RadioGraphics

Quality Initiatives

Imaging Pregnant Patients with Suspected Pulmonary Embolism: What the Radiologist Needs to Know[1]

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ONLINE-ONLY CME

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LEARNING OBJECTIVES

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

- Discuss the advantages and disadvantages of various imaging modalities in the diagnosis and evaluation of pulmonary embolism during pregnancy.
- Describe various methods of dose reduction with use of these imaging modalities.
- List the components of appropriate risk management in this setting.

TEACHING POINTS

See last page

Pregnancy is associated with a fivefold increase in the prevalence of venous thromboembolism, and pulmonary embolism is a leading cause of maternal death. However, the diagnosis of pulmonary embolism during pregnancy is challenging because classic clinical symptoms are often absent and physiologic changes during pregnancy can mimic pulmonary embolism. Concerns about exposure of the fetus to ionizing radiation and intravenously administered contrast material, as well as potential medicolegal issues, further complicate the diagnosis. Although diagnostic imaging plays an important role in this setting, there are currently no widely accepted guidelines for radiologists and clinicians to follow. Thus, radiologists should be familiar with the advantages and disadvantages of available imaging modalities, methods for dose reduction, radiation risks, and medicolegal risk management guidelines.

Abbreviations: DVT = deep venous thrombosis, V/Q = ventilation-perfusion

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Introduction

Teaching Point

Pulmonary embolism is the leading preventable cause of maternal death during pregnancy. A diagnosis of pulmonary embolism in pregnancy has important implications, including the need for prolonged anticoagulation therapy, delivery planning, and possible prophylaxis during future pregnancies, as well as concern about future oral contraceptive use and estrogen therapy (1–4). Thus, when pulmonary embolism is suspected clinically, there is a need for confident and definitive diagnosis or exclusion of this entity.

The clinical pathway for evaluating pregnant patients with suspected pulmonary embolism has been a topic of debate and is highly variable, depending on institutional preferences, resource availability, and the individual practice patterns of radiologists and referring clinicians (4–6). In the absence of standard guidelines, there is a need to familiarize radiologists with the relative merits and limitations of various tests used for the evaluation of suspected pulmonary embolism in pregnancy.

Although diagnostic imaging can be performed safely during pregnancy, it is important that radiologists be aware of methods of minimizing radiation risk to both mother and fetus. In addition, because imaging during pregnancy involves a medicolegal risk, radiologists should be aware of salient risk management guidelines for such imaging. In this article, we discuss and illustrate currently available diagnostic imaging tests in terms of advantages, disadvantages, clinical implications, and future outlook; summarize current estimates of radiation exposure to the mother and fetus; describe dose reduction techniques; and discuss risk management initiatives, thereby allowing the radiologist to provide the most appropriate care.

Epidemiologic Considerations

Pregnancy is associated with an approximately fivefold increased risk for pulmonary embolism due to a variety of contributing factors, including increased venous stasis, pregnancy-related hypercoagulability, prolonged bed rest, diminished fibrinolysis, and familial predisposition. An estimated 2%–20% of pregnant patients with clinically suspected pulmonary embolism prove to have this pathologic condition (7–13).

Pulmonary embolism has been reported to complicate one in 1000–10,000 pregnancies in the prenatal period (2,9,10). Although it has been widely held that the risk of pulmonary embolism increases with each successive trimester and in the puerperal period after birth, it is important to note that some studies have found similar risk through all three trimesters (1,7,10,11,13). Because the mortality rate for untreated pulmonary embolism in pregnancy approaches 15%–30%, a timely and accurate diagnosis is important (3,7,8,11).

Clinical and Laboratory Evaluation of Suspected Pulmonary Embolism in Pregnancy

Teaching Point

As in the general population, the clinical diagnosis of pulmonary embolism in pregnant patients is hampered by the poor sensitivity and specificity of clinical findings. In pregnant patients, the diagnosis of pulmonary embolism is complicated by normal physiologic changes during pregnancy (eg, leg swelling, pain, dyspnea, tachypnea, tachycardia, palpitations) that may mimic signs and symptoms classically associated with pulmonary embolism (14).

Thus, it is challenging to categorize and triage pregnant women into risk groups for pulmonary embolism with established parameters such as the Wells and Geneva criteria (6,15). Beyond pulmonary embolism, shortness of breath in pregnancy has a broad differential diagnosis that includes physiologic changes, peripartum cardiomyopathy, tocolysis-induced pulmonary edema, aspiration pneumonitis, pneumonia, amniotic fluid embolism, pneumothorax, and complications from gestational trophoblastic neoplasms (16).

Although the D-dimer assay has been established as a viable screening method in the general population, its role in pregnant patients is limited by a rise above reference levels as the pregnancy progresses, producing false-positive results. A normal D-dimer value (which varies depending on the D-dimer assay being used) may be helpful in assessing pregnant patients with suspected pulmonary embolism, since it has been suggested that the negative predictive value remains accurate regardless of trimester. However, radiologists should be mindful that, as in the general population, pulmonary embolism has been documented in pregnant patients despite the presence of normal D-dimer values (17,18). New reference

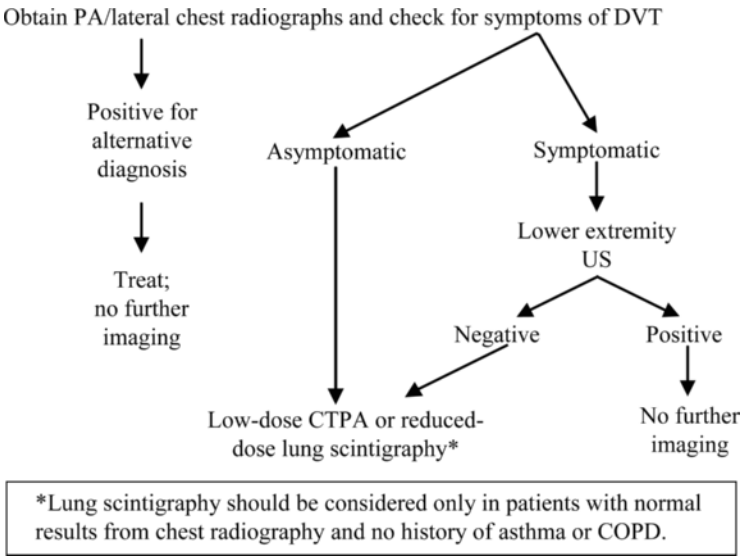


Figure 1. Diagram presents a potential algorithm for imaging pregnant patients with suspected pulmonary embolism. *COPD* = chronic obstructive pulmonary disease, *CTPA* = CT pulmonary angiography, *DVT* = deep venous thrombosis, *PA* = posteroanterior.

ranges for normal D-dimer levels for each trimester and novel serum markers such as fibrin monomer complex may play a future role in the management of suspected pulmonary embolism in pregnant patients (19,20).

