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MRI of Acute Abdominal and Pelvic Non-obstetric Conditions in Pregnancy

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Abstract
Purpose of Review The evaluation of abdominal and pelvic pain in the pregnant patient presents unique challenges due to altered physiology and implications of radiation exposure on the fetus. In many instances, a radiologist must consider the potential risk of fetal injury from ionizing radiation and maintaining diagnostic quality imaging. This article will focus on the role of MR imaging and its applications in a variety of acute abdomen and pelvic non-obstetric conditions potentially affecting the pregnant patient.
Recent Findings Non-contrast MR imaging is routinely employed in the presence of an initial equivocal ultrasound. However, MR is playing an increasingly more important role in the imaging of the pregnant patient, potentially surpassing the utility of conventional imaging techniques.
Summary As radiologists become more comfortable interpretating abdominal and pelvic MRI, MR will play a bigger role in imaging the pregnant patient in the emergency room, in the years to come.

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Introduction

To both the medical professional and the lay person, it is well known that ionizing radiation is potentially deleterious to humans. In a pregnant patient, there are additional considerations which should be made when medical imaging is performed. A balance between the potential risk of fetal injury from the imaging technique (exposure to ionizing radiation, contrast agents, etc.) and maintaining imaging of diagnostic quality must be managed [1•]. A national trend of increasing utilization rates of imaging has led to a greater exposure of pregnant patients to ionizing radiation in the recent past. A 10-year study, published in 2009, of radiologic examinations in 3285 pregnant patients discovered that the total number of imaging examinations had increased by 121%, with CT utilization continually increasing yearly, over that time period [2]. The implications of this trend are complicated by the fact that up to 11% of pregnant patients who are admitted to a trauma service were not known to be pregnant at the time of admission [3]. Even healthcare professionals often have less than satisfactory awareness about the dosage and radiation risks of imaging their pregnant patients, which can negatively influence their clinical decision making [4]. It is prudent to increase the awareness of radiation dosages and the effects various imaging modalities can potentially have on the pregnant patient, both of which can lower wasteful utilization of radiological services, and prevent potential fetal harm [4].

Ultrasonography is the first-line diagnostic imaging modality in the obstetric pregnant patient, and if needed, is generally the first-line imaging performed of the rest of the maternal abdomen and pelvis. Additionally, it is the only imaging examination required for the majority of pregnancies [5]. "B-mode" or gray-scale images are most widely used, and consist of the acoustic impedance of 2-D cross sections of a selected volume of tissue, which allows for a rapid and dynamic assessment of moving fetuses. This permits a general fetal observation in real-time, without ionizing radiation [5]. Although there is a theoretical risk of heat injury and cavitation, when used correctly, ultrasound has an excellent safety profile with the risk of fetal harm being extremely low [6, 7].

An important purpose of all diagnostic imaging is to identify serious or potentially life-threatening pathology in the mother and/or fetus which would require prompt intervention. Less than adequate imaging can delay such a diagnosis, and any delay in diagnosis and treatment can potentially increase maternal and fetal morbidity. In the pregnant patient with a suspected acute non-obstetric abdominal and/or pelvic disorder, the sonographic findings may prove to be definitive in securing an accurate diagnosis in some patients, but unfortunately often not in a substantial percentage of pregnant patients [5, 6]. MRI is becoming the preferred second-line imaging modality when abdominal/pelvic sonographic images are equivocal or non-diagnostic. Images with greater detail are obtained through MRI, and as with ultrasonography utilizes no ionizing radiation.

There are no reported cases of maternal or fetal injury due to MRI, to our knowledge, and multiple safety studies have been performed at 1.5 Tesla magnetic field strength or lower. While many MRI scanners operate at 1.5 Tesla, some MRI scanners operate at 3 Tesla, and may potentially increase the risk of tissue heating at these higher field strengths; however, if used judiciously, MR at 3 Tesla may be safe for the fetus [8•, 9]. Additionally, the base of the IV contrast agent used in MR, gadolinium, crosses the placenta, and can eventually become reabsorbed into the fetal circulation, may potentially cause teratogenicity at higher concentrations, and is not recommended in pregnant patients except in very selected circumstances [10].

Anatomic and Physiologic Considerations in Acute Abdominal and Pelvic Pain in Pregnancy

Anatomic displacement of abdominal contents and loss of physical examination and radiological landmarks must be considered when imaging a pregnant patient. Compared to in the non-pregnant patient, the approach to acute abdominal and pelvic pain of non-obstetrical origin in pregnant patients is similar, but has some caveats. The gravid uterus adapts numerous anatomic changes in order to nurture the fetus. Over the course of an uneventful pregnancy, a woman should gain 30 lb on average, and have a shift in their point of gravity. Other changes include, but are not limited to, a twice-fold increase in force across weight-bearing joints, exaggerated lordosis of the lower back, forward tilt of the neck, and a downward displacement of the shoulders, all of which simultaneously make room for the enlarged uterus and changed center of gravity [11, 12]. Ligamentous laxity of the pelvis develops as well [11]. The increased mobility of the pelvic joints predisposes the pelvic area to pain and structural damage during pregnancy and the post-partum period, which can be confused with other processes [12–14].

In the first trimester, there is frequently mild abdominal pain due to the stretching of the round ligament. As the pregnancy progresses, abdominal and pelvic pain is mostly attributed to normal fetal positional changes, as well as uterine enlargement [15]. By 12 weeks of gestation, the gravid uterus enlarges beyond the pelvis, and starts to anatomically displace the other intraperitoneal organs [15]. The localization of pain and peritoneal signs becomes more challenging due to the expanding uterus stretching out the abdominal and pelvic wall, and compressing the viscera [15]. High concentrations of maternal hormones including progesterone can reduce the tone and contraction pressure of the ureters, and the vessels of the suspensory ligament of the ovary enlarge and can compress the ureter between the bony pelvis, leading to hydronephrosis and hydroureter, particularly on the right side [16]. The ureters become elongated and tortuous, which can become displaced and obstructed, causing urinary stasis/obstruction, frequently mimicking clinical signs of nephrolithiasis and/or urinary tract infection, but also predisposing pregnant women to these conditions [16].

With increasing uterine volume, the appendix often migrates from the right lower quadrant to the right mid abdomen [17, 18]. By the fourth month of pregnancy, appendicitis can present with pain occurring anywhere from the mid-umbilicus to the right upper quadrant. Estrogen levels increase steadily during pregnancy, and reach their peak in the third trimester, leading to a greater secretion of hepatic biliary cholesterol, which predisposes pregnant patients to cholelithiasis, cholecystitis, and common bile duct calculi [19]. Pancreatitis is also increased in incidence; the most common predisposing cause of pancreatitis is cholelithiasis, and less commonly hypertriglyceridemia [20]. In the multiparous patient, prior cesarean sections can cause adhesions. As the uterus grows into the abdominal cavity, the small bowel may become compressed, leading to a greater risk of developing small bowel obstruction [21].

Other changes in pregnancy include an increased incidence of functional cysts in the first trimester of pregnancy, which increases the risk of ovarian torsion [17]. Finally, the leading cause of non-obstetric death in pregnant women is trauma, which complicates upwards of 1 in 12 pregnancies. Due to the normal increase in blood volume, elevation of the diaphragm, delayed gastric emptying, and the enlarged gravid uterus, the assessment and management of trauma differs in the pregnant patient and can be challenging [22].

Fetal Radiation Dose Reduction and Risk

It is recommended by the U.S. Nuclear Regulatory Commission that women should not be exposed to more than 5 rad (0.05 Gy) during the course of their entire pregnancies [23, 24]. The developing embryo is most vulnerable to ionizing radiation during the first 2 weeks after conception, and survival becomes "all or nothing" at this stage. In early gestation, the rate of fetal growth is extremely rapid, and the early fetus is the most radiation sensitive [25]. Teratogenesis, growth restriction, and carcinogenesis are not observed at this point in time due to any ionizing radiation-induced damage; the embryo either survives undamaged, or is resorbed [26].

After 2 weeks post-conception, organogenesis begins. While lethality is rare, any injury caused to the fetus by radiation-induced cell death or its effects on cell migration and proliferation can lead to sequelae, including growth restriction and congenital malformations [27, 28]. There is evidence of carcinogenesis that can be attributed to the exposure of a fetus to substantial ionizing radiation in utero, with estimates of both solid and non-solid tumors increasing in incidence by 6% per 100 rads of exposure (1 Gy) [29]. Central nervous system conditions often arise at such exposures (e.g., microcephaly, eye abnormalities, and cognitive deficits) [26]. If other congenital malformations occur without any of the above-mentioned sequela, then the aforementioned malformations should not necessarily be attributed to ionizing radiation exposure [30].

As a fetus matures into viability (20–25 weeks of gestation), the threshold for ionizing radiation exposure until injury is estimated at 10–20 rads (0.1–0.2 Gy). While the average IQ loss is estimated at 25–31 points per 100 rad (1 Gy) of exposure in a fetus of 8–15 weeks of post-conception, the estimated IQ loss at 20–25 weeks falls to 13–21 points per 100 rads of exposure [25]. If the radiation exposure is primarily in the third trimester, radiation-induced non-cancer health effects are unlikely, at nearly all radiation dosages [25].

There is a possibility of maternal health risks if the cumulative exposure from diagnostic imaging exceeds 5 rads [25]. Fortunately for the vast majority of pregnant patients, imaging procedures typically expose their fetuses to fewer than 5 rads throughout the course of the pregnancies. Additionally, for all patients, pregnant or not, diagnostic imaging is usually staggered over a period of time, which is a safer exposure than that of an acute exposure [29, 31]. However, clinicians and radiologists will not know the eventual amount of radiation a fetus could be exposed to throughout pregnancy, and a cautious approach to imaging is therefore indicated. There should be an attempt to reduce or, if possible, eliminate ionizing radiation exposure to pregnant patients at every instance, but without compromising diagnostic accuracy [29].

Safety of MR Imaging in Pregnancy

MRI has been used for fetal and pregnant maternal assessment for over 20 years [29, 32]. Because there is no ionizing radiation in MRI as noted, as well as its excellent soft-tissue contrast even without IV contrast administration, MRI is generally an excellent option for imaging the pregnant patient with known or suspected acute abdominal and pelvic conditions [29]. There are, however, concerns regarding fetal injury through heating effects, as well as the effects of the relatively loud acoustic noise. In a study of nearly a million and a half pregnant patients, of whom 1737 underwent MRI, the MRI exposure during the first trimester was not correlated with an increased risk of congenital malformations, childhood cancers, vision or hearing loss, stillbirth, or death [9].

