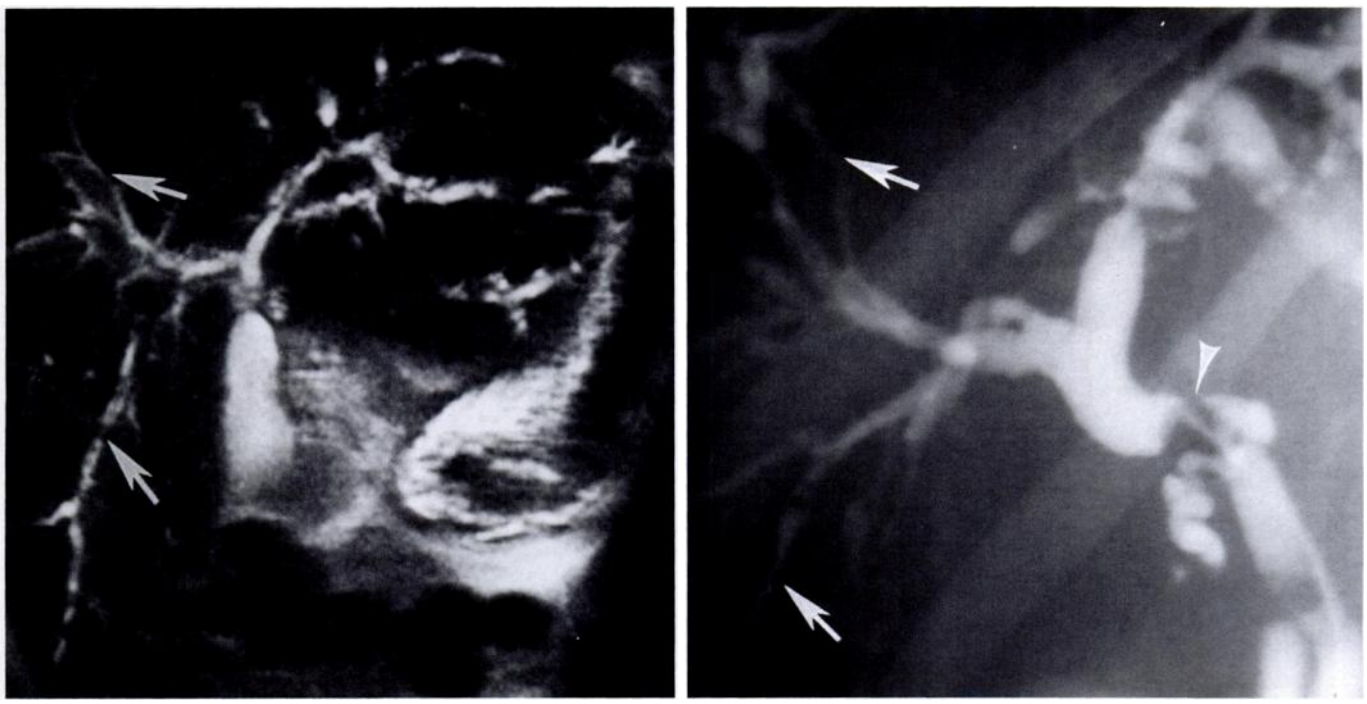
Figure 6. Chronic pancreatitis in a 47-year-old man with chronic abdominal pain. **(a)** MRCP image demonstrates dilatation of the pancreatic duct (arrows) and its side branches. Multiple intraductal calculi (arrowheads) are present. **(b)** MRCP image shows a stricture of the intrapancreatic bile duct (arrow), resulting in intrahepatic bile duct dilatation. The dilated pancreatic duct within the pancreatic head (arrowhead) is also seen. **(c)** ERCP image demonstrates pancreatic and biliary ductal dilatation, the biliary stricture (arrow), and the intraductal calculi (arrowheads).

that occur with cholangiocarcinoma; delineation of the biliary tract in cases of proximal obstruction where ERCP may not be successful and in distal obstructions where percutaneous transhepatic cholangiography may be limited; generation of three-dimensional images with postprocessing techniques such as maximum intensity projection and multiplanar reformatting, which allow better planning of surgical and percutaneous procedures as well as radiation therapy.

