Biliary, Pancreatic, and Hepatic Imaging for the General Surgeon

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Disorders of the hepatobiliary system and pancreas are commonly encountered by the general surgeon. Recent refinements in cross-sectional and other imaging technologies have greatly enhanced the ability to make definitive preoperative diagnoses and help better select patients who will benefit from surgical intervention. It is critical that surgeons treating these patients have a good understanding of the usefulness and limitations of these imaging modalities to deliver optimal and efficient care. This article provides an overview of these imaging modalities within the context of those disorders most commonly seen in general surgical practice.

**BILIARY**

**Cholelithiasis and Cholecystitis**

Laparoscopic cholecystectomy is currently the most frequently performed abdominal surgery in the United States.\textsuperscript{1,2} Transabdominal ultrasonography (US) is the primary imaging modality used to evaluate for the presence of cholelithiasis, with a sensitivity of 96\% to 98\% and specificity of 95\% for gallstones greater than 2 to 5 mm in size.\textsuperscript{2,3} Sonographically, cholelithiasis is characterized by echogenic foci, which cause acoustic shadows and are gravitationally dependent (Fig. 1).\textsuperscript{3} Stones less than 2 to 3 mm (microlithiasis) are seen inconsistently on transabdominal US but can be seen with greater sensitivity on endoscopic ultrasonography (EUS).\textsuperscript{4} This has clinical

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doi:10.1016/j.suc.2010.10.005 surgical.theclinics.com
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applicability in the work-up of idiopathic pancreatitis, which is often associated with microlithiasis.\textsuperscript{5,6} The presence of lower-amplitude, nonshadowing echoes layering in the dependent portion of the gallbladder on US constitutes biliary sludge, which represents an intermediate step in gallstone formation. This sludge can cause cholecystitis, cholangitis, and pancreatitis by the same mechanisms as larger stones and warrants similar therapeutic interventions.\textsuperscript{3,7–9}

Cholelithiasis has a 1\% to 2\% likelihood of leading to acute cholecystitis or other complications each year.\textsuperscript{1–3} Several signs, seen on US, are suggestive, but not necessarily diagnostic, of acute cholecystitis, including the presence of gallstones or sludge, luminal distension, wall thickening of greater than 3 mm, pericholecystic fluid, sonographic Murphy’s sign (ie, the presence of maximal tenderness elicited by direct pressure of the US transducer over the gallbladder), and increased Doppler flow.\textsuperscript{1,3,10} The greater the number of findings present, the more likely the diagnosis, in the proper clinical context.\textsuperscript{3} Ralls and colleagues\textsuperscript{11} showed that the presence of gallstones with concurrently observed wall thickening or sonographic Murphy’s sign had a positive predictive value (PPV) of 92\% to 95\% for acute cholecystitis, whereas the absence of all 3 of these signs had a negative predictive value (NPV) of 95\%.

Computed tomography (CT) is less sensitive (75\%) than US in the detection of cholelithiasis because of the variable appearance depending on composition; more heavily calcified stones are easier to see than those with high cholesterol content, which are isodense with bile.\textsuperscript{3,12} Therefore, CT has a limited role in the initial evaluation of patients with suspected cholelithiasis. It is important to be aware of CT findings of cholelithiasis-related complications, because it is being used increasingly as a screening examination in patients presenting with abdominal pain. CT findings of acute cholecystitis include most of those noted on US, with pericholecystic stranding representing a specific CT sign of acute cholecystitis.\textsuperscript{3} However, the primary usefulness of CT in this setting is to assist in evaluation for complications such as emphysematous changes or acute pancreatitis.\textsuperscript{3}

Recently, magnetic resonance imaging (MRI) and magnetic resonance cholangiopancreatography (MRCP) have gained widespread use in the secondary evaluation of cholelithiasis-related complications such as choledocholithiasis.\textsuperscript{2,3} Gallstones produce little signal because of the restricted motion of water and cholesterol within the crystalline lattice of the stones. They are best seen on T2-weighted images, which produce bright bile against which the signal voids of gallstones can stand out prominently (Fig. 2). Gadolinium-enhanced, fat-suppressed, T1-weighted images are sensitive for inflammatory changes within the gallbladder wall, and T2-weighted images will show increased signal intensity with cholecystitis.\textsuperscript{2}

Acute acalculous cholecystitis manifests the same clinical and radiologic findings of acute calculous disease but without evidence of gallstones. This diagnosis must be

Fig. 1. Transabdominal US with layering, shadowing (S), echogenic foci consistent with gallstones (GS) and thickened gallbladder wall (WT).
considered in critically or chronically ill hospitalized patients with unexplained abdominal pain or sepsis. Consequently, the general surgeon will often be called on to evaluate such patients who are noted to have gallbladder wall thickening or other findings suggestive of acalculous cholecystitis. To avoid the potential morbidity of nontherapeutic biliary procedures, it is important to recognize that several nonbiliary conditions, including hepatitis, hypoproteinemia, congestive heart failure, and chronic liver failure, can also produce many of these findings on US and CT. Hepatobiliary scintigraphy provides physiologic imaging of the gallbladder and can be helpful in such scenarios. Hepatobiliary scintigraphy is performed most commonly with hepatic iminodiacetic acid (HIDA) scanning using technetium-labeled analogues that are taken up by hepatocytes and actively transported through the biliary system. The absence of gallbladder filling 1 hour after intravenous (IV) injection of the isotope is suggestive of cholecystitis, whereas nonfilling after 4 hours is diagnostic provided the isotope has moved through the common bile duct. Alternatively, administration of 0.04 mg/kg of IV morphine induces spasm of the sphincter of Oddi, facilitating filling of the gallbladder. Continued nonfilling 30 minutes after morphine augmentation is equally predictive of the diagnosis of acute cholecystitis and shortens study duration. A recognized limitation of HIDA scanning is the need for patient transport to nuclear medicine, a move that can be hazardous for critically ill patients.

