

Smart IVC: Automatic Measurement of Inferior Vena Cava Diameter

Background

Critically ill patients often suffer from an excessively high or low fluid volume, with symptoms such as tissue edema and insufficient tissue perfusion, due to vascular regulatory dysfunction and poor cardiac reserve. It is necessary to carry out fluid management for critically ill patients. Volume status evaluation and volume responsiveness evaluation are the core of fluid management. Volume status evaluation is the overall evaluation of the body's circulatory volume based on the patient's pathophysiological status. Volume responsiveness evaluation is the evaluation of cardiac preload reserve function, that is, the response potential of cardiac preload to volume [1, 2].

The methods to evaluate the volume status of critically ill patients include volume-related history evaluation, clinical performance evaluation, and hemodynamic evaluation. Cardiac preload is a common index of hemodynamic evaluation.

Fluid challenge is the gold standard for volume responsiveness evaluation. 500 ml of crystalloid solution or colloidal solution is infused in 15-30 minutes to determine a patient's response and tolerance to volume based on the change of cardiac output. This method is time-consuming and cumbersome and exposes the patient to the risk of fluid overload, resulting in peripheral and pulmonary edema. At present, the indexes and methods for clinical prediction of volume responsiveness include functional hemodynamic indexes of heart–lung interactions, mini fluid challenge and passive leg raising.

Clinical Values

Vena cava is the closest return vessel to the right atrium and can effectively reflect the right atrium function and heart–lung interactions. The vena cava diameter changes with the change in right atrium pressure. Compared with the related indexes of the arterial system, such as blood pressure, heart rate, and aortic diameter, the vena cava diameter can better reflect a patient's volume status. At present, the diameter of inferior vena cava (IVC) is clinically used to evaluate the central venous pressure (CVP), volume status, and volume responsiveness [3, 4].

Indication	Note
Volume responsiveness	Most reliable for patients with mechanical ventilation
Central venous pressure	Approximate value for patients with spontaneous breathing
Pericardial effusion	Non-distensible IVC, which excludes cardiac tamponade
Right-sided heart failure	Distensible IVC, a typical sign of pulmonary heart disease and serious tricuspid regurgitation

Figure 1 Clinical significance of IVC evaluation

The orifice of the hepatic vein into the IVC and the orifice of the IVC into the right atrium (subcostal IVC long axis view) can be observed through the acoustic window of subcostal, and the periodic changes of the IVC diameter with respiration can be observed. For patients who breathe spontaneously, the intrathoracic pressure is negative during inhalation, causing the IVC to be collapsible. For patients with positive pressure ventilation, the intrathoracic pressure is positive

during inhalation, causing the IVC to be distensible.

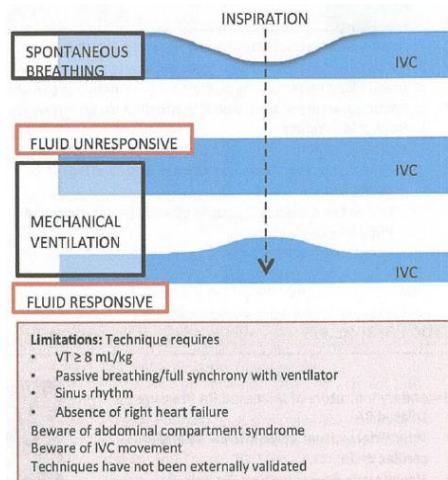


Figure 2 Schematic diagram of the IVC under spontaneous breathing and mechanical ventilation

Studies show a close relationship between the IVC diameter and the CVP under spontaneous breathing. The CVP is about 0-5 mmHg when the IVC diameter is less than 2.1 cm and the collapsibility index is greater than 50%. The CVP is about 10-20 mmHg when the IVC diameter is greater than 2.1 cm and the collapsibility index is less than 50%. In other cases, the CVP is about 5-10 mmHg. In the case of mechanical ventilation, especially complete mechanical ventilation, volume responsiveness can be evaluated based on the IVC diameter variation or distensibility index. Volume responsiveness is predicted to occur when the IVC diameter variation is greater than 12% or the distensibility index is greater than 18%. Doctors can conduct fluid management in an easy and safe manner by measuring the IVC diameter through ultrasonography. However, this method requires dynamic evaluation based on different respiratory support conditions, with a series of limiting factors. It is clinically necessary to select an appropriate evaluation method based on specific conditions [5, 6].

