Chest imaging in pregnant patients with COVID-19: Recommendations, justification, and optimization

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Abstract

Evaluation of COVID-19 related complication is challenging in pregnancy, due to concerns about ionizing radiation risk to mother and the fetus. Although there are instances when diagnostic imaging is clinically warranted for COVID-19 evaluation despite the minimal risks of radiation exposure, often there are concerns raised by the patients and sometimes by the attending physicians. This article reviews the current recommendations on indications of chest imaging in pregnant patients with COVID-19, the dose optimization strategies, and the risks related to imaging exposure during pregnancy. In clinical practice, these imaging strategies are key in addressing the complex obstetrical complications associated with COVID-19 pneumonia.

Introduction

Corona virus disease of 2019 (COVID-19) is a viral disease caused by severe acute respiratory syndrome-Coronavirus-2 (SARS-COV-2).[1] The disease first originated in the Hubei province of China, later sweeping through the continents and evolving to become a global pandemic. The detailed insights into the disease manifestations, heterogeneity, and physiological behavior of the virus, including pulmonary and extra pulmonary manifestations of COVID-19, are being better understood with new research studies and clinical experiences.

There is a relative higher risk of COVID-19 infection during the time of pregnancy,[2] thereby creating constraints and clinical dilemma on proceeding with the use of an appropriate radiological investigation.[3] The clinical pathway for evaluating COVID-19 and its associated complications in pregnancy is highly variable, depending on the institutional preferences, availability of resources, practice pattern of referring clinicians, and interpreting radiologist.

Imaging studies which involve radiation exposure like chest X-ray and chest CT scan are indispensable in the management of COVID-19 patients. Radiologists around the globe should be familiar with merits and limitations of various chest imaging modalities in evaluation of COVID-19 pneumonia and its complications during pregnancy. In this review, we aim to summarize the current recommendations on indications of chest imaging in pregnant COVID-19 patients

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including chest X-ray, CT chest, CT pulmonary angiogram, chest ultrasound, and cardiac MRI, with emphasis on imaging risks and dose optimization strategies.

Features of COVID-19 in pregnancy

Epidemiology

Recent surveillance data from the Centers for Disease Control and Prevention (CDC), in the women aged between 15 to 44 years, showed pregnant women were more likely to be hospitalized, requiring an intensive care unit (ICU) care or ventilation.[4] However, large cohort study from the United Kingdom observed that the rates of ICU admission or maternal mortality in severe disease were similar to non-pregnant women in the reproductive age group.[5] Pregnant women are more susceptible to infections owing to the immunity changes during the time of pregnancy.[6] There are guidelines from the CDC, the American College of Obstetricians and Gynaecologists (ACOG), the Society for Fetal-Medicine (SMFM), and the Royal College of Obstetrics and Gynaecologists (RCOG) related to the management of COVID-19 in pregnancy.[7–13]

Complications related to COVID-19 in pregnancy

Chest complications related to COVID-19 in general include a spectrum of findings related to airway, alveolar, vascular, and cardiac involvement. Recent studies have shown an increased incidence of complications in pregnancy due to COVID-19, especially preeclampsia, eclampsia, HELLP syndrome, and increased risk for maternal mortality.[14] Furthermore, the complications are augmented with pre-existing or underlying comorbidities like obesity, diabetes mellitus, systemic hypertension, and cardiac diseases.[15]

Diagnosis and clinical severity classification in pregnancy with COVID-19

RT-PCR is considered the reference standard for diagnosis of COVID-19 in pregnancy.[16] Prior studies have reported the RT-PCR positive rates in asymptomatic pregnant women between 50 and 89%,[17–19] while false negative rates varied from 17 to 63%.[20] The categorization of pregnant patients with COVID-19 based on the severity of illness is similar to other adult patients with COVID-19. They are categorized into asymptomatic, mild, moderate, severe or, critical[21] (Table 1). There are instances when the initial clinical presentation related to an upper or lower respiratory tract infection related to bacterial or other non-COVID-19 viral infection may raise the suspicion for COVID-19,[22] the imaging in such a scenario may be tailored according to the disease severity, clinical suspicion, and the trimester.

