

Ultrasound for Non-invasive Hemodynamic Monitoring Part 1

翁健瑞 醫師

台北醫學大學 模擬醫學教育中心

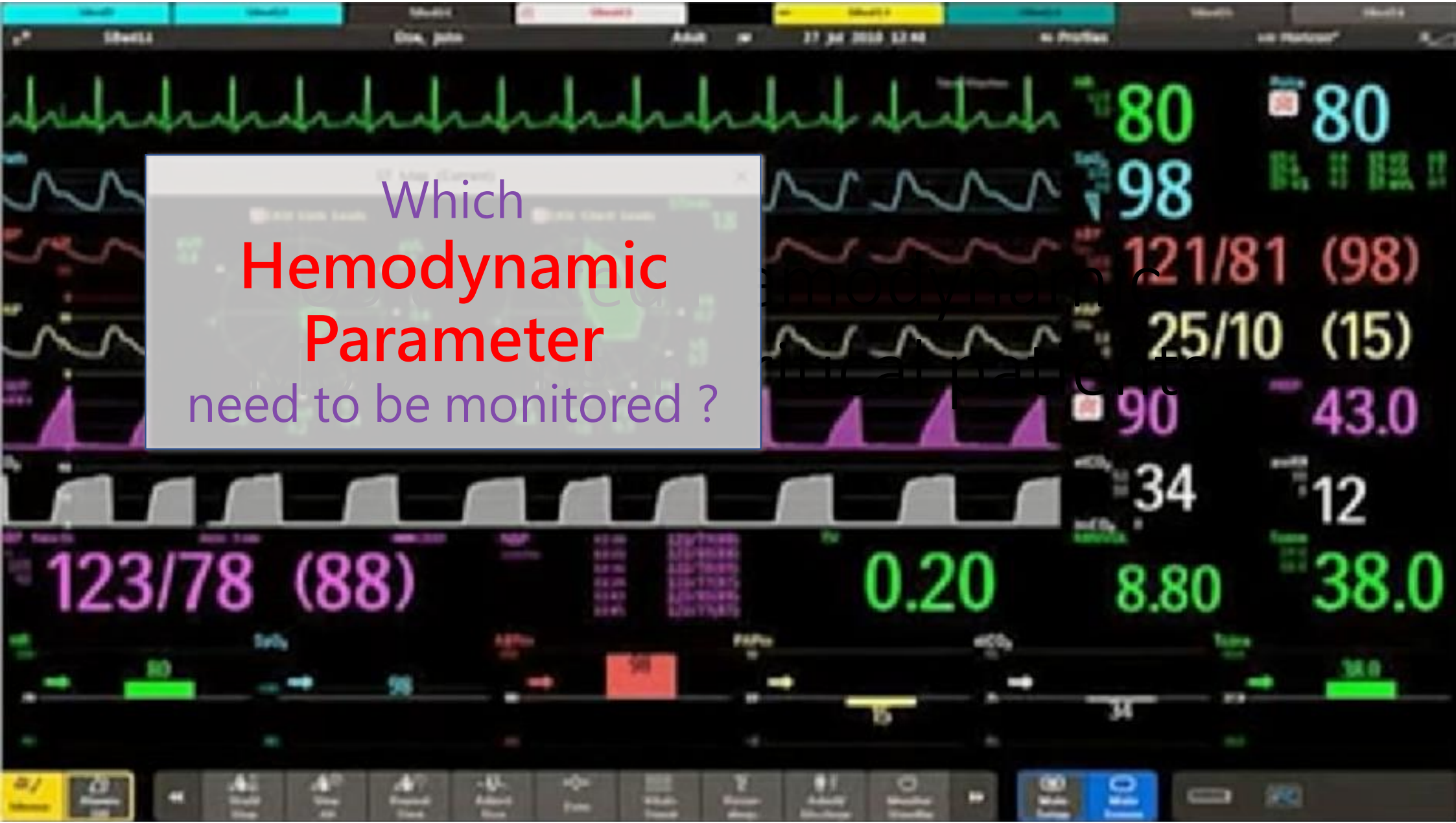
部立雙和醫院 急重症醫學部 緊急救護暨急救技能訓練中心

Post-6 h ICU admission

- 69 y/o 女性
- BP **100/50** mmHg, PR **140** bpm
- 3L NS + CVC + Norepinephrine
- WBC 24000/cm³, S_{Cr} 1.5mg/dL



Which
**Hemodynamic
Parameter**
need to be monitored ?



Macro

Invasive

Calibrated

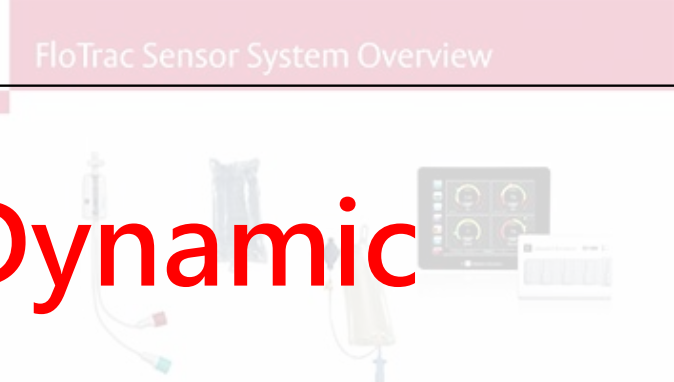
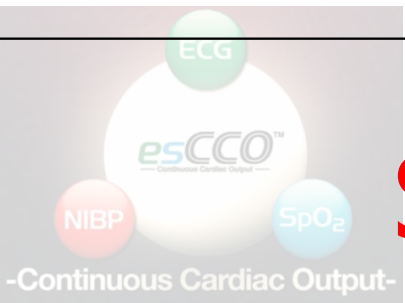
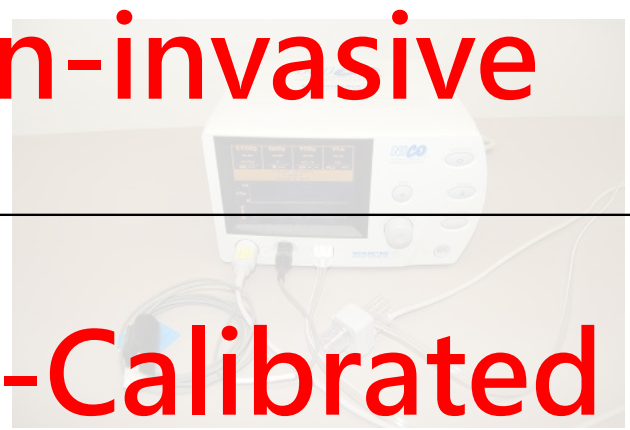
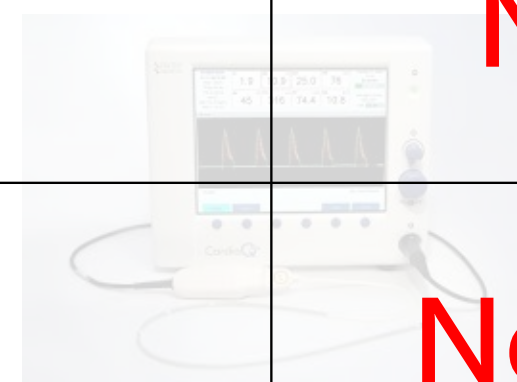
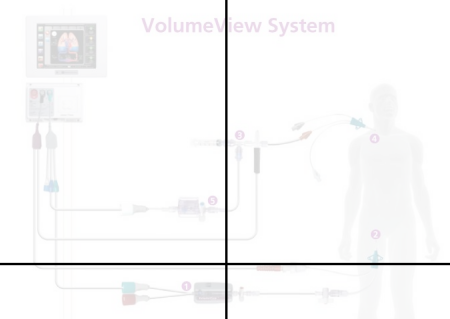
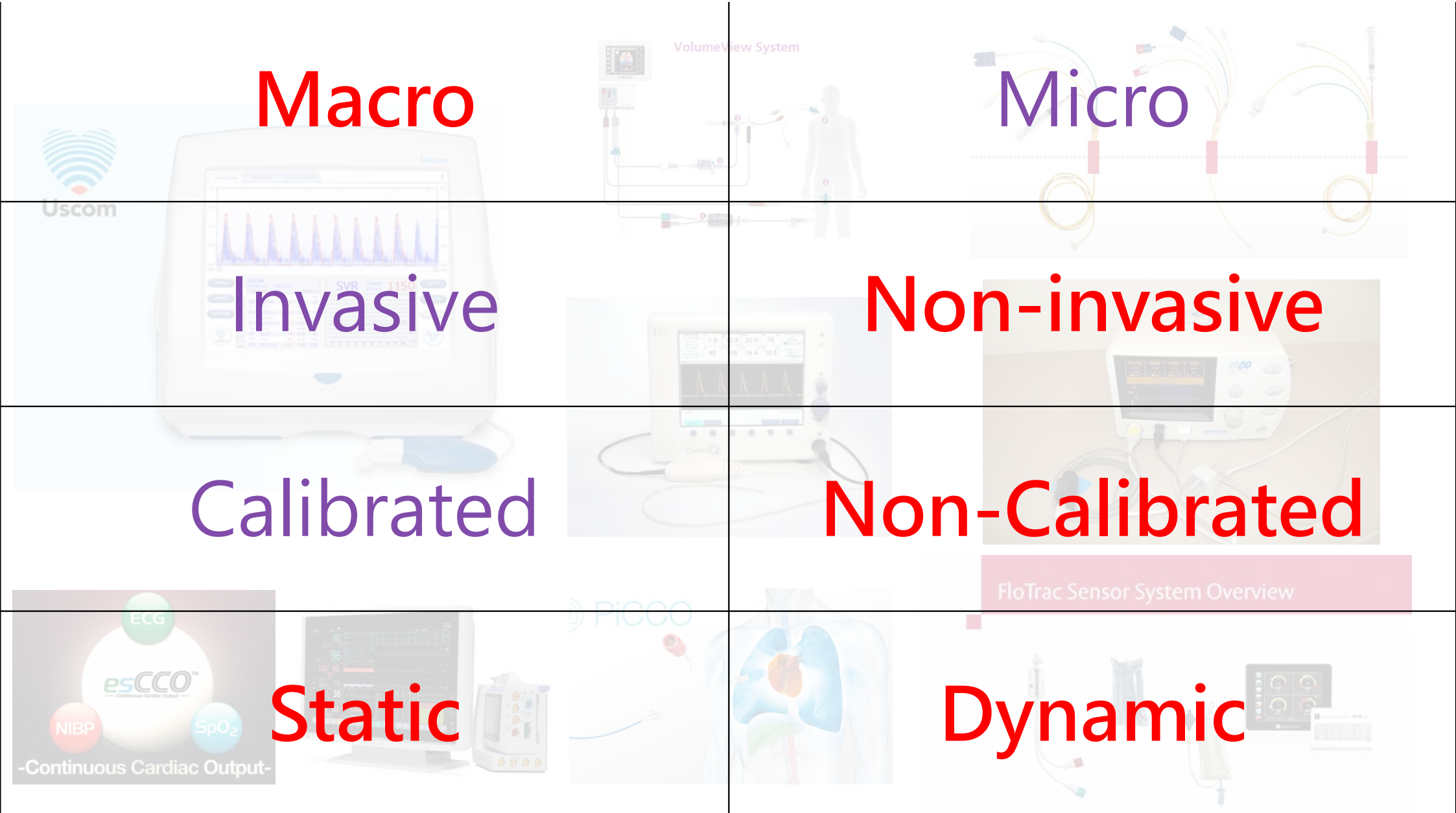
Static

