RadioGraphics

Imaging in Pregnant Patients: Examination Appropriateness[1]

LEARNING OBJECTIVES

After reading this article and taking the test, the reader will be able to:

■ Describe the basic concepts of radiation risks to the developing fetus at various gestational ages.

■ Discuss the role of CT and the appropriate uses of US and MR imaging in pregnancy.

■ List the theoretical risks of contrast agents administered during pregnancy and techniques to decrease radiation dose to the fetus.

TEACHING POINTS
See last page

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A recurring source of contention between clinicians and radiologists continues to be examination appropriateness when imaging pregnant patients. With the multitude of references on potential radiation risks to the fetus, radiologists tend to be cautious and hesitant about exposing the fetus to radiation. This tendency is often interpreted by referring physicians as intrusion into and delay in the care of their patients. The risk burden of radiation exposure to the fetus has to be carefully weighed against the benefits of obtaining a critical diagnosis quickly and using a single tailored imaging study. In general, there is lower than expected awareness of radiation risks to the fetus from imaging pregnant patients. Modalities that do not use ionizing radiation, such as ultrasonography and magnetic resonance imaging, should be the preferred examinations for evaluating an acute condition in a pregnant patient. However, no examination should be withheld when an important clinical diagnosis is under consideration. Exposure to ionizing radiation may be unavoidable, but there is no evidence to suggest that the risk to the fetus after a single imaging study and an interventional procedure is significant. All efforts should be made to minimize the exposure, with consideration of the risk versus benefit for a given clinical scenario.

See the commentary by Levine following this article.

Introduction

Radiologists are best suited to suggest a study for imaging a pregnant patient presenting for an acute condition and to prepare a protocol for the study. The type of imaging study is planned in close consultation with the clinical team and targeted to the clinical scenario. Ultrasonography (US) should always be the initial modality for evaluation of a pregnant patient, with other modalities used only if US results are nondiagnostic.

A recurring debate in many radiology practices is the concern of radiologists about performing an examination that exposes a fetus to radiation. The result is that the referring clinicians postulate that the cautious radiologist is dictating how they care for their patients. A recent literature review (1–3) demonstrated that in general, there is a lower than expected awareness of radiation risks associated with imaging pregnant women both among radiologists and among clinicians. Given the confusion surrounding this topic and the increasing use of imaging in the pregnant patient (4), we believe this is a timely topic. In addition, it is our hope that the information in this article may be used as a framework for radiologists for developing a consensus with clinical teams on imaging pregnant patients (2).

After a discussion of radiation risks associated with medical imaging, we present several commonly encountered clinical scenarios and discuss the radiation risks associated with various imaging techniques. We focus on computed tomography (CT), magnetic resonance (MR) imaging, and fluoroscopy. We do not discuss risks associated with plain radiography, as it has a significantly lower dose than CT and, with the exception of trauma cases, it is not the imaging modality of choice. In addition, for a stepwise approach we provide algorithms used at our institution when evaluating pregnant patients. The expertise of the radiologist and the availability of resources are important factors that dictate the choice of diagnostic imaging modality and are different at various institutions. Hence, the current practices at various institutions may differ slightly given the availability of various resources.

Radiation Effects

The effects of radiation exposure have been studied extensively. Although there are multiple variations on the theme, the risks of radiation can be categorized as stochastic and nonstochastic effects.

Stochastic Effects

Stochastic effects are the result of cellular damage, likely at the DNA level, causing cancer or other germ cell mutation. Stochastic effects have no threshold value and are theorized to occur with exposure to any amount of ionizing radiation. The severity of radiation-induced stochastic effects is independent of the radiation dose. Historically, the radiation dose estimated for stochastic effects, as based on probability, was established at 50 mGy (5 rad) (5). It is thought that this level provides a margin of safety from higher exposures that may otherwise pose risk in pregnancy above the baseline (6–8). It is reported that the relative risk of childhood cancer after 50-mGy exposure is 2; this means that there may be an increase in the probability of childhood cancer from 1 in 1000 to 2 in 1000 (7). However, over time this value has become antiquated and possibly overconservative, as no documented radiation effects have been definitely proved at this level.

In 2008, the American College of Radiology (ACR) produced practice guidelines for imaging pregnant patients and provided an approximation of fetal risk at various gestational ages with differing radiation exposure (Table 1) (6,9,10). These values are based on estimates calculated from animal studies, epidemiologic studies of survivors of the atomic bombings in Japan, and studies of groups exposed to radiation for medical reasons (eg, radiation therapy for carcinoma of the uterus) (11). As shown in Table 1, the ACR suggested that theoretical risks are not likely at doses less than 100 mGy (10 rad) (10).

Nonstochastic Effects

Nonstochastic effects (aka, threshold effects or deterministic effects) are caused by exposure to radiation at high doses. These effects are predictable and involve multicellular injury, which can include chromosome aberrations. Threshold effects follow a linear progression, with risk in-

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Table 1
Potential Radiation Effects on the Fetus by Gestational Age and Radiation Exposure

Gestational Age (wk)	Potential Effects by Radiation Exposure		
	<50 mGy	50–100 mGy	>100 mGy
0–2	None	None	None
3–4	None	Probably none	Possible spontaneous abortion
5–10	None	Uncertain	Possible malformations
11–17	None	Uncertain	Possible deficits in IQ or mental retardation
18–27	None	None	IQ deficits not detectable at diagnostic doses
>27	None	None	None applicable to diagnostic medicine

Note.—Reprinted, with permission, from reference 10.

