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Review Article

Advances in the application of ultrasonographic parameters for fluid management in obstetric anesthesia

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Abstract: Ultrasound provides a valuable non-invasive approach for fluid management in obstetric anesthesia. Ultrasonographic parameters assist anesthesiologists to effectively assess the fluid status of parturients and reduce related complications. In addition to conventional parameters, which have been widely validated in clinical practice, we provide new insights into arterial parameters such as peak velocity, velocity-time integral, corrected flow time, and vein-related parameters, including the internal jugular vein and its collapsibility index, the inferior vena cava and its collapsibility index, as well as subclavian vein and its collapsibility index. These parameters can potentially enhance fluid management in obstetric anesthesia.

Keywords: Ultrasonographic, fluid management, obstetric anesthesia

Introduction

Intrathecal anesthesia is the main approach for obstetric anesthesia, as it reduces the risks associated with general anesthesia, such as difficult airway and aspiration. However, the incidence of hypotension after intrathecal anesthesia in parturients is relatively high, reaching up to 70% [1]. This hypotension after intrathecal anesthesia can lead to adverse reactions such as nausea, vomiting, arrhythmia, respiratory distress, fetal acidosis, and hypoxia [2-4], which are related to adverse outcomes for both the mother and the newborn. Hypotension after intrathecal anesthesia is primarily caused by factors such as vascular compression and venous vasodilation. Maintaining an adequate fluid status can help alleviate the mother's relative hypovolemic state and maintain hemodynamic stability. Therefore, fluid therapy has long been the most common preventive measure in clinical practice [5]. However, with increasing research, the empirical use of fluid therapy in obstetric patients has been questioned [6]. Therefore, some international guidelines now recommend fluid assessment before fluid therapy [7].

Fluid assessment indicators include static indicators and dynamic indicators. Traditional static indicators encompass central venous pressure (CVP) and pulmonary artery wedge pressure (PAWP). However, extensive research has confirmed that both CVP and PAWP cannot accurately reflect the body's fluid status [8], and both procedures are invasive. Traditional dynamic indicators are derived from cardiopulmonary interactions, such as stroke fluid variation (SVV) and pulse pressure variation (PPV). Although the accuracy of the above two dynamic indicators in predicting fluid response is relatively high [9], they are only applicable to mechanically ventilated patients, with limited predictive value in spontaneously breathing patients. Furthermore, these indicators are somewhat invasive, associated with complications and contraindications, limiting their application in obstetric anesthesia.

In recent years, point-of-care ultrasound (POCUS) has been widely used in obstetric

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anesthesia, assisting in procedures such as punctures and nerve blocks. It offers benefits such as non-invasiveness, radiation-free, simplicity, real-time dynamics, and repeatability [10, 11]. Ultrasonographic parameters, such as artery corrected flow time (FTc), show promise in evaluating fluid status in obstetric patients [12], providing potential benefits for the early diagnosis and treatment of hypotension after epidural anesthesia. In this article, we summarize multiple ultrasonographic parameters and explore their advancements in fluid management for obstetric anesthesia.

Hemodynamic changes in women undergoing obstetric anesthesia

During pregnancy, a series of physiological changes occur in pregnant woman to support the growing fetus. These changes significantly impact hemodynamics, particularly during obstetric anesthesia. Cardiac output typically increases during pregnancy, mainly due to an increase in stroke volume [13, 14], ensuring sufficient blood supply to both the fetus and the pregnant woman. However, the administration of anesthesia, especially certain anesthetic drugs, can affect cardiac function, potentially causing a decrease in cardiac output to some extent. Blood pressure can also fluctuate during anesthesia. In some cases, there may be a temporary decrease in blood pressure immediately after anesthesia induction, which requires close monitoring and appropriate management. Additionally, changes in peripheral vascular resistance may further influence blood pressure and overall hemodynamic stability. The increase in blood volume and its redistribution during pregnancy, particularly to the uterus and placenta, also contributes to hemodynamic alterations. Anesthesia can disrupt this redistribution, potentially causing imbalances in regional blood perfusion.