Current guidelines set forth by the U.S. Food and Drug Administration strongly discourage the use of IV gadolinium-based contrast agents in the imaging of pregnant patients. Gadolinium crosses the placenta, and can remain in the amniotic fluid for the entirety of the pregnancy, with unknown long-term effects on the fetus [9]. Animal studies have shown possible teratogenic effects of gadolinium contrast agents, but at dosages which are 2–7 times higher than the standard amounts used in humans [33]. Fetal kidneys recycle gadolinium into the amniotic fluid, where then it can be recirculated by the fetus.

The authors almost never perform IV contrast-enhanced abdominal/pelvic MRI in pregnant patients, with the exception of absolute necessity, such as in the staging of certain malignancies [1•]. If there is a critical need for IV contrast-enhanced MRI, there should be a consultation with the referring clinicians, and the patient should be counseled as to any possible risks of undergoing the procedure. The ACR generally recommends that informed consent should be obtained from a pregnant patient before an MRI examination.

Appendicitis

Appendicitis has been estimated to occur in 1 in 300–1 in 10,000 pregnancies; despite this large range, appendicitis is by far the most common non-obstetric cause of abdominal pelvic pain in pregnancy requiring surgery [34]. In a cohort study of 362,219 pregnancies, the incidence of appendicitis was slightly more common in the 2nd trimester, and the lowest rates of appendicitis were in the 3rd trimester [35].

Generally, acute appendicitis presents with right lower quadrant pain, fever, and leukocytosis, but accurate diagnosis is difficult due to the anatomic and physiological changes of pregnancy (Fig. 1) [1•]. The expansion of the gravid uterus displaces the appendix from the right lower quadrant by the 3rd trimester, and can obscure localized tenderness indicative of appendicitis (Fig. 2) [18]. There is also an increased serum leukocyte count in pregnancy, so this cannot be confidently relied on as an indicator for appendicitis [36]. Additionally, there are atypical symptoms which can develop, including diarrhea, increased urinary frequency, and dysuria [37]. McBurney's point tenderness can be less pronounced during pregnancy, as the anterior abdominal and pelvic wall may be stretched away from the inflamed appendix [37]. There is an increased incidence of potential complications, including premature labor, fetal morbidity, and even fetal mortality, especially with appendiceal perforation [1•]. If appendicitis remains undiagnosed, fetal loss rates can be as high from 35 to 55% in appendiceal perforation, and 1.5% without appendiceal perforation [18]. Any delay in the diagnosis of appendicitis in pregnant women can contribute to a higher risk of perforation and other complications [29, 38]. Laparoscopic surgery is not without its risks as well; one study reported fetal loss as high as 43% with negative laparotomy results

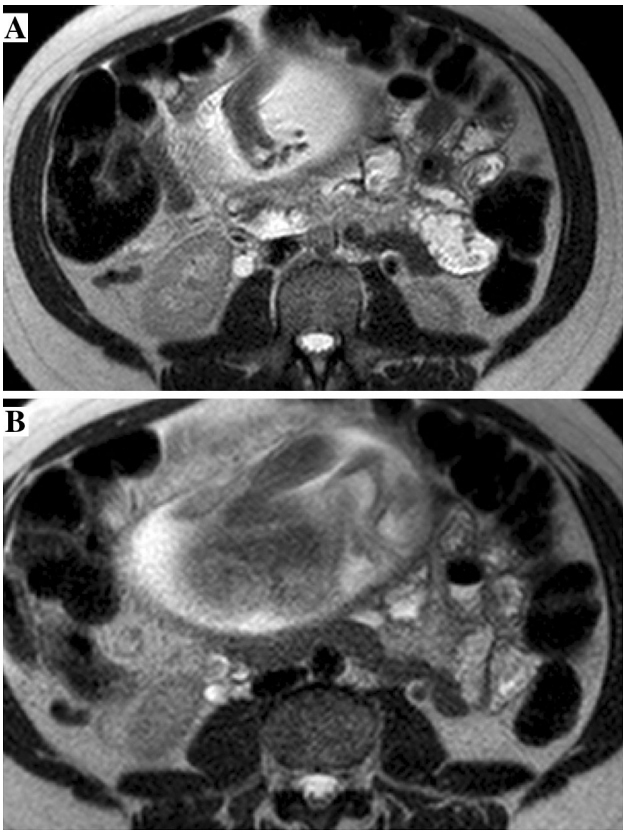

Fig. 1 Axial T2-weighted MR images of the normal appendix in a pregnant woman. There is a blind-ending, gas-filled tubular structure which is located just posterior to the cecum. There is mild distension of the colon. The patient was then treated for constipation, with successful resolution of symptoms

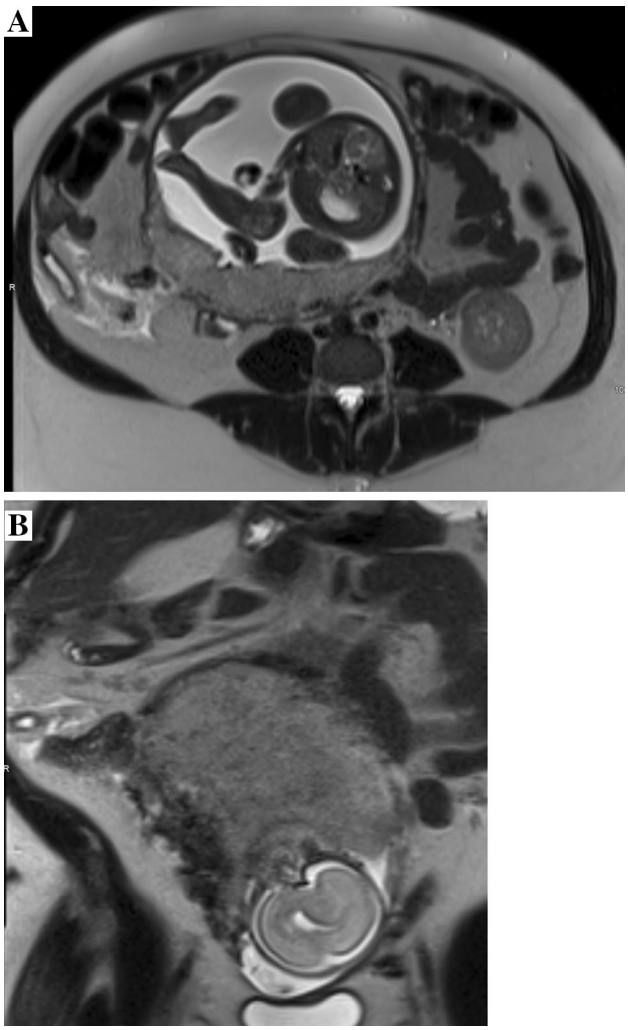

Fig. 2 30-year-old pregnant woman with right mid and lower quadrant pain, fever, elevated serum white blood cell count, and acute appendicitis. Axial (**a**) and coronal (**b**) T2 HASTE MR images reveal the fluid-filled T2 hyperintense lumen of a diffusely thickened appendix in the right lower quadrant, with a lumen diameter of 11 mm, and periappendiceal fat stranding. A tiny appendicolith is seen as a focus of T2 low signal in the lumen of the appendix. Note the gravid uterus

[36]. A timely and accurate diagnosis of appendicitis is therefore crucial in the pregnant patient.

Ultrasound is the first imaging examination usually performed for suspected appendicitis in pregnancy, although it has substantial limitations. The ACR Appropriateness Criteria recommends the first-line use of US in suspected appendicitis due to its lack of ionizing radiation, availability, cost, and the dynamic information provided through real-time graded compression [1•, 39]. Sonographic findings of a normal appendix will reveal an appendix which is compressible and less than 6 mm in diameter; these findings are the same in both pregnant and non-pregnant women [40••]. Appendicitis is seen with a transverse diameter greater than 6 mm, a tubular, blinding-ending, non-compressible structure, and inflammation of the adjacent fat [1•]. Multiple studies have demonstrated that the sensitivity, specificity, and accuracy of sonography in appendicitis can vary widely, but in general is relatively poor. A cohort study done in 2003 found that ultrasound examinations yielded a sensitivity of only 18% in diagnosing appendicitis [36]. In another study, in 33 pregnant patients diagnosed and treated with acute appendicitis, US demonstrated a sensitivity of 50%; the appendix was not identified on 88% of examinations [41]. Such wide ranges of predictive value in ultrasound are in part dependent on the body habitus of various populations of women, gestational age, differences in overlying bowel gas, the equipment used, and the training and expertise of the sonographer or radiologist [36].

If ultrasound results are equivocal, MRI is the second-line imaging modality, as defined by the ACR Appropriateness Criteria [1•]. On MRI, appendicitis is diagnosed after appreciating a distended appendiceal diameter of 7 mm or greater, and an appendix which is filled with T2 hyperintense fluid. T2 hyperintense signal may also be present around the appendix, due to periappendiceal inflammatory fat stranding [42•]. In a study of 140 patients with suspected appendicitis, Konrad et al. reported a visualized appendix only 7% of the time by ultrasound, while MRI revealed the appendix 80% of the time [40••].

A study of over 700 pregnant patients with suspected appendicitis demonstrated that MRI had a sensitivity, specificity, and accuracy of 96.8, 99.2, and 99.0%, respectively, in the diagnosis of appendicitis. Over 90% of ultrasound examinations were equivocal [18]. On sonography, non-visualization of the appendix does not equate with the absence of acute appendicitis. In contrast, with MRI, such non-visualization effectively excludes appendicitis [18]. In a report of 212 women who underwent MRI for suspected appendicitis, Kereshi et al. found that there was never an occurrence of a non-visualization of the appendix, and then subsequent acute appendicitis requiring surgery [42•]. While there may also be differences in expertise and training which may affect the sensitivity and specificity rates of the diagnosis of appendicitis on MRI, in a study of 146 pregnant women with suspected appendicitis imaged using single-shot turbo spin-echo (SSH-TSE) T2-weighted MR sequences, there was little correlation in the diagnostic performance between a less experienced radiologist and a more experienced radiologist [43].

