Abdominal Pain in Pregnancy: Diagnoses and Imaging Unique to Pregnancy—Review

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Objective

Abdominal pain during pregnancy can be caused by a wide variety of diseases including disorders of the obstetric, gynecologic, gastrointestinal, hepatobiliary, genitourinary, and vascular systems. Some causes are unique to pregnancy, are exacerbated by pregnancy, or require an altered imaging algorithm for diagnosis during pregnancy. The educational objectives of this review article are for the participant to exercise, self-assess, and improve his or her understanding of the imaging evaluation of abdominal pain during pregnancy.

Conclusion

This article reviews the causes of abdominal pain that are unique to pregnancy as well as some of the more common and severe causes of abdominal pain in which the imaging workup differs in the pregnant population. The relative advantages of using ultrasound, CT, and MRI to help establish the cause of the pain are also reviewed.

Introduction

A wide variety of diseases, including disorders of the obstetric, gynecologic, gastrointestinal, hepatobiliary, genitourinary, and vascular systems, can present as abdominal pain during pregnancy [1–3] (Table 1). The clinical diagnosis of an intraabdominal disease in pregnant women is often obscured by concurrent maternal physiologic and anatomic changes [3, 4]. Guarding in the setting of peritonitis may not occur because of the loss of elasticity in the abdominal wall musculature [2]. Leukocytosis in pregnancy is less useful in clinical evaluation because WBC count is typically elevated in pregnancy, ranging from 6,000–16,000 cells/μL during the first and second trimesters to 20–30,000 cells/μL at the end of the third trimester [3]. Ureteral compression and displacement of intraabdominal organs, including the appendix, by the gravid uterus may also confound the clinical presentation [2].

A delay in the diagnosis of many of the causes of abdominal pain can be threatening to both the mother and the fetus [3, 5]. Imaging can clarify a confusing clinical picture and expedite diagnosis. Ultrasound is widely used as the initial diagnostic imaging technique during pregnancy because of its availability, portability, and lack of ionizing radiation. Ultrasound often can elucidate the cause of abdominal pain, particularly if pain is due to an obstetric and gynecologic abnormality. However, evaluation of the bowel, pancreas, ureters, and mesenteric vasculature may be limited on ultrasound because of patient body habitus, a small field of view, and the presence of overlying structures. Air within the bowel can particularly limit evaluation of the mesenteric vessels, pancreas, and bowel.

MRI is also a useful technique for imaging pregnant patients given the lack of ionizing radiation. Several recent studies have shown that MRI is valuable in evaluating abdominal pain during pregnancy, especially in the diagnosis of appendicitis, which is the most common cause of an acute abdomen in pregnancy [6–8]. To date, no deleterious effects to the developing fetus exposed to MRI have been reported. Therefore, no specific consideration for MRI during the first, second, or third trimester has been recommended [9]. The use of MRI for the evaluation of abdominal pain during pregnancy may be dependent on institutional availability and radiologist experience. A recent guidance document for safe MR practices from the American College of Radiology (ACR) does not recommend the routine use of gadolinium during pregnancy [9]. Gadolinium-based MR contrast agents are known to pass through the placenta to the fetal circulation. The contrast material is then excreted by the fetal kidneys into the amniotic fluid where the agent can remain for an indeterminate amount of time. To date, no large, well-controlled studies have been performed to document the presence or absence of adverse fetal effects resulting from maternal gadolinium administration. Therefore, the potential risks to the fetus remain unknown [9].

Examinations using ionizing radiation—in particular, CT—can also accurately diagnose many causes of abdominal pain during pregnancy. A risk–benefit analysis is particularly warranted before performing an examination involving ionizing radiation on a pregnant or potentially pregnant patient. However, most diagnostic imaging stud-
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TABLE I: Causes of Abdominal Pain in Pregnant Women by Organ System

<table>
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<tr>
<th>Organ System</th>
<th>Cause</th>
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<td>Obstetric</td>
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<td>Ectopic pregnancy</td>
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<td>Adnexal torsion</td>
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<td>Uterine leiomyoma</td>
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<td>Endometriosis</td>
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<td>Pelvic inflammatory disease</td>
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<td>Intestinal obstruction</td>
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<td>Gastroesophageal reflux</td>
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<td>Peptic ulcer disease</td>
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<td>Hepatobiliary</td>
<td>HELLP syndrome</td>
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<td>Acute fatty liver of pregnancy</td>
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<td></td>
<td>Cholelithiasis or choledocholithiasis</td>
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<td>Acute cholecystitis</td>
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<td>Acute pancreatitis</td>
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<td>Hepatitis</td>
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<td>Genitourinary</td>
<td>Hydronephrosis of pregnancy</td>
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<td>Vascular</td>
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<td>Mesenteric vein thrombosis</td>
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<td>Gonadal vein syndrome</td>
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<td>Aneurysm rupture</td>
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<td>Vasculitis</td>
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Note—HELLP = hemolysis, elevated liver enzymes, low platelet count.

ies utilizing ionizing radiation do not expose the fetus to a radiation dose high enough to result in developmental or neurologic deficits. Therefore, ionizing radiation examinations can still be offered to pregnant women when the study is in the best health interest of the mother and the patient understands the minimal and unknown risks to the fetus [10]. For example, CT remains the most reliable technique for depicting obstructing urinary tract calculi in pregnant women [11]. Based on our experience with a low-dose renal calculus protocol (160 mA and 140 kVp on a 16-MDCT scanner), the mean radiation dose delivered to the female pelvis is 16 mGy and to the fetus, 4–7.2 mGy and 8.5–11.7 mGy at 0 and 3 months of gestation, respectively [12]. This dose is below the recommended 50-mGy (5-rad) maternal dose limit for avoiding deterministic radiation effects (i.e., effects that have a radiation threshold below which they should not occur) such as fetal teratogenesis [13]. There is no known maternal radiation limit for fetal stochastic effects (i.e., effects that can occur regardless of radiation dose) such as carcinogenesis; therefore, radiation levels should be kept as low as reasonably achievable (ALARA) for all ionizing radiation studies [13].

