Imaging the Pregnant Patient for Nonobstetric Conditions: Algorithms and Radiation Dose Considerations

Shital J. Patel, MBBS • Deborah L. Reede, MD • Douglas S. Katz, MD • Raja Subramaniam, PhD • Judith K. Amorosa, MD

Use of diagnostic imaging studies for evaluation of pregnant patients with medical conditions not related to pregnancy poses a persistent and recurring dilemma. Although a theoretical risk of carcinogenesis exists, there are no known risks for development of congenital malformations or mental retardation in a fetus exposed to ionizing radiation at the levels typically used for diagnostic imaging. An understanding of the effects of ionizing radiation on the fetus at different gestational stages and the estimated exposure dose received by the fetus from various imaging modalities facilitates appropriate choices for diagnostic imaging of pregnant patients with nonobstetric conditions. Other aspects of imaging besides radiation (ie, contrast agents) also carry potential for fetal injury and must be taken into consideration. Imaging algorithms based on a review of the current literature have been developed for specific nonobstetric conditions: pulmonary embolism, acute appendicitis, urolithiasis, biliary disease, and trauma. Imaging modalities that do not use ionizing radiation (ie, ultrasonography and magnetic resonance imaging) are preferred for pregnant patients. If ionizing radiation is used, one must adhere to the principle of using a dose that is as low as reasonably achievable after a discussion of risks versus benefits with the patient.

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Introduction
Recent surveys have shown a lower than desirable level of awareness among health care professionals about dosimetry and radiation risks associated with imaging pregnant women for nonobstetric medical conditions (1,2). It is therefore not surprising, nor uncommon, to experience a dilemma when faced with a pregnant patient requiring diagnostic imaging. The overriding question is, “What is the preferred diagnostic study for the clinical problem at hand that at the same time will carry the least risk to the fetus?” An understanding of the effects of ionizing radiation on the fetus at different gestational stages and the estimated exposure dose received by the fetus from various diagnostic imaging modalities permits rational choices when making decisions about patient imaging and management. Other aspects of imaging besides radiation (ie, contrast agents) carry potential for fetal injury as well and must be taken into consideration.

Algorithms for diagnostic imaging of pregnant patients for common clinical scenarios such as pulmonary embolism (PE), acute appendicitis, urolithiasis, biliary disease, and trauma are addressed in this article. These recommended algorithms are based on a review of recent pertinent English-language medical publications and include an assessment of peer-reviewed results. We present these as protocols, most of which are currently used in our departments, and provide the rationale for their use, along with case demonstrations. Note that the expertise of the diagnosing physicians, availability of resources, and institutional preferences are important factors that govern the choice of diagnostic imaging study that is ultimately used.

Effects of Ionizing Radiation on the Fetus

Radiation-induced Teratogenesis
The biologic effects of ionizing radiation are produced by physical and chemical processes that lead to either cell death, resulting in morphologic effects, or changes in the nuclear DNA, which lead to carcinogenesis or genetic mutations (3). The effects of radiation on the fetus are dependent on the gestational age and radiation dose and are summarized in Table 1 (3–7).

Radiation-induced Carcinogenesis
There is strong evidence to support increased childhood cancer risk from irradiation of the fetus in utero (8,9). However, many aspects of radiation-induced childhood cancer remain controversial. The high risk estimate of 6% excess cases per gray of exposure, derived from the largest case-control study, has been questioned due to the less than expected number of cases reported among Japanese atomic bomb survivors (ie, one cancer-related death was reported as opposed to 8.8 estimated deaths before the age of 16 years) (8). In addition, although the largest case-control study showed an increased risk of all childhood cancers, the second largest study showed a larger risk of leukemia compared to that of solid tumors (9). Epidemiologic data support the presence of risk from irradiation throughout pregnancy (8). In

### Table 1

<table>
<thead>
<tr>
<th>Gestational Period</th>
<th>Effects</th>
<th>Estimated Threshold Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before implantation (0–2 wk after conception)</td>
<td>Death of embryo or no consequence (all or none)</td>
<td>50–100 mGy</td>
</tr>
<tr>
<td>Organogenesis (2–8 wk after conception)</td>
<td>Congenital anomalies (skeleton, eyes, genitals)</td>
<td>200 mGy</td>
</tr>
<tr>
<td></td>
<td>Growth retardation</td>
<td>200–250 mGy</td>
</tr>
<tr>
<td>Fetal period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8–15 wk</td>
<td>Severe mental retardation (high risk)†</td>
<td>60–310 mGy</td>
</tr>
<tr>
<td></td>
<td>Intellectual deficit</td>
<td>25 IQ point loss per gray</td>
</tr>
<tr>
<td></td>
<td>Microcephaly</td>
<td>200 mGy</td>
</tr>
<tr>
<td>16–25 wk</td>
<td>Severe mental retardation (low risk)‡</td>
<td>250–280 mGy</td>
</tr>
</tbody>
</table>

*Data based on results of 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) (3–7).

