Smart VTI: Automatic Measurement of Blood Velocity Time Integration for Left Ventricular Outflow Tract

Background

Hemodynamics is a discipline that studies the movement of blood in the circulatory system and the movement pattern of blood components among tissues. This pattern helps identify changes in cell metabolism and organ functions. Hemodynamics allows clinicians specializing in critical cases to determine the treatment direction and set specific treatment goals based on physiological indicators. Clinicians can select an appropriate treatment method and then limit and quantitatively adjust the treatment method based on the continuous changes of target values.

Cardiac output (CO) is an important parameter in hemodynamics and the main determinant of oxygen delivery [1]. CO is equal to the product of the stroke volume (SV) and heart rate.

$$\mathrm{CO} = \mathrm{SV} \times \mathrm{HR}$$

SV evaluation is essential for dynamically evaluating the systolic function of the heart because the ejection caused by each contraction of the heart is the main driving force of SV. Fluid challenge is the gold standard for clinically evaluating volume responsiveness. 500 mL of crystalloid solution or colloidal solution is infused in 15-30 minutes to determine a patient's response and tolerance to volume through the change of CO. Therefore, CO must be continuously monitored and dynamically evaluated [2-4].

Common clinic methods of CO measurement and monitoring include pulmonary artery thermodilution, magnetic resonance imaging, and impedance cardiography. Pulmonary artery thermodilution is the gold standard for CO measurement, but it is invasive, expensive, and complex. Magnetic resonance imaging cannot be used in bedside mode. Impedance cardiography has poor anti-interference ability and is unstable and limited by many factors.

Clinical Values

As bedside ultrasonography is becoming more common, the method of calculating SV and CO by measuring the blood velocity time integration (VTI) of left ventricular outflow tract (LVOT) through ultrasonography, has acquired more and more clinical approval.

The principle of using pulsed wave Doppler (PW) to measure SV is as follows. Assume that the distribution of blood velocities in the LVOT is basically even. The area under the blood velocity-time curve in a cardiac cycle (that is, the blood VTI) is equal to the distance of blood ejection in a cardiac cycle. This distance multiplied by the cross-sectional area of the LVOT is equal to the volume of left ventricular ejection in a cardiac cycle, that is, SV.

$$SV = VTI \times \pi \times \frac{D^2}{4}$$

Clinical studies show that the numerical value calculated by this method is close to that measured by a pulmonary artery flotation catheter [5, 6].

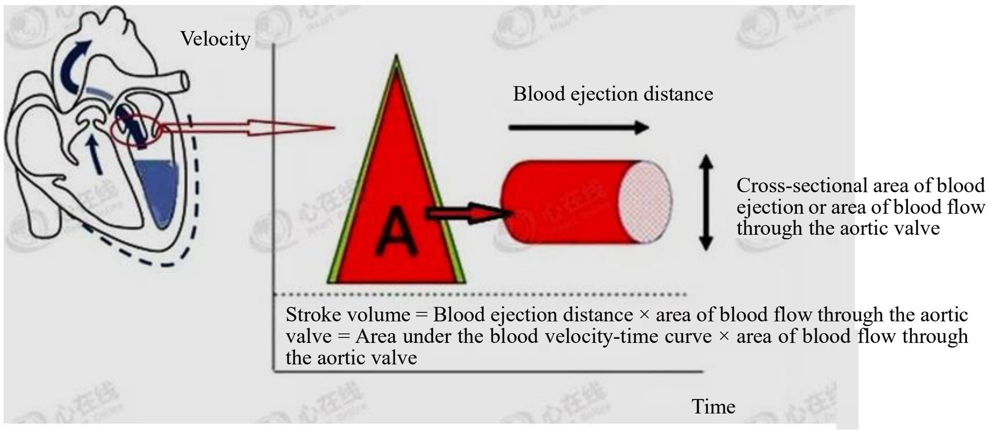


Figure 1 Schematic diagram of SV measurement through ultrasonography PW

The method of VTI measurement using ultrasonography is as follows.

(1) Target the apical five chamber view with a phased array.

(2) Enter Color and PW modes in sequence.

(3) Place the PW sampling gate in the center of the LVOT about 5 mm away from the aortic valve.

(4) Adjust the position of the sampling gate to make the PW spectrum meet the conditions of narrow band single peak and hollow triangle in the systole phase.

(5) After the PW spectrum is acquired, trace the spectrum to get the VTI [3, 4].