Similar to gadolinium-based MR contrast agents, iodinated IV contrast agents have been shown to cross the placenta to the fetal circulation and ultimately to be excreted into the amniotic fluid. No teratogenic fetal effects from a single in utero exposure to iodinated contrast material at diagnostic doses have been reported. However, there have also been no published large, well-controlled studies investigating potential teratogenic effects from iodinated contrast agents. In early reports, investigators described transient congenital hypothyroidism after amniofetography using iodinated contrast material [14]. However, more recent small studies of pregnant patients receiving iodinated contrast material as part of a CT protocol did not show any effect on thyroid function [15]. Similar to its recommendations with regard to gadolinium-based contrast agents, the ACR recommends IV iodinated contrast administration during pregnancy only when it is deemed necessary for prompt and accurate evaluation of the pregnant patient’s medical condition [16].

This review focuses on the causes of abdominal pain that are unique to pregnancy as well as some of the more common and severe causes of abdominal pain in which the imaging workup differs in the pregnant population compared with the nonpregnant population. This article also explores the relative advantages of using different imaging techniques including ultrasound, CT, and MRI to help establish the cause of the pain.

Obstetric Causes

During the first trimester of pregnancy, common causes of abdominal and pelvic pain include early pregnancy failure and ectopic pregnancy. During the second and third trimesters, causes of pain include preterm labor and the less common, but more severe, complications of placental abruption and uterine rupture.

Early Pregnancy Failure

Spontaneous abortion occurs in approximately 10–12% of known first trimester pregnancies. Although the patient may be asymptomatic, spontaneous abortion commonly results in pain and vaginal bleeding [17].

Ultrasound is the initial diagnostic test of choice for a first trimester patient with pain and bleeding. Ultrasound can confirm early pregnancy failure with high specificity if no fetal cardiac activity is detected by the time the embryo measures 5 mm in length or if the pregnancy is known to be 6.5 weeks without an embryo with a heartbeat [18].
Additional sonographic findings such as abnormal gestational sac size or shape and embryonic bradycardia may be suggestive of a poor outcome but are not definitive for early pregnancy failure. Large gestational sacs without a yolk sac or an embryo are worrisome. The most widely accepted “discriminatory” sizes of the gestational sac using endovaginal ultrasound are an 8-mm mean sac diameter by which a yolk sac must be visualized and a 16-mm mean sac diameter by which an embryo must be visualized for the pregnancy to be considered normal [19, 20]. However, a range of higher discriminatory values has been reported in the literature, with mean sac diameter values up to 13 mm for visualization of the yolk sac and 18 mm for visualization of the embryo proposed before considering a pregnancy abnormal [19–21]. Given this range of values, use of the discriminatory sac size is limited.

Worrisome findings on ultrasound also include slow embryonic cardiac activity, irregular gestational sac, and low position of the gestational sac [22]. Embryonic heartbeat rates below 80 beats per minute (bpm) at 6.0–6.2 weeks or below 100 bpm at 6.3–7.0 weeks’ menstrual age are associated with a very high rate of early pregnancy failure [23].

When the ultrasound examination either shows worrisome features or is inconclusive, such as in cases with an embryo smaller than 5 mm without a heartbeat, follow-up ultrasound is indicated. Follow-up ultrasound is typically performed 5–7 days later to allow measurable growth. Correlating sonographic findings with maternal serum level of β-HCG can also help indicate whether early pregnancy failure has occurred. A gestational sac is expected to be visible when the β-HCG level is above 2,000 mIU/mL (third international reference preparation) and the embryo when the β-HCG level is above 10,800 mIU/mL [24].

Ectopic Pregnancy

Ectopic pregnancy, which remains the most frequent obstetric cause of death in pregnancy, often presents with abdominal or pelvic pain in the first trimester [25]. The incidence of ectopic pregnancy has been increasing steadily since 1970. This increased incidence correlates with an increase in the prevalence of risk factors for ectopic pregnancy including sexually transmitted diseases and assisted reproductive techniques [26, 27]. Ultrasound plays an instrumental role in ruling out an ectopic pregnancy if it...
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Symptoms of placental abruption are variable but often include vaginal bleeding and abdominal or pelvic pain. Placental abruption is defined as uterine separation of the placenta from the myometrium and accounts for 10–25% of prenatal deaths [35]. In most cases, ultrasound does not show any signs of abruption because the hemorrhage resulting from placental separation can pass through the cervical os. Sonographic findings suggestive of placental abruption, when they are visible, are usually due to hematomas. Visualization of a hematoma is clinically important because these pregnancies have a worse prognosis [35]. The most common location of hematomas in this setting is subchorionic (i.e., between the uterine wall and chorionic membrane) [36]. Retroplacental (behind the placenta) and preplacental (in front of the placenta) hematomas are less common. The sonographic appearance of a hematoma varies with its acuity. Acute hematomas are hyperechoic to isoechoic (Fig. 3). Initially, the only finding of an acute or subacute hematoma on ultrasound may be an abnormally thickened placenta. In}

these cases, T1-weighted MRI may be used to help distinguish high-signal hematomas from the lower-T1-signal-intensity placenta [37]. Hematomas more than 1–2 weeks in age appear progressively more hypoechoic [36].

