Acute abdominal and pelvic processes account for more than half of all surgical procedures performed in the emergency setting. Rapid and accurate diagnosis in the emergency department is essential for the appropriate management of these acute conditions. Magnetic resonance (MR) imaging is an attractive modality for diagnostic imaging in patients for whom the risks of radiation or the potential nephrotoxicity of iodinated contrast agents is a major concern, such as pregnant and pediatric patients. MR imaging is most useful for evaluating pregnant patients with acute lower abdominal pain believed to have an extrauterine cause, such as appendicitis or ovarian torsion. Other patients with other conditions commonly seen in the emergency setting may be better evaluated with another cross-sectional imaging modality. Imaging protocols should be adapted to the constraints of acute illness, with emphasis placed on minimizing the duration of image acquisition, and should include strategies to decrease motion-related artifacts. A prudent approach is to select the imaging modalities that can best depict a particular subset of clinical conditions to help narrow the differential diagnosis. Disadvantages of MR imaging include its high cost, the limited availability of MR imaging systems and trained radiologists, and the incompatibility of MR imaging systems and the equipment used for intensive care and monitoring of patient status.

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Abbreviations: ACR = American College of Radiology, SE = spin echo, STIR = short inversion time inversion recovery

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Introduction

Rapid and accurate diagnosis is essential for the appropriate management of acute abdominal and pelvic conditions in the emergency department. Emergent abdominal surgical procedures account for approximately 53% of all nontrauma-related surgical interventions performed in the acute care setting (1). Four-quadrant screening ultrasonography (US) and computed tomography (CT) traditionally have been the dominant cross-sectional imaging modalities for evaluating acute abdominal and pelvic conditions. The relatively high cost of magnetic resonance (MR) imaging, in addition to its limited availability and generally lengthy examination times, has been a major deterrent to its use in the emergency setting. However, MR imaging also offers a number of advantages, and it is the imaging modality of choice for abdominopelvic evaluations in selected patients with specific conditions (eg, pregnant women with symptoms of acute appendicitis or adnexal torsion).

The article provides an overview of the advantages and disadvantages of MR imaging in comparison with CT, US, and other modalities for the diagnosis of acute abdominopelvic conditions in the emergency department. The optimization of MR imaging protocols for use in the emergency setting is discussed in detail. MR imaging features of various common acute conditions (acute appendicitis, adnexal torsion, pelvic inflammatory disease, fibroid degeneration, endometriosis, hematometra, acute epiploic appendagitis, and Crohn disease) are described and, where appropriate, compared with CT and US findings.

Advantages and Disadvantages of MR Imaging

According to Saini et al, the technical cost of an examination with US, CT, and MR imaging at their tertiary-care center was $50, $112, and $267, respectively (2). The greater cost of MR imaging compared with that of US or CT is a major hindrance to the use of MR imaging in the acute care setting.

However, the lack of ionizing radiation and the excellent safety profile of the gadolinium-based contrast agents used in MR imaging are two major advantages. MR imaging also provides superior contrast resolution and excellent characterization of pathologic tissue. Its capability for direct multiplanar imaging without the need to reposition the patient also is useful for determining the origin of lesions in the abdomen and pelvis, although multiplanar reformatting of multidetector CT image data makes modern CT competitive with MR imaging in this respect.

One of the limitations of MR imaging is a contraindication to the use of gadolinium in early pregnancy because of its classification as a class C drug. The safety of MR imaging for the fetus also has not been proved according to Food and Drug Administration guidelines. Thus, it is prudent to perform MR imaging of pregnant patients only when US findings do not suffice to establish the diagnosis and when CT cannot be used because of concerns regarding the risk of radiation to the fetus. However, gadolinium-enhanced MR imaging may be performed if nonviability of the fetus has been confirmed by other test results (3). Other limitations of MR imaging include poorer spatial resolution compared with that of CT, increased sensitivity to motion-related artifacts, and limited compatibility with equipment used in intensive care and monitoring of patients (4). CT is many times faster than MR imaging, even when the latter is performed with fast gradient-echo sequences, and therefore CT is more suitable for diagnostic imaging of an acutely ill patient who may be unable to cooperate and lie still for the duration of MR image acquisition. Finally, most radiologists are more familiar with the appearance of acute abdominal and pelvic conditions on CT scans than they are with the MR imaging features, and their lack of familiarity with the latter is a hindrance to the use of MR imaging in an emergency setting.

