MRI: Is There a Role in Obstetrics?

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Abstract: Magnetic resonance imaging has a complementary role in obstetrical imaging to ultrasound (US). Although US has advantages as an initial imaging technique, there are significant numbers of patients who cannot be adequately evaluated for a variety of reasons including calvarial calcification, oligoanhydramnios, or simply obesity. MR can provide additional information that cannot be obtained by US and is invaluable in central nervous system anomaly evaluation, airway management, and planning for postnatal intervention. Newer techniques established in the postnatal population such as spectroscopy, diffusion-weighted imaging, and functional imaging have future applications in the fetus.

Key words: MRI, fetus, congenital anomalies, prenatal diagnosis

Introduction

Magnetic resonance imaging (MRI) is a rapidly evolving imaging modality, which over the last decade with the development of increasingly faster sequences and methods of image processing offers a powerful complement to ultrasound (US) for the evaluation of challenging obstetrical problems, and the promise of new possibilities.1,2

Fetal MRI has been performed since the early 1980s, but with the development during the late 1990s and early 2000s of imaging sequences, which can be obtained within a single breath-hold, MR has found increasing utility. Previously, the use of MR in imaging the fetus was restricted mostly to neurological imaging. However, now with increasingly more rapid MR imaging techniques that minimize the effects of fetal motion, MRI now has an increasing role in the evaluation of other organs and regions, such as the lung, chest and abdominal wall, genito-urinary and gastrointestinal system, the abdominal wall and pelvis, the placenta, and the uterus. MRI should be used when US imaging is not possible, practical or when there is significant US image degradation which compromises diagnosis or exclusion of disease. The primary indication for the adjunct use of MR imaging is when an abnormality is detected and cannot be fully characterized with US. Unusual circumstances arise when additional imaging and perspectives are needed such as with conjoined twins. In the future, functional and anatomic evaluations,
which exploit other physical properties, may be used. As MR images are without radiation, it is increasingly used for the evaluation of maternal diseases.

**Comparison of MRI and US**

US is the initial method of choice for fetal imaging. It is the modality of choice for screening for fetal abnormalities and for gestational age assessment as it is less expensive and portable. US still has difficulties. Three-dimensional (3D) techniques and prospective rendered imaging have improved the size of the imaging field of view, but fields of view remain limited with the inability to easily display more advanced gestations in a single view. US image quality is operator dependent, relying upon the skill of examiner. Image quality is also dependent upon maternal body habitus, fetal positioning with difficulties of cephalic presentations, spine position, and obscuration of the placenta.

MRI is free of many of the restrictions of US. As image formation does not rely on energy reflection, it is free of bone and attenuation artifacts. MR imaging is largely independent of maternal body habitus and the main limitation for larger patients is the MR gantry opening (Fig. 1). Although with MRI the region of interest can be small such as a posterior fossa, large field of view imaging can also be performed with the image encompassing the entire fetus in 1 image. By varying the T1 and T2 weighting of the pulse sequences tissue characterization can be performed, fat versus soft tissue, blood, or even iron detection. MRI is not as dependent upon fluid as US and imaging can be performed in the anhydramniotic patient. There is good correlation with established US biometric measures and with fixed positions of adjacent image planes, volumetric measurements by planimetry can be readily obtained of any organ with great accuracy. MRI can obtain biometric information that US cannot. MR imaging improves with advancing gestational age as opposed to US when imaging becomes progressively more difficult. MRI is still rapidly evolving with improving spatial and temporal resolutions, whereas US is a more mature technology. There are future potentials with techniques such as spectroscopy, white matter tractography, diffusion-weighted imaging (DWI), and functional imaging. MRI does have some disadvantages. Most of the current common sequences are obtained as static images and as a result it is difficult to assess fetal movement. The fetal heart is still poorly imaged compared with US, but it is now imaged on an experimental basis. MRI bone nonvisualization an advantage for neurological imaging, but a disadvantage for the imaging of skeletal dysplasias and calcified lesions.