Chronic acalculous cholecystitis or biliary dyskinesia is also best evaluated with HIDA scanning. Delayed onset of gallbladder filling and slow biliary-to-bowel transit time are associated with chronic gallbladder dysfunction. However, the most reliable criteria for the diagnosis is the gallbladder ejection fraction (EF) observed after administration of synthetic cholecystokinin (CCK) infusion. A gallbladder EF of less than 30% to 40% following 3 to 30 minutes of CCK infusion is predictive of symptom relief after cholecystectomy, provided a supportive clinical setting. A limitation of HIDA with EF has been inconsistency in diagnostic thresholds and dosing durations. An ongoing Society of Nuclear Medicine multicenter trial is expected to identify and standardize the optimal infusion methodology. Reproduction of pain during the CCK infusion has been regarded as supportive of the diagnosis of chronic cholecystitis, but several investigations have not supported this.
**Gallbladder Polyps**

Polypoid lesion of the gallbladder (PLG) is a term used to describe a range of elevated mucosal lesions including adenomas, small adenocarcinomas, cholesterol polyps, and adenomyomatosis hyperplasia.\(^3,19,20\) The critical aspect of PLG differentiation is to determine which are at risk for containing, or progressing to, neoplasm. US is the most widely validated imaging modality for these lesions, which typically appear as immobile, nonshadowing echogenic masses (Fig. 3). Patients with symptomatic lesions should undergo cholecystectomy. Patients who are asymptomatic with PLGs 1 cm or larger have an 8% to 11% risk of malignancy and should also undergo cholecystectomy.\(^{19,21–23}\) Lesions that are less than 1 cm have not been associated with neoplasm in the Western population and can therefore be managed nonoperatively, but are recommended to undergo interval US follow-up every 6 months for several years to ensure stability.\(^{19,22}\) EUS seems to be more sensitive than US in PLG detection but has not been shown to better differentiate malignant from benign lesions.\(^{19,22}\)

**Gallbladder Carcinoma**

The most common presentation of gallbladder adenocarcinoma radiographically is a subhepatic mass replacing or obscuring the gallbladder (Fig. 4). Less-frequent presentations include focal or diffuse gallbladder wall thickening or an intraluminal mass.\(^3\) On US, malignancies of the gallbladder appear as hypo- or isoechogenic, irregularly shaped lesions. Gallstones are noted in 80% of cases and are occasionally surrounded by the tumor, a finding specific for gallbladder cancer.\(^{23}\) Overall sensitivity of US in this setting is 85%, with an accuracy of 80%.\(^{23}\)

CT does not show the mucosal characteristics of gallbladder carcinoma as clearly as US but identifies the presence of liver metastasis or local extension of the tumor. The sensitivity, specificity, PPV, NPV, and accuracy of modern multidetector CT for the primary site of gallbladder cancer are 84%, 71%, 93%, 48%, and 82%, respectively.\(^{24}\) These tumors show early uptake of contrast within the arterial phase on CT, unlike the delayed uptake typical of cholangiocarcinoma.\(^{23}\)

MRI is useful in the evaluation of primary gallbladder neoplasms and metastatic sites. Gallbladder adenocarcinoma appears as hypo- or isointense on T1-weighted
images and is heterogeneously hyperintense on T2-weighted images. The primary shows irregular rim early enhancement after gadolinium administration, helping to distinguish neoplastic changes from those of chronic cholecystitis, which is characterized by smooth early enhancement. MRI is accurate for local hepatic invasion, with nearly 100% sensitivity, and also carries a 92% sensitivity in detection of local lymph node involvement. These attributes make MRI the most appropriate secondary imaging modality for evaluation after US in most cases of suspected gallbladder cancer.

Even with concurrent CT scanning, positron emission tomography (PET) does not seem to offer additional benefit to that achieved with US and MRI in regard to primary tumor evaluation, but can be helpful in determination of lymph node involvement (94% PPV) and distant metastasis (95% sensitivity).

**Choledocholithiasis**

Choledocholithiasis complicates 3% to 15% of cases of symptomatic cholelithiasis. Common duct stones may pass harmlessly with time into the duodenum, but severe complications such as cholangitis or pancreatitis can occur. Prevention of such complicated courses, as well as differentiation from other causes of biliary obstruction, makes the diagnosis of choledocholithiasis extremely important.

US is typically the initial imaging modality and can show shadowing echogenic foci within the common bile duct (Fig. 5). Obesity and interference from duodenal gas limit
the usefulness of US for choledocholithiasis, with reported sensitivity ranging between 25% and 63%. The presence of visualized stones on US is highly specific, at 95% to 100%, with PPV of approximately 100%.\textsuperscript{4,27–29} It is therefore reasonable to act on positive US findings of choledocholithiasis, but there is no assurance of the reliability of negative findings. US is more sensitive (up to 91%) for indirect findings of choledocholithiasis, such as biliary duct dilatation greater than 6 mm.\textsuperscript{26} Such findings are nonspecific and warrant additional radiologic investigation in most instances.

CT does not substantially enhance the imaging of choledocholithiasis beyond that provided by US.\textsuperscript{4,27,28,30} CT cholangiography techniques can increase the sensitivity for choledocholithiasis to the 96% range but are limited by a high incidence of nausea and decreased accuracy in the jaundiced patient.\textsuperscript{26,31,32} Noncholangiographic CT with coronal reconstruction has been found to be of some increased benefit in other biliary disorders but does not seem to enhance the diagnosis of choledocholithiasis.\textsuperscript{33}

MRCP has become the imaging modality of choice in assessment of choledocholithiasis for several authorities.\textsuperscript{26,30,34,35} The study is performed with T2-weighted images obtained by rapid acquisition (to minimize breathing artifact), which can be reformatted into three-dimensional, rotatable images. Common duct stones appear as filling defects of variable intensity within the biliary system on MRCP (Fig. 6), with a sensitivity of 81% to 100%, specificity of 73% to 100%, PPV of 63% to 97%, NPV of 84% to 100%, and accuracy of 82% to 92%.\textsuperscript{4,26,30,34,36–38} Comparisons of MRCP with direct cholangiography via endoscopic retrograde cholangiopancreatography (ERCP) have shown equivalent results with the noted advantages of concurrent hepatic and pancreatic imaging with MRCP, in addition to the noninvasive nature of MRCP.\textsuperscript{26,30,39}

The use of MRCP can be limited by patient factors such as claustrophobia, morbid obesity, or indwelling foreign bodies such as pacemakers. In addition, duodenal gas interference causes decreased sensitivity of MRCP for biliary disorders in the periampullary bile duct (Fig. 7).\textsuperscript{40} The sensitivity of MRCP is also diminished to approximately 70% in the setting of common duct stones less than 5 mm in diameter.\textsuperscript{38}

EUS involves the use of a high-frequency US probe on a specialized upper endoscope to facilitate close proximity US imaging of the pancreas, distal bile duct, local lymph nodes, and vessels.\textsuperscript{4,41} Placement in the duodenal bulb provides high-resolution US images that can show common duct stones as small as 2 mm (Fig. 8). Experience with EUS for choledocholithiasis has shown a sensitivity of 84% to 97%, specificity of 86% to 100%, PPV of 98% to 100%, NPV of 88% to 97%, and accuracy of 91% to 99%.\textsuperscript{4,26–30,36,37,42–49}

Limitations of EUS include the inherent risks of upper endoscopy and conscious sedation, poor visualization of the biliary system proximal to the hepatic hilum, Fig. 6. MRCP with multiple filling defects consistent with choledocholithiasis.
operator dependency, limited availability, and anatomic limitations in some patients having previously undergone upper gastrointestinal operations.\textsuperscript{4,26,44} Advantages include the lack of ionizing radiation or contrast exposure and the ability to accurately image small stones and those in the distal common bile duct.\textsuperscript{4,30,44,50} These advantages provide an argument to favor EUS as the primary preoperative imaging modality for evaluation of possible choledocholithiasis at institutions where the expertise is available.\textsuperscript{4,30,37} For difficult presentations, MRCP and EUS can be complementary, with the former providing good assessment for intrahepatic and proximal biliary causes, whereas the latter can better show smaller stones and the periampullary region.