MR Imaging Protocols

MR imaging protocols should be tailored to the patient’s clinical condition, and image acquisition time should be minimized. The use of oral contrast material is optional. The combination of ferumoxsil (Gastromark; Mallinckrodt Medical, St. Louis, Missouri) and dilute barium sulfate (Readi-Cat 2; E-Z-Em Canada, Westbury, New York) has provided excellent depiction on both T1-weighted and T2-weighted images without causing magnetic susceptibility artifacts (5). Gadolinium-based contrast agents such as gadopentetate dimeglumine (Magnevist; Berlex Laboratories, Wayne, New Jersey) are routinely used intravenously except in pregnant patients and patients with marked renal impairment. T1-weighted images with fat saturation are obtained before and after the administration of an intravenous contrast agent.
MR imaging protocols used in an emergency setting can be broadly classified into two groups: free-breathing protocols and breath-hold protocols. The use of a free-breathing protocol is preferable for patients who are unable to hold their breath for longer than 20 seconds (6). With the use of free breathing, the most reproducible position is at end expiration. Magnetization-prepared T1-weighted sequences and single-excitation half-Fourier T2-weighted sequences are the mainstay of free-breathing protocols. With both sequence types, image data are acquired on a section-by-section basis at the rate of approximately one section per second.

T1-weighted breath-hold sequences include dual-echo sequences that produce both in-phase and out-of-phase images. In patients with acute abdominal conditions, these sequences can be used to define hemorrhagic collections, which have high signal intensity on T1-weighted images. Artifacts due to air, metallic objects, or hemosiderin and calcium deposits are more visible on T1-weighted images obtained with longer echo times. T2-weighted images obtained with a half-Fourier single-shot spin echo (SE) or a half-Fourier rapid acquisition with relaxation enhancement provide excellent depiction of the pancreaticobiliary tree, ascites, pleural effusion, hydrenephrosis, and fluid-filled bowel. Contrast-enhanced T1-weighted imaging with a fat-saturated three-dimensional volumetric isotropic acquisition (proprietary sequence acronyms include VIBE, THRIVE, FAME, and LAVA) allows coverage of the liver in 20–30 seconds with an interpolated section thickness of 3–4 mm. The upper abdomen is imaged in three contrast enhancement phases: arterial, portal venous, and delayed venous (7). The use of coherently balanced steady-state sequences (TrueFISP, FIESTA), which are sensitive to the T2/T1 ratio rather than to T1 or T2 separately, also has been advocated. Such sequences play an increasing role in abdominal imaging, especially for visualization of the anatomy before organ transplantation or for evaluation of vessels for thrombosis or dissection (8). The advantage these sequences provide over single-shot fast SE sequences for the evaluation of blood vessels is that the signal in a thrombus appears hypointense in comparison with the higher signal intensity of flowing blood. Coherently balanced steady-state sequences also are useful for evaluating fluid-filled bowel loops (9). Thus, a typical MR imaging protocol for emergency evaluation of the abdomen includes axial and coronal single-shot fast SE, axial short inversion time inversion recovery (STIR), axial T1-weighted in-phase and out-of-phase, axial and coronal steady-state pre- cession, and unenhanced and contrast-enhanced three-phase volumetric acquisitions.

Clinical Applications

MR imaging is an excellent modality for assessing pelvic abnormalities, particularly in pregnant and pediatric patients, because it does not involve exposure to ionizing radiation. Depending on the patient’s condition, the duration of the MR imaging examination can be shortened, and the protocol can be tailored on the basis of clinical manifestations to answer a specific diagnostic question.

