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Point-of-Care Ultrasonography in the Intensive Care Unit for the Obstetric Patient

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ABSTRACT

Point-of-care ultrasonography (POCUS) is a tool that can be used to evaluate critically ill obstetric patients, in the same way as for nonpregnant patients. With knowledge of the physiology and anatomical changes of pregnancy, POCUS can provide meaningful information to help guide clinical management. A POCUS cardiothoracic evaluation for left and right ventricular function, pulmonary edema, pleural effusion, and pneumothorax can be performed in pregnancy. A Focused Assessment with Sonography in Trauma examination in pregnancy is performed similarly to that in nonpregnant patients, and the information obtained can guide decision-making regarding operative versus nonoperative management of trauma. POCUS is also used to glean important obstetric information in the setting of critical illness and trauma, such as fetal status, gestational age, and placental location. These obstetric evaluations should be performed rapidly to minimize delay and enable pregnant patients to receive the same care for critical illness and trauma as nonpregnant patients.
Key words: obstetrics, POCUS, pregnancy, trauma, ultrasound

Point-of-care ultrasonography (POCUS) is a tool that can be used to evaluate critically ill obstetric patients, in the same way as for nonpregnant patients. In addition to knowledge of the physiology and anatomical changes of pregnancy, POCUS can provide meaningful information to help guide clinical management. Point-of-care ultrasonography is also used to glean important obstetric information in the setting of critical illness and trauma, such as fetal status, gestational age, and placental location. These obstetric evaluations should be performed rapidly to minimize delay and allow pregnant patients to receive the same care for critical illness and trauma as nonpregnant patients.

Indications

The rate of antepartum and postpartum admissions to intensive care units (ICUs) in the United States has been rising over the past 30 years.[1] The reasons for pregnancy-related ICU admission include conditions

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specific to pregnancy, such as hemorrhage and hypertensive disorders of pregnancy, as well as nonobstetric conditions such as diabetic ketoacidosis, thyroid storm, respiratory failure due to pneumonia or asthma, and cardiopulmonary failure in the setting of baseline cardiac disease.[2] Trauma in pregnancy, as well as surgical complications from obstetric and nonobstetric surgery, may also lead to ICU admission. Given the multitude of reasons for an admission to the ICU in pregnancy, coupled with the growing body of research on the use of POCUS in treating critically ill patients, it is paramount to understand how to employ this tool in decision-making for care of the critically ill obstetric patient.

Obstetric Ultrasonography

Ultrasonography has long been used in pregnancy to assess the placenta, amniotic fluid, and fetal anatomical structures and growth.[3] In the ICU, transabdominal ultrasonographic imaging can be performed to rapidly evaluate many fetal-placental structures. The first parameter to identify is fetal number, that is, singleton pregnancy versus multifetal gestation. The next parameter to identify is fetal presentation, which will determine whether a patient is an appropriate candidate for vaginal delivery in the ICU. Fetal presentation is defined as the anatomical part of the fetus located in the lower uterine segment, closest to the pelvic inlet.[4] In term singleton pregnancies, the most common fetal presentation is cephalic. The fetal presentation is an essential consideration in determining the mode of delivery. Depending on many other clinical factors, a patient with a fetus in the cephalic presentation may be a candidate for a vaginal delivery. If a fetus is noncephalic and a cesarean delivery is planned, the type of fetal malpresentation helps determine the type of cesarean delivery performed. In the ICU, or during a trauma resuscitation for a pregnant patient, fetal cardiac activity may need to be rapidly assessed to determine fetal viability. In the second or third trimester, the fetal heart rate usually ranges from 110 to 160 beats per minute as calculated via peak-to-peak frequency using the M-mode on ultrasonography. The simplest way to rapidly determine gestational age in a critically ill obstetric patient is to measure fundal height. At 20 weeks of gestation, the fundal height approximates the level of the umbilicus. After 20 weeks, assuming normal fetal growth in a singleton pregnancy, the distance in centimeters from the pubic symphysis to the uterine fundus approximates the gestational age in weeks (within 3 cm).[4] Point-of-care ultrasonography can be used to better approximate gestational age through estimation of fetal weight in the second and third trimesters. Estimation of fetal weight is a composite from 4 measurements: biparietal diameter, head circumference, femur length, and abdominal circumference. The femur length and biparietal diameter best approximate gestational age in the third trimester.[5,6] The abdominal circumference is most affected by fetal growth disorders and thus has the greatest variation in estimating gestational age.[5] Therefore, in a critical situation in which rapid determination of gestational age is necessary to direct clinical care, femur length is the preferred measurement, but in an emergency any of the measurements that can be obtained quickly will suffice.