In the setting of acute abdominal pain with signs and symptoms of appendicitis, MRI has the additional utility of revealing an alternative diagnosis to explain a patient's pain, if present [42•]. Kereshi et al. observed the MRI findings of a group of patients with suspected appendicitis in pregnancy, and found other sources of abdominal/pelvic pain, which included uterine fibroids, hydronephrosis, cholelithiasis, adnexal masses, and pyelonephritis [42•]. MRI can therefore have high diagnostic value in the workup of appendicitis in pregnancy.

Nephrolithiasis and Pyelonephritis

Nephrolithiasis occurs in approximately 1 in every 1500–3000 pregnancies [44]. In those pregnant patients who develop nephrolithiasis, the majority present in the 2nd or 3rd trimester. The most common presenting symptoms are acute flank pain radiating to the groin or lower abdomen/pelvis, and hematuria. For the majority of these women, it is the first occurrence of calculi, as the pregnant state increases the risk of urinary tract calculus formation [44]. Due to the anatomical and physiological changes of pregnancy, there is a natural propensity to develop urinary stasis, as noted, and eventually nephrolithiasis [44, 45•]. Increases in progesterone will dilate the ureters and renal pelvis, and the gravid uterus can compress the bladder, thereby decreasing its capacity, and leading to a diminished fluid intake during late pregnancy [45•]. Additionally, the pregnant state is associated with an increase in urine calcium excretion, and a rise in the alkalinity of urine, both of which increase the incidence of calcium oxalate calculi [46]. Nephrolithiasis in the pregnant patient may present with acute lower abdominal/pelvic pain which may be similar to that of appendicitis and even ovarian torsion, and thus diagnostic imaging has utility in this situation (Fig. 3) [47].

The presence of urolithiasis is associated with a risk of recurrent miscarriage, elevation in blood pressure, gestational diabetes, and an increased incidence of cesarean deliveries, amongst other potential complications [48]. Transabdominal ultrasound is the first-line test for diagnosis in suspected urolithiasis in the pregnant patient [49]. If such scans are inconclusive, a transvaginal US can be employed to increase detection rates of distal ureteral calculi [48]. However, several studies have shown that

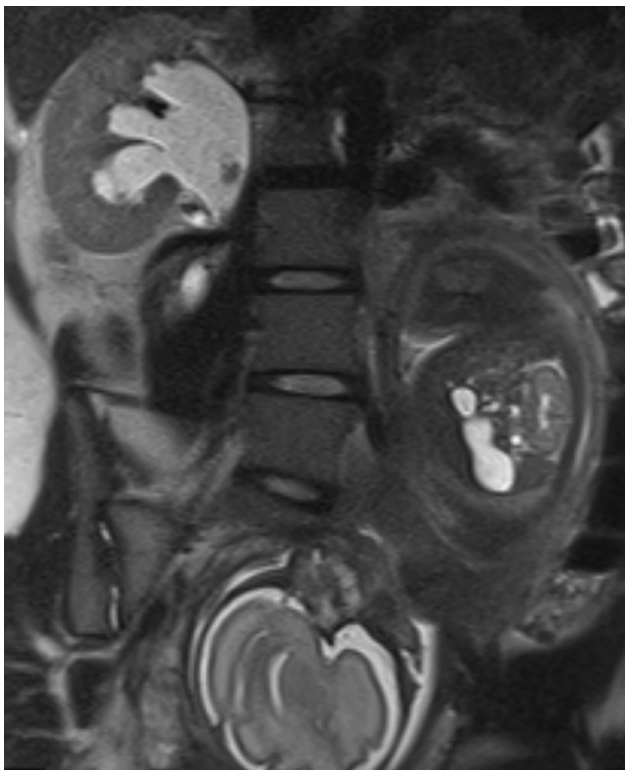

Fig. 3 T2 HASTE coronal MR image reveals right ureteropelvic junction calculus and associated hydronephrosis in a pregnant patient

ultrasound has a poor sensitivity for ureteral calculi; Butler et al. found over a 13-year period that calculi were only visualized in 60% of renal US examinations in women with confirmed nephrolithiasis. US is also limited by the experience of the operator and by the patient's body habitus, and specifically in nephrolithiasis, US interpretation can be complicated by physiologic hydronephrosis and by routine difficulty in visualizing the mid to distal thirds of the ureters [45•].

MRI should be considered in the setting of the pregnant patient with suspected nephrolithiasis, if US fails to help establish a diagnosis and if symptoms persist despite conservative management [45•, 47]. MRI can be done specifically of the urinary tract, as a magnetic resonance urography examination (MRU). The application of MRI is especially helpful in nephrolithiasis due to its ability help distinguish between pathologic and "physiologic" hydronephrosis; in proximal to mid physiologic hydronephrosis, the uterus and iliopsoas muscle compress the distal ureters to cause a "natural" hydronephrosis and hydroureter, particularly on the right, whereas if there is a distal ureteral calculus, the entire ureter is dilated [45•]. Additionally, MRI is helpful in demonstrating complications and/or alternative diagnoses, especially pyelonephritis (Fig. 4) [45•].

MRI may not directly show smaller calculi in the urinary tract. On T2-weighted MR images, urinary calculi, if identifiable, are T2 hypointense filling defects in an otherwise hyperintense urinary tract; a standing column of urine and diffuse ureteral dilation is consistent with distal obstruction, and, as noted an associated ureteral calculus, if not tiny. Other MR findings include perinephric and periureteral edema, as well as obstruction at the level of the

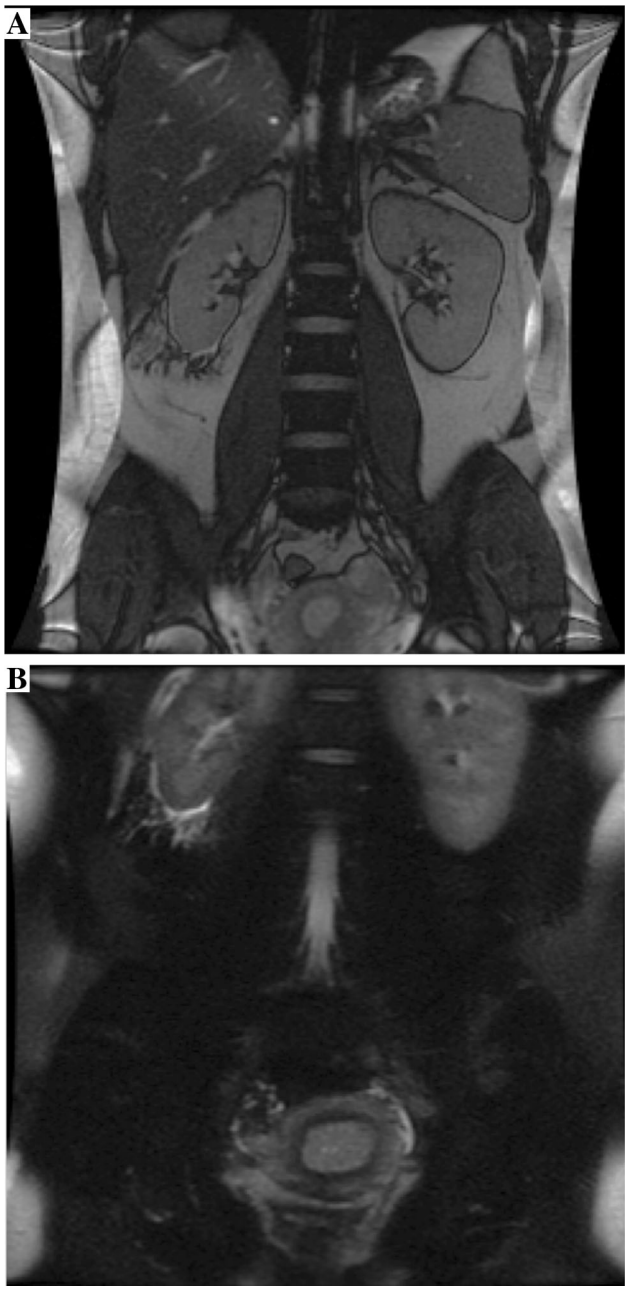

Fig. 4 33-year-old pregnant presents with right flank pain, and pyelonephritis. Coronal GRE (**a**, **b**) and T2-weighted fat-suppressed MR images reveal edema adjacent to the lower pole of the right kidney. There was no right hydronephrosis or hydroureter, and no calculus was identified. Note the fluid in the endometrium, in this patient in the first trimester

ureteropelvic or ureterovesical junction. The sensitivity of MRI increases in relation to the size of the ureteral calculus and the volume of urine around it [50]. Although MRI can have a sensitivity as high as 84% and a specificity of 100%, it has several disadvantages in the imaging of nephrolithiasis. There is, as noted, limited depiction of smaller calculi in particular.

Hepatobiliary Tract Conditions (Gallstones, Cholecystitis, Common Duct Calculi, and Pancreatitis)

The pregnant state increases the synthesis of hormones, including estrogen and progesterone, as noted. Estrogen increases cholesterol secretion, while progesterone reduces bile acid secretion, both of which will supersaturate bile with cholesterol [51]. Additionally, progesterone slows the emptying of the gallbladder, leading to bile stasis, substantially increasing the risk of developing cholelithiasis. In pregnant women, gallbladder disease may mimic simple upper digestive complaints (Fig. 5) [52]. In a study of 3254 pregnant women, all who were negative for gallstones at initial sonography, gallbladder abnormalities (new sludge, progression of sludge, and/or new gallstones) in 7.1% of the group by the second trimester, and in 10.2% of the women 4–6 weeks post-partum, and approximately 1% needed a cholecystectomy in their first post-partum year [51]. It was further seen that gallbladder sludge and small stones resolved and disappeared in 61 and 30% of the patients post-partum, respectfully [51]. Gallbladder contraction, often due to a fatty meal, on a lodged stone, can lead to pressure and pain, with the stone advancing down the biliary tract with relaxation [51].