Pathophysiology of anesthetized women in obstetrics

During pregnancy, cardiac output increases significantly to meet the increased blood supply demands of the pregnant uterus and fetus, while blood volume expands. These changes can also lead to alterations in heart rate and blood pressure responses. During anesthesia, maintaining hemodynamic stability is critical to avoid potential adverse effects on both the mother and fetus [15]. The respiratory system undergoes certain modifications as well. The diaphragm is elevated due to the growing uterus, resulting in a reduction in functional residual capacity. This can make anesthetized women more prone to issues such as atelectasis and oxygen desaturation. To mitigate these risks, appropriate ventilation strategies must be employed to ensure adequate oxygen supply. Hormonal changes, particularly elevated progesterone levels, also impact anesthetic management. Progesterone can affect smooth muscle tone and airway reactivity, increasing the risk of airway complications. Additionally, pregnancy affects the metabolism and elimination of anesthetic drugs due to altered liver and kidney function, necessitating careful dose adjustments. The placental-fetal unit introduces unique considerations during obstetric anesthesia. Anesthetic agents must be carefully selected and managed to minimize potential risks to the fetus while ensuring the comfort and safety of the mother. Any disruptions in uteroplacental perfusion can have serious consequences for the fetus. The ultrasound parameters and their clinical significance are shown in **Table 1**.

Artery related parameters

Arterial blood flow peak velocity (Vpeak)

Arterial blood flow peak velocity (Vpeak) refers to the highest speed at which blood flows through an artery within a specific period [16]. It is an important parameter in the assessment of arterial blood flow conditions, offering valuable information for diagnosing various vascular disorders, such as stenosis or abnormal blood flow patterns. The change in Vpeak during the respiratory cycle is known as the respirophasic artery peak velocity variation, commonly represented as ΔVpeak. The formula for calculating ΔVpeak is: (maximum peak velocity - minimum peak velocity)/[(maximum peak velocity + minimum peak velocity)/2] × 100 [17]. Common sites for measuring Vpeak include the left ventricular outflow tract (LVOT), aorta (AO), carotid artery (CA), femoral artery (FA), and brachial artery (BA). Aortic Vpeak was initially studied due to its proximity to the LVOTS and its strong correlation with stroke volume (SV). However, technically, there are some difficulties in measuring aortic Vpeak at the bedside, whether using transesophageal or trans-

Table 1. Ultrasound parameters and clinical significance

Ultrasound parameters	Definition	Clinical significance
Artery Related Parameters		
Peak Velocity (Vpeak)	The highest speed blood flows through an artery within a specific period	Assess arterial blood flow conditions
Velocity time integral (VTI)	The highest velocity achieved by the blood flowing through an artery during a specific period	Assess arterial hemodynamics
Corrected flow time (FTc)	The ejection time of the left ventricle during systole	Reflect cardiac preload
Vein related parameters		
Internal jugular vein (IJV) and internal jugular vein collapsibility index (IJV-CI)	Calculated by evaluating certain characteristics or changes in the internal jugular vein under specific conditions	Reflect internal jugular vein
Inferior Vena Cava (IVC) and Inferior Vena Cava collapsibility Index (IVC-CI)	A measure or index related to the behavior and characteristics of the inferior vena cava	Assessed using ultrasound or other imaging techniques
Subclavian Vein (SCV) and Subclavian Vein collapsibility Index (SCV-CI)	A specific index or measure related to the subclavian vein	Reflect the degree of collapse or change in the diameter of the subclavian vein under certain conditions or during specific physiological or clinical evaluations

thoracic ultrasound [18]. Most obstetric surgeries are performed under spinal anesthesia, with patients being awake and some parturients experiencing pain stress, so the application of transesophageal and transthoracic ultrasound is limited. Peripheral arteries such as the carotid artery, brachial artery, and femoral artery are more superficial, making measurement easier and more feasible. Xu et al. measured the aortic ΔVpeak, arterial corrected flow time (FTc), and the diameters of the inferior vena cava (IVC) at end-inspiration (IVCins) and end-expiration (expIVC), along with the IVC collapsibility index (IVC-CI) in patients undergoing elective cesarean sections. Their results showed that aortic ΔVpeak and corrected flow time (FTc) are reliable methods for predicting fluid responsiveness in elective parturients [19].