Finally, fetal-placental status can also be evaluated by examining amniotic fluid level and placental location. Although amniotic fluid level is traditionally assessed by measuring and summating the depth of fluid in each of the 4 quadrants of the intrauterine cavity, an effective alternative is to evaluate the maximal vertical pocket (MVP), which is obtained by simply identifying the largest intrauterine pocket of fluid. In a singleton fetus that is nonanomalous and viable, the MVP ranges from 2 to 8 cm. Oligohydramnios is defined as an MVP less than 2 cm, whereas polyhydramnios is when the MVP is greater than 8 cm. A fluid pocket that is without a fetal part, free-floating umbilical cord, or umbilical cord insertion site should be measured. Knowing the placental location is also important for delivery and surgical planning. Placentation can be evaluated with POCUS to screen for pathologies such as placenta previa and placenta accreta spectrum disorders. Although placenta accreta spectrum disorders are more difficult to diagnose on ultrasonography, POCUS can be used to screen for markedly abnormal placentation. Digital cervical examination should be avoided in a patient without prior placental evaluation to prevent maternal-fetal bleeding. Transabdominal POCUS has excellent sensitivity and negative predictive value in identifying placenta previa.[7] However, in uncertain cases, transvaginal ultrasonography may be necessary, which is beyond the

scope of a POCUS evaluation. Thus, transabdominal POCUS can be used to characterize amniotic fluid status and placental location to rapidly triage a pregnant patient with unknown obstetric status presenting with critical illness.

Nonobstetric Ultrasonography

In addition to pregnancy evaluation, POCUS can be used in the critically ill obstetric patient to assess maternal cardiopulmonary and intra-abdominal systems. For the respiratory system, POCUS lung protocols have been validated in pregnancy for infectious etiologies such as COVID-19 pneumonia as well as hypertensive disorders.[8-11] Although data are limited for test performance compared with the nonpregnant population, lung POCUS can be used to evaluate for B-lines, pleural effusions, consolidation, and evidence of pneumothorax in critically ill obstetric patients when anatomical factors are taken into account, as discussed below. For cardiac evaluation, assessment of left ventricular ejection fraction, pericardial fluid, and right ventricular function by means of transthoracic echocardiography is similar to that in the nonpregnant patient.[12] These brief cardiac evaluations can be used to aid in the diagnostic workup of acute cardiopulmonary failure secondary to obstetrics-related pathologies such as hypertensive disorders of pregnancy, peripartum cardiomyopathy, and amniotic fluid embolism, as well as critical illnesses such as pulmonary embolism, pneumonia, transfusion-associated circulatory overload, and lung injury. Brief cardiac and pulmonary evaluations can be used in a pregnant patient in the same way as for a nonpregnant patient for urgent assessment of undifferentiated shock physiology.

The intra-abdominal spaces can also be evaluated in the critically ill obstetric patient. For example, a Focused Assessment with Sonography in Trauma (FAST) examination can be performed in the appropriate clinical setting to evaluate for the presence of free fluid, as in the nonpregnant patient. The sensitivity for detection of free fluid in pregnant patients ranges from 61% to 85%, and the specificity is up to 99%.[13,14] These and other studies have shown that the FAST examination in pregnancy can not only be performed but also acted upon in the appropriate clinical setting to expedite timely care, including transfer to the operating room for hemodynamic stabilization. Performing cardiac, pulmonary, and intra-abdominal ultrasonography examinations for critical care purposes in pregnancy can yield important clinical information for expedited management, as in the nonpregnant patient.

