REVIEW

Point-of-care ultrasound in pregnancy: gastric, airway, neuraxial, cardiorespiratory

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Purpose of review
This review focuses on the use of point-of-care ultrasound (PoCUS) in the obstetric context for airway management and assessment of aspiration risk, the placement of neuraxial blocks and the diagnosis and follow-up of cardiorespiratory dysfunction.

Recent findings
Gastric ultrasound is a useful aspiration risk assessment tool in pregnant patients. Total gastric fluid assessment models and specific cut-offs between high-risk and low-risk stomachs are presented. Airway assessment is useful to detect specific changes in pregnancy and to guide airway management. Handheld ultrasound devices with automated neuraxial landmark detection capabilities could facilitate needle placement in the future. Lung and cardiac ultrasonography is useful in the management of preeclampsia, pulmonary arterial hypertension and peripartum cardiomyopathy.

Summary
Owing to its noninvasiveness, ease of accessibility and lack of exposure to radiation, PoCUS plays an increasing and essential role in aspiration risk assessment, airway management, neuraxial anaesthesia and cardiorespiratory diagnosis and decision-making during pregnancy.

Keywords
airway, cardiorespiratory, gastric, neuraxial, point-of-care ultrasound

INTRODUCTION

Since its introduction in anaesthesia a decade ago, ultrasound and its many applications have revolutionized clinical practice, and become indispensable. In obstetric practice, ultrasound was already ubiquitous for managing foetal well being and its extension to monitor maternal care was a natural step [1]. Pregnancy has been associated with difficult airway access, increased risk of gastric content aspiration, acute cardiovascular failure and respiratory compromise [2,3]. Point-of-care ultrasound (PoCUS) answers a well defined clinical question at the patient's bedside in a limited time frame with easily recognizable findings that directly influence clinical decision-making [4]. This review focuses on the use of PoCUS in the obstetric context for airway management and assessment of aspiration risk, the placement of neuraxial blocks, and the diagnosis and follow-up of cardiorespiratory dysfunction.

GASTRIC ULTRASOUND

Gastric PoCUS is an aspiration risk assessment tool that could help avoid pulmonary aspiration (1 : 4000 general anaesthetics) [5]. Practitioners consider (term) pregnant patients as high-risk for aspiration. This is because of anatomical and physiological changes, the urgency of interventions and the higher chance of a difficult airway [6,7]. Anaesthesiology societies have published fasting guidelines but they apply to healthy patients for elective surgery only [8]. Gastric PoCUS assesses the stomach's antrum for its qualitative (empty, solid, clear fluid, thick fluid) and quantitative nature (total gastric fluid volume estimation [9]). This permits to individualize aspiration risk and to tailor the anaesthetic technique. The technique has been well described and is performed following a standardized protocol,

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KEY POINTS

- Point-of-care ultrasound allows easy, noninvasive, fast answers at the bedside to well defined clinical questions.
- PoCUS plays an increasing and essential role in aspiration risk assessment, airway management and neuraxial anaesthesia.
- Cardiorespiratory PoCUS is useful for diagnosing and decision-making of preeclampsia, peripartum cardiomyopathy and pulmonary hypertension during pregnancy.