Because of the limitations of clinical and laboratory assessment for pulmonary embolism in pregnancy, diagnostic imaging plays a crucial role in establishing or excluding the diagnosis. In the following section, we discuss the relative risks of radiation exposure to the mother and fetus.

Radiation Exposure to Mother and Fetus

Although diagnostic imaging is widely considered clinically warranted in pregnant patients with suspected pulmonary embolism, radiologists should be aware of the associated radiation risks to the mother and fetus, including risks of teratogenesis and carcinogenesis (following the stochastic effect principle) (21–24). However, we emphasize that fetal risks from radiation doses of less than 50 mGy are negligible, and that doses of 100 mGy result in a combined increased risk of organ malformation and the development of childhood cancer of only about 1% (23,24).

Teaching Point

In this context, it is important to note that even a combination of chest radiography, lung scintigraphy, computed tomographic (CT) pulmonary angiography, and traditional pulmonary angiography exposes the fetus to around 1.5 mGy of radiation, which is well below the accepted limit of 50 mGy for the induction of deterministic effects in the fetus and similar to background radiation exposure to the fetus of 1.1–2.5 mGy (3,21,25). The estimated risk of radiation-induced carcinogenesis is controversial, but even high in utero exposure (1–2 mGy) associated with extensive imaging for pulmonary embolism is not likely to affect more than one in 1000 children per rad of exposure (24). Given these premises, diagnostic imaging can be considered safe for the evaluation of suspected pulmonary embolism in pregnancy when appropriate diagnostic algorithms and dose reduction strategies are applied.

Diagnostic Imaging Tests

Although it is widely recognized that radiologic and nuclear medicine examinations that may provide relevant diagnostic information should not be withheld during pregnancy, it is important that radiation doses be kept as low as reasonably achievable ("ALARA") so as to minimize risks while maintaining diagnostic quality (23). Thus, in the assessment of suspected pulmonary embolism in pregnant patients, work-up should begin with readily available tests that provide diagnostic information with use of little or no ionizing radiation. These "first-line" examinations include chest radiography and lower extremity ultrasonography (US). If these tests prove to be nondiagnostic, a "second-line" examination such as lung scintigraphy or CT pulmonary angiography should be performed. Figure 1 illustrates a practical algorithm for evaluating pregnant patients with suspected pulmonary embolism.

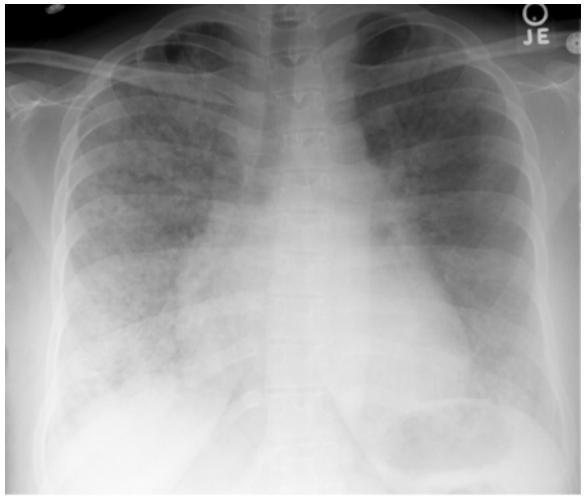
First-Line Imaging Tests

Chest Radiography.—Chest radiography is a low-dose examination that screens for other potential causes of symptoms (Fig 2) and may occasionally obviate further imaging by establishing an alternative diagnosis such as pneumothorax. Even if chest radiography does not provide a viable alternative diagnosis, it may still be valuable in helping determine whether to perform lung scintigraphy (considered only if chest radiographic findings are normal, to minimize the nondiagnostic rate) or CT pulmonary angiography (which is usually diagnostic even in the setting of chest radiographic abnormalities) (26,27). It is important to note that a normal chest radiograph does not exclude pulmonary embolism.

Lower Extremity US.—Lower extremity US is a noninvasive test that allows direct assessment of deep venous thrombosis (DVT) without the use of ionizing radiation. The main advantage of this test is that a positive result is considered sufficient to justify the use of anticoagulation therapy and should eliminate the need for further imaging (Fig 3). The overall estimated prevalence of venous thrombi in pregnant patients ranges from 0.06% to 8%, but the prevalence among those with clinically suspected pulmonary embolism is uncertain (7,10,13,18). A unique predisposition for DVT of the left lower extremity (approximately 75%–96% of cases) has been shown in pregnant patients and is thought to be related to compression of the left common iliac vein by the crossing right iliac artery or to increased mass effect by the gravid uterus (10,13,18,28).

Lower extremity US is clearly indicated as a first-line test among pregnant women with symptoms of DVT; however, as in the general population, its role in the absence of leg symptoms is uncertain (29). In addition, it is unclear whether the distal (below the knee) veins should be included given the reported range of the diagnostic accuracy of US in these veins and whether such a diagnosis will alter treatment or outcomes (30).

It is important to be aware that negative examination results warrant further imaging in the setting of clinically suspected pulmonary embolism



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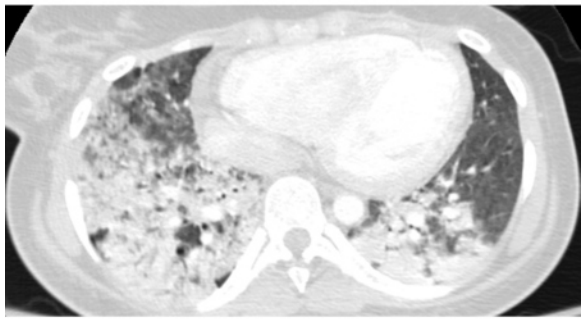


b.