Table 2
Estimated Average Fetal Radiation Doses from a Single Acquisition with a 64-Row Multidetector Volume CT Scanner

Type of CT Examination	Dose (mGy)	CT Protocol		Imaging Parameters	
		Section Thickness (mm)	Noise Index	Tube Current–Time Product (mAs)	Pitch
CT of the chest	0.02	2.5	30	80	1.375
CT pulmonary angiography	0.02	1.25	30	88	0.984
CT of the abdomen	1.3	2.5	36	110	1.375
CT of the kidney, ureter, and bladder	11	2.5	36	110	1.375
CT of the pelvis	13	2.5	36	130	1.375
CT of the abdomen and pelvis	13	2.5	36	130	1.375
CT angiography	13	2.5	30	130	1.375

Note.—Average fetal dose was estimated by using the ImpactScan CT patient dosimetry calculator, version 1.0 (*http://www.impactscan.org*).

creasing with increasing dose (6,8). Historically, the threshold dose has been estimated to be 150 mGy (15 rad) (12). At this dose, it is recommended that the pregnancy be assessed for the need for intervention, such as termination. Theoretical risks at the threshold dose include a less than 3% chance of cancer development, a 6% chance of mental retardation, loss of IQ points by 30 points per 100 mGy, and a 15% chance of microcephaly (6–8). However, the risks depend on the timing of the exposure (as shown in Table 1); in early gestation, spontaneous abortion can occur, and in the brain, the effects are markedly dependent on the timing of the insult.

Although there is theoretical risk with any exposure to ionizing radiation, the average fetus is exposed to much less than 50 mGy (5 rad) from a single diagnostic study. Table 2 shows the average values for fetal radiation dose after a single acquisition for various CT examinations in pregnant patients at our institution. Given the low radiation exposure, fear of fetal radiation exposure should not delay imaging studies that may help identify underlying maternal pathologic conditions (6,8,13).

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Table 3
Recommendations by the ACOG and the ACR on Use of CT in Pregnancy

ACOG Recommendations	ACR Recommendations
Perform necessary examinations only after clinical work-up	Keep radiation levels as low as reasonably achievable
Iodinated contrast material is safe in pregnancy	Iodinated contrast material is likely safe in pregnancy
Counsel for radiation exposure	Counsel for radiation exposure

Concerns about Use of Imaging (Other than US) in Pregnancy

Guidelines for Use of CT

The role of a radiologist is to estimate the fetal risk from known radiation dose from a particular examination and to help formulate a plan that provides minimal fetal radiation exposure but at the same time is able to accurately answer the clinical question. Table 3 presents a comparison of the guidelines proposed by the American Congress of Obstetricians and Gynecologists (ACOG) and those outlined by the ACR (10,14).

There are situations wherein the risk of irradiating the fetus is much less than the risk of not making a critical diagnosis in the mother (9,15), an assertion endorsed by the International Commission on Radiological Protection. For example, to evaluate the seriously injured pregnant patient with blunt abdominal trauma, CT (4) is the most accurate and cost-efficient diagnostic tool available (16,17). We are cautious when performing a CT examination in pregnant patients (11). At our institution, we use a low-dose CT protocol that entails reducing the scan range (if clinically allowable), decreasing the tube current, and increasing the pitch in comparison with those of the standard protocol. In some cases, it may be possible to reduce the kilovoltage without compromising image quality.

The radiation doses resulting in fetal anomalies and risks are far and above those typically seen in medical imaging, as shown in Table 1 (12). When medical imaging is being considered, radiation dose to the fetus is most concerning after multiple consecutive studies have been performed and the accumulation of radiation dose nears the threshold dose.

Overall, the best practice, as emphasized by the 2008 ACR practice guidelines for imaging pregnant or potentially pregnant adolescents and women with ionizing radiation, is as follows (10): "To maintain a high standard of safety, particularly when imaging potentially pregnant patients, imaging radiation must be applied at levels as low as reasonably achievable (ALARA), while the degree of medical benefit must counterbalance the well-managed levels of risk."

Radiation dose from a CT scan can be greatly reduced when proper technique is used. Table 4 outlines the common dose reduction techniques used at our institution (18–24).

MR Imaging

Advantages of MR imaging are lack of ionizing radiation, multiplanar capability, and excellent soft-tissue contrast (14,25). The risks of MR imaging in pregnant patients have been investigated with computer simulations and animal models. Although we are unaware of any controlled studies, the risk to the fetus at 1.5-T magnet strength appears negligible and is outweighed by the potential benefit of making a necessary diagnosis (11). Safety at higher field strengths has not yet been adequately assessed.

In 2007, the ACR guidelines for MR imaging practices recommended that MR imaging be used when the risk-benefit ratio warrants the study. The risk to the fetus may be associated with potential heat effects of the magnetic field, specifically in the first trimester (5); however, the benefit to the pregnant patient may outweigh this risk as well. Another risk of MR imaging to be considered is the potential for acoustic injury. However, further investigative studies make this risk seem less likely, as noise is attenuated through amniotic fluid and is usually delivered to the fetus at less than 30 dB (5).

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Table 4
Dose Reduction Techniques for CT of Pregnant Patients

One size does not fit all: do not use standard protocols

Decrease kilovoltage for small patients

Decrease milliamperage and use automatic tube current modulation

Increase pitch to >1

Obtain a single scout view and avoid directly imaging the fetus for planning purposes

Limit the field of view

Avoid imaging in multiple phases

Use more recently available novel reconstruction algorithms to reduce noise in images, thus allowing reduction of milliamperage or increase in noise level requirements during scanning

Lead shielding of the mother; most pronounced effect with circumferential shielding

Internal barium shielding with use of oral 30% barium sulfate solution

Local quality assurance program to monitor CT protocols and the resulting dose

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In 1991, the Safety Committee of the Society of Magnetic Resonance Imaging stated that "MR imaging may be used in pregnant women if other non-ionizing forms of diagnostic imaging are inadequate or if diagnosis would otherwise require exposure to ionizing radiation. Pregnant patients should be informed that, to date, there has been no indication that the use of clinical MR imaging during pregnancy has produced deleterious effects" (26,27). The utility of MR imaging in pregnancy has been enabled with the development of single-shot fast spin-echo sequences (28,29).