†Because this is a period of rapid neuronal development and migration.
light of the existing uncertainties, a cautious approach is warranted, and every attempt should be made to decrease radiation exposure to the fetus.

**Effects of Diagnostic Radiation Exposure on the Fetus**

The approximate fetal radiation exposure during most radiologic studies that use ionizing radiation is less than 0.05 Gy (Fig 1) (3,10–12). The natural background radiation dose to the fetus during pregnancy is approximately 1 mGy. The 1977 Report 54 of the National Council on Radiation Protection and Measurements contains the following statement (3): “The risk [of abnormality] is considered to be negligible at 5 rad (0.05 Gy) or less when compared to the other risks of pregnancy, and the risk of malformations is significantly increased above control levels only at doses above 15 rad (0.15 Gy). Therefore, the exposure of the fetus to radiation arising from diagnostic procedures would rarely be cause, by itself, for terminating a pregnancy.” The “risks of pregnancy” referred to in this statement include the normal risks of pregnancy: 3% risk of spontaneous birth defects, 15% risk of spontaneous abortion, 4% risk of prematurity and growth retardation, and 1% risk of mental retardation (13).

**CT during Pregnancy**

The estimated radiation exposure is low for CT when the fetus is outside the field of view. Therefore, CT of the head, cervical spine, or extremities (excluding the pelvis and hips) can be safely performed during any trimester of pregnancy. Chest CT is also considered a low-dose examination provided the fetus is excluded from the primary beam. Hurwitz et al (11) recently provided estimates for fetal radiation doses during early gestation when 16-row multidetector CT is used to image for suspected renal stones, appendicitis, or pulmonary emboli. The authors concluded that the estimated radiation doses are too low to induce fetal neurologic deficits. They also concluded that maternal imaging for appendicitis at their estimated CT doses may double the fetal risk of developing childhood cancer. Even though this is a theoretical risk, it emphasizes the need for attempts to decrease radiation dose when performing abdominal and pelvic CT, such as decreasing the milliampere-seconds value, z-axis modulation, and increasing scan pitch (Table 2) (14). Ultrasonography (US) and magnetic resonance (MR) imaging should be considered for use as an alternative examination whenever possible.

**MR Imaging during Pregnancy**

MR has been used to evaluate obstetric and fetal diseases for over 20 years (15). There has been no evidence of harmful effects to the fetus based on numerous clinical and laboratory investigations so far (15). However, some authorities express continuing concern about the safety of MR examinations in pregnancy. The primary safety concerns are the heating effects of radiofrequency pulses and the effects of acoustic noise on the fetus (16).

According to the American College of Radiology’s 2007 white paper for safe MR practices, MR imaging may be used in pregnant patients if considered necessary by the referring physicians and attending radiologists, irrespective of gestational age (17). Written informed consent is recommended to document the patients’ understanding of the risk-benefit ratio and the alternative diagnostic options available, if any (17). The patient can be informed that there are no known harmful effects from use of clinical MR imaging to date, at 1.5 T or lower magnetic field strengths (15). There is lack of experience with use of field strengths greater than 2.5 T, and they should be avoided at present (3).
US during Pregnancy
To our knowledge, there are no documented adverse effects on the fetus from diagnostic US. The U.S. Food and Drug Administration has proposed an upper limit of 720 mW/cm\(^2\) for the spatial-peak temporal average intensity of the ultrasound beam for obstetric US (18). Doppler US can produce high intensities and should be used judiciously, keeping the exposure time and acoustic output to the lowest level possible (19).

Use of Intravenous Iodinated Contrast Material during Pregnancy
The fetus is exposed to iodinated contrast media because the contrast agent crosses the placenta. These constitute U.S. Food and Drug Administration category B drugs; that is, animal reproduction studies have not demonstrated a fetal risk, but there are no controlled studies in pregnant women and they should be used only after assessing the potential risk-benefit ratio (20).

Depression of fetal thyroid function is a potential harmful effect that can be produced by exposure of the fetal thyroid to free iodide (21). However, the likelihood is that the fetal thyroid is exposed to the free iodide for only a short time. To our knowledge, there is a lack of well-controlled studies to assess these effects. If the mother received any iodinated contrast material during her pregnancy, the thyroid function of her baby should be checked in the first week of life, which is already standard practice in the United States for all newborns irrespective of prenatal iodide exposure (21).