Preterm Labor

Preterm labor is defined as uterine contractions strong enough to cause cervical dilatation and effacement between 20 and 37 weeks’ gestation. The abdominal pain that accompanies these contractions is often clinically distinguishable, so imaging is typically not indicated for diagnosis. However, ultrasound evaluation of cervical length is the most sensitive predictor of preterm birth. The shorter the cervical length measures, the higher the risk of preterm birth. Also, the earlier a shortened cervical length is found, the higher the risk of preterm birth. A normal cervical length is more than 30 mm between 14 and 30 gestational weeks [38–40]. Cervical funneling is also associated with an increased risk of preterm labor. Funneling occurs when the internal os is open proximally and gradually narrows, approximating the appearance of a cone. If funneling is present, the cervical length is almost always shortened. However, the presence of funneling in a patient with a normal cervical length does not increase the risk of preterm birth.

Uterine Rupture

Uterine rupture is a rare, catastrophic event that often presents with severe abdominal pain. Predisposing factors include previous uterine surgery, including cesarean deliveries and myomectomy, and congenital uterine malformations. Uterine rupture can occur during labor or before delivery such as in cases of interstitial ectopic pregnancies that rupture [41]. Only a very short time interval for successful intervention exists once uterine rupture has occurred, so imaging in this setting may consume valuable
time. If imaging is performed, ultrasound, CT, or MRI may show herniation of the gestational sac contents (Fig. 4). The choice of imaging technique will depend on patient stability and technique availability at a given institution.

**Gynecologic Causes**

Common gynecologic causes of pain during pregnancy include complications related to adnexal masses, ovarian torsion, and leiomyomas. Adnexal masses are often first detected at the time of a routine first trimester dating or second trimester anatomic survey ultrasound examination [2]. Ovarian torsion and leiomyoma degeneration both have a higher incidence during pregnancy [42–44].

**Adnexal Masses**

Adnexal masses occur in approximately 2% of all pregnancies [3]. Adnexal masses are not a usual cause of pain, with 65% of these masses being asymptomatic and discovered incidentally on physical examination or sonography [2]. The size of the mass also does not necessarily dictate whether it will cause pain [2, 3]. However, if an adnexal mass is compressed, if it compresses an adjacent organ or organs, as is more likely to occur during pregnancy in association with an enlarging gravid uterus, or if it becomes complicated by torsion, hemorrhage, or rupture, the adnexal mass may present with pain. Imaging evaluation of the adnexa should be performed, starting with ultrasound, in all pregnant women presenting with pain [42, 45]. Ultrasound provides the ability to distinguish adnexal masses that are small, uncomplicated, and likely to spontaneously resolve from those that appear larger and more complex with a higher likelihood of malignancy, torsion, or persistent pain from mass effect during pregnancy.

The most common adnexal masses during pregnancy are corpus luteum or other functional ovarian cysts. The differential diagnosis for a complex-appearing adnexal mass includes hemorrhagic corpus luteum cyst, ovarian cystadenoma, and ovarian teratoma. However, approximately 1–8% of adnexal masses found during pregnancy are malignant [42]. Therefore, when the sonographic appearance of an adnexal mass is not specific, MRI can be used for further characterization to help determine patient management during pregnancy [45, 46] (Fig. 5). Complex adnexal masses, particularly if they are already a source of pain, may warrant surgical removal during pregnancy because of an increased risk of torsion, rupture, and malignancy [47].

**Ovarian Torsion**

The incidence of ovarian torsion is increased during pregnancy, complicating 1 in 800 pregnancies. This increased incidence is most likely related to an increased incidence of adnexal masses. Up to 7% of adnexal masses reportedly result in ovarian torsion during pregnancy [42, 43]. However, torsion can also occur in an otherwise normal ovary, usually the right ovary [2, 3]. During pregnancy, ovarian torsion most commonly occurs between 6 and 14 weeks’ gestation when uterine enlargement is most rapid [3, 45]. However, in at least one study, up to 45% of cases of ovarian torsion presented during the second and third trimesters [48].

Sonography is the preferred imaging technique for the diagnosis of ovarian torsion, with the diagnosis made by a combination of gray-scale and color Doppler findings. The most consistent finding is an enlarged ovary [43, 49]. Additional findings include a twisted vascular pedicle, pelvic free fluid, and a coexistent ovarian mass. The color Doppler findings are often variable. The most frequent finding on Doppler evaluation of the ovary is either reduced or absent arterial flow. However, ovarian arterial waveforms may be detectible in the setting of torsion. This is theorized to be either due to venous thrombosis alone eliciting symptoms or due to the dual blood supply of the ovary [49, 50]. If the ultrasound findings are indetermi-

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**Fig. 4**—Uterine rupture in woman 15 weeks’ pregnant who presented with severe abdominal pain. **A** and **B**, Gray-scale sagittal ultrasound images show fetus (arrow, A) superior to uterine fundus (arrowheads, A) and distension of endometrium with heterogeneous hypoechoic material (arrowheads, B) due to hemorrhage after uterine rupture. Abdominal pregnancy resulting from rupture of interstitial ectopic pregnancy was diagnosed at surgery and pathology.
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nate for torsion, MRI may better show ovarian edema resulting from early or intermittent ovarian torsion [45] (Fig. 6).