such as the I-AIM protocol [9,10]. The antrum is identified in both the supine and right-lateral decubitus (RLD) position with a low-frequency transducer in the epigastrium. It presents itself as a hollow viscus with the aorta and left lobe of the liver as anatomical landmarks [9,10]. The empty antrum is flat with a bull's eye appearance. Solid food can be appreciated in a dilated antrum as hyperechoic content with ring-down artefacts. Clear fluids present as hypoechoic content. Some pregnancy-related issues as fast breathing, moving fetus, displaced anatomy, a hyperdynamic circulation and the steep angle between xiphoid and abdomen make the pregnant population a technically demanding group [11▪▪]. The RLD is often contraindicated because of maternal or foetal compromise where left uterine tilt needs to be preserved. This results in a feasibility rate of 88% in term patients versus more than 97% in nonpregnant counterparts [11▪▪]. Gastric PoCUS in pregnancy, therefore, seems to be a more advanced skill, which has possible implications for training requirements. Antral depth and the distance between the antrum and aorta increase during pregnancy [12]. The amount of clear fluids can be estimated by measuring the antral cross-sectional area (CSA) in the RLD and the use of a validated mathematical model. Several models are available but the Perlas model is the most widely used: $\mathrm{GV\ (ml)} = 27 + (14.6 \times \text{right-lat CSA}) - (1.28 \times \text{age})$ [13]. It was originally validated for nonpregnant adults in the RLD and clear fluids only. Arzola *et al.* [14] presented the first model to predict gastric fluid volumes for late pregnancy. $\mathrm{Volume\ (ml)} = -327.1 + 215.2 \times \log\ (\mathrm{CSA})\ (\mathrm{cm}^2)$. Another model was recently presented by Roukhomovsky *et al.* [15]. The large 95% confidence interval (CI) limits, however, of both models raise questions about the accuracy and applicability.

The Perlas grading system offers a simple and alternative identification of low-volume versus high-volume states based on the qualitative assessment of the antrum only [9]. It is defined as grade 0 when it appears empty in both positions. It is classified as grade 1 when fluid is present in the RLD only, which correlates with low gastric volumes. A grade 2 antrum (fluid in both positions) correlates with a high aspiration risk. The equivalence of this system between pregnant and nonpregnant patients was examined in a cohort study that examined women before and after elective caesarean sections. The authors reported excellent agreement between Perlas grades in pregnant and postpartum states (kappa 0.81) [12]. Arzola *et al.* [16] described high interrater reliability when a qualitative assessment was performed to discriminate a stomach with no content, clear fluid and solid content. Using MRI in third trimester pregnant patients, the grading scale was reported to allow with good performance the diagnosis of clear fluid volumes greater than 0.8 ml/kg [11▪▪,15].

A threshold of gastric volume over which the aspiration risk increases, remains controversial but data suggest that volumes up to 1.5 ml/kg are normal in fasted subjects [17]. To distinguish between stomach volumes with high or low aspiration risk, different cut-offs in pregnant patients have been proposed. Some authors propose a cut-off CSA value varying from 7 to 10 cm^2 in the RLD [14,18–20]. Other authors focus on a cut-off in the supine position or propose a composite ultrasound scale that combines the Perlas grading with a supine CSA measurement [15,21]. This can be useful for emergency decision-making but until more data are available, we recommend obtaining both views if possible and the RLD should be primarily used to measure antral CSA.

Some authors examined gastric emptying in different stages of pregnancy (term, nonterm, whether or not in labour) with different nutritional regimes (fasted, sports drink, light meal) [18–24].

Although gastric PoCUS is an exciting new tool in the anaesthetist's armamentarium, one must be mindful that it apprehends only one element of individual aspiration risk being gastric content, apart from other factors as the anaesthetic technique, comorbidities or airway management events.

AIRWAY ULTRASOUND

Obstetric patients have higher incidences of difficult airway versus nonpregnant patients with a failed intubation rate that has remained unchanged between 1970 and 2015 [11▪▪,25,26]. This rate is 2.6/1000 general anaesthetics for obstetric procedures and 2.3/1000 for caesarean sections [11▪▪].

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This is because of the physiological changes, such as obesity, enlarged breasts and fluid retention that causes soft tissue mucosal airway oedema [25]. This oedema can enhance during the course of pregnancy and increases the Mallampati score. The decrease in airway calibre escalates during labour and after delivery. Labour has also been associated with decreased pharyngeal volume.