In our study, 32 patients had malignant obstruction. Findings at half-Fourier RARE MRCP enabled correct diagnosis of the presence and level of obstruction and of the cause of obstruction as malignant in all the patients. In the detection of malignant obstruction, the sensitivity of 100% of half-Fourier RARE MRCP represents an improvement compared with gradient-echo and two-dimensional fast SE sequences, which have sensitivities that range from 61% to 86%, respectively (1,3) (confidence interval, 68%, 95% [for sensitivity of 86% |3|]). The improved spatial resolution afforded by the half-Fourier RARE sequence allows visualization and characterization of the stricture and the duct distal to it, which was not consistently possible with earlier sequences. The diagnostic capabilities of MRCP in the evaluation of abdominal disease in general and of malignant obstruction in particular are complemented with use of T1-weighted gradient-echo sequences. Specifically, unenhanced and gadolinium-enhanced fat-saturation T1-weighted gradient-echo sequences are crucial in the demonstration of tumor extent and lymphadenopathy.

In two of the 265 patients referred for suspected pancreaticobiliary disease, MRCP and MR imaging enabled identification of pancreatic head enlargement and strictures of the intrapancreatic bile duct, which were highly suggestive of malignancy. Pathologic examination revealed focal pancreatitis but no malignancy. It is likely that the distinction between benign and malignant strictures cannot be made in all instances owing to occasional morphologic similarities; this is true for both MRCP and ERCP. Guibaud et al (3) reported difficulty in diagnosing ampullary carcinomas with MRCP. No ampullary tumors occurred in our patients.

The obvious disadvantage of MRCP is



a. b.

Figure 7. AIDS cholangiopathy in a 32-year-old man. **(a)** MRCP image shows irregularity and stenoses of the slightly dilated intrahepatic bile ducts (arrows). Note that the ducts in the periphery of the liver are depicted. **(b)** ERCP image obtained after balloon occlusion (arrowhead) demonstrates irregularity and stenoses of the intrahepatic bile ducts (arrows) similar to that seen in **a**.

that it does not allow stent placement, as do ERCP and percutaneous biliary drainage procedures. However, in our study, MRCP used in conjunction with MR imaging enabled detection of tumors and determination of resectability and obviated preoperative ERCP and stent placement in five (16%) of the 32 patients with malignant obstruction.

With the improved spatial resolution provided by the half-Fourier RARE sequence, MRCP may become an important technique in the evaluation of chronic pancreatitis. In patients with chronic pancreatitis, MRCP demonstrated not only the dilated pancreatic duct but also ectatic side branches, strictures, and intraductal stones as small as 2 mm in diameter. Although only two patients had ERCP-confirmed strictures, half-Fourier RARE MRCP depicted them in both cases.

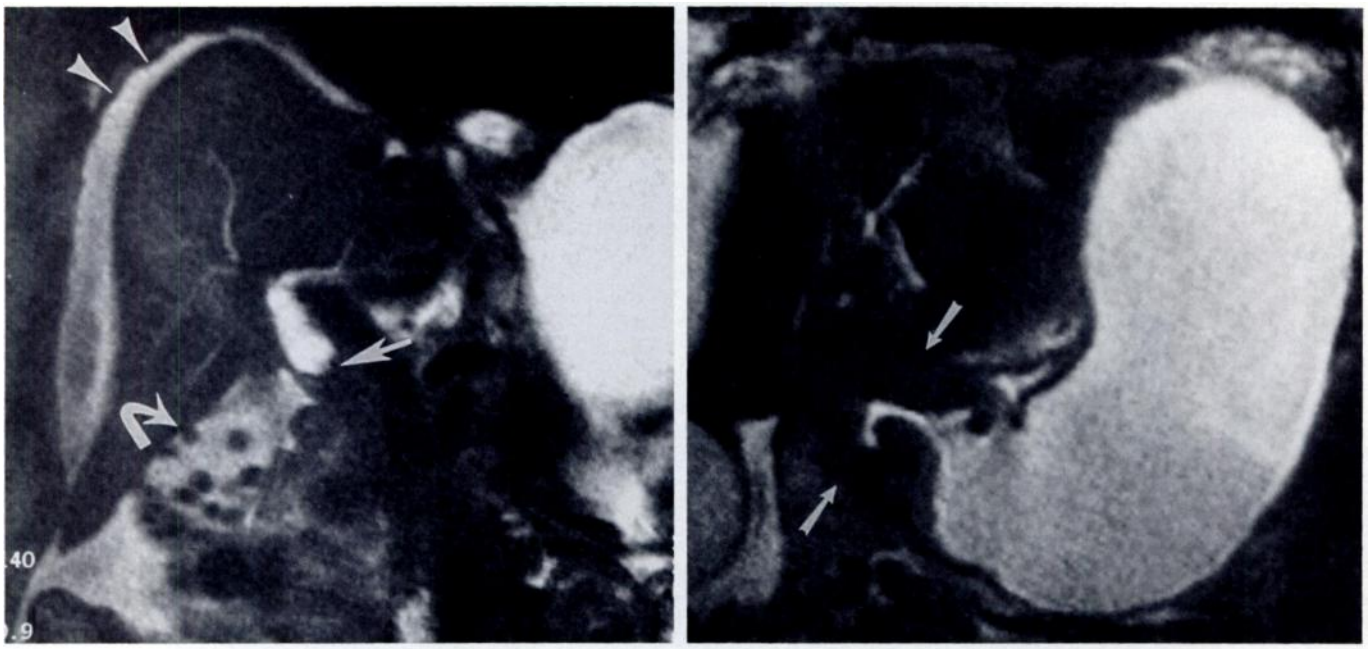
The accurate delineation of ductal anatomy is crucial in the evaluation of patients being considered for surgical drainage such as pancreaticojejunostomy. In this subset of patients, MRCP provides clear depiction of ductal anatomy without the attendant risks of ERCP. Although in our study intraductal stones as small as 2 mm in diameter were identified with MRCP and ERCP, it is unlikely that MRCP will be able to enable identification of small stones in minimally dilated side branches of the pancreatic duct.