**Safety**

MR imaging of the fetus has been approved by the American College of
Obstetrics and Gynecology and the American College of Radiology, but because of relatively few studies, it is advised that its use be restricted in the first trimester. Of the human studies available, none have found ill effects. There are several areas of concern with MR safety: magnetic fields, radiofrequency (RF) energy used for image formation, acoustic noise, and contrast agents. Static magnetic fields at typical strengths yield no effect to the patient. At higher levels, >2.0 T, movements of patients within the magnetic field can affect sensory organs with sensations of vertigo or metallic tastes, but these effects are transitory. The greater concern with static fields is common to all patients with implanted metallic objects, pacemakers. Ferromagnetic objects brought into the scanning room that may inadvertently enter the magnet bore while a patient is being imaged and safety precautions must be observed.

Of potential concern is the RF energy used for imaging. With sufficient strength RF energy can result in tissue heating in models, but at the levels used in clinical imaging, no heating has been noted in studies measuring heating effects in porcine models. Like US, the amount of energy deposited in the body for image formation is monitored and regulated. This amount of energy deposition also appears not to be a concern at conventional magnetic field strengths. Flexing of magnetic coils in the imaging gantry causes noise during imaging. Although for some sequences maternal hearing protection is needed, little noise reaches the fetus. In general, as with any evolving technology, risk benefit ratios should be assessed and the use of MR during periods of organogenesis should be avoided.

In 2006, a new syndrome of nephrogenic systemic fibrosis was described in small numbers of patients who were given higher doses of gadolinium-based MRI contrast agents. These cases were restricted to patient populations with renal insufficiency. These patients developed soft tissue fibrous sclerosis felt due to activation of circulating fibroblasts by free/unbound gadolinium. No cases of nephrogenic systemic fibrosis have been identified in the population that had contrast as a fetus. As there is some evidence that gadolinium-based contrast agents cross the placenta, gadolinium-based agents should not be used during pregnancy.

**Contraindications for MRI**

There are contraindications to MRI which are common to all patients. Patients should be screened for implanted ferromagnetic devices for their MRI compatibility. Others devices, such as joint prostheses, will distort the local magnet field and create image artifacts. Long wires from pacemakers, neurostimulators, or even electrocardiogram monitoring leads on the skin surface can generate heat or electrical current from the changing magnetic fields. All of these safety issues are well documented and characterized.

**Examination Performance**

MR imaging of the fetus can be challenging, but nonetheless, with some preparation and attention to detail, high-quality images are obtainable in the vast majority of patients and most examinations can be performed without direct physician supervision.

Little patient preparation is needed for fetal MR imaging. Although mild sedation was often used in the past with longer examinations, it is rarely needed currently. The patient is encouraged to start the examination with an empty bladder. Postprandial imaging has been used, as some state that the fetus is less active several hours after meals. One positions the patient based on maternal comfort and most patients are able to lie in supine position while some in more advanced stages of pregnancy are more comfortable in a left lateral decubitus position.
The routine ultrafast pulse sequences for fetal MR imaging are typically T2-weighted pulse sequences with various brand names depending on the MRI scanner manufacturer. For the Siemens (Siemens Medical Solutions, Erlangen, Germany) MR scanner (1.5 T, Sonata), the ultrafast T2-weighted pulse sequences are the HASTE and True FISP, and for the General Electric (General Electric Healthcare, Milwaukee, WI) scanner are the single shot fast spin echo and FIES- TA. The fast T1-weighted pulse sequences are not as robust as the T2-weighted sequences, may be difficult to obtain and the resolution is low. These fast T1-weighted pulse sequences are indicated for further evaluation of possible hemorrhage and the thyroid gland for goiter.