Figure 2. Pulmonary hemorrhage in an 18-year-old woman at 29 weeks gestation with a history of pulmonary hemosiderosis. The patient presented with shortness of breath. Chest radiograph **(a)** and CT pulmonary angiographic image **(b)** display diffuse ground-glass opacities and consolidation suggestive of pulmonary hemorrhage. No pulmonary embolism was found.

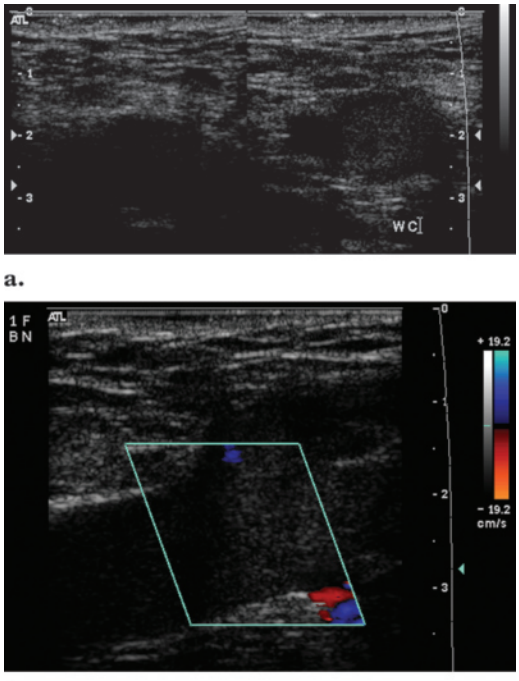
for two reasons: *(a)* pulmonary embolism may occur in the absence of evidence of DVT, and *(b)* isolated DVT of the pelvic veins (ie, iliac and gonadal veins) may occur with patent lower extremity veins in a substantial minority (~20%–29%) of the general population (10,31–34). The true prevalence of pelvic DVT in the pregnant population is uncertain but is suspected to be higher than that in the general population (35).

Second-Line Imaging Tests

CT Pulmonary Angiography.—CT pulmonary angiography has gained widespread acceptance as the new standard of reference for di-

Table 1
Overview of CT Pulmonary Angiography

Component	Description
Advantages	Multiple trials documenting its high sensitivity and specificity in the general population
	Short acquisition time and ease of access and interpretation
	Capacity to definitively depict clot and provide an alternative diagnosis
	Negative test effectively excludes diagnosis of pulmonary embolism in most low- to intermediate-risk populations
Disadvantages	Physiologic changes of pregnancy may increase the nondiagnostic rate
	High maternal breast radiation dose
	Inherent false-positive and false-negative rates, especially in low- and high-risk patients, respectively, according to clinical risk criteria
	Risk associated with use of iodinated contrast material (contraindicated in patients with a history of anaphylactic reaction)
Clinical implications	Provides confident diagnosis
	Estimation of clot burden may be useful for comparison to future examinations (Fig 4)
	Alternative diagnosis (eg, pneumonia) may stop work-up (Fig 2)
	Nondiagnostic results may require repeat examination or serial US
Future outlook	Already considered the new standard of reference for imaging in the general population
	New guidelines pending to determine recommended role in pregnant population
	Clinical application of dose reduction techniques to minimize overall radiation dose without compromising accuracy (Fig 8, Table 4)



a.

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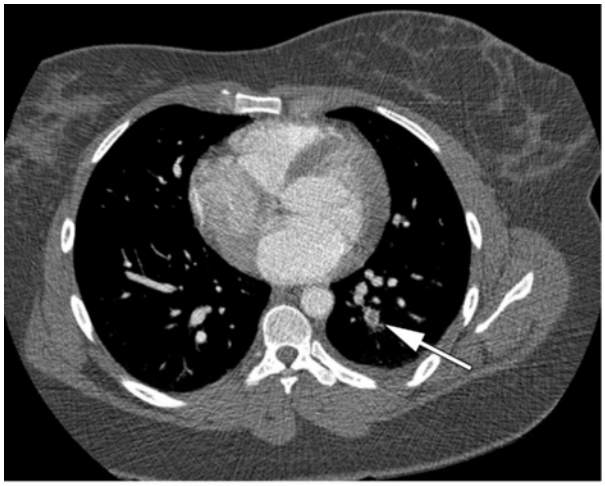
Figure 3. DVT of the left common femoral vein in a 31-year-old woman at 33 weeks gestation with a history of DVT and heterozygote prothrombin mutation. The patient presented with left lower extremity swelling and occasional chest pain. **(a)** Gray-scale US image of the lower extremity shows noncompressible echogenic thrombus within the left common femoral vein. *WC* = with compression. **(b)** Color Doppler US image of the lower extremity shows lack of flow within the left common femoral vein. Work-up for pulmonary embolism was withheld and anticoagulation therapy initiated.

agnosing pulmonary embolism in the general population due to its high sensitivity and specificity and potential cost effectiveness (6,12,15,36–38). It is also commonly used in pregnant patients with suspected pulmonary embolism. For example, in a survey of the Society of Thoracic Radiology membership, 75% of respondents reported having performed CT pulmonary angiography in pregnant patients (5). The advantages of CT pulmonary angiography (Table 1) include its rapidity, widespread accessibility, direct depiction of clot



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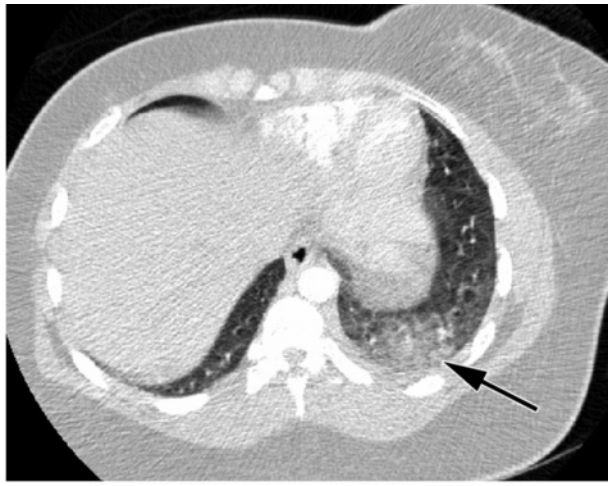

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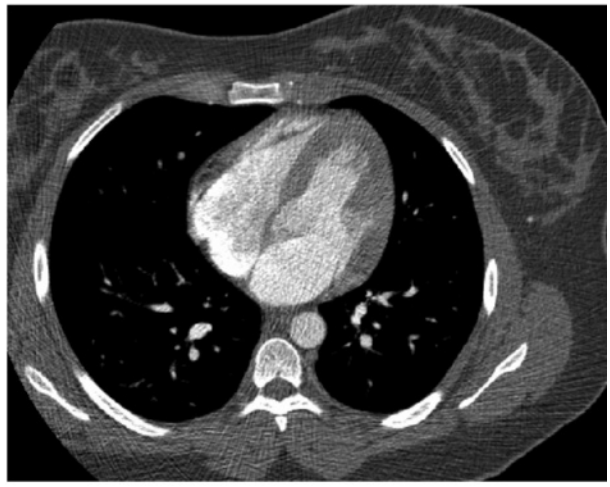


c.

