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ADVANCEMENTS IN THE CLINICAL APPLICATION OF INFERIOR VENA CAVA DIAMETER AND COLLAPSE INDEX IN ULTRASONOGRAPHY DURING ANESTHESIA

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Abstract: Fluid management involves static and dynamic indicators. Static indicators include pulmonary artery wedge pressure and central venous pressure, whereas dynamic indicators include stroke volume variation, the inferior vena cava collapsibility index, the pulse perfusion variability index, pulse indicator continuous cardiac output, and Flotrac based on cardiac output. However, most of these techniques are frequently used in intensive care units owing to their combination of clinical characteristics, cost, invasiveness, anesthetic risk, procedure time, and operability. Concurrently, ultrasound techniques have recently received more attention from anesthetists because of their ease of learning and use and lower cost. This article discusses the clinical application of inferior vena cava diameter and blood vessel assessment intraoperatively during general anesthesia.

Keywords: inferior vena cava collapsibility index, inferior vena cava, fluid management

1. INTRODUCTION

Hemodynamic fluctuations are common during the perioperative period. Prolonged intraoperative hemodynamic instability often affects the prognosis and prolongs the hospital stay of patients. In addition to advanced age, myocardial depression during anesthesia, different degrees of autonomic agitation or depression, chronic systemic diseases, and poor blood volume status associated with prolonged fasting are important precipitating factors. Therefore, appropriately assessing the intravascular fluid status of patients and using this information to guide volume management is particularly important. Currently, pulmonary artery catheters, pulse indicator continuous cardiac output (PiCCO) testing systems, and Vigileo systems have been used to assess intraoperative volume management for targeted therapies; however, their widespread use remains controversial because of the complexity of the procedure, invasiveness, and complications such as local hematoma, pneumothorax, infection, and venous thrombosis [1]. The extensive use of the inferior vena cava collapsibility index (IVCCI) to evaluate volume status has been supported by recent guidelines [2]. Additionally, further research has been conducted in recent years to support the use of IVC diameter (IVCD) and the IVCCI to measure blood volume [3,4]. In this study, we reviewed the available literature and discussed the clinical application of ultrasound measurements of IVCD and IVCCI.

2. PHYSIOLOGICAL BASIS OF THE IVC CORRELATION COEFFICIENT

The IVC is the largest venous vessel in the body and is driven into the posterior inferior aspect of the atria by the differential pressure generated by normal breathing and the negative pressure from the right atrium [5]. Suat et al. [6] have reported that the IVC was consistently lower in hypovolemic individuals than in those with normal blood volume, suggesting that the IVC is, to some extent, responsive to blood volume. When the body is in an inspiratory state of spontaneous breathing, negative pressure is created in the thorax, which increases venous return to the heart, causing the IVC to temporarily collapse. During the expiratory phase, venous return decreases, and the IVCD returns to baseline [7]. The opposite is true for positive pressure ventilation, where positive intrathoracic pressure during inspiration lowers the venous return of the heart and increases the internal

IVCD. Intrathoracic pressure drops to 0 at the time of expiration, enhancing venous return to the heart and minimizing internal IVCD.

The PiCCO system is an advanced hemodynamic monitoring device that integrates various static and dynamic hemodynamic data in conjunction with transcardiopulmonary thermodilution and pulse contour analysis. Its accuracy as a gauge of cardiac output is widely known, however, the requirements for intra-arterial and invasive manipulation of central venous restrict its use in severely ill patients or those at high risk of complex and severe hemodynamic disturbances [8]. In a comparison of the accuracy of different indices for predicting volume response in patients with septic shock combined with myocardial depression, Shin et al. [9] found that the accuracy of IVC ultrasound indices and PiCCO indices were similar. This suggests that IVC ultrasound indices, which are readily available, reproducible, inexpensive, noninvasive, and free of complications, may be more advantageous in the perioperative period.

3. ULTRASOUND COLLECTION AND CALCULATION TECHNIQUES FOR IVC CORRELATION COEFFICIENTS

3.1 Ultrasound views and selection mode

With the patient in the supine position, subcostal transabdominal long-axis, transabdominal short-axis, and right transabdominal coronal long-axis views of the midaxillary line can be used to examine the IVC. The subcostal transabdominal long-axis approach in mode B is preferred over mode M for ultrasound imaging [10,11], as the diaphragmatic movement during breathing causes caudal displacement of the IVC, resulting in two different positions during inspiration and expiration [12]. Subsequently, the IVC can be identified from the Doppler waveform and respiratory time delay. Notably, measurements of the internal diameter of the IVC are often obtained on imaging 2–3cm distal to the right atrium in a subcostal long-axis view [13]. However, one study has shown that measurements of the IVC at the left kidney vein trunk and 2 cm posterior to the entrance of the liver vein were equivalent. This implies that liver fibrosis or cirrhosis may cause poor narrowing and that the parenchyma in the area may have an impact on how the hepatic part of the IVC collapses. Therefore, IVCCI values of the left renal vein may be more reliable in cases of suspected substantial liver disease [12].