ERCP has been regarded as the nonoperative gold standard for biliary imaging, with a sensitivity of 84% to 97%, specificity of 87% to 100%, PPV of 79% to 100%, NPV of 93% to 96%, and accuracy of 89% to 97% in the diagnosis of choledocholithiasis.\textsuperscript{4,26,29,30,43–45,51} In addition, ERCP has the advantage of allowing for stone removal and biliary drainage (\textbf{Fig. 9}). However, the procedure is invasive, with complication rates as high as 15% and mortality ranging between 0.2% and 1.5%.\textsuperscript{26,52,53} Acute pancreatitis is the most common notable complication, occurring in approximately 5% of cases. The instrumentation of an obstructed biliary system also poses the risk of cholangitis, particularly if drainage cannot be accomplished. Other substantial morbidities include duodenal and biliary perforation and bleeding.\textsuperscript{26,52–54} Because of

\begin{figure}[h]
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\includegraphics[width=\textwidth]{fig7}
\caption{Periampullary region of decreased sensitivity on MRCP. (A) MRCP interpreted as normal. (B) A 5-mm distal common bile duct stone (arrow) found on intraoperative cholangiography (IOC) after negative MRCP. The stone was removed via transcystic choledochoscopy.}
\end{figure}

\begin{figure}[h]
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\includegraphics[width=\textwidth]{fig8}
\caption{Choledocholithiasis on EUS. Stone (arrow) within common bile duct (CBD) with adjacent pancreatic duct (PD). (Courtesy of Sanjay Garuda, MD, Columbus, OH.)}
\end{figure}
these risks, ERCP is now reserved for patients with a high likelihood of interventional need based on clinical and/or less-invasive imaging findings.\textsuperscript{30,55–58} Intervention via ERCP for choledocholithiasis is successful in 90% to 97% of cases, although 2 or more sessions are required in up to 25% of cases.\textsuperscript{30}

Peroral cholangioscopy, as initially described in the 1970s, involved the passage of a small daughter scope through a duodenoscope to directly visualize the bile duct. Early users of the modality were limited by the need for 2 endoscopists and limited resolution.\textsuperscript{59–61} More recently, single-operator cholangioscopes with greater resolution and irrigation/operating channels have become available. In experienced hands, choledocholithiasis can be visualized in 90% of cases and the scope permits passage of an electrohydraulic lithotripsy probe or holmium laser for therapeutic purposes.\textsuperscript{61} Currently, experience with peroral cholangioscopy is limited but it seems to have great potential for future diagnostic and therapeutic biliary applications.

The first series of direct cholangiography performed intraoperatively was reported in 1932 by Mirizzi.\textsuperscript{62} Through the early 1970s, intraoperative cholangiography (IOC) was performed using static images, a time-consuming process that often required repeating.\textsuperscript{63} The performance of IOC was greatly aided by the development of c-arm, high-definition fluoroscopy with application as described by Berci and colleagues\textsuperscript{64} and others in the late 1970s, allowing for increased resolution and speed of the procedure, the ability to obtain multiple images, and the opportunity to perform fluoroscopically guided biliary interventions.\textsuperscript{63,64} Several different instruments and approaches to cannulating the cystic duct laparoscopically have been described, including reusable cholangiograspers, which allow for placement and fixation of 4 to 5 French catheters (Fig. 10).\textsuperscript{63,65} Laparoscopic IOC can be performed successfully in 92% to 97% of cases,\textsuperscript{66–68} typically adding approximately 15 minutes of operating time to cholecystectomy.\textsuperscript{26,66,69,70} In addition to providing imaging of the biliary tree, IOC also helps minimize the risk of injury to the common bile duct.\textsuperscript{71–73}

In the diagnosis of choledocholithiasis, IOC is 80% to 98% sensitive, 76% to 97% specific, with a PPV of 84% to 100%, NPV of 90% to 98%, and an accuracy of 95% to 100%.\textsuperscript{4,26,30,46–49,51} The success rate and diagnostic ability of IOC is equivalent to ERCP but without the risk of acute pancreatitis.\textsuperscript{74} As well as an observed rate of common bile duct stones of 8% to 12% on IOC performed after ERCP (because of either false negative ERCP or interval passage of stones),\textsuperscript{66} this provides support for an up-front surgical approach for patients presenting with symptomatic biliary

![Fig. 9. Common duct clearance with ERCP. (A) MRCP obtained for evaluation of acute pancreatitis showing filling defects consistent with choledocholithiasis (arrows). (B, C) Balloon sweep of duct during ERCP. (Courtesy of James Edison, MD, Columbus, OH.)](image-url)
disease suggestive of choledocholithiasis. Confirmed choledocholithiasis can then be addressed with laparoscopic common bile duct exploration, with equivalent outcomes to ERCP but with an overall shorter hospital stay and decreased expenses.

MRCP, EUS, and/or ERCP can then be limited to use in patients at risk for alternative diagnoses or in the rare instances in which IOC cannot be completed.

A substantial source of false-positive studies in both ERCP and IOC is incidental air-bubble instillation into the biliary system during cannulation and injection of contrast. These can often be simply dealt with by manipulating the operating room (OR) table or flushing them through the system, but they can be persistent (Fig. 11A). Definitive assessment of these and other filling defects seen on IOC can be made by direct examination with choledochoscopy (see Fig. 11B). Choledochoscopy performance can be simplified by initially passing the scope transcystically into the duodenum under fluoroscopy with flexible wire guidance (Fig. 12). Patients with confirmed choledocholithiasis can be managed with basket retrieval of the stones or stone manipulation into the duodenum under choledochoscopic visualization (Fig. 13).

The capital outlay costs of purchasing laparoscopic choledochoscopes is problematic for many ORs and can be circumvented by using a flexible ureteroscope for laparoscopic cases and a flexible cystoscope for open cases.