The ability of half-Fourier RARE MRCP to resolve third-order bile ducts and short segment stenoses makes this technique well suited to the evaluation of intrahepatic bile duct disease, such as primary sclerosing cholangitis and AIDS cholangiopathy. Visualization of third-order bile ducts is possible with ERCP but necessitates instrumentation and injection with large amounts of pressure, which may induce sepsis and chronic infection. The principal advantage of MRCP in this setting is its ability to depict the entire biliary tract and to enable identification of isolated obstructions and dominant strictures without instrumentation. Performance of large prospective studies of patients with primary sclerosing cholangitis and AIDS cholangiopathy is necessary to determine the sensitivity of MRCP in the identification of subtle intrahepatic ductal changes associated with these diseases.

As surgical biliary procedures such as liver transplantation and biliary-enteric anastomoses are performed with greater frequency, the need for noninvasive means of examining the biliary tract has increased. In the initial months after such procedures, biliary catheters are often in place and provide a means of performing direct cholangiography. However, after catheter removal, visualization of the surgically altered biliary tract necessitated performance of ERCP or percutaneous transhepatic cholangiography until the introduction of MRCP.

In some patients with biliary-enteric anastomoses, the altered anatomy of the gastrointestinal tract, such as that associated with a Whipple procedure, precludes cannulation of the duct during ERCP. The improved spatial resolution of half-Fourier RARE MRCP compared with other sequences allowed depiction of duct-to-duct anastomoses in 10 of 10 patients in our study, as well as of associated complications, such as strictures and stones. In addition, negligible susceptibility effects of the half-Fourier RARE sequence permitted ductal visualization without image degradation even in the presence of numerous surgical clips.

Two-dimensional fast SE MRCP has been shown to be highly accurate in the identification of anatomic variants in the pancreaticobiliary system (5,6). Taourel et al (6) were able to detect the cystic duct in 74% and the bile duct bifurcation in 81% of their patients. In our study, the half-Fourier RARE sequence allowed visualization of the cystic duct in 91% and the bile duct bifurcation in 89% of con-



a. b.

Figure 8. Gastric carcinoma resulting in failed ERCP. **(a)** MRCP image shows obstruction of the extrahepatic bile duct (straight arrow) secondary to lymphadenopathy. The scalloped appearance of the peritoneum (arrowheads) represents carcinomatosis. Gallbladder calculi (curved arrow) are seen. **(b)** MRCP image that includes the stomach demonstrates marked antral narrowing (arrows) secondary to carcinoma, which results in outlet obstruction.

trol patients. This improved visualization may further improve depiction of subtle variations of the biliary tract such as aberrant bile ducts and variants of cystic duct anatomy that may predispose patients to inadvertent ligation during laparoscopic cholecystectomy. Additional investigation is warranted to determine the cost-effectiveness of MRCP in this setting. MRCP is also useful in the detection of anomalies of the pancreatic duct such as pancreas divisum (5,10). In our experience, 1-mm-diameter ventral ducts were identified.

Whereas US will likely remain the screening modality of choice for gallbladder calculi, MRCP enables reliable identification of the gallbladder even in a nonfasting patient. In two of the cases in our study, MRCP depicted gallbladder stones that were not detected at US owing to bowel gas and obesity.