Micro

Non-invasive

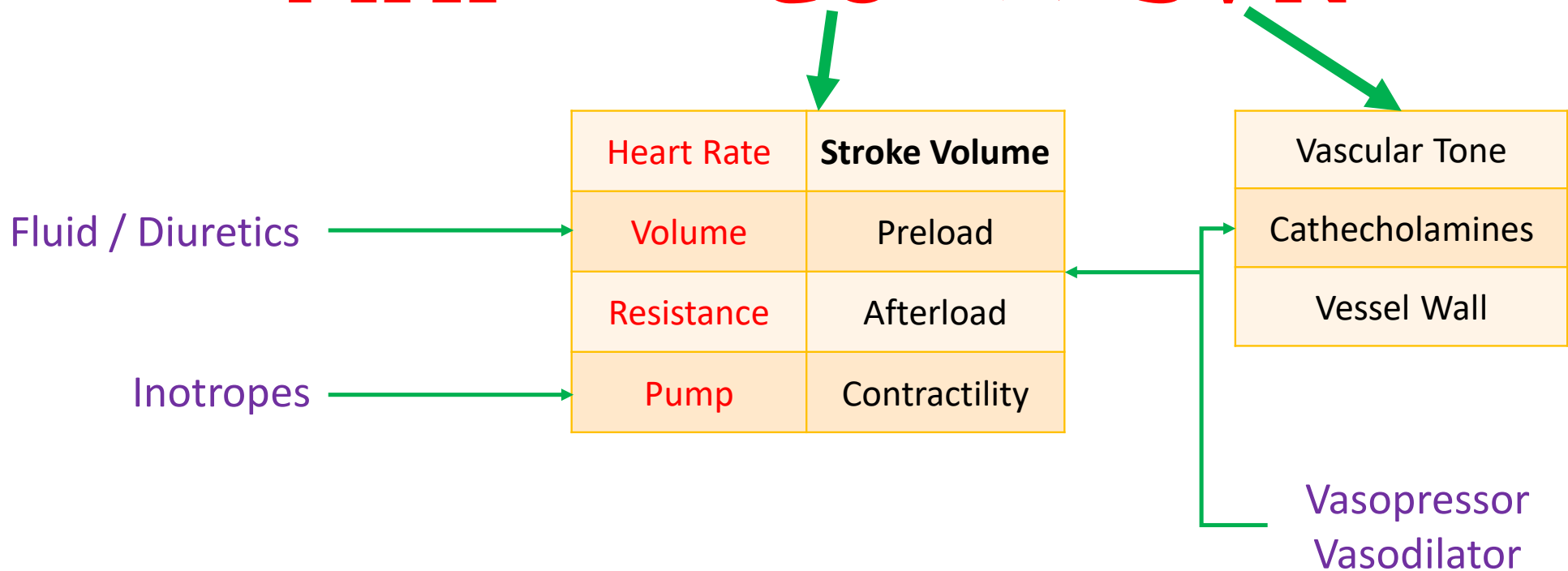
Non-Calibrated

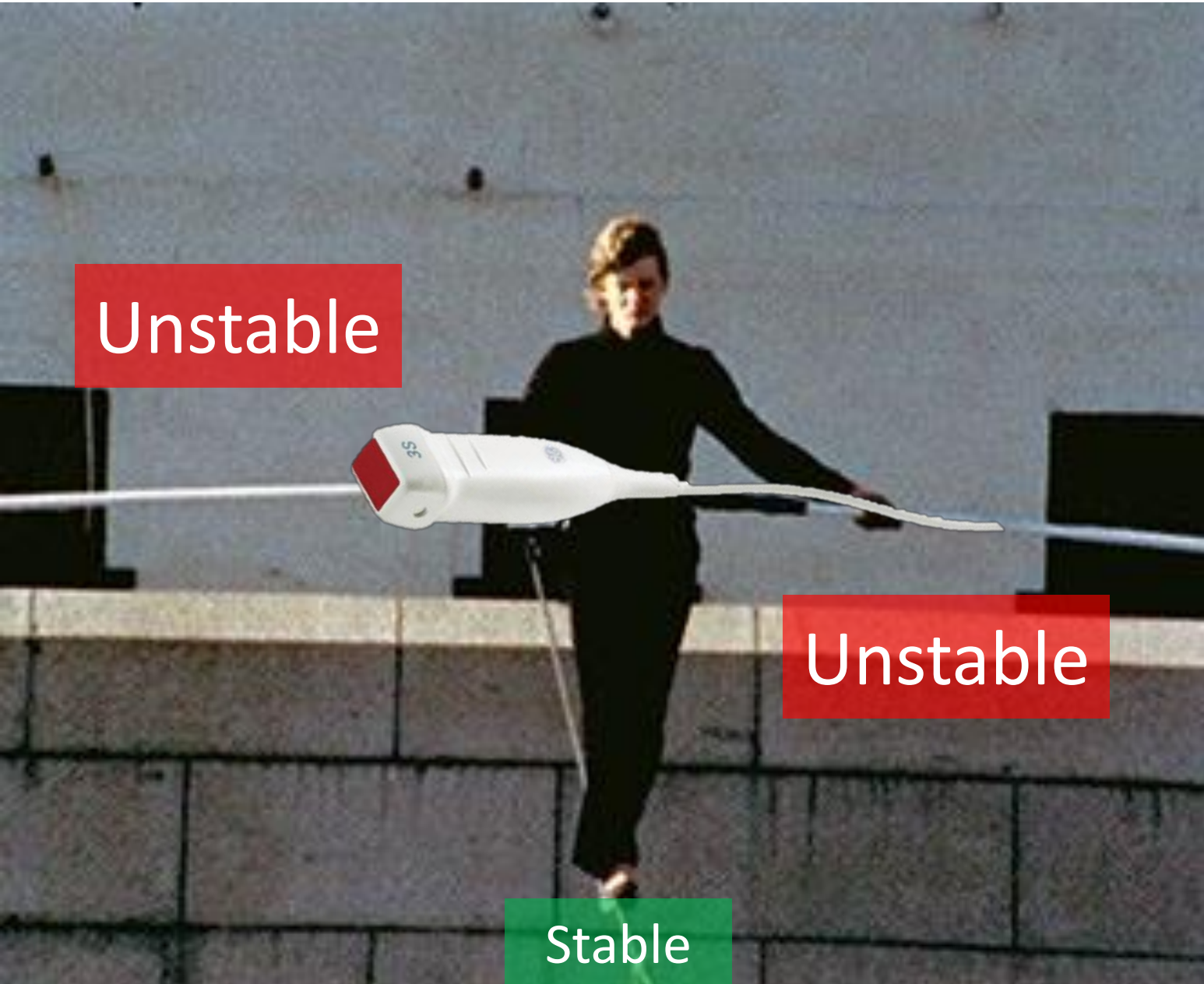
Dynamic



Determinants of Tissue Perfusion

$$\text{MAP} = \text{CO} \times \text{SVR}$$





Unstable

Unstable

Stable

Cardiac Output
Volume Status
Fluid Responsiveness

Diagnostic

Guiding

Monitoring



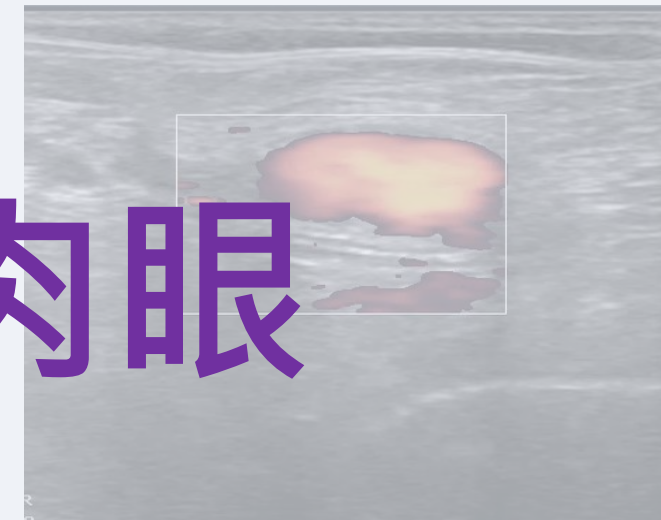
Eyeballing 肉眼



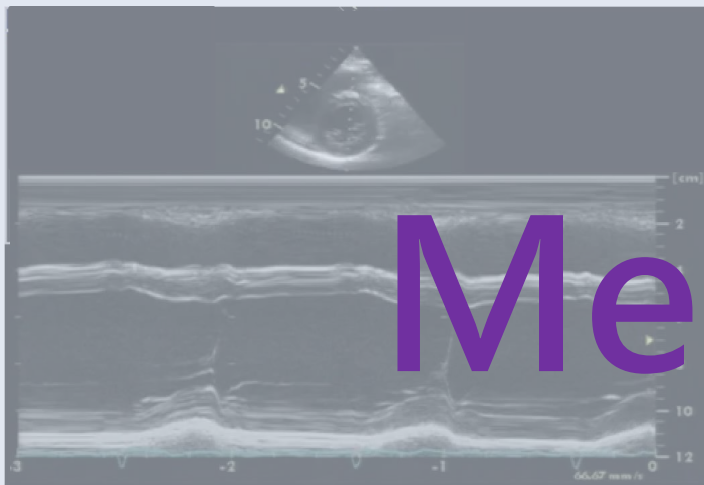
B-Mode



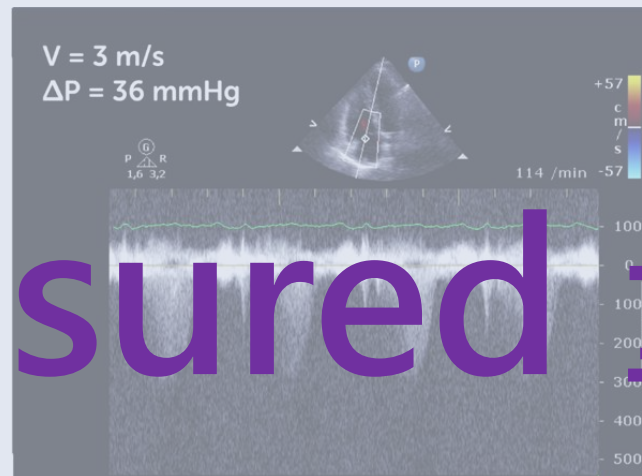
Color Doppler



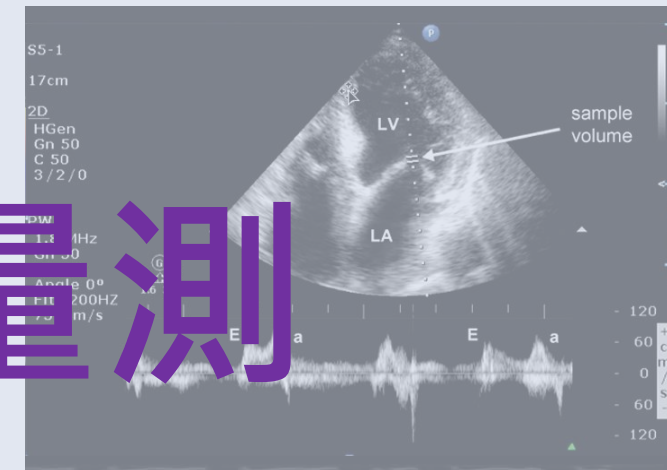
Power Doppler



M-Mode



Continuous Wave Doppler



Pulsed Wave Doppler

Measured 量測

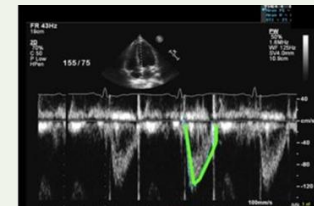
Cardiac Output (Stroke Volume)

Doppler
Echocardiography



CSA_{LVOT}

X



VTI_{LVOT}

X

PR

~~Stroke Volume (SV)~~ Ejection Fraction (EF)

2D Volumetric

~~Simpson's Method~~

M-Mode

FS, EPSS, MAPSE

Qualitative

Eyeballing

Ejection Fraction \neq Stroke Volume

Stroke Volume \neq Cardiac Output

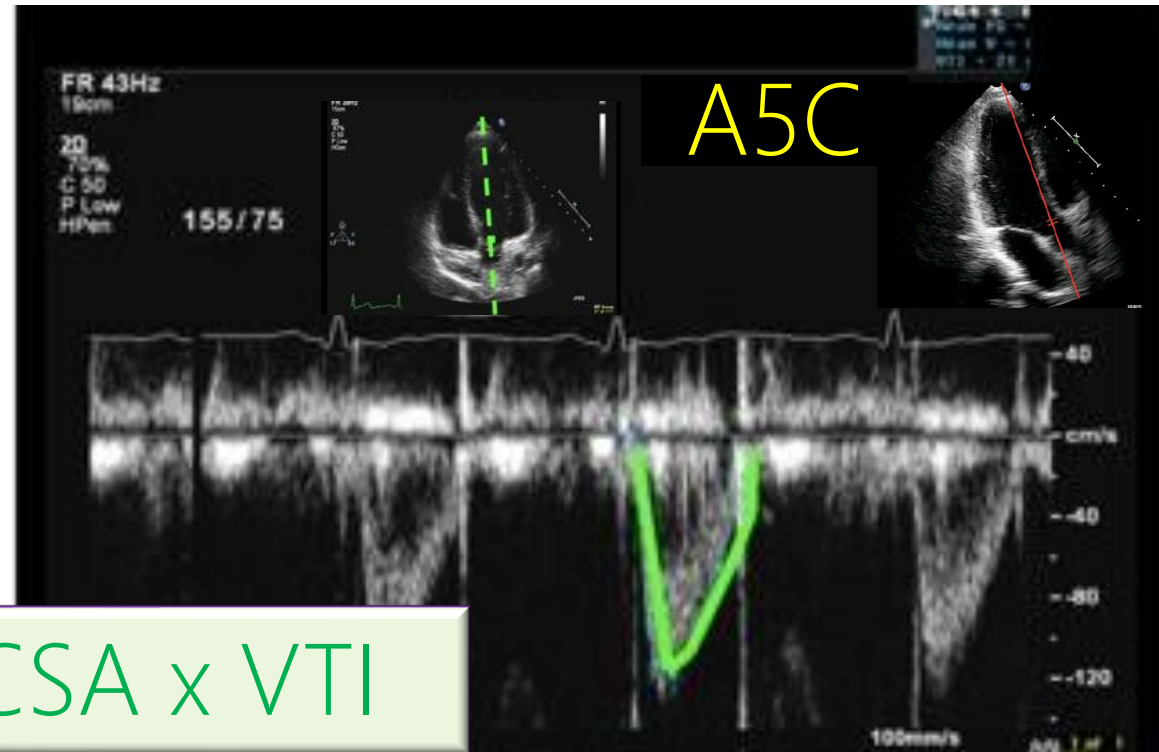
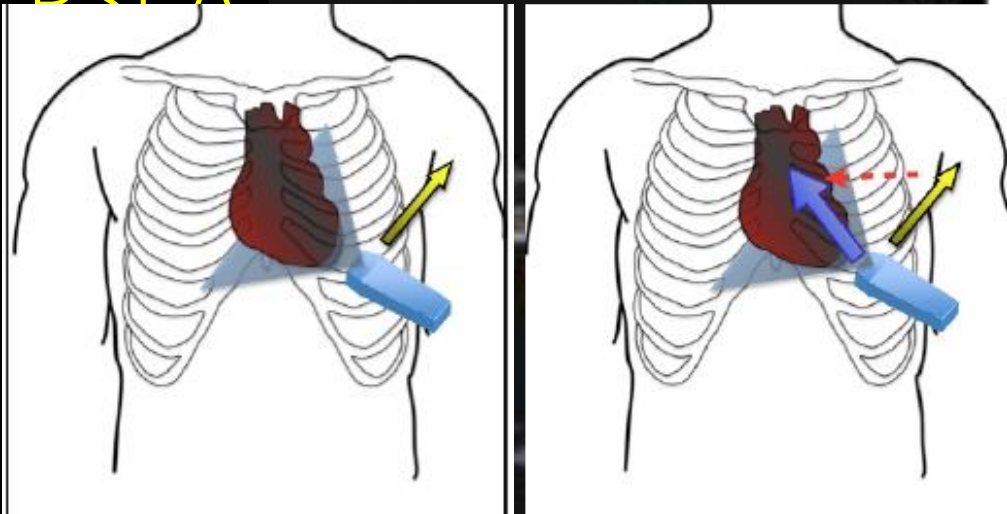
CO/SV

LVOT Method

LVOTD

PWD

CSA



$$SV = CSA \times VTI$$

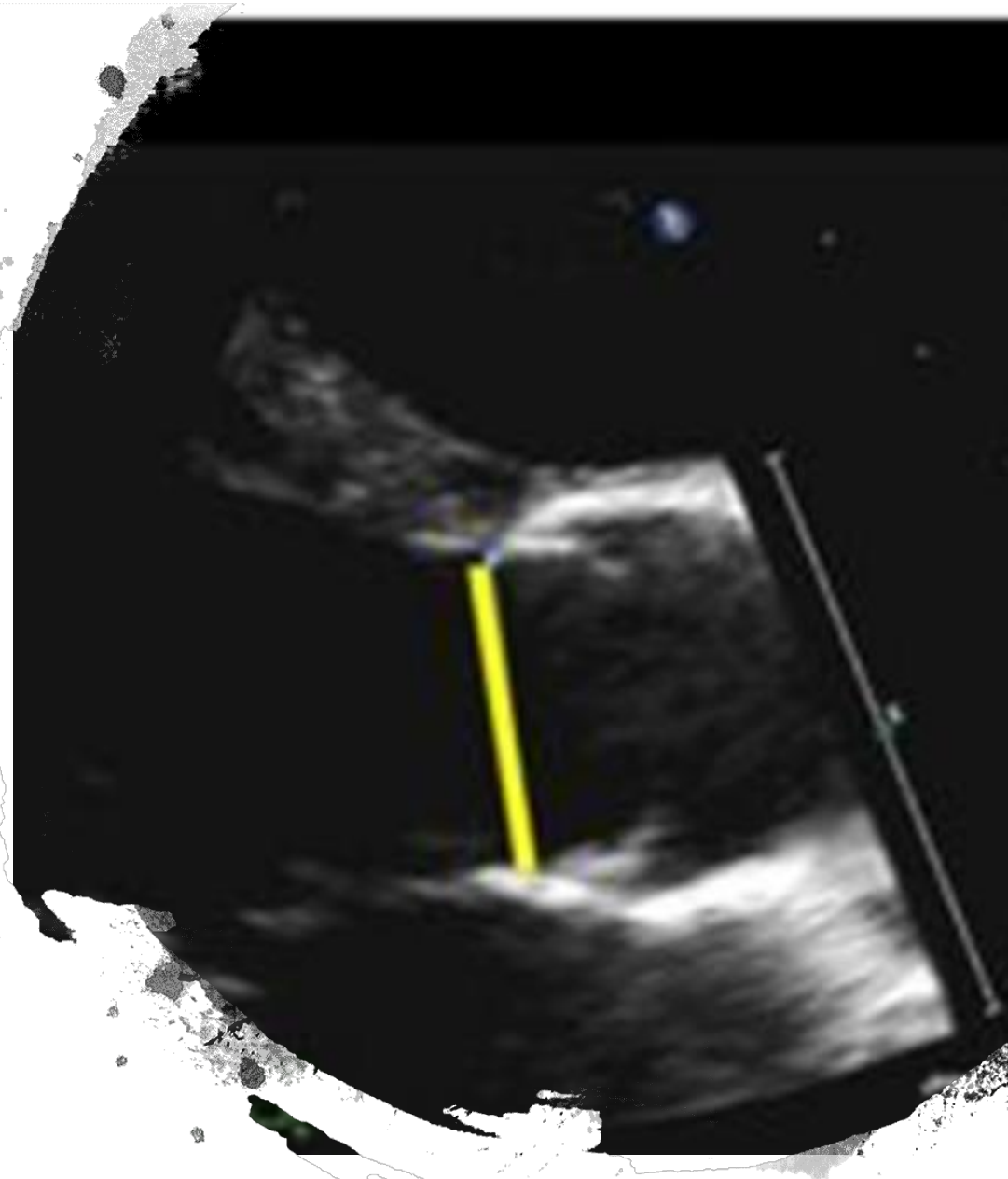
CSA (cm²)

x

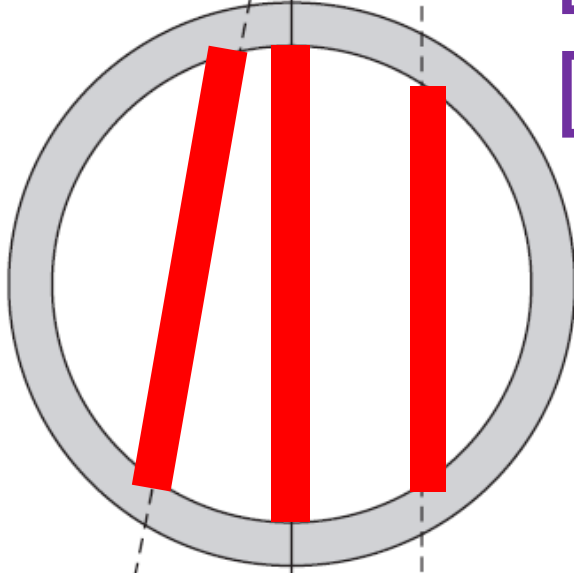
VTI (cm)

Q1: 下列那一項不會造成
LVOT Diameter的測量誤差?

- A. 測量點不在Aortic Annulus上
- B. 垂直LVOT測量
- C. 測量在diastole
- D. 測量在外徑 (Outer to outer diameter)



LVOT Diameter



Cross-section of LVOT

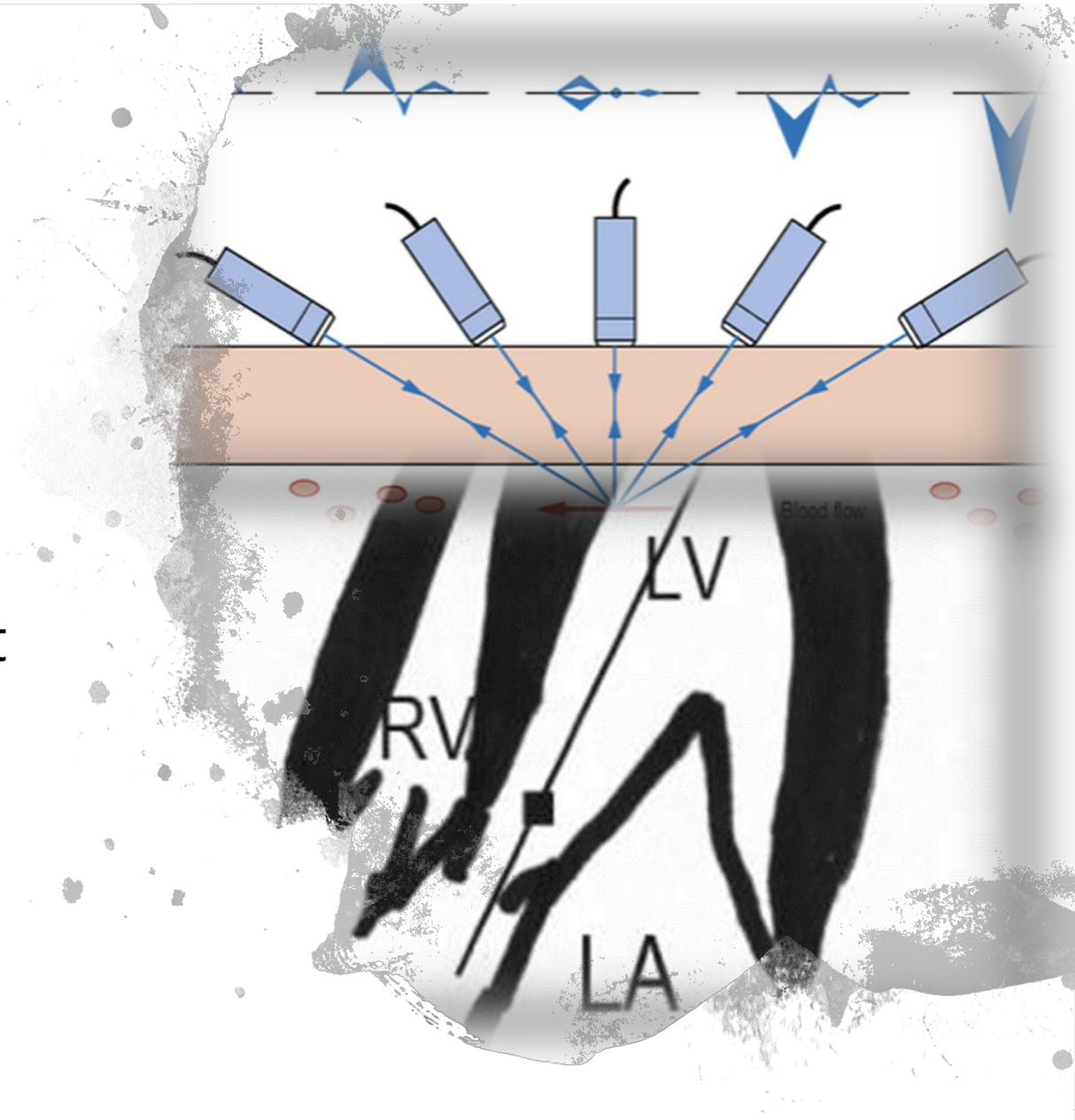
Oblique plane

Tangential plane

Proper longitudinal plane

VTI_{LVOT} Pitfalls

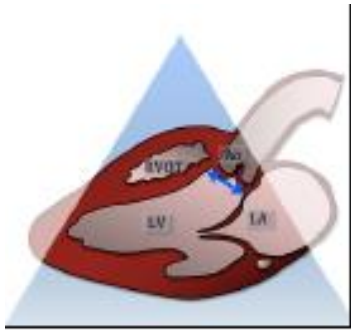
- Doppler Angle
- Foreshortening
- Respiration Motion Artifact
- Arrhythmia: Af
- Avoid Ectopic Beat



