Pictorial Essay

Functional MR Cholangiography: Diagnosis of Functional Abnormalities of the Gallbladder and Biliary Tree

OBJECTIVE. Our objective was to describe the technique and utility of functional MR cholangiography (fMRC) in the evaluation of the gallbladder and biliary tree.

CONCLUSION. FMRC has the potential to provide a comprehensive examination for the anatomic and functional assessment of the gallbladder and biliary tree. Complex anatomic abnormalities and functional disorders can be shown by fMRC, including biliary obstruction and extravasation.

Functional MR cholangiography (fMRC) is an emerging technique that has the potential to provide a comprehensive evaluation for the anatomic and functional assessment of the gallbladder and biliary tree. FMRC is performed with a contrast agent such as mangafodipir trisodium (Teslascan, Nycomed Amersham), which is excreted via the biliary system, where it causes T1 shortening of bile [1]. Hence, an fMRC sequence can be performed as a high-resolution T1-weighted 3D gradient-recalled echo (GRE) sequence. With its intrinsic high signal-to-noise ratio, this sequence affords a smaller pixel size than that achieved by conventional single-shot fast spin-echo MRC, sonography, and scintigraphy. As such, not only can anatomic abnormalities such as strictures, filling defects, and subtle ductal anomalies be detected, but functional abnormalities such as cholecystitis, ductal obstruction, and biliary extravasation can be definitively established. In this pictorial essay, we will discuss the fMRC technique, its advantages over other techniques, and provide examples that illustrate the value of fMRC (Figs. 1–11).

Technique

Although several hepatobiliary contrast agents are being developed that may be suitable for the performance of an fMRC sequence in the future [2], mangafodipir trisodium is a U.S. Food and Drug Administration–approved contrast agent for the evaluation of liver lesions [3, 4] and is used for fMRC imaging [1, 5]. FMRC imaging constitutes an off-label use of mangafodipir trisodium. As of March 2004, manufacturing of mangafodipir had been suspended by Nycomed Amersham, but resumption of manufacturing is expected.

FMRC images of the biliary tree are obtained as follows: Approximately 10–20 min after the injection of mangafodipir (dose, 5 μmol/kg or 0.5 mL/kg administered at 2–3 mL/min), high-resolution 3D GRE images are obtained in coronal, coronal oblique, and axial planes (TR/TE, 6/2.2; flip angle, 40°; field of view, 28 cm²; matrix, 256 × 128; 3.0-mm slice thickness with zero fill interpolation to yield 64 images per slab at 1.5-mm increments with 1.5-mm overlap; number of excitations, 0.5; bandwidth ± 62 kHz), usually requiring two slab overlapping prescriptions. If initial images do not show contrast material in the biliary tree, this sequence can be repeated as needed at later intervals to obtain additional delayed imaging. If clinically indicated, we advocate that delayed imaging be performed at 2-hr intervals after injection.
as needed, until visualization of the contrast agent in the gallbladder and duodenum is possible (Figs. 2 and 3). The exact time interval at which delayed imaging is executed is in part dependent on the availability of the MR scanner.

Because the excretion of mangafodipir into the biliary tree interferes with successful visualization of biliary fluid on conventional T2-weighted MRC sequences (Fig. 4), conventional MRC imaging must be performed before excretion of mangafodipir into the biliary tree. If a conventional T2-weighted MRC sequence is not desired, delayed imaging of the biliary tree may be performed after the IV administration of mangafodipir without the performance of a conventional single-shot fast spin-echo MRC.

Hence, fMRC imaging can be performed in two ways, as a combined study with conventional MRC (combined MRC) or as a delayed postcontrast study without conventional MRC (fMRC alone). The advantage of combined MRC is that additional information obtained from the T2-weighted contrast agent within the ducts may further support findings seen on fMRC images. The disadvantage is that additional delayed imaging may be required if mangafodipir has not been excreted into the biliary system on early images. However, when additional delayed imaging is performed, the transit time of contrast agent into the biliary tree and gallbladder may be determined and be of value in some instances, such as in the diagnosis of chronic cholecystitis and partial biliary duct obstructions, entities in which delayed filling of the gallbladder and biliary tree occurs (Figs. 2 and 3). Also, on occasion, high-signal-intensity bile may have a similar signal intensity to that of the contrast material. It is useful to distinguish excretion of contrast material in the gallbladder from

Fig. 1.—55-year-old woman with acute cholecystitis and metastatic disease to liver. A, Axial single-shot fast spin-echo (SSFSE) MR cholangiography (MRC) image (TR/TE, infinite/186) shows gallbladder (GB) wall thickening and some distention. B, Coronal SSFSE MRC image (infinite/190) shows calculus (C) in GB neck. C, Axial functional MRC image (6/2.2, flip angle, 40°) 4 hr after mangafodipir trisodium injection shows contrast agent in common bile duct (CBD). Calculus (C) is again noted in GB neck, but contrast agent has not passed into GB, confirming acute cholecystitis and cystic duct obstruction by calculus. Multiple metastatic liver lesions are present.
Fig. 2.—83-year-old woman with chronic cholecystitis.