Pregnancy Anatomy and Physiology

The anatomical and physiological changes of pregnancy must be accounted for when performing cardiopulmonary POCUS in the critical care setting. In pregnancy the heart is displaced to the left, elevated cephalad, and rotated on its long axis, an anatomical change that is critical to be aware of for adequate cardiac image acquisition.[5] Additionally, changes in cardiac function related to hypervolemia begin to occur as soon as 5 to 8 weeks of gestation, with resultant increases in cardiac output, heart rate, and stroke volume throughout pregnancy. As plasma volume expands, the left ventricular end-systolic and end-diastolic dimensions also expand; therefore, ejection fraction remains relatively constant.[12,15] Additionally, pregnant patients may have some degree of benign pericardial effusion.[5]

As with the cardiac system, the respiratory system undergoes significant changes during pregnancy that are important to consider in POCUS evaluations. Throughout gestation, the diaphragm elevates approximately 4 cm as functional residual capacity, expiratory reserve volume, and residual volume all decrease. However, minute ventilation increases during pregnancy as a result of progesterone-mediated stimulatory action and increased tidal volume from decreased functional residual capacity. Pregnancy is a state of compensated respiratory alkalosis. When evaluating the pulmonary spaces in pregnancy, it is important to consider the elevated diaphragm. In patients without intrinsic pulmonary disease, pleural disease, or recent thoracic surgery, the anterior lung zone is the preferred location to evaluate for pneumothorax in the supine position.[16] The posterolateral spaces can also be evaluated for pleural effusions and pneumothorax.[16] However, elevation of the diaphragm in pregnancy raises the intra-abdominal contents (bowel), and the elevated hypoechoic structures of the bowel may make evaluating for lung points and pleural effusions more difficult. As a result of hypervolemia, increased hydrostatic pressure, and decreased residual

volume during pregnancy, isolated B-lines can be found in the absence of intrinsic lung or cardiovascular pathology.[10,17,18] However, abnormal findings on lung ultrasonography such as B-lines in multiple zones consistent with pulmonary edema as well as consolidation and air bronchograms suggestive of infection can be identified in the same way as in the nonpregnant patient.[19] In summary, POCUS can be performed in the critically ill obstetric patient to evaluate the pulmonary system in the same way as in the nonpregnant patient when anatomical and physiological factors are considered.

The abdominopelvic organs also undergo significant change during pregnancy, with implications for POCUS in the critical care setting. Most importantly, the uterus experiences marked growth. In the nonpregnant state during the reproductive years, the uterus weighs approximately 70 g; during pregnancy, the term uterus can weigh nearly 1100 g.[5] As the uterus expands throughout pregnancy and elevates out of the pelvis, other abdominal organs are affected. With the uterine fundus possibly almost reaching the liver, the stomach and intestines are displaced laterally and superiorly, and the appendix is displaced upward and can reach the right flank.[5] Although the cause is unknown, the spleen can enlarge by up to 50% in pregnancy.[5] In the urinary system, the bladder can be elevated, and at term, the bladder base is pushed ventral and cephalad.[5] As FAST examinations require ultrasonographic views of the right and left upper quadrants where the liver, bowel, kidneys, and spleen can be displaced in pregnancy, it is important to be aware of these anatomical changes. For the pelvic component of the FAST examination, approximating the level of the cervicovaginal junction with the bladder can be more difficult owing to these changes in pregnancy.[14] As with the cardiopulmonary evaluations in pregnancy, knowledge of anatomical changes of the abdominopelvic organs in pregnancy is important for the use of POCUS in the critical care setting.