Evaluation of COVID-19 pneumonia in pregnancy

(1) Utility of chest X-ray

Recommendations. The position statement by Fleischner society and ACOG recommends that routine imaging should not be used in asymptomatic or mild illness severity patients and also in intubated stable patients with COVID-19.[8,23] The ACOG and SMFM recommends chest X-ray in patients with moderate clinical risk based on illness severity and underlying comorbidities in all trimesters,[10] while the RCOG recommends that the radiographic investigations such as chest radiograph and CT chest should be performed in pregnant patient with COVID-19 as for the non-pregnant adult and chest imaging should be performed when indicated and should not be delayed over concerns of fetal radiation exposure, as the maternal well-being is paramount.[13] In practice, chest X-ray should not be used for arriving at a diagnosis of COVID-19 in pregnant patients, instead it is recommended to rely on RT-PCR confirmation of the disease status. Follow-up chest X-ray should be judiciously considered only when there is further clinical deterioration and situations that would impact patient care.

Table 1. Clinical disease spectrum in patients with COVID-19.

Illness severity	Clinical signs or symptoms
Asymptomatic or pre-symptomatic patients	Viral positive (RT-PCR or NAAT) without any symptoms
Mild illness	Patients with COVID-19 symptoms, without dyspnea, shortness of breath
Moderate illness *	Clinical or imaging assessment showing COVID-19 pneumonia with oxygen saturation (SpO2) >94% at room air or sea level
Severe illness *	Respiratory rate >30 per minute, SpO2 < 94% on room air or at sea level, ratio of arterial partial pressure of oxygen to fraction of inspired oxygen (PaO2/FiO2) < 300, or chest X-ray showing lung infiltrates with >50% involvement
Critical illness *	Patients with respiratory failure, septic shock, or multiorgan dysfunction

COVID-19-corona virus disease 2019; NAAT- nucleic acid amplification test, RT-PCR- reverse transcriptase polymerase chain reaction.* Disease severity that might require an imaging with chest X-ray, CT chest, or CT pulmonary angiogram depending on the clinical assessment and disease status

Table 2. Dose descriptors relevant for dose optimization.

Dose descriptor	Units	Definition	Calculation	Effect on radiation dose	Dependant CT parameters
CTDI (vol)	mGy	Measure of radiation from CT scanner assessed with 16 or 32 cm phantom	Weighted average to depict radiation across the phantom	Linear relationship between CTDI (vol) and exposure dose	Tube voltage, current, pitch, and phantom
Dose length product (DLP)mGy-cm	mGy-cm	Indicator of extend of Z-axis coverage and CTDI (vol)	CTDI (vol) x length of scan in cm	Linear relationship between CTDI (vol) and exposure dose	CTDI (vol), scan length, and number of acquisitions
Effective dose	mSv	Theoretical uniform whole body dose	DLP x conversion factor (k)	Linear relationship between mSv and absorbed dose	DLP, patient size, and radio sensitivity of involved organs
Size specific dose estimate (SSDE)	mGy	Dose measured for patient size/habitus	CTDI x correction factor dependant on patient diameter	Automated tube current modulation results in large dose for larger patients	Patient body contour along Z-axis and positioning within the gantry
Absorbed dose	mGy	Ionizing radiation absorbed (Joule) by tissue (kg)	Estimated from size specific dose estimate (SSDE)	—	DLP, patient size, and organ scanned

Optimization strategies in chest x-ray. In routine chest X-ray, the pelvis or gravid uterus is generally not exposed to direct X-ray beam, and can be safely performed with optimization strategies.[24] However, in third trimester due to gravid uterus reaching the upper abdomen, parts of fetus can get exposed to a direct X-ray beam, and this needs to be taken care of using an appropriate technique. Dose optimization strategies to reduce the maternal and fetal dose include collimating on the lungs and avoiding upper abdomen as much as possible with an abdominal lead shield[25] placed over the abdomen or back depending on Antero-Posterior (AP) or Postero-Anterior (PA) radiographs, respectively, and also to limit the chest radiograph to frontal view and avoiding a lateral radiograph.[24]

(2) Utility of CT

Pattern of lung involvement in COVID-19 includes ground glass opacities (GGO), GGO with consolidation, and only consolidation are similar to non-pregnant patients.[26–29] However, the imaging findings have close overlap with other viral lung infections like influenza virus, MERS-COV, SARS, H1N1, H5N1, and H7N9.[26,27]

Recommendations. The position statement by the American College of radiology (ACR)[30] recommends against the use of CT scan as a first-line investigation or for follow-up to assess progression of COVID-19. The Fleischner Society advocates CT scan only in patients with functional impairment, hypoxemia, or after recovery from infection. The SMFM, ACOG, and RCOG recommend that CT chest should not be withheld in pregnant patients when clinically indicated.[10,13] Thus, in pregnant patients the CT chest should be undertaken only in instances where there is functional impairment, hypoxemia, or both.