Neurological Imaging

Fetal MRI has rapidly developed over the past 15 years into an extremely useful examination. It has been spurred on in part by the advances in fetal medicine and surgery for accurate and fast diagnosis and the development of very fast pulse sequences that allow for quality delineation of the fetus with elimination of significant fetal motion. Fetal MRI is only an adjunct to traditional US, which is still the primary imaging modality for the fetus. Fetal MRI is indicated when the US examination is not conclusive, complicated pregnancy, and to confirm US findings.4-6

Fetal MRI is not performed during the first trimester of pregnancy because of the small size of the fetus and the inability of MRI to adequately evaluate the fetus at this early gestational age. MRI is a complementary examination in the evaluation of the fetus during the second and third trimester of pregnancy.

The most common indications for fetal MRI are to evaluate the brain, spine, soft tissues of the neck, and certain types of body abnormalities. Evaluation of the lateral ventricle for ventriculomegaly is the most requested reason for the fetal MRI examination. The atrial diameter of the lateral ventricle with an upper limit of 10 mm is the standard used (as with US) for lateral ventricular measurement during the second and third trimester of pregnancy. Ventriculomegaly may be due to obstructive hydrocephalus, developmental (insufficient brain tissue) or brain tissue loss from destructive process (Fig. 2).7

The common abnormalities of the brain demonstrated on fetal MRI include congenital malformations, hemorrhage, hypoxic ischemia, tumors, and vascular malformations. The common abnormalities of the spine demonstrated on fetal MRI of the spine include congenital malformations (spinal dysraphism), tumors, and hemorrhage (Fig. 3).8

There are several types of anterior neck masses such as teratomas, cystic hygromas, and goiters, which may produce significant airway compression in the fetus and require the exit procedure (ex utero intrapartum treatment) for control of the airway at delivery. Fetal MRI can help to distinguish the type of neck mass and to assess the airway for significant compression (Fig. 4).9

Non-neurological Fetal Imaging

Fetal MRI is expanding beyond neurological imaging and is finding applications in imaging of the thoracoabdominal trunk. The greatest use is evaluation of thoracic abnormalities, but fetal body MR imaging has uses in imaging of all the organs of the abdominal pelvic cavity, abdominal wall, and the placenta. Some of the applications in biometry include volume analysis.

BIOMETRY

After several decades of the use of US, large databases have been developed for a
wide variety of biometric measurements normalized to fetal maturation and outcomes. These databases are still evolving with development of 3D and 4D US. MR is undergoing that same process with MR-based measurements that correspond to standard US parameters. It has been demonstrated that MR measurements have good correlation with the corresponding US measurements for standard biometric measurements. In addition, there are new measurements that exploit many of the unique properties of MRI and are undergoing validation.

In addition to conventional unidimensional measures such as head or abdominal circumference, MRI volumetric measures can be readily obtained. As opposed to free-hand US techniques, MR images are obtained with uniform-slice thicknesses and spacing within each series in a uniform geometric relationship. Although the use of planimetry, measuring the area of the cross section of the organ of interest, multiplied by the thickness and number of sections, organ volumes can be calculated.

This is a standard technique well validated with MRI in a wide variety of organs. Planimetry is often more accurate than pathology measurements because of collapse of the organ from loss of perfusion in the postmortem state. There is some success with 3D US, for measurement of lung volumes, but these calculations are hampered from bone artifacts. New MRI-based measurements can be obtained, such as total amniotic fluid volume and whole fetal body volume measurements that result in more accurate assessment of true fetal body weight than estimation from standard US biometry. In addition, MRI-based databases are being developed for wide variety of measurements including central nervous system (CNS), lung volume, liver, and kidneys.