Acute Appendicitis

Acute appendicitis is the most common nonobstetric surgical condition during pregnancy and the most common surgical emergency in children. The symptoms of acute appendicitis in pregnant patients often are nonspecific because the appendix and omentum are displaced by the gravid uterus. Moreover, leukocytosis, which in nonpregnant patients may be predictive of appendicitis, may occur as a normal physiologic condition during pregnancy.

Currently, CT and US are widely used for the preoperative diagnosis of acute appendicitis in adults. Although US is the first-line investigation for suspected appendicitis in a pregnant patient, MR imaging is better than CT as the second-line imaging modality when US results are nondiagnostic or equivocal. According to the American College of Radiology (ACR) appropriateness criteria, MR imaging is more appropriate than CT for use in pregnant patients with right lower quadrant pain, fever, and leukocytosis. MR imaging also is an attractive alternative after US for the evaluation of pregnant and pediatric patients, for whom exposure to ionizing radiation is a major concern (10). MR imaging can be helpful for diagnosing a wide variety of conditions, including appendicitis, abscesses, colitis, ovarian disease, pyelonephritis, fibroid degeneration, hemorrhage, and intussusception (11).

Although the safety of MR imaging to the fetus has not been proved, no proved human teratogenic or carcinogenic effects of MR imaging have been described in the literature. According to an ACR white paper about MR imaging safety, pregnant patients may undergo MR imaging at any
Figure 1. Normal appendix during the second trimester of pregnancy. Coronal (a) and axial (b) T2-weighted fast SE MR images demonstrate an intermediate-signal-intensity tubular structure (arrow) that arises from the inferomedial aspect of the feces-laden cecum. The appendix has a diameter of 6 mm, contains no intraluminal fluid, and is located posterior to the gravid uterus.

Figure 2. Acute appendicitis in a 20-year-old pregnant patient. (a, b) Axial MR images obtained with a T2-weighted fat-suppressed fast SE sequence (a) and a STIR sequence (b) show a dilated appendix with a diameter of 12 mm, wall edema, and appendicoliths (arrowheads) in the right lower quadrant. The periappendiceal rim of high signal intensity in b is indicative of inflammation. (c) Axial unenhanced CT image shows two appendicoliths (arrowheads) in the prominent appendix, with a periappendiceal rim of high attenuation due to inflammation.
stage of pregnancy if the radiologist determines that it is warranted by the risk-benefit ratio. After a discussion with the ordering physician, the radiologist should document that the following three criteria have been satisfied: first, the information could not be obtained with US; second, the information to be obtained with MR imaging likely will affect the care of the patient, the fetus, or both; and third, it is not prudent to postpone imaging until the patient is no longer pregnant (3).

At our institution, when appendicitis is suspected, we initially perform MR imaging in three planes with a single-shot fast SE sequence, followed by a STIR sequence and a T2-weighted fat-suppressed fast SE sequence in the plane in which the appendix is best depicted. If the patient is not pregnant, these sequences are followed by T1-weighted imaging before and after the administration of contrast material. The imaging time is reduced by adjusting the examination protocol after localization of the appendix. The typical MR imaging room time is less than 30 minutes per examination. Although the use of intravenous contrast material with T1-weighted fat-suppressed sequences provides excellent results for the diagnosis of acute appendicitis, its use is contraindicated during pregnancy, especially in the first trimester. The MR imaging protocol used for other pelvic indications is similar. We do not use oral contrast material. However, Pedrosa et al reported the use of a combination of 300 mL of ferumoxsil (Gastromark) and 300 mL of dilute barium sulfate (Readi-Cat 2) in a study of 51 consecutive patients; and others have reported similar uses of oral contrast material (12–20).

The normal appendix is a blind tubular structure with a diameter of less than 7 mm and a wall thickness of less than 2 mm (Fig 1). It is seen at MR imaging in an estimated 65% of patients, at minimum, and it is best depicted on T2-weighted images (11–14). STIR sequences are sensitive to an edematous and inflamed appendix but are least likely to depict the normal appendix. The inflamed appendix has a caliber of 7 mm or more and a thickened wall that appears hypointense on T1-weighted images and hyperintense on T2-weighted images (Figs 2–6). The lumen may or may not have a signal intensity similar to that of fluid. Periappendiceal fat inflammation has a hypointense signal on T2-weighted images, a finding that is consistent with edema. MR imaging has reported sensitivity of 97%–100%, specificity of 92%–93.6%, and accuracy of 92%–94% for the diagnosis of acute appendicitis (15–17).
Figure 4. Acute appendicitis in a nonpregnant patient. Axial (a) and coronal (b) contrast-enhanced T1-weighted MR images show the enlarged appendix (arrow) with a diameter of 8 mm and an enhancing wall.