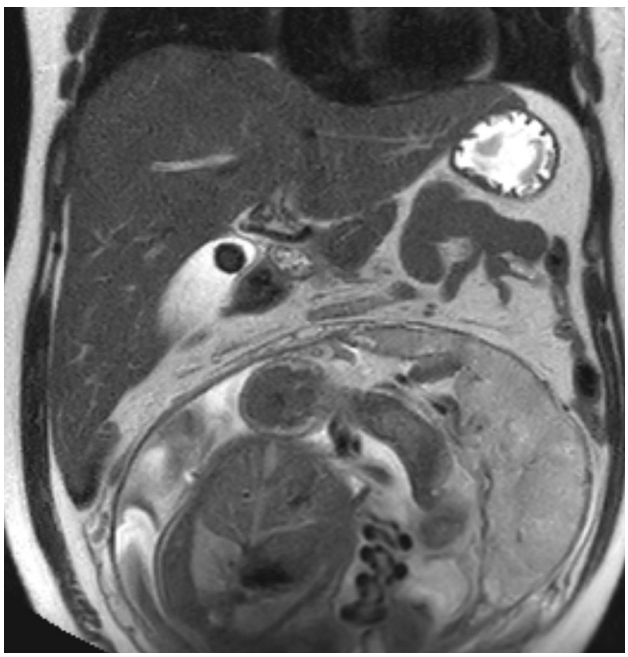

Fig. 5 T2-weighted single-shot fast-spin echo coronal MR image of cholelithiasis without cholecystitis in a 41-year-old pregnant woman. There is a 2-cm calculus in the gallbladder

Acute cholecystitis is the second most common non-obstetric disorder requiring surgery during pregnancy. The formation of gallstones can further lead to choledocholithiasis, obstructive jaundice, and pancreatitis, all of which can increase maternal and fetal mortality [51]. Ultrasound is the first imaging modality employed in any patient with right upper quadrant pain, whether pregnant or

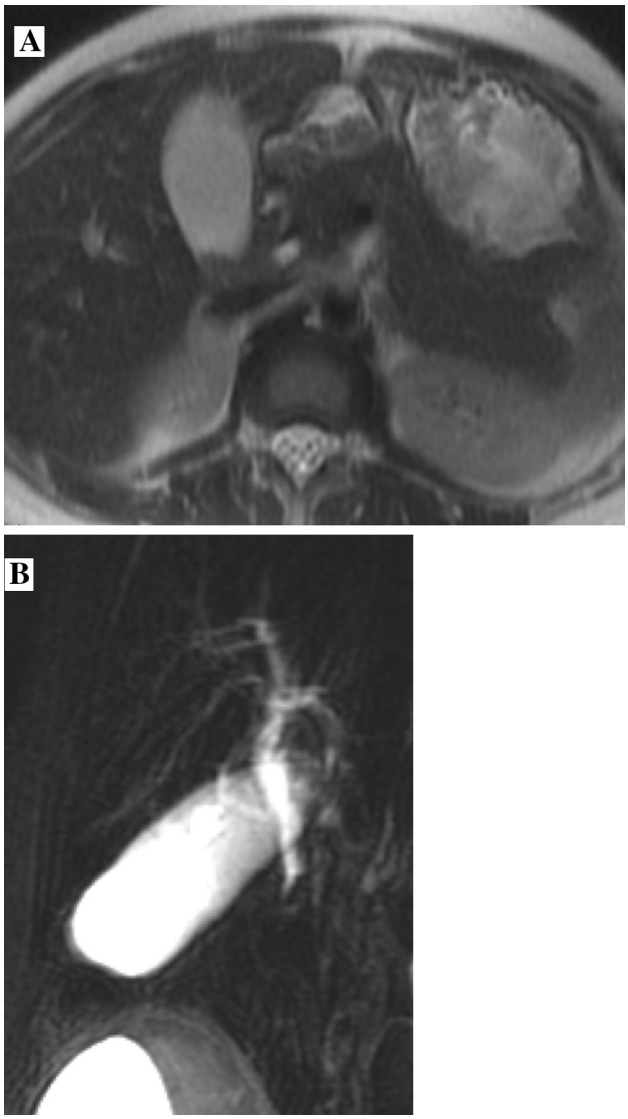

Fig. 6 32-year-old, 27-week pregnant woman with right upper quadrant pain. Initial sonography demonstrated cholelithiasis (not shown). Axial single-shot fast-spin echo image (**a**) demonstrates multiple small dependent calculi in the gallbladder. MRCP image (**b**) shows a distal common bile duct calculus (arrow) with mild dilatation of the common bile duct, but no evidence of a common duct calculus

not [52]. Gallstones are easily visualized on sonography, with a sensitivity and specificity often nearing 100% in some studies [52]. Findings on ultrasound including thickening of the gallbladder wall, pericholecystic fluid, gallstones, and a sonographic Murphy's sign, are, in combination, strongly suggestive of acute cholecystitis [52]. The gravid uterus may interfere with the quality and adequacy of the ultrasound examination for identifying common duct calculi; the sensitivity is as low as 20% [52, 53]. ERCP is effective in revealing and then for treating common bile duct calculi, but ionizing radiation is a concern [53]. Additionally, ERCP can increase the risk of pancreatitis, sepsis, hemorrhage, and upper gastrointestinal perforation [53].

Magnetic resonance cholangiopancreatography (MRCP) is an established technique which produces detailed images of the hepatobiliary and pancreatic systems [53]. MRCP has been evolving as a modality since its inception, and recent developments permit slice thickness of 1 mm or less (Fig. 6). Additionally, it has a near-100% reported accuracy for the evaluation of biliary obstruction [53]. MRCP has replaced ERCP for diagnostic purposes [53]. MRCP does not need contrast for most hepatobiliary pathologies, and there is no ionizing radiation [54]. MRCP can also reveal more complex and uncommon pathologies, including intrahepatic biliary stones and choledochal cysts (Fig. 7) [53].

It has been previously demonstrated that ERCP with sphincterotomy, without fluoroscopy, could be done successfully, but there are risks of injury, such as the accidental cannulation of the cystic duct or a retained stone, due to the increased technical challenges of not using contrast or fluoroscopy [7, 54]. In situations where ERCP must be performed, an MRCP preceding the ERCP can improve the efficiency and safety of the procedure. MRCP in the pregnant patient with obstructing gallstones can then lead to an ERCP without fluoroscopy [53, 54].

In a study done utilizing MRCP in biliary pancreatitis in pregnant patients, it was seen that an obstructing gallstone was detected on sonography, MRCP was employed before non-fluoroscopic ERCP was performed (Fig. 8). MRCP was not only able to confirm the location of obstruction,

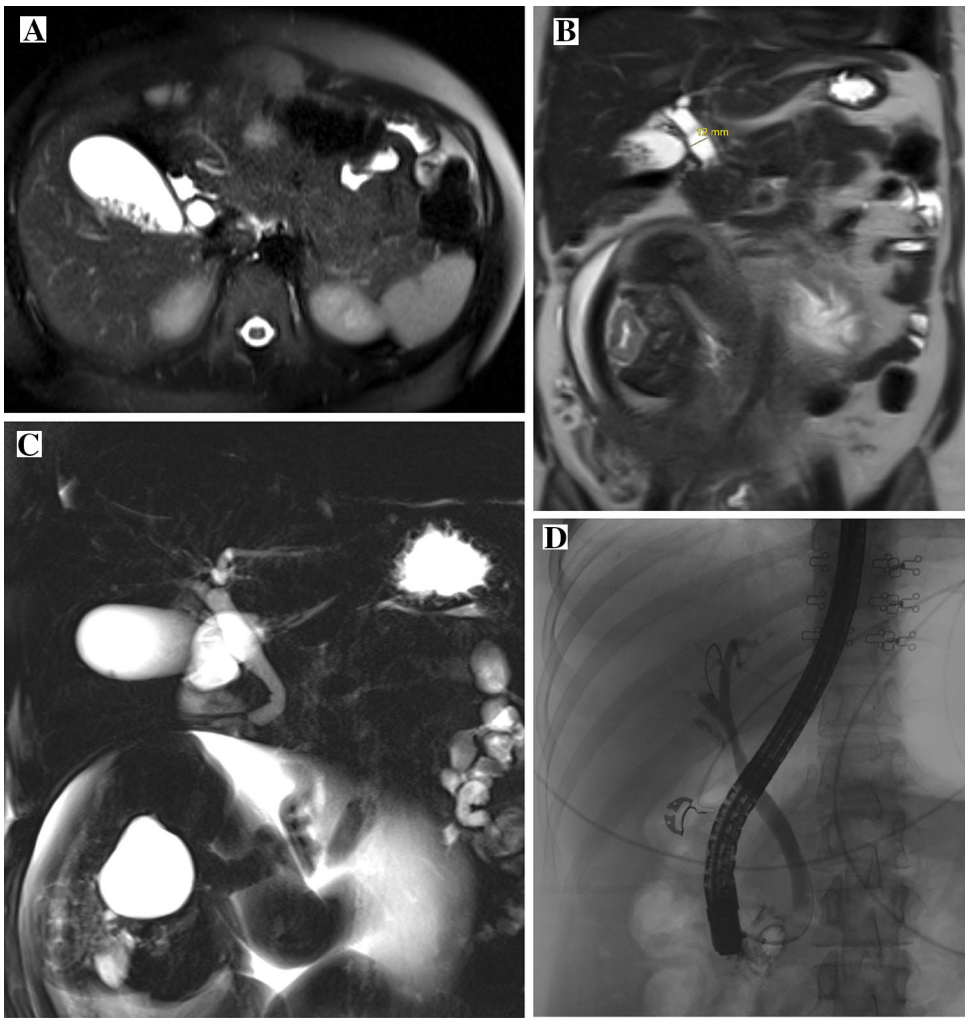

Fig. 7 22-year-old pregnant woman with multiple gallstones. Axial (**a**) and coronal (**b**) T2-weighted images, as well as MRCP HASTE slab image (**c**) and intrahepatic biliary dilatation. Two days later, ERCP (**d**) was performed, and a 5-mm sphincterotomy was performed. ERCP revealed tiny non-obstructing debris in the proximal common bile duct, and intrahepatic biliary ductal dilatation. A stent was left in place in the common bile duct to prevent recurrent calculus formation