**Chest**

After neurological abnormalities, imaging of the chest is the next most common indication for fetal MRI. With multiplanar capabilities, good soft tissue contrast
resolution characteristics, MRI can demonstrate a wide variety of pulmonary lesions and mediastinal masses, as well as defining the diaphragms, associated defects, and lung volumes. The common T2-weighted series in which fluid demonstrates high signal, affords good delineation of the fluid-filled pharynx, tracheobronchial tree, and fluid that may be within the esophagus. The fetal thymus is a relatively large organ of intermediate signal intensity with T2-weighted images, is located in the superior upper mediastinum and may even appear to extend into the neck. As the fetal lungs mature, there is progressive decline in T1-weighted signal and proportionate increase in T2-weighted fluid sensitive signal as bronchial branching progresses and the developing alveoli become fluid filled. This pulmonary T2 signal contrasts with the lower signal mediastinal structures and lower signal intense liver and spleen.

**FIGURE 3.** Fetal magnetic resonance imaging sagittal T2-weighted Haste sequences in 2 different fetuses with myelomeningoceles. A, 34-week GA fetus with lumbosacral myelomeningocele with low lying tethered spinal cord extending through opening in posterior elements of the spine and a large herniated sac projecting beyond the plane of the back (black arrows). B, 24-week GA fetus with lumbosacral myelomeningocele with large opening in the posterior elements of the spine, low lying tethered spinal cord which extends through the opening flush with the plane of the back (short white arrows) and Chiari II malformation (long white arrow) with tissue extending from posterior fossa to upper cervical canal and hydrocephalus of the lateral ventricles (black arrow).

**FIGURE 4.** Fetal magnetic resonance imaging sagittal T2-weighted Haste sequence in 24-week GA fetus with cystic hygroma at the floor of the mouth (black arrow) without any significant compression on the airway (white arrows).
The low-signal diaphragm contrasts with the fluid-filled stomach and small bowel and defines their relationship. Many thoracic and pulmonary masses are cystic and the fluid component of these lesions is readily apparent against the background of lesser signal intense soft tissues of the chest and midrange signal intensity of the lungs. The bright signal fluid within the stomach and small bowel also readily defines their position and relationship with the diaphragm. Dynamic longitudinal steady-state free precession series can also document fetal diaphragmatic motion.

When a pulmonary mass is detected, thoracic MRI is a useful adjunct. When compared with US, use of MRI lead to a change in diagnosis or additional information in the evaluation of thoracic abnormalities. The most common pulmonary masses are bronchopulmonary sequestration (BPS) and congenital cystic adenomatoid malformation of the lung (C-CAM). Congenital diaphragmatic hernias (CDH) may also be discussed with these lesions. Mediastinal masses are less frequent. There are indications that MRI may be able to define lung maturity. MRI temporal resolution is approaching a point where fetal cardiac MRI may be possible and this has already been achieved with some animal models.

BPS
BPS can be classified as 1 of 2 similar entities, extralobar and intralobar sequestrations. The less common extralobar sequestration has its own investing pleura separating it from the lung, whereas the more common intralobar sequestration is located within the pleura of the normal lung. Both forms appear echogenic on US and triangular, and appear with increased T2 signal on MRI. Cysts are uncommon and their presence suggests the possibility of an overlap state, or that the lesion is a C-CAM. Extralobar sequestrations are most often left sided and can be either supradiaphragmatic, or less commonly infradiaphragmatic. The extralobar variant almost always has its arterial supply from the adjacent descending aorta with the venous drainage through the inferior vena cava azygous system, or into the pulmonary veins. MRI can identify the origin of the extralobar BPS but the sensitivity of the artery detection has not yet been defined. In contradistinction to intralobar sequestration, extralobar sequestrations have a higher incidence of associated anomalies. MRI may be beneficial to evaluate the other anomalies and to differentiate the occasional subdiaphragmatic extralobar sequestrations from other lesions such as neuroblastoma. The added benefit of MRI is still evolving but it has a role in circumstances of difficult imaging by other means.