Clinical Pitfalls

The FAST examination in pregnancy requires consideration of anatomical and physiological changes to integrate POCUS into clinical care. The FAST examination relies on detection of free fluid, and during pregnancy there is physiologic free fluid in the pelvis. Therefore, in pregnancy there is a higher chance of false-positive detection of free fluid.[13] Additionally, it can be difficult for a clinician to differentiate intrauterine versus extrauterine free fluid in the patient with a term pregnancy without the requisite experience.[14] However, the clinical utility of ruling out pathological free fluid through a negative study is no different from that in a nonpregnant patient. Although the sensitivity of detecting pathological free fluid in pregnancy may be slightly less owing to physiologic free fluid, to date no recommendations have been made to alter scanning technique or interpretation of a FAST examination. The clinical interpretation and use of a FAST examination for trauma in pregnancy therefore are no different from that in a nonpregnant patient. In a hemodynamically unstable pregnant trauma patient with clinical suspicion of intra-abdominal injury and a positive FAST examination, one should prepare for operative exploration, in the same way as for a nonpregnant patient. In a hemodynamically stable pregnant patient with a positive FAST examination, one should proceed with evaluation for sources of free fluid as in the nonpregnant patient while considering etiologies specific to pregnancy. Thus, free fluid detected during a FAST examination in pregnancy should be interpreted with the same clinical approach as for the nonpregnant patient, and clinical management should not occur in the absence of ultrasonography findings. A summary of nonobstetric POCUS assessments in pregnancy is shown in Table 1.

Scan Techniques

This article focuses on scanning techniques for obstetric parameters, as descriptions of cardiac, pulmonary, and intra-abdominal ultrasonography techniques can be found in other articles in this series.[20-22] For all routine obstetric ultrasonography examinations in the second and third trimesters, a standard curvilinear transducer with a frequency of 2 to 5 MHz is sufficient. This transducer and frequency setting provide a wide field of view and adequate penetration for evaluating pelvic structures.[4] Furthermore, this transducer is routinely available on obstetric units.[23] Although it is beyond the scope of this review, transvaginal ultrasonography can be used for precise placental location and characterization when evaluating for placenta previa and placenta accreta spectrum disorders.

Table 1: Summary of Nonobstetric Point-of-Care Ultrasonography Assessments in Pregnancy

Ultrasound Parameter	Assessment	Considerations for Pregnancy
Cardiac	Left ventricular ejection fraction, right ventricular function, pericardial space	Ejection fraction usually remains constant; benign pericardial effusions are normal
Pulmonary	Pulmonary edema, consolidation, pleural effusion, pneumothorax	Isolated B-lines can be normal; elevated hemidiaphragm is important to consider when evaluating for pleural effusion and pneumothorax
Intra-abdominal FAST examination	Free fluid in the suprapubic and right and left upper quadrants	Slight decrease in sensitivity of FAST examination to detect pathologic fluid due to physiologic free fluid of pregnancy

Abbreviation: FAST, Focused Assessment with Sonography in Trauma.

To evaluate for fetal presentation, a sagittal view is obtained with the bladder and lower uterine segment in view, and the presenting fetal part is visualized (Figure 1). This view is obtained by placing the probe just superior to the maternal pubic symphysis in a sagittal fashion. Noncephalic presentation of the fetus is considered fetal malpresentation. In 3% to 5% of term singleton pregnancies, the malpresenting fetus is in the breech presentation with either frank, complete, or footling breech presentation. Although many factors affect the decisions regarding mode and timing of delivery, it is paramount to first understand whether the patient is a candidate for vaginal delivery by understanding fetal presentation.

To assess fetal heart rate, the most common method is to use the M-mode over a cross-sectional view of the fetal heart (Figure 2). The time between cardiac peaks is measured, and the frequency is then determined. Amniotic fluid level is another ultrasonographic method to evaluate fetal status. To evaluate for MVP, a sagittal view of the uterine cavity is obtained with color Doppler assistance to identify a pocket of fluid without umbilical cord or a fetal part (Figure 3). If a sagittal view is not successful in identifying an MVP, a transverse view can be obtained to identify the 4 intrauterine quadrants to measure MVP.

Another obstetric parameter that may need to be determined urgently in a critical care setting is gestational age. For example, in a maternal cardiac arrest, a resuscitative hysterotomy is recommended if after 4 to 5 minutes of resuscitation there is no return of spontaneous circulation.[24] This recommendation is made for maternal benefit in assisting resuscitation by relieving aortocaval compression by the gravid uterus and because of evidence of improved neonatal outcomes when delivery is begun within 4 to 5 minutes.[24] However, it is crucial to know the gestational age, as resuscitative hysterotomy is recommended only after 20 weeks' gestation. Although fundal height may be used, a rapid POCUS evaluation can aid this important determination. A full review