Fluoroscopy

The pregnant patient may occasionally present to the emergency department with symptoms necessitating fluoroscopically guided procedures, such as placement of a peripheral intravenous central catheter, a tunneled central venous catheter or port, a nephrostomy tube, or a drain. In such instances, dose reductions techniques are employed, including intermittent or pulsed fluoroscopy, low-dose-level settings, narrow collimation, removal of the grid, dose spreading, adjustment of beam quality (copper filter), and avoidance of image magnification (30).

Contrast Material

Additional considerations when imaging a pregnant patient include exposure to contrast agents. To our knowledge, no well-controlled studies have been performed on the use of oral contrast material, intravenous iodinated contrast material, or intravenous gadolinium contrast material in pregnancy. Oral contrast material is not considered a threat to pregnant patients given its intraluminal administration and excretion and is not discussed herein. In fact, intraluminal barium can act as internal shielding (11,22).

Intravenous iodinated contrast material has been shown to cross the human placenta and enter the fetus when given in usual clinical doses, and there is concern about damage to the fetal thyroid related to iodine uptake (11). However, in vivo tests of intravenous iodinated contrast material in animals have shown no evidence of mutagenic or teratogenic effects with lower-osmolality contrast media (11,14,31). Given the lack of definitive evidence of complications from intravenous iodinated contrast material, it is thought to be generally inert and safe in pregnancy. However, thyroid function should be checked in the first few days of life, if the mother received iodinated contrast material during the pregnancy (11).

Toxic effects of gadolinium have been demonstrated in animals that received high doses; however, no adverse effects have been demonstrated in the small number of human studies done to date (11,27). Although gadolinium-based contrast material crosses the human placenta when given in clinical doses, no direct toxic effects have been shown in humans (32). The theoretical risk is that gadolinium chelates may accumulate in the amniotic fluid and dissociate over time, releasing the toxic free gadolinium ion, the clinical

Table 5
Processes of Prospective and Retrospective Fetal Dose Estimation

Prospective dose estimation
    TLD is placed on the patient at the level of the uterus
    TLD is sent to the manufacturer for readout
    Physicists estimate fetal dose from the TLD reading
    If the fetal dose is below 50 mGy (trigger level), then dose information is entered into the dosimetry report
    If the estimate is 50 mGy or greater, the physicists work up a detailed dosimetry report taking into account other variables (fetal depth and patient size) (28)*
    The detailed dosimetry report is placed in the patient's chart

Retrospective dose estimation
    Physicist estimates the average dose to the uterus (fetus)
    If the fetal dose is below 50 mGy (trigger level), then dose information is entered into the dosimetry report
    If the estimate is 50 mGy or greater, the physicists work up a detailed dosimetry report taking into account other variables (fetal depth and patient size) (28)*
    The detailed dosimetry report is placed in the patient's chart

*Numbers in parentheses are references.

significance of which is uncertain (31). Consequently, the Committee on Drugs and Contrast Media recommends that radiologists confer with the referring physician and discuss the potential clinical benefit of MR imaging over that of other modalities and the necessity of gadolinium for diagnosis (27,32). However, gadolinium is a class C drug, and its safety in humans is not proved.

Informed Consent

It is good practice to obtain informed consent from pregnant patients undergoing a diagnostic imaging examination to document the patient's comprehension of the alternative options, as well as the risks and benefits of the procedure to be performed. In addition, since there have been no controlled trials, to our knowledge, it is our belief that informed consent for contrast material–related risk should be obtained from patients receiving intravenous contrast material, iodinated contrast material, or gadolinium contrast material. At our institution, informed consent is obtained for all cross-sectional imaging studies, including MR imaging and studies involving radiation exposure to the fetus.

Fetal Dosimetry

At our institution, the medical physicist is typically contacted by the radiologist or the referring physician to make an estimate of the fetal dose. If the patient underwent head scanning or is in the

first 2 weeks of the pregnancy, no such estimation is needed (6). The fetus will be exposed to insignificant scatter radiation when a head examination is performed; in the first 2 weeks after conception, there is an all-or-nothing response with either spontaneous abortion or normal development. Prospective dose estimation is done less often than retrospective dose estimation owing to the urgency of imaging examinations.

At institutions without a medical physicist, we suggest use of a thermoluminescent dosimeter (TLD) to determine the dose to the surface of the patient. TLDs are typically available from the radiation safety office or can be ordered directly from Landauer (Glenwood, Ill). We estimate that the fetal dose is about one-third of the entrance dose for the average patient (33); the approximate fetus dose can be calculated with this rule of thumb. If the estimated dose is 50 mGy or greater, a consulting physicist will be needed to work up the detailed dosimetry report.

In addition, Wagner et al (6), McCollough et al (34), and Angel et al (35) have described methods of fetal dose calculation for various radiology examinations. The reader could refer to these sources to determine a course of action based on the TLD reading, the gestational age of the fetus, and other non–radiation-related concerns that may contribute to the decision-making process. However, we strongly recommend that the dosimetry be performed by a medical physicist only. The process of estimating fetal radiation dose is presented in Table 5.
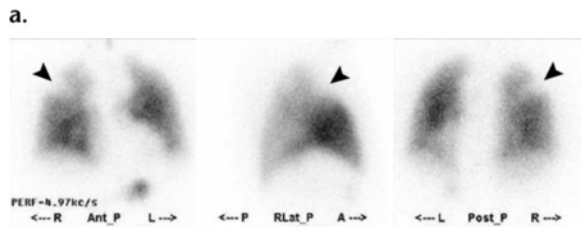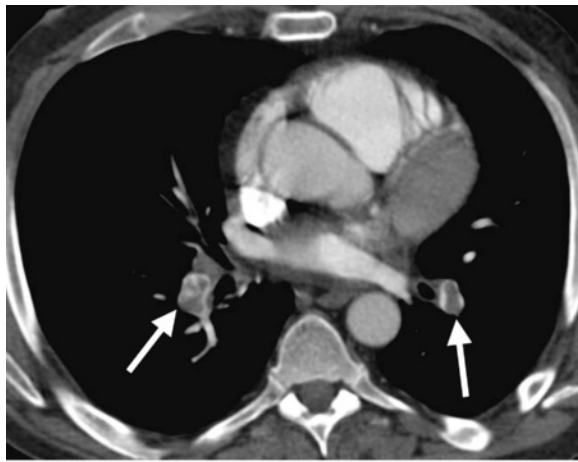
a.