Leiomyomas

Uterine leiomyomas are commonly encountered during pregnancy, with 1 in 500 pregnant women hospitalized for a leiomyoma-related complication [44]. Approximately half of all leiomyomas grow during pregnancy, mainly in the first trimester because of rising estrogen levels [51]. Abdominal pain and uterine contractions can result from necrosis and degeneration of leiomyomas secondary to rapid growth. “Red degeneration” is the most common type of degeneration during pregnancy and occurs when a leiomyoma outgrows its blood supply with resulting hemorrhage. Such leiomyomas can appear on ultrasound as circumscribed masses with cystic spaces or heterogeneous echogenicity [51, 52].

Fig. 5—Ovarian torsion in woman 11 weeks’ pregnant who presented with 2 days of lower abdominal and pelvic pain. A, Transverse gray-scale transabdominal ultrasound image through pelvis shows cystic and solid midline mass (arrows). Separate normal right ovary was seen transvaginally (not shown). Separate left ovary was not seen on transabdominal or transvaginal ultrasound. MRI was performed for further evaluation 1 hour later. B, Coronal T2-weighted fast spin-echo MR shows enlarged, partially necrotic left ovary (black arrows) and cystic mass arising from left ovary (white arrow) with few septations in inferior aspect of mass (arrowhead). Left ovary and mass were surgically removed later that day. Pathology results were torsed, necrotic left ovary with mucinous cystadenocarcinoma of left ovary serving as lead point mass.

Fig. 6—Degenerated fibroid in woman 17 weeks’ pregnant who presented with right-sided abdominal pain. A and B, Transverse (A) and sagittal (B) transabdominal ultrasound images show exophytic fibroid (straight arrows) extending from right lateral aspect of uterus. Inner hypoechoic region with low-level echoes (arrowheads) represents cystic degeneration secondary to necrosis. Intrauterine fetal head (curved arrow, A) is seen.
Ultrasound can further confirm a degenerating leiomyoma as the source of pain if the patient experiences pain when the probe is directly placed over the leiomyoma [44]. On MRI, red degeneration of a leiomyoma manifests as peripheral or diffuse high signal intensity on T1-weighted images and corresponding variable signal intensity with or without a low-signal-intensity rim on T2-weighted images [48]. Leiomyomas are also the most common solid adnexal masses in pregnancy [45]. Exophytic leiomyomas have the potential to torseduring pregnancy, causing pain due to loss of blood supply and rapid necrosis.

**Gastrointestinal Causes**

Gastrointestinal causes of pain during pregnancy include appendicitis and other inflammatory, infectious, and obstructive processes of the bowel. These diseases are neither unique to nor more common in pregnancy but can be more difficult to diagnose during pregnancy. The approach to imaging the bowel of a pregnant patient also differs from that of a non-pregnant patient because ultrasound and MRI are typically preferred over techniques that impart ionizing radiation such as radiography and CT.

**Appendicitis**

Appendicitis is the most common nonobstetric reason for emergency surgery during pregnancy, occurring in approximately 1 in 1,500 deliveries [53]. Early diagnosis is important because a 66% increased incidence of appendiceal perforation during pregnancy—with a resulting increased rate of fetal loss and maternal mortality—has been reported with surgical delays greater than 24 hours from the time of symptom onset [53]. Clinically diagnosing appendicitis during
pregnancy is difficult because of multiple factors including, first, the variable appendiceal position (the appendix is gradually displaced upward during pregnancy); second, limited physical examination of the gravid abdomen; and, third, the nonspecificity of symptoms such as nausea, vomiting, guarding, and leukocytosis during pregnancy [2, 3, 54].

The primary options for imaging pregnant patients with suspected appendicitis are ultrasound, MRI, and CT. Ultrasound is usually the first imaging technique of choice because of its availability, lack of ionizing radiation, and lack of need for IV contrast material. The sonographic criteria for diagnosing appendicitis in pregnant patients are the same as in nonpregnant patients: visualization of a dilated (> 6–7 mm in diameter), aperistaltic, noncompressible, and blind-ending tubular structure arising from the cecum. The outer diameters of both a normal appendix and an inflamed appendix are known to vary on ultrasound, with reported normal appendix diameters ranging from 2 to 13 mm and inflamed appendix diameters from 6 to 30 mm [55]. Therefore, an appendix with a diameter of between 6 and 7 mm without additional features of acute inflammation may be considered indeterminate for appendicitis [56]. Associated findings, such as appendiceal wall thickening (> 2 mm), appendicoliths, and surrounding hyperechoic inflamed fat, or hypoechoic fluid may also be seen sonographically (Fig. 8). However, ultrasound of the appendix is a highly operator-dependent examination that can be further limited by the pregnant body habitus. Sensitivities ranging from 50% to 100%, specificities ranging from 33% to 92%, accuracies ranging from 73% to 93%, and negative predictive values ranging from 64% to 88% have been reported for the sonographic diagnosis of appendicitis in the general adult population [57–62]. In addition, an elevated or retrocecal appendix may be difficult to find sonographically and a ruptured appendix may have nonspecific findings on ultrasound. Therefore, a negative ultrasound examination does not exclude the possibility of appendicitis and if there remains high clinical suspicion for appendicitis (persistent right lower quadrant pain of uncertain cause), additional imaging should be considered [63].