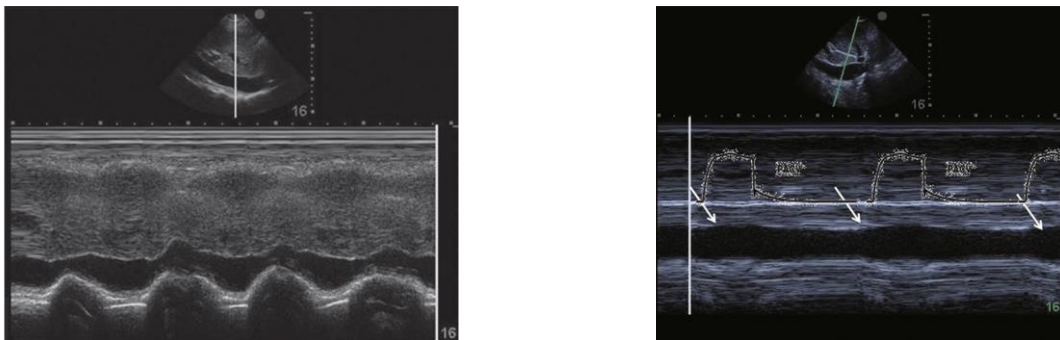


Figure 3 IVC collapses while spontaneous breathing IVC distention while mechanical ventilation

At present, the clinical method to measure the IVC diameter is as follows: Target the subcostal IVC long axis view with a phased array or convex array, place the M-line about 2 cm away from the orifice of the IVC into the right atrium, save a film of at least two respiratory cycles, and measure the maximum IVC diameter, minimum IVC diameter, and diameter variation in the M mode.

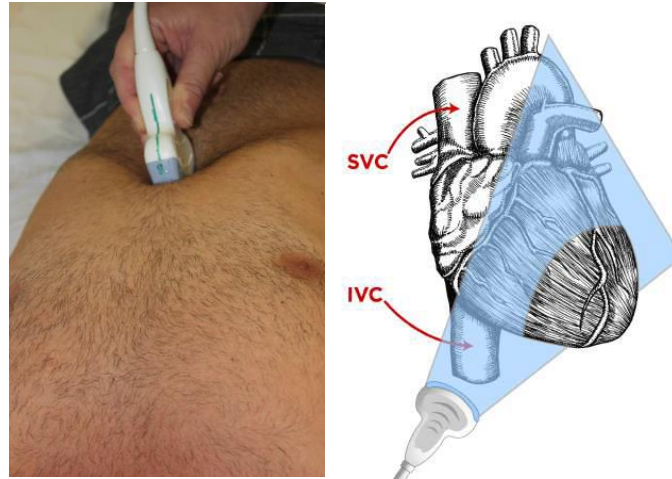


Figure 4 IVC imaging technique and anatomic sketch

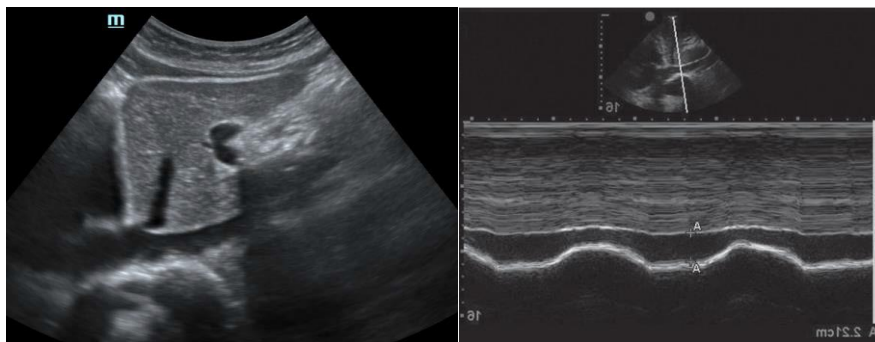


Figure 5 Standard view and method for measuring the IVC diameter

The preceding procedure is complex and the M-line positioning is limited by subjective factors, causing poor repeatability. Therefore, this method has limited clinical use.