Accurate airway assessment is the first and most important step in airway management [26]. The Obstetric Anaesthetists' Association states that airway assessment must be performed before induction of general anaesthesia [11▪▪,27]. Guidelines suggest the clinical evaluation of Mallampati classification, thyromental distance, interincisor distance and BMI. However, these tests have low sensitivity and specificity with limited and unreliable predictive value [11▪▪]. Airway PoCUS provides better imaging in tissues like the epiglottis, vocal cords and membranes [26]. It confirms correct tracheal tube placement and increases the rate of accurate identification of the cricothyroid membrane compared with palpation [28]. Two methods have been described, namely the transverse and longitudinal techniques. The transverse technique is faster in morbidly obese women versus the longitudinal technique but both methods are equally accurate [29]. Knowing the depth to airway before emergency, cricothyroidotomy improves success rate but if ultrasound is not possible, one could predict depth to the airway by using the patient's weight. The depth to airway lumen strongly correlates with weight ($r = 0.855$, $P < 0.001$) as demonstrated in a prospective observational two-centre study [30]. A prospective case–control study comparing airway changes with ultrasound in 25 normotensive and 25 preeclamptic pregnant women in early labour demonstrated that the Mallampati score increased from prelab or to postlabour in both groups ($P = 0.001$ and 0.002, respectively) [31]. The authors concluded patients with prolonged labour are more susceptible to airway dimension changes and that airway PoCUS may provide useful information.

ULTRASOUND FOR NEURAXIAL ANESTHESIA

Obstetric neuraxial anaesthesia may be challenging and the overall incidence of difficult neuraxial blockade is 4% [32]. Ultrasound imaging is used to facilitate needle placement by identifying the midline of the spine and the intervertebral level and measuring epidural space depth. Some excellent reviews describing the technique and sonoanatomy are beyond the scope of this article and are not included in this review [33▪,34].

Compared with the traditional landmark-based technique, preprocedural ultrasound reduces the number of punctures, decreases the risk of failed epidural analgesia and is associated with higher patient satisfaction [35]. The evidence is especially convincing in patients with difficult spinal anatomy or high BMI, showing that even experienced anaesthesiologists achieve higher first-pass rates and shorter needling time when using ultrasound [36]. Tubinis *et al.* [37▪] recently determined that ultrasound rapidly identifies the midline even in severely obese parturients (BMI $\geq$35 kg/m^2), reducing the epidural placement time.

A recent study investigated the accuracy of a handheld ultrasound device with automated neuraxial landmark detection capabilities [38▪▪]. The authors reasoned that despite the advantages of ultrasound assistance for neuraxial procedures, widespread adoption might be limited by technical skills and difficulty in acquiring or interpreting the images. The device was programmed to calculate the depth to epidural space and identify bony landmarks. The automatically marked interspace allowed first pass needle placement in 87% of cases.

The same device was used before spinal anaesthesia in 150 patients undergoing scheduled caesarean section. In patients with BMI at least 30 kg/m^2, its use resulted in 26% greater first insertion success rates, a 21% decrease in needle insertions, and a 38% decrease in needle passes [39▪▪]. Ghisi *et al.* [40] confirmed these results in their study comparing the device to palpation for spinal anaesthesia in obese patients undergoing orthopaedic surgery. Other automated spinal landmark identification software has been developed, for example, by Oh *et al.* [41]. Their success rate for dural puncture at first attempt was 92%. Automated devices provide an interesting development. Comparison to landmark-based or nonautomatic techniques must be researched. The educational applications of automated ultrasound devices are promising as they might help novices as a teaching aid when first learning to perform neuraxial techniques.

CARDIORESPIRATORY ULTRASOUND

Pregnancy is associated with a transient morphological, hemodynamic and functional adaptation of the maternal heart that is not only necessary for the progression of a successful pregnancy but also imposes a load on the heart [42]. Cardiovascular changes involve an increase in blood volume, significant reduction in systemic vascular resistance and increase in heart rate (Table 1). The echocardiographic parameters show an increase in left ventricular (LV) end-diastolic volume and a lesser increase

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Table 1. Common differences in ultrasound between pulmonary arterial hypertension, preeclampsia and peripartum cardiomyopathy

	PAH	PE	PPCM
LV EF	Normal	Normal	Depressed
LV DF	Relaxation disorder	Normal – Moderate DD	Moderate to severe DD
LV size	Normal but often 'D'-shaped	Normal	Often dilated
RV	RV hypertrophy – progressive RV dilatation & RV dysfunction	Mild RV dysfunction	Moderate RV dysfunction
LUS			
–IS	A-profile	A-profile	A-profile
+IS	–	B-profile	B-profile