C-CAM
C-CAM originally described in 1949 is a developmental mass of proliferated terminal bronchioles that may communicate with the airways. There is a spectrum of abnormalities and these are typically classified on the basis of the size of the associated cysts. Although C-CAM and BPS can appear similar, the presence of cysts favors a diagnosis of C-CAM. C-CAM may have a benign prognosis, but microcystic C-CAMs may undergo progressive enlargement and can cause fetal demise from compression of adjacent structures.

On US, C-CAM is generally detected at about the 20th week and appears as a cystic or echogenic solid appearing mass. With MRI, all C-CAMS share with a characteristic appearance of increased T2 signal, due to the cystic components of the lesions even though the smaller cysts cannot be individually resolved (Fig. 5). The true sensitivity for MRI in the dictation of C-CAM is still not known. It is unclear as to the added benefit of MRI with C-CAM. It may be helpful for presurgical planning with volumetric assessment or serial assessment of lesion size.
CDH
MRI is valuable in cases of CDH both in the diagnosis of the entity and prediction of outcomes. CDH is a developmental defect of primarily the posterolateral portion of the diaphragm, mostly on the left, which results in the herniation of intra-abdominal contents into the chest. On the left, this may include the stomach, small bowel and with more advanced defects, solid organs including spleen and liver. With the less common right-sided hernias, it is the liver that is primarily displaced into the chest.

On US the diagnosis is typically straightforward, but often additional information is needed. Without additional findings, morbidity and mortality is mostly due to pulmonary hypoplasia as a result of compression of the lungs by displaced abdominal organs. The lung contralateral to the diaphragmatic hernia may also be involved if the degree of hernia displaces the mediastinum into the contralateral hemithorax compressing the opposite lung. Fetal MRI can confirm the finding, differentiate CDH from other cystic pulmonary lesions that could mimic CDH, better define the position of the liver on the left for “liver up, liver down” determinations, and define the pulmonary space with improved definition of the liver in the less common right-sided CDH (Fig. 6).

Additional data exists that by evaluating the contralateral and compressed ipsilateral lung, predictions of postnatal outcomes can be made. Despite improved prenatal diagnosis, CDH remains a life-threatening condition with a high mortality rate. Some centers have reported up to 93% survival, but this is most likely due to referral and selection bias with reports up to 35% mortality in live births occurring before referral. Many parameters have been proposed to predict outcomes including lung-to-head ratios. Several studies claim predicted mortality is 100% for a ratio of < 1 and 100% for a ratio of > 1.4. However, the large majority of examinations results in a ratio between these 2 limits and other studies have not confirmed a value of the lung/head circumference ratio for predicting postnatal clinical course or survival. Other studies suggest that relative and absolute fetal lung volumes determined with MRI planimetry have increased predictive value as opposed to measurements of a single lung cross section. Controversy exists as to the relative predictive powers of a variety of different lung volume indices. Larger
population sample sizes will be needed to determine which index is the most useful.

**MEDIASTINAL MASSES**

Mediastinal masses are often fluid filled such as foregut and esophageal duplication and bronchogenic cysts. Esophageal atresias may also be well-defined when fluid is present in a distended portion of the esophagus. Mediastinal teratomas are often heterogenous in signal intensity with the higher signal fluid component and lower T2-signal fat component that will then become brighter when fat sensitive T1-weighted sequences are applied.

**LUNG MATURITY**

Respiratory distress syndrome is a common problem affecting 1 out of 160 births with a 5% mortality rate. Pulmonary immature is a frequent cause of neonatal mortality. As a consequence, there has been tremendous interest in the use of MRI to predict fetal lung maturity.

