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Use of magnetic resonance cholangiography in the diagnosis of choledocholithiasis

B. P. Gallix,[1] D. Régent,[2] J.-M. Bruel[1]

[1]Service d' Imagerie Médicale, Hôpital Saint-Eloi, 80, Avenue Augustin Fliche, 34295 Montpellier Cedex 05, France
[2]Département de Radiologie, Hôpitaux de Brabois, Rue du Morvan, 54511 Vandoeuvre-les-Nancy, France

The diagnosis of choledocolithiasis is pivotal for therapeutic planning in patients with symptomatic gallbladder stones. The classically estimated prevalence of common bile duct (CBD) stones in patients who have undergone cholecystectomy for symptomatic cholelithiasis is estimated to 15% [1]. This prevalence is higher in elderly patients (15–60%) than in patients younger than 60 years [2]. With the increased number of laparoscopic cholecystectomies, pre- or peroperative diagnosis of choledocolithiasis has become more critical.

The diagnosis of CBD stones with noninvasive imaging remains a challenge. Transcutaneous sonography and unenhanced helical computed tomography (CT) have a sensitivity of 20–80%, in diagnosing choledocolithiasis according to the literature. However, the specificity of sonography and CT is higher than 90% [3–5].

From a practical point of view, when a CBD stone is detected by a noninvasive method, especially with CT, the positive predictive value is good enough for planning a surgical procedure that should include intraoperative cholangiography (IOC) and stone extraction, if necessary. When no stone is seen with sonography and/or CT, a more sensitive test, and usually a more invasive one, is required to definitively rule out a CBD stone. This assessment could be performed before surgery with either endoscopic retrograde cholangiography (ERC) or endoscopic ultrasonography (EUS). Systematically performed IOC could also replace preoperative evaluation according to surgical researchers. For a long time, ERC has been considered the diagnostic gold standard, with a sensitivity of 95% in detecting choledocolithiasis [6], even though it may miss small stones, especially when the CBD is dilated. EUS is the more accurate imaging test for evaluating extrahepatic bile ducts. EUS should be considered a minimally invasive procedure, with minimal morbidity and mortality (even duodenal perforation remains a rare but severe complication), but it requires general anesthesia and no previous gastric surgery. Moreover, it is a highly operator-dependant procedure, and it does not allow a therapeutic approach other than an endoscopic sphincterotomy.

The limitations of these noninvasive an invasive procedures emphasize the need of a noninvasive reproducible imaging test with both a high accuracy for the diagnosis of choledocolithiasis and the ability to provide a preoperative mapping of the bile ducts. Magnetic resonance (MR) cholangiography has given radiologists the opportunity to display the biliary tract by combining the advantages of projectional and cross-sectional imaging.

Technique

MR cholangiography refers to pulse sequences that produce bright-signal biliary fluid without any administration of contrast medium. MR cholangiographic images are generated with heavily T2-weighted gradient-echo or echo-train spin-echo sequences. With optimized parameters, these sequences produce a strong tissue differentiation between bright static or slowly flowing fluid (including bile) and dark background soft tissue. The addition of the fat-saturation technique improves differentiation between bile and surrounding adipose tissue. MR cholangiographic studies were initially performed with a heavily T2-weighted gradient-echo-based steady-state pulse sequence [7–9]. However, these sequences are limited in their ability to detect nondilated bile ducts because of a low signal-to-noise ratio and sensitivity to motion artifacts.

Clinical experience with MR cholangiography suggests that variants of the rapid acquisition with relaxation enhancement (RARE) sequences, such as two-dimensional (2D) fast spin-echo (FSE) or turbo spin-echo (TSE), three-dimensional (3D) FSE or TSE, multislice

Correspondence to: B. P. Gallix

half-Fourier acquisition single-shot TSE (HASTE), and single-shot RARE, provide images superior to those with gradient-echo techniques [10–12]. From a practical point of view, FSE or TSE techniques differ fundamentally from HASTE or single-shot RARE in the type of respiratory artifact reduction, namely respiratory triggering and breath-holding.

FSE and TSE sequences produce multiple contiguous thin-slice images. For 2D acquisition, images should be acquired in both the axial and coronal planes. The source images may be reconstructed to create 3D views by using maximum intensity pixel projection (MIP) software (Fig. 1). With thin slices, stones are depicted as areas of signal void surrounded by bright bile on source images (Figs. 2–4). When using MIP reconstruction, stones can be obscured by bright surrounding bile, especially in dilated ducts. Therefore, both the source images and multiplanar or 3D reformatting should be reviewed to avoid false-negative results.