Use of Intravenous Paramagnetic Contrast Agents for MR Imaging in Pregnancy
Animal studies show potential fetal toxic effects of intravenous gadolinium contrast agents. Growth retardation and congenital anomalies have been observed when these agents were administered at doses two to seven times higher than those used in humans (22). Gadopentetate dimeglumine has been used in pregnant women, inadvertently as well as for clinical purposes. To our knowledge, there have been no known adverse effects to human fetuses to date (21,23). The American College of Radiology’s 2007 white paper for safe MR practices addresses this issue. The paper emphasizes the need for a “well documented and thoughtful risk-benefit analysis” and that the decision to use contrast agents should be “based on overwhelming potential benefit to the patient and fetus outweighing the theoretic but potentially real risks of long-term exposure of the developing fetus to free gadolinium ions” (17,24).

Use of Intravenous Contrast Agents during Lactation
The levels of iodinated and gadolinium contrast agents in the neonatal circulation from breastfeeding after the lactating mother has received any of these intravenous agents are reportedly very low (21,25). The risk from this low exposure is not sufficient to justify the cessation of breastfeeding for 24–48 hours (21,25). Thus, breastfeeding may be continued as usual after administration of intravenous contrast agents to a lactating mother.

Imaging in Different Clinical Scenarios
Based on a review of the literature, imaging algorithms are presented for common nonobstetric medical conditions during pregnancy. Each algorithm is based on the following principles:

1. If an imaging study is required for evaluation of a pregnant patient, a modality that does not use ionizing radiation (US or MR imaging) should be the first imaging procedure of choice.
2. If a study with US or MR imaging is neither feasible nor desirable and ionizing radiation is used, keep the radiation dose to the fetus as low as reasonably achievable.

Imaging in Pulmonary Embolism
Rationale for Imaging
Pregnant patients reportedly have an increased prevalence of venous thromboembolism that is five times that of the nonpregnant state (26). This may be attributed to increased venous stasis as well as the hypercoagulable state associated with pregnancy. PE is reportedly associated with a high mortality in pregnancy (up to 15%), and treatment with anticoagulants is also associated with maternal and fetal morbidity (26,27). A pregnant patient with a diagnosis of PE may need to consider prophylactic anticoagulation in future pregnancies and to avoid use of oral contraceptives. Therefore, it is imperative to either diagnose or exclude PE in pregnant patients if there is a clinical suspicion.

Unfortunately, clinical symptoms and signs are nonspecific, as is also the case in nonpregnant patients. Also, D-dimer values cannot be used to screen for venous thromboembolism as in the nonpregnant population, because of the progres-
sive increase in these levels during normal pregnancy. To our knowledge, thresholds for normal levels of D-dimer in different trimesters have yet to be definitely established (28). Thus, diagnostic imaging has to be relied on to diagnose or exclude PE (Fig 2).

**Role of Compression US of the Lower Extremities**

Compression US is recommended as the initial imaging study for suspected cases of PE in pregnancy. It does not require ionizing radiation and can be accurately used to diagnose proximal lower extremity deep vein thrombosis (DVT) (95% sensitive and 98% specific, for the thighs) (29). Since the treatment for DVT and PE is the same, a positive compression US result avoids the need for additional imaging. The limitations of compression US include lack of studies validating the above recommendation and its low sensitivity for detection of iliac vein DVT, which is more common in pregnant than in nonpregnant patients (27). In one series of nonpregnant patients, 10% of patients with a high clinical suspicion of PE and negative US results had angiographically proved PE (28). Therefore, a negative compression US result still warrants further testing.

**CT Angiography of the Chest versus Ventilation-Perfusion Scanning**

CT angiography has a higher sensitivity (81%–91%) and specificity (93%–97%) than ventilation-perfusion scanning for detection of emboli in the main, lobar, and segmental pulmonary arteries (26). The sensitivity of a high probability ventilation-perfusion scan is only 41% (26). Most recent articles state that the radiation dose to the fetus from CT angiography of the maternal chest is similar to or lower than that from a ventilation-perfusion scan (2,11,26,30). A summary of calculations from two of these articles is provided in Tables 3 and 4 (26,30). Note that CT venography of the pelvis and lower extremities, which is routinely performed as part of the PE protocol in some institutions, is not performed in pregnant patients.

Other causes for a pregnant patient’s symptoms can be detected at thoracic CT, such as pulmonary edema, pneumonia, and pleural effusions (Fig 3). Even though we recommend CT angiography over ventilation-perfusion scanning for diagnosis of PE for the reasons stated earlier, it is prudent to note that there have been recent articles indicating a potential increased risk of

<table>
<thead>
<tr>
<th>Examination</th>
<th>Calculated Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single row detector helical CT</td>
<td>0.026</td>
</tr>
<tr>
<td>Multirow detector helical CT</td>
<td>0.013</td>
</tr>
<tr>
<td>Ventilation-perfusion scintigraphy</td>
<td>0.11–0.20</td>
</tr>
</tbody>
</table>

*Parameters were 120 kVp, 250 mAs, 3-mm section thickness, pitch = 1.7.*
†Parameters were 120 kVp, 85 mAs, 16 × 0.5 mm section thickness, pitch = 1.4.
‡With 40 MBq of $^{99m}$Tc albumin aggregates and krypton 81m inhaled for 2 min.

