RADIOLOGIC
CLINICS OF
NORTH AMERICA

Radiol Clin N Am 41 (2003) 89–96

MR cholangiopancreatography

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MR cholangiopancreatography (MRCP) is still a rapidly evolving technique, but has been already accepted as clinically useful and is widely used to evaluate biliary or pancreatic diseases in a noninvasive way. This technique uses MR imaging to visualize stationary or slow-moving fluid, such as bile, displaying them as high signal intensity. Heavily T2-weighted sequences are generally used for MRCP with single-shot echo-train spin echo technique achieving the most widespread use. Recent studies show that MRCP is comparable with or more useful than other techniques, such as ultrasound, CT, and endoscopic retrograde cholangiopancreatography (ERCP) to study choledocholithiasis, malignant obstruction of the biliary or pancreatic ducts, congenital anomalies, and chronic pancreatitis [1–7]. With further improvements of hardware and technique, MRCP is expected to replace diagnostic ERCP to examine the biliary and pancreatic ducts in the near future.

Comparison with ERCP

MR cholangiopancreatography is noninvasive and safe, because it does not require anesthesia or injection of intraductal or intravenous contrast agent. On current MR imaging systems high-quality images can be obtained consistently. It has been reported that MRCP is useful in patients after incomplete or unsuccessful ERCP [8]. In some patients, such as those who have undergone surgery with biliary enteric anastomosis or Billroth II, it may not be possible to perform ERCP, so MRCP is the modality of choice to evaluate these postsurgical patients [9]. Unlike ERCP, MRCP produces images of the ducts in their natural state, because it does not involve distention of the ducts by injected contrast medium. ERCP cannot evaluate extraductal structures directly, whereas MRCP can be combined with conventional MR imaging for the evaluation of extraductal disease, such as tumors. ERCP has advantages over MRCP, which include direct therapeutic interventional procedures that may be performed concurrent with diagnostic imaging. ERCP is generally a safe procedure, but still associated with nonnegligible morbidity and mortality rates [10]. Also, technical failures occur in up to 10% of cases because of unsuccessful cannulation of the common bile duct (CBD) or pancreatic duct [8,11]. In some institutions MRCP is gradually replacing ERCP as a primary diagnostic imaging modality to evaluate the biliary system and pancreatic duct. This article reviews recent progress of MRCP techniques and clinical applications of MRCP for the evaluation of various biliary and pancreatic diseases.

MRCP techniques

MR cholangiopancreatography uses heavily T2-weighted images to visualize stationary or slow-moving fluids in the biliary system and pancreatic duct with high signal intensity. For this purpose, single-shot echo-train spin echo technique is used most commonly. Echo-train spin echo technique uses a single 90-degree pulse followed by multiple refo-

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PII: S0033-8389(02)00064-7

cusing 180-degree pulses. Extremely long echo trains of 100 to 150 refocusing 180-degree pulses and long effective TE are used to produce heavily T2-weighted images. Because of the heavy T2-weighting of this sequence, signals from the fluid in the biliary system and pancreatic duct are hyperintense, whereas the signal of background tissue is rendered hypointense, enabling excellent depiction of the biliary system and pancreatic duct. Single-shot echo-train spin echo sequence can be performed as single-slab acquisition or multiple thin-slice acquisition. In the single-slab approach, a thick collimation (30 to 70 mm) single section is acquired in an oblique coronal plane, obtained in 2 to 3 seconds (Fig. 1). The single slab can be acquired in various rotations to view the biliary system and pancreatic duct from different angles. ERCP-like images can be acquired without maximum intensity projection (MIP) postprocessing. This technique is useful to provide an overview of the biliary system and pancreatic duct, but is not effective at demonstrating small intraductal structures, such as bile duct stones. This is because visualization of small intraductal signal void structures is obscured by surrounding intraductal high signal from fluid. It is important also to acquire a multiple-slice thin-collimation sequence to examine the details of the intraductal structures. Slice thickness of 3 to 4 mm is needed to detect small intraductal stones. Three-dimensional reconstruction may be performed by MIP postprocessing from the thin-collimation source images (see Fig. 1). Volume-averaging effects can obscure small stones and subtle mural irregularity, however, so source thin section images must always be reviewed [1].