PERF-4.97kc/s
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b.

Figure 1. Pulmonary embolism in two pregnant patients. **(a)** Bilateral pulmonary emboli in a 27-year-old woman in the first trimester with a history of worsening shortness of breath. Axial contrast material–enhanced CT image shows bilateral pulmonary emboli (arrows). **(b)** Segmental pulmonary embolus in a 34-year-old woman in the first trimester with a history of worsening shortness of breath, normal chest radiographic findings, and a severe allergy to iodinated contrast material. Images from a ventilation-perfusion (V/Q) scintigraphic study show a mismatch in the right upper lobe (arrowhead) due to a segmental pulmonary embolus.

Clinical Scenarios with Algorithms

Pulmonary Embolism

Venous thromboembolism is a leading cause of maternal mortality. Pregnancy increases the risk of deep venous thrombosis by a factor of five, with thromboembolism occurring in 0.5–3.0 of 1000 pregnancies (22). In the pregnant patient, the D-dimer assay is used mainly for its negative predictive value (11,22,36).

Appropriate diagnosis of deep venous thrombosis can obviate further work-up in a pregnant patient with symptoms of pulmonary embolism. Hence, we first perform chest radiography with an abdominal shield and vascular US. If results of these examinations are equivocal or unavailable, we recommend CT pulmonary angiography with abdominal shielding (Fig 1) (14,18,31,33).
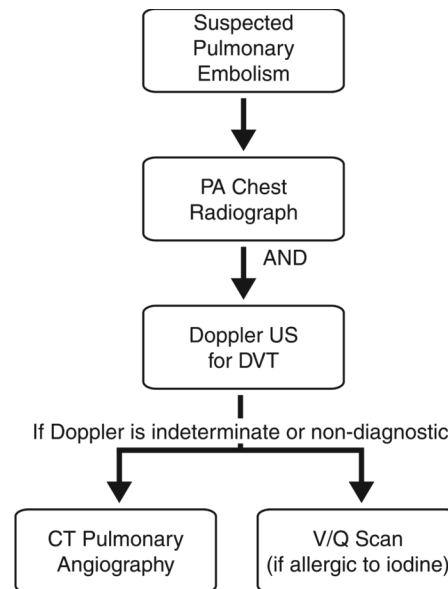

Figure 2. Algorithm for work-up of suspected pulmonary embolism in a pregnant patient. *DVT* = deep venous thrombosis, *PA* = posteroanterior.

CT pulmonary angiography is a more definitive examination with radiation exposure comparable to that of V/Q scanning (31). However, CT also allows identification of other causes of chest pain when the results are negative for pulmonary embolism (22,31). In addition, when CT of the chest is performed in the first trimester and the early second trimester, scatter to the uterus is small and therefore radiation exposure to the fetus is limited. If the patient is allergic to iodinated contrast agents, V/Q scanning can be performed.

At V/Q scanning, PE characteristically causes abnormal perfusion with preserved ventilation (mismatched defects). The Prospective Investigation of Pulmonary Embolism Diagnosis studies I and II defined criteria for diagnosis of pulmonary embolism (37,38). A V/Q study with normal findings essentially allows exclusion of pulmonary embolism, with a negative predictive value close to 100% (39). The algorithm used at our institution for imaging a pregnant patient suspected of having a pulmonary embolism is shown in Figure 2.

Appendicitis

Appendicitis is the most common cause of surgical abdomen in pregnancy, with a prevalence of
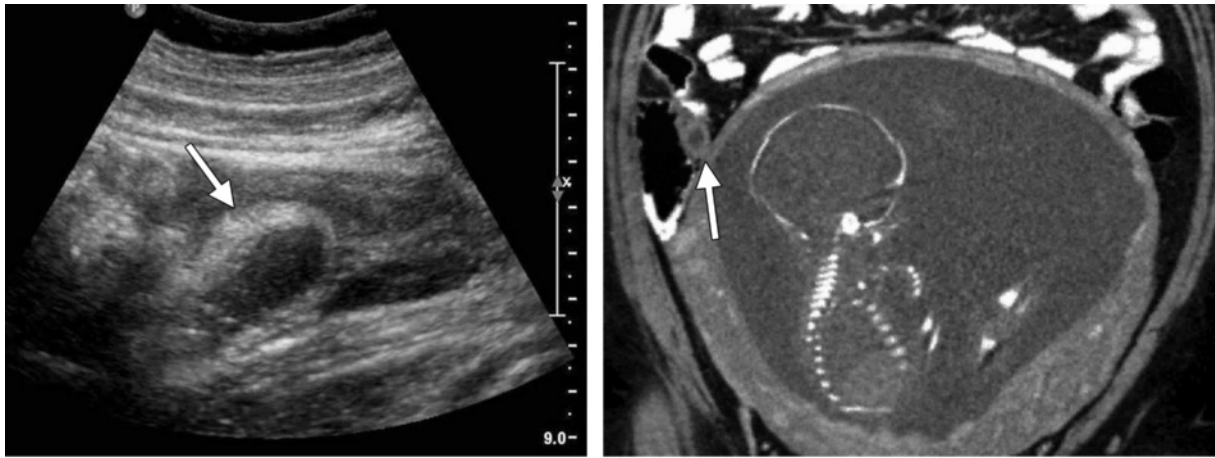
Figure 3. Appendicitis in two pregnant patients. **(a)** Acute appendicitis in a 35-year-old patient in the third trimester with a history of nausea, vomiting, fever, and abdominal pain. US image shows an enlarged dilated tubular structure measuring 10 mm in diameter in the right lower quadrant (arrow), a finding suggestive of acute appendicitis. **(b)** Acute appendicitis in a 28-year-old patient in the third trimester with a history of acute pain in the right lower quadrant. Coronal contrast-enhanced reformatted CT image shows an enlarged appendix measuring 9 mm in diameter (arrow).