Currently, thin sections can be obtained of the entire fetal lung during a single-maternal breath-hold in any plane desired. The MRI appearance of the lungs parallels the pattern of lung development. With increasing fluid in the alveoli, T2 signal increases with fetal development. Around 18 to 22 weeks, fetal lung parenchyma has moderate increased signal in comparison with muscle, liver and is mildly increased in comparison with amniotic fluid. With continuing development of the lung and increasing pulmonary fluid production there is continual increase in the T2-fluid signal. Although there is a trend for increasing T2 signal with increasing maturation, the changes are not specific enough to predict maturity in any particular fetus. Quantization of MR signal is difficult because of field strengths, varying patient size affecting the magnetic field and absorbed RF energy, and other effects. As a consequence of the difficulties of measuring absolute pulmonary signal return, other methods such measuring ratios between lung signal and a fluid reference standard, (ie, cerebral spinal fluid) are under investigation and are of interest.

As the fetus develops, the fetal lung volumes increase and accurate, reproducible measurements can be obtained with MRI. Fetal lung volumes hold promise for a metric of lung maturity. As with other MRI biometrics, there are only smaller numbers of patients in published

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**FIGURE 6.** Coronal True FISP MR in a 33-week gestation with congenital diaphragmatic hernia. A, The open arrow demonstrates a dextroposition of the heart. B, The closed arrow demonstrates an infradiaphragmatic position of the stomach. C, The arrow head show the small bowel within the left chest displacing the heart to the right as seen in image A.
series. There is lack of standardization of technique with some varying inclusion or exclusion of the pulmonary hila.\textsuperscript{11} Measurements must be standardized not just with gestational age, but also with fetal weight which becomes increasingly variable with advancing fetal age.\textsuperscript{12} Once these are obtained, clinical outcomes must be determined to assess the predictive value of the pulmonary volume measurements.

Other methods of fetal lung maturity are investigation. An intriguing application of MR spectroscopy is the potential in measuring amniotic fluid choline and other surfactant components. There is a trend for in vivo and ex vivo spectroscopic correlation of amniotic fluid samples, however, the technique is proving technically difficult, but still is potentially an alternative to a maturity amniocentesis.\textsuperscript{13} In addition, DWI that measures bulk fluid motion in organs has been attempted with minimal success to date.

**Fetal Cardiac MRI**

Although cardiac MR is now a standard tool in the evaluation of pediatric and structural heart disease, it has little role in the prenatal population. Single-plane cardiac images can be obtained with high temporal resolutions and good spatial resolution in the neonatal population, but this is dependent upon proper electrocardiogram monitoring-triggered gating, which cannot be achieved in the prenatal population. If proper gating is possible, fetal motion still renders proper image plane selection difficult. Rapid advances in MR imaging may make fetal cardiac imaging possible.\textsuperscript{14}

**Abdominal Imaging**

**Renal Imaging**

Genitourinary anomalies are common and account for between 14% and 40% of anomalies detected on fetal US. Most fetal urinary tract abnormalities are well seen with US with the anechoic fluid from urinary obstruction or cyst formation forming inherent contrast with the surrounding soft tissues of the retroperitoneum, however, oligohydramnios is often present. MR may be of a particular advantage when the renal anomaly has resulted in oligohydramnios and US imaging difficult (Fig. 7). In this circumstance MR may have improved delineation of the anomaly. MRI findings of ureteric duplication, ectopic ureters, posterior urethral valves, multicystic dysplastic kidneys, polycystic kidneys, and renal agenesis have all been described. Although only a few studies have been published, diffusion-weighted MR imaging may have a future role in fetal renal functional evaluation.

**Gastrointestinal**

With fluid filling the gastrointestinal tract with resulting T2 signal allows MRI to readily determine a level of obstruction. Later in gestational development when
there is a smaller amount of fluid in the colon in comparison with the fluid poor-protein and high-protein content meconium, the meconium acts as a T1-weighted contrast agent and outlines the colon. The presence of meconium helps outline pelvic masses that tend to be fluid filled and T2 weighted (Fig. 8).

**FIGURE 8.** Sagittal True FISP MR image in a 32-week gestation with gastroschisis and polyhydramnios. The closed arrow demonstrates an extra-abdominal liver. The open arrow shows the cord insertion.