Usually, to obtain ERCP-like MRCP images, single-shot echo-train spin echo sequence is performed by using a very long effective TE value (eg, 1000 milliseconds) without fat-suppression technique or a long effective TE value (eg, 250 to 400 milliseconds) with fat-suppression technique. With these images, however, it is not possible to evaluate periductal structures, such as tumors, which may cause narrowing or obstruction of the ducts. Also, fluids with relatively short TE, such as concentrated bile or mucinous fluid, may produce very little signal with long effective TE sequences, and that may obscure small bile ducts or mucinous lesions. To overcome those drawbacks of MRCP with long effective TE, an intermediate effective TE (80 to 100 milliseconds) can be used. This produces images where not only all fluid including concentrated bile and mucinous fluid is bright, but also periductal structures are well depicted. The combination of images with intermediate effective TE and ERCP-like MRCP images gives detailed evaluation of both intraductal and periductal structures.

Disease processes

Benign disease

Cystic diseases of the bile duct

Congenital cystic lesions of the bile duct can be classified according to Todani's classification system [12]: type I, choledochal cyst; type II, diverticulum of extrahepatic ducts; type III choledochocele; type IV, multiple segmental cysts; and type V, Caroli's dis-

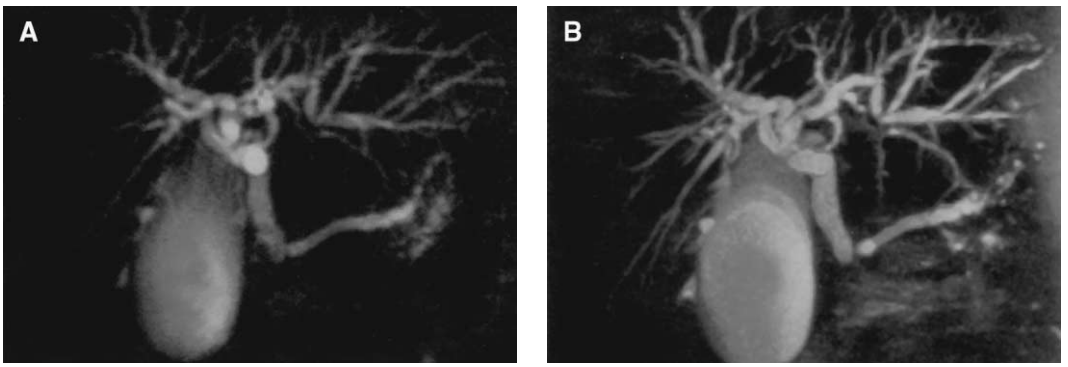

Fig. 1. Comparison of thick-slab MRCP and three-dimensional maximum intensity projection (MIP) reconstruction MRCP in a patient with a pancreatic head carcinoma. (A) Coronal thick-slab single-shot echo-train spin echo MRCP. (B) Three-dimensional MIP reconstruction obtained from thin-slice collimation source images. Dilatation of the biliary tree and pancreatic duct and definition of the level of obstruction are demonstrated on both images. The three-dimensional MIP reconstructed image, however, demonstrates more details of the biliary tree and the pancreatic duct. (*From* Bader TR, Semelka RC. Gallbladder and biliary system. In: Abdominal-pelvic MRI. New York: Wiley Liss; 2002. p. 319–71; with permission.)

ease. MRCP can be effective and comparable with ERCP for the evaluation of these lesions. Also, the combination of MRCP and gadolinium-enhanced T1-weighted images is useful to diagnose associated findings, such as gallstone disease and cancer. MRCP has been demonstrated to be effective in evaluating choledochal cyst [13,14], choledochocele [15], and Caroli's disease [16].

Congenital variants of the biliary system

Anatomic variants of the cystic duct have received much attention recently because of their higher risk of complications during cholecystectomy. In a study evaluating anatomic variants of the biliary tree, MRCP could demonstrate accurately various variants, such as a low cystic duct insertion, a medial cystic duct insertion, a parallel course of the cystic and hepatic ducts, and an aberrant right hepatic duct [17].

Pancreas divisum

Pancreas divisum is the most common anatomic variant of the pancreas resulting from failure of fusion of the duct of the embryonic dorsal pancreas and the duct of the ventral pancreas [18]. As a result, the pancreas has two separate ductal systems. The incidence of this anomaly is reported to be between 1.3% and 6.7% of the general population [19]. In patients with pancreas divisum, the minor papilla may cause impaired pancreatic drainage and result in chronic pancreatitis [20]. Another clinically relevant issue with pancreas divisum is that at ERCP only the ventral duct can be cannulated through the major papilla, and a small ventral duct may be misdiagnosed as an obstructed pancreatic duct. On MRCP images, pancreas divisum can be diagnosed by the finding of dorsal dominant pancreatic duct running anteriorly to the CBD and draining into the minor papilla. A study evaluating 108 patients who underwent both ERCP and MRCP demonstrated exact correlation between the two techniques for the depiction and exclusion of pancreas divisum [21].