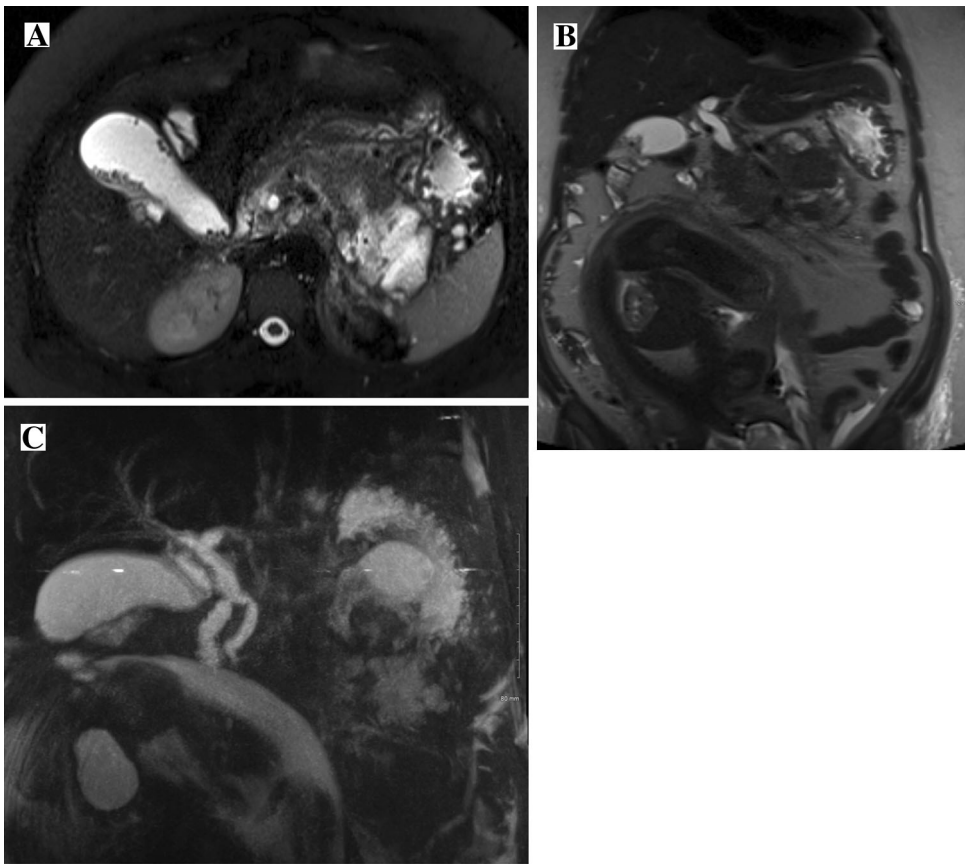

Fig. 8 30-year-old pregnant woman with biliary pancreatitis. Axial (**a**) and coronal (**b**) T2-weighted, fat-suppressed single-shot fast-spin echo, as well as maximum intensity projection reconstruction from an MRCP (**c**), reveal an enlarged heterogeneous pancreas with moderate peripancreatic stranding surrounding the pancreatic body and tail, representing acute pancreatitis. There is also a large complex fluid collection surrounding the body and tail of the pancreas, with hemorrhagic and proteinaceous components, representing pancreatic and peripancreatic necrosis. Mild biliary ductal dilatation is also present, with narrowing of the common bile duct at the level of the ampulla. Gallbladder distension seen with numerous gallstones and cystic duct stones, and choledocholithiasis at the level of the ampulla. ERCP (not shown) performed 1 day later revealed common bile duct sludge and a calculus

but also to reveal the exact number of calculi present. This allowed a subsequent ERCP to be done without radiation with less technical difficulty, eliminating fetal exposure to radiation [54]. The authors advocated for a treatment plan consisting of sonography, MRCP, non-fluroscopic ERCP, and immediate laparoscopic cholecystectomy as a viable treatment plan for biliary pancreatitis in the pregnant patient [54].

Small Bowel Obstruction

Adhesions are the most common cause of small bowel obstruction (SBO) in the general population, usually due to previous abdominal surgery [55]. A pregnant patient with a prior cesarean section history is at an increased risk of developing adhesions, as noted, and therefore SBO. This can be further complicated by the gravid uterus expanding into the abdomen, as noted (Fig. 9) [56]. Bowel obstruction occurs most commonly in the 3rd trimester or post-partum, and the presence of a bowel obstruction substantially increases the risk of morbidity for both the mother and fetus, with an estimated fetal loss of between 17 and 50%, and of maternal death from 2% to upwards of 20% [55, 57]. As the gravid uterus displaces abdominal contents during gestational maturity, relevant clinical symptoms will present at atypical locations, making accurate diagnosis more challenging [57]. While SBO in pregnancy is rather rare, with an incidence ranging from between 1 and 1500 to 1 in 66,000 deliveries, once a diagnosis of SBO is made, a swift and effective diagnosis must take place to ensure the best outcome for both the mother and the fetus [57].

Ultrasound can be used in the initial evaluation of suspected small bowel obstruction in the ED setting [55, 58]. Sonography can frequently lead to a correct diagnosis of SBO, but it is not as useful in determining the location, source, and possible complications of the obstruction [58]. CT is the most sensitive imaging modality for SBO. Sonography only had a 23% sensitivity for determining the cause of obstruction, which was much lower than the 87% sensitivity achieved with CT [58]. However, MRI should be considered as an alternative modality in the imaging of known or suspected SBO in the pregnant patient, as it uses no ionizing radiation, and it produces images and results comparable to CT [59].

SBO in pregnant is a relatively rare occurrence, and thus, there is limited literature to our knowledge on the efficiency of MRI versus other modalities. The MR appearance of SBO is the same as on CT [47]. The development of rapid scanning techniques has made MR of the small bowel more practical.

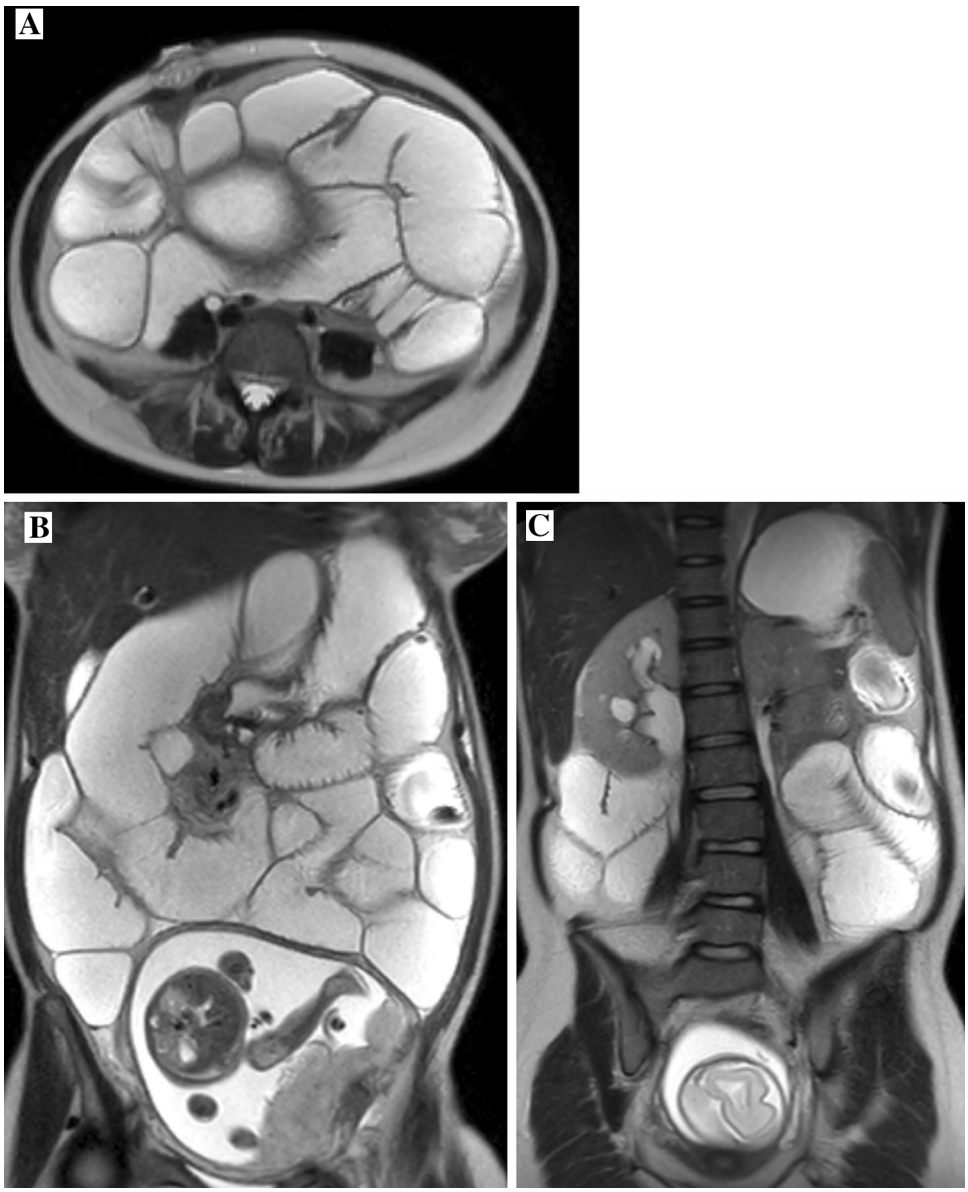

Fig. 9 27-year-old pregnant woman with acute bowel obstruction, history of Crohn disease, and colectomy with ileostomy. Axial (**a**) and coronal (**b**, **c**) T2-weighted MR images reveal prior colectomy with right lower quadrant end-ileostomy. High-grade small bowel obstruction causing up to 5-cm dilation of small bowel loops is seen, with a transition point at approximately 10-cm proximal to the ileostomy (not shown), due to adhesions from prior surgery. Note physiological hydronephrosis of the right kidney

Inflammatory Bowel Disease (Crohn Disease, Ulcerative Colitis)

Crohn disease and ulcerative colitis are the two main forms of inflammatory bowel disease (IBD). The severity of the disease at the beginning of pregnancy impacts the management throughout gestation; 66% of patients who conceived during an active period of symptoms continued to display active disease or worsening of their IBD [60]. Active disease also leads to more fetal complications (growth restriction) and a greater chance of miscarriage [60]. The role of imaging is to assess the progression of the disease, in order to determine if clinical observation, medical management, or surgery is indicated [61]. The approach and management in patients with acute IBD flares are similar in both the pregnant and non-pregnant patients [60]. Patients with IBD tend to be younger, and therefore may need repeated imaging over the course of their lifetime to monitor for disease progression and response to therapeutic measures.