Intraoperative US has been described by several investigators as a study for choledocholithiasis that is equally sensitive as IOC, with the advantage to the patient and operating team of avoiding radiation exposure. Intraoperative US can be
performed either laparoscopically or open and, in experienced hands, can be performed within 7 minutes with a sensitivity of 96% to 100% and specificity of 99% to 100%\cite{66,67}. It does not require cystic duct cannulation and can be performed successfully 95% to 99% of the time, which is slightly better than IOC\cite{67,68}. However, it does not delineate ductal abnormalities and anatomic variation as well as IOC, and has a fairly steep learning curve. Perhaps most importantly, intraoperative US does not allow for as expeditious a transition to interventional maneuvers as does IOC\cite{66}.

**Cholangiocarcinoma**

Cholangiocarcinoma (CC) is classified anatomically as intrahepatic (5%–10% of cases) perihilar (60%–70%), or distal (20%–30%)\cite{87–90}. Intrahepatic CC typically

![Image](image.png)

**Fig. 12.** Fluoroscopic passage of choledochoscope (*large arrow*) past multiple common duct stones (*small arrows*) using flexible guide wire.

![Image](image.png)

**Fig. 13.** Choledochoscopy. (A) Stone on intraoperative choledochoscopy. (B) Basket retrieval of stone. (C) Choledochoscope within duodenum.
presents as, and is managed in similar fashion to, hepatocellular carcinoma (HCC), whereas perihilar and distal tumors present most commonly with obstructive jaundice. Surgical resection remains the only potentially curative treatment modality. A minority of patients seem resectable on presentation, and approximately 25% of these are found to have unresectable disease on exploration. Curative surgery requires extensive resections, typically major hepatectomy for intrahepatic and perihilar CC or pancreaticoduodenectomy for distal CC, each of which carries significant risk of morbidity. The preoperative radiographic assessment for resectability is consequently as critical as that for diagnosis. Radiographic criteria for resectability of intrahepatic CC mirror those of HCC, whereas resectability of distal CC is identical to that of other periampullary malignancies. Perihilar CC presents unique challenges in both diagnosis and determination of respectability because CC tends to grow along the biliary tree and frequently invades proximally, resulting in nonresectability.

The most common findings with CC on US is indirect evidence such as proximal biliary ductal dilatation, hepatomegaly, and hepatic atrophy, which are detected with a sensitivity of 80% to 96% and carry a poor specificity of 20% to 40%. US has poor sensitivity for detecting metastases in the lymph nodes (LN) (37%), liver (66%), and peritoneum (33%). The addition of color flow Doppler enhances the sensitivity of US for portal vein (PV) occlusion (100%) and infiltration (83%), but sensitivity for hepatic arterial involvement remains poor (43%). Consequently, additional imaging modalities are required in essentially all cases for accurate diagnosis and determination of resectability.

Both CT and MRI can image the primary site of CC in 70% to 90% of cases as lesions that are hypo- or isodense relative to normal hepatic parenchyma and tend to remain so during arterial and portal venous phases before showing enhancement during delayed phase images. This is reflective of the hypovascular desmoplastic composition typifying CC, and contrasts with the arterial enhancement seen with most cases of gallbladder cancer and HCC. MRI additionally allows cholangiographic capability and the opportunity of tissue differentiation based on different pulse sequences with increased signal being noted within most CC primary sites on T2-weighted images. This capability results in near 100% sensitivity in diagnosing biliary obstruction, 98% accuracy in identifying the level of obstruction, and an 88% to 95% accurate assessment of the cause of obstruction; performance equivalent to that of direct cholangiography. Given this cholangiographic performance, the ability to concurrently evaluate for intra-abdominal local or distant metastasis and its noninvasive nature, MRCP has become the imaging modality of choice in evaluation of biliary strictures and CC (Fig. 14A). An accurate assessment of resectability of CC is rendered by MRI/MRCP in 70% to 80% of cases, a rate equivalent to that provided by the combination of CT and direct cholangiography in prospective comparison. From a strategic standpoint, it is important to recognize that stenting and percutaneous drainage procedures cause mild bile duct wall inflammation that is indistinguishable on MRI from CC spread. Consequently, MRCP should be performed before interventional procedures whenever possible.

EUS is a more sensitive modality for the periampullary region, with the ability to show lesions as small as 2 mm, and is therefore a helpful adjunct to MRCP when distal biliary abnormalities are suspected. Determination of LN involvement by MRI is 66% to 74% accurate, whereas the sensitivity and specificity for PV invasion are 78% and 91%, respectively. Evaluation of hepatic arterial invasion is more limited, with a 58% to 73% sensitivity and 93% specificity. These limitations can also be offset by EUS, which seems to be more accurate at determination of...
An additional benefit of EUS is the ability to perform direct-guided, fine-needle aspiration (FNA) on primary tumors as well as local LNs with sensitivity, specificity, and accuracy of 86% to 89%, 100%, and 88% to 91%, respectively. Hypothetically the risk of needle tract seeding should be less than that of percutaneous FNA/biopsy given the shorter needle tract, but data concerning this are limited currently.

Evaluation of metastatic disease from several neoplasms has recently been aided with the development of PET scanning, particularly when fused with CT. PET does not currently have a routine role in CC, although it can be helpful when there is a question of possible metastatic disease.

Direct cholangiography in the setting of CC is typically performed via ERCP or percutaneous transhepatic cholangiography (PTC). The choice between ERCP and PTC is dictated by institutional experience and anatomic characteristics of the tumor. Distal CC tends to be better imaged via ERCP, whereas hilar and intrahepatic lesions typically can be viewed better with PTC (Fig. 14B, C). Both modalities carry an overall sensitivity of 75% to 85%, a specificity of 70% to 75%, and an accuracy of 95% in identifying the presence and extent of CC. The invasiveness of both procedures is a notable limiting factor, favoring routine use of MRCP with or without EUS during the diagnostic stage of most cases unless the development of cholangitis demands early interventional therapy. The primary role of direct cholangiography in CC is in palliative or preoperative stenting procedures to relieve...

Fig. 14. Cholangiocarcinoma. (A) Perihilar cholangiocarcinoma on MRCP with right hepatic duct (RHD), left hepatic duct (LHD), common bile duct (CBD), and tumor site (CC) noted. (B) ERCP evaluation. (C) Percutaneous transhepatic cholangiogram. (D) Palliative and therapeutic stenting with bilateral approach taken to address clinical cholangitis. (Courtesy of Andrew Verrill, MD, Columbus, OH.)
biliary obstruction (see Fig. 14D). In addition, direct cholangiography affords the opportunity of obtaining brush cytology and/or biopsy specimens, which can assist with making a definitive diagnosis. Although these sampling methods carry sensitivities ranging from 10% to 80% in the diagnosis of CC, the experience of most authorities has been at the lower end of this range, reflective of the substantial associated desmoplastic reaction and low cellularity seen in many CCs. This limitation has frequently led to the need to make definitive treatment decisions without the advantage of tissue diagnosis.