DF, diastolic function; EF, ejection fraction; IS, interstitial syndrome; LUS, lung ultrasound; LV, left ventricle; PAH, pulmonary arterial hypertension; PE, preeclampsia; PPCM, peripartum cardiomyopathy; RV, right ventricle.

in LV end-systolic volume. LV function remains stable in the first trimester but declines somewhat toward the end of pregnancy. The ejection fraction remains stable [42–44] (Fig. 1). Heart disease is the leading cause of nonobstetric mortality during pregnancy. Therefore, understanding the maternal cardiac function during normal pregnancy is important for the recognition of cardiac disease.

CARDIAC DYSFUNCTION DURING PREGNANCY

We present three important cardiovascular-related diseases that lead to increased morbidity and mortality during pregnancy. Preeclampsia is related to increased systemic vascular resistance and LV diastolic dysfunction. Pulmonary arterial hypertension (PAH) is related to increased pulmonary vascular resistance and right ventricular (RV) dysfunction. Severe LV systolic dysfunction and even failure predominates in peripartum cardiomyopathy (PPCM). Furthermore, RV dysfunction is common in pulmonary hypertension (PHT), PPCM, and preeclampsia.

(1) Serious preeclampsia is characterized by severe hypertension and end-organ dysfunction. It is associated with increased systemic vascular resistance, diastolic dysfunction and pulmonary edema [45]. Echocardiography shows increased left atrial size, LV diastolic dysfunction with increased LV filling pressures (E/e') and LV wall thickness. Signs of RV dysfunction and an

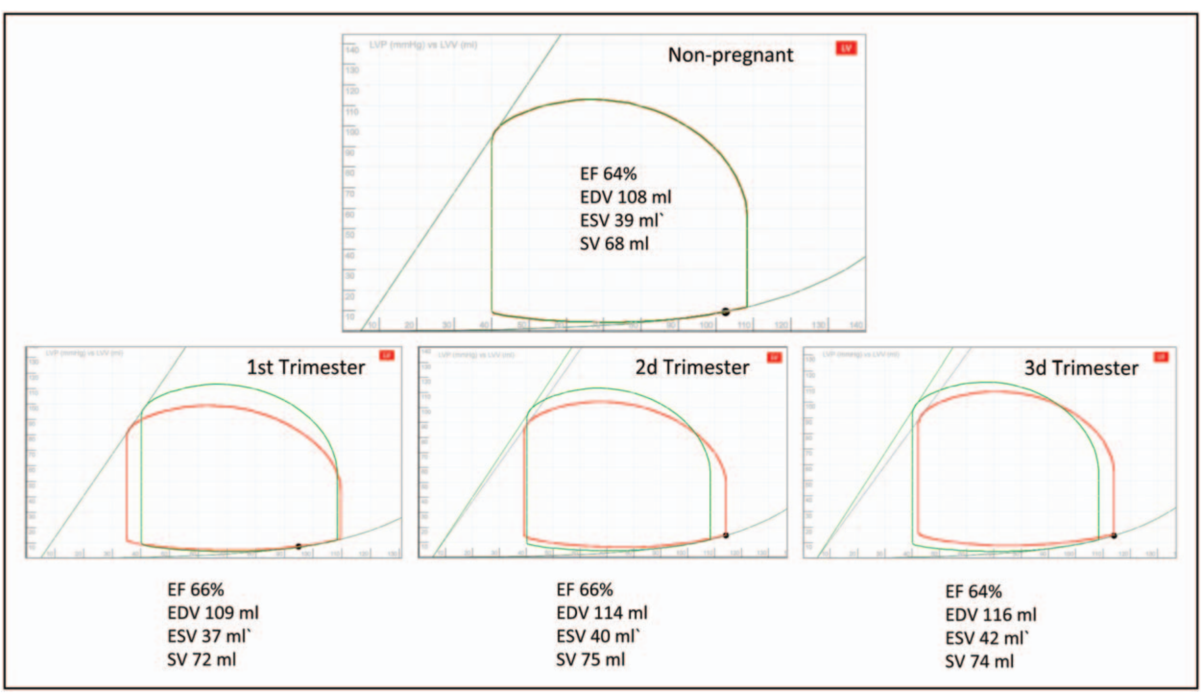

FIGURE 1. Cardiovascular changes during pregnancy.