CT-based techniques are currently the usual imaging utilized in IBD, but MR is becoming increasingly utilized, because of the elimination of ionizing radiation [61, 62]. There is limited literature on the use of MR in Crohn evaluation in the acute abdomen, in pregnancy, to our knowledge. However, in the emergency setting, the authors primarily obtain multiplanar non-contrast T2-weighted MR sequences. In recent years, the role of MR has expanded to include the assessment of extraluminal and extraintestinal manifestations of IBD, as well as discerning between inflammatory changes and fibrotic strictures [61, 62].

Ovarian Torsion

Adnexal torsion is the total or partial rotation of the ovary and/or fallopian tube, leading to reduced venous return from the ovaries, and eventually infarction, if untreated. Ovarian physiological cysts and benign neoplasms are the common predisposing risk factors for ovarian torsion in non-pregnant individuals, including cystic teratomas, hemorrhagic cysts, and cystadenomas [63–65]. Upwards of 86–95% of patients with ovarian torsion had an underlying ovarian mass or cyst [64]. Such masses or cysts cause the ovary to swing on its vascular pedicle and eventually twist on itself. The ligamentous laxity from the physiological increase of progesterone during pregnancy further increases the risk of torsion [66•]. Pregnancy is associated with an increased risk of ovarian torsion; 10–22% of all ovarian torsions occur during pregnancy; an enlarged unilateral ovary with a co-existent mass is usually present [63, 67].

Prompt diagnosis is crucial, as hemorrhage and necrosis of the ovary will eventually occur without intervention (Fig. 10) [65]. Ovarian torsion occurs most often during the first trimester due to the presence of a corpus luteal cyst [67]. Torsion has a decreased incidence in the third trimester, due to the gravid uterus decreasing the mobility of the adnexa [65]. Sonography is the initial imaging modality, and allows for a dynamic assessment of the ovaries, as well as an assessment of flow. MR, which can be performed emergently after equivocal sonography, will show an enlarged ovary which is bright on T2-weighted images, with free fluid in the vicinity, and obliteration of fat planes [65]. Subacutely hemorrhagic ovarian cysts will be hyperintense on T1-weighted images, and cystic ovarian neoplasms will appear as complex heterogeneous solid/cystic masses [1•].

MR findings of ovarian torsion are similar in both the pregnant and non-pregnant patient. In pregnancy, MR is the imaging modality of choice after ultrasound [65, 66•]. MRI allows for the evaluation of not only the adnexa, but of the uterus and gastrointestinal tract as well [66•]. The high soft-tissue contrast reveals an abnormal ovary or an alternative cause of pelvic pain (e.g., a necrotic fibroid), which guides appropriate management [66•].

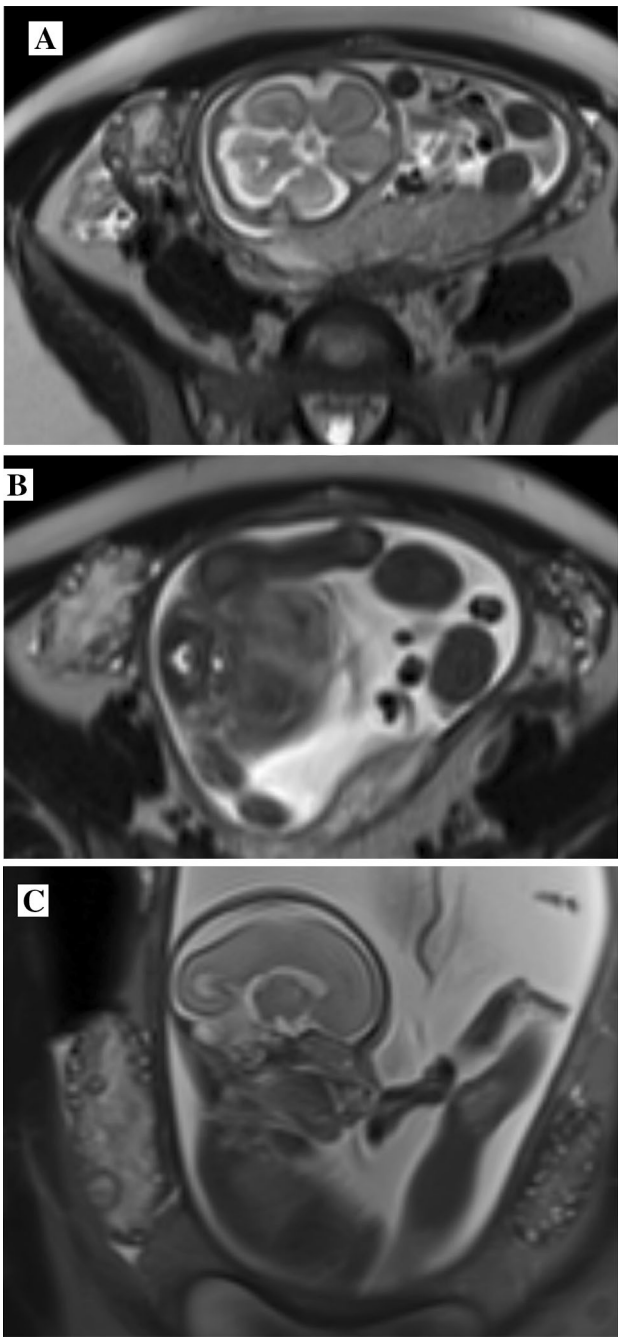

Fig. 10 30-year-old 24-week pregnant woman with marked right lower quadrant pain. Axial (**a**, **b**) and coronal (**c**) T2-weighted MR images reveal marked enlargement of the right ovary, to 7.7-cm diameter, with diffuse hyperintense stromal signal and multiple small peripheral follicles, representing ovarian torsion, with marked edema and surrounding inflammatory fat stranding and trace adjacent fluid. Note normal appearance of the left ovary

Trauma

Acute trauma is the leading cause of non-obstetric maternal death, affecting 5–8% of all pregnancies [68]. Fetal loss occurs in approximately 50% of pregnant women with severe trauma, with a smaller frequency of fetal loss (1–5%) occurring after minor trauma. Because the majority of trauma in the pregnant female is seemingly "minor," most fetal loss actually occurs after such trauma [68]. Trauma in the pregnant patient presents unique considerations, because there are two individuals for whom evaluation and management should be done. The physiological changes in pregnancy, including a rise in cardiac output,

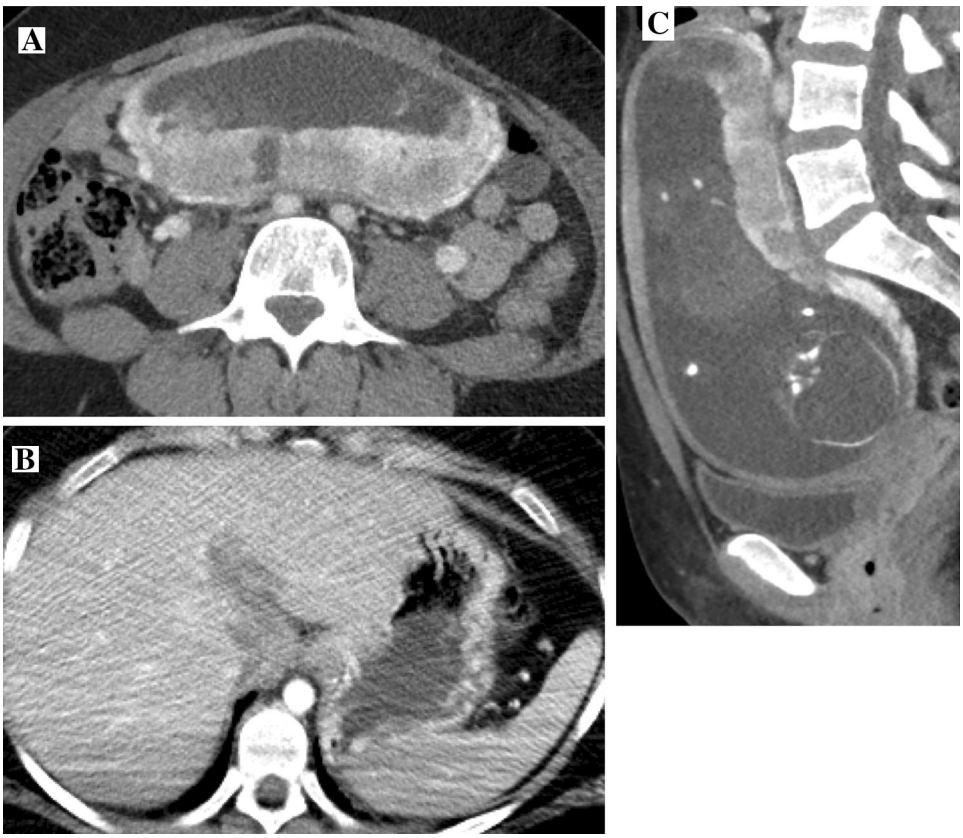

Fig. 11 Pregnant woman with multiple rib and extremity fractures after a motor vehicle collision. CT of the abdomen and pelvis (**a** axial mid abdominal image; **b** axial upper abdominal image; **c** sagittal reformation) shows a maternal liver laceration, as well as a multi-focal placental abruption. The fetus survived

increased oxygen demands, the physiologic anemia of pregnancy, and the enlargement of the gravid uterus, must all be considered when assessing and treating a pregnant patient [69•]. Additionally, many women can present with obstetrical complications in a trauma setting, including contractions, vaginal bleeding, and abdominal and pelvic pain upon initial presentation [70].

The initial goal of management is prioritizing the stabilization of the mother [69•]. The National Center for Injury Prevention and Control states that a pregnant patient at greater than 20 weeks gestation should be transported to a facility which is both capable of a timely trauma evaluation and which can appropriately manage potentially life-threatening injuries [69•]. Minor trauma (light bruising, limited lacerations, or contusions) may need a more limited evaluation, and can be appropriately assessed with selected maternal and fetal imaging, although as noted, caution should be used in performing such evaluations [69•]. Acceleration-deceleration forces such as those from a motor vehicle collision can cause uterine distortion and placental abruption, while direct abdominal trauma can cause uterine rupture, both of which constitute major injuries [70]. Compression injuries to the abdomen, violence, and motor vehicle collisions are some of the major causes of injury in such patients, and thus need a prompt and accurate workup [69•].