When available, MRI is the next preferred examination for evaluating the appendix in pregnancy also because of its lack of ionizing radiation. Recent studies have shown that MRI can reliably diagnose acute appendicitis during pregnancy with 100% sensitivity and 94% specificity [7, 64]. MR examinations for appendicitis in pregnancy at our institution include an oral contrast preparation (300 mL of barium sulfate [Readi-CAT 2, E-Z-EM] and 300 mL of ferumoxsil [GastroMARK, AMAG Pharmaceuticals]) started 2 hours before the examination. These agents are used because they are the oral contrast preparations already available in our department for other CT (barium sulfate) and MR (ferumoxsil) examinations, and this specific negative oral contrast preparation has been previously described in the literature as a means of limiting bowel susceptibility artifact and confirming appendiceal patency [7].

The MR examination then consists of the following sequences: axial, sagittal, and coronal T2-weighted single-shot fast spin echo (SSFSE), axial T1-weighted dual gradient-echo,

**Fig. 9**—Acute appendicitis in 30-year-old pregnant woman who presented with right lower quadrant pain. Ultrasound findings were normal. A and B, Axial (A) and sagittal (B) T2-weighted single-shot fast spin-echo MR images reveal dilated (1.2 cm) appendix with high-T2-signal-intensity luminal contents (straight arrow) due to fluid and adjacent periappendiceal fat stranding and fluid (arrowheads); these findings are indicative of periappendiceal inflammation. Low-signal-intensity oral contrast material fills cecum (curved arrow, B). Acute appendicitis without perforation was diagnosed at surgery.
axial true fast imaging with steady-state precession (FISP), and axial STIR. The multiplanar T2-weighted SSFSE images allow imaging of the bowel in a relatively motionless state and help to confirm the location of the appendix in more than one plane. The axial T1-weighted gradient-echo images are obtained to help confirm appendiceal patency by showing blooming artifact from air or oral contrast material in the appendix lumen from out-of-phase to in-phase imaging. The axial true FISP images also help differentiate high-signal-intensity adrenal vessels from the lower signal intensity of a normal appendix, and the axial STIR sequence is used to highlight any periappendiceal edema or fluid associated with appendicitis.

The largest study to date of MRI for appendicitis in pregnant patients has described the following criteria for diagnosing acute appendicitis in this population: an appendix diameter of > 7 mm with high-T2-signal-intensity luminal contents, appendiceal wall thickening (> 2 mm), or periappendiceal fat stranding and fluid [7] (Fig. 9). An appendix with high-T2-signal-intensity luminal contents and a diameter of between 6 and 7 mm on MRI without associated wall thickening or periappendiceal inflammatory changes may be considered indeterminate for appendicitis and warrants close clinical follow-up [7, 65].

Appendicitis can also be readily diagnosed on CT using the same criteria in pregnant patients as in nonpregnant patients [12]. CT is generally performed if MRI is unavailable or if the patient has contraindications to MRI to prevent a delay in the diagnosis and treatment of a possible appendicitis. Sensitivities ranging from 72% to 100%, specificities ranging from 83% to 99%, accuracies ranging from 78% to 98%, and negative predictive values ranging from 64% to 99% have been reported for the CT diagnosis of appendicitis in the general adult population [58, 59, 61, 62, 66].

Infectious Diseases and Inflammatory Bowel Disease

Infection and inflammation of the bowel are additional potential causes of acute abdominal pain during pregnancy. Inflammatory bowel disease has a peak incidence in women of...
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reproductive age. Disease activity is largely independent of pregnancy; however, activity during pregnancy is associated with increased fetal loss rate and fetal growth retardation [3]. Ultrasound is often the first imaging study chosen for evaluating localized or generalized abdominal pain during pregnancy and may reveal a thick-walled segment of bowel in the setting of active infection or inflammation [67]. However, cross-sectional imaging is commonly required to evaluate the entire extent of disease as well as any associated complications such as bowel obstruction, fistulas, or abscess formation.

Both MRI and CT can show the presence, extent, and complications of infectious and inflammatory bowel diseases. MR examinations without or with an oral preparation (MR enterography) using T2-weighted SSFSE images can readily depict thick-walled segments of small and large bowel and associated complications in pregnant patients and nonpregnant patients [65, 68]. Similar to CT, findings of Crohn’s disease on MRI include segmental bowel wall thickening and small-bowel involvement. Additional findings such as bowel stenosis with prestenotic dilatation, fibrofatty proliferation, increased vascularity of the vasa recta, and mesenteric adenopathy may also be readily depicted on both CT and MRI [69]. The role of MRI in evaluating ulcerative colitis is less established, but MRI can reportedly show the continuous colonic wall thickening and loss of haustral folds characteristic of ulcerative colitis [70].

