ECHOCARDIOGRPHY IN CARDOAC OUTPUT AND FLUID RESPONSIVENESS

- Managing patients with hemodynamic instability can be very challenging.

- Determination of cardiac output (CO) is one of the most important tasks when caring for such patients

Cardiac output monitoring

- Methods of CO monitoring are broadly classified as follow

- Invasive

- Minimally invasive
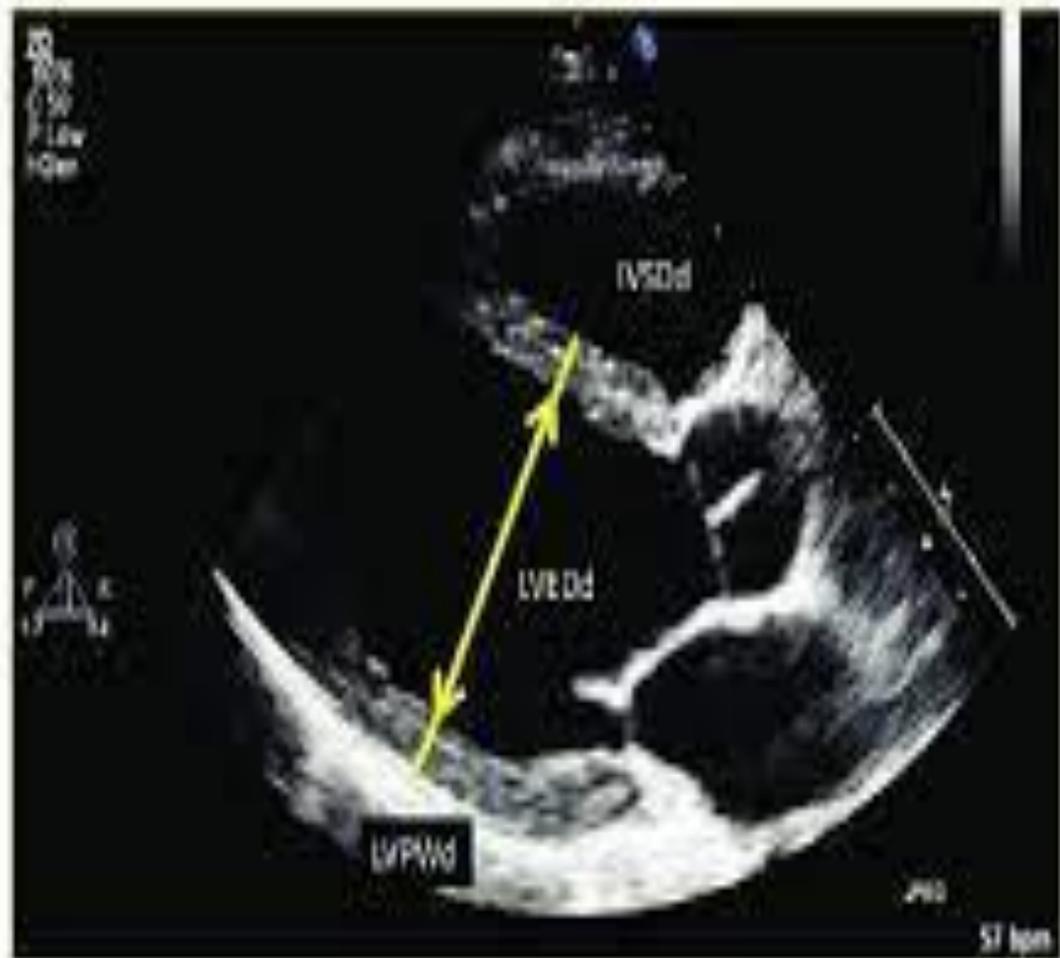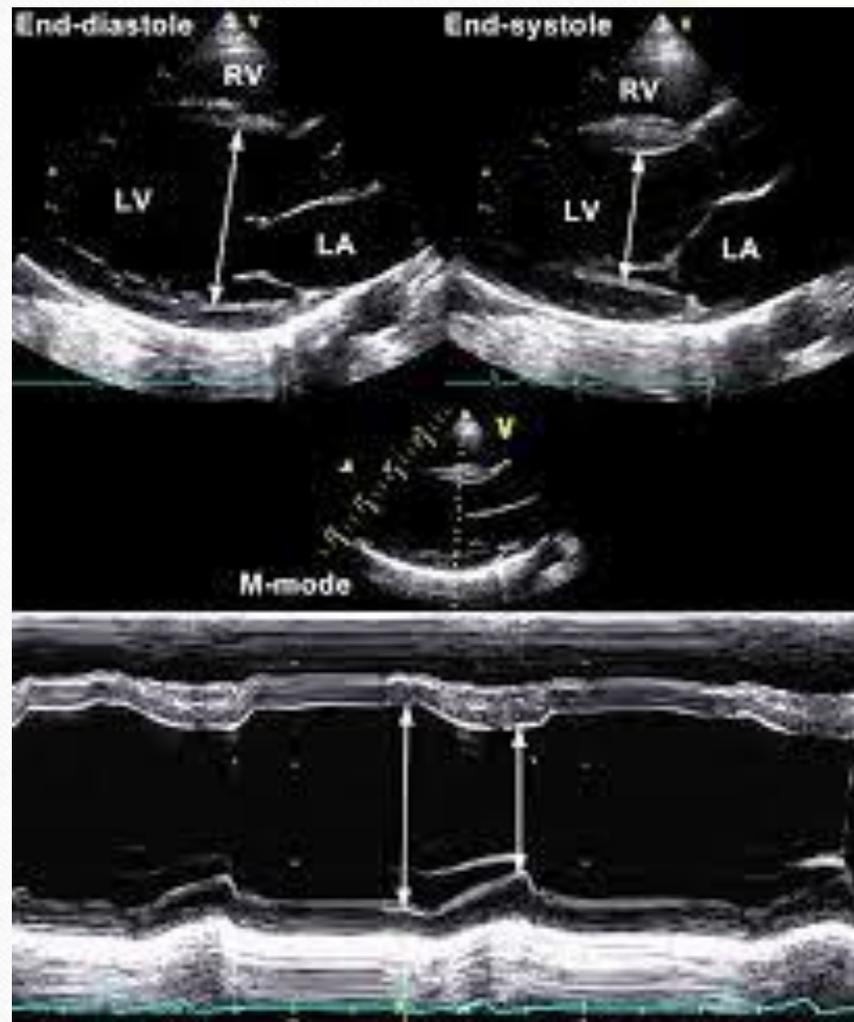
- Non invasive