Placenta

MR imaging of the placenta has been found to correlate well with US findings and is a useful adjunct\(^{15}\) and has advantages in imaging of the placenta if the placenta is difficult to image with US because of obscuration by the fetus or maternal habitus. The most common indication for placental MR is the evaluation of placenta accreta. If the underlying endometrium is deficient, such with prior cesarean section, the trophoblasts invade and penetrate into the myometrium. Placenta accrete is classified upon the degree of invasion. In placenta accrete the chorionic villi attach to the placenta, but do not invade. With placenta increata, the villi invade into the myometrium and with precreta the villi invade and pass through the myometrial wall often invading the adjacent tissues. Although the diagnosis of placenta percreta can be made with confidence, differentiation between increata and acreta, or the exclusion of accreta is often problematic. Similar findings are seen with US with focal thinning of the involved myometrium and with bulging. As with many areas of fetal MRI, US and MR appear to have complementary roles in the evaluation of placenta accreta with similar sensitivities and specificities but with the abnormality occasionally seen with 1 modality better than with the other. This suggests a role for placental MR when the diagnosis with US is difficult or uncertain.

Other roles for MR placental imaging are undergoing evaluation. The morphologic-related and ageing-related changes of the placenta are similar with US and MR, but newer techniques which other physiological parameters, such as DWI, are now available and their utility must be assessed.

**Special Uses**

**CONJOINED TWINS**

Fetal MR imaging has proven useful in a number of less common but significant ways. In the rare circumstance of conjoined twins, MRI has a significant adjunctive role with the large field of view and lack of bone artifacts. We have found it useful for the delineation of the often complex overlap in the body structures in conjoined twins (Fig. 9).

**FAMILY COUNSELING**

This is somewhat less described in the literature, but MR images seem to be
more readily understood by the families than the corresponding US images. This institution has multidisciplinary family counseling session and the review of the fetal MR imaging anatomic display appears readily comprehensible to nonphysicians as compared with US. This may be because of the wider field of view of MRI that gives added points of reference or the ability to rotate images into a more familiar anatomic orientation for presentation.

**AUTOPSY**
MR imaging can be used at a postmortem stage. The number of autopsies is declining and imaging can at times perform an

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**FIGURE 9.** True FISP images in a set of thoracopagus conjoined twins. A, The closed arrows show superior and inferior extent of the shared heart, liver, and small bowel in a sagittal projection. B, At level of the heart in the transverse plane, the arrow head demonstrates a shared ventricle. C, At level of the upper abdomen in the transverse plane, the black arrow demonstrates the shared liver. D, Through the mid abdomen in a transverse projection, an open arrow shows the shared small bowel.
adjunct, rapid, less-invasive method of diagnosis. Occasionally, the diagnosis is not certain at the prenatal state or additional clarifications are necessary. Postmortem MR can be performed quickly, without undue disturbance and seems readily understood and accepted by the families.

**Maternal MR Imaging**

With the heightened awareness of ionizing radiation from computed tomography, MRI is increasingly used for the evaluation of concomitant maternal disease, particularly imaging of the acute abdomen. Evaluation of acute abdominal pain in the pregnant patient is difficult because of the normal physiological and anatomic alterations that occur with pregnancy, which can confound the clinical picture, and limitations in imaging modalities. US is the imaging modality of choice in pregnant patients. However, it is operator dependent and may be limited because of bowel gas and the enlarged gravid uterus. Computed tomography typically is not performed because of safety concerns related to fetal radiation exposure. MRI, therefore, is increasingly used in pregnant patients with abdominal pain when US is nondiagnostic. MRI is considered safe in pregnancy (regardless of the trimester) and can produce high-resolution, multiplanar images of the entire abdomen and pelvis. It allows for accurate evaluation of the gastrointestinal, biliary, urinary, and gynecologic systems.