**Table 3**

Estimates of Fetal Radiation Dose from Chest CT Angiography in the First through Third Trimesters versus Ventilation-Perfusion Scanning

<table>
<thead>
<tr>
<th>Examination</th>
<th>Calculated Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-trimester CT angiography</td>
<td>0.003–0.020</td>
</tr>
<tr>
<td>Second-trimester CT angiography</td>
<td>0.007–0.076</td>
</tr>
<tr>
<td>Third-trimester CT angiography</td>
<td>0.051–0.130</td>
</tr>
<tr>
<td>Lung scanning</td>
<td>0.100–0.370</td>
</tr>
</tbody>
</table>

*Data based on the mean fetal dose calculated for 23 pregnant patients with different physical characteristics in different trimesters by Winer-Muram et al (26).*
†Helical CT parameters were 120 kVp, 100 mAs, 2.5-mm section interval, 11-cm craniocaudal distance, and pitch = 1.
‡With 37–74 MBq of macroaggregates of human serum albumin labeled with technetium 99m ($^{99m}$Tc).
maternal radiation-induced breast cancer with CT angiography (28,31). Moreover, to our knowledge, there are no published data comparing the performance of these modalities in pregnant patients.

Table 5 is a summary of modifications that can be adopted to decrease the radiation exposure during CT angiography of the chest (32). Worthy of mention is a recent article describing a phantom experiment that used enteric barium sulfate as an internal shield in an attempt to decrease fetal irradiation during chest CT (33).

Role of MR Imaging
MR imaging techniques are being developed for diagnosis of PE in nonpregnant patients. The use of gadolinium contrast material precludes the routine use of MR angiography in pregnant patients (see the section on use of intravenous paramagnetic contrast agents for MR imaging). We are not aware of any literature supporting the use of direct thrombus imaging (ie, not requiring gadolinium) in pregnant patients for evaluation of PE (34). MR imaging can be used to detect pelvic deep vein thrombosis and can be used when pelvic thrombosis is suspected (35).

Imaging in Acute Appendicitis
Rationale for Imaging
Acute appendicitis is the most common nonobstetric emergency requiring surgery during pregnancy (36). Appendicitis in pregnant patients is associated with premature labor, fetal morbidity and mortality, and a higher rate of perforation (43% vs 4%–19% in the general population) (36,37). Normal physiologic and anatomic changes in pregnancy limit the use of clinical signs that suggest a diagnosis of appendicitis (eg, absence of right lower quadrant pain and the presence of nausea, vomiting, and leukocytosis in normal pregnancy) (37,38). The delay in diagnosis of appendicitis in some pregnant women contributes to the higher risk of perforation.

Surgery is the treatment of choice but is not without risks. Preterm labor, fetal loss, and decreased birth weight have all been reported, although with decreasing frequency over the years (38,39). One series reported a high rate of negative laparotomy results (14%–43%) in patients without imaging studies, which emphasizes the need to make an accurate preoperative diagnosis (39) (Fig 4).

Role of Graded Compression US
In an initial series of 42 pregnant patients in whom US was used for detection of acute appendicitis, 100% sensitivity, 96% specificity, and 98% accuracy were reported (40). The ability to image the appendix was greater in the first and early second trimesters. In the third trimester, visualization improved when the patient was imaged in the left lateral decubitus position (40). Another study of 22 pregnant patients (all in the first and second trimesters) reported 66% sensitivity and 95% specificity (41).

Despite the variable sensitivity, US is still recommended as a first-line test because of the lack
of fetal radiation exposure and its ability to survey the pelvis for alternate diagnoses (eg, ovarian torsion). Imaging findings diagnostic of appendicitis at US are a blind-ended nonperistaltic tubular structure arising from the base of the cecum (usually at the site of tenderness) measuring more than 6 mm in diameter (7 mm in some articles), with a thick wall and associated inflammatory changes in the mesenteric fat. When an appendicolith is present, it is usually associated with marked acoustic shadowing (40,41).

There is superior migration and rotation of the appendix as pregnancy progresses. This decreases the sensitivity of US in late pregnancy (42). US is also limited by operator dependence, presence of bowel gas, and obesity. Therefore, if US results are negative or indeterminate for appendicitis in pregnancy and a definitive alternative diagnosis is not identified, further imaging is required to diagnose or exclude appendicitis and other diagnoses.