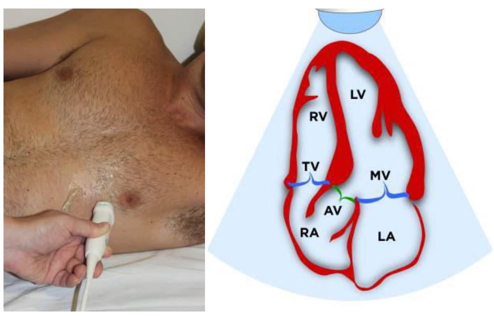


Figure 2 Imaging technique in the apical five chamber view and anatomic sketch

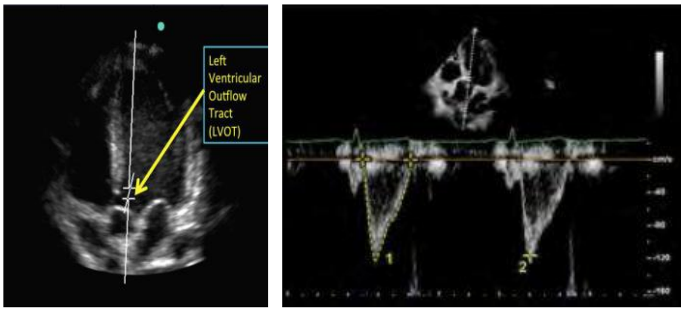


Figure 3 Position of the PW sampling gate and method of tracing for VTI measurement

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

Technical Solution

Smart VTI combines advanced image processing algorithm and pattern recognition method to automatically position the PW sampling gate in the LVOT on an ultrasound image (apical five chamber view) and calculate the PW spectrum to get the VTI in one click. Smart VTI supports real-time and non-real-time operations in least steps. Smart VTI outputs the stroke volume variation (SVV) and VTI trending graph derived from repeated measurement, allowing ICU doctors to dynamic evaluate patients' hemodynamic status.

Figure 4 Procedure of traditional VTI measurement

Figure 5 Procedure of VTI measurement through Smart VTI

	Number of steps	Duration
Common measurement	11	About 30s
Smart VTI measurement	2	Less than 5s

Automatic Positioning

In Smart VTI, a feature of the LVOT target area extracted from the apical five chamber view image, is used by pattern recognition method. This enables automatic positioning of the target area.

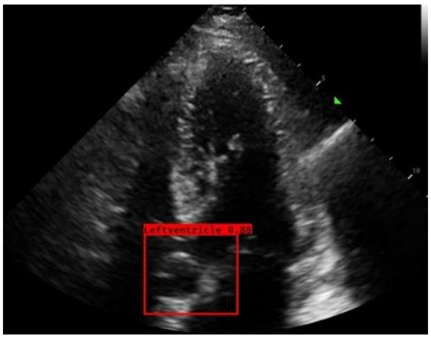


Figure 6 Target area automatic positioning

Automatic Measurement

Based on the target area in the LVOT calculated on a B image, the algorithm automatically positions the matched PW sampling line and sampling gate and acquires the LVOT blood flow spectrum. The position of the sampling gate is editable.

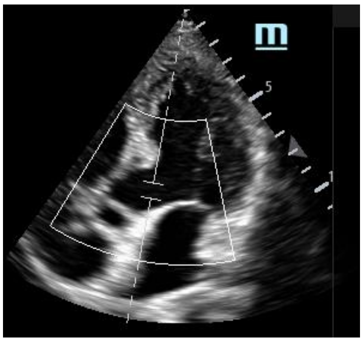


Figure 7 Positioning of the PW sampling line and sampling gate based on the target area

The algorithm performs adaptive threshold segmentation based on the PW spectrum of the LVOT. The PW spectrum is prone to interference signals because the PW sampling gate is easily affected by myocardial motion. In this algorithm, interference signals are removed through filter design, and the PW spectrum is automatically traced and the VTI is automatically calculated. The tracing is editable.

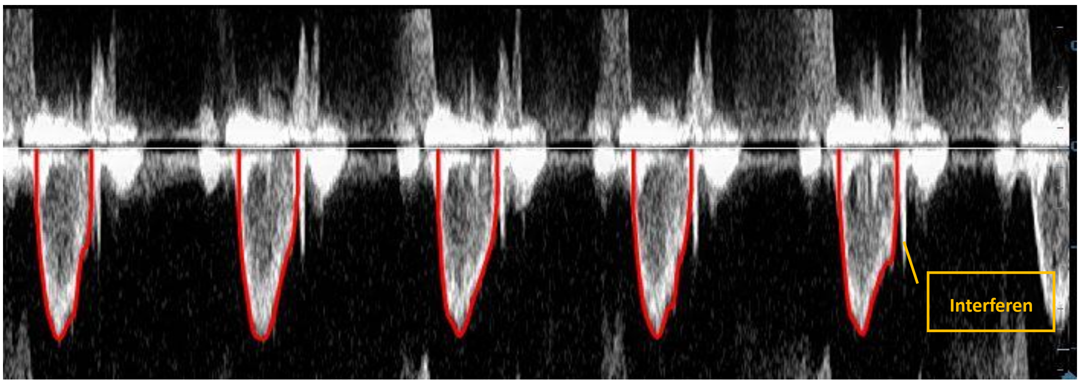


Figure 8 Automatic tracing

Parameter Display

The Smart VTI algorithms provide the following parameters: LVOT VTI, heart rate (HR), and maximum blood velocity (LVOT Vmax).