Cholecystolithiasis

The primary imaging modality for cholecystolithiasis is sonography. MRCP, however, is highly sensitive and accurate in diagnosing cholecystolithiasis and can outperform ultrasound and CT [1]. The most reliable approach to detect gallstones with MRCP is with the use of single-shot T2-weighted sequences, such as MRCP (Fig. 2).

Choledocholithiasis

Accurate diagnosis of stones in the biliary ducts is crucial because their presence is a difficult challenge for cholecystectomy. Ultrasound and CT imaging show relatively low sensitivity and accuracy for the diagnosis of bile duct stones [22–25]. ERCP is considered the gold standard procedure for the evaluation of the biliary system and has a major advantage over other imaging modalities because of its ability to perform therapeutic interventions and diagnosis. Even in diagnostic ERCP alone, however, the rate of major complications or death is not negligible and the rate of failed ERCP is 5% to 20% [10,26,27].

MR cholangiopancreatography has been shown to be an excellent method for detecting bile duct stones (see Fig. 2). It is superior to CT or ultrasound and comparable or superior to ERCP in detecting bile

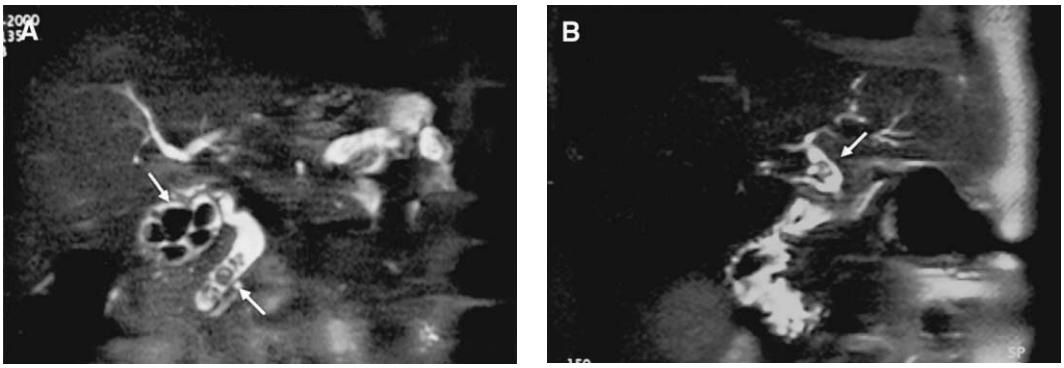

Fig. 2. Gallstone disease. (A) Coronal thin-slice single-shot echo-train spin echo MRCP in a patient with gallstones and common bile duct (CBD) stones. Multiple gallstones and CBD stones are clearly demonstrated (*arrows*). (B) Coronal thin-slice single-shot echo-train spin echo MRCP in a patient with a CBD stone after liver transplantation. A CBD stone is demonstrated in the dilated graft CBD. (*From* Bader TR, Semelka RC. Gallbladder and biliary system. In: Abdominal-pelvic MRI. New York: Wiley Liss; 2002. p. 319–71; with permission.)

duct stones [1,2,4,28]. On thin-slice source images, stones appear as signal void lesions and can be detected as small as 2 mm in dilated and nondilated ducts [1]. On thick-slab images, large- or medium-sized stones in normal-caliber ducts are easily detectable, but small stones that are completely surrounded by fluid may be obscured and difficult to detect because of volume-averaging effects.

There are several pitfalls and mimickers of stones with MRCP. Intraductal air bubbles (pneumobilia) may mimic the appearance of stones. An important differentiating feature from stones is that air bubble filling defects lie on the nondependent portion of the bile duct against the wall on axial images. Blood clots may appear indistinguishable from bile duct stones. Other pitfalls that may mimic bile duct stones include (1) tortuosity of the bile duct running in and out of the imaging plane; (2) merging of the cystic duct into the CBD when observed en face on coronal images, which may result in a round hypointense focus; (3) metallic clips; and (4) extraductal compression from the right hepatic or the gastroduodenal artery, which may result in a signal void focus [4,29]. Correct diagnosis usually can be achieved by careful attention to the exact location of these foci and interpretation of thick-slab MRCP or MIP reconstructed images in conjunction with the thin-slice source images.