Single-shot RARE and HASTE techniques can be performed in a breath-hold period, with a scan time of 1–20 s. These breath-hold approaches can be performed in a thick-slice mode (20–70 mm thick) or as thin multiple single-section slices (5 mm). The thick-slice method provides a projectional view of the biliary system as a whole in a manner similar to direct cholangiography (Figs. 5, 6). In single thick-slice mode, CBD stones are displayed as low signal intensity areas that represent an average of the stone signal void and the hyperintense surrounding bile in the entire voxel (Fig. 7). Small calculi may be then totally obscured if they are located in dilated bile duct. Therefore, additional axial thin multislice images should be performed to avoid false-negative results.

Potential sources of misdiagnosis than obscuration of stones in markedly dilated ducts may be encountered. Because a signal void within the bile duct is not specific for calculi, the presence of an air bubble, blood clot, or sludge ball may result in false-positive results (Figs. 8, 9). Axial thin slices allow differentiation of pneumobilia, where the signal void area is present anteriorly in the nondependent position from the calculi that lie in the dependent position of the bile duct lumen (Figs. 2, 3). Classically, the superior pancreaticoduodenal artery crosses the inferior aspect of the CBD, and the signal void from the arterial flow may mimic a CBD stone (Fig. 10); this pitfall can be avoided by examining adjacent images that display the tubular appearance of the vessel. The biliary tract may also be obscured by artifacts caused by surgical clips.

Detection of a small CBD stone impacted in an inflammatory ampullary stenosis may be difficult with MR cholangiography. However, an ampullary carcinoma can simulate an impacted distal CBD stone (Fig. 11). Pre- and post–gadolinium-enhanced T1-weighted sequences may be helpful in differentiating an unenhanced impacted stone from an enhanced tumor.

Results

The data available on the accuracy of MR cholangiography in the diagnosis of choledocholithiasis is still preliminary (Table 1), and no outcomes studies are available to determine the clinical impact of MR cholangiography on the management of patients with suspected CBD stones.

In 1993, Ishizaki et al. [13] first demonstrated the clinical value of MR cholangiograhy in the diagnosis of choledocholithiasis. Using gradient-echo sequences, they correctly diagnosed all six cases of CBD stones in a group of 20 patients presenting with bile duct obstruction. However, Reinhold et al. [10] compared 2D echo-train spin echos with gradient-echo sequences and demonstrated that FSE sequences provided better visualization of the biliary tree. Several studies in the literature have demonstrated the accuracy of 2D echo-train spin echo in the diagnosis of CBD stones. When using non–breath-hold 2D echo-train spin echo and a body coil, MR cholangiography has a sensitivity of 57–100% and a specificity of

Fig. 1. MIP reconstruction of a set of coronal heavily T2-weighted 2D echo-train spin-echo images demonstrates the normal common bile duct (*arrow*) and cystic duct (*arrowhead*). *GB* gallbladder, *D* duodenum.

Fig. 2. Choledocholithiasis. Heavily T2-weighted 2D echo-train spin-echo transverse source image shows a signal void area posteriorly (*arrow*) that represents a stone in the distal common bile duct. Note the thick gallbladder (*asterisk*) wall due to acute cholecystitis.

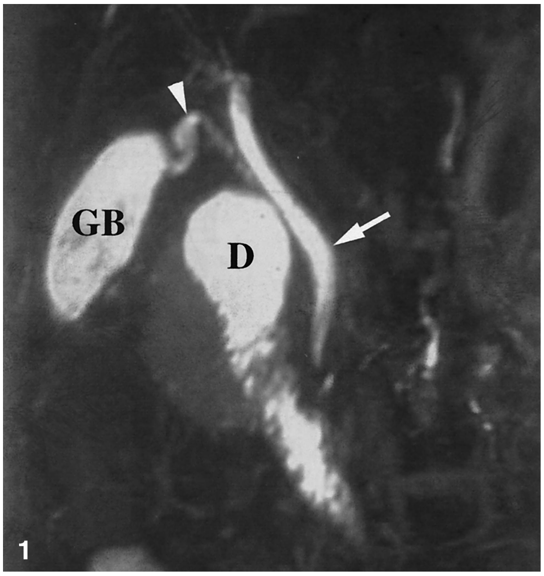
Fig. 3. Choledocholithiasis. Heavily T2-weighted 2D echo-train spin-echo transverse source image demonstrates two stones (*arrow*) in the dilated distal common bile duct. Note the normal pancreatic duct (*arrowhead*) close to the distal CBD. *GB* gallbladder.