Figure 4. Pulmonary embolism in a 25-year-old woman at 14 weeks gestation who presented with chest pain and hemoptysis. **(a, b)** CT pulmonary angiographic images show acute thrombus within the left lower posterior basal segmental artery (arrow in **a**) and peripheral consolidation suggestive of infarction (arrow in **b**). **(c)** CT pulmonary angiographic image obtained for suspected recurrent pulmonary embolism 6 months after treatment shows resolution of the thrombus seen in **a**.

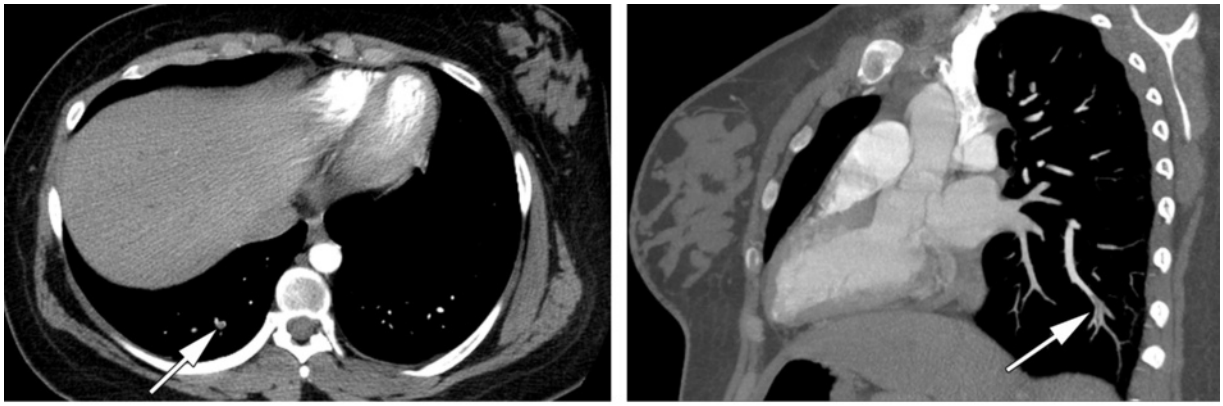
burden (Figs 4, 5), and capacity to help diagnose alternative causes (36,38–40).

Relative disadvantages include radiation exposure to the maternal breasts and fetus and risks related to iodinated contrast material. In addition, it has been suggested that the nondiagnostic rate of CT pulmonary angiography may be slightly higher in pregnant patients due to increased circulatory volume and altered cardiac output, which may increase flow artifacts (7). On the other hand, a recent study showed comparable image quality in pregnant and nonpregnant patients (41). Although CT venography is often performed in the general population, its routine use is not recommended in pregnancy due to dose concerns (36).

In keeping with the "as low as reasonably achievable" principle, radiologists should be familiar with dose reduction methods used with

Table 2
Methods of Reducing the Radiation Dose to the Maternal Breast and Fetus at CT Pulmonary Angiography

Thin-layer bismuth breast shield
Lead shielding
Reduction in tube current
Reduction in tube voltage
Increase in pitch
Increase in detector collimation thickness
Reduction of z-axis
Oral barium preparation
Elimination of lateral scout image
Fixed injection timing rather than test run
Elimination of any additional CT sequences



a. b.

Figure 5. Pulmonary embolism in a 21-year-old woman who presented with chest pain. The patient had undergone cesarean section 6 days earlier. Axial **(a)** and oblique **(b)** CT pulmonary angiographic images show a subsegmental pulmonary embolism in the right lower lobe (arrow).

Table 3
Comparison of Standard and Reduced-Dose CT Pulmonary Angiography Protocols

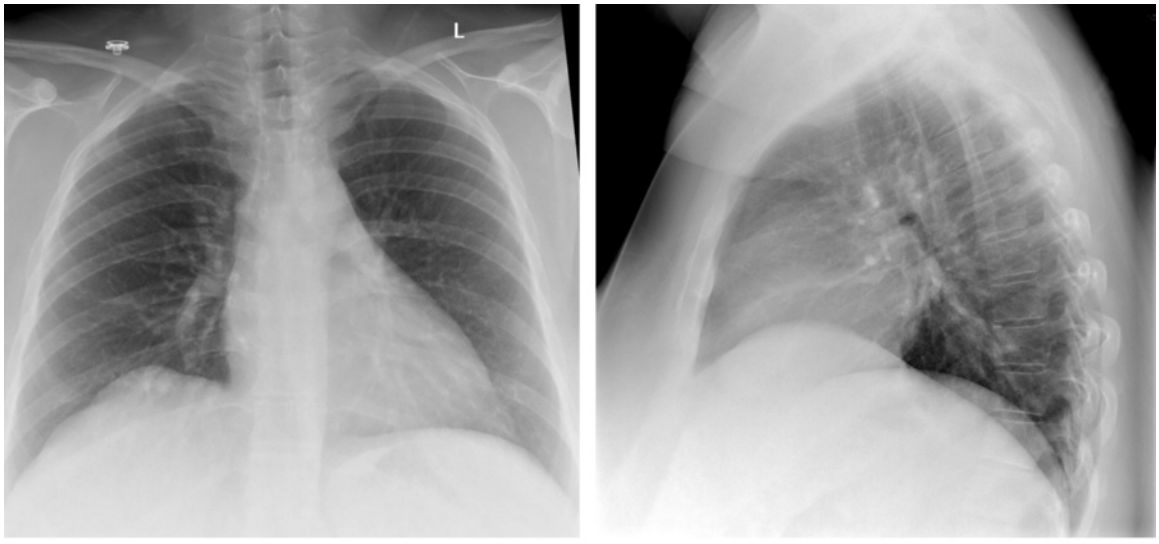
Parameter	Standard Protocol	Reduced-Dose Protocol
Kilovolt peak	120	100
Milliamperage	200	100
Scanning range	Entire thorax	Aortic arch to diaphragmatic domes
Bolus timing	Automatic trigger	Standard 15-sec delay
Injection rate (mL/sec)	4	4
Effective dose (mSv)*	10.2	2.7

*Estimated dose calculated with CT dose index/dose-length product generated by CT scanner (41).