Primary sclerosing cholangitis

Primary sclerosing cholangitis is characterized by chronic fibrosing inflammation of the biliary system of unknown etiology. The diagnosis of primary sclerosing cholangitis is made by cholangiographic findings supported by histologic results. The imaging appearance of primary sclerosing cholangitis is characterized by multiple, irregular strictures and saccular dilatations of the intrahepatic and extrahepatic bile ducts producing a beaded appearance. The conventional imaging modality for the diagnosis of primary sclerosing cholangitis is ERCP. Complications from ERCP, however, may result in progression of cholestasis in patients with primary sclerosing cholangitis [19,30]. MRCP has been shown to be useful for the diagnosis and follow-up of primary sclerosing cholangitis (Fig. 3) [31,32]. A study evaluating MRCP in patients with primary sclerosing cholangitis demonstrated that MRCP has shown a sensitivity and specificity to depict primary sclerosing cholangitis of 85% to 88% and 92% to 97%, respectively [32]. Diagnostic challenges include that subtle changes of mild primary sclerosing cholangitis may be difficult to detect by current MR imaging techniques, and cirrhosis may cause distortion of the intrahepatic bile ducts and mimic primary sclerosing cholangitis. A major strength is that MRCP provides visualization of bile ducts proximal to even severe stenoses, which may not be evaluable by ERCP.

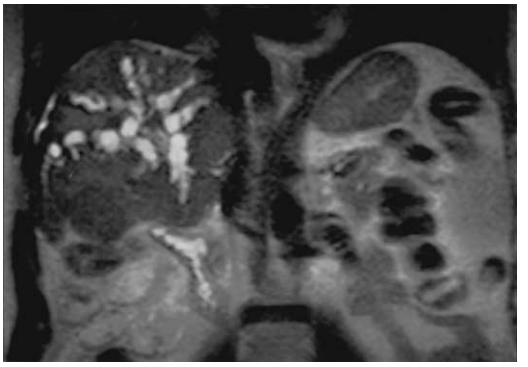

Fig. 3. Primary sclerosing cholangitis. Coronal single-shot echo-train spin echo MRCP demonstrates multiple irregular strictures and dilatations of the biliary tree. (*From* Bader TR, Semelka RC. Gallbladder and biliary system. In: Abdominal-pelvic MRI. New York: Wiley Liss; 2002. p. 319–71; with permission.)

Postsurgical biliary complications

The most common postsurgical biliary complication is benign biliary stricture [33,34]. MRCP can visualize the biliary tree distal and proximal to a high-grade stricture or complete obstruction. The bile ducts distal to a stenosis, however, may be collapsed and nonvisualized on MIP-reconstructed images leading to overestimation of the stricture. Thin-section source images must be used to evaluate the extent of high-grade stenoses, because even small amounts of fluid in collapsed ducts can be depicted on these images.

Other postsurgical biliary complications include retained bile duct stones, biliary leak, and biliary fistula. These conditions can be evaluated effectively by MRCP.

In patients with biliary-enteric anastomoses, it may be difficult or impossible to perform ERCP. On the other hand, MRCP is very effective in evaluating the anatomy of the anastomosis, strictures of the anastomosis, strictures of the biliary ducts, and biliary stones proximal to the anastomosis, in up to 100% of patients [1,35]. Thin-section source images should be examined thoroughly because the biliary-enteric anastomosis and stones may be obscured on thick-slab and MIP-reconstructed images by the high signal intensity of surrounding bile and bowel fluid. Also, metallic surgical clips and pneumobilia can also

Fig. 4. Chronic pancreatitis. Coronal single-shot echo-train spin echo thin section MRCP source image shows dilated main pancreatic duct and its side branches. (*From* Bader TR, Semelka RC. Gallbladder and biliary system. In: Abdominal-pelvic MRI. New York: Wiley Liss; 2002. p. 319–71; with permission.)

produce artifacts that should not be mistaken as stones or strictures.

Chronic pancreatitis

On ERCP typical findings of chronic pancreatitis include dilatation, narrowing or stricture, or irregularity of the pancreatic duct [30]. Prominent dilatation of side branches is a feature of chronic pancreatitis (Fig. 4) that helps distinguish this entity from obstructed pancreatic duct caused by pancreatic cancer. A study evaluating 30 patients with chronic pancreatitis undergoing ERCP and MRCP demonstrated sensitivity and specificity of 91% and 92%, respectively, and excellent correlation between ERCP and MRCP was reported [36].