EF

End-Point Septal Separation < 7mm

EPSS > 10 mm \approx EF < 30 %

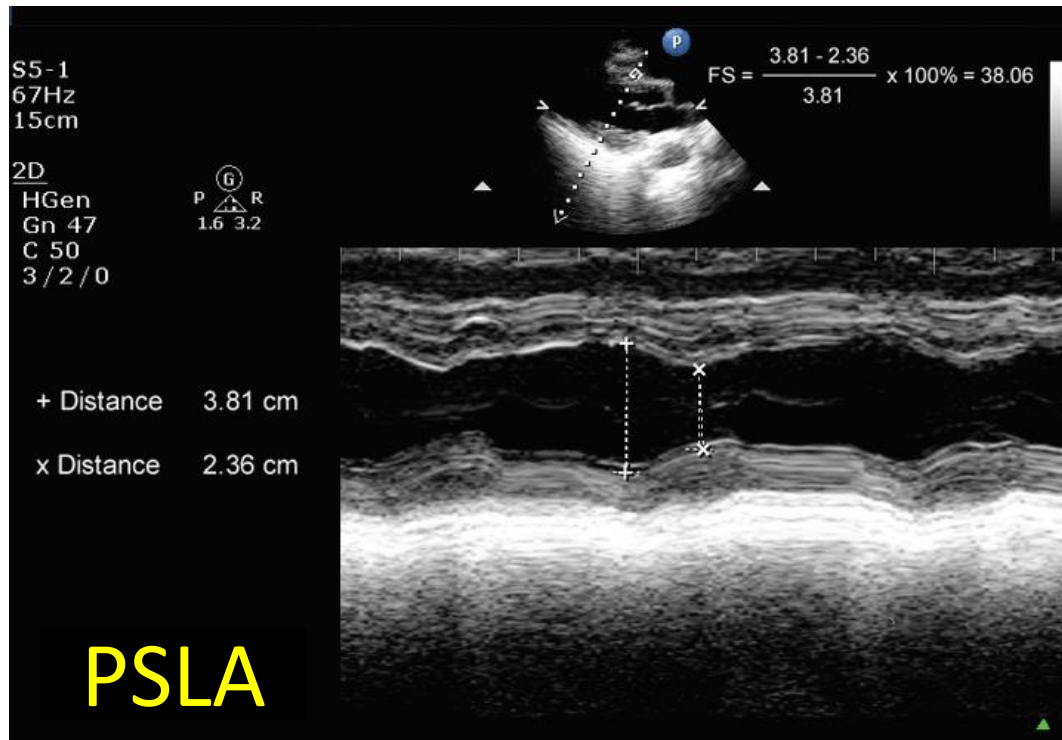


MS/AR; Septal hypertrophy; Paradoxical septal motion

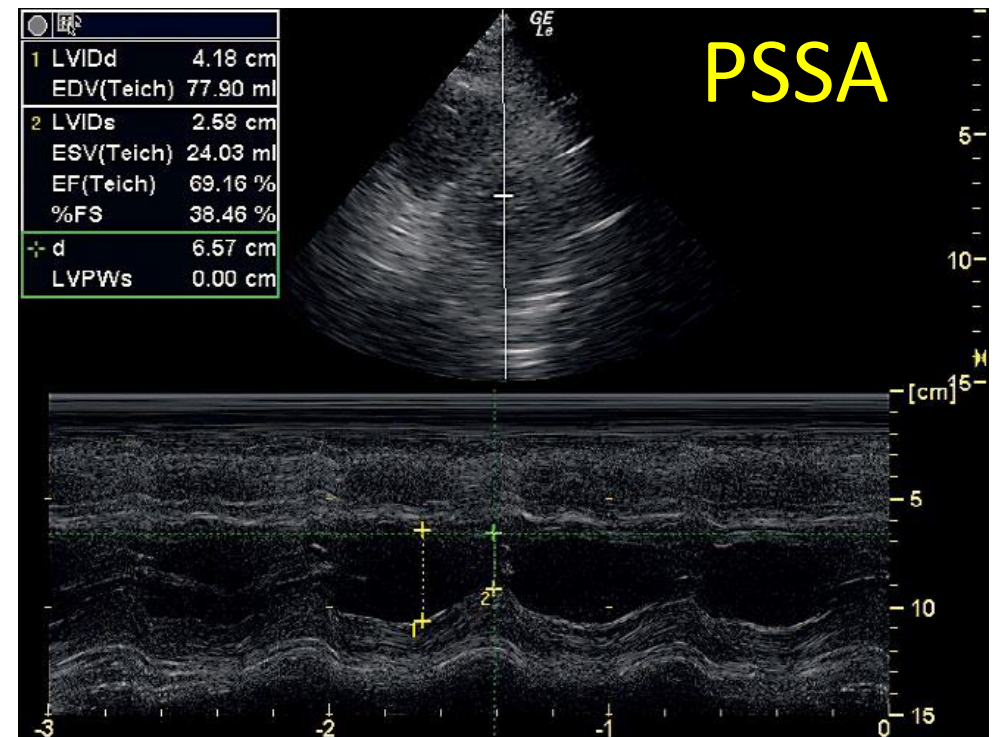
EF

(25~45%)

$$\text{Fractional Shortening (FS)} = \frac{EDD - ESD}{EDD} \times 100\%$$



LVIDs & LVIDd



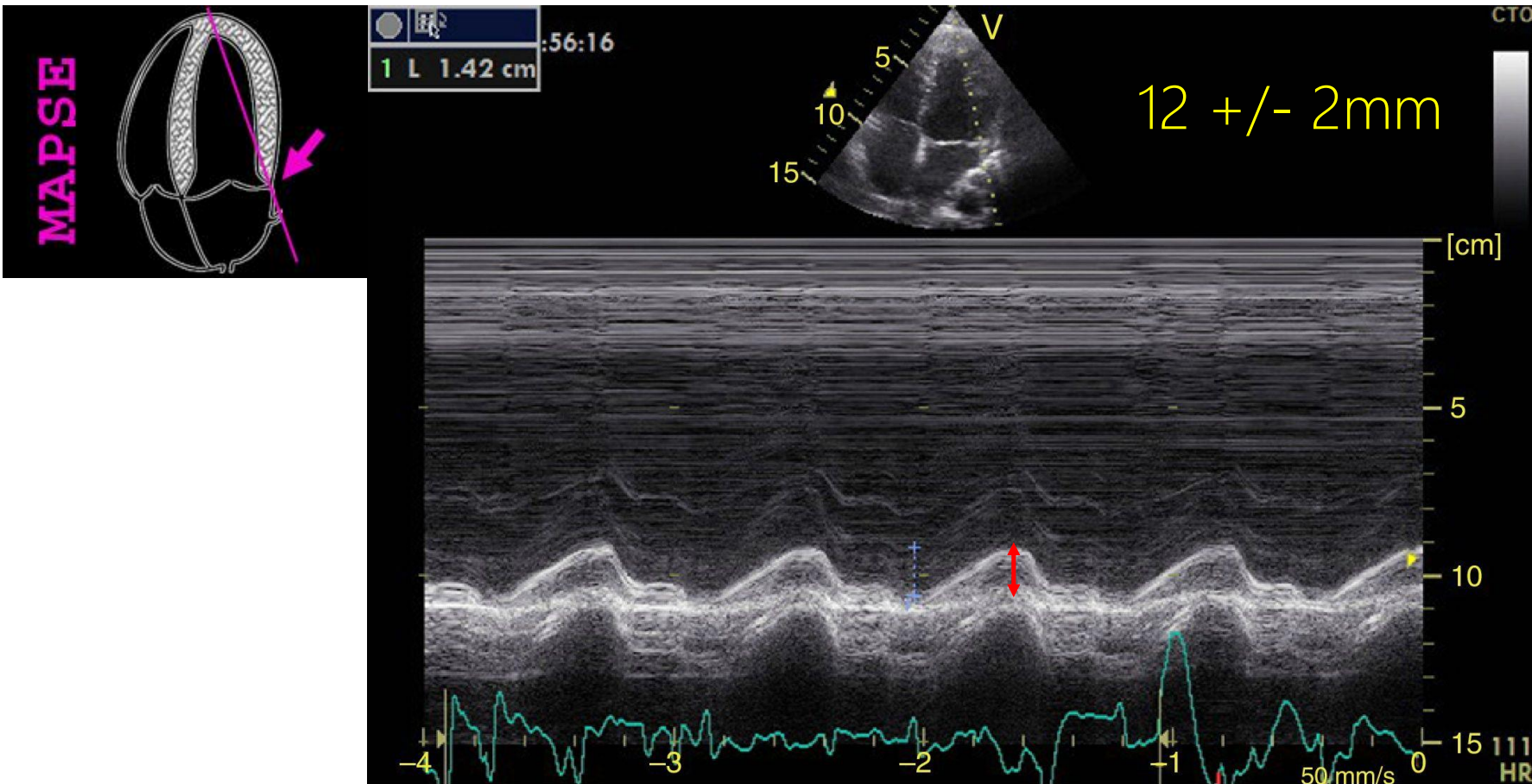
LVIDs & LVIDd

EF

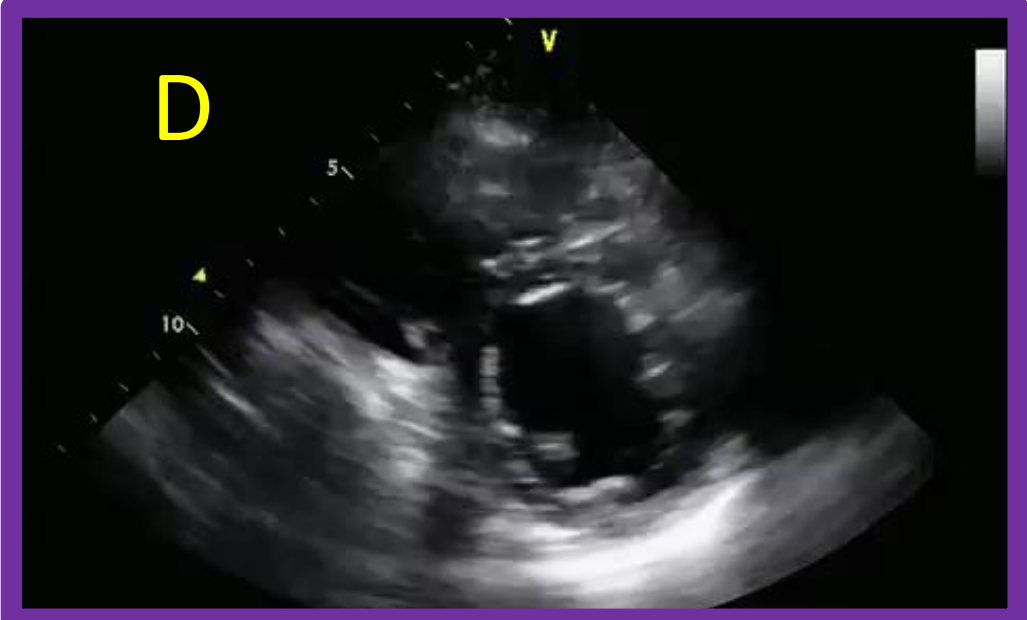
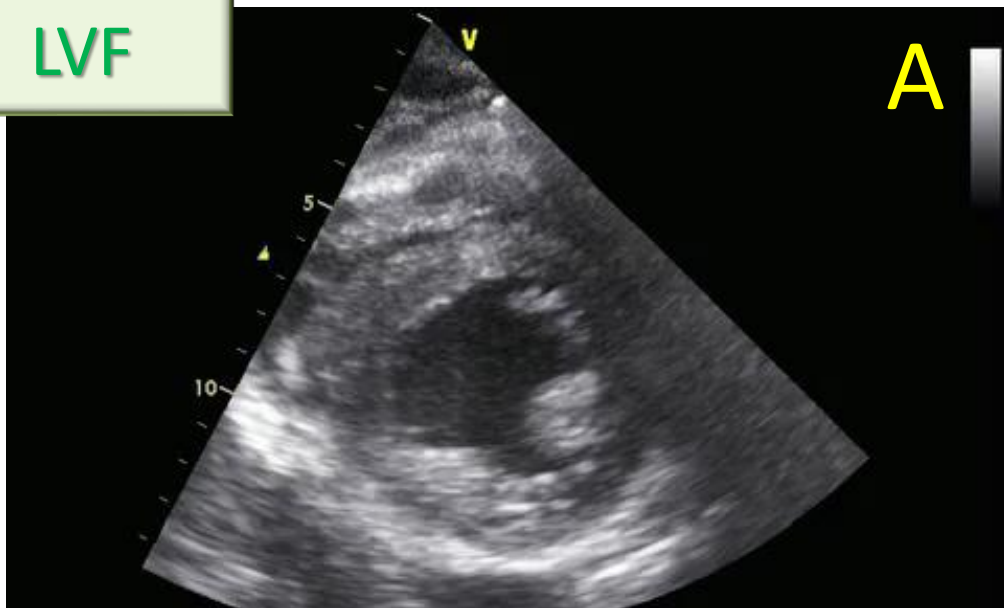
MAPSE 12 +/- 2mm

(Mitral Annular Planar Systolic Excursion)

MAPSE < 8 mm \approx EF < 30 %



LVF



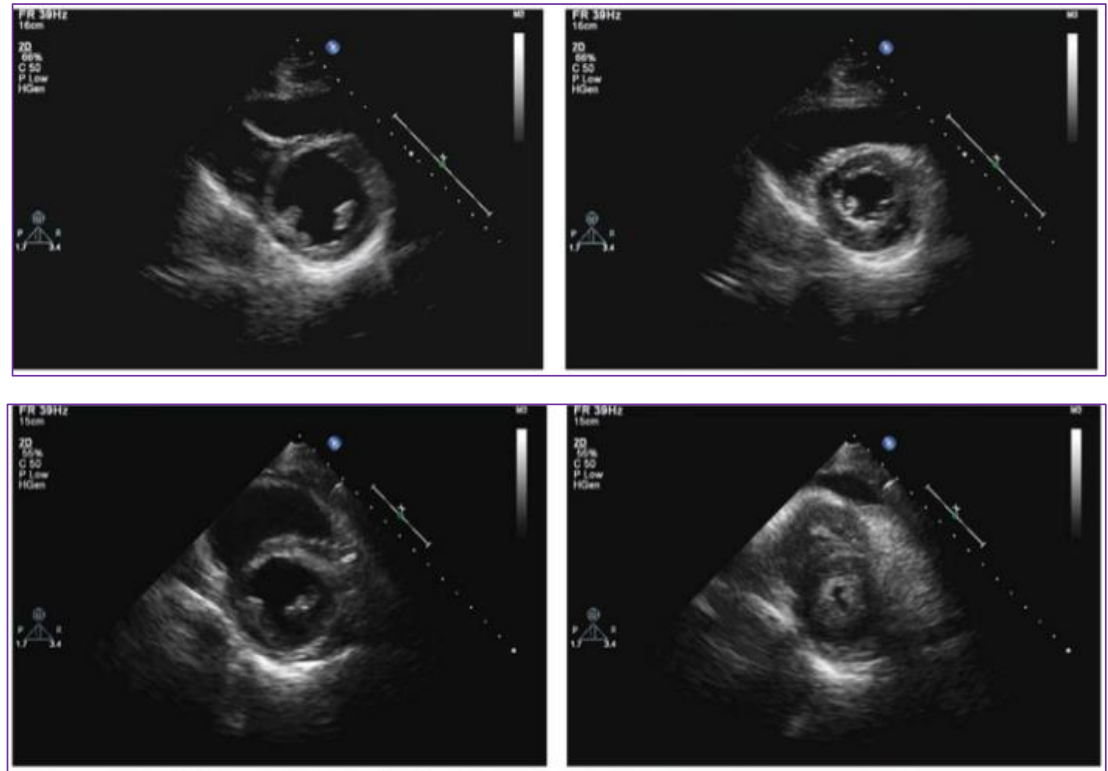
LVF

Eyeballing LV Function

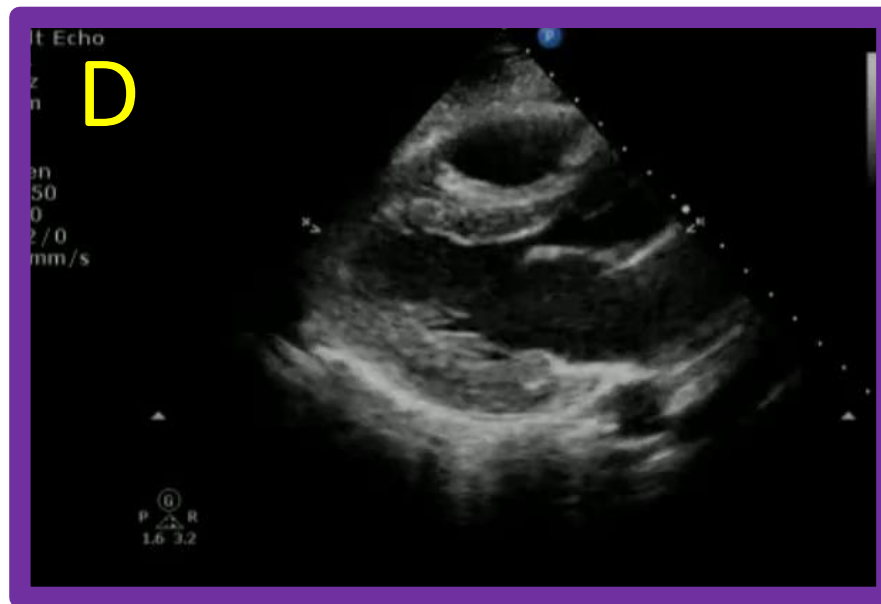
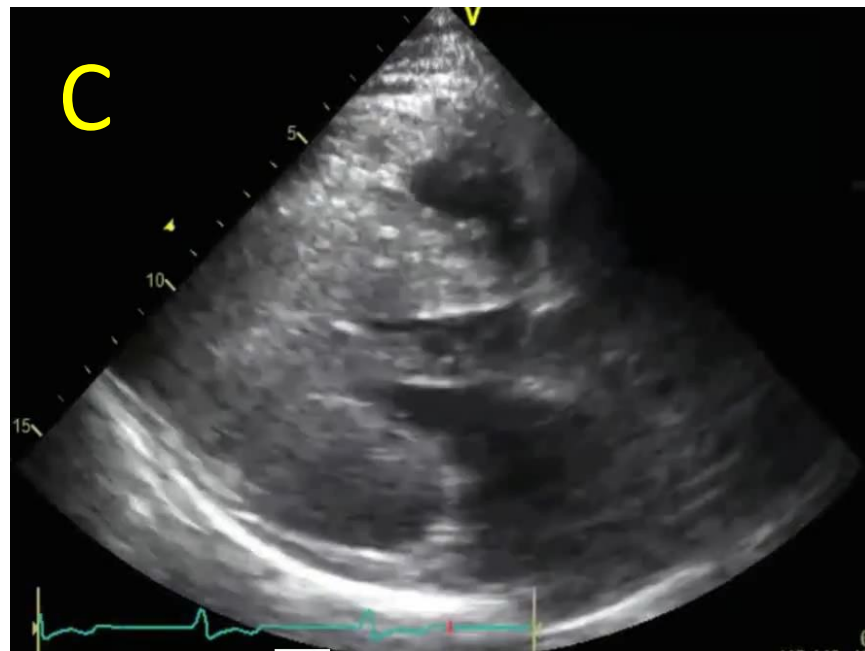
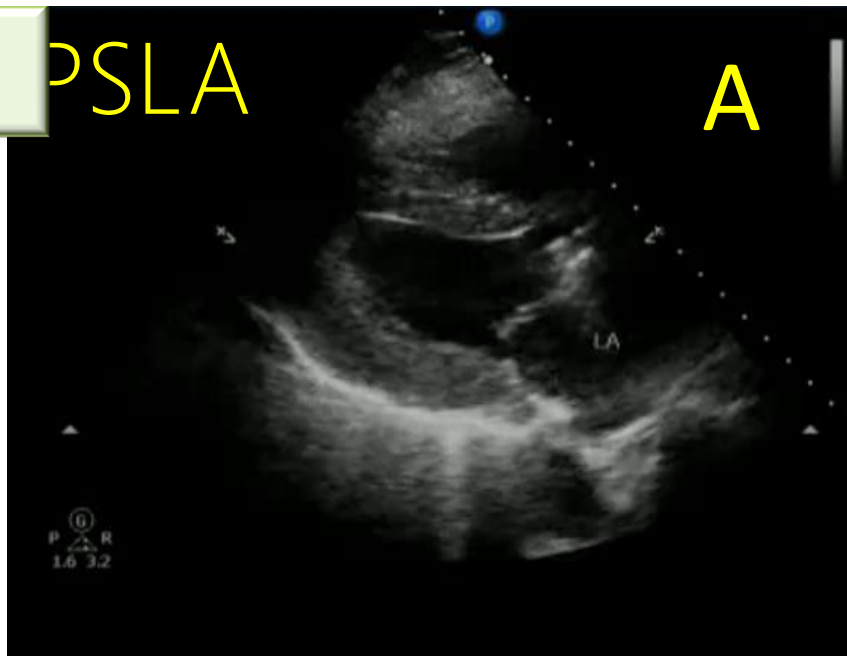
Inward motion