Unlike other lower respiratory tract viral infections, respiratory decompensation in COVID-19 pneumonia happens later in the disease.[31] Hypoxemia related to acute respiratory failure in pregnancy manifests with partial pressure of oxygen (PaO2) <60 mmHg on room air, that corresponds to oxygen saturation (SpO2) <90 mmhg on room air or sea level.[32,33]

Optimization and dose reduction strategies in CT. Although CT chest do not directly expose the pelvis or gravid uterus to ionizing radiation and can be performed in pregnancy after justification of the benefits, the radiologists should be aware of the dose reduction descriptors[34] and strategies while performing a CT chest or CT pulmonary angiogram for pregnant patients with COVID-19 (Tables 2 and 3). The most common strategies include reducing mA, kVp, Z-axis of acquisition, and iterative reconstruction algorithms.[21,35–37] Reduction in exposure parameters to a certain level is possible with trade-off in image quality without altering the diagnostic accuracy of images. Dose reduction strategies unrelated to CT imaging parameters include reducing the length of scan with strict collimation from the lung apices to diaphragm to minimize maternal and fetal dose and use of lead shield coverage over the maternal abdomen and bismuth breast shield to maternal breasts. Although, the lead shielding to wrap the abdomen during the CT chest scan may reassure the patient of the safety of fetus, the fetal dose received due to CT chest is primarily related to internal scatter, which is not altered by abdominal shielding.[38] The use of breast shielding

Table 3. Dose optimization strategies.

CT parameter	Optimization recommendations
Tube current modulation	Check tube current saturation and adjust parameters like tube voltage and speed to attain maximal dose reduction
Optimal tube voltage at equivalent radiation dose	Selection of most efficient tube voltage that can reduce dose as much as possible depending on the scanner efficiency
Longitudinal scan range	Aortic arch to the diaphragm avoiding the upper abdomen as much as possible
Scan modes	Use low dose, ultra-low dose modes, high pitch dual energy modes
Noise reduction image reconstruction algorithms	Noise reducing, spatial resolution preserving algorithms like iterative reconstruction at low radiation dose
Body size regulated CT protocols	Using best-fit equation than dose table or charts
Other CT parameters independent dose reduction strategies	Elimination of lateral scout image
	Fixed injection timing instead of bolus triggering
	Avoiding test run
	Single phase sequence
	Abdominal lead shielding

is controversial as it can degrade the image quality due to increased noise and make the automatic exposure control unpredictable. However considering the increased radio-sensitivity of breast parenchyma in pregnancy, breast shielding can be selectively used with proper training.[39,40] In such a scenario, the dose reduction strategies implemented in pregnant patients should be utilized in non-pregnant young females undergoing COVID-19 imaging as well.

Overall, the dose reduction strategies should be tailored depending on the resources available with the institution, and the focus should be on implementing a low dose or ultra-low dose strategies for CT imaging in pregnant patients with COVID-19 and to bring down the effective dose below 3 mSv.[41]

(3) Utility of chest USG

The International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) recommends using an ultrasound for lung examinations in pregnant patients with COVID-19 as it has the advantage of being radiation free and can be performed at the same time along with obstetric ultrasound which in turn saves time and improves the clinical workflow. Also it can be considered as an alternate when chest radiograph or CT scan is not available.[42] On ultrasound, the normal horizontal "A-lines" (A-lines refers to horizontal echogenic reverberation artefacts that occur in normal lungs, beneath the pleural line at multiples of distance between the ultrasound probe and visceral-parietal pleural interface) are replaced by abnormal "B-Lines" when there is early loss of aeration but not completely consolidated (B-Lines refers to artefact in ultrasound caused as a result of loss of aeration in alveolar-interstitial space). While a consolidation results in absence of A- and B-lines, with a hyperechoic "white lungs".