Neoplastic diseases

Cholangiocarcinoma

Cholangiocarcinoma can be classified into three types according to the anatomic location: (1) peripheral type, originating from peripheral bile ducts in the liver; (2) hilar type (Klatskin's tumor), originating from the confluence of the right and left hepatic ducts; and (3) extrahepatic type, originating from the main hepatic ducts, common hepatic duct, or CBD [37,38]. Ductal obstruction is observed in all cases of Klatskin's tumor and extrahepatic cholangiocarcinoma. Evaluation of the level of obstruction is important for treatment planning. In a study evaluating malignant perihilar biliary obstruction in 40 patients including 26 Klatskin's tumors, it was reported that MRCP was as effective as ERCP at detecting the presence and the level of biliary obstruction (40 of 40 cases on MRCP and 38 of 38 cases on ERCP) [39]. The disadvantage of ERCP is that it may result in sepsis caused by overdistention of an obstructed biliary duct with stagnant bile colonized by bacteria, and additionally ERCP may be unable to provide sufficient biliary opacification to evaluate adequately the region of narrowing. MRCP, however, can demonstrate the bile duct proximal to the obstructing site safely and efficiently (Fig. 5).

The authors' routine procedure is to evaluate patients with possible cholangiocarcinoma with tissue imaging sequences in addition to MRCP. Special emphasis is made on T1-weighted fat-suppressed spoiled gradient echo acquired 2 to 5 minutes following gadolinium administration because it is the most consistent technique to demonstrate cholangio-

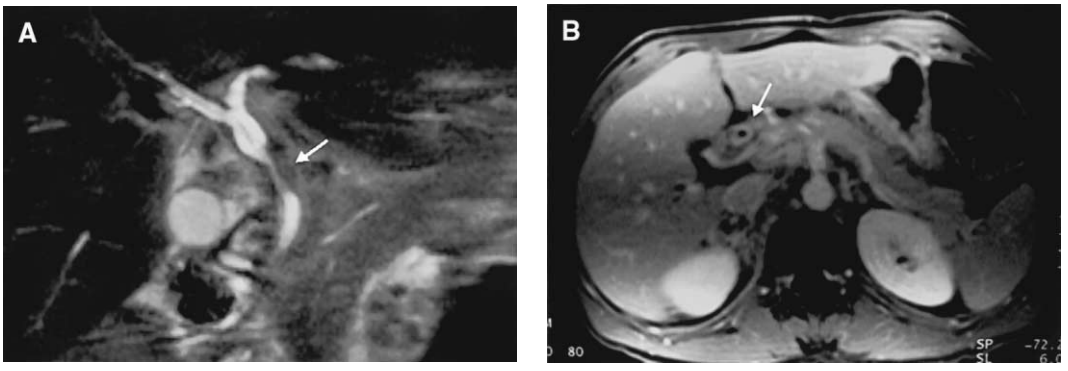

Fig. 5. Cholangiocarcinoma. (A) Coronal single-shot echo-train spin echo thin section MRCP source image shows an irregular stricture of the common bile duct (CBD) caused by cholangiocarcinoma (*arrow*). (B) Transverse 2-minute postgadolinium fat-suppressed spoiled gradient echo image shows circumferential thickening and moderate enhancement of the extrahepatic CBD caused by cholangiocarcinoma (*arrow*).

carcinoma, which appears as moderately enhancing tissue (see Fig. 5) [40].

Pancreatic cancer

Typical pancreatographic features of pancreatic cancer include irregular narrowing or obstruction of the main pancreatic duct and dilatation proximal to the lesion. Pancreatic head tumors also result in obstruction of the CBD. MRCP is able to evaluate the pancreatic duct proximal to an obstructing site that ERCP may be unable to demonstrate (Fig. 6). In a study evaluating 124 patients with a suspicion of pancreatic cancer, MRCP was as effective as ERCP for the detection of the pancreatic cancer with sensitivity and specificity of 84% and 97%, respectively, for MRCP, and sensitivity and specificity of 70% and 94%, respectively, for ERCP [41]. As with other malignant tumors, when pancreatic ductal adenocarcinoma is suspected clinically, the authors routinely perform tissue imaging sequences. T1-weighted spoiled gradient echo acquired immediately following gadolinium administration is the most consistent technique to demonstrate pancreatic cancer (see Fig. 6) [42].