Figures 5, 6. (5) Perforating appendicitis in a 16-year-old girl. (a, b) Contrast-enhanced T1-weighted MR images (a at a level higher than b) show extensive peritoneal enhancement in the right lower pelvis surrounding the perforated appendix, which appears as an enhancing tubular structure in a (arrows) and has a thickened and enhancing wall in b (arrow). (c) Contrast-enhanced CT image obtained with rectally administered contrast material shows soft-tissue infiltration (arrow) at the base of the cecum, with thickening of the adjacent small-bowel wall. The lack of visibility of the appendix at CT prompted MR imaging. (6) Gangrenous appendicitis in a pregnant patient. Axial T2-weighted MR image shows a dilated, fluid-filled appendix (arrow) to the right of the uterus, with appendiceal wall thickening to 5 mm.
Oto et al demonstrated progressive cranial displacement of the appendix and cecum during pregnancy. The location of the appendix is usually caudal to the level of the iliac crest during the first trimester and cranial to it during the third trimester (13).

**Adnexal Torsion**

Adnexal torsion most commonly occurs in the first 3 decades of life. It most frequently involves an ovary and the corresponding fallopian tube. Torsion of the fallopian tube leads to vascular compromise, which, if unrelied, can cause irreversible hemorrhagic infarction of the tube and the ovary. Early diagnosis is critical to save the ovary.

According to the ACR appropriateness criteria, US is the imaging modality of choice for evaluation of an adnexal mass or adnexal torsion in premenopausal as well as postmenopausal women. Although US is the modality most commonly used for the diagnosis of adnexal torsion, its effectiveness is particularly limited in patients with a large body habitus and those in whom the ovaries are not visible because of intervening structures. Moreover, an ovary that is affected by torsion may still demonstrate flow at Doppler US because of a secondary blood supply via the uterine artery branches.

The suitability of MR imaging is equal to that of CT in patients in whom an adnexal lesion is believed to be present, according to the ACR criteria; however, in postmenopausal women with a complex or solid adnexal mass depicted at US, MR imaging is considered superior to CT. MR imaging and CT are used mainly when the presence of acute torsion with a pelvic mass is suspected or when the signs and symptoms are suggestive of a subacute or chronic condition.

The MR imaging features of ovarian torsion, which have been well described, include ovarian enlargement with stromal edema (Fig 7) (18–20). The common CT and MR imaging features of adnexal torsion include thickening of the twisted fallopian tube, smooth thickening of the wall of the cystic ovarian mass, ascites, and uterine deviation to the side of torsion. Less common findings include hemorrhage in the thickened tube, hemorrhage within the adnexal mass, and hemoperitoneum. An associated benign ovarian cyst or

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**Figure 7.** Adnexal torsion. (a) Axial T2-weighted MR image shows an enlarged left ovary (arrows) with stromal edema indicated by widely scattered follicles. The left fallopian tube is thickened and has a whorled appearance. (b) Contrast-enhanced T1-weighted MR image demonstrates the thickened left fallopian tube, an absence of central ovarian parenchymal enhancement, and an enhancing ovarian rim (arrows).
benign neoplasm is seen in most cases. Cystic teratoma is the most common benign neoplasm associated with ovarian torsion. If there is an associated mass, the wall of the mass may show eccentric thickening. The findings of a hemorrhagic fallopian tube, hemorrhagic ovarian mass, and hemoperitoneum are indicative of hemorrhagic infarction due to torsion. To detect hemorrhage, it is important to apply a T1-weighted sequence with fat suppression. A lack of enhancement of mural nodules or septa within the tumor is indicative of vascular compromise.