Arterial blood flow velocity time integral (VTI)

Arterial blood flow velocity time integral (VTI) can be used as a composite parameter for the assessment of systolic cardiac function, blood volume, and cardiac output (CO) [20]. Brun et al. measured the change in aortic VTI (ΔVTI) before and after passive leg raising (PLR) in critically ill pre-eclamptic women, and their results showed that an increase of more than 12% in aortic ΔVTI (PLR) could accurately predict fluid responsiveness, with a specificity and sensitivity of 100% and 75%, respectively [21]. Zieleskiewicz et al. [12] demonstrated that aortic ΔVTI (PLR) could predict post-spinal hypotension in parturients, with a threshold of 8%, an area under the ROC curve (AUC) of 0.8, sensitivity of 94%, specificity of 73%, positive predictive value of 70%, and negative predictive value of 85%. This suggests that aortic ΔVTI (PLR) may help guide individualized treatment in obstetric anesthesia. Similarly, Feng et al. measured aortic ΔVTI in parturients in both supine and left lateral positions and showed that aortic ΔVTI, combined with baseline heart rate and left ventricular end-diastolic area (LVEDA) changes induced by position, could more accurately predict post-spinal hypotension during cesarean section compared to using a single parameter [22]. However, obtaining aortic ΔVTI requires transthoracic echocardiography, which involves specific equipment and training, making its use somewhat challenging. Recent studies have shown that carotid artery VTI and its respiratory variation are directly related to aortic ΔVTI [23]. Carotid artery VTI is easily accessible and has practical value. Sidor et al. found that carotid artery VTI-derived total flow is positively correlated with cardiac output, making it a potential indicator for assessing fluid responsiveness and guiding fluid management [24]. Dai et al. measured carotid artery blood flow (CABF) and carotid artery VTI and found that the optimal critical values for predicting fluid responsiveness in elective cesarean section patients with spontaneous breathing were 175.9 ml/min (sensitivity 74.0%, specificity 78.0%) for CABF and 8.7 cm/s (sensitivity 67.0%, specificity 90%) for carotid artery VTI [25]. Aortic ΔVTI remains a valuable predictive indicator for fluid responsiveness and post-spinal hypotension in cesarean section patients. However, when transthoracic echocardiography is not feasible or available, carotid artery VTI serves as a practical and accessible alternative [26].

Corrected flow time (FTc)

Flow time (FT) refers to the ejection time of the left ventricle during systole, which can reflect cardiac preload [27]. However, since FT is influenced by heart rate, it must be corrected for heart rate when comparing FT across different individuals or within the same individual at varying heart rates, known as corrected flow time (FTc) [28, 29]. FTc is mainly influenced by left ventricular preload and is related to myocardial contractility and afterload, but it is not affected by autonomous respiration. Literature reports that measuring FTc of the descending aorta via transesophageal ultrasound can assess vascular fluid status, guide fluid therapy, improve prognosis, and reduce complications [30]. However, transesophageal ultrasound is generally used in intubated or sedated patients, and it is highly operator-dependent, making its application limited in obstetric surgery. The carotid artery, being superficially located and having a wider diameter, allows for easier measurement of FTc via ultrasound. In 2014, Blehar et al. first measured carotid artery FTc to assess fluid status using ultrasound and showed that carotid artery FTc increased by 41 ms (14.9%) after intravenous fluid administration, suggesting that carotid artery FTc could be a new method for measuring fluid status [31]. In recent years, multiple studies have shown a strong correlation between carotid artery FTc and fluid status. A recent meta-analysis, which included 2 cesarean section studies, showed that carotid artery FTc has high diagnostic accuracy in predicting intraoperative hypotension and fluid responsiveness [32].