**Emerging Role of MR Imaging**

MR imaging has been shown to have high sensitivity and specificity for detection of appendicitis and other lower abdominal and pelvic pathologic conditions in pregnant patients with acute right lower abdominal pain, in a relatively limited number of initial studies. MR imaging was used to correctly identify normal findings as well as abdominal and pelvic pathologic conditions in all but one of 29 pregnant patients, the latter of whom had ovarian torsion (43). In another series of 12 pregnant patients suspected to have appendicitis, MR imaging was used to make the correct diagnoses in all patients, whereas US did not demonstrate the appendix in 11 of the 12 patients (44). The appendix was visualized in 86.9% of another MR series of 23 pregnant patients with right lower quadrant pain. An abnormal appendix
suggestive of appendicitis was seen in three of the four patients with subsequently proved appendicitis (45).

A very recent series included 51 pregnant patients suspected to have appendicitis (46). The imaging protocol included administration of a negative oral contrast agent (a mixture of ferumoxsil and barium sulfate) to reduce susceptibility artifacts and improve visualization of a fluid-filled appendix. MR imaging had an overall sensitivity of 100%, specificity of 93.6%, prevalence-adjusted positive and negative predictive values of 1.4% and 100%, and accuracy of 94%. The authors concluded that MR imaging should be used to exclude acute appendicitis in pregnant women suspected to have appendicitis but with inconclusive US results (46,47), and we concur with their conclusions (47).

The MR imaging findings of appendicitis in that study included an appendix with a fluid-filled lumen (hyperintense on T2-weighted fat-suppressed images and hypointense on T1-weighted images) and edematous wall (hypointense on T1-weighted images and slightly hyperintense on T2-weighted images). Inflammatory changes in the surrounding fat manifested as areas of high signal intensity on the T2-weighted fat-suppressed images and low signal intensity on the T1-weighted images (Fig 5). In the same series, US was performed in 48 of the 51 patients; however, the appendix was visualized in only two patients. This raises the possibility of using MR imaging as a first-line study instead of US. However, note that many patients screened with US may have a non-appendiceal cause of pain elucidated with the study and thus not need MR imaging.

Role of Abdominal and Pelvic CT

One hundred percent sensitivity was reported in a series of seven pregnant patients imaged with CT in whom the clinicians suspected appendicitis (48). A very recent retrospective study comprising 78 pregnant women with abdominal pain reported a 92% sensitivity, 99% specificity, and 99% negative predictive value of abdominal and pelvic CT for the diagnosis of appendicitis (49). Therefore, if MR imaging cannot be performed (contraindicated or not available), CT of the abdomen and pelvis should be used as a second-line test. Intravenous and oral contrast agents are preferred to improve visualization of the appendix (Fig 6).

Although the risk of delaying the diagnosis of appendicitis with subsequent possible perforation outweighs the potential risk of developing radiation-induced childhood cancer, clinicians and radiologists should be aware of the theoretical risk associated with an abdominal and pelvic CT study (ie, approximately one cancer per 500 fetuses exposed to 30 mGy) (50). This information should be used to prevent a nonchalant approach to use of abdominal and pelvic CT, promote better communication with the referring clinicians, and encourage more avid efforts to keep the radiation dose as low as possible (eg, by decreasing the milliampere-seconds value, using z-axis modulation, and increasing the pitch) (Table 2).
Imaging in Urolithiasis

Urolithiasis is the most common painful nonobstetric condition and nonobstetric reason for hospitalization in pregnant patients (51,52). In a series of pregnant patients with renal colic, 28% of patients with abdominal pain had an incorrect admitting diagnosis based on clinical evaluation, which underscores the limitations of clinical diagnosis. These diagnoses included appendicitis, diverticulitis, and placental abruption (53). Normal physiologic changes that occur during pregnancy can mimic pathologic conditions, further limiting accurate diagnosis (eg, physiologic dilatation of the collecting system vs true hydronephrosis). Fortunately, approximately 70%–80% of ureteral calculi in pregnant patients have been reported to pass spontaneously (52,54). However, if misdiagnosed or inadequately treated, urolithiasis can be complicated by pyelonephritis and premature labor induced by renal colic, with or without coexisting infection (Fig 7) (52).
Figure 8. Urolithiasis in a 37-year-old woman with right flank and right lower quadrant pain in the third trimester of pregnancy. (a) Sagittal US image of the right kidney shows moderate hydronephrosis. (b, c) Doppler US images show RIs of 0.84 in the right kidney (b) and 0.70 in the left kidney (c). The absolute RI of the right kidney (0.84) and the RI difference between the right and left kidneys (0.14) are consistent with obstruction. (d) US image of the bladder shows a distal right ureteral calculus. (e) US image shows a ureteral jet on the left side. No right ureteral jet was visualized, a finding consistent with an obstructive distal right ureteral calculus.
Role of US in Diagnosis of Urolithiasis

The reported sensitivities for detection of renal or ureteral calculi with sonography range from 34% to 95.2% (52,53). Our experience is consistent with the lower end of this range. A frequently encountered diagnostic challenge is the difficulty in distinguishing hydronephrosis from physiologic dilatation, the latter of which is the most common cause of renal pelvic and ureteral dilatation during pregnancy. Doppler US for calculation of the intrarenal resistive index (RI) may help differentiate between these entities (Fig 8). Normal pregnancy does not usually affect the intrarenal RI, and an elevated RI (>0.70) should not therefore be attributed to pregnancy (55). RI elevation usually occurs within 6 hours after acute obstruction. One study noted that the difference in RI between the normal and abnormal kidneys may help differentiate between these possibilities, a difference of 0.04 or greater being considered abnormal (Table 6) (56).