Ideal CO monitoring

- Minimal or non invasive
- Continues
- Cost effective
- Reproducible
- Reliable during various physiological states
- Have fast response time

Echo as cardiac monitor

- Echocardiographic methods are well validated and may provide an alternative to thermodilution methods.

- Echocardiography has the potential to noninvasively measure

- left-sided filling pressures and guide volume assessments in hospitalized patients who may be at risk for both systolic and diastolic heart failure.

- two dimensional (2D) and Doppler indices can be used to monitor stroke volume (SV) and overall volume status. and fluid response

- monitoring LAP with transmitral and tissue Doppler imaging (TDI)

- right atrial pressure (RAP) using vena cava respiratory dynamics.

Two-Dimensional Echocardiographic Monitoring Parameters

- **LV Chamber Dimensions**.

- Cardiac chambers can be measured serially to look for ventricular filling during focused examination of volume status.

- A small LV internal diameter at end-diastole (LVIDD) can be indicative of hypovolemia;

- Hypovolemia is best monitored using end-diastolic measurements, because a low LVIDS could also depict decreased systemic vascular resistance (SVR), increased inotropic state, or decreased ventricular filling.

- Both RV and LV internal diameters can be measured serially to monitor response to fluids.
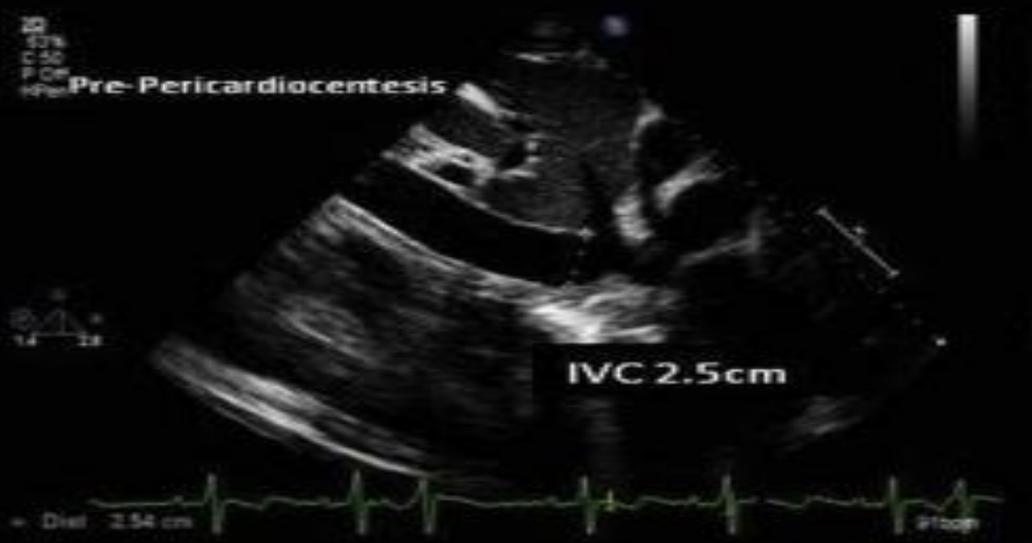
- **Inferior Vena Cava (IVC) Size and Collapsibility**.

- Hypovolemic patients can be identified using measurement of both size and collapsibility of the IVC for estimation of RAP.

- Fluid responsiveness of patients can be measured using 2D or M-mode assessment of IVC parameters.

- Routine measurements in size of the IVC and collapsibility with respiration have been used in patients with shock to reliably guide fluid management decisions.

- Because IVC collapse will not occur in patients on positive pressure ventilation due to inspiration-induced reductions in venous return, it should not be used to monitor RAP in this setting. Instead distensability index can be used

Before Inspiration — Pre-Pericardiocentesis — IVC 2.5cm

After Inspiration — Pre-Pericardiocentesis — IVC 2.1cm

Post-Pericardiocentesis — IVC 1.2cm
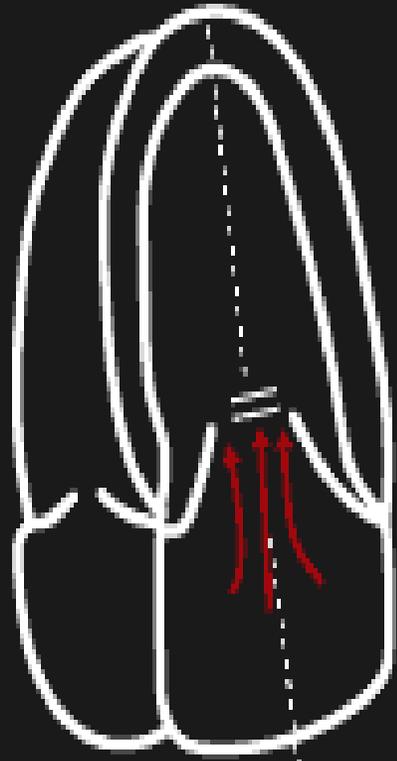
Post-Pericardiocentesis — IVC 0.3cm

Doppler Monitoring Parameters

- Mitral Inflow. Mitral inflow velocities,

- both peak early diastolic velocity (E) and late diastolic velocity (A), are commonly used to determine patterns of diastolic dysfunction and can also be used to serially monitor LAP.

- The mitral E wave represents the LA-LV gradient during early diastole and thus is preload dependent.