A. Precontrast thick-slab single-shot fast spin-echo MR cholangiography (MRC) image (TR/TE, infinite/800) shows distention of gallbladder and gallstones (arrow), features of chronic cholecystitis. Distinction from acute cholecystitis is difficult by conventional MRC images alone.

B. Early axial mangafodipir trisodium–enhanced 3D gradient-recalled echo functional MRC (fMRC) image (TR/TE, 6/2.2; flip angle, 40°) performed within 40 min of injection shows contrast agent in duodenum (arrow) but no filling of gallbladder (GB).

C. At 40 min, coronal fMRC image (6/2.2; flip angle, 40°) shows contrast material in duodenum (D) but no filling of gallbladder (GB).

D. Two hours later, after injection of morphine sulfate, coronal fMRC image (6/2.2; flip angle, 40°) shows contrast agent is present in cystic duct (CD) and gallbladder (GB).

(Fig. 2 continues on next page)
native bile (Fig. 2E). If, however, imaging with fMRC alone is needed, mangafodipir may be injected and subsequent imaging can take place several hours after injection, potentially eradicating the need for delayed imaging. Suspected acute cholecystitis is an ideal setting for which fMRC alone may be sufficient (Fig. 1). For indications other than acute cholecystitis, including suspected biliary ductal obstruction (Figs. 5–7) and biliary leaks (Fig. 11), we perform combined MRC. An fMRC sequence is valuable in the evaluation of a potential liver transplant donor for detection of variant biliary ductal drainage [5] (Figs. 9 and 10).

Comparison with Other Techniques
Our arsenal of techniques for evaluation of the biliary tree includes sonography, conventional MRC, hepatobiliary scintigraphy, CT, endoscopic retrograde cholangiography (ERC), and percutaneous transhepatic cholangiography (PTC).

Sonography is typically the initial technique used for the assessment of the biliary tree and although it is a highly sensitive technique for the evaluation of the gallbladder [6], it is limited in cases in which the biliary ducts are not dilated and for the evaluation of the extrahepatic biliary tree [7]. Conven-
**Fig. 4.**—66-year-old woman with common bile duct calculi.  
**A,** Axial single-shot fast spin-echo MR cholangiography (MRC) image (TR/TE, infinite/186) obtained after mangafodipir trisodium administration shows low-signal-intensity fluid in common bile duct (CBD), obscuring its evaluation.  
**B,** Corresponding axial functional MRC (image 6/2.2; flip angle, 40°) shows filling defect (calculus) in CBD surrounded by contrast material. Duodenal contrast material (D) indicates nonobstructing biliary calculus.

**Fig. 5.**—68-year-old man with carcinoma of pancreas, metastases to liver, and partial obstruction of common bile duct.  
**A,** Coronal single-shot fast spin-echo MR cholangiography (MRC) image (TR/TE, infinite/186) shows narrowing of common bile duct (CBD) by mass (M). Multiple hepatic lesions are noted, some of which represent metastatic disease.  
**B,** Coronal oblique maximum-intensity-projection mangafodipir-enhanced functional MRC (fMRC) image 6/2.2; flip angle, 40°) obtained from reconstruction of 3D data set again shows marked narrowing of CBD at level of mass (M). Contrast material is present in duodenum (D) and appeared approximately 4 hr after IV administration. Delayed transit time indicates partial obstruction by mass.  
**C,** Axial fMRC image (6/2.2) taken at level of severe ductal narrowing shows contrast in CBD. Partially obstructing mass (M) is marked. Multiple lesions are again identified in liver.
Fig. 6.—57-year-old woman with pancreatic cancer. 
A, Thick-slab single-shot fast spin-echo MR cholangiography (MRC) image (TR/TE, infinite/800) shows classic double duct sign of pancreatic carcinoma.  
B, Axial delayed functional MRC (fMRC) image (TR/TE, 6/2.2; flip angle, 40°) obtained several hours after mangafodipir trisodium injection shows enhancement of liver parenchyma without excretion of contrast agent into biliary tree. This finding persisted at 24 hr. Tumor completely obstructs biliary tree.