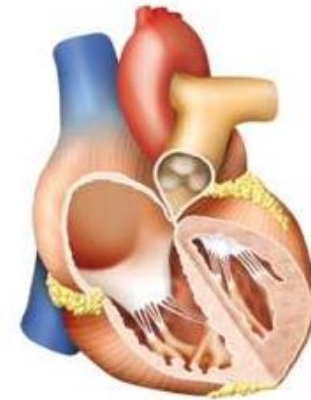
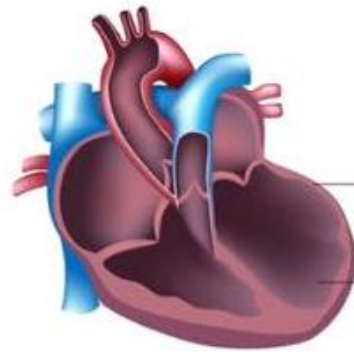
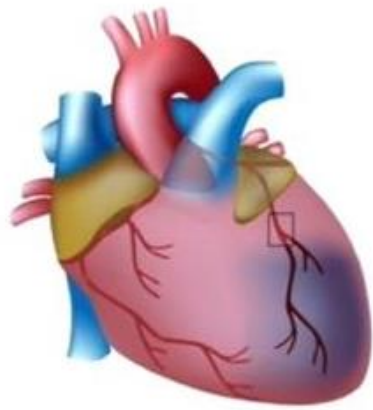
Myocardial thickening

Global vs Regional



LVF PSLA

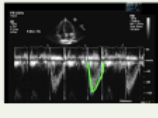


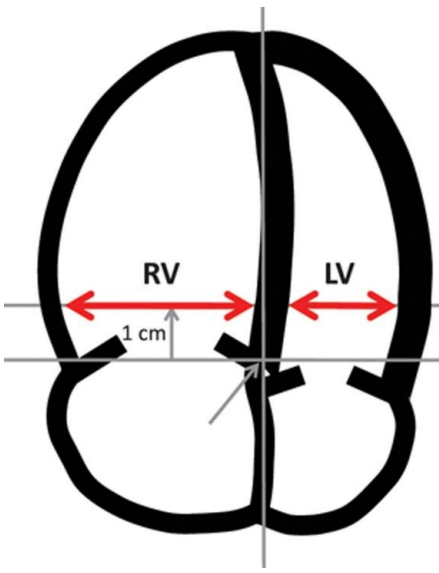
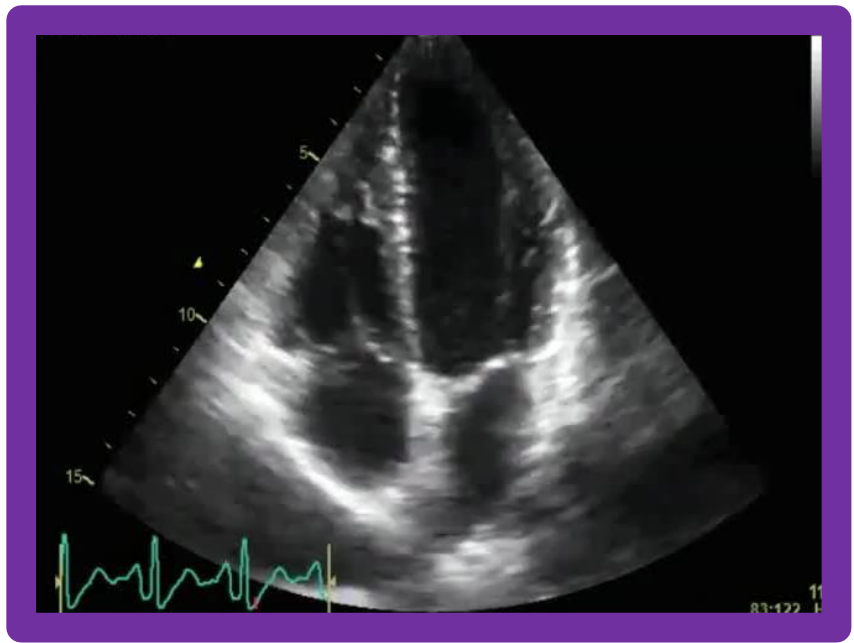
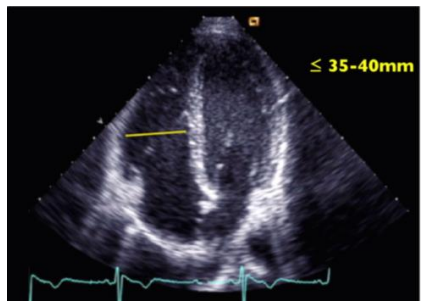
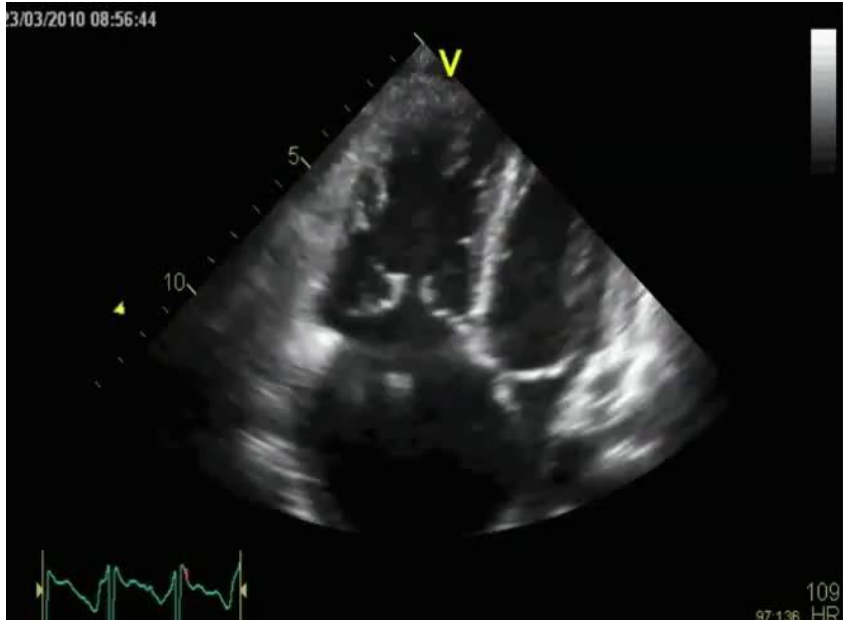


LV Function

Cardiac Output
(Stroke Volume)

~~Stroke Volume (SV)~~
Ejection Fraction (EF)

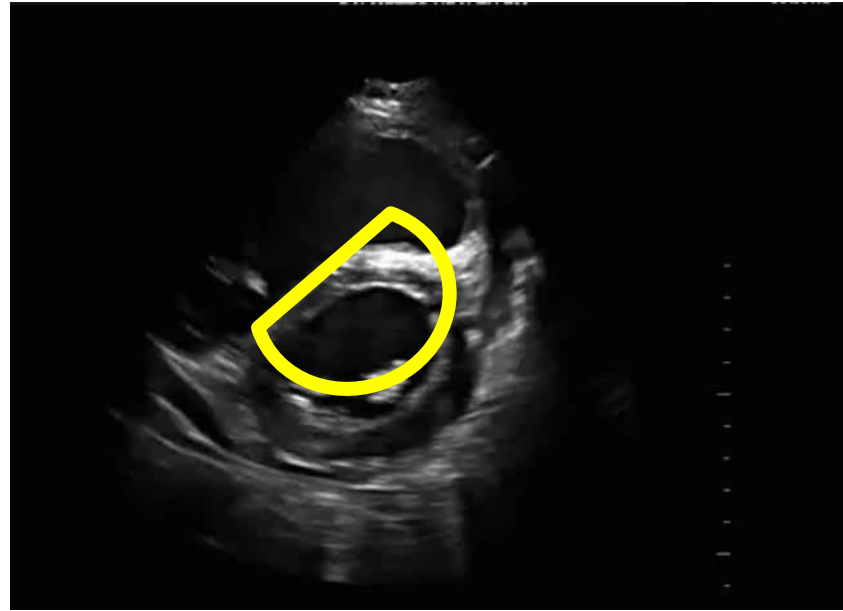
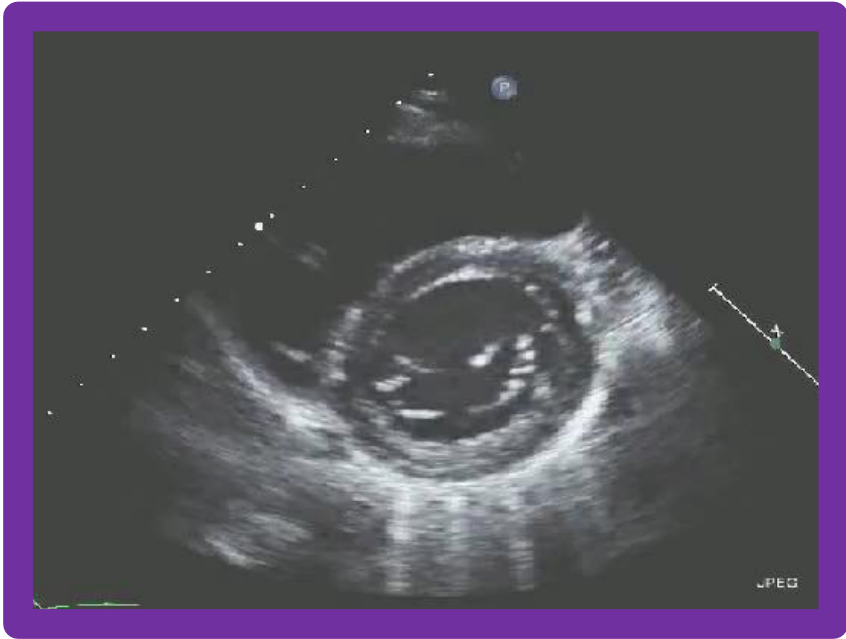
Doppler Echocardiography	 CSA_{LVOT} X	2D Volumetric	Simpson's Method
	 VTI_{LVOT} X	M-Mode	FS, EPSS, MAPSE
	PR	Qualitative	Eyeballing



$$RV:LV > 1:1$$

RV Strain

Rt Chamber
Equity



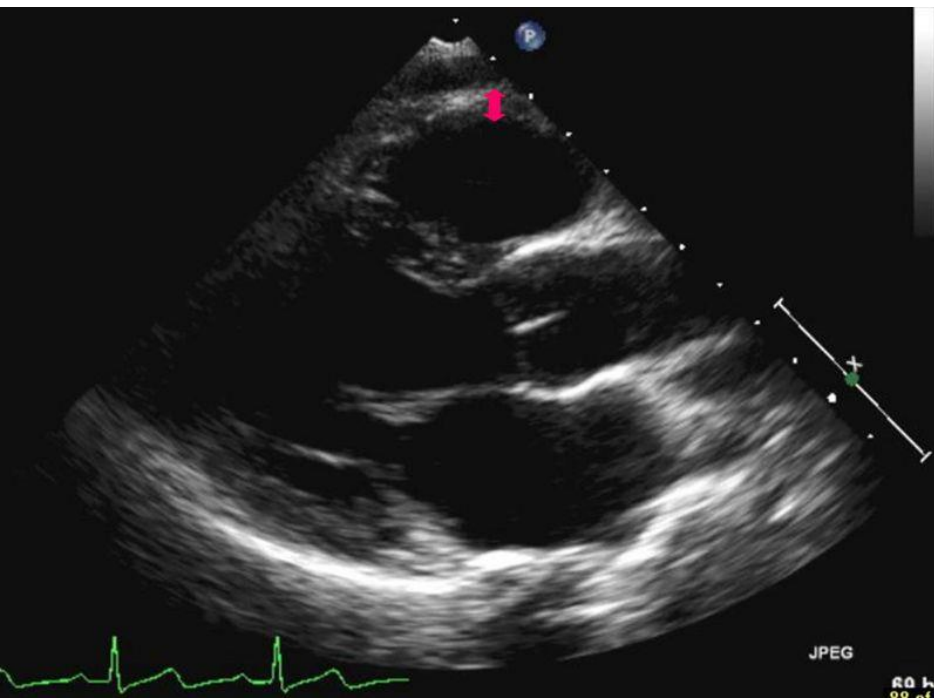
RV Strain

D-sign

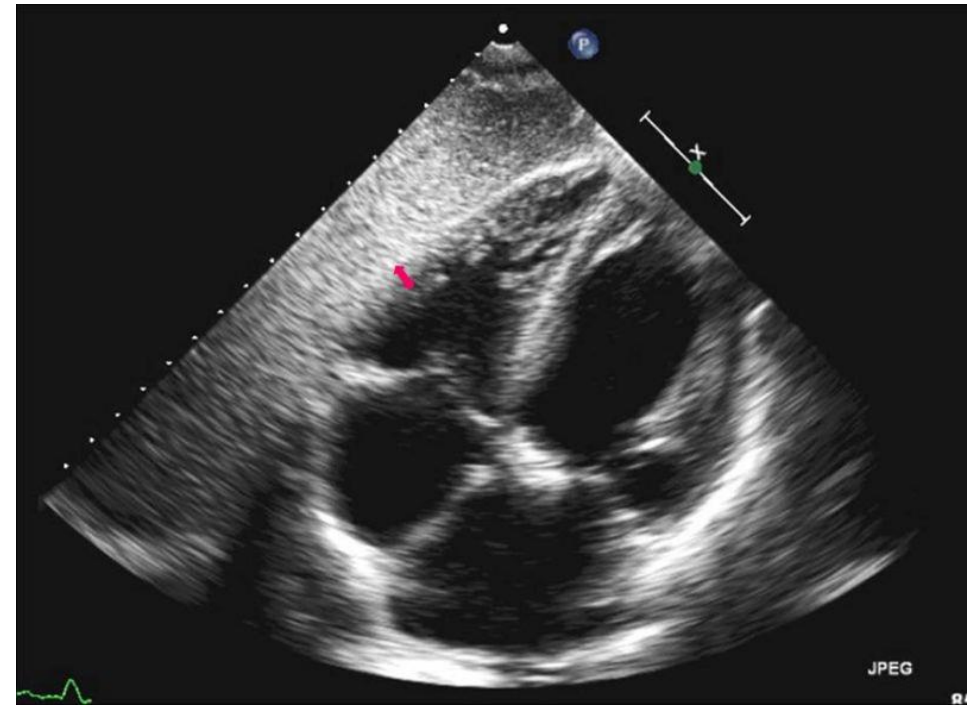
Rt Chamber
Equity

Rt Chamber
Equity

RV Thickness

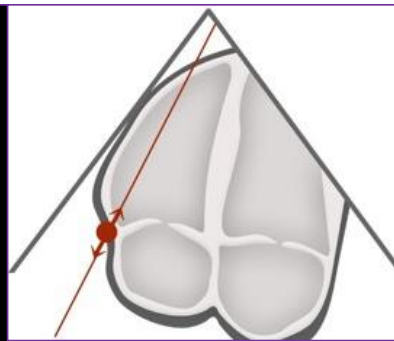


>5mm

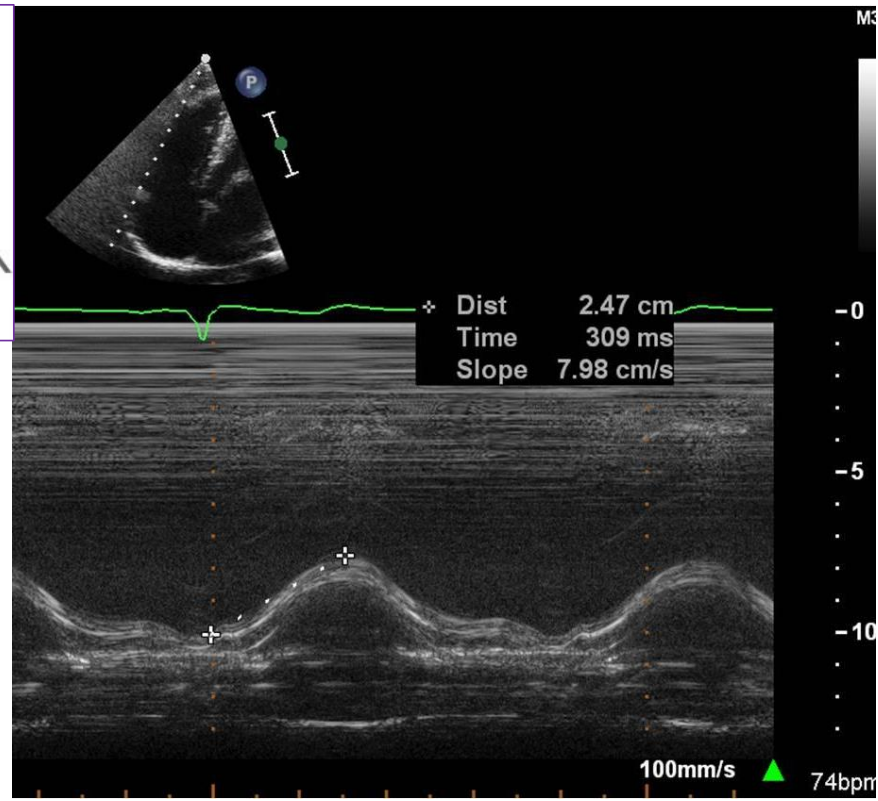


TAPSE (Tricuspid annular planar systolic excursion)

	Abnormal Cutoff
TAPSE	≤ 17 mm

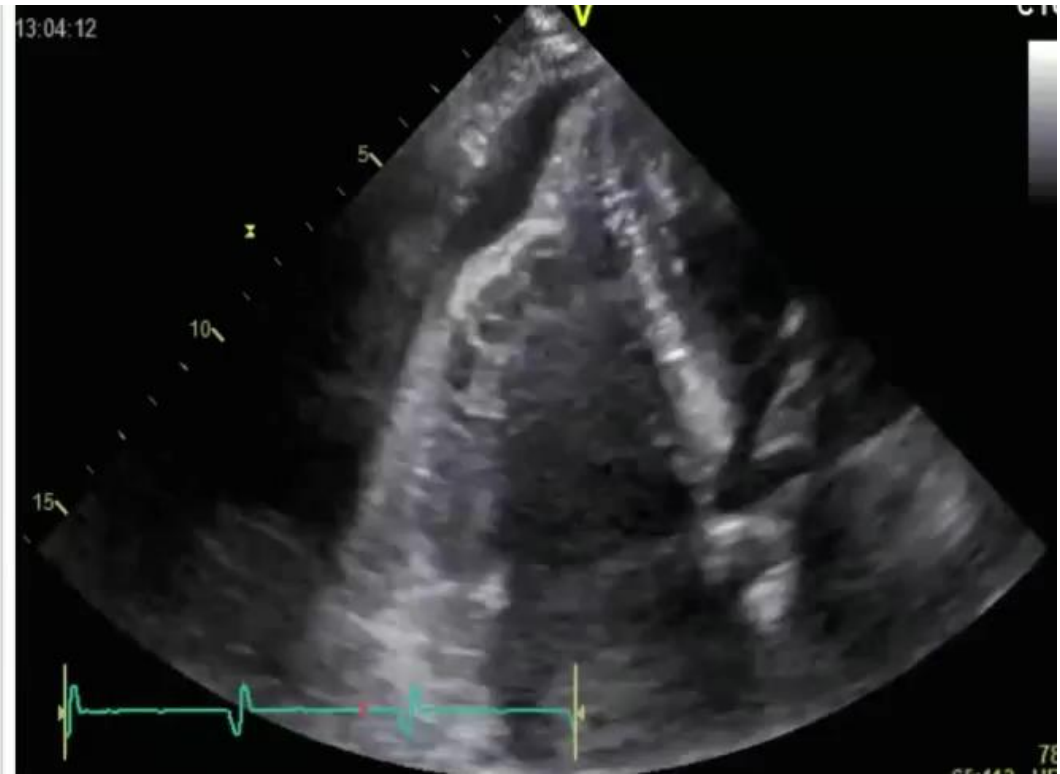
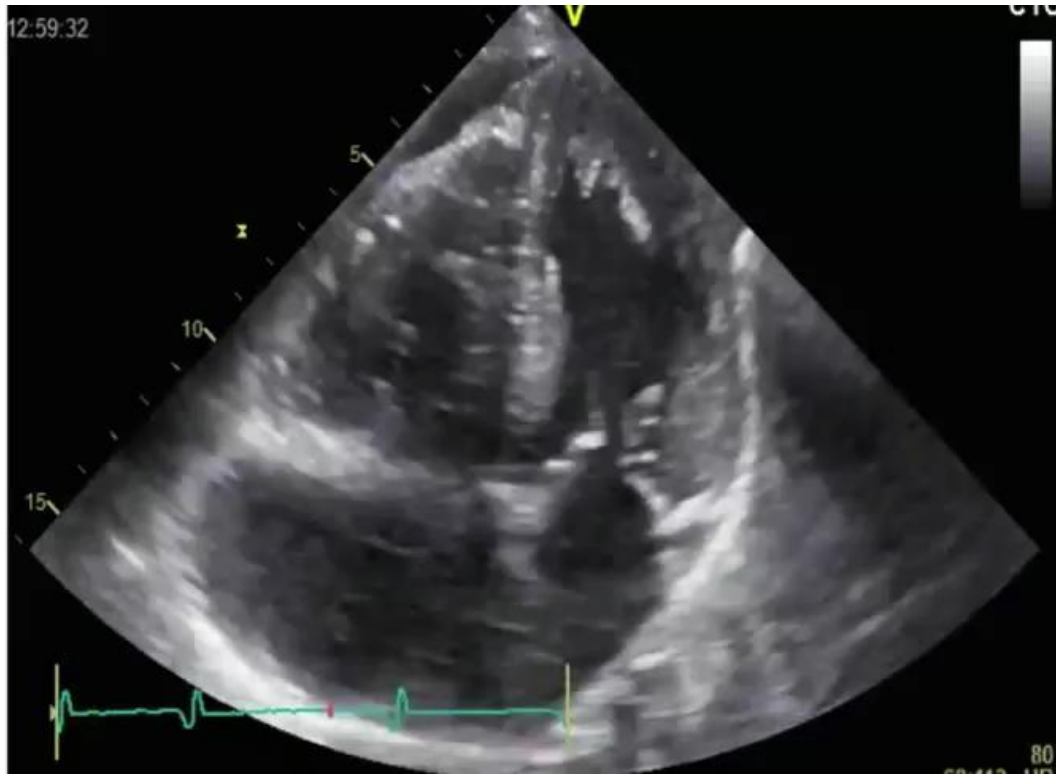