Absence of a ureteral jet on the suspected side of obstruction has been reported to have a sensitivity of 100% and a specificity of 91% (57). Approximately 15% of asymptomatic pregnant women have been reported to have absent unilateral jets (58). Patients should be imaged in the contralateral decubitus position to decrease false-positive results (58). US is somewhat time-consuming and requires hydration, which permits better detection of ureteral jets by increasing the difference in specific gravity between the incoming urine and urine in the bladder (58). This may not be well tolerated by all pregnant patients. Transvaginal US is recommended to detect distal ureteral calculi, particularly if results of transabdominal US are normal or inconclusive (59).

A retrospective analysis of the utility of sonography for evaluation of suspected cases of urolithiasis in pregnancy, performed at one of our institutions, showed sonography to have a poor yield. However, a normal sonogram may obviate the use of further imaging if there is no continuing clinical concern about a significant alternative diagnosis other than renal colic or pyelonephritis, although we believe that additional prospective investigations comparing some combination of US, low-dose CT, and MR imaging for suspected cases of renal colic may be warranted (60). Despite the above disadvantages, US is still currently suggested as a first-line test because it does not involve the use of ionizing radiation or iodinated contrast material, is noninvasive, and is relatively cost-effective.

Role of MR Urography

MR urography should be considered as a second-line test when use of US fails to establish a diagnosis and there are continued symptoms despite conservative management. High sensitivity has been reported for detection of urinary tract dilatation and identification of the site of obstruction (61). In a series of 24 pregnant patients with symptomatic hydronephrosis, MR urography was noted to show different appearances in physiologic hydronephrosis and pathologic obstruction (62). Renal enlargement and perirenal fluid suggestive of obstruction were absent in physiologic dilatation (Fig 9). In addition, physiologic dilatation demonstrated a characteristic tapering due to extrinsic obstruction of the middle third of the ureter by the uterus (62). Hormone-related relaxation also contributes to physiologic dilatation of the ureters during pregnancy. Physiologic renal and ureteral dilatation is more common on the right. Limitations of MR urography include limited visualization of small calculi and relatively high cost.

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Use of the RI for Diagnosis of Urolithiasis in Pregnancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI Measurement Used</td>
<td>Sensitivity (%)</td>
</tr>
<tr>
<td>RI of abnormal kidney ≥ 0.70</td>
<td>45</td>
</tr>
<tr>
<td>RI difference between abnormal and normal kidneys ≥ 0.04</td>
<td>95</td>
</tr>
</tbody>
</table>

Note.—Data from Shokeir et al (56), who calculated RIs in 22 pregnant women with acute unilateral urinary tract obstruction.
Role of Imaging Studies That Use Ionizing Radiation

A comparison of the radiation exposure from nuclear medicine examinations, intravenous urography, and CT of the abdomen and pelvis without intravenous contrast material is provided in Table 7. Although nuclear scans are associated with the least radiation and do not require iodinated contrast material, they are limited by poor anatomic detail, nonvisualization of calculi, and the need for frequent voiding to decrease fetal radiation exposure from urinary bladder activity (51,54). In the past, some authors have advocated use of three-phase intravenous urography (usually consisting of scout, 30-second or 1-minute, and 20-minute images) as a second-line test for detection of urolithiasis in pregnant patients (51,53,54). There is a potential for increased fetal radiation exposure from intravenous urography if delayed images are required and when a higher radiation dose is needed to penetrate the maternal abdomen in the latter stage of pregnancy. Superimposition of the fetal skeleton on the urinary system can obscure visualization of calculi. For these reasons, intravenous urography is not recommended as a second-line test.

The use of low-dose CT for detection of calculi has been validated in the general population (63,64). A recent article reports fetal radiation doses ranging from 4 to 7.2 mGy and from 8.5 to 11.7 mGy at 0 and 3 months of gestation, respectively, from a renal stone imaging protocol that uses a relatively low tube current (160 mA, 140 kVp) and a 16-row multidetector CT scanner (11). These doses are lower than those reported in Table 7. The current trend of using low-dose multidetector CT coupled with the high accuracy (>95% sensitivity and >98% specificity) for detection of calculi in the general population have lowered the threshold for use of abdominal and pelvic nonenhanced CT as a second-line test in pregnancy (Fig 10).