One of the most common indications for maternal MR imaging is suspected acute appendicitis. Although US should be performed initially, the appendix is usually superiorly displaced by the gravid uterus and may not be visible sonographically. Multiple studies have shown MRI to be valuable in the diagnosis of acute appendicitis with 1 series of 51 patients showing MRI to have a sensitivity of 100%, specificity of 94%, and accuracy of 94%.\(^{16}\) The most reliable finding is a dilated appendix measuring >7 mm in diameter. Additional findings include appendiceal wall thickening, periappendiceal inflammation and fluid, and a periappendiceal abscess or phlegmon.

MRI may also demonstrate other bowel pathology, such as small bowel obstruction or inflammatory bowel disease.\(^{17}\) For small bowel obstruction, MRI can show the degree and level of obstruction. For inflammatory bowel disease, MRI may show active disease as areas of bowel wall thickening and edema, along with complications, such as fistula or abscess formation. Other gastrointestinal abnormalities detectable with MRI include herniated bowel through an abdominal wall defect, terminal ileitis, diverticulitis, epiploic appendagitis, mesenteric adenitis, and omental infarction.

Acute cholecystitis and biliary obstruction are typically diagnosed with US, but these conditions are also well demonstrated with MRI. In the case of acute cholecystitis, MRI findings include gallbladder distention, gallbladder wall thickening, cholelithiasis, and pericholecystic fluid.\(^{18}\) With biliary obstruction, both US and MRI/magnetic resonance cholangiopancreatography will show dilated bile ducts. However, MRI is much more sensitive than US for the detection of choledocholithiasis. In addition, MRI may demonstrate acute pancreatitis by demonstrating peripancreatic inflammation and fluid, along with pancreatic pseudocysts and abscesses.

Physiological hydronephrosis is common in pregnancy secondary to hormonal effects on the urinary tract and compression of the distal ureters by the gravid uterus. US is excellent at demonstrating hydronephrosis but typically is unable to visualize the ureters. MRI, however, allows for good visualization of the ureters and accurate diagnosis of ureteral stones. Typically, MR findings of an obstructive ureteral stone include a dark filling defect within the ureter on T2-weighted images, hydronephrosis, and hydroureter to the level of the stone.\(^{17,18}\) Other urologic
conditions, such as pyelonephritis, can also be demonstrated with MRI but generally do not require imaging.

There are many gynecologic disorders that may cause acute abdominal pain during pregnancy, including ovarian torsion, ovarian cysts and masses, endometriosis, and uterine leiomyomas. These disorders usually are diagnosed with US, although MRI may be helpful for challenging cases.

**Future**

A continued rapid pace in the development and improvement of MR imaging is anticipated and these advances in MR imaging for the adult patient are often applicable to fetal imaging and these advances are rapidly transferred. Of great importance for the moving fetus, faster pulse sequences are being developed and these spurred the growth of fetal imaging in the last decade. Initially in the 1980s and 1990s pulse sequences were prolonged taking up to tens of minutes to perform, then minutes, now imaging can be performed with simple breath-hold techniques. Currently, some sequences now have <100 ms acquisition times. There is a continuing trend to higher magnetic field strength imaging. Although images can be obtained at lower strength magnets, most MR imaging now done with magnetic field strengths of 1.5 T. Continued coil development is occurring for more signal and high spatial resolution. DWI has long been used is neurological imaging and is now being increasingly used in abdominal imaging applications. In the last few years functional MRI is now more widely available. MR tractography can delineate brain white matter pathways. With faster image acquisitions, ungated real-time fetal cardiac MR may soon be possible.

**Summary**

Although US has many advantages and will likely never be replaced as a primary imaging modality for the fetus, MR fetal imaging has an established role in further characterizing fetal CNS lesions and to a lesser extent in the evaluation of thoracic and abdominal pathology. It is a useful adjunct for imaging difficult patients and problem solving. MRI can perform much now and is still rapidly evolving.

**References**