Fig. 4. Choledocholithiasis in a patient with acute pancreatitis. Coronal heavily T2-weighted 2D echo-train spin-echo image demonstrates several stones (*arrow*) in a nondilated distal common bile duct. Note the high signal intensity of the pancreatic head (*asterisk*) due to the presence of peripancreatic fluid and edema of the gland. *D* duodenum.

Fig. 5. Aberrant hepatic duct and pancreas divisum. Heavily T2-weighted single-shot RARE image. Projectional view of the biliary system as a whole obtained with thick-slice MR cholangiogram demonstrates an aberrant insertion of the posterior right hepatic duct (*arrow*) and an abnormal insertion of the dorsal pancreatic duct into the duct of Santorini (*arrowheads*).

Fig. 6. Excluded biliary segment. Heavily T2-weighted single-shot RARE projectional view with thick-slice MR cholangiogram demonstrates the obstruction (*arrow*) of the right hepatic duct due to a surgical clip placed across the duct during laparoscopic cholecystectomy. Complete overview of the biliary tree shows the dilated right biliary tract upstream to the obstruction (*asterisk*) and the normal CBD (*arrowhead*).

Fig. 7. Gallstones and choledocholithiasis. Heavily T2-weighted single-shot RARE projectional view with thick-slice MR cholangiogram demonstrates multiple areas of low signal intensity (*arrowhead*) within the gallbladder that represent gallstones. There is a suggestion of a small area of low signal intensity (*arrow*) that represents a calculus in the distal CBD. *GB* gallbladder.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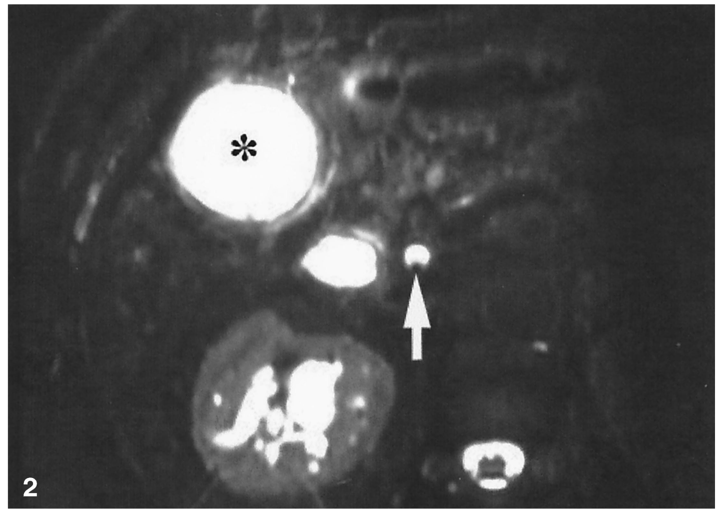
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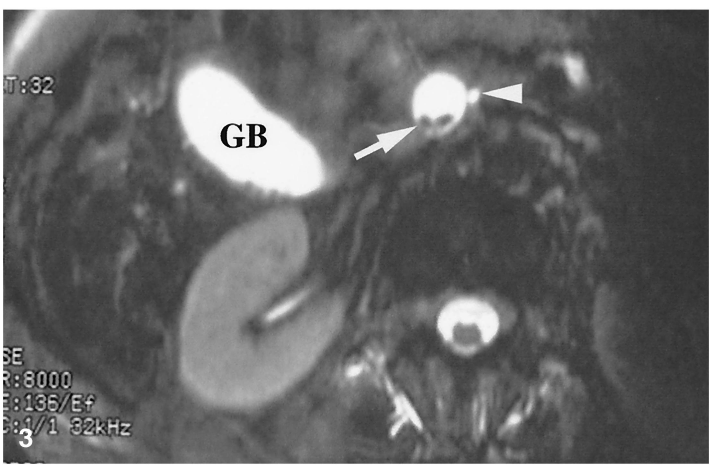
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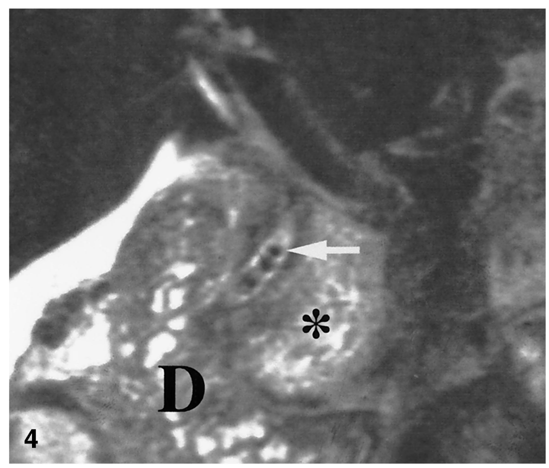
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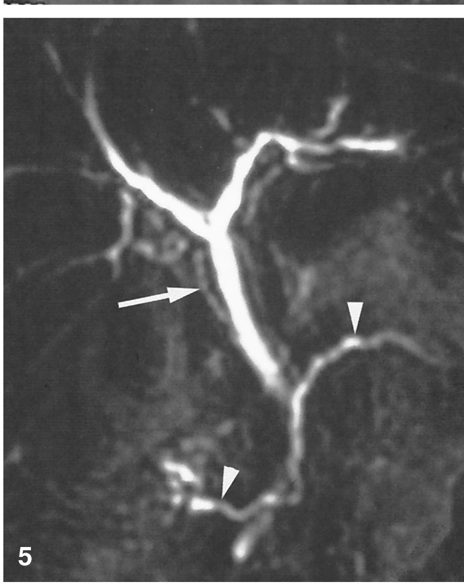
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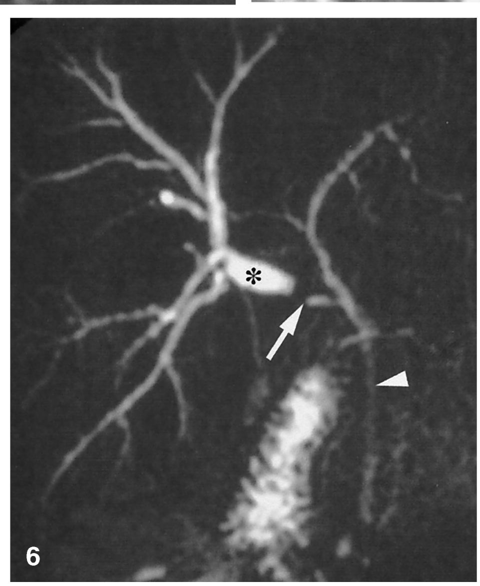
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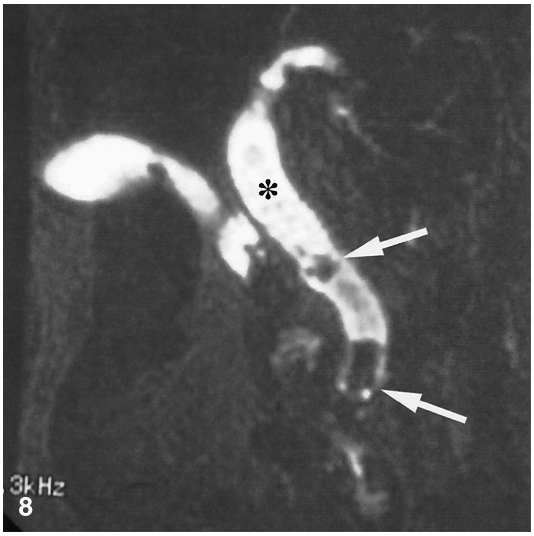