Table 7

<table>
<thead>
<tr>
<th>Imaging Study*</th>
<th>Estimated Dose (mGy)</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{99m}$Tc MAG$_3$ scanning</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>$^{99m}$Tc DTPA scanning</td>
<td>4.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Intravenous urography</td>
<td>10</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>CT of the abdomen</td>
<td>49</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>CT of the pelvis</td>
<td>79</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

Source.—Reference 54.  
*DTPA = diethylenetriaminepentaacetic acid,  
MAG$_3$ = mercaptoacetyltriglycine.
Avoidance of Radiation Exposure with Treatment of Renal Colic

A conservative approach including rest, intravenous fluids, and analgesic therapy is recommended for initial management in all pregnant patients with ureteral calculi and renal colic (52,53). However, if the symptoms persist or complications develop, therapeutic interventions may be required. Although traditionally placed under fluoroscopic guidance, ureteral stents can be placed under direct visualization via a ureteroscope or with US guidance (51,52). Laser lithotripsy via a ureteroscope is considered safe; however, extracorporeal shock wave lithotripsy is contraindicated in pregnancy due to potential harmful effects of shock waves on the fetus (51,52). If indicated, percutaneous nephrostomy can be performed under US guidance. Percutaneous nephrolithotomy should be avoided because it requires a significant amount of fluoroscopy time (51).

Imaging in Biliary Disease

Symptomatic biliary tract disease in pregnancy is uncommon (65,66). US is the initial study of choice for diagnosis (Fig 11). The management of biliary colic and acute cholecystitis is controversial, with more recent evidence favoring surgical over medical management (65,66). Complications such as obstructive jaundice, gallstone pancreatitis, and peritonitis are associated with high maternal and fetal mortality and may require ERCP or surgical interventions (65). The fetal radiation exposure during ERCP is reported to be within safe limits (67,68). Use of intraductal endoscopic US can potentially increase the yield of ERCP without the risk of radiation (69). However, intraductal endoscopic US is not readily available.

In a large series of nonpregnant patients, MR cholangiopancreatography had a high sensitivity (98%) and specificity (84.4%) for diagnosis of
biliary disease (70) (Fig 12). Another prospective study of 32 nonpregnant patients concluded that MR cholangiopancreatography is comparable to ERCP for diagnosis of choledocholithiasis and that ERCP should be reserved for patients who need interventions (69). To our knowledge, there are no studies evaluating the use of MR cholangiopancreatography in pregnant patients. Nevertheless, MR cholangiopancreatography should be used before ERCP or surgical interventions because it is noninvasive and not associated with complications as compared with ERCP, particularly pancreatitis. MR imaging can also depict other causes of abnormal liver function test results (Fig 13).

**Imaging in Trauma**

Trauma is the leading nonobstetric cause of maternal death (71,72). Approximately 6%–7% of pregnant women sustain trauma, most commonly from motor vehicle collisions (71–73). Physiologic changes during pregnancy can mask the seriousness of an injury. Fetal death can occur with both minor and major trauma (71). The reported rate of fetal mortality after blunt trauma ranges from 3.4% to 38%, secondary to placental abruption, maternal death, or shock (72). Thus, after maternal trauma, there is a need for rapid and accurate imaging. Concerns about fetal radiation exposure should neither deter nor delay radiologic evaluation. A pregnant patient with blunt abdominal injury or unconsciousness poses the greatest dilemma for imaging. Any examination that does not involve direct exposure to the maternal abdomen (eg, head CT or chest CT) should be performed without concerns about fetal radiation effects (Fig 14).

**Role of US in Blunt Abdominal Trauma**

US results are considered positive if there is free intraperitoneal fluid or evidence of solid organ injury. In a study by Ormsby et al (74), detection of free fluid in the abdomen alone, in both the abdomen and pelvis, or in the pelvis alone was significantly associated with intraabdominal injury compared to those cases without any free fluid, for both pregnant and nonpregnant reproductive age women. The most common sites of accumulation of free fluid in the pregnant patient are the right and left upper quadrants and the dependent portion of the pelvis (75).

The reported sensitivity and specificity for detection of intraabdominal injury in pregnant women with US range from 61% to 83% and from 94% to 100%, respectively (75–77). The most important question is: What should be done if the US results are negative? Some studies report false-negative US results and recommend further imaging or clinical follow-up (76,78). On the other hand, a recent study showed that in patients with negative US results, 96% did not need additional testing that used ionizing radiation, and US was therefore recommended as an accurate screening tool (77). In that study, the patients who had false-negative findings were diagnosed as...
Figure 13. Hepatocellular carcinoma in a 30-year-old woman who presented to the emergency department with right upper quadrant pain in the second trimester of pregnancy. The patient was not aware that she was pregnant. Her medical history was significant for hepatitis B. (a) Sagittal US image of the right upper quadrant shows multiple large echogenic masses. MR imaging was performed to further characterize the lesions. (b, c) Coronal T2-weighted MR images show the extensive infiltrating hepatic masses. The fetus is also seen in c. Percutaneous biopsy demonstrated hepatocellular carcinoma.