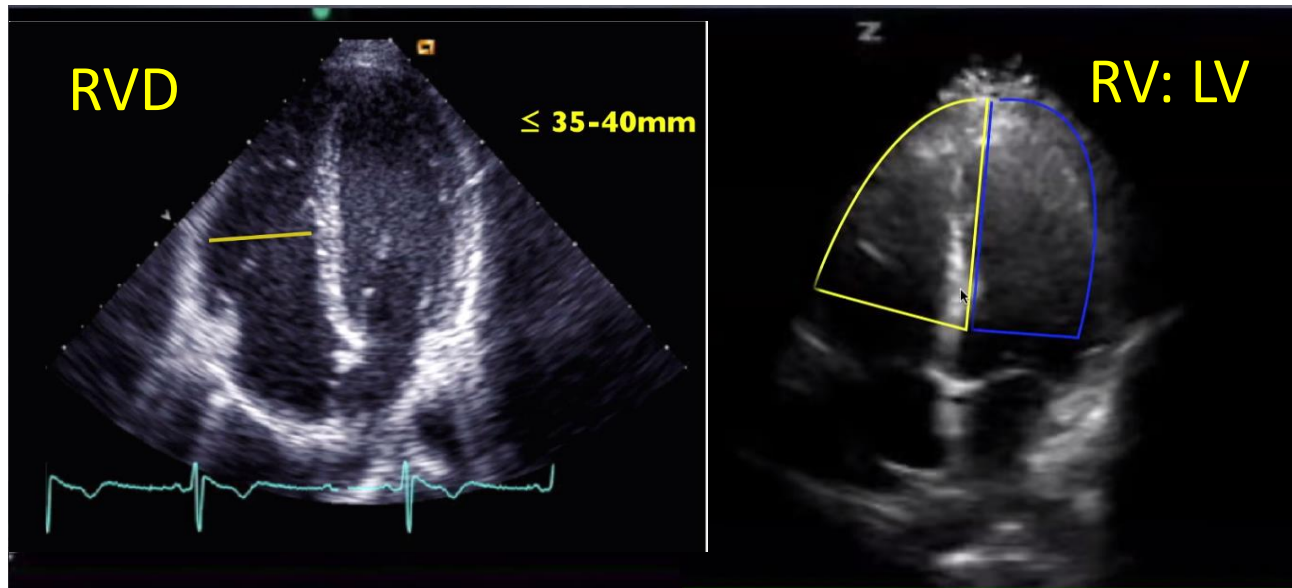
Rt Chamber
Equity



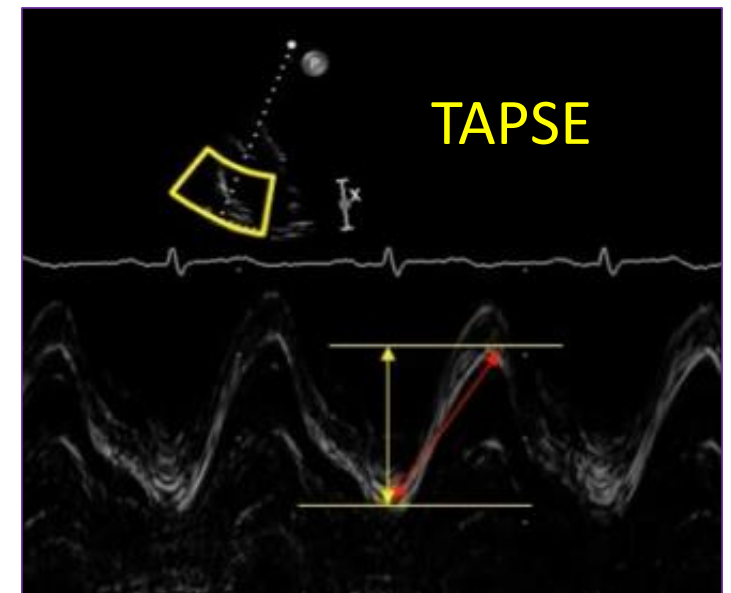
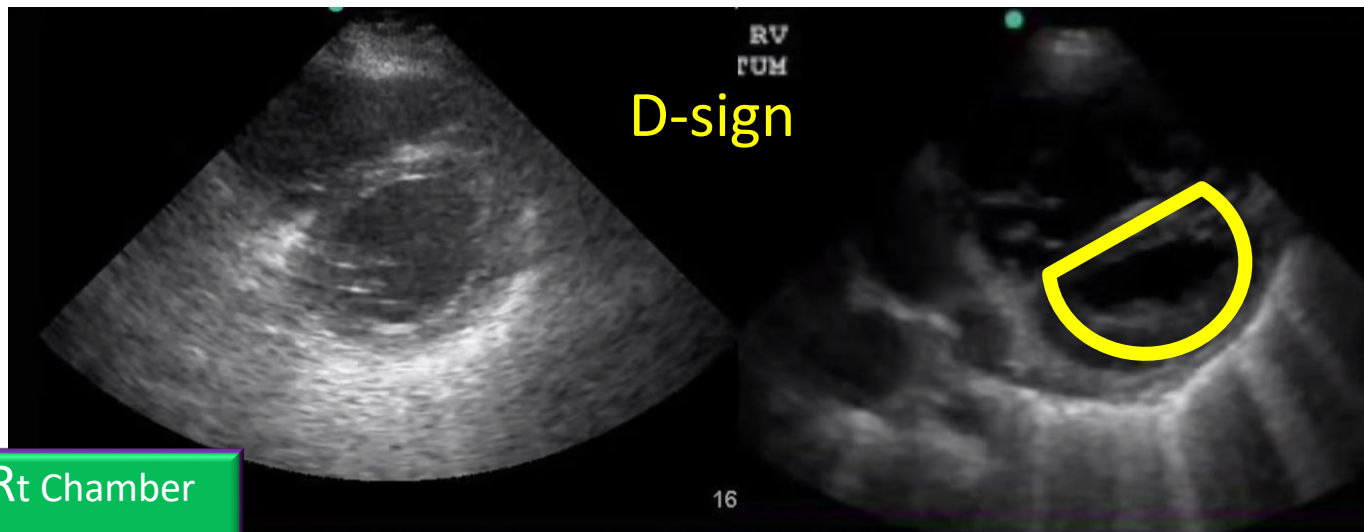
Rt Chamber
Equity

McConnell's Sign





RV Function



Rt Chamber
Equity

IVC

~

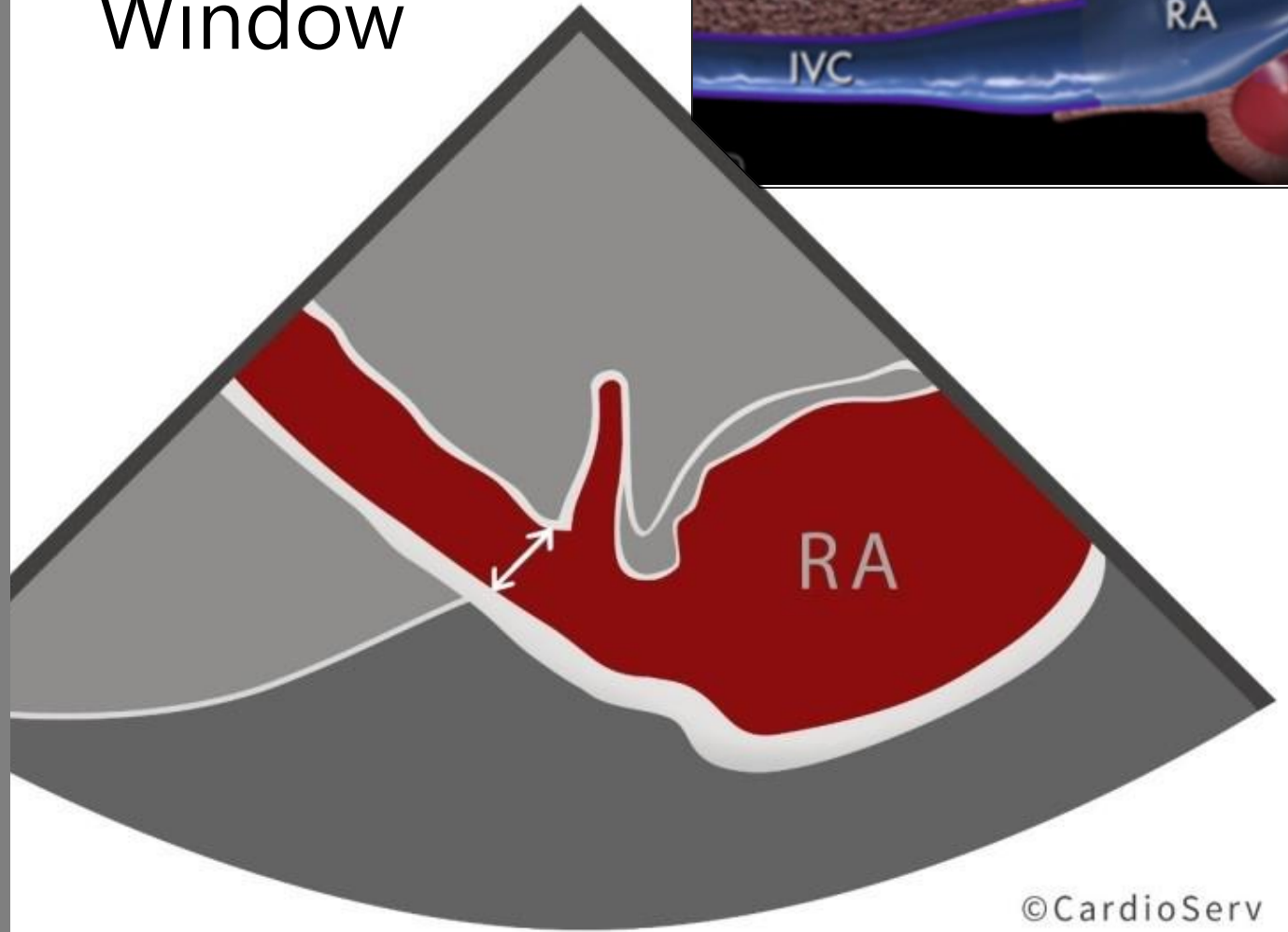
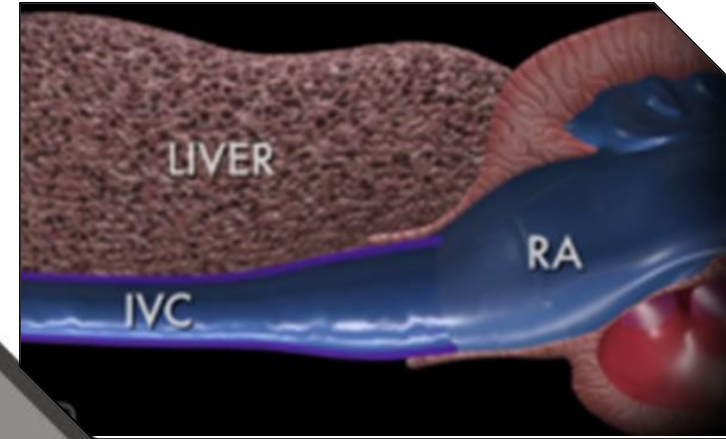
RAP

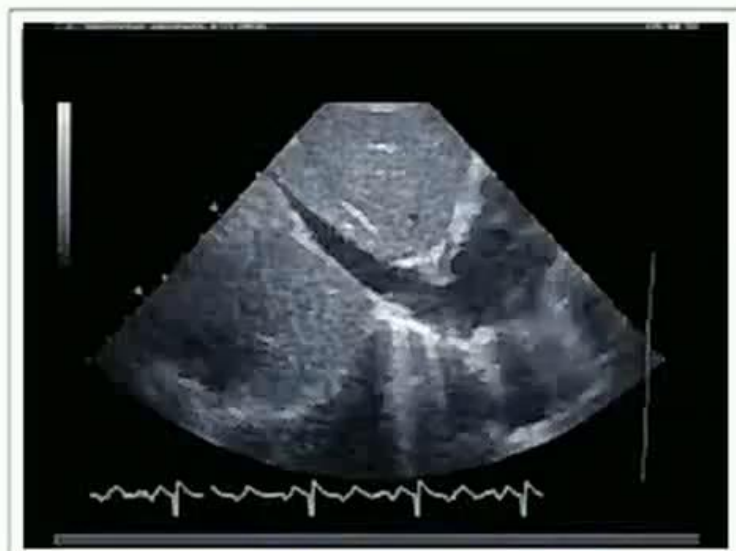
(Right Atrial Pressure)

≠

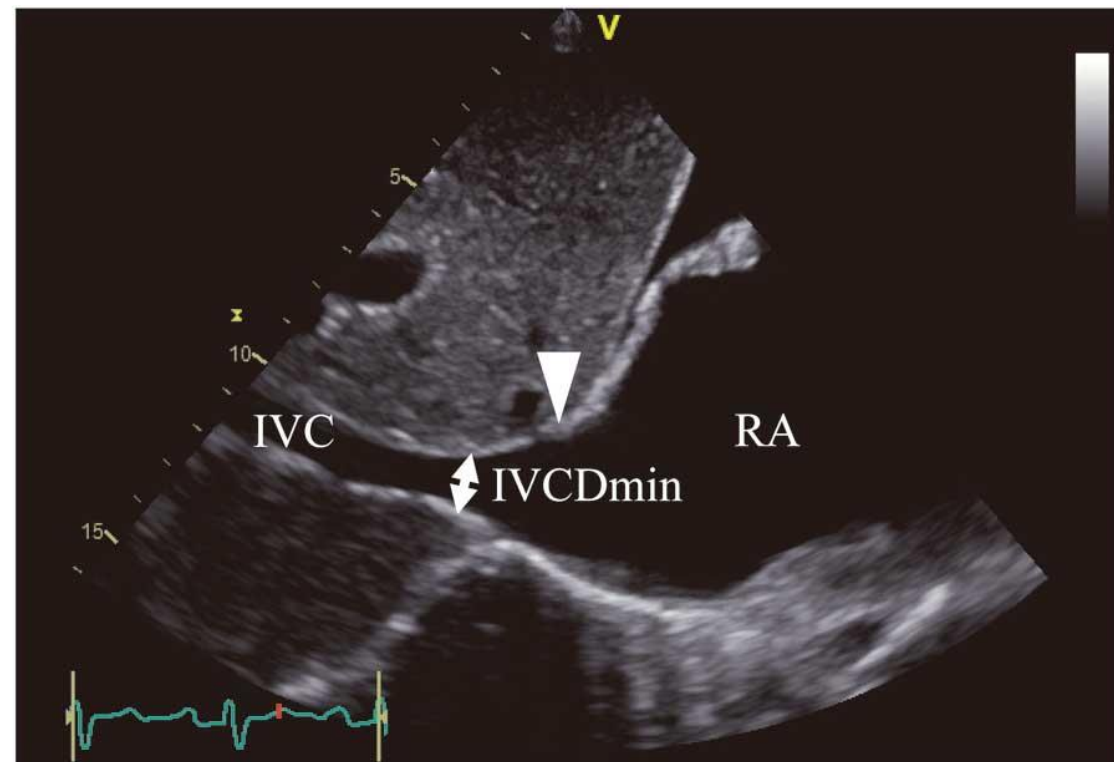
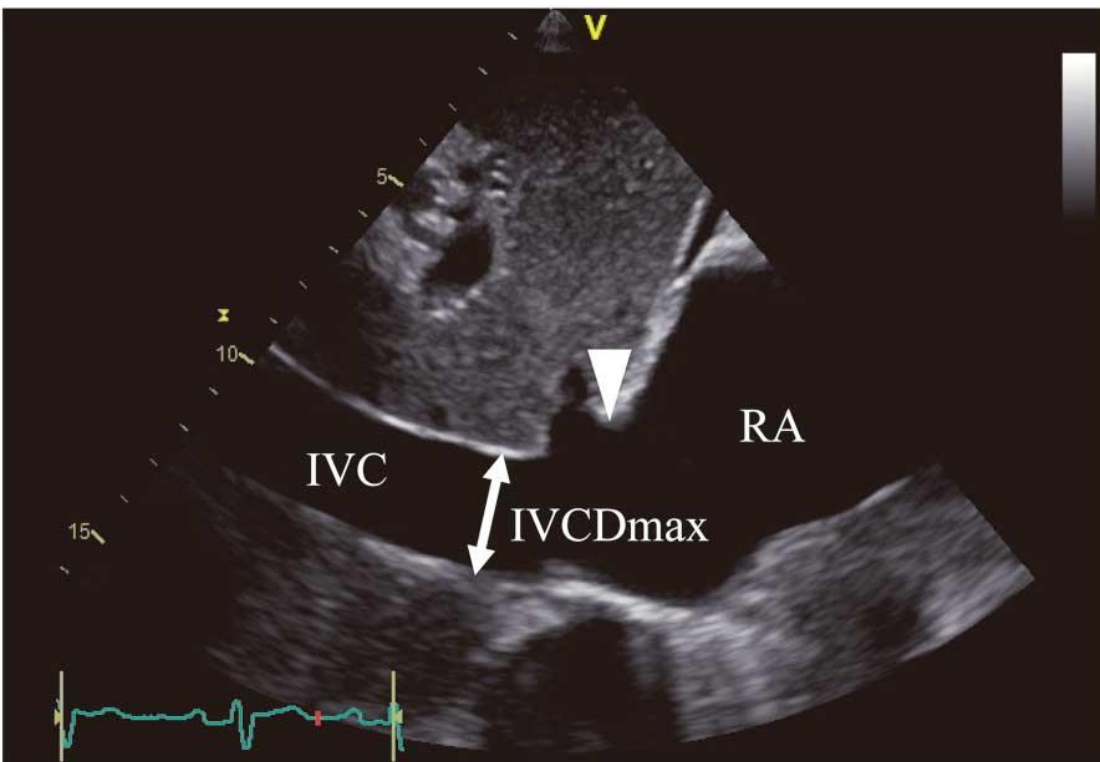
Venous Return