Evaluation of pulmonary embolism in pregnancy with COVID-19

Utility of CT pulmonary angiogram

Pulmonary embolism is reported to occur commonly in patients with COVID-19 with a reported incidence ranging from 0.7–57%, more often associated with severe disease.[43] Pregnancy is associated with a five-fold increased risk for developing pulmonary embolism, due to decreased fibrinolysis, hypercoagulability status, venous stasis, and prolonged bed rest. Pulmonary embolism is also a leading cause of maternal death during pregnancy, and the diagnosis during pregnancy has significant implications in planning of delivery and anticoagulation therapy.[44,45] In planning an imaging for COVID-19 to rule out pulmonary embolism, all patients should have been thoroughly evaluated on the pre-test probability of pulmonary embolism using Pulmonary embolism rule out criteria,[46] Wells score,[47] Geneva score,[48] and D-Dimer when indicated. The role of D-dimer assay is limited in pregnant patients as the value can arise above the reference levels as the pregnancy progresses.[49] However, normal D-dimer levels have a high negative predictive value in ruling out pulmonary embolism.

Diagnostic imaging with CT pulmonary angiography is considered a clinically warranted investigation in pregnant patients suspected of pulmonary embolism with COVID-19.[13] However, the initial workup should focus on non-ionizing imaging techniques like lower extremity color Doppler ultrasound. Although the prevalence of lower limb deep vein thrombosis with clinically suspected pulmonary embolism in COVID-19 is uncertain, the advantage of getting a positive deep vein thrombosis on duplex ultrasound is considered sufficient to justify the use of anticoagulation therapy, thereby eliminating the need for further CT pulmonary angiography.[50] If the initial tests are non-diagnostic, CT pulmonary angiography should be

performed as a second line investigation. Figure 1 summarizes a practical diagnostic algorithm for evaluating a pregnant patient with suspected pulmonary embolism in COVID-19.[51] In a setting of COVID-19, the CT pulmonary angiography is preferred over V/Q scintigraphy as it can be used to assess the severity of lung changes for COVID-19 as well.

If there is a positive pulmonary embolism, deep vein thrombosis, or when there is maternal hypoxemia, an obstetric ultrasound for fetal growth, amniotic fluid, and color Doppler imaging should be performed when necessary to assess the extent of fetal hypoxemia.[52]

Risks related to contrast media

The risks related to iodinated contrast material include the possibility of nephrotoxicity and allergic reactions, with similar relative risks for pregnant and general population. The contrast should not be administered when there is prior major allergic reaction to iodinated contrast material or an underlying impaired renal function. Although, the iodinated contrast crosses the placenta to reach the fetus, there are no reported risks for the fetus. There is a theoretical risk of contrast-induced thyroid dysfunction and hence thyroid function screening should be performed in neonates although there is no convincing evidence to support the same.[53,54]

The use of gadolinium should be restricted in pregnancy as few studies have shown association between gadolinium exposure in utero to still births and neonatal deaths. The US Food and Drug Administration (FDA) has categorized gadolinium as pregnancy class 3 drug.[55]

Evaluation of myocarditis in pregnancy with COVID-19

Utility of Cardiac MRI

There is evidence of varying manifestation of myocardial injury associated with ongoing or recently recovered COVID-19 patients, with myocarditis being the most common pattern (in 40% cases) while other complications include myocardial ischemia, right ventricular strain, cardiac thromboembolism etc.[56] Few studies have indicated that the mapping abnormalities and cardiac involvement can be picked up early in the disease with cardiac MRI.[57] Cardiac MRI has shown to be a safe imaging in pregnancy with no risk to the mother. Theoretical concerns of teratogenesis, acoustic damage, and tissue heating have not been sufficiently proven in humans. Moreover in cardiac MRI, field of view is away from the fetus, thereby further reducing the potential harm.[58] There is no different risk in relation to different trimesters as per the American College of Radiology (ACR).[59] The information related to utility of cardiac MRI in pregnant patients with COVID-19 is limited, and with the absence of
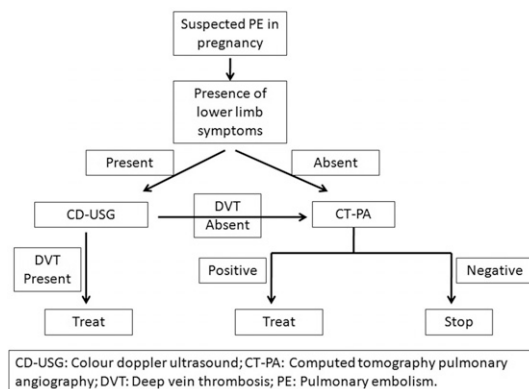

Figure 1. Diagnostic algorithm for evaluation of pregnant patients with COVID-19 suspected of pulmonary embolism.

specific recommendations, the use of cardiac MRI can be considered in pregnancy on a case-to-case basis, and also on the resource availability.