**Pelvic Inflammatory Disease**

Pelvic inflammatory disease most commonly originates in infection that ascends from the fallopian tubes. It is seen in sexually active patients and manifests with nonspecific low abdominopelvic pain. Immediate antibiotic treatment is the therapy of choice. Possible sequelae of pelvic inflammatory disease include tubo-ovarian abscess, ectopic pregnancy, and infertility.

MR imaging, given the lack of a radiation-associated risk and the relative safety of gadolinium-based contrast agents, is an attractive alternative to CT for the evaluation of pelvic inflammatory disease. US only poorly depicts the changes characteristic of pelvic inflammatory disease, other than an abscess or hydrosalpinx. Compared with US, MR imaging provides superior depiction of adnexal edema. T2-weighted fat-saturated images show parametrial signal hyperintensity due to edema. A tubo-ovarian abscess appears with mild signal hyperintensity on T1-weighted images and high signal intensity on T2-weighted images because of internal debris. At contrast-enhanced MR imaging, an abscess has a thick enhancing wall. Occasionally, an adjacent fluid-filled tubular structure, which represents an inflamed fallopian tube, is seen: Hydrosalpinx, which may manifest with acute lower abdominal pain, is well depicted at MR imaging (Fig 8).

**Fibroid Degeneration**

Fibroid degeneration may cause localized pain, tenderness, fever, and leukocytosis that last a few days. When fibroids increase in size, they may outgrow their blood supply; degeneration (most commonly hyaline, myxoid, cystic, or red degeneration) often follows. During pregnancy, enlargement of the uterus may interfere with the blood supply to fibroids and cause either cystic degeneration or infarction of the fibroids.

In pregnant patients with acute pelvic pain, fibroid degeneration may be diagnosed on the basis of US findings. MR imaging may be helpful in complicated cases but should not be used indiscriminately. T1-weighted MR images may show diffuse or peripheral high signal intensity from hemorrhage (20). A hyperintense rim around a fibroid may be due to obstructed veins at the periphery of the mass. Edema, which may precede degeneration, may cause a diffuse increase in the signal intensity of uterine fibroids on T2-weighted images. Degenerated fibroids have
higher signal intensity and greater heterogeneity on T2-weighted images (Fig 9) and show less marked contrast enhancement than do cellular fibroids (21).

Other Pelvic Abnormalities
Endometriosis represents extrauterine implantation of endometrial mucosa. This ectopic mucosa responds to cyclic hormonal changes and eventu-

ally bleeds, forming hemorrhagic cysts or hemorrhagic ascites in the cul-de-sac. The commonly involved structures are the ovaries, cul-de-sac, posterior uterine wall, uterosacral ligaments, anterior uterine wall, and bladder dome (22). Although US and CT are capable of depicting the hemorrhagic cysts known as endometriomas and CT may show hyperattenuation indicative of blood products, the presence of blood is more conclusively established on the basis of the MR imaging appearance (specificity of >90%). On T1-weighted images, endometriomas appear as areas of “lightbulb” signal hyperintensity, unlike cysts and abscesses, which have low signal intensity on T1-weighted images (23). The signal

Figure 9. Fibroid degeneration. (a) Axial T2-weighted MR image, obtained in a pregnant woman with right lower quadrant pain at 28 gestational weeks, shows an 8-cm-diameter necrotic fibroid (arrows) with a central area of high signal intensity. (b) Axial STIR MR image demonstrates two large fibroids (arrows) with necrotic centers. (c) Pelvic US image obtained 3 weeks earlier shows a single fibroid without any central cystic areas.
The hyperintensity of endometriomas is even more pronounced on images acquired with fat suppression. This T1-weighted signal hyperintensity is due to the presence of intracellular as well as extracellular methemoglobin. On T2-weighted images, endometriomas may demonstrate signal hypointensity due to the presence of old blood products (presumably the result of periodic bleeding), unlike cysts or abscesses, which appear hyperintense on T2-weighted images (Fig 10). An appearance of shading (signal hypointensity on T2-weighted images) may be produced by T2 shortening in an adnexal cyst that has hyperintense signal on T1-weighted images. The area of shading most often either completely occupies the cyst or is seen as a dependent layer (fluid level). Endometriotic cysts contain high concentrations of protein and iron from recurrent hemorrhage, and these contents are believed to produce the effect of shading. Hemorrhagic functional ovarian cysts are most often solitary, are brighter than endometriomas on T2-weighted images, and do not generally exhibit shading. The T2-weighted signal intensity of endometriomas also may decrease in response to medical treatment with buserelin acetate (24).