Bowel Obstruction

Bowel obstruction is a third gastrointestinal emergency that can arise during pregnancy with an incidence of 1 in 2,500 deliveries. Maternal mortality associated with bowel obstruction is as high as 6% and is most commonly secondary to adhesions [71]. Pregnant patients more commonly present with bowel obstruction in the third trimester perhaps because of increased mass effect of the enlarging gravid uterus on the large and small bowel with resulting bowel displacement [72]. Clinically diagnosing bowel obstruction in a pregnant patient can be difficult because the gravid uterus limits physical examination and because some of the symptoms of bowel obstruction (abdominal pain, nausea, vomiting) are also common symptoms of pregnancy. However, the onset of such symptoms after the first trimester should raise the possibility of other gastrointestinal abnormalities or diseases such as intestinal obstruction [2].
Ultrasound is again often the first imaging study of choice for evaluating generalized abdominal pain in pregnancy and may show dilated loops of bowel with fluid levels and aperistalsis with long-standing or high-grade obstruction, but ultrasound does not reliably depict the point or cause of bowel obstruction. Therefore, cross-sectional imaging with MRI or CT is again often required for further characterization (Fig. 10). Similar to imaging bowel inflammation or infection, MR studies for bowel obstruction can be performed with the use of multiplanar T2-weighted SSFSE imaging and may be performed with or without oral contrast preparation [73]. If MRI cannot be performed expeditiously or expertise in MR interpretation is not readily available, CT may be performed because the risk of delayed diagnosis and treatment of a potential bowel obstruction may pose a greater risk to the fetus than radiation exposure from a diagnostic examination.

Hepatobiliary Causes

Two hepatic complications unique to pregnancy that can present with acute abdominal pain are HELLP (hemolysis, elevated liver enzymes, low platelet count) syndrome and acute fatty liver of pregnancy (AFLP). Although pancreatitis is not unique to pregnancy, the approach to imaging pregnant patients with pancreatitis differs from that of the nonpregnant patient.

HELLP Syndrome

HELLP syndrome is a rare but serious condition that most commonly presents in the late third trimester or early postpartum period in association with severe preeclampsia or eclampsia. It is estimated that up to 10–28% of preeclampsia pregnancies are associated with some degree of HELLP syndrome [3]. Patients with HELLP syndrome variably present with hemolytic anemia, thrombocytopenia (< 100,000/mm³), and liver function test abnormalities (elevated lactate dehydrogenase level, > 600 U/L; elevated bilirubin level, > 1.2 mg/dL; or elevated aspartate aminotransferase level, > 70 U/L) [2]. The deposition of intravascular fibrin deposits in the liver with HELLP syndrome results in various hepatic manifestations ranging from hepatic congestion and edema to hepatic necrosis, hemorrhage, and rupture, which can require emergent cesarean delivery, exploratory laparotomy, or hepatic embolization [74]. The clinical presentation of HELLP syndrome is variable and nonspecific. Patients most commonly present with abdominal pain and nausea. Patients with severe complications of hepatic rupture and hemorrhage may present with abdominal pain that radiates to the right upper quadrant or right shoulder and with hypovolemic shock [3].

The main role of imaging in patients with clinically diagnosed HELLP syndrome is to identify the hepatic complications. Ultrasound, CT, or MRI can be used to assess the presence and extent of hepatic injury. The selected imaging technique will depend on availability, patient stability, and whether the patient is postpartum. Ultrasound can show intra- and extrhepatic hematomas and fluid collections. CT and MR examinations can further reveal the extent of hepatic damage and can help distinguish among hepatic edema, necrosis, and hemorrhage [74] (Fig. 11).

Acute Fatty Liver of Pregnancy

AFLP is also a rare but serious hepatic complication unique to pregnancy that can be fatal. It is characterized by microvascular fatty infiltration of the liver and can result in both hepatic and renal failure. Patients also typically present in the late third trimester or early postpartum period with symptoms of abdominal pain, vomiting, and jaundice. Similar to HELLP syndrome, management of AFLP centers on prompt delivery and supportive care [3]. AFLP can be difficult to differentiate from HELLP syndrome and preeclampsia or eclampsia clinically. However, histologically HELLP syndrome and AFLP can be readily differentiated because HELLP syndrome is characterized by periporal hemorrhage, sinusoidal fibrin deposition, and occasional peripoortal necrosis, whereas AFLP is characterized by microvesicular fatty infiltration with occasional necrosis and inflammation [2].

Imaging with ultrasound, CT, or MRI may also help distinguish between HELLP syndrome and AFLP as well as depict the extent of hepatic complications. However, in the early stages of AFLP the liver may appear normal [75]. The imaging of patients with suspected AFLP will depend on technique availability, patient stability, and pregnancy status. Ultrasound is often the first technique of choice for pregnant and unstable patients and can reveal diffuse increased heterogeneity and echogenicity of the hepatic echotexture. If the patient is postpartum, CT is often the first imaging study of choice and may reveal diffuse decreased hepatic attenuation. The role of MRI for diagnosing AFLP has not been determined, but MR examinations performed with T1-weighted dual gradient-echo in-phase and out-of-phase sequences can readily depict hepatic steatosis by showing loss of hepatic signal intensity from in-phase to out-of-phase images.