Two emerging adjunctive modalities to direct cholangiography have the potential to substantially enhance preoperative diagnosis and staging of CC. Peroneal cholangioscopy, an extension of ERCP techniques, permits direct visualization of the bile duct, with sensitivities and specificities up to 100% and 80%, in patients with CC. Cholangioscopy also can be performed percutaneously, although published experiences with this technique are more limited.

Intraductal ultrasound (IDUS) uses small-diameter probes that can be inserted over a 9-mm guide wire at the time of direct cholangiography, providing US views that are 89% accurate at determining the benign or malignant nature of biliary strictures and 82% accurate at determining resectability. As with any US procedure, the accuracy of IDUS is operator dependent.

**PANCREAS**

**Acute Pancreatitis**

More than 300,000 patients are hospitalized each year with acute pancreatitis (AP) and 20,000 ultimately die from the condition. The diagnosis of AP is usually made when a patient has 2 of the following 3 criteria: upper abdominal pain, increased pancreatic enzymes, and imaging findings of pancreatic inflammation. In addition to the diagnostic yield, imaging assists with determination of the cause, severity, and prognosis of AP.

AP cannot be definitively diagnosed with plain abdominal films, but abdominal radiography is performed in many cases to rule out other causes of upper abdominal pain, such as gastrointestinal perforation. Inconsistently seen findings suggestive of pancreatitis include localized sentinel loop formation caused by focally dilated small bowel with distal spasm caused by the inflammatory process. Similarly, a colon cutoff sign occurs via the same mechanism and can be seen at the splenic flexure, descending colon, or transverse colon. Peripancreatic inflammation can cause widening of the duodenum or produce a generalized ileus with multiple air-fluid levels. Chest films may reveal left-sided pleural effusions, pulmonary infiltrates, or elevation of the left hemidiaphragm.

US is the primary imaging modality in screening for gallstones or ductal abnormalities associated with AP. The inflamed pancreas can be visualized successfully between 62% and 90% of the time. Overlying intestinal gas and large body habitus can severely limit the examination of the pancreatic head and common bile duct.

CT is the most useful modality for making the diagnosis of AP. Patients should receive oral and IV contrast (except if contraindicated for ileus or renal insufficiency) for optimal sensitivity. CT can identify peripancreatic inflammation, nonuniform parenchymal density, acute fluid collections, hematoma, splenic and PV thrombosis, peripancreatic gas, and pancreatic necrosis (Figs. 15 and 16). The severity of inflammation and necrosis can be graded according to the Balthazar criteria or CT severity index, which have important prognostic implications. A recent study placed greater emphasis on the presence of extrapancreatic complications, such as
ascites, pleural effusions, or intestinal involvement, which also correlate with patient outcomes. MRI is a viable alternative to CT for imaging AP and has been shown to possess similar diagnostic ability. T2-weighted images of the pancreas depict the severity of surrounding edema and may be superior in characterizing fluid collections and determination of cause. Arvanitakis and colleagues showed an MRI severity index to be superior in both sensitivity and specificity when characterizing AP compared with CT criteria. MRCP also shows ductal anatomy better than CT.

EUS is primarily useful in cases of idiopathic AP, most of which are caused by micro-lithiasis. The sensitivity of EUS for stones less than 2 to 3 mm makes the modality the optimal study currently available to select out patients who will benefit from cholecystectomy in this setting. EUS also permits more accurate assessment of retained choledocholithiasis compared with MRCP and other noninvasive modalities and is safe to use in pregnant patients and in those with contraindications to MRI. ERCP is of limited use in AP because of the risk of worsening the process. Although performing ERCP is not routinely recommended, patients with AP who benefit from early ERCP are those with cholangitis or severe pancreatitis with evidence of retained stones.

**Pancreatic Cysts**

Incidental pancreatic cysts are being discovered more frequently as abdominal imaging has increased, and it seems that as many as 1% of inpatients have a detectable pancreatic cyst. Most (85%–90%) pancreatic cystic lesions are pseudocysts related to a prior episode of pancreatitis or trauma resulting in a pancreatic ductal...
disruption. Although these instances can result in free spillage of pancreatic fluid into the free peritoneal cavity (pancreatic ascites) most are walled off and remain localized. Such collections present for less than 4 weeks lack a well-defined wall and are termed acute fluid collections to distinguish them from pseudocysts, which are more mature collections that will typically be encased in a fibrous wall after 4 to 6 weeks. Uncomplicated pseudocysts typically appear as simple fluid collections (hypo- or anechoic on US, central low attenuation on CT without septation), which are noted to contain high levels of amylase if aspirated (Fig. 17). In the absence of infection, bleeding, mass effect, or other complications, pseudocysts can be observed regardless of size.

Cystic neoplasms represent 10% to 15% of pancreatic cystic masses and are suggested by the presence of internal septa, multiple cysts, or lack of prior history of pancreatitis. The 3 most common cystic neoplasms of the pancreas are serous cystadenomas (also known as microcystic adenomas), mucinous cystic neoplasms (also known as macrocystic adenomas), and intraductal papillary mucinous neoplasms (IPMN). Serous cystadenomas most commonly occur within the pancreatic head of older female patients and are composed of multiple cysts that are hyperintense on T2-weighted MRI and create a honeycomb appearance (Fig. 18). Also frequently noted is the presence of a central stellate scar and heterogeneous contrast enhancement. Serous cystadenomas typically have a benign course with operative intervention being reserved for symptomatic or enlarging cases. Mucinous cystic neoplasms of the pancreas tend to occur within the body or tail and radiographically appear as multilocular, enhancing, complex cystic masses, often with a solid component, which contain mucin but do not communicate with the main pancreatic duct. It is difficult to distinguish between a mucinous cystadenoma and cystadenocarcinoma, so resection is favored for most mucin-containing neoplasms. IPMNs encompass a spectrum of mucin-producing cystic neoplasms arising from the pancreatic ductal epithelium. They are classified into main or branch duct types based on their point of origin, with the main duct subtype carrying an increased potential for malignancy (Fig. 19). Imaging findings of IPMNs are variable and can mimic mucinous cystic neoplasms, chronic pancreatitis, or adenocarcinoma.

Either CT or MRI is an appropriate initial study for the radiologic evaluation of a cystic pancreatic lesion. However, there is a paucity of data on the accuracy of these imaging techniques in diagnosing pancreatic cysts because of the extensive overlap in early morphology of IPMN and mucinous cystic neoplasm (MCN), and between neoplastic
cysts and reactive cystic lesions. Obstruction of the common bile duct, dilation of the main pancreatic duct, mural nodularity, large size, or multifocal involvement are all ominous findings but, because of the inability to effectively diagnose pancreatic cystic lesions, sole reliance on CT or MRI is not recommended.