Figure 14. Algorithm for maternal imaging in pregnant women after trauma (71–78). IV = intravenous.
within 24 hours of the injury. A concurrent examination of the fetus can also be performed with US.

Role of CT in Blunt Abdominal Trauma
CT is more sensitive than US for detection of small amounts of fluid, retroperitoneal hemorrhage, and organ injury (14,78). However, US is more suited for the rapid triage of patients in unstable condition. If CT is used, attempts should be made to decrease the radiation exposure because of the potential carcinogenic risk to the fetus. To our knowledge, there is no large-scale study that supports the use of CT in all pregnant women with blunt abdominal trauma or after US with negative results. Acquisition of more data on this issue is warranted.

Role of MR Imaging in Blunt Abdominal Trauma
Although MR imaging is theoretically a potential alternative to CT, to our knowledge there is no literature supporting the use of abdominal and pelvic MR imaging in this emergency setting. MR imaging has relatively long acquisition times, it is difficult to access the MR imaging units from triage areas at most institutions, and monitoring the patient is more difficult if resuscitation is needed during the procedure.

Fetal Evaluation in Trauma
When the mother’s condition is stabilized, a rapid obstetric US study should be performed to assess fetal heart rate and the placenta (position and abnormalities). If the fetus is viable, continuous fetal electronic monitoring should be provided. Ideally, the mother and baby should be monitored continuously and accompanied by appropriate medical personnel when in the radiology department. Mothers in the third trimester should be placed in the left lateral decubitus position as much as possible to avoid vena caval obstruction (72,78).

Counseling the Pregnant Patient about Imaging Procedures
Counseling the pregnant patient is important to decrease the anxiety associated with diagnostic procedures and for medicolegal purposes. It is important to use terms that can be understood by the patient (3,6). The patient should be informed that for most diagnostic procedures the risk of congenital anomalies, miscarriage, birth defects, or mental retardation is negligible and that though the risk of development of childhood cancer and leukemia is real, it is small compared to other spontaneous risks during pregnancy (79) (see the section “Effects of Diagnostic Radiation Exposure on the Fetus”).

The imaging options available should be described, and consequences of delaying or refusing imaging must also be explained. When MR imaging is used, the patient should be told that there are no known risks to the fetus. However, its safety has not been proved and cannot be guaranteed (17).

Conclusions
The pregnancy status of all women of childbearing age should be determined before use of ionizing radiation (by using menstrual history or a urine pregnancy test as deemed appropriate). If the required diagnostic information can be obtained with an imaging modality that does not use ionizing radiation, it should be used as a first-line test. If a study that uses ionizing radiation has to be performed, keep the radiation dose to the fetus as low as possible (preferably below 50 mGy [ie, 5 rad]). The risks and benefits of performing or not performing the examination should be communicated. Documentation of the radiation dose to the fetus, particularly if the fetus is in the field of view, is highly recommended.

Acknowledgment: We thank R. Thomas Bergeron, MD, for his inspiration and help with editing the initial drafts of the manuscript.

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Wagner LK, Huda W. When a pregnant woman with suspected appendicitis is referred for a CT scan, what should a radiologist do to minimize potential radiation risks? Pediatr Radiol 2004;34:589–590.


Imaging the Pregnant Patient for Nonobstetric Conditions: Algorithms and Radiation Dose Considerations

Shital J. Patel, MBBS, et al

The 1977 Report 54 of the National Council on Radiation Protection and Measurements contains the following statement (3): “The risk [of abnormality] is considered to be negligible at 5 rad (0.05 Gy) or less when compared to the other risks of pregnancy, and the risk of malformations is significantly increased above control levels only at doses above 15 rad (0.15 Gy). Therefore, the exposure of the fetus to radiation arising from diagnostic procedures would rarely be cause, by itself, for terminating a pregnancy.”

Most recent articles state that the radiation dose to the fetus from CT angiography of the maternal chest is similar to or lower than that from a ventilation-perfusion scan (2,11,26,30).

The delay in diagnosis of appendicitis in some pregnant women contributes to the higher risk of perforation.

Thus, after maternal trauma, there is a need for rapid and accurate imaging. Concerns about fetal radiation exposure should neither deter nor delay radiologic evaluation.

Counseling the pregnant patient is important to decrease the anxiety associated with diagnostic procedures and for medicolegal purposes. It is important to use terms that can be understood by the patient (3,6).
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