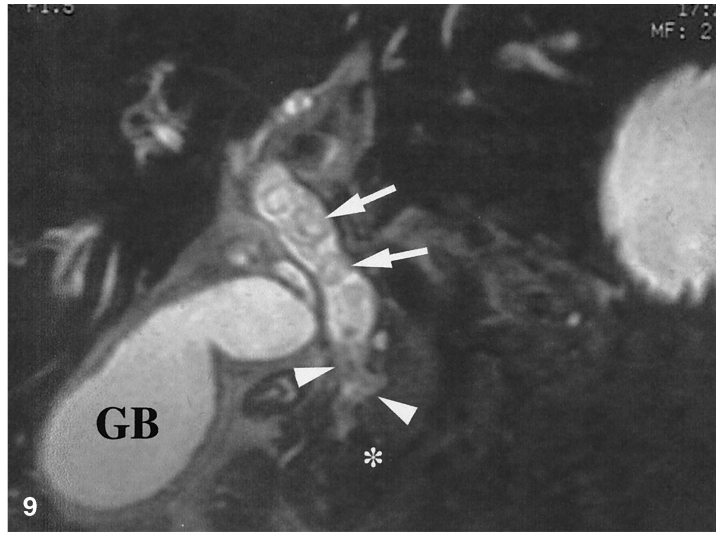

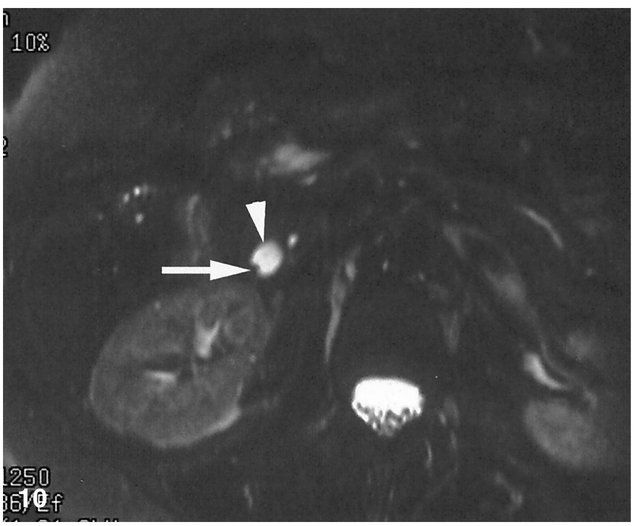

Fig. 8. Pneumobilia. Heavily T2-weighted single-shot RARE with thin-slice MR cholangiogram demonstrates multiple areas of signal void (*arrows*) in the dilated extrahepatic duct (*asterisk*). No stone was demonstrated by the ERC performed before the MR cholangiography. Sphincterotomy resulted in extensive pneumobilia. In the absence of transverse thin sections, differentiation of pneumobilia from choledocholithiasis is not possible.

Fig. 9. Protein plugs in a patient with acute pancreatitis. Coronal heavily T2-weighted 2D echo-train spin-echo image demonstrates several areas of heterogeneous low signal intensity (*arrows*) in a dilated CBD and a stenosis of the distal CBD (*arrowheads*) at the level of the pancreatic head (*asterisk*). Cholecystectomy with intraoperative cholangiography performed immediately after MR cholangiography showed the stenosis due to inflammation of the pancreatic head but no stones in the CBD. Note the thick gallbladder (*GB*) wall due to acute cholecystitis and peripancreatic inflammatory changes.

Fig. 10. Superior pancreaticoduodenal artery. Heavily T2-weighted 2D echo-train spin-echo transverse source image demonstrates a small signal void spot (*arrow*) close to the inferior aspect of the CBD (*arrowhead*) that may mimic a CBD stone.

73–100% in diagnosing choledocolithiasis [11, 14–17] (Table 1). More recently, with breathing-averaged 2D FSE sequences and a phased-array multicoil, Reinhold et al [18] obtained a 90% sensitivity and a 100% specificity in a population of 110 patients explored for biliary obstruction. With the same technique, Varghese et al. [19] obtained almost identical results (sensitivity of 93% and specificity of 99%) in a population of 100 patients.

The breath-hold single-slice projection technique using HASTE sequences best demonstrated the biliary tree and periampullary area [20] and provided better image quality than did echo-train spin echo because of a higher contrast-to-noise ratio [21]. However, bile duct stones were best depicted on thin breath-hold multislice sequences [20]. Using breath-hold single-slice projection and thin mutislice HASTE sequences, Fulcher et al. [22] found 100% sensitivity and specificity in a population of 265 patients being investigated for biliary obstruction. In a smaller series, de Ledinghen et al. [23] reported a sensitivity of 100% and a specificity of 73%.

