MR Imaging in Gastrointestinal Emergencies

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Accurate and rapid diagnostic imaging is essential for the appropriate management of acute gastrointestinal conditions. Computed tomography (CT) is the modality most often used in this setting because of its widespread availability and the relative speed, ease, and uniformity with which evaluations can be performed. CT allows the diagnosis of a wide spectrum of acute gastrointestinal diseases with the adjustment of only a few variables in the acquisition protocol. For example, the contrast material volume, injection rate, and delay before image acquisition can be manipulated to enhance vascular or organ-specific contrast for myriad gastrointestinal diagnoses. Magnetic resonance (MR) imaging has similarly robust potential, although its integration into the acute care setting requires greater technical and logistical effort. Improved MR imaging sequences, advances in coil technology, streamlined imaging protocols, and increased technical and professional familiarity with the modality make it an increasingly attractive option when there is concern about patient radiation exposure or allergy to iodinated contrast material. A variety of acute abdominal conditions, including pancreatic and biliary tract trauma, choledocholithiasis, gallbladder disease, acute pancreatitis, and appendicitis can be rapidly and accurately demonstrated with MR imaging. MR imaging also can play a vital role in the follow-up assessment of treatment response and in the diagnosis of indeterminate findings at CT or ultrasonography. Nevertheless, incompatibility of patient monitoring devices with the MR magnet, lack of MR imaging system availability, and the acuity of illness may limit the use of the modality.

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Introduction
The number of emergency department visits has increased substantially in the past decade (1–3). Increased patient volume has led to an accelerated effort to rapidly and accurately diagnose acute gastrointestinal disease to allow appropriate triage and management. The spectrum of acute gastrointestinal disease is broad and is generally subdivided according to whether the cause of disease is traumatic or nontraumatic. The use of computed tomography (CT) in examining hemodynamically stable patients with traumatic injuries is well established (4,5). By contrast, the higher cost, increased acquisition time, and limited availability of magnetic resonance (MR) imaging have been major deterrents to its use for assessing acute gastrointestinal conditions, whether the cause is traumatic or nontraumatic. However, certain advantages exist with MR imaging in some patient subgroups (6). For example, MR imaging is particularly useful for evaluating pregnant patients who have symptoms of appendicitis (7). MR imaging also can be used to further delineate or follow up equivocal CT findings in patients with multiple traumatic injuries (eg, pancreatic and biliary duct disruptions) and to monitor previously diagnosed acute gastrointestinal disease, especially in young patients, in whom radiation exposure is of concern.

The article surveys the current indications for the use of MR imaging in patients with acute gastrointestinal diseases of both traumatic and nontraumatic causes. MR imaging protocols are discussed in detail, with particular attention to focused and rapid image acquisition techniques. The MR imaging appearances of various acute gastrointestinal disorders are described and, where appropriate, compared with CT findings.

MR Imaging Protocols
MR imaging protocols in the acute care setting should be tailored to concisely address diagnostic considerations, and the sequences should be chosen to minimize acquisition time. Negative oral contrast agents are helpful in improving the specificty of MR cholangiopancreatography and MR enterographic studies, but their use is optional and depends on the stability of the patient. At our institution, we use a 50/50 vol/vol combination of ferumoxsil (GastroMark; Mallinckrodt Medical, St Louis, Mo) and barium sulfate suspension. The use of intravenous gadolinium-based contrast agents also is optional because many acute gastrointestinal conditions involve inflammation, edema, and structural derangements that can be demonstrated or inferred by combining fluid-sensitive sequences with three-dimensional (3D) volumetric techniques for anatomic correlation. We have found utility in intravenously administered gadoxetate disodium (Eovist; Bayer Healthcare Pharmaceuticals, Wayne, NJ), which has a partial hepatobiliary excretion route. The contrast agent is administered in a dose of 0.1 mL per kilogram of body weight and at a rate of 2 mL/sec, with an imaging delay sufficient to allow evaluation of bile duct injuries and bile leaks.