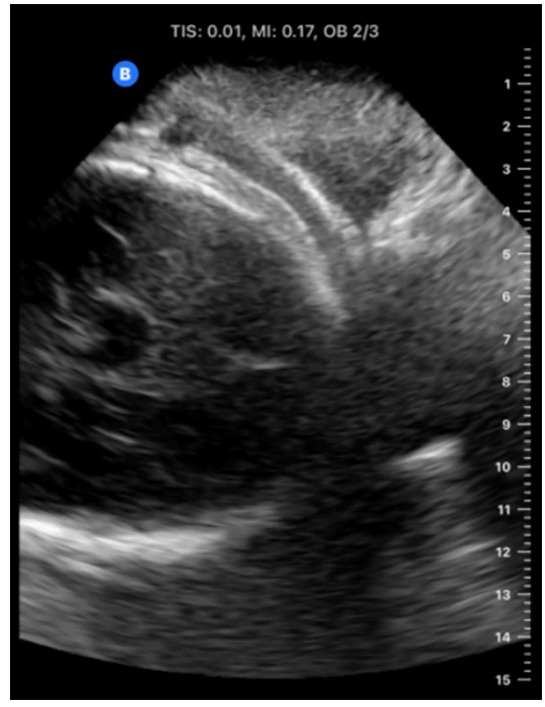

Figure 1: Sagittal view of cephalic presentation with bladder and lower uterine segment visualized. MI indicates mechanical index; TIS, thermal index for soft tissue.

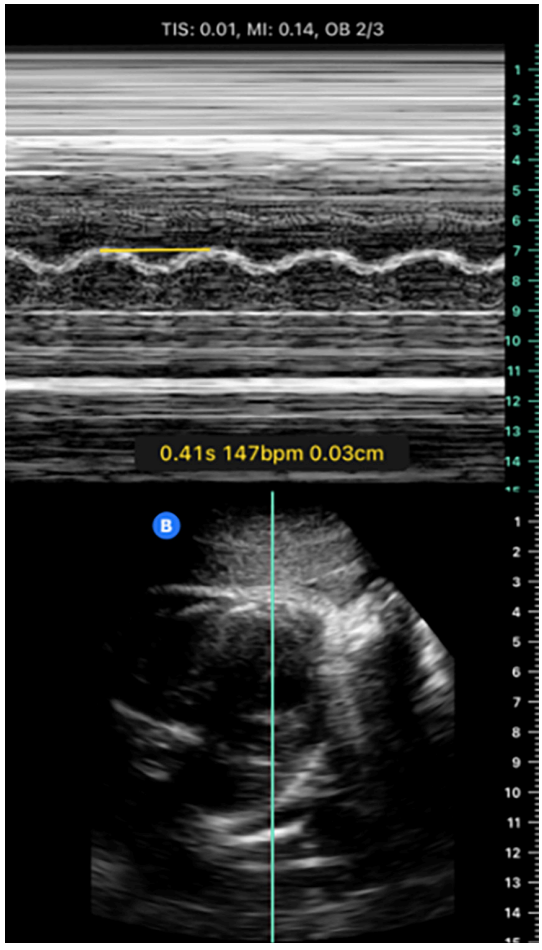

Figure 2: Sagittal view to assess fetal heart rate as determined by M-mode. BPM indicates beats per minute; MI, mechanical index; TIS, thermal index for soft tissue.

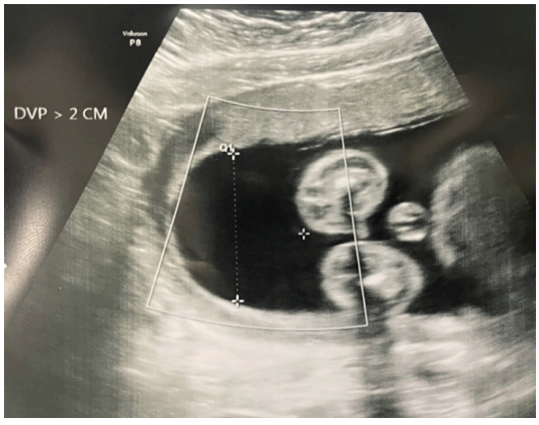

Figure 3: Transverse view of maximum vertical pocket without fetal part or umbilical cord as detected by color Doppler. DVP indicates deepest vertical pocket.