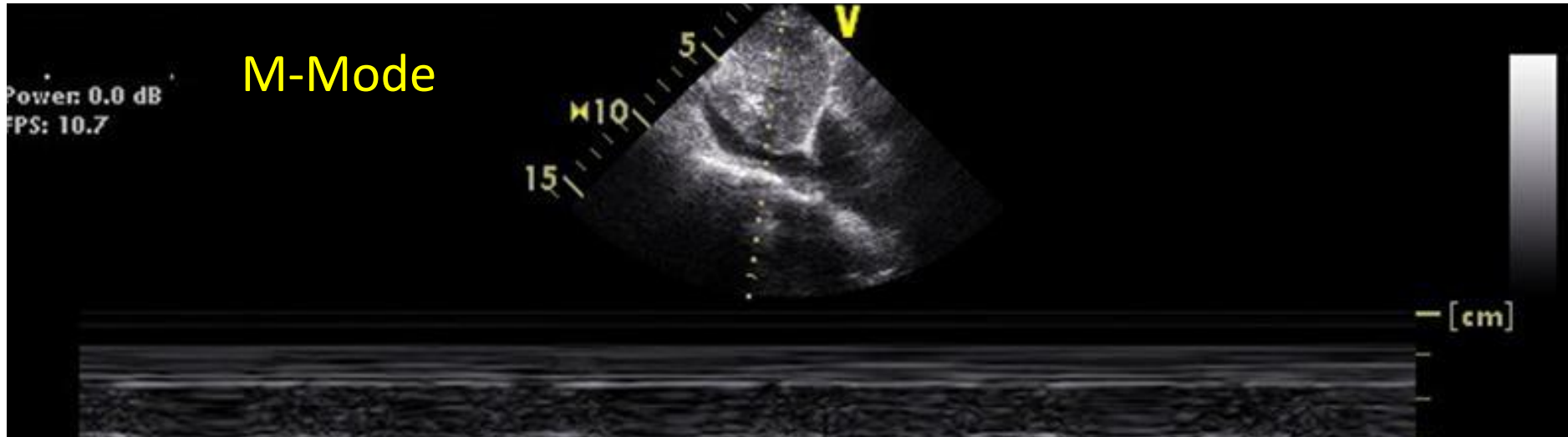
Subcostal Window





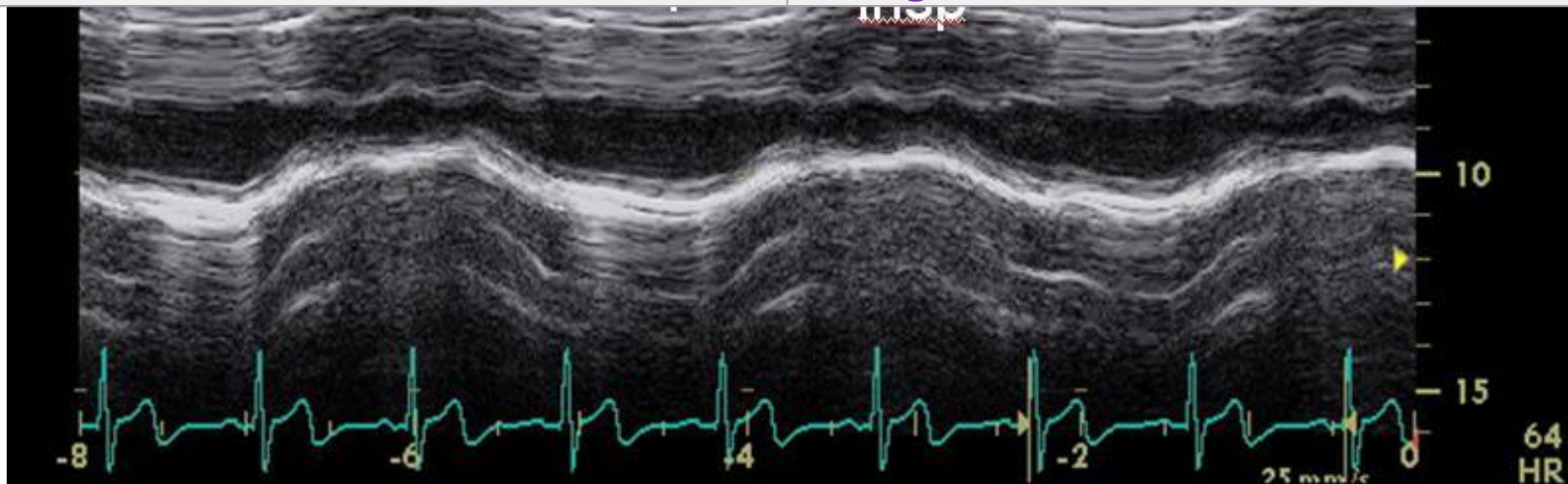
2cm from junction or Distal to hepatic vein





Size

Dynamic Change



Expiration

Inspiration

Exp

IVC Collapsibility Index (cIVC)

Spontaneous breathing



Positive pressure ventilation

Normo or hypervolemic patient



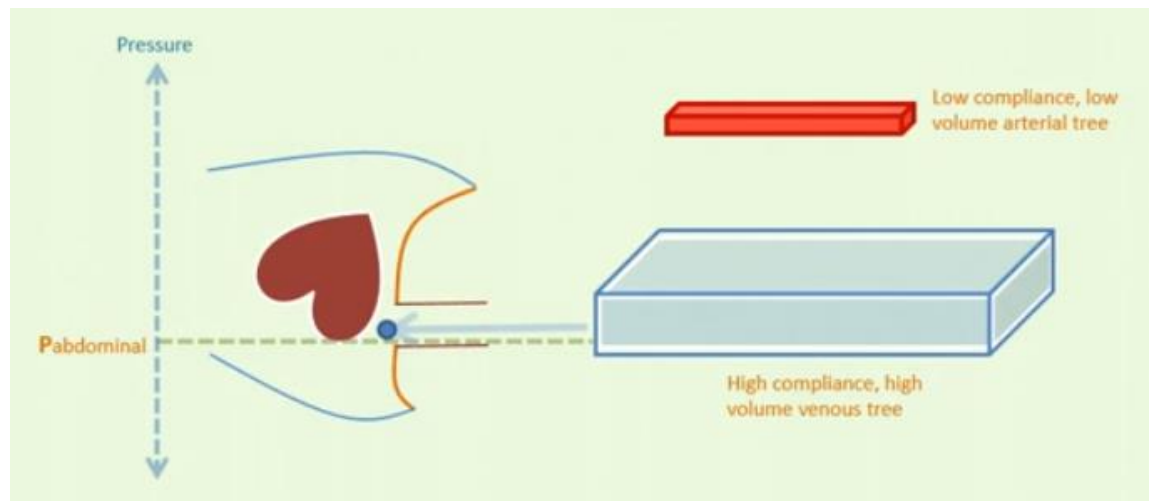
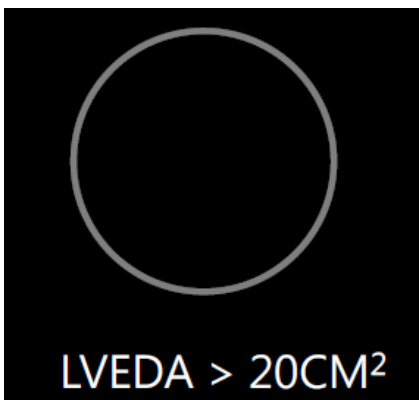
IVC Distensibility Index (dIVC)

IVC Variation Index (Δ IVC)

Hypovolemic patient



Clinical Context



Pressure within
IVC

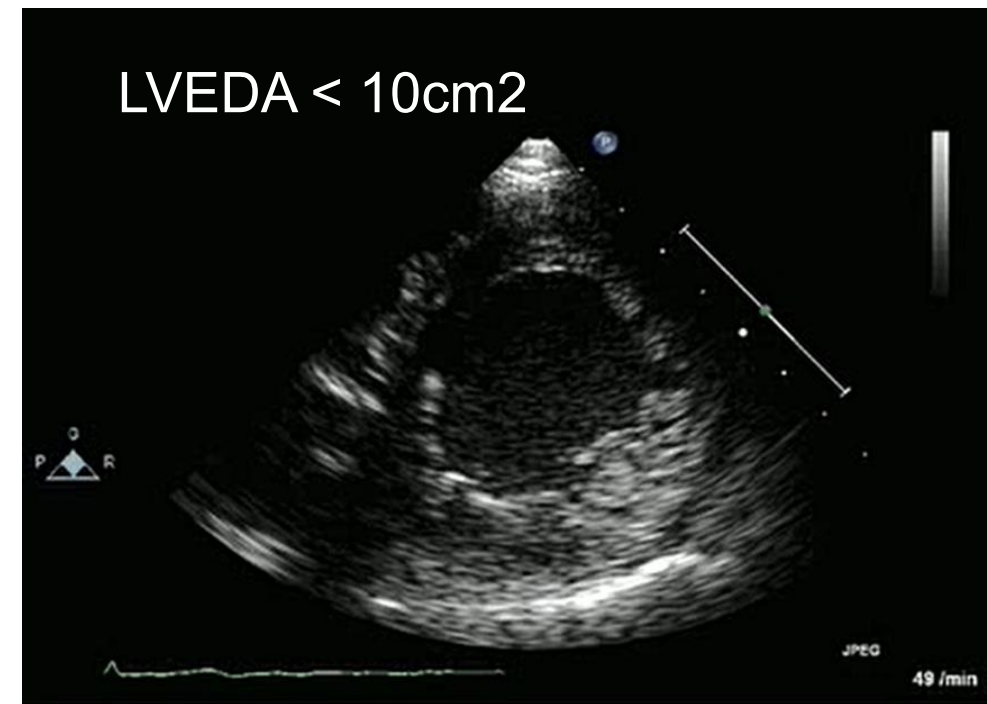
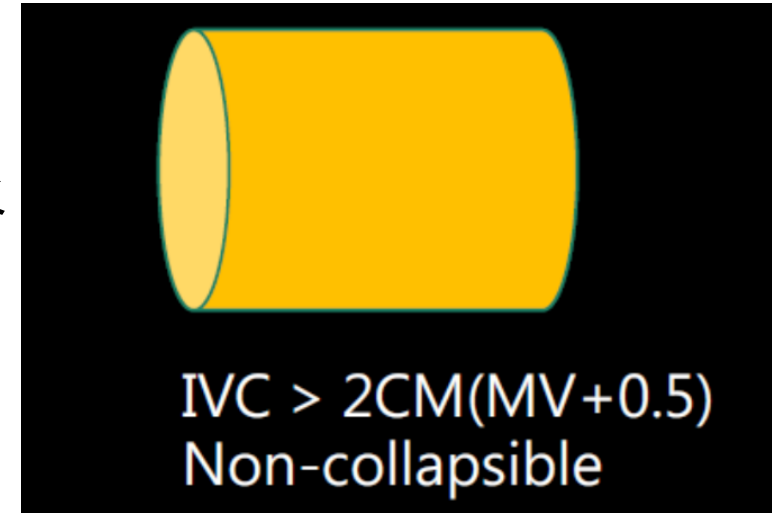
Venous Return
Cardiac Function

Pressure within
Intrathoracic Cavity

Pressure within
Abdominal Cavity

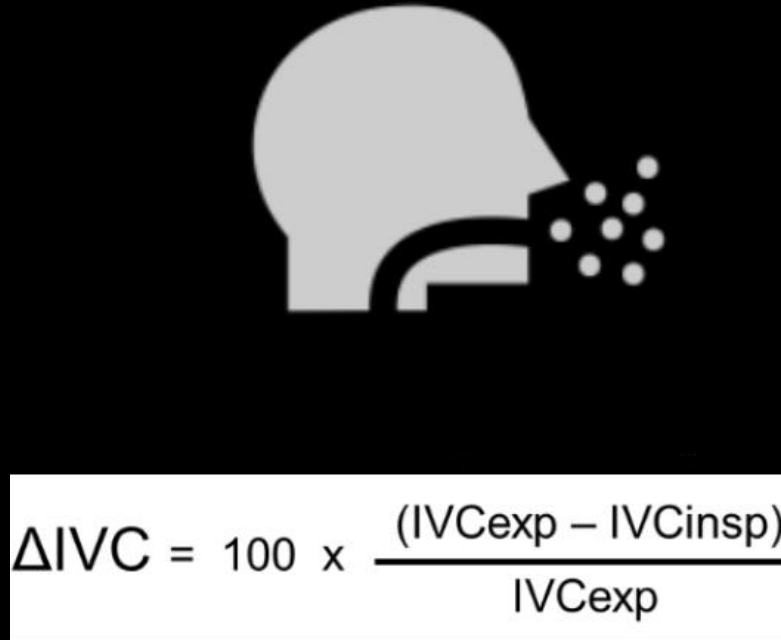
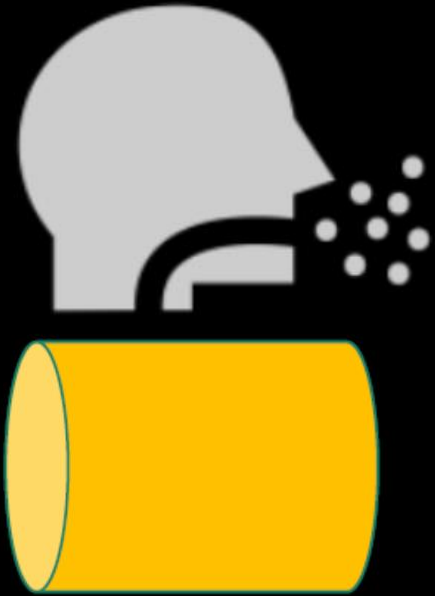
Q: 以下何者不會造成右側的現象

- A. Obstructive Shock:
PE, Tension PTX, Tamponade
- B. Increased Intrabdominal pressure
- C. ↑ Intrathoracic Pressure:
Status asthamticus
- D. Chronic comorbidities:
Right heart failure



Diameter

Collapsibility



$$\Delta IVC = 100 \times \frac{(IVC_{exp} - IVC_{insp})}{IVC_{exp}}$$

Normal
< 2.1 cm

Normal
> 50 %

IVCD

cIVC

RAP

N

N

3

N

A

8

A

N

8

A

A

15

Diameter

Collapsibility



IVC < 1CM (MV+0.5)
Collapsible



IVC > 2CM(MV+0.5)
Non-collapsible



IVC Collapsibility

$$\Delta IVC = 100 \times \frac{(IVC_{exp} - IVC_{insp})}{IVC_{exp}}$$

cIVC > 40 %

cIVC < 15 % **X**

RAP

≠

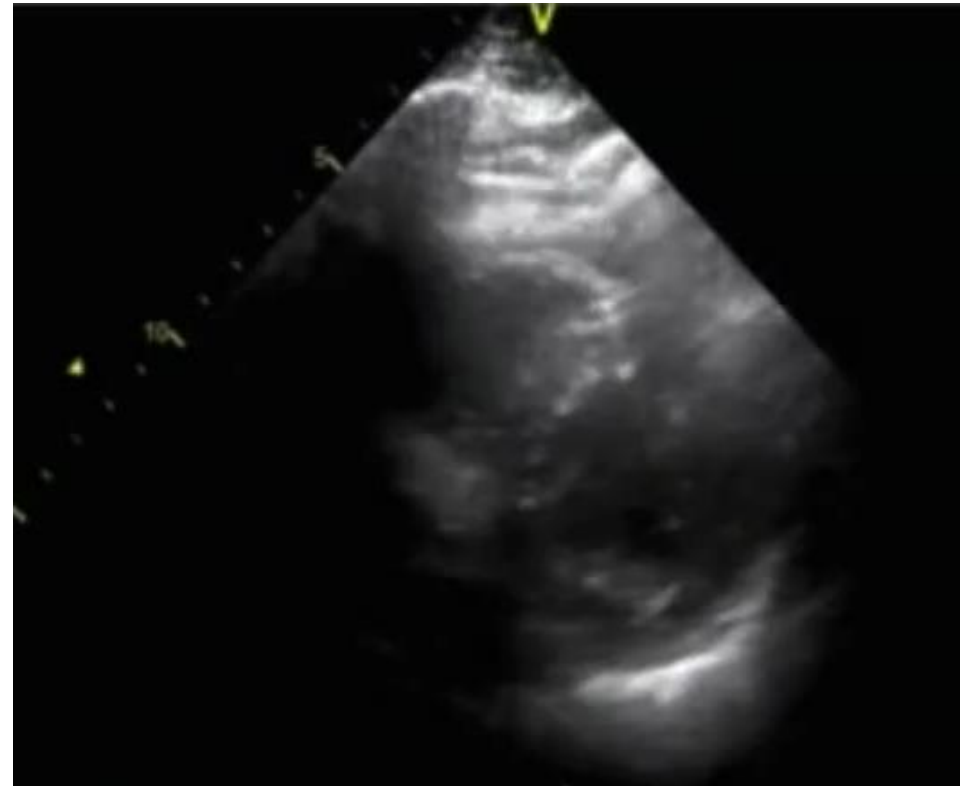
Volume
Status

≈

Fluid
Responsiveness

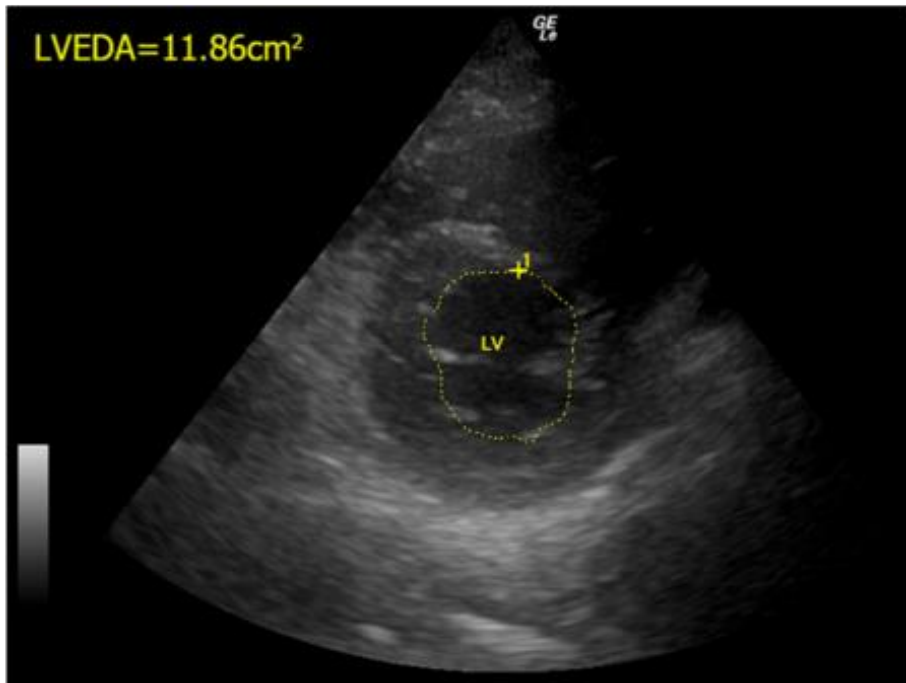
Severe
Hypovolemia

Chamber size ↓ , Hyperdynamic heart, Kissing papillary muscle sign

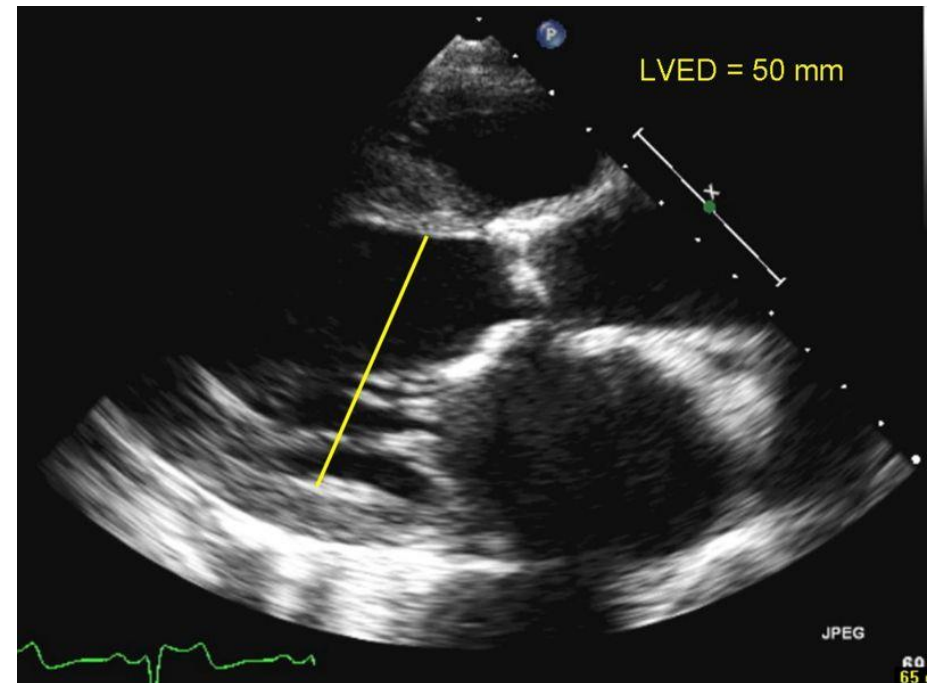


Severe
Hypovolemia

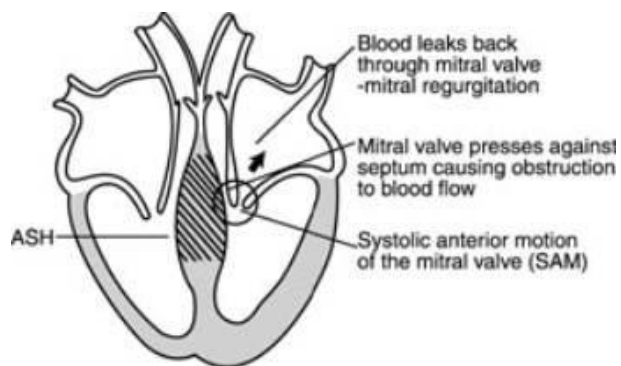
Size



LVEDA < 10 cm² (VS > 20 cm²)
(PSAX)