EUS plays an important role in establishing the diagnosis of pancreatic cysts, not only by allowing further imaging features to be obtained but also by using FNA for sampling cyst contents. Cyst septations, solid components, and mural nodules are more likely to occur in cystic tumors, whereas pseudocysts are likely to show internal echogenic debris with surrounding parenchymal edema. EUS features alone are not typically diagnostic because even experienced endosonographers have poor interobserver agreement in the diagnosis of neoplastic versus nonneoplastic cystic lesions. Brugge and colleagues showed low sensitivity (56%), specificity (45%), and diagnostic accuracy (51%) in a large multicenter study on the differentiation between mucinous cystadenoma, cystadenocarcinoma, and nonmucinous lesions with EUS features. More definitive data can be obtained via FNA-obtained cyst fluid analysis, which may differentiate benign lesions from malignant ones. Fluid containing mucin, high levels of carcinoembryonic antigen, or atypical cells is worrying for underlying malignant or premalignant cystic lesions and warrant resection in the appropriate clinical setting.

**Fig. 18.** Large serous cystadenoma. (A) T2-weighted MRI with honeycomb appearance of serous cystadenoma (SC) and dilated pancreatic duct (PD). (B) Polycystic mass seen on exploration. The patient underwent pancreaticoduodenectomy for 8-cm SC that was increasing in size and obstructing the pancreatic duct.

**Fig. 19.** Large IPMN. (A) CT after presentation with gastric outlet obstruction revealing duodenal (D2) obstruction by large pancreatic mass (M) found to be an IPMN. The patient underwent pancreaticoduodenectomy with negative margins. (B) Findings in the OR: IPMN invading duodenum (D2) but free from the inferior vena cava and other critical structures.
Pancreatic Cancer

Pancreatic cancer is the fourth leading cancer-related cause of death in the United States.\textsuperscript{152} Because of its metastatic tendencies and late presentation, few patients are surgical candidates and those who are typically require extensive operative procedures such as pancreaticoduodenectomy or en-block distal pancreatectomy. In addition to diagnosis, imaging modalities play a vital role in identifying patients in whom surgery will be beneficial, and then helps guide the plan and conduct of operative intervention.

CT remains the most useful imaging modality for diagnosing and staging of pancreatic cancer. Multidetector CT protocols are able to characterize pancreatic parenchyma and surrounding viscera in multiple temporal phases. The pancreas is maximally enhanced after the arterial phase and, because most pancreatic adenocarcinomas are hypovascular, they tend to appear dark at this phase before gradually becoming isointense with normal parenchyma (Fig. 20A).\textsuperscript{145} The sensitivity of CT is nearly 100\% for lesions greater than 2 cm, but is only 70\% for smaller lesions.\textsuperscript{153,154} For staging purposes, CT has been reported to identify tumor extension and vascular invasion with greater than 90\% accuracy.\textsuperscript{149,155–157}

MRCP is comparable to CT in evaluating pancreatic masses, with the advantage of providing a more sensitive evaluation for hepatic metastasis and better definition of the ductal anatomy (see Fig. 20B; Fig. 21).\textsuperscript{145,156,158,159} Lopez-Hanninen and colleagues\textsuperscript{159} prospectively reported a sensitivity of 95\% for MRI in 66 patients with suspected solid pancreatic tumors. Tumor extension and vascular involvement were accurately classified in 89\% and 94\%, respectively, in those patients undergoing resection.

The sensitivity for EUS is comparable to CT and MRI in detecting pancreatic lesions of more than 2 cm, but the modality provides a more accurate assessment of smaller lesions, with the ability to detect lesions as small as 2 mm.\textsuperscript{160} In meta-analysis, EUS was shown to have a higher rate of tumor detection (97\% vs 73\%), higher sensitivity for vascular invasion (91\% vs 64\%) (Fig. 22), and higher accuracy in determining resectability (91\% vs 83\%) versus CT.\textsuperscript{116} A retrospective comparison of EUS, PET, MRI, and laparoscopy for the detection and staging of potentially malignant pancreatic tumors reported a higher sensitivity with EUS than with PET and MRI (98\% vs 88\% vs 88\%, respectively), although differences did not reach statistical significance.\textsuperscript{161} EUS with FNA also allows for tissue diagnosis because pancreatic masses or suspicious LN can be assessed with reported sensitivities of 76\% to 90\%.\textsuperscript{156,162,163}

![Fig. 20. Pancreatic adenocarcinoma. (A) CT findings of hypovascular 2-cm mass in pancreatic head with adjacent superior mesenteric vessels (SMV, SMA). (B) MRCP findings of dilated common bile and pancreatic ducts.](image-url)
seeding along EUS-FNA tracts, bleeding, and pancreatitis are rare but significant complications that can occur, dampening enthusiasm for routine use on patients with symptomatic, resectable disease.\textsuperscript{164,165} Current data do not support the routine use of PET or PET/CT in the setting of pancreatic cancer.\textsuperscript{166}

**HEPATIC**

**Benign Masses**

Benign conditions of the liver are common; with autopsy series showing that up to 52\% of patients display some type of benign liver abnormality.\textsuperscript{167} These abnormalities may be difficult to differentiate from malignant processes. The most common benign conditions noted on liver imaging include cysts, abscesses, hemangiomas, focal nodular hyperplasia (FNH), adenomas, and regenerative cirrhotic-associated nodules. It critically important to distinguish these benign pathologies from malignant conditions, and radiographic imaging plays a central role in this.

**Benign Cysts**

Nonmalignant cysts within the liver occur in up to 5\% of the world’s population and may be congenital or acquired by infection or trauma.\textsuperscript{168} Radiographic studies and patient history can determine the type of cyst and, therefore, its natural history.

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**Fig. 21.** MRCP delineation of ductal anatomy. (A) Dilated common bile duct (CBD) and pancreatic duct (PD) associated with duodenal mass on T2-weighted MRI. (B) Dilated PD after resectional portion of pancreaticoduodenectomy. (C) Large dysplastic villous adenoma within pancreaticoduodenectomy specimen.

**Fig. 22.** EUS showing involvement of the superior mesenteric artery (SMA) by pancreatic head mass (M).
guide management. US is suggested as the first imaging modality for evaluation of liver cysts because of its simplicity, low cost, lack of radiation exposure, and sensitivity and specificity of more than 90%. A simple liver cyst on ultrasound appears unilocular and anechoic, with smooth margins and a thin wall. Posterior wall enhancement is noted, caused by the difference in sound wave reflection between the cyst fluid and the solid liver parenchyma. Multiloculation, internal debris, or septation suggest the possibility of a neoplastic cyst, prompting further investigation.