of estimating fetal weight is beyond the scope of this review, but both the biparietal diameter and femur length can be used to rapidly estimate gestational age in a nonanomalous fetus. The biparietal diameter is obtained by first identifying the corpus septum pellucidum at the level of the thalami. At this cross-sectional view of the fetal central nervous system, the entire fetal calvarium should be visualized, whereas the orbital sockets and posterior fossa structures should not be visualized. With this view, the distance from the anterior outer calvarium to the posterior inner calvarium at a perpendicular angle from the midline falx is measured (Figure 4). The femur length is the best single measurement for estimating gestational age in the third trimester[25]; a femur length greater than 4 cm is associated with viability.[6] The femur length is measured by identifying an anterior femur so that the whole bone is visualized and measuring the distance between the 2 diaphyses (Figure 5). This distance is measured in centimeters (or millimeters) and approximates fetal age based on standardized growth curves, most commonly through the Hadlock formulation.[5]

To evaluate for placental location, a sagittal view across the abdomen can be used. The placenta can be located on the anterior, posterior, lateral, or fundal aspect of the uterus (Figure 6). Once the placental location is determined, in the critical care setting it may be necessary to quickly identify the relationship between the placenta and the internal cervical os. Although definitions can vary, a placenta is considered low-lying if its edge is within 1 to 2 cm of the internal cervical os.[5] A complete placenta previa is when the placenta covers the internal cervical os.[5] The edge of the placenta can be identified in a transverse fashion, and once the edge is located, the sagittal view is useful for approximating the distance between the placental edge and the internal cervical os.[4] Ultrasonographic evaluation of placenta accreta spectrum disorders is beyond the scope of this review. Another placental pathology that can be assessed with the aid of POCUS is placental abruption, when the placenta and uterine decidua layer separate prematurely. Placental abruption is a clinical diagnosis, but in the critical care setting POCUS can aid in this evaluation when a retroplacental hematoma is visualized as either a hypoechoic, isoechoic, or hyperechoic structure. In sum, POCUS can

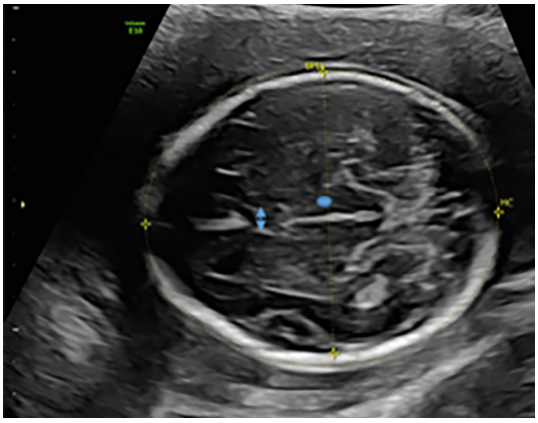

Figure 4: Transverse view of biparietal diameter estimation of gestational age. Arrow indicates cavum septum pellucidum. Dot indicates thalami.

be used to quickly evaluate placental location in the critical care setting to assist in the diagnostic evaluation of obstetric conditions or when an emergency necessitates delivery planning. A summary of obstetric POCUS assessments is provided in Table 2.

Tips and Pearls

A common pitfall when evaluating the critically ill obstetric patient is delay in workup and management due to concerns about the fetus. With rare exceptions, stabilization of maternal status is the highest priority for optimizing fetal status, and POCUS should be used in the same way as for the nonpregnant patient. Although it is not the standard of care in advanced trauma life support, a "fetal FAST" protocol has been proposed for patients presenting with trauma.[26] The "fetal FAST" scan comprises all of the elements discussed in this article and involves evaluating obstetric parameters as an adjunct to the primary trauma survey.[26] The fetal FAST scan includes obtaining fetal number, documenting cardiac activity, assessing fetal presentation, measuring femur length to determine gestational age, evaluating placental location, and measuring MVP.[26] This POCUS assessment can be performed in tandem with the work of the primary care team to expedite appropriate treatment. As described here and elsewhere in this series, POCUS evaluations of the cardiopulmonary and intra-abdominal systems can be performed in the pregnant patient in the same way as for the nonpregnant patient for the management of critical illness, trauma, and undifferentiated shock.