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increased RV afterload are often present, confirmed by a reduction in strain, tricuspid annular plane systolic excursion (TAPSE), and PHT. In one-third of patients, TAPSE is less than 16 mm [46]. Severe preeclampsia is associated with an increase in extravascular lung water (EVLW) and diastolic LV dysfunction [47]. It is associated with an increase in EVLW prior to delivery and immediately postpartum. These findings are in accordance with the well established association of preeclampsia with a higher incidence of pulmonary edema. Furthermore, lung ultrasound (LUS) is able to identify increased levels of EVLW in preeclampsia before the appearance of clinical signs of pulmonary edema. The presence of B lines (>2 B-lines between two ribs) at the anterior chest wall indicates that filling pressures are high (pulmonary artery occlusion pressure >18 mmHg) and that EVLW is excessive. This specific interstitial syndrome pattern is also referred to as the B-profile [48,49]. The number of B-lines is correlated with increasing severity of interstitial or alveoli involvement and worsening of New York Heart Association class [50]. Therefore, LUS could assist in reducing the development of complications associated with fluid over-resuscitation and identify sever preeclampsia patients who require diuretic therapy [51]. (Fig. 2)

(2) PPCM is defined as LV dysfunction of unknown cause occurring at the end of pregnancy or the first month postpartum. A poor functioning LV with volumetric dimensions comparable with idiopathic dilated cardiomyopathy at the end of pregnancy is key for diagnosis. The LV EF is nearly always less than 45% and the prognosis is highly dependent on the recovery of the LV EF. Higher LV end-diastolic and a lower ejection fraction or fractional shortening indicate poor LV recovery. None of the LVs with a baseline of fractional shortening less than 0.30 and a LV end-diastolic diameter greater than 6 cm recovered within 1-year postpartum [52]. In addition, RV fractional area change greater than 30% was independently associated with subsequent LV recovery and clinical outcome [53]. A TAPSE less than 14 mm is found in greater than 50% of patients with PPCM, indicating that RV systolic function is even worse in PPCM compared with idiopathic dilated cardiomyopathy. LUS has been endorsed by the Acute Heart Failure Committee of the Heart Failure Association of the