On CT, the wall of a simple hepatic cyst typically will not enhance after IV contrast administration, and the Hounsfield units will be in the water range, from 0 to 10. CT is a good modality for cysts larger than 1 cm and can be used to determine the anatomic relationship of the cyst to bile ducts and vasculature. MRI is not commonly used as the primary imaging study for simple hepatic cysts, but knowledge of MRI characteristics of cysts is important if they are noted incidentally while imaging for other conditions. A benign hepatic cyst appears homogeneous and hypointense on T1 images, is bright and hyperintense on T2 images, and does not enhance after gadolinium contrast administration.

**Neoplastic Cysts**

Biliary cystadenomas are neoplastic, premalignant cysts, and biliary cystadenocarcinomas are their malignant counterpart. On US or CT, these lesions are multiloculated, with septae or papillary frond–like projections within the cyst. However, all imaging modalities have limitations in diagnosing these cysts, and the physician must maintain

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**Fig. 23.** Hepatic cyst versus neoplasm with illustration of benefits of MRI with different pulse sequences. (A) CT with contrast (venous phase) with small cyst (open arrow) appearing similar to metastatic lesion (solid arrow). (B) T2-weighted MRI with the cyst appearing bright because of high fluid content (open arrow), whereas the metastatic lesion is barely visible (solid arrow). (C) Gadolinium-enhanced T1-weighted MRI images showing no enhancement of the cyst (open arrow) but typical heterogenous enhancement of the metastatic lesion (solid arrow). (Adapted from Hussain SM, Semelka RC. Hepatic imaging: comparison of modalities. Radiol Clin North Am 2005;43:938; with permission.)
a high index of suspicion. These lesions are more common in middle-aged women and occur more frequently in the right hepatic lobe. Malignant cysts account for only 10% of all neoplastic hepatic cysts, with invasion into surrounding liver and contrast enhancement suggesting malignancy. Before surgery, biliary cystadenoma typically cannot be differentiated reliably from biliary cystadenocarcinoma by radiographic or cytologic findings, leading some investigators to recommend an aggressive surgical approach to these lesions.

**Hepatic Abscess**

Pyogenic liver abscesses may result from biliary, colonic, hematogenous, or cryptogenic sources, and imaging is crucial to quickly diagnose and percutaneously treat the condition. On contrasted CT or MRI, a hepatic abscess appears as a multiloculated, thick-walled lesion that can appear similar to a malignant lesion. There will be peripheral rim enhancement after contrast administration (ie, the double target sign) caused by increased wall permeability (Fig. 24). Air within a cystic hepatic lesion, with Hounsfield units in the range of −1000 to −100, in a patient who has not undergone some type of intervention is diagnostic for hepatic abscess.

**Hemangiomas**

The most common benign liver tumors are hemangiomas, occurring in up to 20% of the population. These tumors are usually found in noncirrhotic livers, are more common in women, and typically are less than 5 cm in diameter. These lesions are well defined, hyperintense on T2-weighted MRI, and, on contrasted CT or MRI, display a characteristic peripheral nodular enhancement on early phases, then have progressive centripetal fill in on later phases (Fig. 25). One study showed that up to 94% of lesions displaying this type of enhancement were hemangiomas, differentiating them from neoplastic lesions.

**FNH**

FNH is the second most common benign liver tumor and has no malignant potential. These lesions are usually singular but may be multiple or associated with other lesions such as adenoma or hemangioma. Focal nodular hyperplasia is usually less than 3 to 5 cm in diameter, typically occurs in a subcapsular location, and is commonly seen in young women. CT can diagnose FNH confidently in most cases by the typical

![Fig. 24. Hepatic abscess on MRI. (A) T2-weighted image with perilesional high signal from edema fluid. (B) T1-weighted image with early rim enhancement after gadolinium administration. The lesion center has no enhancement and variable low signal (arrow). (Adapted from Martin DR, Danrad R, Hussain SM. MR imaging of the liver. Radiol Clin North Am 2005;43:864; with permission.)](image)
early and bright enhancement with subsequent washout (see Fig. 25B).\textsuperscript{171,173,180} On delayed scans, most of these lesions are isointensifying to the liver. A central scar is more common in larger lesions and, when present, results in the lesion remaining centrally bright because of delayed washout.\textsuperscript{180} Up to 20% of FNH have a nonclassic appearance, including presence of a pseudocapsule, dilated sinusoids, or vessels surrounding the lesion.\textsuperscript{181} MRI has been suggested to be the most sensitive (70%) and specific (98%) imaging modality for FNH\textsuperscript{182} because of the additional information available from differing pulse sequences. FNH is iso- or hypointense on T1 imaging and is isointense or minimally hyperintense on T2 imaging (see Fig. 25A).\textsuperscript{173} If present, the central scar is of high intensity on T2 imaging and low intensity on T1 imaging.\textsuperscript{173,183}

**Hepatic Adenoma**

Hepatic adenomas are almost exclusively diagnosed in young women taking oral contraceptives, so clinical history is useful when coupled to radiographic imaging. There is a risk of hemorrhage or rupture, and a small risk of malignant transformation. Adenoma, the fibrolamellar variant of hepatocellular carcinoma (HCC), and FNH are all typically hypervascular lesions. Because of management being significantly different, accurate radiographic diagnosis is critical. Hepatic adenomas are well defined without lobulation or calcification, and central hemorrhage may be noted in up to 40% of symptomatic patients.\textsuperscript{184} Smaller adenomas are hyperattenuated lesions relative to the surrounding liver, with up to 80% of lesions having nearly homogeneous enhancement, unless there has been recent hemorrhage. Larger adenomas may be more heterogeneous on CT imaging and can have less-specific features. Adenoma characteristics on MRI vary within the literature, ranging from hypo- to hyperintense compared with the liver. Fat, necrosis, and hemorrhage within the adenoma contribute to its heterogeneous and varied appearance on MRI. Most adenomas are hyperintense on T1 images but heterogeneous on T2 images.\textsuperscript{173,184} Because of the variable radiographic findings, adenoma may be diagnosed more accurately by what is not
noted on imaging. Typically, the fibrolamellar variant of HCC has calcifications and lobulations, possible surrounding tissue invasion, and is also associated with lymphadenopathy in most cases.\(^{185}\) FNH can have central scarring and is typically more homogeneous on imaging.