Technical Solution

Smart IVC combines image processing algorithm and pattern recognition method to automatically position the target area in the IVC on an ultrasound image and measure the IVC diameter. Smart IVC supports real-time and non-real-time operations in least steps, allowing you to efficiently record clinical conditions and ultrasound signs.



Figure 6 Procedure of traditional IVC measurement



Figure 7 Procedure of IVC measurement through Smart IVC

	Number of steps	Duration
Common measurement	11	About 20s
Smart IVC	2	Less than 4s

Automatic Positioning

In Smart IVC, feature of the IVC target area extracted from subcostal IVC long axis view image, is used by pattern recognition method. This enables automatic and real-time positioning of the target area. You are prompted to reacquire images when the input image quality does not meet the requirements of the subcostal IVC long axis view.



Figure 8 Target area automatic positioning

Automatic Measurement

The algorithm automatically acquires the anatomical M-line used to measure the IVC diameter based on the IVC target area calculated in the B mode. The position and angle of the anatomical M-line are adjusted in real time by a tracking algorithm. When the image changes, the anatomical M-line is automatically adjusted to an appropriate position to be perpendicular to the direction of the vascular wall.

User can manually edit the position and angle of the anatomical M-line acquired by the algorithm if it is inaccurate. The algorithm continues tracking based on the adjusted anatomical M-line. To ensure algorithm accuracy, user is advised to edit the anatomical M-line to be about 2 cm from the right atrium orifice and roughly perpendicular to the vascular wall, with the midpoint located in the central area of the vascular lumen.

On the anatomical M-line, the low echo area in the middle is the blood vessel, and the high echo area on both sides of the low echo area is the vascular wall. By using edge detection and other methods, the algorithm acquires the distance between the vascular walls, that is, the IVC diameter.

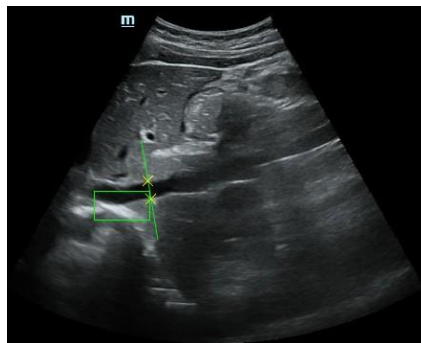


Figure 9 Positioning of the anatomical M-line based on the target area

Parameter Display

IVC moves periodically with respiration. Smart IVC outputs the maximum IVC diameter (Dmax) and minimum IVC diameter (Dmin) once per respiratory cycle.

Clinical studies indicate the necessity to accurately evaluate the volume status, CVP, and other indexes based on the actual clinical scenario during IVC analysis. Therefore, Smart IVC provides the clinical scenarios "spontaneous breathing" and "mechanical ventilation" on the screen. After you select a clinical scenario, the screen displays related parameters: collapsibility index (CI) for spontaneous breathing and distensibility index (DI) and respiratory variation for mechanical ventilation. The calculation formulas are as follows.

$$CI = (Dmax - Dmin)/Dmax$$

$$DI = (Dmax - Dmin)/Dmin$$

$$Variation = (Dmax - Dmin)/[(Dmax + Dmin)/2]$$

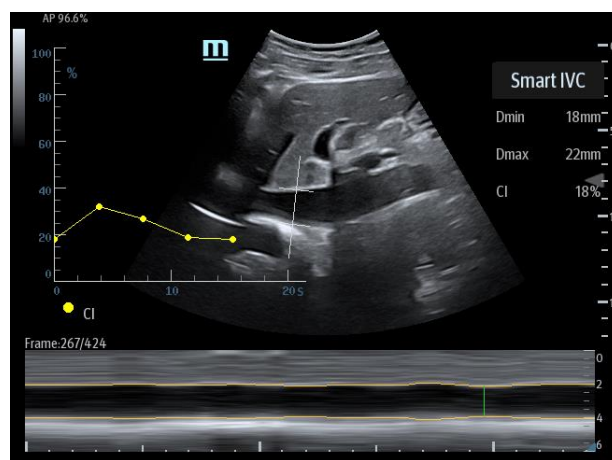


Figure 10 Smart IVC UI

Conclusion

- Automatic IVC measurement in one click
- Applicable to a wide range of clinical scenarios based on big data samples
- Support operations on real-time or frozen cine
- Editable results
- Fast respiratory status annotating and automatic parameter matching

Reference Documents

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