The high prevalence of CBD stones in these cases (21–70%) may be explained by the fact that inclusion in the study was limited to patients with clinically or biologically suspected biliary obstruction. MR cholangiography was never evaluated as a preoperative method for screening patients who underwent cholecystectomy because of symptomatic cholecystolithiasis.

The results of these studies indicate that there is no clear consensus about which MR cholangiographic sequence is most appropriate for showing choledocholithiasis. One of the main limitations of the studies that have tried to evaluate the accuracy of MR cholangiography in the diagnosis of CBD stones is the absence of an unquestionable gold standard, especially for small calculi. The sensitivity of direct cholangiography (ERC, IOC), generally used as the reference technique, is limited for detecting small choledocholithiases because stones may be obscured by the surrounding contrast material [6]. Morever, false-positive results due to air bubbles may be encountered with direct cholangiography. Thus, comparison of

Table 1. Sensitivity and specificity of magnetic resonance cholangiography in the diagnosis of choledocholithiasis

Reference	*n* patients	Prevalence of CBD stone	Sequence	Coil	% Sensitivity	% Specificity
11	24	28	2D FSE	Body	71	NA
14	126	25	2D FSE	Body	81	98
28	30	22	3D TSE	Body	100	94
15	45	42	2D TSE	Body	95	85
29	23	65	HASTE	Body	93	89
16	108	21	2D FSE	Body	88–92	91–98
18	110	30	2D FSE	Phased array	90	100
22	265	NA	HASTE	Phased array	100	100
23	42	31	HASTE	Phased array	100	73
17	70	70	2D TSE	Body	57	100
19	100	30	2D FSE	Phased array	93	99

2D, two dimensional; 3D, three dimensional; CBD, common bile duct; FSE, fast spin echo; HASTE, half-Fourier acquisition single-shot turbo spin echo; NA, not available; TSE, turbo spin echo

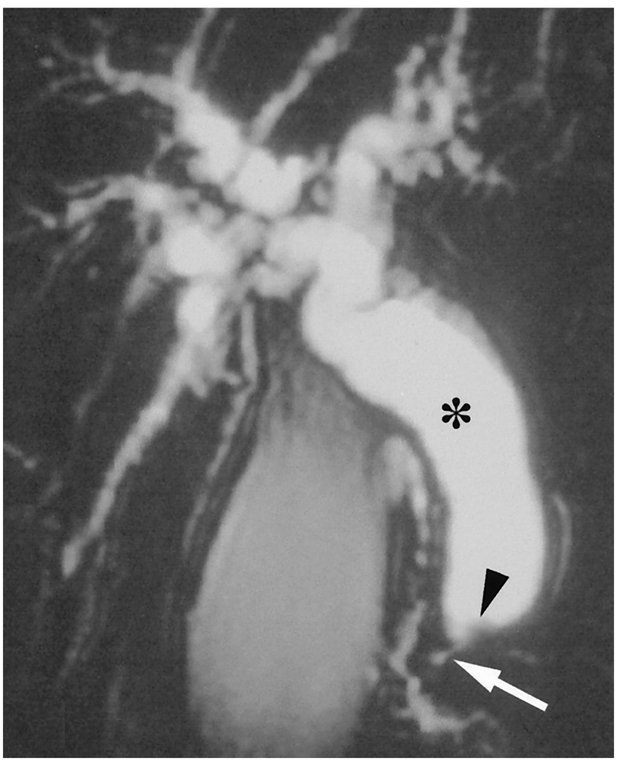

Fig. 11. Ampullary carcinoma. Heavily T2-weighted single-shot RARE projectional view with thick-slice MR cholangiography demonstrates a markedly dilated biliary tree (*asterisk*) and an obstruction at the level of the ampulla (*arrow*). The ampullary mass bulges in the distal CBD and creates an intraluminal defect that may mimic a stone (*arrowhead*).

the accuracy of MR and direct cholangiography in the diagnosis of choledocholithiasis is not possible.

The refinement of MR cholangiographic sequences, including the use of a phased array multicoil and breath-hold technique, has led to the production of high-quality images with the capability to detect even small calculi. The best display of the biliary tract is provided when using single-slice projection techniques, and thin multi-slices demonstrate intraluminal material best.