In our experience, a free breathing or respiratory triggering technique is preferable to breath-hold protocols in the acute setting because patients often have difficulty with breath holding, and respiratory motion may compromise image quality. Single-excitation half-Fourier T2-weighted turbo spin-echo (SE) sequences and two-dimensional T1-weighted gradient-recalled echo (GRE) sequences may be applied with either free breathing or respiratory triggering. Useful fluid-sensitive sequences include short inversion time inversion-recovery, or STIR, and respiratory-triggered T2-weighted chemically fat-suppressed turbo SE techniques. Coherently balanced steady-state sequences provide clear depiction of the abdominal and pelvic anatomy and may be used as a white-blood imaging technique for evaluation of the major vessels without requiring the use of a gadolinium-based contrast material. Three-dimensional isotropic volumetric T1-weighted sequences (variously named THRIVE, VIBE, LAVA, and FAME by their respective vendors) require a typical breath hold of 15–20 seconds for coverage of a single organ. Although that requirement may limit their usefulness in the acute setting, these sequences produce high-resolution 2–3-mm-thick interpolated sections and allow the acquisition of
dynamic phase images after the administration of an intravenous gadolinium-based contrast agent (rate, 2 mL/sec; volume, 20 mL).

Our MR imaging protocol for emergent evaluation of the abdomen and pelvis includes the following sequences: axial breath-hold in-phase and out-of-phase T1-weighted GRE, axial and coronal breath-hold T2-weighted single-shot turbo SE, axial T2-weighted fat-suppressed turbo SE with respiratory triggering (or short inversion time inversion recovery), and steady-state free precession. Thick-slab MR cholangiopancreatographic, respiratory-triggered T2-weighted turbo SE, and volumetric T1-weighted sequences are added as necessitated by the clinical indication and with consideration of the total acquisition time and the patient’s ability to tolerate breath-hold acquisitions (Table). The duration of the MR imaging examination is typically 20–30 minutes (6,8).

Clinical Applications

Traumatic Injuries to the Pancreas and Biliary Tract
Visceral injuries in patients with blunt abdominal trauma most commonly involve the liver, spleen, and kidneys (9). Injuries to these organs usually can be diagnosed without difficulty at CT. By contrast, injuries to the pancreas and biliary tract may be more subtle and may be overlooked in patients with trauma involving multiple organs. Although pancreatic and biliary injuries are uncommon, delays in their diagnosis are associated with high morbidity and mortality, and their early diagnosis...
The forces necessary to sustain a pancreatic injury are commonly high enough to impact adjacent structures such as the stomach, liver, duodenum, spleen, and vasculature. Indeed, isolated pancreatic injuries are rare; three or more organs are usually involved. The pancreatic body or neck is most commonly injured (65%), followed by the head or, with equal frequency, the tail (12). Injuries to the pancreatic head, which is in close proximity to the inferior vena cava, superior mesenteric vein, and portal vein, are more commonly fatal because of acute hemorrhage (13,14).

Figure 1. Pancreatic laceration in a patient with blunt abdominal trauma. (a) Axial contrast-enhanced CT scan demonstrates a peripancreatic region with intermediate attenuation characteristic of fluid and a focus of abnormal hypodensity in the pancreas (arrow), findings suggestive of contusion or laceration. (b) Axial unenhanced MR image obtained with a T2-weighted fat-suppressed turbo SE sequence depicts a laceration in the pancreatic neck (arrow). (c) Axial contrast-enhanced MR image obtained with a T1-weighted fat-suppressed GRE sequence shows the extent of the pancreatic injury (arrow).

Teaching Point

Therefore is critical (10). CT findings in pancreatic and biliary injuries may be nonspecific or overlooked because they are associated with multiple other injuries, and the symptoms and clinical findings are often unreliable and nonspecific. MR imaging of the pancreas and biliary tract in patients with blunt trauma to multiple organs can provide important diagnostic information (11).

Pancreatic injuries are uncommon; they occur in less than 2% of patients with blunt abdominal trauma. However, their early diagnosis is critical because delayed complications such as fistulas, abscesses, hemorrhage, and sepsis may lead to significant morbidity and mortality. The pancreas is susceptible to crush injury from impaction against the vertebral column. Common mechanisms of pancreatic trauma include bicycle injuries (in children) and automobile and motorcycle accidents.
Pancreatic injury due to blunt abdominal trauma in a 42-year-old patient. (a) Axial MR image obtained with a T2-weighted single-shot turbo SE sequence demonstrates a pancreatic fluid collection that communicates with the main pancreatic duct through a ductal disruption (arrow). (b) Maximum intensity projection (MIP) image from 3D MR cholangiopancreatography shows the extent of the peripancreatic fluid collection (arrows) and depicts a normal common bile duct (arrowhead).

**Figure 3.** Pseudocyst in a patient with pancreatic duct injury. Axial MR image obtained with a T2-weighted single-shot turbo SE sequence shows a pseudocyst (arrow), a delayed complication of previously diagnosed pancreatic duct disruption due to blunt abdominal trauma.