CT pulmonary angiography in pregnant patients (Table 2). The most common method for reducing dose is to alter CT acquisition parameters, including decreasing the milliamperage, kilovolt peak, and craniocaudal (z-axis) extent of acquisition. Recently, Litmanovich et al (41) compared the use of a modified, low-dose CT pulmonary angiography protocol in pregnant patients with that of a standard-dose protocol in matched controls. They were able to achieve significant decreases in the calculated effective dose relative to the standard protocol, while maintaining diagnostic quality (Table 3). Dose reduction methods unrelated to the CT imaging parameters include the use of bismuth breast shields to decrease maternal breast dose and of oral barium and lead shielding to minimize radiation exposure to the fetus (25,42–46).

Table 1 provides an overview of CT pulmonary angiography in terms of advantages, disadvantages, clinical implications, and future outlook (5–9,15,17,36,39,40,47–49).

Lung Scintigraphy.—Lung scintigraphy (ventilation-perfusion [V/Q] scanning) has been used less frequently in the general population in the era of CT pulmonary angiography, but it is interesting to note that a majority of Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED) II investigators currently recommend this method for the evaluation of pulmonary embolism in pregnant patients (6). Although scintigraphy is diagnostic when the results are



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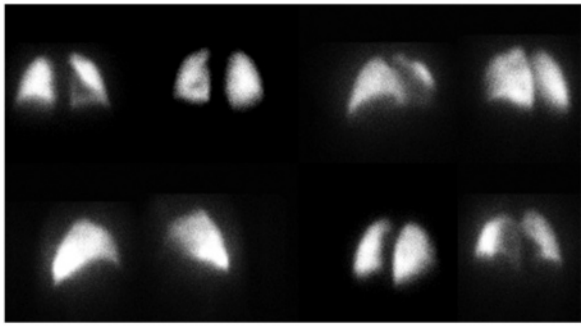


c.

Figure 6. Posteroanterior **(a)** and lateral **(b)** chest radiographs and perfusion-only V/Q scan (4 mCi of technetium-99m macroaggregated albumin) **(c)** obtained in a 38-year-old woman at 24 weeks gestation who presented with shortness of breath and occasional hemoptysis show normal findings.

normal or indicate a high probability of pulmonary embolism, it is nondiagnostic when interpreted as indicating an intermediate probability or when a low-probability study is coupled with a high clinical suspicion for pulmonary embolism (36,50,51). Interestingly, 73%–92% of V/Q scans in pregnant patients have demonstrated normal findings (Fig 6) (7,26). It is reasonable to reserve V/Q scanning for patients with normal chest radiographic findings and no history of asthma or chronic lung disease, since diagnostic results may be achievable in up to 97% of this patient population (26,27).

Teaching Point

Dose reduction can be readily achieved by eliminating the ventilation portion of the examination in patients with normal perfusion and by decreasing the dose of the perfusion component by 50%. Such methods are commonly used in pregnant patients. For example, in a survey of nuclear medicine centers in the United States, over 75% of respondents reported using half-dose perfusion techniques in the pregnant population (52). The ability to make an accurate diagnosis with the perfusion scan alone has been confirmed by prior studies (25,36,53). Table 4 lists additional means of dose reduction (52).

The relative advantages and disadvantages of scintigraphy are summarized in Table 5, along with clinical implications and future outlook (2,5–9,26,27,36,48,50–55). The major advantage of scintigraphy over CT pulmonary angiography is the lower radiation dose to the maternal breast; its major disadvantage is its inability to provide an alternative diagnosis in the absence of pulmonary embolism.

Magnetic Resonance Imaging.—Magnetic resonance (MR) imaging has potential advantages for imaging the pregnant population due to its lack of ionizing radiation and the absence of proved harmful effects to the mother or fetus (49). Recent

Table 4
Methods of Reducing Fetal Radiation Dose at Lung Scintigraphy

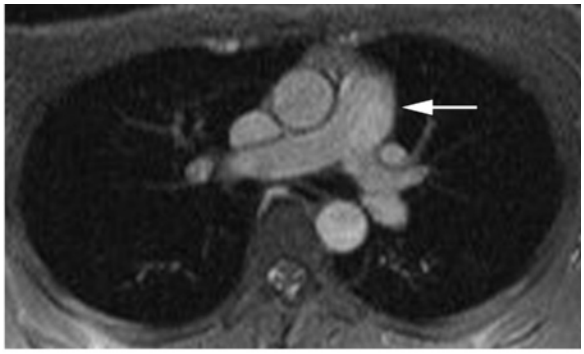
Reduce dose of perfusion agent
Reduce dose of ventilation agent
Eliminate ventilation portion of scan
Either encourage patient to void frequently or insert Foley catheter to reduce fetal exposure to radiotracer in the bladder

Table 5
Overview of Lung Scintigraphy

Component	Description
Advantages	Radionuclide poses minimal inherent risk and is considered safe for use during pregnancy
	Low maternal breast radiation (30–630-fold less than with CT pulmonary angiography)
	Age and health status of majority of pregnant population minimizes nondiagnostic rate compared with general population
Disadvantages	Inability to provide alternative diagnosis in the absence of pulmonary embolism
	Limited access and interpretability after hours at some centers
	Long acquisition time
	3%–25% nondiagnostic rate leading to further imaging
Clinical implications	Clinically helpful only if normal probability, low probability (Fig 5), or high probability
	Withholding treatment in low-risk patients with nondiagnostic results may be acceptable
	Nondiagnostic rate reduced by excluding patients with lung disease or abnormal chest radiographs
	Fetal dose minimized with use of low-dose perfusion–only technique without compromise in accuracy
	Can be used in patients with contrast material allergy or impaired renal function
Future outlook	Mixed recommendations as initial second-line test, favored by PIOPED* II investigators as means of imaging in pregnancy
	Lower breast dose and lower nondiagnostic rate in the pregnant population may suggest a role later during pregnancy or the postpartum period, when radiation risk to glandular breast tissue is presumed higher