- The mitral A wave is the LA-LV gradient during late diastole and is affected by changes in LV diastolic function and LA compliance.
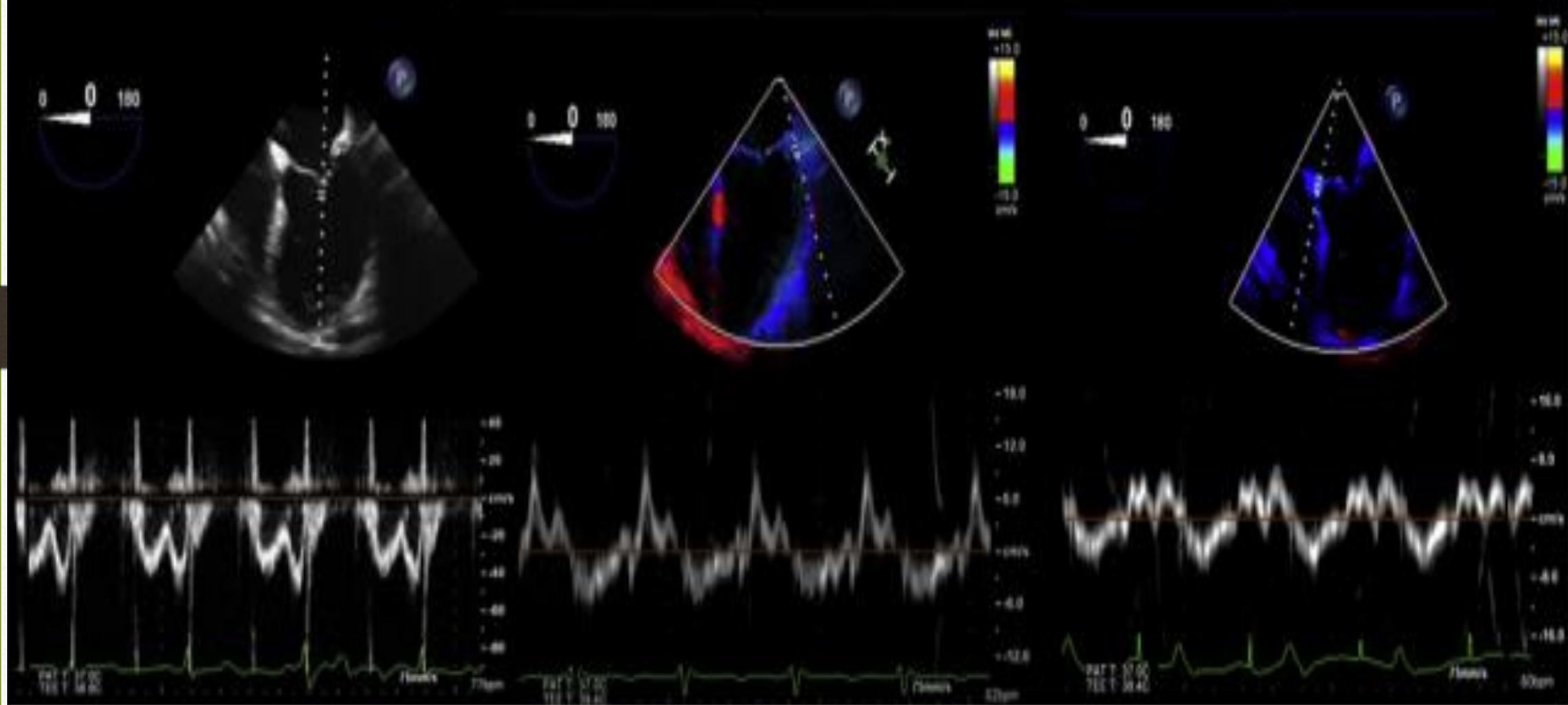
TDI

- PW TDI is a sensitive indicator of LV diastolic function.

- TDI measures mitral annular velocities during both systole and diastole at the end expiration.

- The measurement of E/e- , where E is the mitral inflow peak early diastolic velocity, is a reliable estimate of LAP when systolic function is normal . Therefore, serial E/e- measurements are practical and reliable measurements that can be performed as a serial assessment of LAP to guide fluid therapy in ambulatory and hospitalized subjects at risk for heart failure.

A: PW for Mitral Inflow E Velocity   B: TDI for e' Velocity Lateral Wall   C. TDI for e' Velocity Medial Wall

Calculated Monitoring Parameters

- SV, Cardiac Output (CO), and SVR Calculations

- Measurement of CO based on volumetric flow across any heart structure.

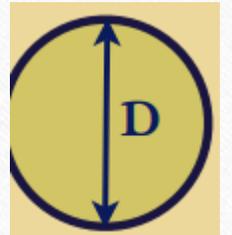- The continuity equation is the basis for CO measurements.

- It states that in the absence of valvular dysfunction or intracardiac shunt blood flow is constant throughout the heart. Based on this assumption, CO is equal to the forward flow across each of the cardiac valves.

- most commonly the left ventricular outflow track (LVOT) is used because its cross section is essentially a circle, unlike other structures (i.e. mitral valve annulus, aortic valve or tricuspid annulus, etc.).