Hematometra is due to an imperforate hymen, which originates from a congenital anomaly of the müllerian duct. The result is an accumulation of menstrual fluid in the endometrial cavity and the superior two-thirds of the vagina. MR imaging conclusively demonstrates the presence of blood products and helps differentiate hematometra from other cystic lesions that may arise at the introitus in adolescent girls. MR images show a distended endometrial cavity that contains blood products, with distention also of the upper part of the vagina. The fluid has a hyperintense signal on T1-weighted images and appears less hyperintense than the bladder on T2-weighted images (25) (Figs 11, 12).

Acute epiploic appendagitis is characterized by an oval fatty lesion, which most commonly is located adjacent to the sigmoid colon and associated with stranding of the periappendicular fat and thickening of the parietal peritoneum (Fig 13). The diagnosis most often is established with CT, and early recognition allows conservative management (26,27).
Figures 11, 12.  Hematometra. (11) Sagittal T2-weighted MR image shows dilatation of the vagina (straight arrows) and resultant cranial displacement of the uterus (curved arrow). (12) Sagittal T2-weighted MR image in a patient with a double uterus shows a dilated vagina that contains subacute blood and dependent debris (arrowheads).

Figure 13.  Acute epiploic appendagitis. (a) Axial STIR MR image shows an oval fatty lesion (arrow) with a high-signal-intensity rim and inflammation in the surrounding fat. (b) Axial contrast-enhanced CT image demonstrates the same lesion (arrow) with a ring sign and surrounding inflammation.
Crohn disease is a subacute or chronic enteritis that usually occurs in the terminal ileum but also may involve other segments of the gastrointestinal tract. CT enterography, small-bowel follow-through study, and CT with oral and intravenous contrast material have higher appropriateness ratings for diagnosing and monitoring Crohn disease than does MR imaging with or without contrast material. However, MR imaging has the advantages of excellent contrast resolution, depiction of any extraluminal disease, and lack of ionizing radiation (28–31). MR imaging features of Crohn disease may include mural thickening, mural enhancement, hypervascularity, abscess, fistula, and stricture (Fig 14). MR enterography and MR enteroclysis have been advocated by some authors as potential imaging modalities of choice for evaluating Crohn disease. Godefroy et al found a sensitivity of 100% and a specificity of 83% for MR enterography in the assessment of Crohn disease in pediatric patients (28).

**Conclusions**

When US findings are nondiagnostic or equivocal, MR imaging is the most appropriate modality for the evaluation of acute appendicitis in pregnant women. It also may be useful for the diagnosis of other pelvic and lower abdominal abnormalities. MR imaging provides an alternative to CT enterography and the small-bowel follow-through study for evaluation of Crohn disease in patients for whom radiation exposure is an important clinical consideration. Although the high cost and restricted availability of MR imaging limit its utility in the emergency setting, the absence of ionizing radiation and the improved contrast resolution make MR imaging an appropriate modality for use in selected patients. Attention to proper MR imaging technique and tailored protocols are essential for optimizing the effectiveness of the examination and maximizing diagnostic accuracy.

**Figure 14.** Crohn disease. Contrast-enhanced T1-weighted MR image shows intense enhancement (circled area) of the terminal ileal wall and the adjacent small-bowel mesentery, findings suggestive of active Crohn disease.

The recently increased awareness of and concern about radiation-related health risks warrant the adoption of a flexible approach to imaging in the emergency setting, particularly in pregnant and pediatric patients.

**References**

MR Imaging of the Acute Abdomen and Pelvis: Acute Appendicitis and Beyond

Ajay Singh, MD et al

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