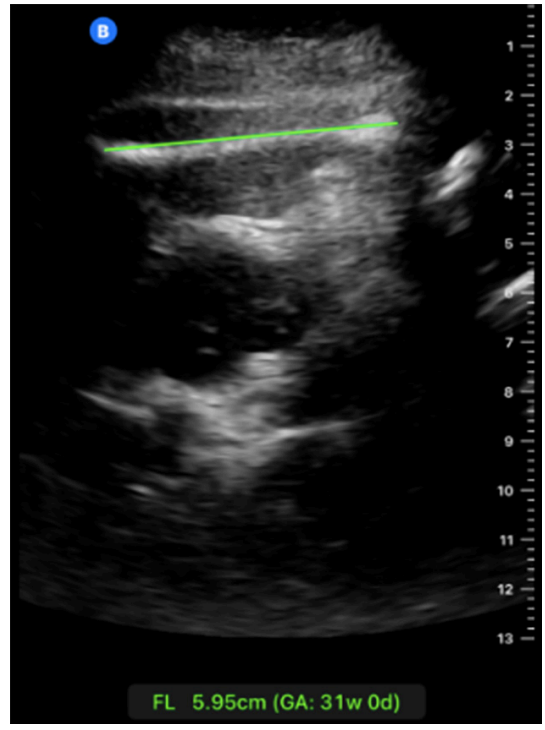

Figure 5: Sagittal view of femur length for estimation of gestational age. FL indicates femur length; GA, gestational age.

Figure 6: Sagittal view of anterior placenta.

Documentation

In the setting of pregnancy, there are no specific modifications to documentation when describing POCUS examinations for maternal

Table 2: Summary of Basic Obstetric Ultrasonography Assessments

Ultrasound Parameter	Assessment	Utility in Critical Care Setting
Fetal presentation	Cephalic, noncephalic	Assessing for mode of delivery (ie, vaginal delivery, type of cesarean delivery)
Fetal status	Fetal heart rate, maximum vertical pocket of amniotic fluid	Evaluating for fetal status (reassuring, nonreassuring) and effect of interventions or resuscitation on maternal fetal status
Gestational age	Estimated fetal weight via composite measurement of head circumference, biparietal diameter, abdominal circumference, and femur length	Femur length is the most useful for determining gestational age with limited information and need to determine fetal viability for indicated interventions such as resuscitative hysterotomy for maternal cardiac arrest.
Placenta	Location of placenta in the uterine cavity (anterior, posterior, fundal), relationship of placenta to internal cervical os	To evaluate if the patient is a candidate for vaginal delivery and screen for abnormal placentation for surgical planning

cardiac, pulmonary, and abdominal assessments. However, documentation of inability to obtain certain views such as a suprapubic view in a FAST examination because of pregnancy should be noted. To document fetal status, the following descriptors for each category are used. For fetal presentation, the fetal presenting part can be described simply as cephalic or noncephalic during critical illness when expediency is necessary. Fetal heart rate is described simply as beats per minute. Maximal vertical pocket for amniotic fluid is characterized in centimeters. Overall estimated fetal weight is described in grams, and a percentile is calculated based on the approximate gestational age. Fetal growth restriction is when the overall estimated fetal weight is less than the tenth percentile, or when the abdominal circumference is less than the third percentile, for the approximate gestational age. Placental location is characterized according to the aspect of the uterus where the predominant part of the placenta is visualized, which can be described as anterior, posterior, lateral, fundal, or low-lying, as reviewed earlier.

Conclusion

When a patient presents after trauma or with critical illness in the setting of unknown obstetric status, minimal knowledge of the pregnancy should not hinder adherence to the usual management paradigm. A rapid evaluation of the pregnancy can be performed with basic knowledge of POCUS techniques. Most importantly, fetal presentation, cardiac activity, and gestational age can be assessed concomitantly with standard management of acute illness. The indicated workup and management for a critical illness should not be deferred or delayed owing to pregnancy alone.

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