*Prospective Investigation of Pulmonary Embolism Diagnosis.

developments in pulmonary MR angiography include techniques to improve spatial resolution, shorten acquisition time, and diminish motion artifacts. A protocol that combines true fast imaging with steady-state precession and gadolinium-enhanced perfusion MR angiography performed with a parallel acquisition technique has displayed a high sensitivity and specificity for pulmonary embolism (100% and 93%, respectively) in the general population compared with 16-detector CT pulmonary angiography (56). The average acquisition time for this technique is approximately 10 minutes (56). Perfusion MR imaging appears to represent the best stand-alone technique (sensitivity and specificity of 100% and 91%, respectively) in that it can provide indirect signs of distal emboli that are not visualized with other techniques. However, because gadolinium-based contrast agents have not been proved to be safe in pregnant patients, there is a need for further improvement in unenhanced MR imaging techniques, which currently allow accurate evaluation of only the central and first-order arterial branches (Fig 7) (48,56). Nevertheless, MR imaging may be valuable in pregnant women with known allergy to iodinated contrast material in whom a scintigraphic



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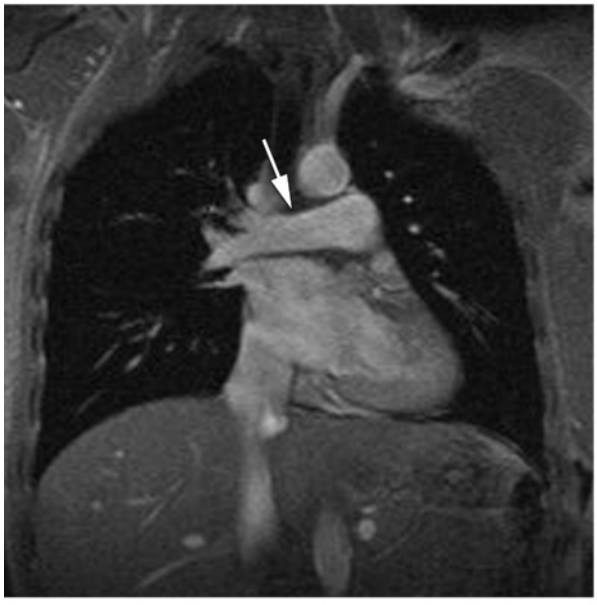

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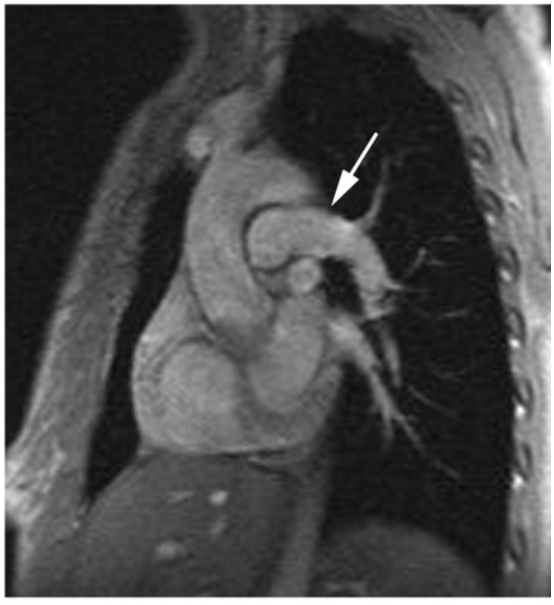

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Figure 7. **(a)** Axial unenhanced gradient-echo MR image obtained in a 23-year-old woman at 12 weeks gestation who presented with chest pain shows normal homogeneous high signal intensity and flow at the level of the main (arrow), right, and left pulmonary arteries. **(b, c)** Coronal **(b)** and sagittal **(c)** two-dimensional cine cardiac-gated gradient-echo MR images help confirm the absence of central filling defects in the proximal right (arrow in **b**) and proximal left (arrow in **c**) pulmonary arteries. Subsegmental branches are not seen.

study is interpreted as intermediate probability or when a low-probability study is coupled with a high clinical suspicion for pulmonary embolism.

Non-gadolinium-enhanced real-time MR imaging has shown a sensitivity and specificity of 89% and 98%, respectively, in the detection of pulmonary embolism compared with CT, with non-gadolinium-enhanced MR angiographic techniques showing highly variable sensitivity and specificity (56,57). Inclusion of DVT imaging with unenhanced techniques is feasible in the pregnant population and may help detect additional thromboembolic disease when imaging findings are negative for pulmonary embolism (31–34,57). A combined DVT–pulmonary embolism MR imaging protocol can be completed in approximately 20 minutes (32). Overall, given the uncertain safety of gadolinium use in pregnant patients and the limited data on the effectiveness of unenhanced techniques, clarification of the role of MR imaging in pregnant patients with suspected pulmonary embolism will require further research and refinement. Table 6 provides an overview of MR imaging in terms of advantages, disadvantages, clinical implications, and future outlook (31–34,48,56,57).

Conventional Pulmonary Angiography.— Conventional pulmonary angiography currently plays a very limited role in the imaging of pulmonary embolism in the general population and has almost no role in the pregnant population. Potential exceptions are *(a)* cases in which other tests such as CT pulmonary angiography and lung scintigraphy are nondiagnostic, and *(b)* cases involving unstable patients with high clot burdens who may not be candidates for venous thrombolysis and thus require mechanical thrombectomy (17,58).