50–70 per 1000 patients (40,41). The biggest difference in evaluation of appendicitis in the pregnant patient versus the nonpregnant patient is the anatomic location of the appendix, which is displaced by the gravid uterus (25,28).

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US with a graded compression technique is used for first-line imaging (42). Sonographic findings of acute appendicitis include a noncompressible tubular structure larger than 6 mm with thickened hyperemic walls, surrounding inflammatory fat stranding, and appendicoliths (43) (Fig 3). In addition, nonperistaltic abnormal bowel can be seen in the right lower quadrant adjacent to the appendix (44). Owing to the variability in operator skills, the appendix is not visualized in as many as 88%–92% of examinations (25,29,45).

Several groups have recently reported the negative predictive value of MR imaging in the evaluation of appendicitis to be 100% (25,29). The imaging findings typically associated with acute appendicitis in pregnancy on single-shot fast spin-echo images include a dilated appendix measuring 7 mm or more, surrounding inflammation, and the absence of blooming effect on T2*-weighted images (suggestive of no intraluminal air). These findings are similar to those seen in nonpregnant patients (28,41).

CT can be performed in the second and third trimesters if MR imaging is unavailable or if there is lack of expertise. Intravenous contrast material is used unless contraindicated due to iodine allergy. The algorithm used at our institution for
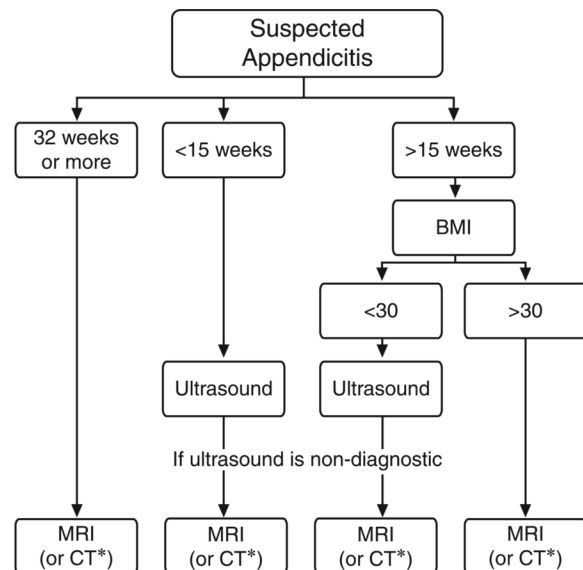

Figure 4. Algorithm for work-up of right lower quadrant abdominal pain in a pregnant patient when there is a strong suspicion of appendicitis. *BMI* = body mass index, ∗ = use CT if MR imaging is unavailable.

imaging pregnant patients suspected of having appendicitis is shown in Figure 4.

Trauma

It is reported that 70 per 1000 pregnant patients sustain an accidental injury sometime during pregnancy, and the injuries most commonly occur in the third trimester. Motor vehicle accidents are the most common cause of injuries
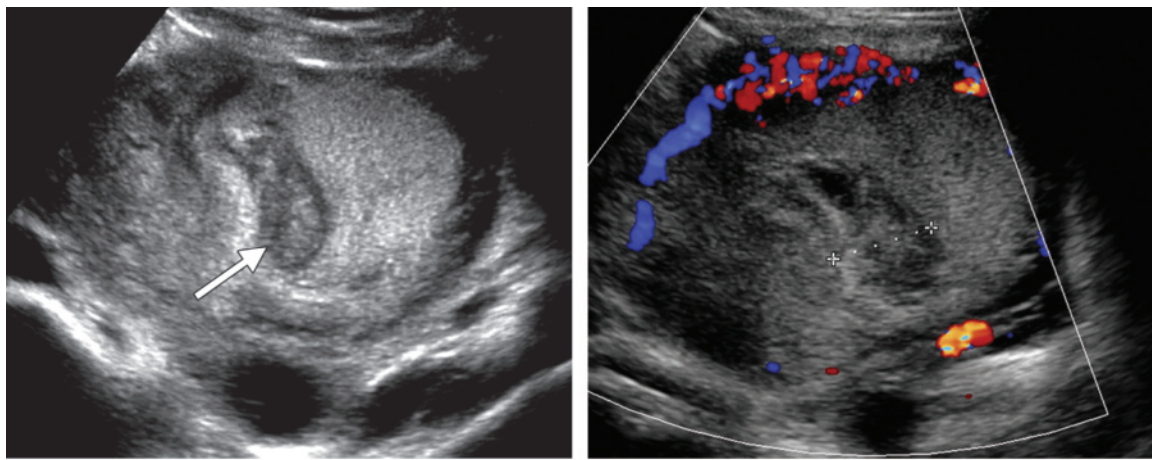
Figure 5. Placental abruption in a 24-year-old patient in the second trimester who was involved in a high-speed motor vehicle collision. **(a)** US image shows a large heterogeneous fluid collection in the retroplacental region (arrow). **(b)** Doppler US image shows no flow, a finding suggestive of hemorrhage from placental abruption.
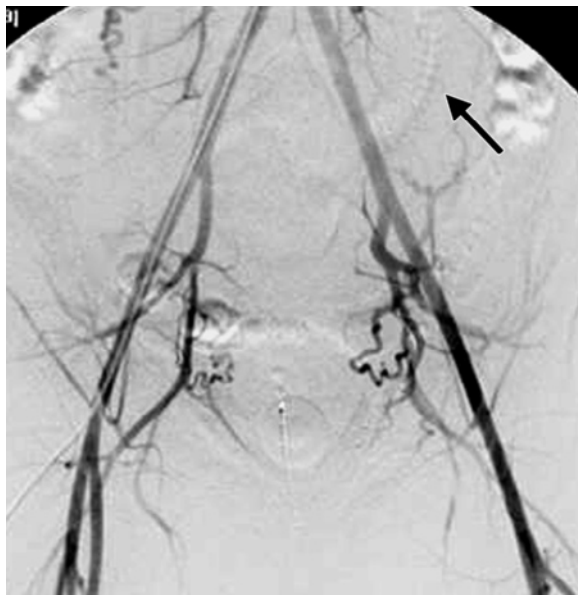