Clinical role

The value of MR cholangiography for detecting calculi, for evaluating bile ducts dilatations and strictures, and for demonstrating the global segmentation of the intra- and extrahepatic bile ducts and their variants has been demonstrated and is now well accepted. Thus, MR cholangiography, a noninvasive test, should play a prominent clinical role in patients with suspected bile disorders. The availability and cost of MR examinations often limit its use in current practice. In contrast, because its invasiveness, ERC should be restricted to therapeutic uses. Because of its low availability with high-quality standards, EUS should be restricted to equivocal cases. MR cholangiography could then be proposed as an alternative under different clinical conditions depending on the risk and availability of direct bile duct approach (ERC, EUS, IOC).

MR may be used when the risk of using ERC is not justified. In patients with acute pancreatitis, MR cholangiography evaluates the gallbladder and the CBD without risk of complications. In patients with low clinical suspicion of choledocolithiasis, MR cholangiography limits the use of ERC only to patients who need a CBD stone extraction by endoscopic sphincterotomy. In patients with a previous cholecystectomy and recurrent bile disorders and those with a contraindication for surgery or general anesthesia, MR cholangiography can be used to display the bile ducts, rule out unnecessary diagnostic ERC, and help to better plan stone extraction by selecting endoscopy or interventional radiology as the therapeutic procedure.

MR cholangiography advantageously replaces transhepatic cholangiography when ERC is either impossible or extremely difficult to perform, as in patients with previous gastric surgery or a long afferent loop in Roux's anastomoses. MR cholangiography may also provide valuable information when ERC is unsuccessful, is related to difficulties in approaching the papilla, and cannulation. For instance, success rates for cannulation and endoscopic sphincterotomy range from 90% to 96% [24, 25].

The role of imaging in the diagnosis of choledocolithiasis before laparoscopic cholecystectomy is still being debated. IOC has been proposed as a screening test for diagnosing CBD stones and intraoperative injury detection, but IOC is more difficult and less accurate during laparoscopic surgery than during open surgery [26]. Even for experienced operators, laparoscopic IOC adds 10–14 min of operating time to the procedure [27]. Moreover, it does not allow precise planning of operative schedules.

Even IOC is less operator dependant than ERC; it requires specific training by laparoscopic surgeons and validated expertise. IOC is time consuming, and its cost effectiveness should be evaluated.

The IOC findings cannot be provided at the right time for better planning of operative schedules or displaying the variations in anatomy of bile ducts for surgical dissection. An aberrant right hepatic duct with a direct insertion into either the common hepatic duct or the cystic duct and a long cystic duct with a low insertion into the distal CBD are clearly depicted by MR cholangiography (Fig. 5) and are considered a high potential risk for bile duct injury in laparoscopic cholecystectomy.

Conclusion

MR cholangiography has the ability to display the biliary tree by combining the advantages of projectional and cross-sectional imaging. Projectional views can delineate the overall anatomy of the biliary tract, depict bile duct dilatation, and localize biliary obstruction with an accuracy very similar to that of direct cholangiography. However, detection of small calculi and subtle intraductal material may be limited on projectional MR and direct cholangiography because stones can be obscured by surrounding bile with high signal intensity or high-density contrast material. MR cholangiography, like endosonography, can provide high-resolution cross-sectional views that best display intraductal abnormalities. Furthermore, a more complete MR examination that includes gadolinium-enhanced T1-weighted dynamic sequences may be performed, if necessary, to differentiate an unenhanced impacted stone from an enhanced tumor.

The absence of consensus about which sequence is most appropriate for showing choledocholithiasis and the lack of outcome studies indicate that the technique is still in its infancy. The accuracy of MR cholangiography is expected to improve, as additional technical refinements on MR technology are likely, thus allowing for the depiction of smaller CBD stones even in nondilated CBD or when impacted in the ampulla. In the near future, MR cholangiography will reach the diagnostic accuracy of direct cholangiography and endosonography in diagnosing CBD stones. Because of its noninvasiveness, there is no doubt that MR cholangiography will replace ERC or endosonography as a nonoperative imaging technique for stone diagnosis.

Detection of CBD stones before or during laparoscopic cholecystectomy is crucial. The clinical role of MR cholangiography during the pre–laparoscopic cholecystectomy work-up has yet to be determined. It will depend not only on the accuracy of laparoscopic intraoperative and MR cholangiography but also on their availability, reproducibility, and cost effectiveness. Large controlled trial and outcome studies are needed to determine the clinical value of MR cholangiography in patients with suspected choledocholithiasis.

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