The following parameters are displayed: LVOT Diam, LVOT Vmax, LVOT Vmean, LVOT PGmean, LVOT PGmax, LVOT VTI, HR, SV, SVV, and CO. LVOT Diam must be manually input or measured in the parasternal long axis view in advance. The algorithm calculates SV, CO, and SVV based on LVOT Diam.

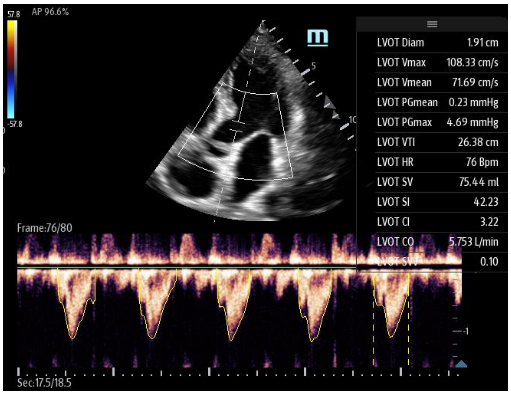


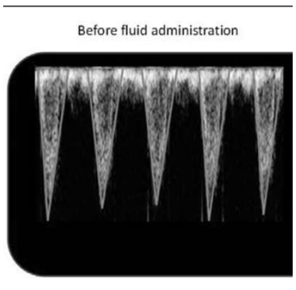
Figure 9 Smart VTI

SVV is the variation of SV in a respiratory cycle:

$$SVV = (SV_{max} - SV_{min})/SV_{mean}$$

Dynamic indexes related to heart–lung interactions are used to evaluate volume responsiveness for patients with complete mechanical ventilation and no arrhythmia. Common ultrasonography-related dynamic indexes include vena cava variation and SVV. Studies show that volume responsiveness is indicated by an SVV value more than 12% and that the positive predictive value exceeds 90%.

Heart–lung interaction evaluation is not applicable to patients with spontaneous respiration or arrhythmia. It is clinically necessary to evaluate the variation of SV and predict volume responsiveness by means of passive leg raising (PLR), fluid challenge, mini-fluid challenge, and other fluid management methods. Therefore, Smart VTI offers a trending curve, allowing users to save VTI/SV acquired in different time (such as before and after PLR) and automatically calculate the output variation.



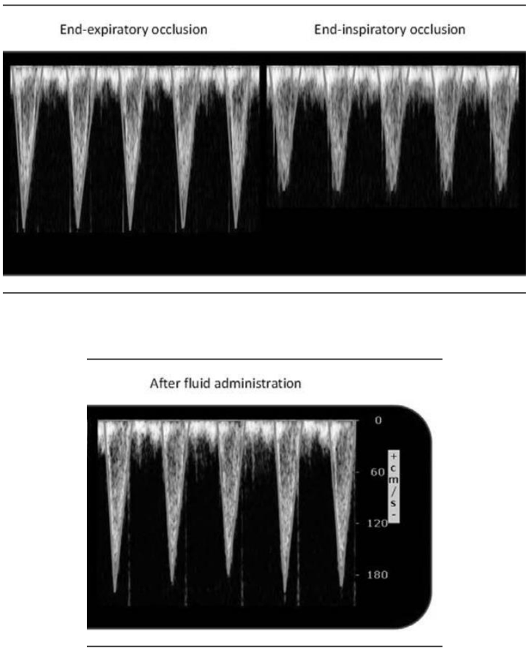


Figure 10 Variation of VTI before and after fluid management

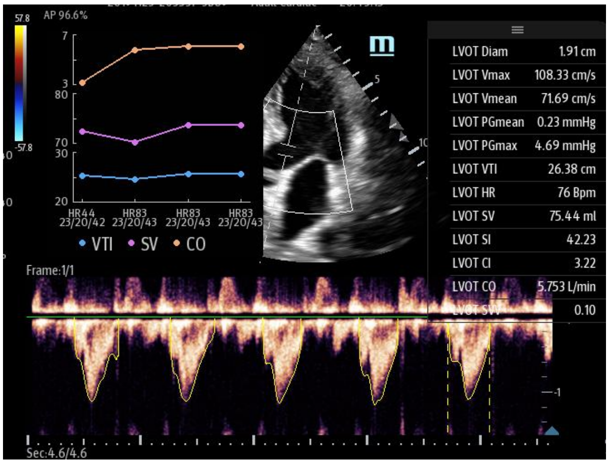


Figure 11 VTI trending graph

Conclusion

- Automatic VTI measurement in one click
- Applicable to a wide range of clinical scenarios based on big data samples
- Support for real-time and non-real-time operations
- Editable results
- Dynamic parameters such as SVV and trending graph

Reference Documents

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6. Carol Mitchell, Peter S. Rahko, et al. Guidelines for Performing a Comprehensive Transthoracic Echocardiographic Examination in Adults: Recommendations from the American Society of Echocardiography