- The first step in measuring CO with echocardiography is to determine stroke volume
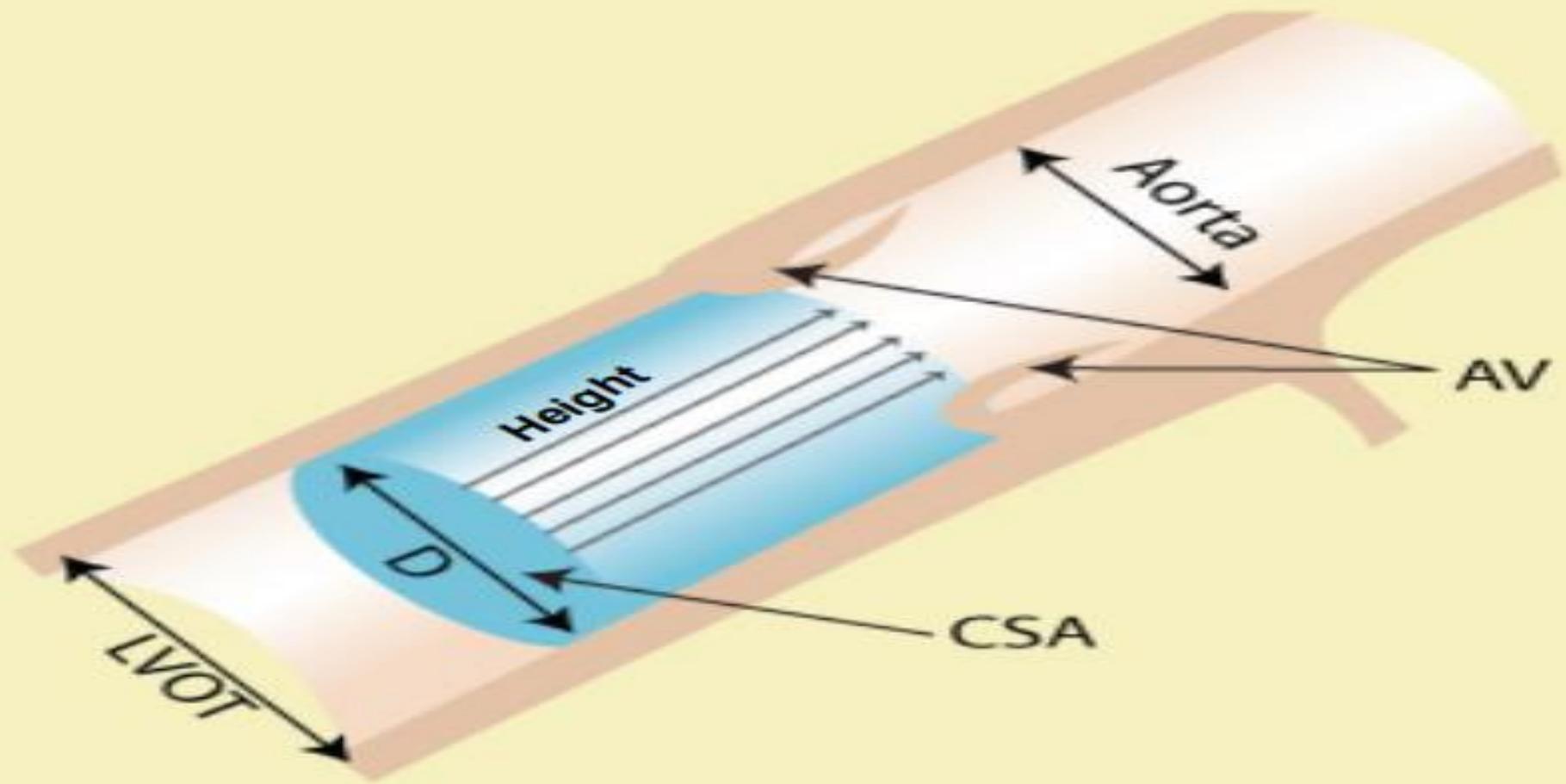
Stroke volume calculation

- Assuming a circular geometry, the LVOT can be thought of as a cylinder , and as such its volume is calculated as the base times its height.

- How is the volume of a cylinder calculated?