3.2 Calculation method

Natural breathing: The same respiratory cycle was used to assess the maximum (IVCDmax) and minimum (IVCDmin) IVCD at the end of inhalation and exhalation, respectively.

IVCCI = (IVCDmax - IVCDmin)/IVCDmax × 100% [13].

Mechanical ventilation: The same respiratory cycle was used to assess IVCDmax and IVCDmin at the end of exhalation and inhalation, respectively.

IVCDI = (IVCDmax - IVCDmin)/IVCDmax × 100% [14].

4. RESEARCH PROGRESS OF IVC IN CLINICAL PRACTICE

According to the guidelines[15], when the patient is deeply breathing, the right atrial pressure (RAP) is between 0 and 5 mmHg (normal range) if the IVCD is ≤ 2.1 cm and IVCCI is > 50%. In contrast, if the IVCD is > 2.1 cm and IVCCI is < 50%, the RAP is between 10 and 20 mmHg. Moreover, if the IVCD is ≤ 2.1 cm and IVCCI is < 50% or if the IVCD is > 2.1 cm and IVCCI is > 50%, the RAP is between 5 and 10 mmHg. However, in the presence of mild IVC collapse (35%), the mean RAP may increase to 15 mmHg.

Patients who are unable to take deep breaths often exhibit quiet respiration, leading to an IVCCI of 20% and elevated RAP. The right atrium, as the return chamber of the superior and inferior vena cava, can be somewhat responsive to fluid status, as indicated by this relationship. Inferior jugular ultrasound can provide some guidance for fluid management, with lower IVCD and higher IVCCI suggesting volume deficiency and, conversely, higher IVCD and lower IVCCI indicating intravascular volume overload. In contrast, a previous study [16] has noted that in East Asians, the optimal IVCDmax and IVCCI cutoff values for detecting elevated RAP (RAP ≥ 10 mmHg) were 17 mm and 40%, respectively. Moreover, when the ratios of both were combined with the above guidelines, the sensitivity and specificity for detecting elevated RAP levels were 75% and 94%, respectively. Notably, the sensitivity and specificity (42% and 99%, respectively) were higher than the current guideline cutoff values (> 21 mm and < 50%, respectively).

4.1 Research Progress of IVC in Critically Ill Patients

Some patients that undergo surgery are transferred to the intensive care units (ICU) owing to severe postoperative complications, such as sepsis, acute heart failure, and renal failure. Sepsis and septic shock are often the main causes of death in patients at ICUs, and timely volume resuscitation is essential for these patients. Currently, several studies [9,17,18] have confirmed the positive significance of IVC ultrasonography in patients with sepsis in terms of volume therapy and volume responsiveness, and a relevant meta-analysis published in 2019 [18] has shown that the predicted IVCCI cutoff values for volume responsiveness were 31–48% for IVCD in the majority of autonomic breathing groups and 31–48% for IVCD in the majority of mechanically ventilated groups. Notably, the predicted IVCCI cutoff was 18–22%; that is, above the cutoff, rehydration expansion increased in cardiac volume per beat. Furthermore, additional data [11] suggest that using an IVCCI cutoff of 23% to 18.5% better predicts the ability to remove 0.5–2 liter of ultrafiltrate during dialysis. Thus, a lower IVCCI may identify critically ill patients with combined renal and right heart failure who have a relatively high intravascular volume, which, in turn, can be used to achieve volume clearance by guiding diuresis, puncture, ultrafiltration, and dialysis. Furthermore, high central venous pressure (CVP) is associated with fluid overload, whereas low CVP is associated with insufficient fluid load. Although the relevance of CVP in directing fluid management has been called into doubt as clinical research has progressed, it remains one of the most often utilized hemodynamic variables in guiding fluid resuscitation for clinical patients, as it is supported by relevant theories and is simple to obtain[19]. CVP has been utilized as a control in certain studies, showing substantial correlations between IVCD and IVCCI measures and CVP in ICU patients, regardless of whether the patients are adults[7] or children[20], and whether they are breathing by Continuous Positive Airway Pressure endotracheal intubation[21] or natural breathing[22]. Federico et al. [20] discovered that when IVCCI is 35%, CVP is lower than normal, and when IVCCI is 20%, CVP is greater than usual in their research of Pediatric ICU patients aged 0 to 16 years. An early meta-analysis[23] suggested that measuring the IVCCI with ultrasound has a significant value in predicting fluid responsiveness (a 10% to 15% increase in cardiac output after fluid administration), particularly in patients undergoing controlled mechanical ventilation and colloidal resuscitation.