Imaging may begin with a portable radiograph of the chest, and of the pelvis if indicated. Ultrasound is then used as the initial diagnostic tool in assessing the pregnant trauma patient. A focused assessment with sonography for trauma (FAST) is a relatively dependable method to detect intra-abdominal and intra-pelvic injuries, and particularly to reveal intraperitoneal free fluid. A fetal evaluation can be performed with the same ultrasound at the bedside, to determine the gestational age, fetal heart rate, and potential placental injuries [70]. While the FAST examination is an invaluable part in the evaluation, and can relatively be easily done in the trauma bay, Richards et al. demonstrated that a FAST exam has only a 61 and 71% sensitivity for revealing intra-abdominal injury in pregnant patients and in non-pregnant women, respectively [71]. Additionally, US is of very limited benefit in detecting active bleeding [72].

CT of the abdomen and pelvis with intravenous contrast is recommended by the ACR in the evaluation of acute trauma in the pregnant patient (Fig. 11) [72]. In an especially serious suspected injury, CT is the proven modality for full evaluation [72, 73]. There is little to no literature to currently support the use of MRI in the initial evaluation of an acutely injured pregnant trauma patient, to our knowledge. Due to the nature of the trauma setting itself, MRI is not a practical or convenient modality [68]. MR requires more time to image, patient monitoring is more difficult,

and IV gadolinium is generally contraindicated [1•]. The utility of MR in the trauma patient can potentially be best seen in a follow-up role [68, 73]. MRI can potentially replace a follow-up CT scan in pregnant patients after trauma [68].

Summary

Non-contrast MRI of the abdomen and pelvis can be used in a wide variety of applications in the pregnant patient suspected of acute non-obstetric disorders, and has been increasingly utilized in the last two decades, especially after an initially equivocal sonogram. MRI is an excellent follow-up imaging technique in many instances, which does not expose a fetus, or the mother, to ionizing radiation, making it an excellent option for pregnant patients with suspected acute abdominal and pelvic conditions. It can be performed at any stage of pregnancy, with no evidence of adverse effects on fetal outcomes, as it is currently being used. As radiologists become increasingly comfortable with interpreting abdominal and pelvic MRI, and as it becomes more widely available as an emergent procedure its utility will continue to increase in the future.

Compliance with Ethical Guidelines

Conflict of interest Amandeep Ahluwalia, Mariam Moshiri, Akshay Baheti, Sachin Saboo, Puneet Bhargava, and Douglas S. Katz each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Recently published papers of particular interest have been highlighted as:
- • Of importance
- •• Of major importance

1. • Baheti AD, Nicola R, Bennett GL, et al. Magnetic resonance imaging of abdominal and pelvic pain in the pregnant patient. MRI Clin North Am. 2016;24(2):403–17. https://doi.org/10.1016/j.mric.2015.11.007. *This paper describes the safety profile and diagnostic utility of MR in acute abdominal and pelvic pain in the pregnant patient.*
2. Lazarus E, Debenedectis C, North D, Spencer PK, Mayo-Smith WW. Utilization of imaging in pregnant patients: 10-year review of 5270 examinations in 3285 patients—1997–2006. Radiology. 2009;251(2):517–24. https://doi.org/10.1148/radiol.2512080736.
3. Giannoudis P. Missed injuries in trauma patients. JBJS. 2012. https://doi.org/10.2106/jbjs.ot.l.00306.
4. Ratnapalan S, Bona N, Chandra K, Koren G. Physicians perceptions of teratogenic risk associated with radiography and CT during early pregnancy. AJR. 2004;182(5):1107–9. https://doi.org/10.2214/ajr.182.5.1821107.
5. Reddy UM, Abuhamad A, Saade GR. Fetal imaging. Semin Perinatol. 2013;37(5):289. https://doi.org/10.1053/j.semperi.2013.06.001.
6. Phillips RA, Stratmeyer ME, Harris GR. Safety and U.S. regulatory considerations in the nonclinical use of medical ultrasound devices. Ultrasound Med Biol. 2010;36(8):1224–8. https://doi.org/10.1016/j.ultrasmedbio.2010.03.020.
7. Kilpatrick CC, Orejuela FJ. Management of the acute abdomen in pregnancy: a review. Curr Opinion Obstet Gynecol. 2008;20(6):534–9. https://doi.org/10.1097/gco.0b013e328317c735.
8. • Ciet P, Litmanovich DE. MR safety issues particular to women. MRI Clin North Am. 2015;23:59–67. https://doi.org/10.1002/jmri.24011. *This paper characterizes the female specific MR hazards concerning radiologists and ordering physicians.*
9. Ray JG, Vermeulen MJ, Bharatha A, Montanera WJ, Park AL. Association between MRI exposure during pregnancy and fetal and childhood outcomes. JAMA. 2016;316(9):952. https://doi.org/10.1001/jama.2016.12126.
10. Committee Opinion No. 723. Obstet Gynecol. 2017;130(4). https://doi.org/10.1097/aog.0000000000002355.
11. Artal R. Guidelines of the American College of Obstetricians and Gynecologists for exercise during pregnancy and the postpartum period. Br J Sports Med. 2003;37(1):6–12. https://doi.org/10.1136/bjsm.37.1.6.
12. Albert HB, Godskesen M, Westergaard JG. Incidence of four syndromes of pregnancy-related pelvic joint pain. Spine. 2002;27(24):2831–4. https://doi.org/10.1097/00007632-200212150-00020.
13. Brandon C, Jacobson JA, Low LK, Park L, Delancey J, Miller J. Pubic bone injuries in primiparous women: magnetic resonance imaging in detection and differential diagnosis of structural injury. Ultrasound Obstet Gynecol. 2012;39(4):444–51. https://doi.org/10.1002/uog.9082.
14. Miller JM, Brandon C, Jacobson JA, et al. MRI findings in patients considered high risk for pelvic floor injury studied serially after vaginal childbirth. AJR. 2010;195(3):786–91. https://doi.org/10.2214/ajr.09.3508.
15. Parangi S, Levine D, Henry A, Isakovich N, Pories S. Surgical gastrointestinal disorders during pregnancy. Am J Surg. 2007;193(2):223–32. https://doi.org/10.1016/j.amjsurg.2006.04.021.
16. Beydoun SN. Morphologic changes in the renal tract in pregnancy. Clin Obstet Gynecol. 1985;28(2):249–56. https://doi.org/10.1097/00003081-198528020-00002.
17. Neto AHDF, Amorim MMRD, Nóbrega BMSV. Acute appendicitis in pregnancy: literature review. Revista da Associação Médica Brasileira. 2015;61(2):170–7. https://doi.org/10.1590/1806-9282.61.02.170.
18. Burke LM, Bashir MR, Miller FH, et al. Magnetic resonance imaging of acute appendicitis in pregnancy: a 5-year multiinstitutional study. Am J Obstet Gynecol. 2015. https://doi.org/10.1016/j.ajog.2015.07.026.
19. de Bari O, Wang TY, Liu M, Paik CN, Portincasa P, Wang DQ. Cholesterol cholelithiasis in pregnant women: pathogenesis, prevention and treatment. Ann Hepatol. 2014;13:728–45.
20. Ramin KD, Ramin SM, Richey SD, Cunningham F. Acute pancreatitis in pregnancy. Am J Obstet Gynecol. 1995;173(1):187–91. https://doi.org/10.1016/0002-9378(95)90188-4.
21. Perdue PW, Johnson HW, Stafford PW. Intestinal obstruction complicating pregnancy. Am J Surg. 1992;164(4):384–8. https://doi.org/10.1016/s0002-9610(05)80910-9.