    - Volume of a cylinder is calculated as the cylinder's base times its hight:

        - volume = base x high
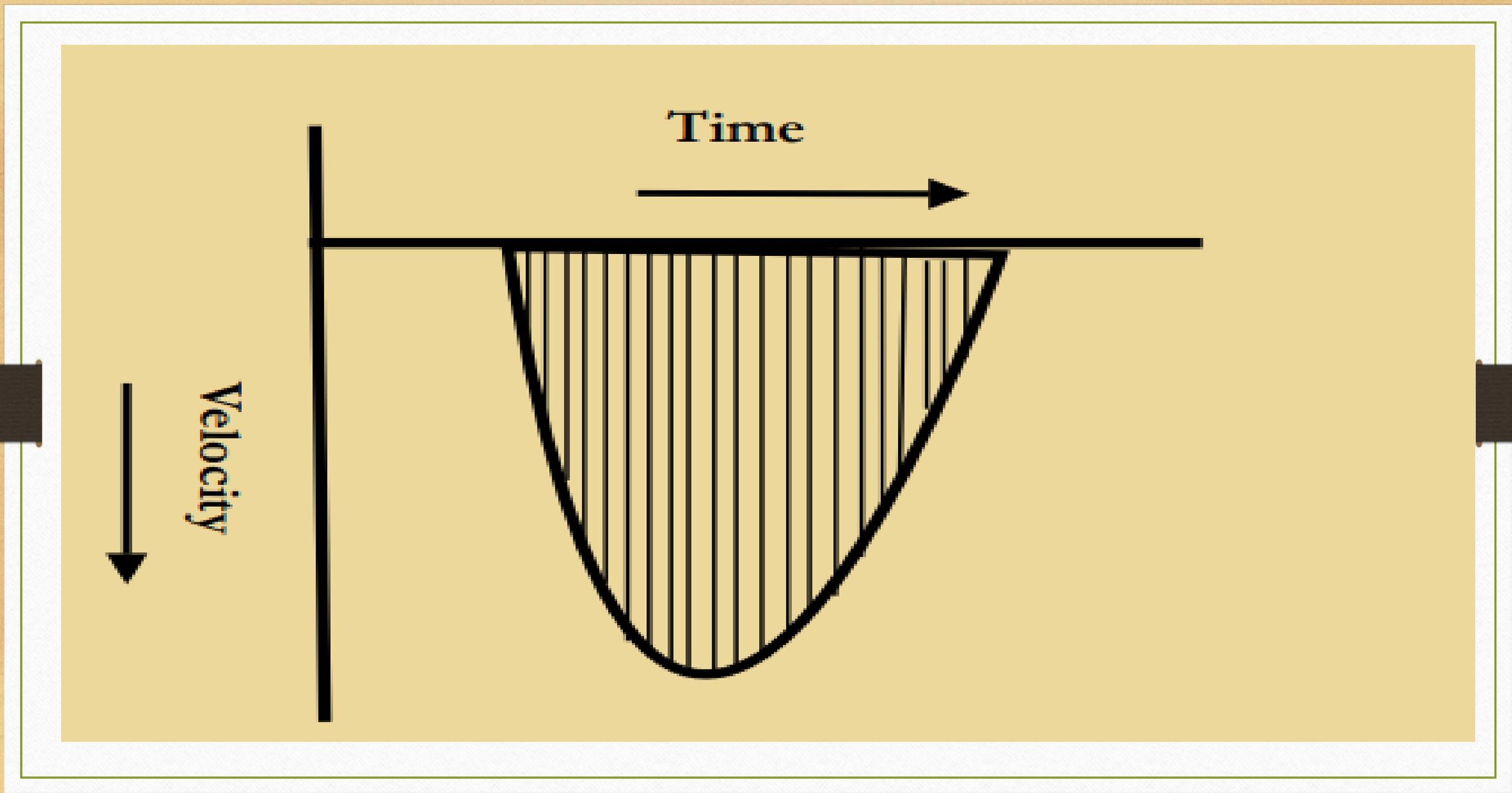
Calculating the cylinder's base

- The base of a cylinder is its cross-sectional area (in cm2).

- The CSA of a circle is calculated from its diameter as $\pi r2$ or $\pi(D/2)2$.

- When measuring CO from the LVOT, its diameter is used to calculate the cylinder's CSA, or base.

    - How is the cross sectional area of a circle calculated?