4.2 Research Progress of IVC in General Anesthesia Patients

Patients undergoing general anesthesia often suffer from post-induction hypotension due to preoperative water fasting and the administration of anesthetic drugs, which are associated with inadequate organ perfusion and poor postoperative outcomes. Some studies now consider IVC ultrasonography to be informative for predicting post-induction hypotension. Articles supporting these views suggest that post-induction hypotension after general anesthesia can be predicted when the IVCCI is above the cutoff value, with some studies suggesting that this cutoff value is approximately 43% [24, 25], which has high sensitivity and specificity. In contrast, when the cutoff value was 50% [26], the predictive specificity was high and the sensitivity was low. Moreover, according to Sadik et al. [27], ultrasound-derived IVC measures were less reliable in predicting hypotension and severe hypotension following propofol-induced anesthesia in healthy adult surgical patients. However, the type of surgery was not provided for their sample group, and preoperative gastrointestinal preparation requirements varied between procedures, which may have contributed to the relatively low incidence of post-induction hypotension (20%) and biased results.

4.3 Research Progress of IVC in Spinal Anesthesia

Post-spinal hypotension (PSAH) is a common complication of lumbar anesthesia. Ceruti et al. [28] concluded that bedside ultrasound-guided infusion before spinal anesthesia reduced the frequency of arterial hypotension following spinal anesthesia and optimized the blood volume status of the patient. In addition, according to Eman et al. [29], the preoperative IVCCI has an excellent accuracy of 84%, a specificity of 77%, and a sensitivity of 84% in predicting the occurrence of PSAH. In their study, Yusuf et al. [30] have shown that ultrasound measurement of end-expiratory IVCD before lumbar anesthesia in older adults was effective in predicting blood gas indicators, such as lactate and pH, and could be the preferred method for predicting post-spinal hypotension. Saranteas et al. [31] found that the ratio of IVCDmax to IVCCI is < 43 improved the accuracy of predicting hypotension after spinal anesthesia in the older individuals compared with IVCCI. In a different study, Roy et al. [32] concluded that preoperative assessment of the IVCCI using ultrasound was a poor indicator of hypotension following spinal anesthesia. In their study, the receiver operator characteristic curve analysis did not show good diagnostic accuracy, with an area under the curve of 0.467. The researchers suggested that this might be related to the clinically significant incidence of hypotension found in the study (19.37%), which was much lower than that in other studies, as well as the fact that breathing induced diaphragmatic movements resulting in two different sites of IVC measurement during the respiratory cycle.

In obstetric patients, IVC ultrasound is more relevant in predicting hypotension to guide fluid replacement and in assessing the intraoperative position. In cesarean deliveries, the cutoff value for IVCCI is 33% [33]. Kundra et al. [34] studied cesarean section patients who delivered in three different positions (supine, prone wedge, and left side position) through a subcostal approach and concluded that patients in the left position had a greater IVCDmax and a lower IVCCI, whereas in the prone wedge position, women who experienced hypotension following lumbar anesthesia had a greater IVCCI.

Fields et al. [35] studied women in three different positions (supine, tilted left, and right) through an intercostal window, and have demonstrated that the IVCDmax of most subjects was greatest in the left-sided tilt. However, there was still a quarter of patients whose IVC decreased with a leftward tilt, suggesting that given the reduced venous return due to pregnancy-related uterine compression of the IVC, a left-tilted position is more often used for cesarean section. However, given the specificity of the patient, bedside IVC assessment may be a helpful complement to determine the optimal position for resuscitation in patients with advanced pregnancy. In addition, the data suggest that IVCCI-oriented fluid resuscitation is effective in reducing transfusions, fluid volume, and bleeding and in improving coagulation in patients with severe postpartum hemorrhage. Therefore, based on the predictive value of the IVCCI for PSAH, it is reasonable to administer fluids and vasoactive drugs at the appropriate time.

5. SUMMARY

In summary, ultrasound IVC monitoring can, to some extent, be a simple and rapid method for predicting hypotension, assessing blood status, and guiding fluid management. However, the specific cutoff values still need to be considered in the context of the specific health statuses of patients and relevant treatment options. Currently, articles proposing partial exclusion criteria for applications from a physiological perspective have been published [36]. In the future, more studies are needed to explore and refine the specific criteria for the application of the IVC correlation coefficient to guide clinical practice in different clinical situations.

DECLARATION OF CONFLICTING INTERESTS

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