The carotid artery FTc stands out from other indicators based on cardiopulmonary interaction and can be used to evaluate the fluid responsiveness of spontaneously breathing patients, with good clinical value in obstetric anesthesia. Singla D et al. showed that ultrasound measurement of carotid artery FTc and ΔVpeak is a reliable method for predicting fluid responsiveness in spontaneously breathing parturients undergoing elective cesarean section [33]. Juri T et al. measured the carotid artery FTc (FTc-1, FTc-2) and FTc change (ΔFTc) in the supine and Trendelenburg positions before anesthesia induction in patients undergoing elective cesarean section. Their results showed that the AUC for predicting hypotension after spinal anesthesia were 0.591, 0.742, and 0.882 for FTc-1, FTc-2, and ΔFTc, respectively. Among the three parameters, ΔFTc was the best predictor, with an optimal threshold of 6.4%, sensitivity of 80.8%, specificity of 85.7%, indicating greater predictive value than the absolute FTc value [34]. Kim et al. measured carotid artery FTc in the supine position before anesthesia in 38 parturients undergoing elective cesarean section. The AUC for FTc predicting the occurrence of hypotension after spinal anesthesia was 0.922, with a cutoff value of 326.9 ms, sensitivity of 95.2%, and specificity of 85.7%. Furthermore, the magnitude of systolic blood pressure decrease was negatively correlated with the pre-anesthesia carotid artery FTc value [35].

Vein related parameters

Internal jugular vein (IJV) and IJV collapsibility index (IJV-CI)

The internal jugular vein collapsibility index (IJV-CI) is a specific parameter used to assess changes in the internal jugular vein, typically by evaluating its diameter during specific conditions [36]. The lumen of the superior vena cava and internal jugular vein is relatively large, with elastic walls. When in a supine position, the pressure in the right internal jugular vein closely reflects the pressure in the superior vena cava and right atrium, making it highly correlated with their pressure changes [37]. Existing evidence suggests that compared to the inferior vena cava collapsibility index (IVC-CI), IJV-CI is a more suitable indicator to assess the fluid status of spontaneously breathing patients [38, 39]. The IJV is relatively superficial, easy to access, and requires less imaging acquisition time compared to the IVC [40]. Changes in the filling and morphology of the IJV can be influenced by internal pressure alterations when the IVC is compressed, potentially affecting venous return. Wu Yue et al. measured the anterior-posterior diameter of the right internal jugular vein in parturients in both the supine and left lateral positions before anesthesia, and the results showed that changes in the IJV diameter in different positions were correlated with supine hypotension syndrome, suggesting that this may be an early clue for predicting post-anesthesia hypotension in parturients [41]. Elbadry et al. found that the IJV-CI was significantly higher in parturients who developed hypotension (46.5%) after spinal anesthesia than those that did not (33.41%). They reported that the sensitivity and specificity of IJV-CI in predicting hypotension after spinal anesthesia were 84.6% and 82.8%, with a critical value of 38.5% [42]. Dai et al. further confirmed that ultrasound measurement of IJV-CI and subclavian vein collapsibility index (SCV-CI) are reliable indicators of fluid responsiveness in elective cesarean section patients, with IJV-CI being more predictive of fluid responsiveness in spontaneously breathing parturients [13]. However, not all studies support these findings. Pharanitharan et al. found that IJV parameters such as maximum diameter, minimum diameter, and IJV-CI during spontaneous and deep breathing were not reliable predictors of postoperative hypotension in elective cesarean section patients [43].

Inferior vena cava (IVC) and IVC collapsibility index (IVC-CI)