Table 6
Overview of MR Imaging

Component	Description
Advantages	No ionizing radiation or iodinated contrast material
	"One-stop shopping" for the evaluation of pulmonary embolism, pulmonary perfusion, and DVT
	Very low prevalence of allergic reaction
Disadvantages	24/7 access and availability of personnel for interpretations not possible at many centers
	Longer acquisition time (10–20 min) and more claustrophobic environment
	Limited capacity to depict subsegmental branches and provide an alternative diagnosis (Fig 7)
	Multiple contraindications including pacemakers and implanted devices
	No clinical trials specifically evaluating the pregnant population
Clinical implications	Positive result allows appropriate treatment and DVT imaging integration
	Mainstream usage in the pregnant population will likely be determined by future studies performed with non-gadolinium-enhanced techniques because contrast agents containing gadolinium have not proved to be safe in pregnancy
	Method of choice for assessing the presence of pelvic vein DVT
Future outlook	Data forthcoming from PIOPED* III trial comparing MR imaging with CT pulmonary angiography/CT venography will likely influence usage and reimbursement
	Newer noncontrast three-dimensional high-resolution respiratory-triggered cardiac-gated acquisitions may allow improved visualization of segmental and subsegmental levels

*Prospective Investigation of Pulmonary Embolism Diagnosis.

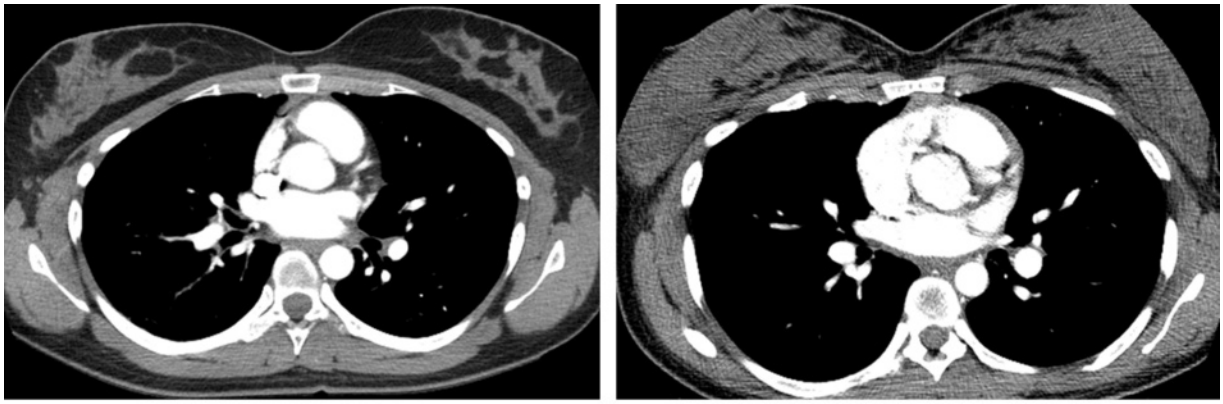
Table 7
Radiation Exposure of Various Imaging Examinations Performed for Pulmonary Embolism

Examination	Effective Whole-Body Dose (mSv)	Fetal Dose (mGy)	Effective Dose per Breast (mGy)
PA/lateral CXR	0.06–0.25	0.01	…
Low-dose perfusion scintigraphy	0.6–1.0	0.1–0.37	0.11–0.3
V/Q scintigraphy	1.2–6.8	0.1–0.8	0.22–0.28
CTPA	2–20	0.01–0.66*	10–70
Low-dose CTPA	2.7	…	…
Pulmonary DSA	3.2–30.1	0.5	…
Evaluation of background radiation	2.5	1.1–2.5	…

Note.—Variation in reported doses is largely related to CT settings, number of CT detectors, trimester, patient age, body mass index, and method of dose calculation. CTPA = CT pulmonary angiography, CXR = chest radiography, DSA = digital subtraction angiography, PA = posteroanterior.
*Data from Winer-Muram et al (3) not included due to outdated CT parameters and generation of CT scanner used in their study.

Radiation Exposure

Recent studies suggest that there is a limited understanding among radiologists, nuclear medicine physicians, and pulmonary specialists regarding the relative amount and significance of radiation exposure in lung scintigraphy and CT pulmonary angiography (59,60). It is likely that some of the confusion may stem from the variation in values reported in the literature. This variation arises from multiple factors, including patient body habitus, stage of pregnancy, radionuclide dose, CT parameters or number of detectors, and method of dose calculation (25,61). Table 7 shows the range of doses used with various imaging tests for



a. b.

Figure 8. Axial CT pulmonary angiographic images obtained in a healthy nonpregnant woman with a standard radiation dose **(a)** and in a pregnant woman with a low-dose protocol **(b)** show no pulmonary embolism and similar image quality

pulmonary embolism as reported by a variety of sources (3,6,22,25,36,46,61–66). A recent study (25) in which fetal dose was calculated with an anthropomorphic model (using a 16-detector CT scanner and traditional CT pulmonary angiography protocol) showed relatively higher doses than did previous studies with single-detector CT and contradicts previous reports that CT pulmonary angiography results in a lower fetal dose than does traditional lung scintigraphy (3,59,64,66). These investigators reported estimated fetal doses with CT pulmonary angiography of 0.24–0.66 mGy up to the end of the first trimester and fetal doses with lung scintigraphy of 0.32–0.36 mGy (25). On the other hand, the fetal dose for 64-section CT performed on a phantom model was recently estimated at 0.06–0.23 mGy, which is lower than the values reported for lung scintigraphy (46). We emphasize that fetal doses with both CT pulmonary angiography and lung scintigraphy are safe (with minimal risk of neoplasm induction), and that the small differences described earlier should not be the only consideration when deciding which study to perform.

Regarding the risk of maternal breast cancer, it has been estimated that a patient's lifetime excess relative risk at age 25 years following one 64-detector CT pulmonary angiographic examination is 1.5% (61). A single 10-mGy dose to the breast has been estimated to increase the lifetime risk of breast cancer in a 30–35-year-old woman by 0.2%–14% (65). However, the risk during pregnancy is likely increased due to the radiosensitivity of the more glandular breast tissue (67). It is important to note that there is an estimated 30–630-fold greater breast dose with CT pulmonary angiography (Table 7) than with low-dose perfusion scintigraphy, with breast dose values well above the traditional 3 mGy used in screening mammography and equivalent to exposure from hundreds of chest radiographs (22,62,63). The cancerous effects of current CT procedures are not expected to be known for 10–30 years and are difficult to extrapolate. Given the increased risk of breast cancer to women who undergo CT pulmonary angiography, it is likely that dose reduction methods used in pregnant patients could be beneficial to other young (nonpregnant) women undergoing this procedure (Fig 8; Tables 2, 3) (25,42–45,52,61,63,68).