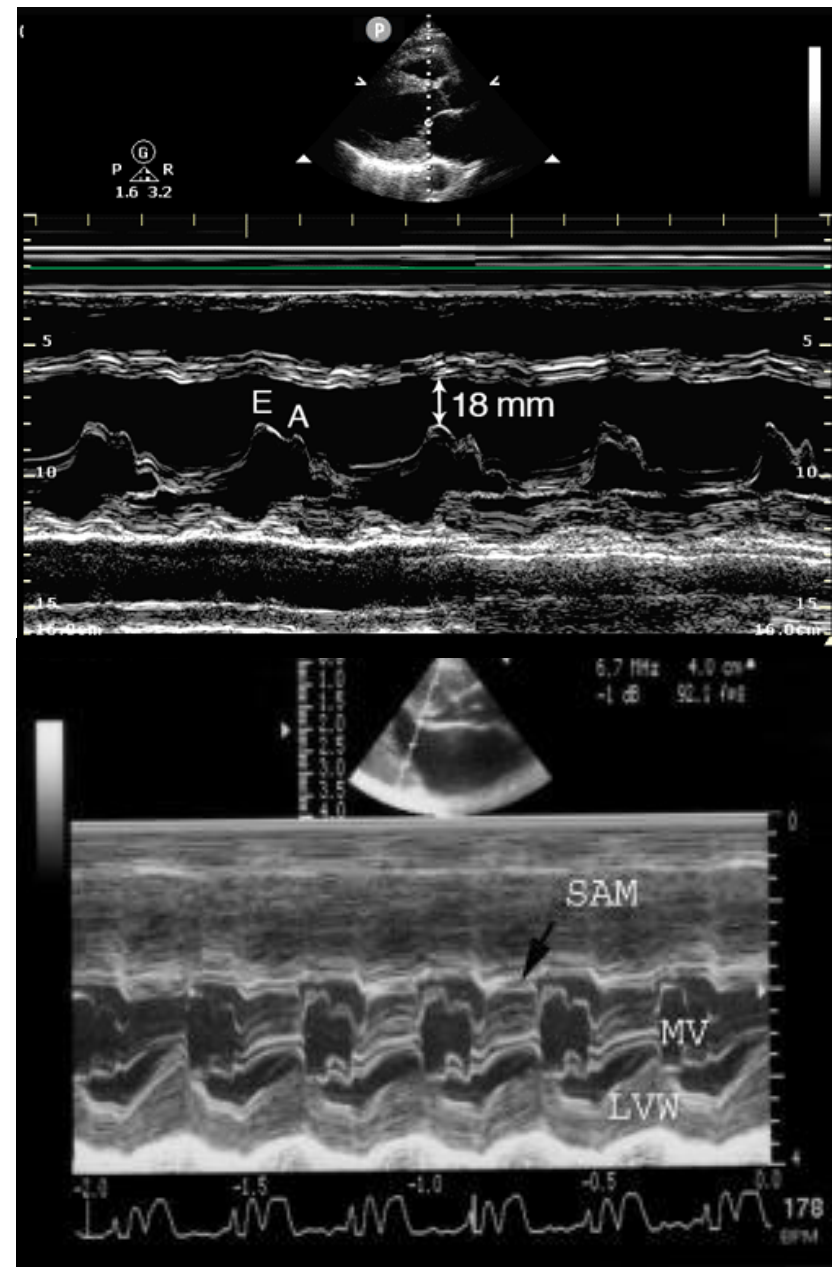


LVEDD < 25 mm
(PLAX)

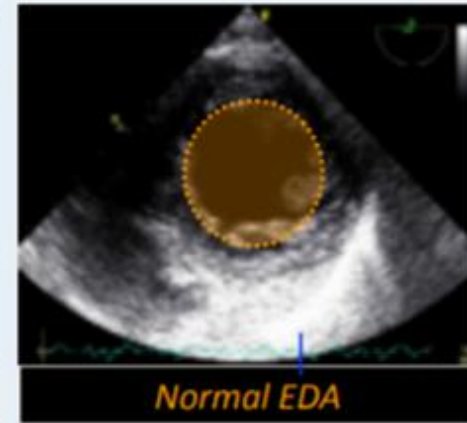
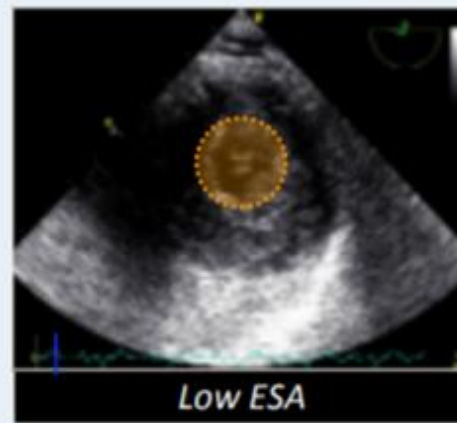
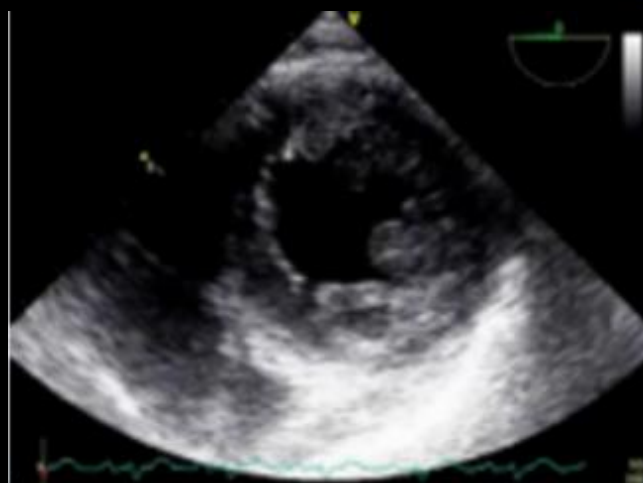
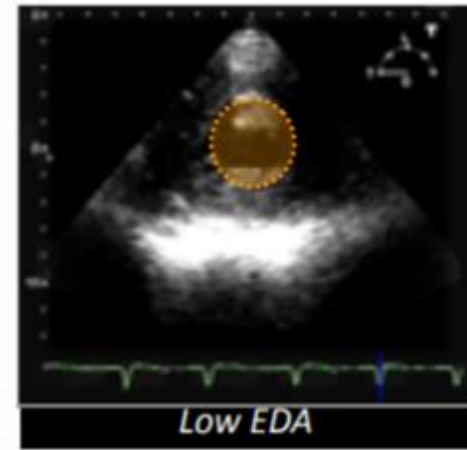
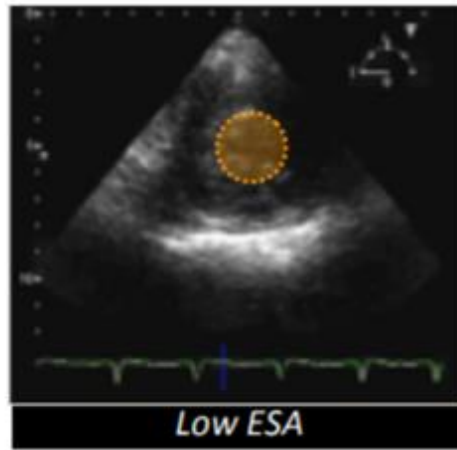
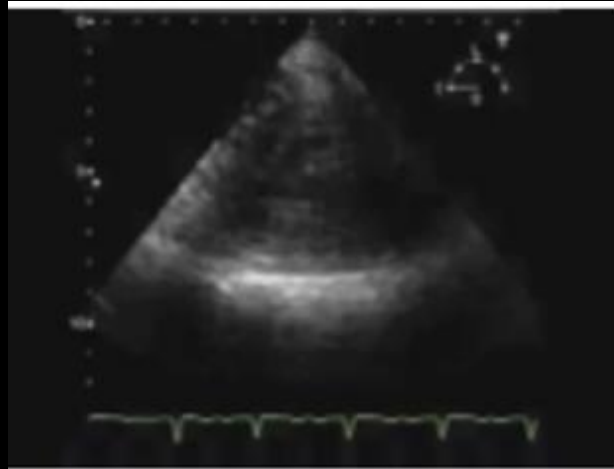


Dynamic SAM of LVOT

Severe Hypovolemia



LOW SVR vs. HYPOVOLEMIA



Volume Status

Static

IVC
Diameter/
Collapsibility

Fluid
Responsiveness

Dynamic

LVEDA/
Eyeballing

Volume Status

Static

Challenge/
Volume
Expansion

Fluid
Responsiveness

Dynamic

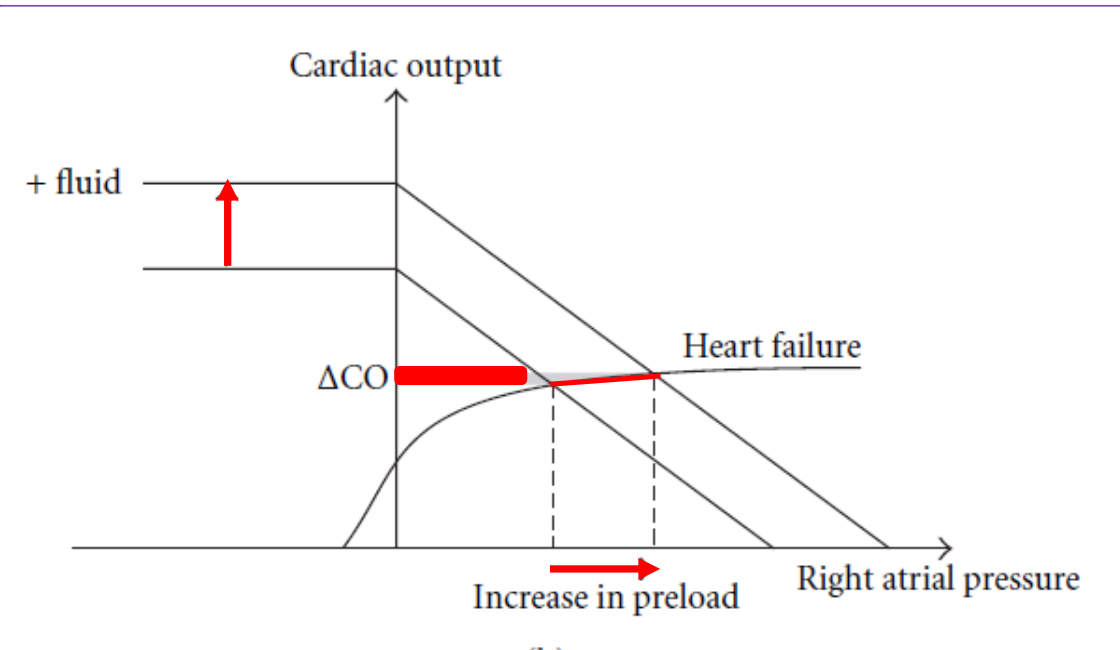
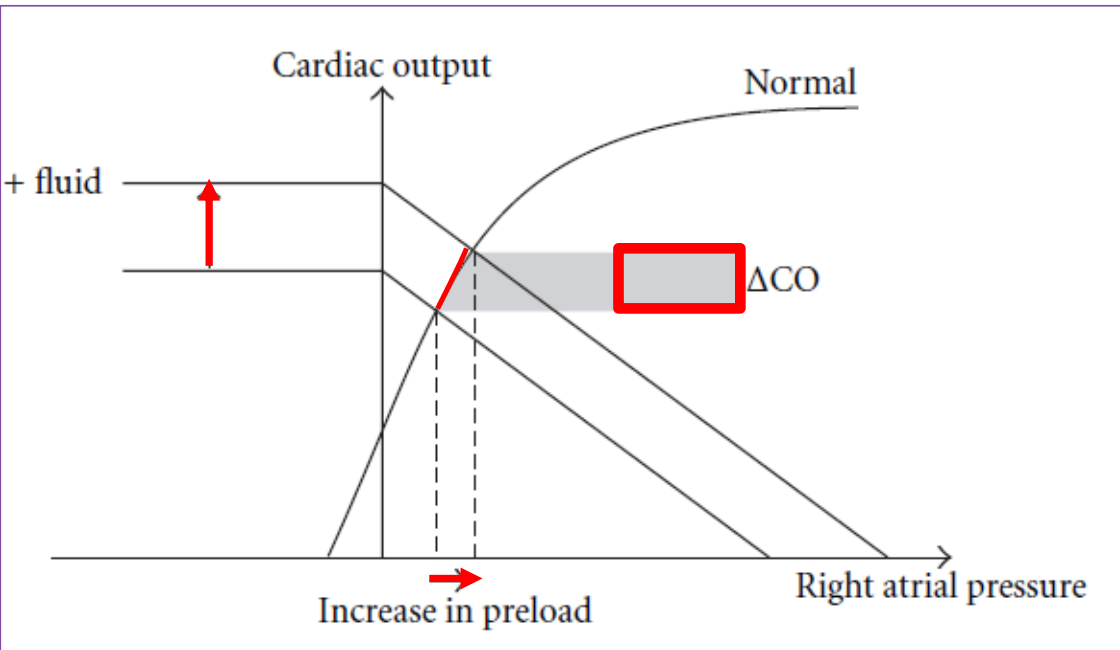
Respiratory
Variations

500-mL
Fluid Challenge

CO
↑ 10~15%

Fluid Responsiveness

Challenge / Volume Expansion



15~20min 灌500ml的水

Passive Leg Raising Test

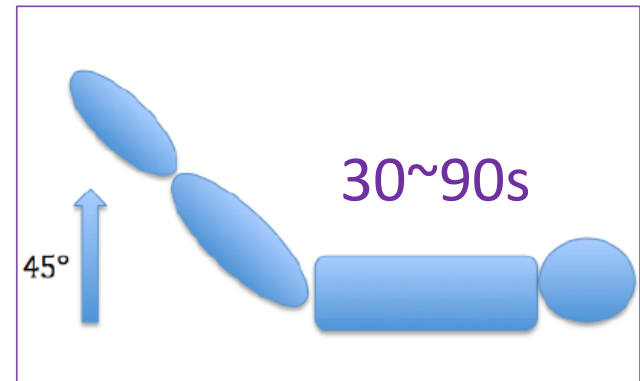
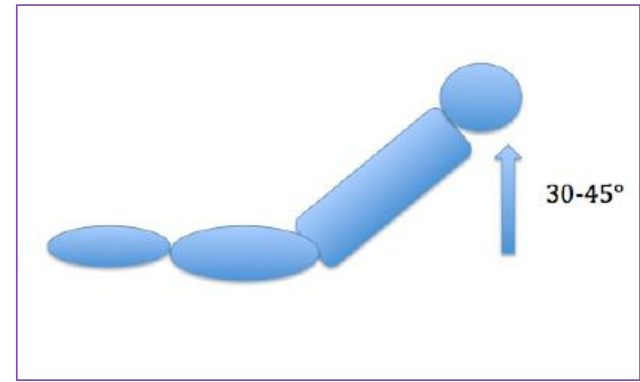


Fluid Responsive

CO ↑ 12~15%

(Sp > 90%; Se > 80%)

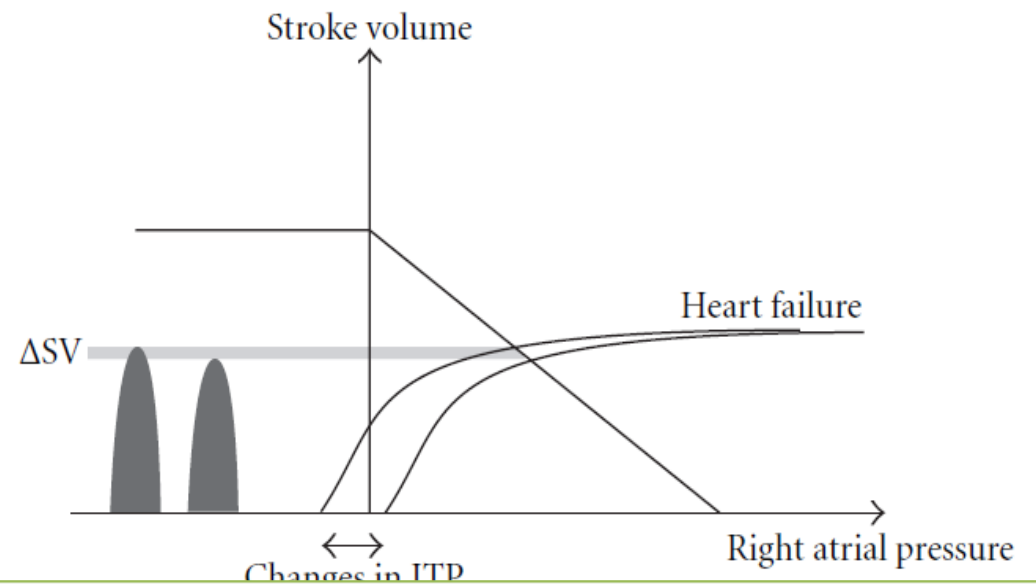
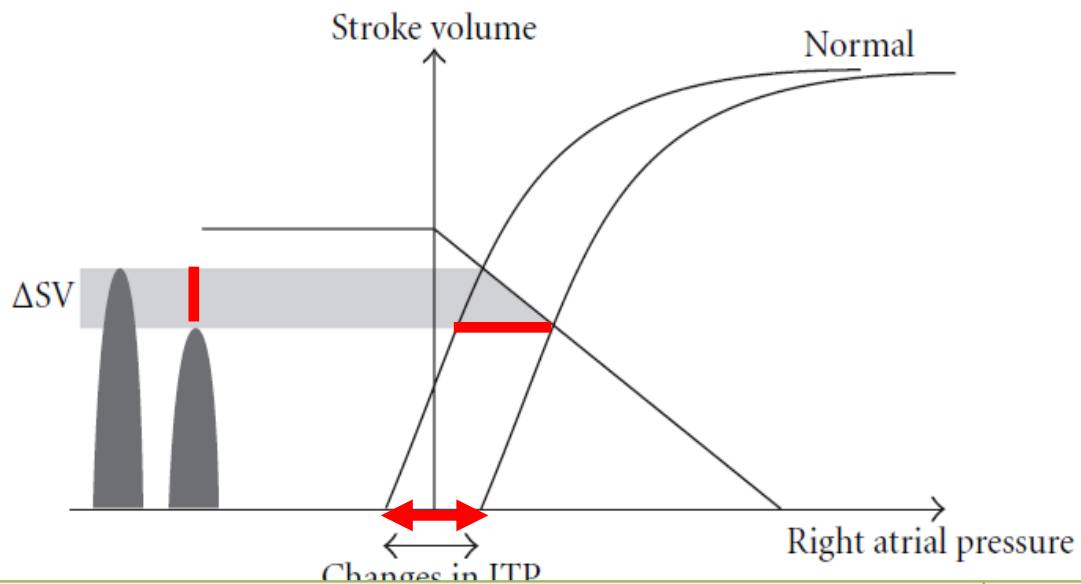
VTI_{LVOT}
VTI_{Aortic}