Figure 6. Normal angiographic results in a 29-year-old patient in the second trimester who was involved in a high-speed motor vehicle collision. CT of the abdomen performed earlier revealed a large pelvic hematoma. Image from digital subtraction angiography shows no active bleeding. The fetal spine is faintly visible (arrow).

during pregnancy, accounting for 66% of trauma cases (46,47). In trauma patients who are pregnant, priority is given to maternal survival and all imaging and procedural protocols for stabilization are followed; however, imaging technical parameters are modified as appropriate. Initial work-up of the pregnant patient includes plain radiography of the chest, lateral radiography of the cervical spine, and US of the placenta and fetus (Figs 5, 6).

In a study by Goodwin et al (48), the sensitivity and specificity of focused abdominal sonography for trauma in pregnant patients were similar to those seen in nonpregnant patients. These authors state that occasional false-negatives occur and that negative results of an initial examination should not be considered conclusive evidence that intraabdominal injury is not present. However, Richards et al (49) found that US was less sensitive in pregnant patients than in nonpregnant patients but was highly specific in both subgroups. The sensitivity of US in pregnant patients was highest during the first trimester. In addition, the most common pattern of free fluid accumulation detected at US in pregnant patients was fluid in the left and right upper quadrants and pelvis; the second most common pattern was isolated pelvic fluid (49,50).

Obvious advantages of sonography include rapid evaluation, no radiation exposure, and no risk of allergic reaction to contrast material. However, the drawbacks include poor resolution and poor penetrability in the pregnant abdomen and dependence on the skills of the sonographer (50). At our institution, US is used in trauma patients with a low level of trauma and a low likelihood of injury. Additional imaging is performed as needed and may include CT of the maternal head, chest, abdomen, and pelvis; MR imaging for neural

Figure 7. Ureterovesical junction calculus in a 24-year-old patient in the second trimester with a history of left flank pain and hematuria. Urinalysis results were negative for infection except for the hematuria. US performed earlier at another institution demonstrated mild left hydronephrosis. CT was performed to investigate the cause of the hematuria. **(a)** Coronal reformatted CT image shows a small ureteric calculus (arrowhead) at the left ureterovesical junction. There is retention of contrast material in the left kidney owing to back-pressure changes from the calculus. **(b)** Oblique thick-section maximum intensity projection CT image shows the calculus (arrowhead) at the left ureterovesical junction with mild left hydroureter (arrows).

injuries; and angiography for active extravasation. No imaging or interventional study is withheld or postponed if deemed necessary.

The most common uterine traumatic injury is placental abruption, with a prevalence of up to 40% after severe blunt abdominal trauma and 3% after minor blunt abdominal trauma (17). Other unique injuries in the pregnant trauma patient include uterine rupture (prevalence of approximately 1%) or direct fetal injury (prevalence of <1%) (9).

US is helpful in evaluating the placenta and fetus as well as detecting maternal large-volume hemoperitoneum and significant solid organ injury. However, bone, viscus, and retroperitoneal injuries are often unnoticed at US (16). CT is the most accurate and cost-efficient diagnostic tool available for evaluation of the hemodynamically stable, seriously injured pregnant patient with blunt abdominal trauma (16,17,47).

Urolithiasis

Calculi in pregnancy are uncommon, with a prevalence of 0.4 to 5 per 1000 pregnancies and an increased prevalence in multiparous women. The large variation is due to the fact that some of these cases may not be symptomatic during pregnancy; hence, determination of the exact number is difficult. Surgical intervention is usually not needed, and approximately 75% of calculi pass spontaneously (51). US is used as the first step in imaging; although not highly specific or sensitive, US is performed because it does not expose the fetus to radiation and allows excellent demonstration of hydronephrosis (52).