Future directions

Using current techniques, MRCP does not provide dynamic information about pancreatic exocrine function; however, research is ongoing to obtain such information using secretin stimulation, and results seem promising [43]. In a study evaluating 31 patients with chronic pancreatitis and 84 patients with suspicion of pancreatic disease, MRCP after secretin stimulation showed reduced duodenal filling in patients with severe chronic pancreatitis [43]. Another advance in MRCP is the use of contrast agents that are hepatocyte-selective and eliminated, at least in part, by the biliary system. With these agents and faster acquisition with thin-section three-dimensional T1-weighted images of the biliary system,

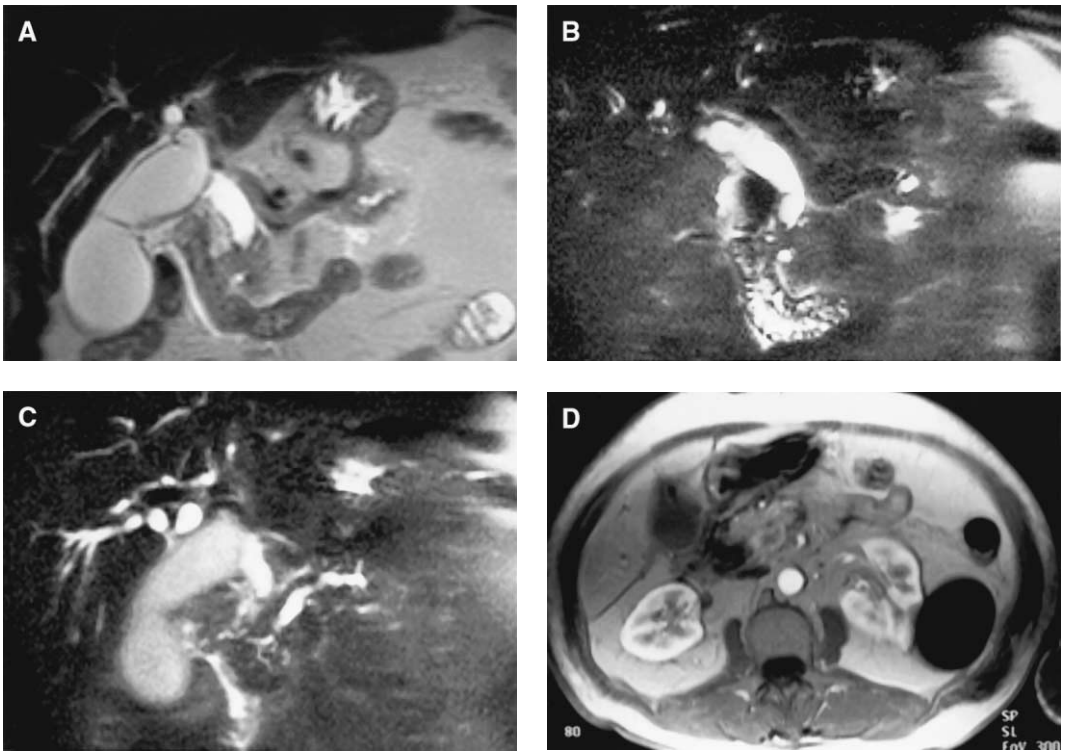

Fig. 6. Pancreatic head adenocarcinoma. (A) Coronal T2-weighted single-shot echo-train spin echo image shows the dilated common bile duct (CBD) and the pancreatic head adenocarcinoma adjacent to the ampulla of Vater. (B,C) Coronal T2-weighted fat-suppressed thin-section MRCP shows obstruction of the CBD and main pancreatic duct with the dilatation of the ducts proximal to the obstructed sites. (D) Transverse immediate postgadolinium spoiled gradient echo image shows low signal intensity mass of the pancreatic head.

demonstration of smaller intrahepatic biliary branches is feasible [44]. This approach may also facilitate detection of functional obstruction or bile duct leak or injury [44].

Summary

Although MRCP is still an evolving technique, it has established itself as clinically useful and comparable with ERCP for the evaluation of various biliary or pancreatic ductal diseases. MRCP is not only comparable with ERCP in its diagnostic ability, but it has the tremendous advantage of being noninvasive. Furthermore, MR imaging is useful in patients with incomplete or failed ERCP, and in patients with certain biliary or gastrointestinal surgical procedures it is the imaging modality of choice. ERCP will remain an extremely important modality because of the great clinical importance for interventional biliary procedures with this technique. Nonetheless, MRCP may in the near future replace most of the diagnostic imaging of the biliary tree, with diagnostic results even more improved with further developments of hardware and technique.

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