**HCC**

HCC is the most common primary liver malignancy, and its incidence has tripled in the United States in the past 30 years. Currently, the age-adjusted incidence is 4.9 cases per 100,000 individuals.\(^{186}\) Most cases of HCC arise in the setting of cirrhosis or hepatitis C or B infection. A meta-analysis on the usefulness of US in detecting HCC found that the sensitivity for detecting early HCC in cirrhotic patients was 63%, but this increased to 94% with routine biennial screening.\(^{187}\)

If a lesion is noted on screening US, or if a patient has an increased \(\alpha\)-fetoprotein level, additional imaging is necessary to evaluate for a dysplastic nodule or HCC. The main diagnostic criteria of HCC is depiction of changes of vascular supply, which is typically reflected by inhomogeneous enhancement in the arterial phase that then washes out to iso- or hypodensity in the portal venous phase (Fig. 26).\(^{173}\) This variability of enhancement across the different phases of contrast administration can be shown on CT, MRI, or, with the recent development of US contrast agents (most involving the use of coated microbubbles to function as an acoustic reflector), by specialized US studies.\(^{102,103,110}\) However, a significant minority of HCC tumors are hypovascular without significant arterial enhancement (Fig. 27).\(^{102,173}\) In this regard, MRI is advantageous in allowing further tissue differentiation based on different pulse sequences, with increased signal being noted on T2-weighted images in more than 90% of HCC cases in contrast with the eqo- or hypointensity seen with regenerative or dysplastic nodules (Fig. 28).\(^{102,103,173,177}\) The sensitivity of MRI is 100% for HCC larger than 2 cm and 89% for those 1 to 2 cm, but decreases to 34% sensitivity for tumors of less than 1 cm, as documented on explant studies.\(^{103,188}\)

Smaller HCCs, less than 3 cm in diameter, tend to present as a solid mass or possible multifocal tumor, whereas larger HCCs tend to behave more as an infiltrative process.\(^{189}\) HCC has a tendency to invade vasculature such as the portal and hepatic veins in up to 40%.\(^{190}\) Less commonly, HCC will invade the biliary system and result in obstructive jaundice.

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Fig. 26. HCC on MRI. (A) Intense heterogenous uptake of contrast during arterial phase. (B) Washout and capsular enhancement (arrow) on delayed images. (Adapted from Hussain SM, Semelka RC. Hepatic imaging: comparison of modalities. Radiol Clin North Am 2005;43:940; with permission.)
Several advanced MRI techniques, such as diffusion-weighted imaging and specialized contrast agents like superparamagnetic iron oxide, are being investigated and used in some centers and may offer benefits in the future.

**Hepatic Metastases**

Although HCC is the most common primary liver tumor in the US, the most common hepatic malignancy overall is metastatic disease. The imaging appearance of hepatic metastases varies depending on the primary, with neuroendocrine tumors tending to

![Fig. 27. Large HCC. (A) MR findings. Subsequent contrast administration did not result in enhancement. (B) HCC in right hepatic resection specimen.](image)

Fig. 27. Large HCC. (A) MR findings. Subsequent contrast administration did not result in enhancement. (B) HCC in right hepatic resection specimen.

![Fig. 28. HCC in cirrhotic liver. (A) The cirrhotic parenchyma contains numerous regenerative dark nodules adjacent to 2 brighter lesions consistent with HCC on nonenhanced T2 images. (B) These 2 lesions (HCC) enhance during the arterial phase of contrast administration. (C) Washout and delayed capsule enhancement (HCC) consistent with HCC is noted on delayed images. (Adapted from Hussain SM, Semelka RC. Hepatic imaging: comparison of modalities. Radiol Clin North Am 2005;43:940; with permission.)](image)

Fig. 28. HCC in cirrhotic liver. (A) The cirrhotic parenchyma contains numerous regenerative dark nodules adjacent to 2 brighter lesions consistent with HCC on nonenhanced T2 images. (B) These 2 lesions (HCC) enhance during the arterial phase of contrast administration. (C) Washout and delayed capsule enhancement (HCC) consistent with HCC is noted on delayed images. (Adapted from Hussain SM, Semelka RC. Hepatic imaging: comparison of modalities. Radiol Clin North Am 2005;43:940; with permission.)
be hypervascular and most solid organ metastasis (breast, colon, lung, pancreatic) being hypovascular with ring enhancement only. Particular attention will be directed to evaluation of colorectal metastasis because this is the most common scenario within which general surgeons will be asked to consider resectional intervention in patients with metastatic disease.

Multiple studies and meta-analyses have attempted to delineate the best imaging modality for detection of colorectal cancer liver metastasis. Bipat and colleagues\textsuperscript{191} reviewed studies published between January 1990 and December 2003 comparing helical and nonhelical CT, MRI, and PET. On a per-patient analysis, this group concluded that PET was the most accurate imaging modality for detecting hepatic metastasis at 94.6% sensitivity, compared with 60.2% for nonhelical CT, 64.7% for helical CT, and 75.8% for MRI. However, they noted no significant difference between MRI and PET for detection of hepatic metastasis on a per-lesion basis.\textsuperscript{191} In a second meta-analysis of literature from 1994 to 2003, and specifically comparing CT with PET, Wiering and colleagues\textsuperscript{192} found that PET had a pooled sensitivity of 96% for hepatic lesions and 95.4% for extrahepatic lesions, superior to CT at 84.1% and 91.1%, respectively. The conclusion of this meta-analysis was that PET can have an influence on the preoperative work-up of patients with potentially resectable colorectal hepatic metastasis, particularly in the detection of extrahepatic disease. A third meta-analysis of literature from 2000 to 2008 compared US, multidetector and helical CT, MRI, and PET. This group found that MRI outperformed the other imaging modalities on a per-patient basis, with 74.8% sensitivity and 97.2% specificity, and also showed better sensitivity than CT on a per-lesion basis, especially when liver-specific contrast was administered.\textsuperscript{193} The most recent meta-analysis reviewing studies from 2004 to 2009 concluded that, on a per-lesion basis, MRI had the highest sensitivity at 87.3%, which was statistically significant compared with CT, PET, and PET/CT. On a per-patient basis, all 4 modalities had comparable sensitivity estimates, ranging from 88.7% for CT to 96.2% for PET/CT.

It is clear from these separate meta-analyses that MRI and PET are superior to CT for the evaluation of patients with colorectal liver metastasis. It is also clear that there is a distinct gap in prospective, randomized data in all of these reviews, which probably contributes to the differing conclusions and sensitivity estimates. Although additional study is needed, current data therefore support obtaining either MRI or PET/CT, or both, before operating on patients with metastatic colon cancer.

**SUMMARY**

Multiple imaging modalities including US, CT, MRI/MRCP, direct cholangiography, and PET are now available to assist surgeons with preoperative assessment of hepatobiliary and pancreatic disorders. Having a thorough understanding of the benefits and limitations of each is necessary to guide optimal management of these cases.

**ACKNOWLEDGMENTS**

The authors wish to thank Paul Buehrer, MD, Mansfield, OH, for editorial supervision.

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