All blunt abdominal trauma patients who are hemodynamically stable routinely undergo an initial CT evaluation to determine the scope and severity of their internal injuries. Both direct and indirect signs of pancreatic injury may be seen in this initial imaging examination. The integrity of the main pancreatic duct is of critical importance in the diagnosis of pancreatic trauma. Ductal laceration is not typically directly visualized at CT; however, secondary CT findings such as a deep parenchymal laceration may be suggestive of ductal injury. In patients in whom the CT findings are not definitive but only suggestive of pancreatic trauma or in whom CT findings of pancreatic injury are present but assessment of the pancreatic duct is needed, MR imaging may be useful. Contusions and lacerations of the glandular parenchyma are well demonstrated with MR imaging. The depth of a pancreatic laceration, especially the distinction between a complete transection of the gland and a partial injury, also can be determined with MR imaging (Fig 1) (15). However, evaluation of the integrity of the main pancreatic duct remains the critical role of MR imaging (Fig 2). Disruption of the main duct is treated surgically or endoscopically with stent placement. After ductal disruption is diagnosed, monitoring for associated delayed complications (e.g., fistula, abscess, or pseudocyst) and treatment follow-up also can be performed with MR imaging (Fig 3). The use of...
MR imaging instead of CT for these purposes is especially important in children and young adults, who constitute a large percentage of patients with pancreatic trauma and for whom the lifetime risk from repeated radiation exposure might well outweigh the benefits (Fig 4).

Blunt abdominal trauma may result also in biliary tract injury, although such occurrences are rare. The gallbladder is the site most often affected, followed by the common bile duct and the intrahepatic ducts (16). Like pancreatic injury, biliary tract injury is associated with multiple organ injuries due to compressive, shearing, or torsional forces. Associated hepatic (91%), splenic (54%), and duodenal (54%) injuries are common and may mask underlying biliary injuries (17). Although CT features may be suggestive of gallbladder injury, findings are typically nonspecific, with fluid and hemorrhage appearing in and around the gallbladder. Biliary duct injuries may be suspected on the basis of the severity of liver lacerations observed on CT images but are not often directly depicted.

The use of MR cholangiopancreatography in the setting of gallbladder trauma is not well established. The MR findings are nonspecific and mimic those seen at CT, with collapse of the gallbladder, pericholecystic fluid, and intraluminal
hemorrhage being the most common (18–20). MR cholangiopancreatography with gadoxetate disodium used as a hepatobiliary contrast agent for delayed phase imaging can depict the origin and extent of bile leaks (Fig 5). Further investigation is necessary to determine the optimal use of gadoxetate disodium for the evaluation of bile duct disruptions.

**Choledocholithiasis**

Choledocholithiasis typically results from the passage of gallbladder stones through the cystic duct into the common bile duct; less commonly, it occurs with the primary formation of stones within the common bile duct. The pathophysiology of the formation of stones is complex, with bile stasis, bactibilia, pH imbalances, increased bilirubin excretion, and sludge formation playing principal roles (21). Regardless of the source of stones, their presence in the common bile duct may lead to acute biliary obstruction with jaundice, fever, cholangitis, pancreatitis, and sepsis.

The possibility of coexistent choledocholithiasis in patients with acute cholecystitis complicates diagnostic imaging and management. Choledocholithiasis is found in 10%–15% of the approximately 600,000 cholecystectomies performed in the United States each year (22,23). The preferred imaging study for detection depends on the clinical manifestations and the level of clinical suspicion. Nearly all patients with right upper quadrant pain and suspected biliary obstruction undergo ultrasonography (US) for evaluation of the gallbladder and bile ducts. The classic findings of acute cholecystitis—including
MR cholangiopancreatography has shown consistently high sensitivity and specificity (97%–99% and 95%–99%, respectively) for the detection of bile duct abnormalities (28). It may play a pivotal role in the management of patients with cholecystitis in whom choledocholithiasis is suspected, because it can help avoid diagnostic procedures that are unnecessarily invasive in the absence of common bile duct stones (eg, ERCP) or help direct surgical management in the presence of stones (Fig 6). Complications of acute cholecystitis, such as gangrenous cholecystitis, can be readily depicted with MR imaging (Fig 7). Impacted cystic duct stones can be demonstrated with MR cholangiopancreatography, enabling the diagnosis of Mirizzi syndrome (Fig 8).
Figure 7. Gangrenous cholecystitis. Axial T1-weighted in-phase (a) and out-of-phase (b) MR images show an area of low signal intensity that produces a blooming artifact in the gallbladder wall (arrow), a finding suggestive of gas. Gangrenous cholecystitis was found in a surgical specimen.