Physiologic hydronephrosis after the second trimester is a diagnostic difficulty. Low-dose CT can be performed if there is a high suspicion for lower urinary tract calculi, since CT has higher sensitivity than US (51,52). Low-dose CT also allows identification of alternative causes of flank pain (Figs 7, 8) (11,25,34,53–55). The algorithm used at our institution for imaging pregnant patients suspected of having urolithiasis is shown in Figure 9.
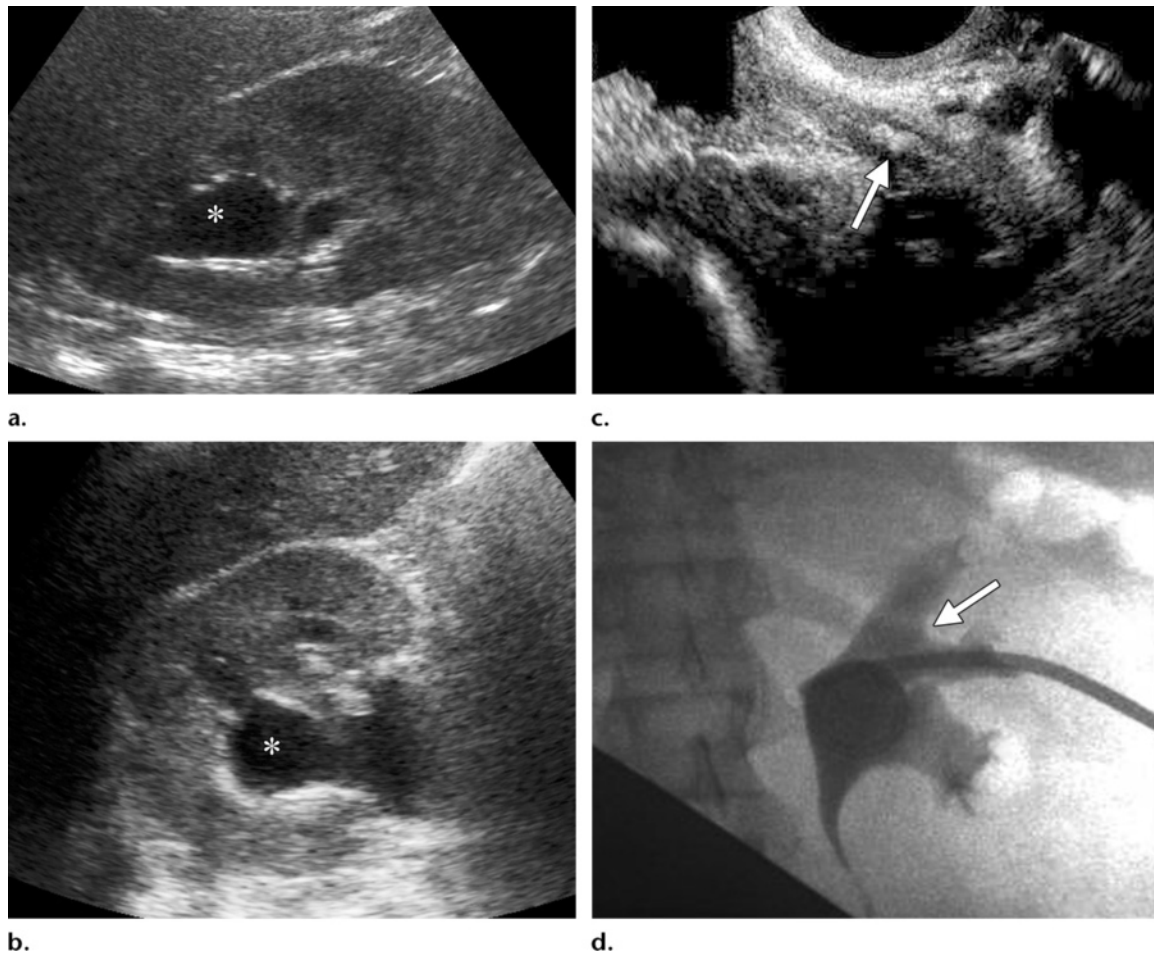
Figure 8. Large ureteric calculus in a 28-year-old patient in the second trimester with acute right-sided pain. **(a, b)** Longitudinal **(a)** and transverse **(b)** US images show hydronephrosis (∗) in the right kidney. Transvaginal US was performed to visualize the distal ureter. **(c)** Image from transvaginal US shows a 7-mm calculus (arrow) obstructing the right ureter at the ureterovesical junction. Because the patient had severe symptoms with sepsis and a relatively large calculus, percutaneous nephrostomy was perfomed. **(d)** Fluoroscopic image obtained during creation of a percutaneous nephrostomy shows contrast material (arrow) and a nephrostomy tube in the renal collecting system. The gravid uterus was not directly irradiated during the procedure.
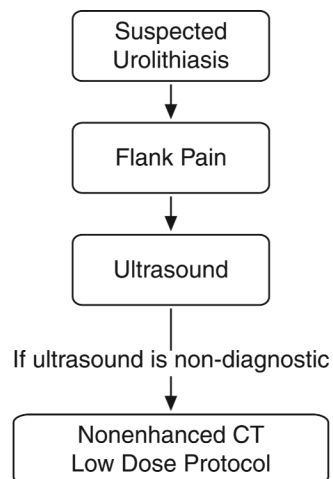

Figure 9. Algorithm for work-up of suspected urolithiasis in a pregnant patient.

10a.

11a.

10b.

11b.

Figures 10, 11.   **(10)** Crohn disease in a 34-year-old patient in the second trimester with nausea, vomiting, and abdominal pain. Axial **(a)** and coronal reformatted **(b)** contrast-enhanced CT images show a stricture in the proximal small bowel (arrow in **a**) with proximal obstruction (arrows in **b**), mucosal enhancement, and fibrofatty proliferation in the surrounding mesentery. **(11)** Internal hernia in a 28-year-old patient in the second trimester. Axial contrast-enhanced **(a)** and coronal reformatted **(b)** CT images show small bowel dilatation with an area of acute narrowing in the right upper quadrant (arrow) and abnormal location of the nondilated small bowel loops. Vascular engorgement is seen as well. Because the patient had a history of gastric bypass, the findings were suspected to represent an internal hernia. A transmesenteric type of internal hernia was found at surgery.

Nonspecific Abdominal Pain

Diseases of the gallbladder, urinary tract, bowel (including the appendix) (Figs 10, 11), ovary (Fig 12), pancreas, and liver can all have similar clinical manifestations. Physical findings can be difficult to interpret in pregnant patients because of the anatomic changes induced by the expanding uterus. Abdominal US is the preferred initial examination, and MR imaging can be performed if necessary. Alternatively, low-dose CT can provide excellent information with minimal radiation exposure (25,34,56).