The role of MRCP is evolving in patients who have experienced failed or incomplete ERCP or in whom ERCP cannot be performed because of surgical alterations to the gastrointestinal tract. ERCP has the disadvantage of being highly operator dependent, which can result in unsuccessful cannulation in as many as 10%–20% of cases (25). Some unsuccessful cannulations are the result of inexperience, whereas others are related to biliary-enteric anastomoses, complete ductal obstructions, and variant anatomy (31). With use of a three-dimensional fast SE sequence, Soto et al (32) demonstrated the utility of MRCP in the evaluation of patients after unsuccessful or incomplete ERCP. In our experience, MRCP provided information that influenced clinical decisions ranging from surgical intervention to clinical surveillance in all 27 patients in this category.

There are limitations of our study that should be discussed in conjunction with our findings. Because all patients were referred directly to undergo MRCP evaluation, rather than both MRCP and ERCP, of the pancreaticobiliary system, a selection bias was introduced. Specifically, this method of recruitment results in examining an unusually large number of patients with difficult or impossible access for ERCP owing to altered anatomy or with a low clinical suspicion for pancreaticobiliary disease. This accounts for the unusual mix of pathologic conditions encountered in this series of patients (ie, 23 with postoperative biliary anatomy versus 14 with calculous obstruction). In addition, because direct cholangiography was not performed in all patients, the potential exists for minimizing false-negative findings for pancreaticobiliary disease, particularly calculous obstruction. However, all patients with negative findings for disease at MRCP were followed up clinically for 4–14 months after MRCP. The follow-up showed no clinical or biochemical evidence of disease in the bile or pancreatic ducts.

In conclusion, MRCP is evolving as a rapid, accurate, noninvasive means of evaluating the biliary tract and pancreatic duct. The technical advances provided by the half-Fourier RARE sequence have improved the quality of MRCP by decreasing imaging time, eliminating respiratory motion artifact, and suppressing susceptibility effects. Findings in our study demonstrate the clinical applications of half-Fourier RARE MRCP in a variety of disease processes ranging from choledocholithiasis to sclerosing cholangitis. One of the major advantages of MRCP is its ability to affect clinical management and decrease the need for diagnostic ERCP. Specifically, MRCP is useful in excluding common bile duct stones, in outlining ductal anatomy and obviating stent placement in patients with resectable tumors, and in demonstrating disease extent in entities such as sclerosing cholangitis.

References

1. Wallner BK, Schumacher KA, Weidenmaier W, Friedrich JM. Dilated biliary tract: evaluation with MR cholangiography with a T2-weighted contrast-enhanced fast sequence. Radiology 1991; 181:805–808.
2. Morimoto K, Shimoi M, Shirakawa T, et al.