Figure 8. Mirizzi syndrome in a 45-year-old man with right upper quadrant pain and jaundice. (a) Radial thick-slab MR cholangiopancreatographic image demonstrates multiple gallbladder stones (arrowhead) with dilatation of the intrahepatic ducts and common hepatic duct (short arrow) but a normal appearance of the common bile duct (curved arrow). A filling defect is visible at the insertion of the cystic duct (long arrow). (b) Axial T2-weighted single-shot turbo SE MR image obtained at the level of the cystic duct insertion depicts an impacted stone (arrow) obstructing the common hepatic duct. (c) ERCP image helps confirm the diagnosis of obstruction of the common hepatic duct by a stone (arrow).
Gallstones are implicated in 50% of patients with acute pancreatitis (29). Acute pancreatitis may occur when stones migrate into the distal common bile duct and obstruct the ampulla of Vater. The management of gallstone-induced pancreatitis involves endoscopic sphincterotomy and retrieval of any impacted stones. Although the technique is highly successful when performed by an experienced person, complications may occur in as many as 10% of cases and may include cholangitis (2%), hemorrhage (1%), pancreatitis (2%), and duodenal injury (1%) (30). Therefore, the judicious use of ERCP should be a foremost consideration, whereas noninvasive imaging is typically performed when the presence of gallstone-induced pancreatitis is suspected.

The clinical manifestations of acute pancreatitis differ from those of acute cholecystitis. Patients with acute pancreatitis more commonly experience severe and persistent epigastric pain with nausea and vomiting and have elevated serum levels of amylase and lipase. CT is helpful for the initial diagnosis in equivocal cases or for early assessment of disease severity with use of the clinically validated CT severity index (31). The utility of MR cholangiopancreatography has proved comparable to that of contrast-enhanced CT for early assessment of acute pancreatitis and determination of disease severity (26). Fluid-sensitive sequences with fat suppression can clearly depict early signs of pancreatitis, including glandular enlargement (edema), periglandular inflammatory changes, and intra- and peripancreatic fluid collections. The added value of MR cholangiopancreatography lies in its ability to help identify choledocholithiasis as the cause of pancreatitis and thus help direct interventional care (Fig 9). Other potential complications of acute pancreatitis that may be readily diagnosed with MR cholangiopancreatography include hemorrhagic pancreatitis, a potentially fatal complication (32). Hemorrhagic pancreatitis occurs when severe inflammation and regional necrosis cause major vessel erosion (with or without pseudoaneurysm formation) with resultant massive bleeding into the pancreatic bed, retroperitoneum, gastrointestinal tract, or peritoneal cavity; the condition requires immediate surgical intervention. Standard T1-weighted sequences depict hemorrhage as a region of high signal intensity within the pancreas or adjacent structures (Fig 10). Regardless of the cause of acute pancreatitis, MR cholangiopancreatography is useful for monitoring and follow-up.
Gastrointestinal Tract Emergencies

MR imaging of the gastrointestinal tract poses several challenges: The selection of an appropriate sequence for the specific indication is important to obtain diagnostically useful images; for example, bowel peristalsis causes image blurring if a 3D volumetric technique is used. Moreover, underdistention of the small bowel with oral contrast agents can lead to decreased sensitivity for the detection of small-bowel abnormalities (33). On the other hand, MR imaging also provides the advantages of excellent contrast resolution and lack of ionizing radiation. It has proven value for several indications in the diagnosis of gastrointestinal disease, and it has become the imaging modality of choice for the evaluation of pregnant patients in whom the presence of acute appendicitis is suspected (34).

Acute appendicitis is the most common gastrointestinal emergency requiring surgery in pregnant patients. The classic manifestations of appendicitis (leukocytosis, fever, and right lower quadrant pain) are nonspecific during pregnancy, and leukocytosis may be a normal physiologic condition in this setting. In addition, the appendix in a pregnant woman is typically displaced from its usual location in the right lower quadrant by the gravid uterus, which may make it more difficult to identify the appendix as the source of pain (34).

Current American College of Radiology (ACR) appropriateness criteria for the evaluation of pregnant patients with leukocytosis and fever recommend the use of targeted right-lower-quadrant US with graded compression as the first-line imaging modality. MR imaging is second, followed by abdominal CT with an intravenous contrast agent (35). The goal of these recommendations is to enable the diagnosis of appendicitis without exposing the fetus unnecessarily to ionizing radiation. Any effects of fetal exposure to high magnetic fields, rapid gradient shifts, and radiofrequency energy deposition during clinical MR imaging remain largely unknown; to our knowledge, no short- or long-term effects have yet been documented or proved (36,37). At our institution, all patients are informed of this fact, and written consent for MR imaging is routinely obtained.