CT enterographic findings correlate with the stage of Crohn disease and have been defined
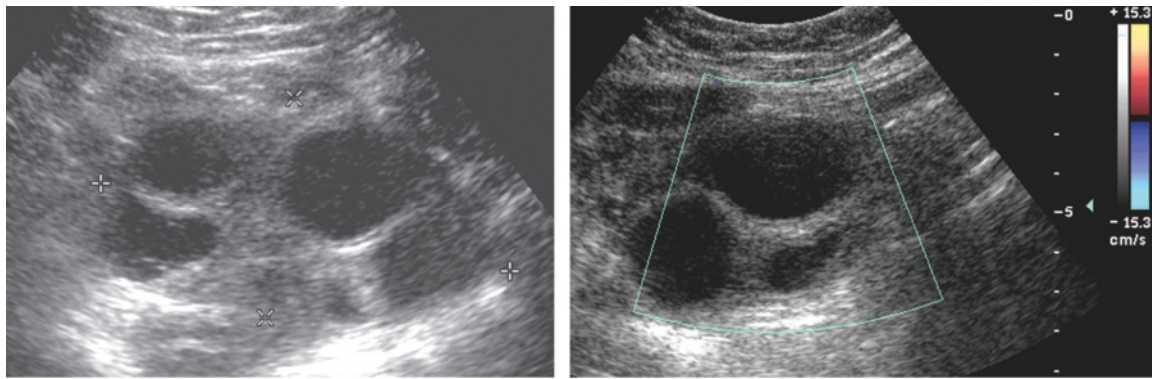
Figure 12.   Ovarian torsion in a 26-year-old patient in the first trimester with a history of severe left-sided pelvic pain. **(a)** US image shows an enlarged left ovary that measures 9.5 × 6.9 × 5 cm. It contains multiple small cystic areas and has a heterogeneous appearance because of edema. **(b)** Doppler US image shows absence of vascularity. These findings are suggestive of ovarian torsion.
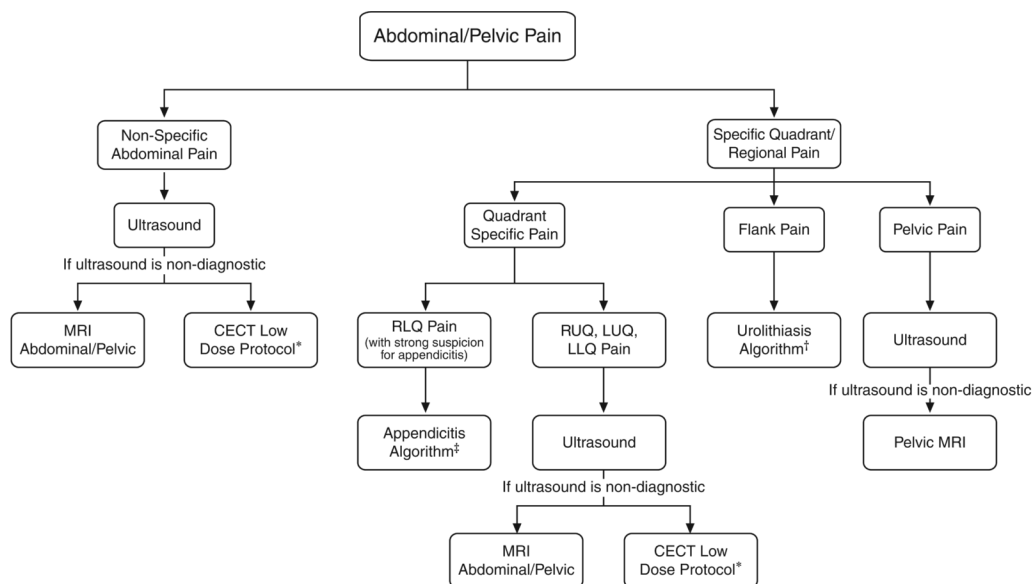

Figure 13.   Algorithm for work-up of abdominal or pelvic pain in a pregnant patient. *CECT* = contrast-enhanced CT, *LLQ* = left lower quadrant, *LUQ* = left upper quadrant, *RLQ* = right lower quadrant, *RUQ* = right upper quadrant, ∗ = use if MR imaging is unavailable, † = see Figure 9, ‡ = see Figure 4.

by Maglinte et al (57). The active inflammatory subtype demonstrates mural hyperenhancement, mural stratification, bowel wall thickening, soft-tissue stranding in the perienteric mesenteric fat, and engorged vasa recta. The fibrostenotic sub-type demonstrates a decrease in luminal diameter with prestenotic dilatation, and the fistulizing or perforating subtype demonstrates abnormal fistulas to adjacent organs, bowel, or skin (57,58). The algorithm used at our institution for imaging pregnant patients with abdominal or pelvic pain is shown in Figure 13.

Conclusions

Modalities that do not use ionizing radiation, such as US and MR imaging, should be the preferred examinations for evaluating an acute condition in a pregnant patient. However, no examination should be withheld when an important clinical diagnosis is under consideration. Exposure to ionizing radiation may be unavoidable, but there is no evidence to suggest that the risk to the fetus after a single imaging study and

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an interventional procedure is significant. All efforts should be made to minimize the exposure, with consideration of the risk versus benefit for a given clinical scenario.

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Imaging in Pregnant Patients: Examination Appropriateness

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Page 1216
Stochastic effects are the result of cellular damage, likely at the DNA level, causing cancer or other germ cell mutation.

Page 1216
Nonstochastic effects (aka, threshold effects or deterministic effects) are caused by exposure to radiation at high doses. These effects are predictable and involve multicellular injury, which can include chromosome aberrations.

Page 1218
"To maintain a high standard of safety, particularly when imaging potentially pregnant patients, imaging radiation must be applied at levels as low as reasonably achievable (ALARA), while the degree of medical benefit must counterbalance the well-managed levels of risk."

Page 1219
In 1991, the Safety Committee of the Society of Magnetic Resonance Imaging stated that "MR imaging may be used in pregnant women if other non-ionizing forms of diagnostic imaging are inadequate or if diagnosis would otherwise require exposure to ionizing radiation. Pregnant patients should be informed that, to date, there has been no indication that the use of clinical MR imaging during pregnancy has produced deleterious effects" (26,27).

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The biggest difference in evaluation of appendicitis in the pregnant patient versus the nonpregnant patient is the anatomic location of the appendix, which is displaced by the gravid uterus (25,28).