Pancreatitis

Pancreatitis is a rare cause of abdominal pain during pregnancy, occurring in 0.1–1% of pregnancies and occurring most commonly in the third trimester [3]. In pregnancy, gallstones are the most common cause of pancreatitis because pregnancy promotes the formation of sludge and stones within the gallbladder due to increased cholesterol synthesis, bile stasis, and decreased gallbladder contraction. In addition, higher levels of maternal estrogen in the third trimester can increase triglyceride synthesis and, in some cases, can induce pancreatitis secondary to hypertriglyceridemia. Increased intraabdominal pressure on the bile ducts in the third trimester has also been proposed as a potential reason for the reported increased incidence of pancreatitis in the third trimester [4, 76].
Abdominal Pain in Pregnancy

In the nonpregnant population, contrast-enhanced CT is usually the study of choice for evaluating complications of pancreatitis. However, during pregnancy ultrasound can first be used to search for the cause and complications of pancreatitis including choledocholithiasis and pseudocyst formation. If ultrasound is normal or indeterminate, MRI with multiplanar T2-weighted SSFSE and axial T1-weighted sequences and MR cholangiopancreatography (MRCP) with heavily T2-weighted sequences can be performed to confirm the diagnosis of pancreatitis and to search for causes and complications of pancreatitis (Fig. 12). Screening the biliary tree for possible stones with MRCP can also help avoid or guide a more invasive ERCP procedure, thus minimizing maternal and fetal risk and exposure to ionizing radiation [13].

Genitourinary Causes

Urinary tract causes of pain during pregnancy include physiologic and obstructive hydronephrosis and infectious causes such as cystitis and pyelonephritis, which do not usually require imaging for diagnosis and treatment. The incidence of urolithiasis is not increased during pregnancy. However, the
approach to imaging urolithiasis and the need to differentiate between physiologic and obstructive hydronephrosis differs between pregnant and nonpregnant patients.

**Hydronephrosis**

Obstructive hydronephrosis typically presents in the second or third trimester and is most commonly caused by urinary tract calculi [13]. Urolithiasis is reportedly detected in 1 in 90 to 1 in 3,800 pregnancies and occurs more commonly in multipara pregnancies with equal involvement of the right and left sides [2]. Hospitalization for pain management is often required for pregnant patients with symptomatic urolithiasis, although 70–80% of all obstructive calculi will spontaneously pass with conservative management [2].

Potential complications of urolithiasis include pyelonephritis and premature labor induced by renal colic with or without concomitant infection.

Physiologic dilatation of the collecting system, which occurs in up to 90% of pregnant patients, can mimic obstructive hydronephrosis clinically and can delay accurate diagnosis [2]. Physiologic hydronephrosis is usually asymptomatic, but it can present with abdominal pain and functional ureteral obstruction [77]. Physiologic dilatation of the renal pelvis and ureter, the major pitfall in the assessment of urolithiasis in pregnant patients, is due to the combination of hormone-related relaxation of the ureters during pregnancy and extrinsic compression of the ureters by the growing uterus and engorged ovarian veins against the iliopsoas muscle [2].

![Image](image-url)

**Fig. 14—** Obstructive hydronephrosis in 31-year-old pregnant woman who presented with right flank pain.

A, Sagittal gray-scale ultrasound image of right kidney shows mild hydronephrosis (arrow). No right-sided perinephric fluid, calculus, ureteral dilatation, or ureteral jet is seen. Subsequent MR examination of abdomen and pelvis was performed 1 day later to further differentiate between obstructive versus physiologic right hydronephrosis.

B and C, Coronal T2-weighted single-shot fast spin-echo MR images through abdomen illustrate moderate right perinephric fluid (arrows, B) and mild right hydroureteronephrosis (arrows, C) with abrupt termination of dilated right ureter at level of pelvic rim (arrowhead, C); these findings are suggestive of obstructive right hydroureteronephrosis. Ureretal calculus was not visible on MR examination. Patient subsequently passed 3-mm calculus.
more commonly seen on the right ureter because of relative protection of the left ureter by the sigmoid colon.

Ultrasound is usually the first imaging technique of choice for evaluating hydronephrosis and urolithiasis during pregnancy with reported sensitivities for renal and ureteral calculi ranging between 34% and 95% [78, 79]. Ultrasound may directly show calculi or reveal secondary findings of acute obstruction such as hydronephrosis with peri-nephric fluid or an absent ureteral jet. The absence of the ureteral jet on the suspected side of obstruction is reported to have a sensitivity of 100% and a specificity of 91% for the diagnosis of obstructive hydronephrosis and indicates complete obstruction [80] (Fig. 13). However, an absent ureteral jet has also been reported in approximately 15% of asymptomatic pregnant women [81]. To decrease false-positive results of absent ureteral jets, patients can be imaged in the contralateral decubitus position (i.e., left posterior oblique to visualize the right ureteral jet) to decrease gravid uterus mass effect on the bladder and ureter. Transvaginal ultrasound and transverse images through the bladder can also facilitate detection of distal ureteral calculi.

Using Doppler ultrasound, the intrarenal resistive index (RI) can be calculated. This value may aid in differentiating between physiologic hydronephrosis and pathologic hydronephrosis because normal pregnancy does not usually affect the intrarenal RI; an elevated RI (> 0.70) should be considered abnormal. The elevation in the RI usually occurs within 6 hours after acute obstruction of the collecting system. The RI as a test for diagnosing obstructive hydronephrosis in pregnancy has a reported sensitivity, specificity, and accuracy of 45%, 91%, and 87%, respectively. However, a difference of 0.40 or greater between the RIs of the normal kidney and the abnormal kidney (ΔRI) is reportedly a better indication of obstruction in the kidney with the higher RI [82]. The sensitivity, specificity, and accuracy of ΔRI for diagnosing acute unilateral ureteral obstruction in pregnant women are reported to be 95%, 100%, and 99%, respectively [82].