22. Muench MV, Canterino JC. Trauma in pregnancy. Obstet Gynecol Clin North Am. 2007;34(3):555–83. https://doi.org/10.1016/j.ogc.2007.06.001.
23. Code of Federal Regulations. Government Publishing Office. http://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol1/xml/CFR-2011-title10-vol1-part20.xml. Accessed 18 Mar 2018.
24. Backgrounder on biological effects of radiation. United States Nuclear Regulatory Commission—protecting people and the environment. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html. Accessed 18 Mar 2018.
25. Bural GG, Laymon CM, Mountz JM. Nuclear imaging of a pregnant patient: should we perform nuclear medicine procedures during pregnancy? Mol Imaging Radionucl Ther. 2012;21(1):1–5. https://doi.org/10.4274/mirt.123.
26. Santis MD, Cesari E, Nobili E, Straface G, Cavaliere AF, Caruso A. Radiation effects on development. Birth Defects Res C. 2007;81(3):177–82. https://doi.org/10.1002/bdrc.20099.
27. Otake M. Review: radiation-related brain damage and growth retardation among the prenatally exposed atomic bomb survivors. Int J Rad Biol. 1998;74(2):159–71. https://doi.org/10.1080/095530098141555.
28. Hall EJ. Scientific view of low-level radiation risks. RadioGraphics. 1991;11(3):509–18. https://doi.org/10.1148/radiographics.11.3.1852943.
29. Patel SJ, Reede DL, Katz DS, Subramaniam R, Amorosa JK. Imaging the pregnant patient for nonobstetric conditions: algorithms and radiation dose considerations. RadioGraphics. 2007;27(6):1705–22. https://doi.org/10.1148/rg.276075002.
30. Power SP, Moloney F, Twomey M, James K, O'Connor OJ, Maher MM. Computed tomography and patient risk: facts, perceptions and uncertainties. World J Radiol. 2016;8(12):902. https://doi.org/10.4329/wjr.v8.i12.902.
31. Brent RL. The effects of embryonic and fetal exposure to x-ray, microwaves, and ultrasound. Clin Obstet Gynecol. 1983;26(2):484–510. https://doi.org/10.1097/00003081-198306000-00030.
32. Shellock FG, Crues JV. Mr procedures: biologic effects, safety, and patient care. Radiology. 2004;232(3):635–52. https://doi.org/10.1148/radiol.2323030830.
33. GE Healthcare. Omniscan package insert. Princeton: GE Healthcare; 2005.
34. Angelini DJ. Obstetric triage revisited: update on non-obstetric surgical conditions in pregnancy. J Midwifery Womens Health. 2003;48(2):111–8. https://doi.org/10.1016/s1526-9523(02)00417-8.
35. Zingone F, Sultan AA, Humes DJ, West J. Risk of acute appendicitis in and around pregnancy. Ann Surg. 2015;261(2):332–7. https://doi.org/10.1097/sla.0000000000000780.
36. Weiss CR, Macura KJ. Diagnosis of ruptured appendicitis during pregnancy. J Women Imaging. 2003;5(4):192–8. https://doi.org/10.1097/00130747-200311000-00005.
37. Sivanesaratnam V. The acute abdomen and the obstetrician. Best Pract Res Clin Obstet Gynecol. 2000;14(1):89–102. https://doi.org/10.1053/beog.1999.0065.
38. Abbasi N, Patenaude V, Abenhaim H. Management and outcomes of acute appendicitis in pregnancy-population-based study of over 7000 cases. BJOG. 2014;121(12):1509–14. https://doi.org/10.1111/1471-0528.12736.
39. American College of Radiology. ACR Appropriateness Criteria; last reviewed 2014. https://acsearch.acr.org/docs/69470/Narrative. Accessed 1 Mar 2018.
40. •• Konrad J, Grand D, Lourenco A. MRI: first-line imaging modality for pregnant patients with suspected appendicitis. Abdom Imag. 2015;40(8):3359–3364. https://doi.org/10.1007/s00261-015-0540-7. *Retrospective study of 140 pregnant patients comparing the efficacy of ultrasound versus MRI in suspected appendicitis.*
41. Israel GM, Malguria N, Mccarthy S, Copel J, Weinreb J. MRI vs. ultrasound for suspected appendicitis during pregnancy. J Magn Reson Imaging. 2008;28:428–33. https://doi.org/10.14196/mjiri.31.48.
42. • Kereshi B, Lee KS, Siewert B, Mortele KJ. Clinical utility of magnetic resonance imaging in the evaluation of pregnant females with suspected acute appendicitis. Abdom Radiol. 2017. https://doi.org/10.1007/s00261-017-1300-7. *Retrospective study of 211 MRI exams to assess the diagnostic performance of MRI with suspected appendicitis and to determine the frequency of non-appendiceal causes of abdominal pain identified by MRI.*
43. Shin I, Chung YE, An C, et al. Optimisation of the MR protocol in pregnant women with suspected acute appendicitis. Eur Radiol. 2017;28(2):514–21. https://doi.org/10.1007/s00330-017-5038-y.
44. Butler E. Symptomatic nephrolithiasis complicating pregnancy. Obstet Gynecol. 2000;96(5):753–6. https://doi.org/10.1016/s0029-7844(00)01017-6.
45. • Masselli G, Derme M, Laghi F, et al. Imaging of stone disease in pregnancy. Abdomin Imag. 2013;38(6):1409–1414. https://doi.org/10.1007/s00261-013-0019-3. *This paper describes the different imaging modalities available to diagnose and manage stone disease and its complications in the pregnant patient.*
46. Ross AE, Handa S, Lingeman JE, Matlaga BR. Kidney stones during pregnancy: an investigation into stone composition. Urol Res. 2008;36(2):99–102. https://doi.org/10.1007/s00240-008-0138-4.
47. Ditkofsky NG, Singh A, Avery L, Novelline RA. The role of emergency MRI in the setting of acute abdominal pain. Emerg Radiol. 2014;21(6):615–24. https://doi.org/10.1007/s10140-014-1232-2.
48. Meher S, Gibbons N, Dasgupta R. Renal stones in pregnancy. Obstet Med. 2014;7(3):103–10. https://doi.org/10.1177/1753495x14538422.
49. Wallace GW, Davis MA, Semelka RC, Fielding JR. Imaging the pregnant patient with abdominal pain. Abdom Radiol. 2011;37(5):849–60. https://doi.org/10.1007/s00261-011-9827-5.
50. Masselli G, Weston M, Spencer J. The role of imaging in the diagnosis and management of renal stone disease in pregnancy. Clin Radiol. 2015;70(12):1462–71. https://doi.org/10.1016/j.crad.2015.09.002.
51. Ko CW, Beresford SAA, Schulte SJ, Matsumoto AM, Lee SP. Incidence, natural history, and risk factors for biliary sludge and stones during pregnancy. Hepatology. 2005;41(2):359–65. https://doi.org/10.1002/hep.20534.
52. Gilo NB, Amini D, Landy HJ. Appendicitis and cholecystitis in pregnancy. Clin Obstet Gynecol. 2009;52(4):586–96. https://doi.org/10.1097/grf.0b013e3181c11d10.
53. Oto A, Ernst R, Ghulmiyyah L, Hughes D, Saade G, Chaljub G. The role of MR cholangiopancreatography in the evaluation of pregnant patients with acute pancreaticobiliary disease. Br J Radiol. 2009;82(976):279–85. https://doi.org/10.1259/bjr/88591536.
54. Polydorou A, Karapanos K, Vezakis A, et al. A multimodal approach to acute biliary pancreatitis during pregnancy. Surg Lap Endosc Perc Tech. 2012;22(5):429–32. https://doi.org/10.1097/sle.0b013e31825e38bb.
55. Webster P, Bailey M, Wilson J, Burke D. Small bowel obstruction in pregnancy is a complex surgical problem with a high risk of fetal loss. Ann R Coll Surg Engl. 2015;97(5):339–44. https://doi.org/10.1308/003588415x14181254789844.
56. Mckenna DA, Meehan CP, Alhajeri AN, Regan MC, Okeeffe DP. The use of MRI to demonstrate small bowel obstruction during pregnancy. Br J Radiol. 2007. https://doi.org/10.1259/bjr/21300878.

57. Daimon A, Terai Y, Nagayasu Y, et al. A case of intestinal obstruction in pregnancy diagnosed by MRI and treated by intravenous hyperalimentation. Case Rep Obstet Gynecol. 2016;2016:1–4. https://doi.org/10.1155/2016/8704035.
58. Suri S, Gupta S, Sudhakar PJ, Venkataramu NK, Sood B, Wig JD. Comparative evaluation of plain films, ultrasound and CT in the diagnosis of intestinal obstruction. Acta Radiol. 1999;40(4):422–8. https://doi.org/10.3109/02841859909177758.
59. Beall D, Fortman B, Lawler B, Regan F. Imaging bowel obstruction: a comparison between fast magnetic resonance imaging and helical computed tomography. Clin Radiol. 2002;57(8):719–24. https://doi.org/10.1053/crad.2001.0735.
60. Hashash JG, Kane S. Pregnancy and inflammatory bowel disease. Gastroenteral Hepatol. 2015;11(2):96–102.
61. Kilcoyne A, Kaplan JL, Gee MS. Inflammatory bowel disease imaging: current practice and future directions. World J Gastroenterol. 2016;22(3):917. https://doi.org/10.3748/wjg.v22.i3.917.
62. Quencer KB, Nimkin K, Mino-Kenudson M, Gee MS. Detecting active inflammation and fibrosis in pediatric Crohn's disease: prospective evaluation of MR-E and CT-E. Abdom Imaging. 2013;38(4):705–13. https://doi.org/10.1007/s00261-013-9981-z.
63. Tsafrir Z, Hasson J, Levin I, Solomon E, Lessing JB, Azem F. Adnexal torsion: cystectomy and ovarian fixation are equally important in preventing recurrence. Eur J Obstet Gynecol Reprod Biol. 2012;162(2):203–5. https://doi.org/10.1016/j.ejogrb.2012.02.027.
64. Heling K-S, Chaoui R, Kirchmair F, Stadie S, Bollmann R. Fetal ovarian cysts: prenatal diagnosis, management and postnatal outcome. Ultrasound Obstet Gynecol. 2002;20(1):47–50. https://doi.org/10.1046/j.1469-0705.2002.00725.x.
65. Smolinski SE, Kreychman A, Catanzano T. Ovarian torsion. JCAT. 2015;39(6):922–4. https://doi.org/10.1097/rct.0000000000000332.
66. • Lourenco AP, Swenson D, Tubbs RJ, Lazarus E. Ovarian and tubal torsion: imaging findings on US, CT, and MRI. Emerg Radiol. 2013;21(2):179–187. https://doi.org/10.1007/s10140-013-1163-3. *This paper illustrates the findings of ovarian and fallopian tube torsion on ultrasound, CT and MRI within the pregnant patient.*
67. Chang S-D, Yen C-F, Lo L-M, Lee C-L, Liang C-C. Surgical intervention for maternal ovarian torsion in pregnancy. Taiwan J Obstet Gynecol. 2011;50(4):458–62. https://doi.org/10.1016/j.tjog.2011.10.010.
68. Manlove W, Fowler KJ, Mellnick VW, Menias CO, Raptis CA. Role of MRI in trauma in the pregnant patient. MRI Fetal Matern Dis Preg. 1999. https://doi.org/10.1007/978-3-319-21428-3_25.
69. • Dhaliwal J. Trauma in pregnancy: an updated systematic review. J Emerg Med. 2014;46(2):321–322. https://doi.org/10.1016/j.jemermed.2013.11.111. *Systemic review of the prevalence, risk factors, complications, and management of trauma during pregnancy.*
70. Goodwin TM, Breen MT. Pregnancy outcome and fetomaternal hemorrhage after noncatastrophic trauma. Am J Obstet Gynecol. 1990;162(3):665–71. https://doi.org/10.1016/0002-9378(90)90979-h.
71. Richards JR, Ormsby EL, Romo MV, Gillen MA, Mcgahan JP. Blunt abdominal injury in the pregnant patient: detection with US. Radiology. 2004;233(2):463–70. https://doi.org/10.1148/radiol.2332031671.
72. Sadro C, Bernstein MP, Kanal KM. Imaging of trauma: part 2, abdominal trauma and pregnancy—a radiologist's guide to doing what is best for the mother and baby. AOR. 2012;199(6):1207–19. https://doi.org/10.2214/ajr.12.9091.
73. Lowdermilk C, Gavant ML, Qaisi W, West OC, Goldman SM. Screening helical CT for evaluation of blunt traumatic injury in the pregnant patient. RadioGraphics. 1999. https://doi.org/10.1148/radiographics.19.suppl_1.g99oc28s243.