Teaching Point

Iodinated Contrast Material

The risks resulting from the use of iodinated contrast material, including allergic reaction and nephrotoxicity, are similar for pregnant patients and the general population. Thus, CT pulmonary angiography should be withheld in pregnant patients with a history of previous major allergic reaction to contrast material or impaired renal function. With regard to the potential risk to the fetus posed by the intravenous administration of contrast material, it is known that contrast agents administered to the mother pass to the fetus either via the placenta or directly from aspirated amniotic fluid. For example, fetal bowel opacification in mothers who have received contrast material has been reported recently and, in fact,

dates back to 1979 (49,69,70). To our knowledge, there have been no studies in humans that have shown fetal risks from intravenous contrast material administered for prenatal CT; however, a theoretic risk is presumed, given the known effect of iodine exposure on infant thyroid function (49,71). Fetal thyroid dysfunction has been reported in some series evaluating the use of amniography, although the fetus is directly exposed to much larger volumes of iodinated contrast material during these examinations than during CT pulmonary angiography (49,72). Although there is no convincing evidence in the literature to support the theoretic risk of contrast material–induced thyroid dysfunction, we point out that thyroid function screening is routinely performed in all neonates in the United States regardless of whether there has been prenatal exposure to contrast material. Although cessation of breastfeeding for 24 hours after contrast material administration is commonly practiced, recent guidelines raise questions regarding this practice and do not recommend termination of breastfeeding (73).

Risk Management

Despite the general consensus that diagnostic imaging is indicated for the evaluation of suspected pulmonary embolism in pregnant patients, radiologists and nuclear medicine physicians should be aware that such imaging involves a medicolegal risk (55). For successful risk management, radiologists should adhere to the following guidelines outlined by Berlin (55) for imaging pregnant patients: *(a)* radiology facilities should have a process for evaluating patients who are pregnant, *(b)* radiologists should be knowledgeable about radiation effects and should be accessible to patients and their referring physicians, and *(c)* all discussions with patients about the risks of radiation exposure should be documented in the radiology report.

Two previous surveys suggest that many radiologists and nuclear medicine physicians are imaging pregnant patients without giving careful attention to these risk management guidelines. For example, a survey of nuclear medicine physicians found that 70% of respondents did not have a written policy addressing lung scintigraphy during pregnancy and that 49% did not obtain informed consent prior to the procedure (52). Similarly, the survey of Society of Thoracic Radiology members mentioned earlier found that 84% of respondents did not have a written policy concerning CT pulmonary angiography in pregnancy and that 40% did not obtain informed consent prior to the procedure (5).

Although it is recommended that radiologists be knowledgeable about radiation effects, it is also important to be aware of a general lack of knowledge about radiation risks among many nonradiologists who are involved in the care of pregnant patients. For example, in a survey by Ratnapalan et al (60) that assessed physicians' perceptions of teratogenic risk associated with radiography and CT performed during pregnancy, 5%–6% of family medicine physicians and obstetricians reported that they would recommend an abortion following abdominal CT performed in early pregnancy. Thus, radiologists should be aware of their responsibility to counsel referring physicians with regard to estimated doses and risks of examinations performed during pregnancy. We recommend that the radiologist discuss each case with the ordering physician prior to obtaining consent. When feasible, it may be helpful to have the ordering physician present for the consent procedure.

With respect to obtaining informed consent, we recommend that the radiologist *(a)* explain the need for imaging to diagnose pulmonary embolism and the importance of the diagnosis for the patient's care, *(b)* provide a brief explanation of the imaging test that has been ordered by the patient's clinical physician, *(c)* summarize the estimated radiation risks to the mother and fetus, and *(d)* confirm the patient's understanding of and consent to the diagnostic imaging test. The low risk of fetal harm with either CT pulmonary angiography or lung scintigraphy compared with spontaneous risk (~15% for spontaneous abortion and 1%–3% for major malformation) should be emphasized (60). Patients past 15 weeks' gestation should be advised of the even lower risk of malformations of the central nervous system.

Although in this article we have focused on the imaging of patients who are known to be pregnant, we recognize that there will be rare instances in which diagnostic tests for pulmonary embolism are performed before a patient is confirmed as pregnant. In such cases, a discussion with the patient and her referring physician may be helpful in confirming the relative safety of the examination and in communicating the estimated fetal-maternal radiation dose involved. Such a

discussion has the potential to avoid unnecessary termination of the pregnancy due to misconceptions about fetal dose and risk (24,73).

Conclusions

To help "deliver" the most appropriate care to pregnant patients with suspected pulmonary embolism, radiologists should be familiar with the relative advantages and disadvantages of available imaging modalities, methods for dose reduction, radiation risks, and risk management guidelines. Diagnostic imaging tests clearly play an important role in the evaluation of pregnant patients with suspected pulmonary embolism but should be performed with careful attention to minimizing radiation risk and in accordance with risk management guidelines.

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Imaging Pregnant Patients with Suspected Pulmonary Embolism: What the Radiologist Needs to Know

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A diagnosis of pulmonary embolism in pregnancy has important implications, including the need for prolonged anticoagulation therapy, delivery planning, and possible prophylaxis during future pregnancies, as well as concern about future oral contraceptive use and estrogen therapy (1-4).

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In pregnant patients, the diagnosis of pulmonary embolism is complicated by normal physiologic changes during pregnancy (eg, leg swelling, pain, dyspnea, tachypnea, tachycardia, palpitations) that may mimic signs and symptoms classically associated with pulmonary embolism (14).

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In this context, it is important to note that even a combination of chest radiography, lung scintigraphy, computed tomographic (CT) pulmonary angiography, and traditional pulmonary angiography exposes the fetus to around 1.5 mGy of radiation, which is well below the accepted limit of 50 mGy for the induction of deterministic effects in the fetus and similar to background radiation exposure to the fetus of 1.1-2.5 mGy (3,21,25).

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It is reasonable to reserve V/Q scanning for patients with normal chest radiographic findings and no history of asthma or chronic lung disease, since diagnostic results may be achievable in up to 97% of this patient population (26,27).

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It is important to note that there is an estimated 30--630-fold greater breast dose with CT pulmonary angiography (Table 7) than with low-dose perfusion scintigraphy, with breast dose values well above the traditional 3 mGy used in screening mammography and equivalent to exposure from hundreds of chest radiographs (22,62,63).