Ultrasound has the advantages of being portable and noninvasive and not exposing the pregnant patient to ionizing radiation or IV contrast material. However, maternal body wall acoustics, the gravid uterus, and overlying bowel gas often limit visualization of the ureter. Therefore, a normal or indeterminate renal ultrasound examination may require additional imaging if there is strong clinical suspicion for urolithiasis.

Further imaging options may depend on the stage of gestation. To limit radiation exposure to the developing fetus, some authors have suggested a limited IV urography examination consisting of a scout film, 10-minute film, and minimal number of additional films if the patient is less than 24 weeks’ gestation and a low-dose CT examination using a low-dose renal calculus protocol if the patient is greater than 24 weeks’ gestation [83]. The high sensitivity (> 95%) and specificity (> 98%) of CT for detecting urinary tract calculi as small as 1–2 mm make CT typically the first imaging technique of choice in nonpregnant patients and the second imaging technique of choice in pregnant patients for diagnosing urolithiasis [13].

MR urography (MRU) with T2-weighted imaging has also been reported to have a high sensitivity for the detection of urinary tract dilatation and for the identification of the site of obstruction. MRU can also help differentiate between physiologic hydronephrosis and obstructive hydronephrosis [84]. Features of obstructive hydronephrosis with MRI include renal enlargement, perinephric fluid, and an abrupt change in the caliber of the ureter above or below the uterus (Fig. 14). In contrast, physiologic hydronephrosis on MRU is characterized by gradual, smooth tapering of the mid ureter due to extrinsic compression between the gravid uterus and iliopsoas muscle [84] (Fig. 15). MRI is also particularly helpful in revealing complications of pyelonephritis. However, it remains a useful second-line examination largely because of its limited ability in detecting small calculi and characterizing the exact size and shape of calculi.

Vascular Causes

Vascular causes of abdominal pain that have a higher incidence in pregnancy include venous thromboembolic disease, gonadal vein dilatation, and splenic artery aneurysm rupture.

Venous Thromboembolic Disease

Both venous stasis and hypercoagulability place pregnant patients at increased risk for venous thrombosis. Venous stasis begins in the first trimester and peaks around 36 weeks of gestation and is likely due to a combination of progesterone-induced venodilation, pelvic venous compression by the gravid uterus, and pulsatile compression of the left iliac vein by the right iliac artery [85]. The hypercoagulable state of pregnancy results from the fact that the hemostatic system is progressively activated to prepare the patient for the hemostatic challenge of delivery.

Most venous thromboembolic events occur in the lower extremities. However, pregnant patients are also at increased risk for pelvic, hepatic (Budd-Chiari syndrome), mesenteric, and gonadal venous thrombi. Mesenteric venous thrombosis is particularly ominous because it can result in bowel infarction and because it is difficult to diagnose given that patients typically present with insidious onset of poorly localized abdominal pain and nonspecific findings on physical examination [3]. Color Doppler ultrasound can diagnose hepatic thrombosis or occlusion, but the role of ultrasound for the diagnosis of pelvic, mesenteric, and gonadal venous thrombosis is limited. MRI or contrast-enhanced CT can diagnose abdominal and pelvic venous thrombosis (Fig. 10B). In the pregnant patient, depending on institution experience and MR availability, MR venography (MRV) may be the preferred imaging test because MRV avoids the use of radiation and can be per-
formed without the use of IV contrast material. Both time-of-flight and true FISP MR sequences can detect flow and depict thrombus in abdominal and pelvic vessels. However, unenhanced sequences can be limited by flow signal artifacts [86]. Treatment of thromboembolic disease during pregnancy requires systemic anticoagulation therapy.

Gonadal Vein Syndrome

Enlargement of the right gonadal vein in the late second and third trimesters of pregnancy has also been reported as a potential cause of abdominal pain [65]. Dilatation of the gonadal vein itself or the resulting extrinsic compression of the ureter by the enlarged gonadal vein has been referred to as “right ovarian vein syndrome” [65]. Rarely, subsequent rupture of the dilated right ovarian vein during pregnancy has been described [87]. Right ovarian vein dilatation is likely a diagnosis of exclusion when it is the only finding on ultrasound, MRI, or CT to account for a pregnant patient’s right-sided pain (Fig. 16).

Splenic Artery Aneurysm

Pregnancy is a major risk factor for the rupture of a splenic artery aneurysm, particularly in the third trimester or during labor. It has been theorized that hormonal changes during pregnancy alter the elastic properties of the arterial wall [88]. Splenic artery aneurysms are usually asymptomatic but can occasionally present as vague epigastric or left upper quadrant pain. If a splenic artery aneurysm ruptures, it can be a catastrophic event associated with both maternal and fetal mortality. Therefore, if a splenic artery aneurysm is detected incidentally in a woman of child-bearing age, elective treatment with splenectomy, artery resection, aneurysm exclusion, or aneurysm embolization is recommended even if the patient is asymptomatic [3, 89]. Splenic artery aneurysms can be detected on abdominal ultrasound, CT, or MRI.

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