Fig. 7.—55-year-old woman with biliary obstruction caused by metastatic ovarian carcinoma, requiring stent placement across common bile duct. Patency of stent was evaluated by MRI. (Reprinted with permission from [1]) 
A, Coronal single-shot fast spin-echo MR cholangiography (MRC) image (TR/TE, infinite/186) shows limited visualization of common bile duct stent. Functionality of stent cannot be assessed.  
B, Axial mangafodipir trisodium–enhanced functional MRC (fMRC) image (6/2.2; flip angle, 40°) shows excretion of contrast material into dilated intrahepatic biliary tree.  
C, Coronal mangafodipir trisodium–enhanced fMRC image (6/2.2; flip angle, 40°) shows excretion of contrast material around stent into duodenum (D), confirming patency.
**Fig. 8.**—45-year-old woman with anatomic variant of biliary tree. Axial mangafodipir trisodium-enhanced functional MR cholangiography image (TR/TE, 6/2.2; flip angle, 40°) shows low cystic duct insertion (CD) and ductal configuration that may increase risk for bile duct injury at laparoscopic cholecystectomy.

**Fig. 9.**—38-year-old woman evaluated as liver transplant donor with mangafodipir trisodium–enhanced functional MR cholangiography (fMRC) shows variant ductal anomaly. Coronal oblique maximum-intensity-projection fMRC image (TR/TE, 5.6/2.5; flip angle, 40°) shows segment IV biliary duct draining into right hepatic duct. Other ducts are labeled. CHD = common hepatic duct, CBD = common bile duct.

**Fig. 10.**—40-year-old man evaluated as liver transplant donor with mangafodipir trisodium–enhanced functional MR cholangiography (fMRC) shows variant ductal anomaly that is only seen by fMRC. A, Coronal single-shot fast spin-echo MRC image (TR/TE, infinite/150) shows no significant abnormality. Ductal system is not well defined. B, Coronal oblique maximum-intensity-projection fMRC image (5.6/2.5; flip angle, 40°) shows right posterior biliary duct (arrow) draining into left duct.
Fayad et al.

MRC is a fast, heavily T2-weighted MR sequence that depicts the fluid-containing biliary tree in a noninvasive manner, requires no contrast agent administration or preparation, and portends none of the complications associated with invasive cholangiography. Both MRC and CT have been established as highly sensitive techniques for the diagnosis of anatomic abnormalities of the gallbladder and biliary tree [8, 9]. However, after imaging with these cross-sectional techniques, a functional assessment of the biliary tree can only be suggested based on associated anatomic findings, including biliary ductal dilatation, stricture, and filling defects. Obstruction of bile flow cannot be definitively diagnosed. For a functional assessment (noninvasively), a second test such as cholescintigraphy is commonly performed.

Hepatobiliary scintigraphy with an iminodiacetic acid derivative such as diisopropyl iminodiacetic acid provides functional information but lacks resolution to show the anatomic cause of obstruction. Filling defects and strictures are uncommonly visualized and the diagnosis of partial obstruction is not

**Fig. 11.**—20-year-old man with end-stage liver disease secondary to argininosuccinase synthase deficiency who underwent liver transplantation and experienced postoperative complication.

A. Axial single-shot fast spin-echo MRI image (TR/TE, infinite/100) shows transplanted liver and marked ascites. Focal perihepatic fluid collection (FL) is identified.

B. Coronal functional MR cholangiography (fMRC) image (6/2.2; flip angle, 40°) shows mangafodipir trisodium in common bile duct. Anastomosis is marked (A). Additional focus of contrast material is present outside biliary tree, compatible with anastomotic leak (arrow). Contrast agent has passed into duodenum (D); there is no evidence of biliary obstruction.

C. Coronal fMRC image (6/2.2; flip angle, 40°) obtained more anteriorly shows contrast agent accumulating outside biliary tree within fluid collection (arrow), compatible with biliary leak.

D. Corresponding diisopropyl iminodiacetic acid scan shows biliary leak (arrow), but site of leak is not clearly depicted. For optimal surgical management, it was important to determine site of biliary extravasation before reoperation.
made in up to 50% of patients [10]. Scintigraphy also has false-positive results in nonfasting patients, patients with severe hepatic failure, and patients with hyperbilirubinemia.

Finally, ERC and PTC provide the opportunity for treatment at the time of diagnosis that the noninvasive techniques discussed here lack. Although invasive cholangiography studies are sensitive diagnostic methods, complications result in as many as 11% of cases [11].

Conclusion

FMRC has the potential to provide a comprehensive examination for the anatomic and functional assessment of the biliary tree and gallbladder. Its compelling advantage is its ability to depict functional information. Partial and complete obstruction may be distinguished along with the inciting anatomic abnormality, a feature particularly useful for treatment planning. In addition, variant bile duct anatomy, complex biliary-enteric anastomoses, biliary stent patency (particularly nonmetal stents), and suspected biliary extravasation can be thoroughly evaluated with fMRC.

References