The inferior vena cava collapsibility index (IVC-CI) is a parameter used to assess the behavior and characteristics of the IVC, typically evaluated using ultrasound or other imaging techniques. The IVC-CI is often employed to evaluate the volume status or fluid responsiveness of a patient [44]. In recent years, ultrasound examinations have confirmed a good correlation between IVC diameter (IVC-d) and its collapse index (IVC-CI) with central venous pressure (CVP) [45]. The American Society of Echocardiography recommends measuring IVC-d and IVC-CI as a rapid, non-invasive method for fluid assessment [46]. Studies by Kundra et al. showed that IVC-CI measured in the supine position can be a valuable parameter for predicting hypotension after spinal anesthesia in cesarean section patients [47]. Dai et al. found that the IVC-CI of hypotensive parturients after spinal anesthesia was significantly higher than that of non-hypotensive parturients (38.27% vs. 23.97%, $P < 0.001$). Using a critical value of 33%, the sensitivity and specificity of IVC-CI for predicting hypotension were 84.6% and 93.1%, respectively. Their study concluded that both IVC-CI and IJV-CI are effective and reliable tools for predicting hypotension after spinal anesthesia in cesarean section patients, with IVC-CI slightly superior in specificity and accuracy [13]. A meta-analysis by Chang et al., which included 12 studies (4 focusing on cesarean section studies), demonstrated the diagnostic reliability of IVC-CI in identifying high-risk patients for post-spinal anesthesia hypotension, with a sensitivity of 77%, a specificity of 82%, and an AUC of 0.85. Zieleskiewicz et al. suggested that an IVC-CI >40-50% could effectively predict fluid responsiveness in cesarean section patients, with measurements taken during standardized deep inspiration and passive expiration to improve predictive accuracy [48]. However, the predictive value of IVC for fluid responsiveness in spontaneously breathing patients remains controversial [49].

In actual application, there are limitations to ultrasound measurement of the IVC. It is difficult to evaluate the IVC-CI in obese individuals or in cases with excessive intra-abdominal gas [50]. Factors such as obesity, large fetal size, and interference from intra-abdominal gas may lead to failure in measuring the IVC in pregnant women. Singh et al. reported a failure rate of approximately 11% for visualizing the IVC in their study of pregnant patients [51]. Additionally, the measurement site of IVC is typically located in the surgical disinfection area during cesarean sections, making it impossible to timely perform ultrasound assessment of the IVC during cesarean section.

Subclavian vein (SCV) and SCV collapsibility index (SCV-CI)

The subclavian vein collapse index (SCV-CI) measures the degree of collapse or change in the diameter of the subclavian vein under certain conditions or during specific physiological or clinical evaluations [52]. The subclavian vein (SCV) is a highly compliant vein, with its size and dynamics influenced by fluid volume in the blood vessels and respiration patterns. Previous studies have shown a correlation between ultrasound measurements of SCV and IVC in assessing vascular fluid status [53]. Zhu et al. found that ultrasound measurement of SCV-CI is a reliable auxiliary tool for evaluating fluid status in surgical ICU patients, with the added benefit that SCV-CI measurements require less time than IVC-CI [54]. Dai et al. found that both ultrasound IJV-CI and SCV-CI are reliable indicators for predicting fluid responsiveness in elective cesarean section patients [13]. In contrast, Yan et al. found that fluid management guided by SCV did not improve post-spinal hypotension in cesarean section patients but reduced the preload fluid required before spinal anesthesia [55]. Reducing preload fluid does not increase the incidence of adverse reactions in mothers and newborns, nor does it increase the total dose of vasopressors. In addition, reducing preload fluid can reduce the cardiac burden on mothers, which is of high clinical significance.

The SCV, adjacent to the clavicle, has a fixed anatomical position that is easily accessible and not affected by factors such as intra-abdominal gas, obesity, pregnancy, or disinfection restrictions in the surgical area. This can bypass measurement failure due to pressure-induced deformation during the imaging process. Therefore, in situations where IVC imaging is difficult (abdominal distension, intestinal gas, morbid obesity, tissue edema) or in emergency situations, SCV-CI can be measured [56].

Conclusions

Ultrasonographic parameters hold significant research potential for fluid management in obstetric anesthesia. Compared to traditional invasive monitoring techniques, ultrasound has the advantages of being radiation-free, with non-invasiveness, rapid assessment, and high repeatability, making it particularly suitable for obstetric anesthesia. Currently, the specific application scenarios and reference values of ultrasonographic parameters in fluid management during obstetric anesthesia remain unclear, warranting more high-quality research to confirm their effectiveness and establish standardized guidelines for their use.

Disclosure of conflict of interest

None.

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