Evaluation of fetal hypoxemia due to maternal pulmonary compromise

Hypoxemia due to maternal respiratory failure in COVID-19 leading to poor oxygenation to placenta and fetus can result in fetal distress.[60,61] Although the emerging evidence suggests vertical transmission is probable, the significance of the same to the neonate is yet to be ascertained. There are emerging data that indicate that this viral infection causes inflammation, villitis, and arteriopathy in placenta.[62,63] Fetal distress and preterm pregnancy are common obstetrical complications of COVID-19.[64] Assessment for acute placental insufficiency and fetal hypoxia can be easily assessed with obstetric Doppler ultrasound.[65,66] The placental and fetal consequences of COVID-19 including the utility of functional MRI in fetal hypoxemia related to COVID-19 remain to be explored.

Radiation exposure thresholds during pregnancy

During the time of pregnancy, the permitted radiation exposure limits are up to 50mGy. The absorbed dose of radiation in a fetus whose mother undergoes chest X-ray and CT scan is 0.002mGy and 0.2mGy, respectively.[43,67] Although the data on the fetal risks from radiation is widely variable in the literature, it is generally agreed that at doses less than 50 mGy, there is no evidence of an increased risk of fetal malformations, developmental delay, or loss of pregnancy (Table 4). There is reported small increased risk of childhood cancer, 1 in 1500 to 2000 versus the 1 in 3000 background rate.[68–70] In this context it is important to note that combined exposure to few chest

Table 4. Effects of radiation induced teratogenesis with gestational age.

Gestational age	Effect on foetus	Estimated dose threshold
Prior to implantation (0–2 weeks after fertilization)	Embryonal death (or) no consequences at all	50–100 mGy
Organogenesis (2–8 weeks after fertilization)	Congenital anomalies (skeleton, eyes, genitals)	200 mGy
	Growth restriction	200–250 mGy
8–15 weeks	Severe intellectual disability (high risk)	60–310 mGy
	Intellectual deficit	25 IQ points loss per 1000 mGy
	Microcephaly	200 mGy
16–25 weeks	Severe intellectual disability (low risk)	250–280 mGy

radiograph or CT pulmonary angiography for evaluation of COVID-19 related complications, the cumulative dose falls well below the accepted limits of 50 mGy during the time of pregnancy.

Informed Consent and patient counseling

Informed consent and patient counseling are important to alleviate the anxiety of patients, while undergoing imaging modalities with radiation exposure like the chest X-ray or CT scan. The attending physician should convey the outweighed benefits of doing an imaging to assess the disease status or to evaluate the complications of COVID-19, as opposed to the risk on the fetus leading to congenital anomalies, birth defects, and miscarriage although negligible for the radiation dose received by the patient. The attending physician and the radiologist should confirm the patients understanding of the estimated risk to mother and fetus. In practice, patient can be explained about the imaging-related radiation exposure by comparing it with background population risk which is approximately 4%, 10%, 10%, and 20% for malformations, genetic diseases, growth retardation, and pregnancy loss, respectively.[71]

Conclusion

Chest radiograph and CT examinations for COVID-19 evaluation deliver minimal radiation dose to the mother and fetus, and rarely exceed the permissible limit of 50mGy. Although this knowledge should reassure pregnant women and attending physician on the greater benefits of undergoing an imaging for COVID-19 evaluation, over the minimal radiation risks, the management strategy should focus on keeping the radiation exposure to both mother and fetus as low as reasonably achievable according to ALARA principles. Radiologists should be aware of the lack of understanding about the radiation risk among the non-radiologist physician who would be requesting an imaging during the care of a pregnant COVID-19 patient, and it's the responsibility of radiologist to counsel the treating physician with regard to various options available for chest imaging including radiation-free modalities like chest USG and cardiac MRI when appropriate for evaluation of COVID-19 related chest complications in pregnancy and to improve patient care.

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