In cooperation with the emergency department and obstetric-gynecologic service at our institution, we developed an algorithm based on the
Figure 11. Acute appendicitis in a 27-year-old pregnant woman with acute abdominal pain and leukocytosis. (a) Axial T2-weighted single-shot turbo SE MR image shows an abnormally dilated appendix with a low-signal-intensity filling defect, findings indicative of an appendicolith (arrow). (b) Axial T2-weighted fat-suppressed single-shot turbo SE MR image depicts periappendiceal inflammation (arrow).

ACR criteria for evaluation of potential appendicitis in pregnant patients. All pregnant patients with leukocytosis, fever, and suspected appendicitis are initially evaluated with a directed US study. We follow the method suggested by Pedrosa et al (8) and use a negative oral contrast agent composed of 300 mL of dilute barium sulfate suspension (Redi-Cat; Bracco, Princeton, NJ) and 300 mL of ferumoxsil (Gastromark; Mallinckrodt, St Louis, Mo). The patient begins drinking this mixture in the emergency department, before transport to a US suite in the radiology department, and scanning is performed 2 hours later. It has been our experience, and early results show, that US delineation of a normal appendix in a pregnant woman is poor (38), particularly in the second and third trimesters of pregnancy. It is our assumption that the patient will likely require MR imaging of the appendix, and we try to minimize the delay between initial presentation and MR imaging. If the MR imaging results are nondiagnostic, the patient proceeds immediately to CT. If necessary, the preparation for CT can be streamlined, since the oral contrast agent given in preparation for US contains barium sulfate. We do not administer intravenous gadolinium- or iodine-based contrast agents for either of these examinations.

Our imaging protocol includes (a) single-shot T2-weighted turbo SE sequences applied in the three orthogonal planes with and without SPIR for fat suppression and (b) axial T1-weighted in-phase and opposed-phase GRE sequences. Respiratory triggering is used if necessary. The total MR image acquisition time is 20–30 minutes (8).

MR imaging has high reported sensitivity (97%–100%) and specificity (92%–93%) for the diagnosis of acute appendicitis (8). The anatomic imaging features of acute appendicitis are similar regardless of the modality used and include a cross-sectional appendiceal diameter of more than 7 mm and wall thickness of more than 2 mm. Single-shot turbo SE sequences are particularly helpful for identifying the location of the appendix. Edema and inflammation appear as T2 signal hyperintensity within the wall or surrounding the appendix; fat-suppressed single-shot sequences are useful for depicting these features (Fig 11). A fluid-filled appendix is another suggestive finding that is readily identified on MR images. It may be difficult, with the abundance of nearby blood vessels and compression or displacement of the appendix by the gravid uterus, to delineate the blind-ended tubular structure that represents the normal appendix. T1-weighted in-phase and
out-of-phase GRE sequences can help locate the appendix when it is air filled; the appendix produces a blooming artifact on in-phase images, which are acquired with a longer echo time (Fig 12). Blooming artifact also may be observed if the appendix fills with an orally administered contrast agent that contains ferumoxsil. In either instance, acute appendicitis is less likely. Some pregnant patients with MR imaging findings suggestive of appendicitis are found to have another acute intraabdominal condition, such as cholecystitis, pyelonephritis, or diverticulitis.

Conclusions

It is technically feasible to perform rapid MR imaging in patients with acute gastrointestinal disorders. Although CT and US remain the frontline diagnostic imaging methods in this setting, the superior soft-tissue contrast and lack of ionizing radiation make MR imaging a valuable and attractive asset for use in selected patient populations. MR cholangiopancreatography can play a pivotal role in the diagnosis of pancreatic duct disruption and biliary tract trauma when CT results are equivocal or nondiagnostic. MR cholangiopancreatography is also of value for detecting cholelithiasis in patients with symptoms of acute cholecystitis or acute pancreatitis, a diagnosis that may lead to a change in therapeutic management. Acute pancreatitis and its potentially fatal complications, such as hemorrhagic pancreatitis, are readily evaluated with MR imaging. MR imaging is also the most appropriate imaging modality for detecting acute appendicitis in pregnant patients when US findings are nondiagnostic. Given the increasing general concern for avoiding unnecessary radiation exposure, MR imaging provides an ideal way to follow the progress of acute gastrointestinal diseases.

References


MR Imaging in Gastrointestinal Emergencies

Jaroslaw N. Tkacz et al

Page 1768
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Page 1770
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Page 1771
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Page 1774
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Page 1776
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