    - Cross sectional area of a circle calculated as $\pi r2$ or $\pi(D/2)2$
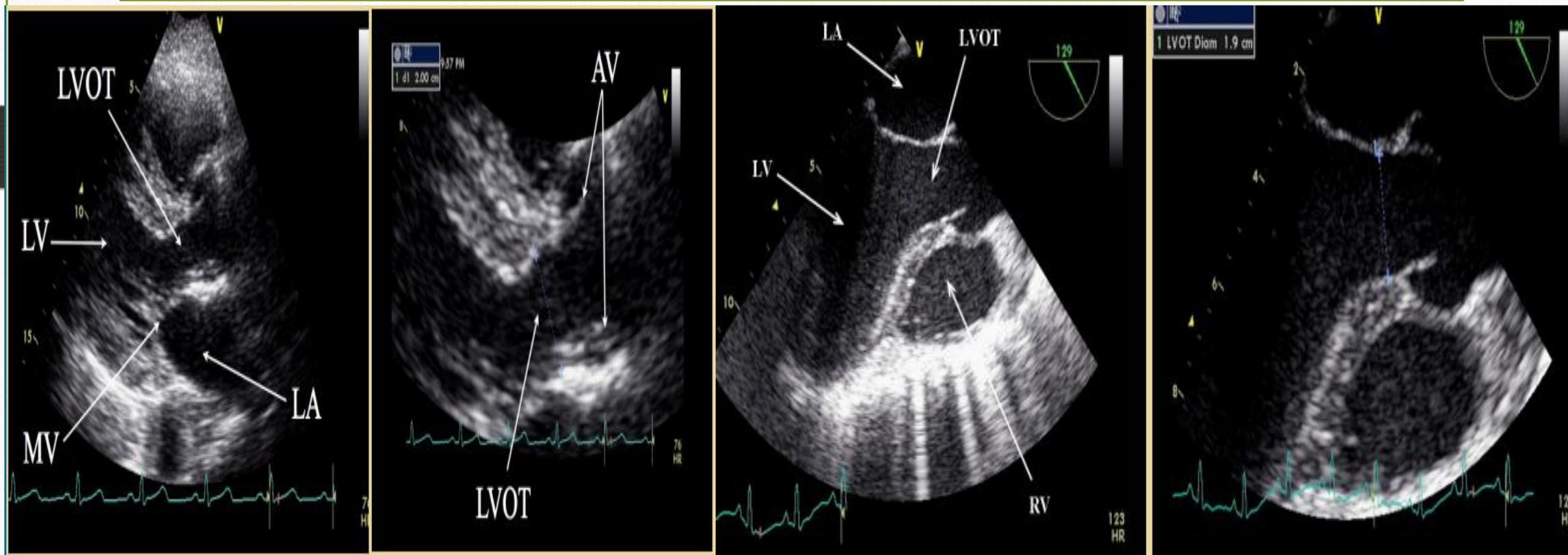
Calculating the cylinder's height

- The height, or distance, can be calculated from the velocities measured by the PWD during the ejection phase as the integral of these velocities.

- Since velocity is the first derivative of distance, the distance can be expressed as the integral of the Doppler systolic Velocity Time Integral (VTI) .

- This distance (in cm) — commonly referred as the stroke distance — is the distance an average blood cell travels during systole, the ejection phase of the cardiac cycle
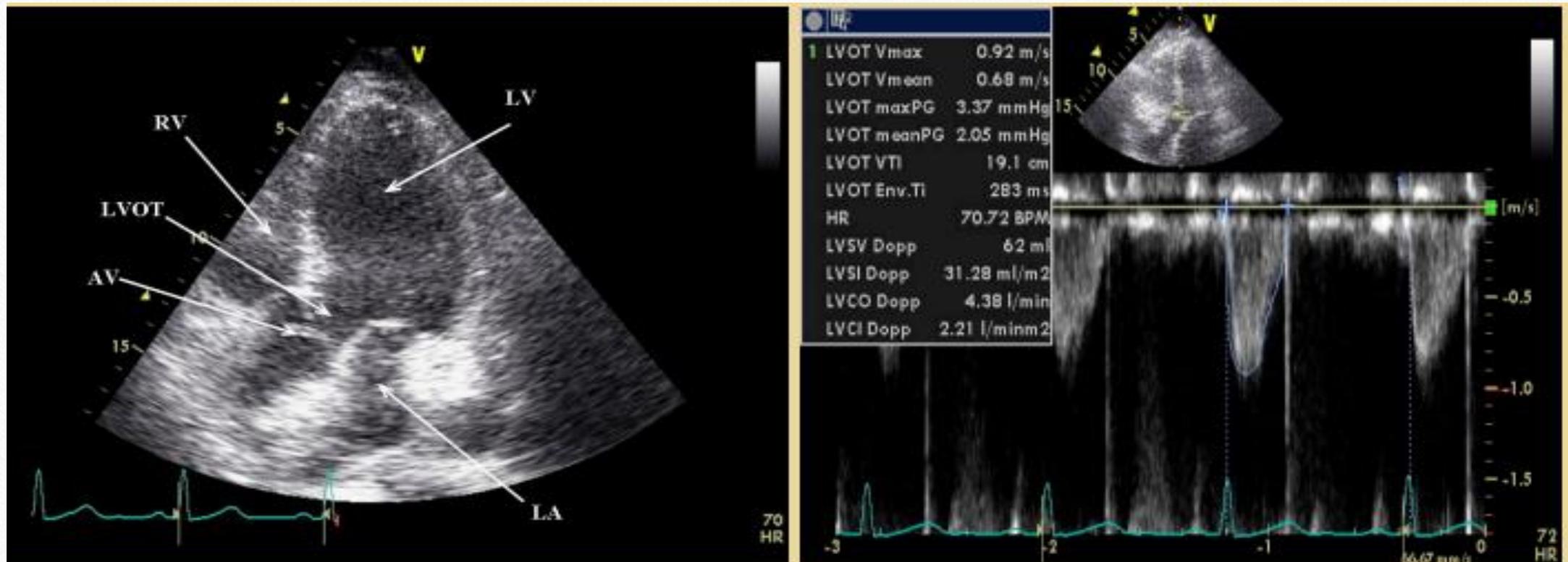
What does the VTI represent?