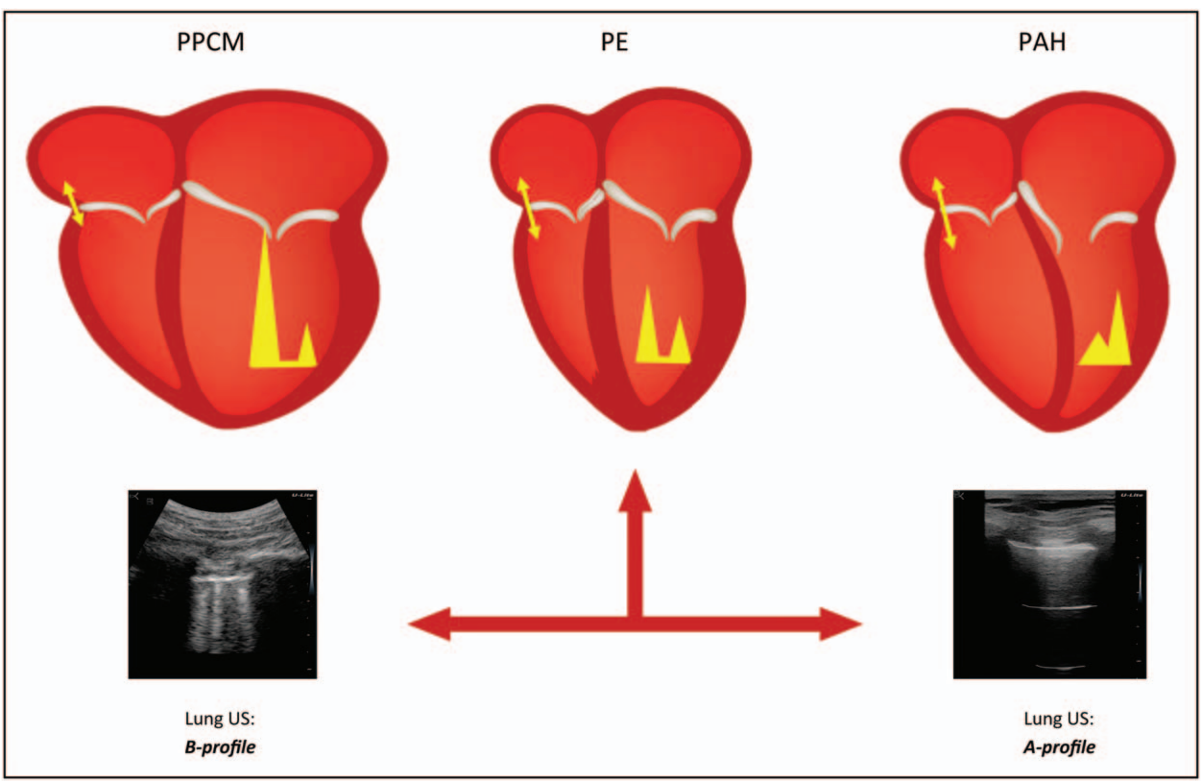

FIGURE 2. Major differences in ultrasound parameters between preeclampsia, pulmonary hypertension and peripartum cardiomyopathy. DF, diastolic function; EDV, end diastolic volume; EF, ejection fraction; ESV, end systolic volume; IS, interstitial syndrome; LUS, lung ultrasound; LV, left ventricle; PAH, pulmonary arterial hypertension; PE, preeclampsia; PPCM, peripartum cardiomyopathy; RV, right ventricle; SV, stroke volume.

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European Society of Cardiology as a future direction for assessing and grading congestion in heart failure. It identifies asymptomatic patients who are going to decompensate and require more aggressive treatment [54] (Fig. 2). Patients with PPCM refractory to medical therapy can be safely treated with the use of mechanical support, even prior to delivery [55▪▪].

(3) PHT is a marker of increased maternal and fetal risk. Maternal death often occurs during delivery or the first weeks postpartum because of RV failure, PHT crisis or sudden cardiac death. The cause of PHT and its association with other forms of heart disease, particularly left heart disease, should be included in risk stratification before and during pregnancy. RV adapts to chronic PHT as in PAH by enhancing RV contractility to maintain cardiac output. Following the development of RV dysfunction, RV dilation leads to change in the shape of the RV (i.e. from triangular to globular), with interventricular septum flattening or reversal of its convexity toward LV [56]. In pregnant patients with PAH, the inability to increase cardiac output leads to right heart failure and may be fatal. Therefore, women with known PAH should be advised not to become pregnant [57]. The maternal mortality because of severe PHT during pregnancy approaches 30%. LUS is complementary to echocardiography and assists in differentiating the causes of PHT in critically ill pregnant patients. LUS in 'primary' PHT or PAH will reveal an A-profile, which indicates that the left atrial filling pressure is low. Secondary PHT, which is usually less severe, may occur as the result of high left atrial filling pressure because of LV heart failure. This may lead to cardiogenic pulmonary edema, revealing a B-profile in LUS (Fig. 2).

CONCLUSION

Owing to its noninvasiveness, ease of accessibility, and lack of exposure to radiation, PoCUS plays an increasing and essential role in aspiration risk assessment, airway management, neuraxial anaesthesia and cardiorespiratory diagnosis and decision-making during pregnancy.

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Conflicts of interest

There are no conflicts of interest.

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