Biliary obstruction: evaluation with three-dimensional MR cholangiography. Radiology 1992; 1833:578–580.
3. Guibaud L, Bret PM, Reinhold C, Atri M, Barkun AN. Bile duct obstruction and choledocholithiasis: diagnosis with MR cholangiography. Radiology 1995; 197: 109–115.
4. Chan Y, Chan ACW, Lam WWM, et al. Choledocholithiasis: comparison of MR cholangiography and endoscopic retrograde cholangiography. Radiology 1996; 200:85–89.
5. Bret PM, Reinhold C, Taourel P, Guibaud L, Atri M, Barkun AN. Pancreas divisum: evaluation with MR cholangiopancreatography. Radiology 1996; 199:99–103.
6. Taourel P, Bret PM, Reinhold C, Barkun AN, Atri M. Anatomic variants of the biliary tree: diagnosis with MR cholangiopancreatography. Radiology 1996; 199: 521–527.
7. Reinhold C, Guibaud L, Genin G, Bret PM. MR cholangiopancreatography: comparison between two-dimensional fast spin-echo and three-dimensional gradient-echo pulse sequences. JMRI 1995; 4:379–384.
8. Barish MA, Yucel EK, Soto JA, Chuttani R, Ferrucci JT. MR cholangiopancreatography: efficacy of three-dimensional turbo spin-echo technique. AJR 1995; 165:295–302.
9. Soto JA, Barish MA, Yucel EK, Siegenberg D, Ferrucci JT, Chuttani R. Magnetic resonance cholangiography: comparison with endoscopic retrograde cholangiopancreatography. Gastroenterology 1996; 110: 589–597.
10. Soto JA, Barish MA, Yucel EK, et al. Pancreatic duct: MR cholangiopancreatography with a three-dimensional fast spin-echo technique. Radiology 1995; 196:459–464.
11. Matos C, Metens T, Deviere J, et al. Pancreatic duct: morphologic and functional evaluation with dynamic MR pancreatography after secretin stimulation. Radiology 1997; 203:435–441.
12. Miyazaki T, Yamashita Y, Tsuchigame T, Yamamoto H, Urata J, Takahashi M. MR cholangiopancreatography using HASTE (half-Fourier acquisition single-shot turbo spin-echo) sequences. AJR 1996; 166: 1297–1303.
13. Regan F, Smith D, Khazan R, et al. MR cholangiography in biliary obstruction using half-Fourier acquisition. J Comput Assist Tomogr 1996; 20:627–632.
14. Ichikawa T, Nitatori T, Hachiya J, Mizutani Y. Breath-held MR cholangiopancreatography with half-averaged single shot hybrid rapid acquisition with relaxation enhancement sequence: comparison of fast GRE and SE sequences. J Comput Assist Tomogr 1996; 20:798–802.
15. Regan F, Fradin J, Khazan R, Bohlman M, Magnuson T. Choledocholithiasis: evaluation with MR cholangiography. AJR 1996; 167:1441–1445.
16. Hirohashi S, Hirohashi R, Uchida H, et al. Pancreatitis: evaluation with MR cholangiography in children. Radiology 1997; 203:411–415.
17. Pasanen P, Partanen K, Pikkarainen P, Alhava E, Pirinen A, Janatuinen E. Ultrasonography, CT, and ERCP in the diagnosis of choledochal stones. Acta Radiol 1992; 33:53–56.
18. Laing FC, Jeffrey RB Jr. Choledocholithiasis and cystic duct obstruction: difficult ultrasonographic diagnosis. Radiology 1983; 146:475–479.
19. Laing FC, Jeffrey RB, Wing VW. Improved visualization of choledocholithiasis by sonography. AJR 1984; 143:949–952.
20. Cronan JJ. US diagnosis of choledocholithiasis: a reappraisal. Radiology 1986; 161: 133–134.
21. Jeffrey RB, Federle MP, Laing FC, Wall S, Rego J, Moss AA. Computed tomography of choledocholithiasis. AJR 1983; 140: 1179–1183.
22. Baron RL. CT diagnosis of choledocholithiasis. Semin Ultrasound CT MR 1987; 8:85–102.
23. Frey CF, Burbige EJ, Meinke WB, et al. Endoscopic retrograde cholangiopancreatography. Am J Surg 1982; 144:109–113.
24. Cotton PB, Chong WK. Complications of endoscopic retrograde cholangiography and therapy. In: Silvis SE, Rohrmann CA, Ansel HJ, eds. Endoscopic retrograde cholangiopancreatography. New York, NY: Igaku-Shoin, 1995; 446–450.
25. Scharschmidt BF, Goldberg HI, Schmid R. Approach to the patient with cholestatic jaundice. N Engl J Med 1983; 308:1515–1519.
26. Sherman S, Lehman GA. ERCP- and endoscopic sphincterotomy-induced pancreatitis. Pancreas 1991; 6:350–367.
27. Cohen SA, Siegel JH, Kasmin FE. Complications of diagnostic and therapeutic ERCP. Abdom Imaging 1996; 21:385–394.
28. Semelka RC, Kroeker MA, Shoenut JP, Kroeker R, Yaffe CS, Micflikier AB. Pancreatic disease: prospective comparison of CT, ERCP, and 1.5-T MR imaging with dynamic gadolinium enhancement and fat suppression. Radiology 1991; 181:785–791.
29. Semelka RC, Kelekis NL, Molina PL, Sharp TJ, Calvo B. Pancreatic masses with inconclusive findings on spiral CT: is there a role for MRI? JMRI 1996; 6:585–588.
30. Fulcher AS, Turner MA. HASTE magnetic resonance cholangiography (MRC) in the evaluation of hilar cholangiocarcinoma. AJR 1997; 169:1501–1505.
31. Onken J, Baillie J, Affronti JP, et al. ERCP in patients following Billroth II gastrectomy: is it tougher and riskier than "ordinary" ERCP? (abstr). Gastrointest Endosc 1992; 38:257.
32. Soto JA, Yucel EK, Barish MA, Chuttani R, Ferrucci JT. MR cholangiopancreatography after unsuccessful or incomplete ERCP. Radiology 1996; 199:91–98.