- The VTI represents the sum of instantaneous velocities during one ejection phase of the cardiac cycle.

- Finally, the SV is calculated by multiplying the base (LVOT CSA) and the height (LVOT VTI) of the cylinder:

  - SV (cm3) = LVOTCSA(cm2) x LVOTVTI(cm)

Echocardiographic windows for measuring LVOT diamete

Echocardiographic windows for measuring VTI

Limitation of use

- CSA determination often leads to the greatest source of error.

- The Doppler signal is assumed to have been recorded at a parallel or near parallel intercept angle, to blood flow.

- Deviations up to 20° in intercept angle are acceptable since only a 6 % error in measurement is introduced.

- Velocity and diameter measurements should be made at the same anatomic site. When the two are measured at different places the accuracy of SV and CO calculations are decreased.

- While the pattern of flow is assumed to be laminar, in reality the flow profile is parabolic. This does have some impact on velocity based calculations.

Echo in assessment of Fluid responsiveness

Monitoring parameter Role Reference	System requirements	Important technical features	Specific values to use while guiding interventions
Transmitral E/e' for LAP Nagueh et al.[15]	Pulsed Doppler Tissue Doppler	Doppler alignment End-expiratory acquisition	E/e' < 8; normal LVEF = normal LAP E/e' ≥ 13; normal LVEF = increased LAP E/A > 2; DT < 150 msec; depressed LVEF = increased LAP E/A < 1 and E < 50 cm/sec; depressed LVEF = normal LAP
IVC size /collapsibility, for RAP Rudski et al.[31], Brennan et al.[32]	2D harmonic	Visualization throughout the respiratory cycle	Size ≤ 2.1 cm; collapses >50% during sniff = RAP 0–5 mm Hg Size > 2.1 cm; collapses >50% during sniff = 5–10 mm Hg Size > 2.1; collapses <50% during sniff = 10–20 mm Hg
LV and RV chamber size, areas, and volumes for intravascular volume status and function Lang et al.[33]	2D harmonic	Optimal alignment; endocardial border visualization*; avoiding foreshortening	Normal ranges: LVIDD men 4.2–5.9 cm* LVIDD women 3.9–5.3 cm* LVEDV 46–106 mL women LVEDV 62–150 mL men LVESV 14–42 mL women LVESV 21–61 mL men RV FAC ≥ 35%
LVOT stroke distance for intravascular volume status Ristow et al.[34]	2D harmonic; pulsed Doppler	Optimal Doppler alignment; visualization of aortic valve leaflet opening	Normal values VTI > 18 cm
PASP for right-sided hemodynamics Lahm et al.[5]	Pulsed Doppler Continuous-wave Doppler	Optimal Doppler alignment	Normal value: PASP < 35 mm Hg
TAPSE RV s for RV function during fluid administration Rudski et al.[31]	M-mode (TAPSE) Tissue Doppler (RV s')	Optimal standard 4C view and alignment with TV annulus and right ventricle	Normal value: TAPSE ≥ 16 mm RV s' ≥ 10 cm/sec