15~20min 灌500ml的水

Passive Leg Raising Test

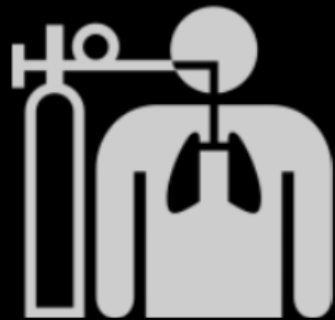
Respiratory Variations



SVV (Stroke Volume Variation)

$$= \frac{(SV_{max} - SV_{min})}{SV_{mean}} \times 100\%$$

IVC Variation Index

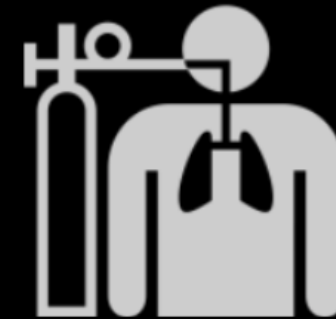


IVC Variation

$$vIVC = 100 \times \frac{IVC_{max} - IVC_{min}}{IVC_{mean}}$$

$vIVC > 12\%$

IVC Distensibility Index

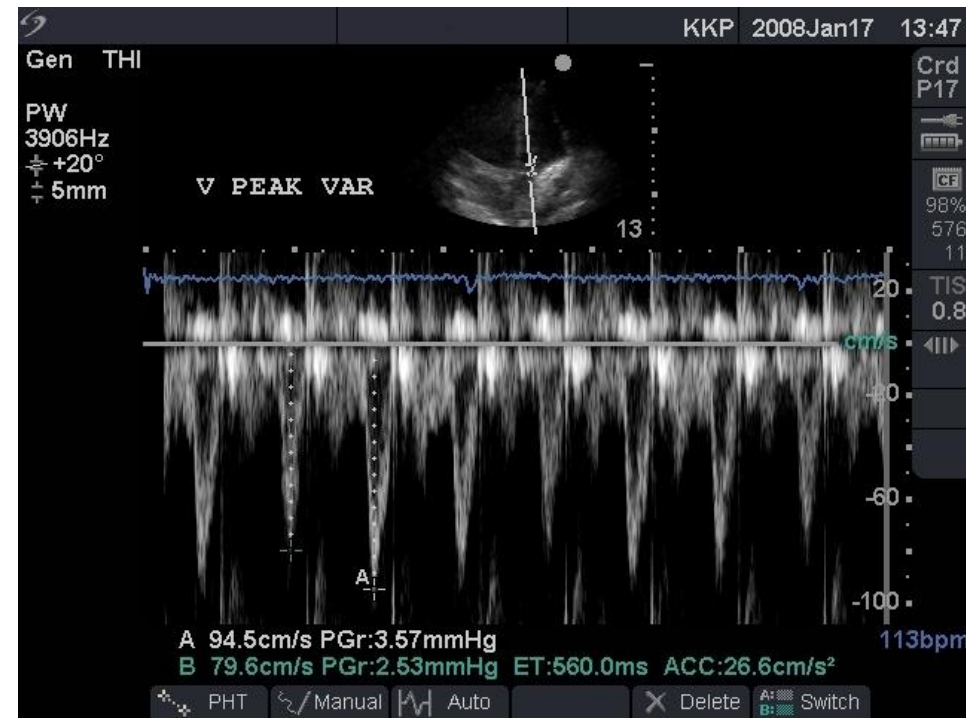
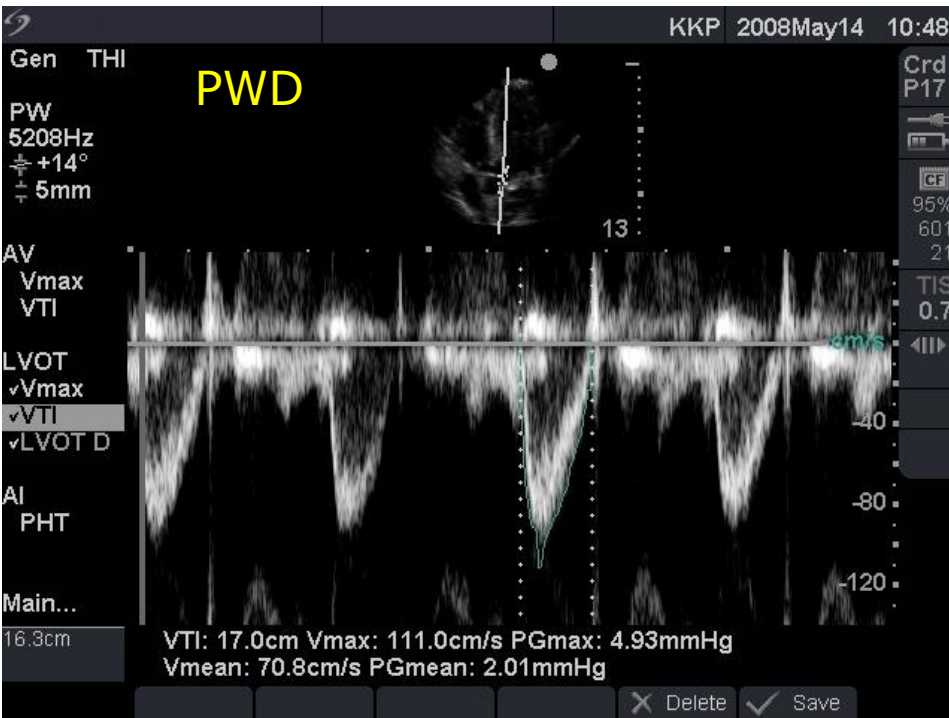


IVC Distensibility

$$dIVC = 100 \times \frac{IVC_{insp} - IVC_{exp}}{IVC_{exp}}$$

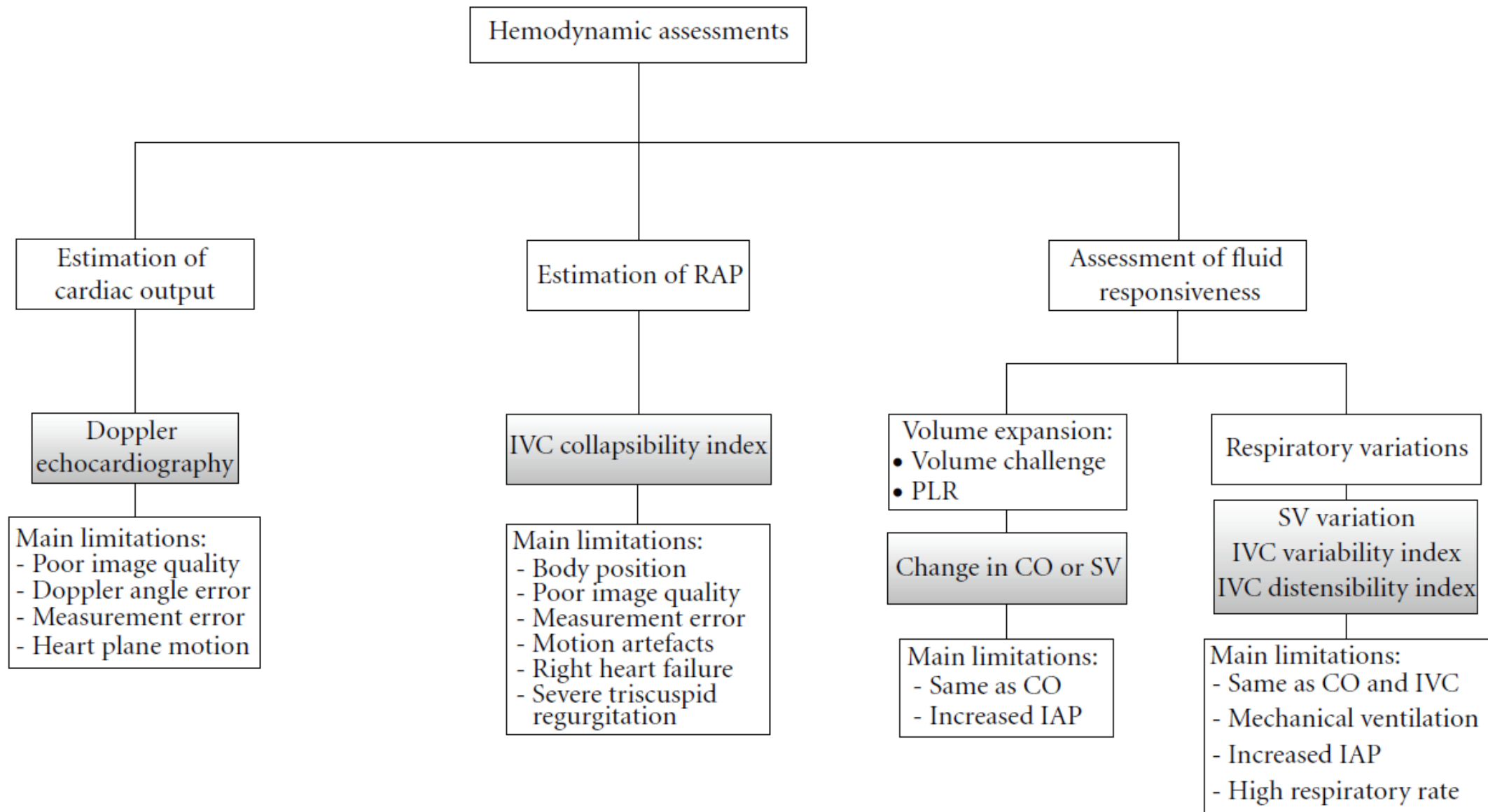
$dIVC > 18\%$

Respiration Variation LVOT VTI or Vmax (>12%)



sensitivity of 100% and a specificity of 89%

Hypovolemia
Entrance

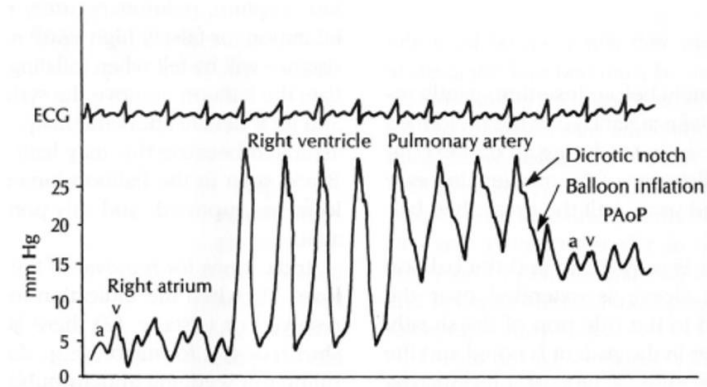


Left heart	<ul style="list-style-type: none"> (i) Dimensions: chamber sizes and thickness (ii) Left ventricular ejection fraction (iii) Regional wall motion abnormalities
Right heart	<ul style="list-style-type: none"> (i) Dimensions: chamber size and thickness (ii) Right ventricular systolic function: FAC or TAPSE (iii) Signs of pressure or volume overload
Valvular pathologies	<ul style="list-style-type: none"> (i) Regurgitations (ii) Stenoses (iii) Prolapses (iv) Presence of vegetation
Aorta	<ul style="list-style-type: none"> (i) Dilatation (ii) Dissection
Estimation of pressures	<ul style="list-style-type: none"> (i) Pulmonary artery systolic pressure (ii) Left ventricular filling pressure (iii) Transvalvular pressure gradients
Other	Pericardial effusion and tamponade

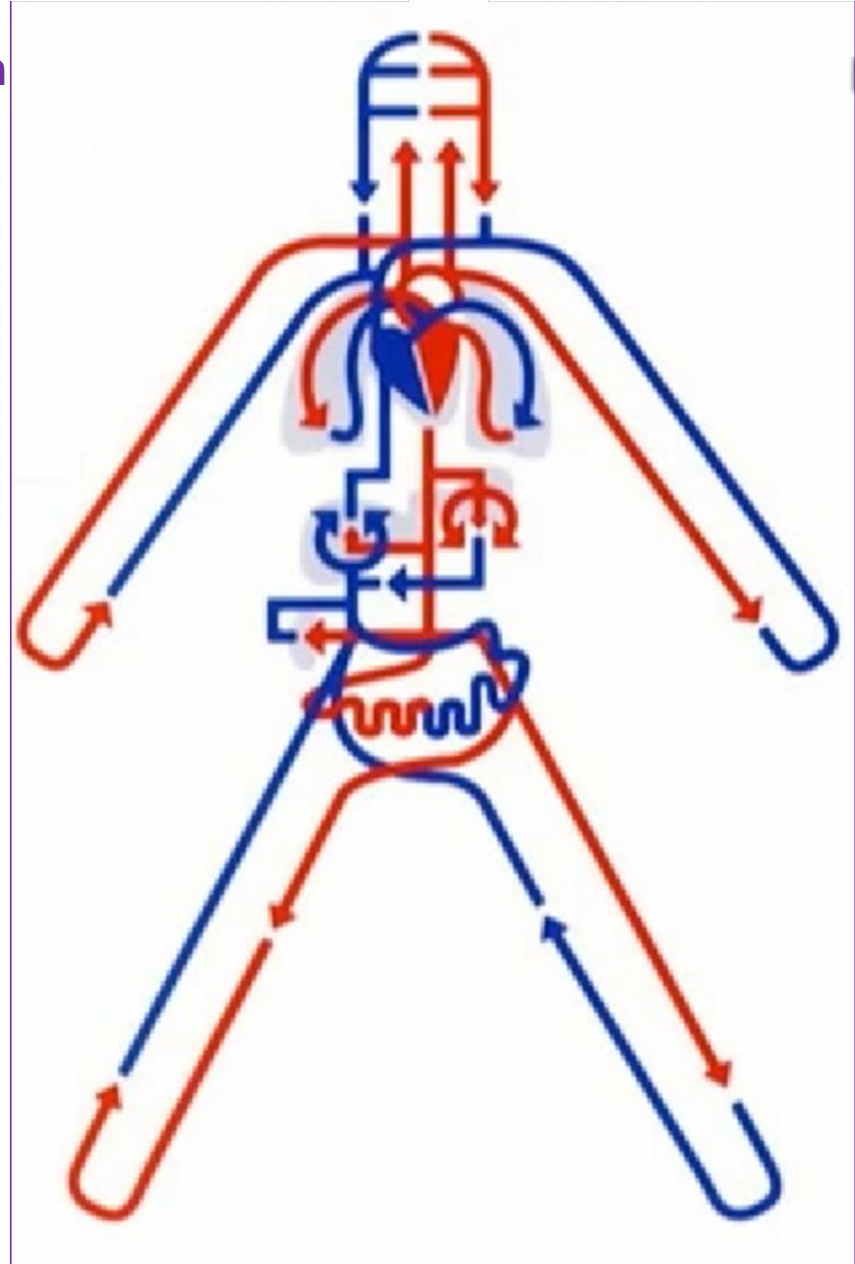
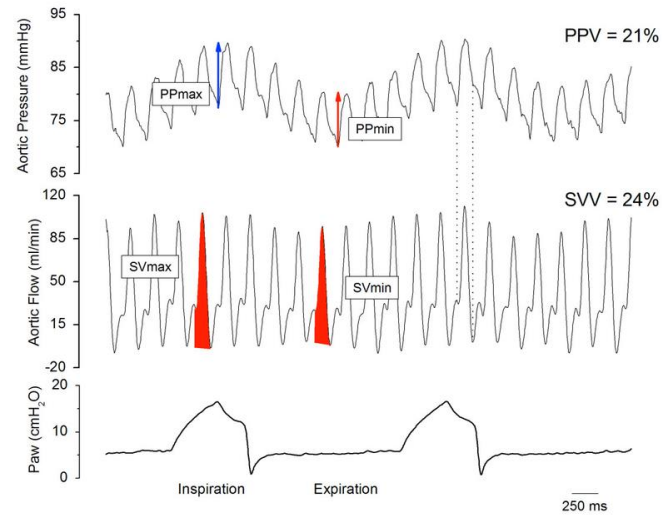
FAC: fractional area contraction; TAPSE: tricuspid annular plane systolic excursion.

Cardiac Output	Heart	Fluid
		Diuretic
Volume Status	IVC	Inotropes
		Vasopressor
Fluid Responsiveness	Pulmonary	Vasodilator

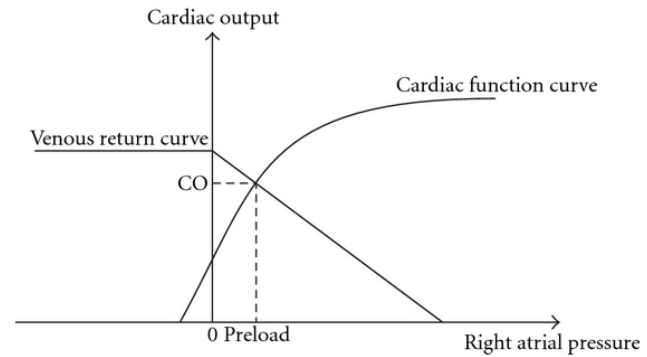
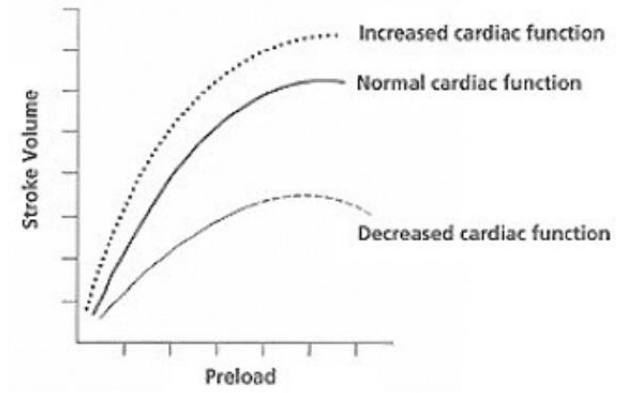
Pulmonary & General Circulation



Effects of Airway Pressure



Heart: Complex Pressure Pump



Effects of Position Changes

Arterial & Venous Pressure

US
Limitations
Gray Zones
Clinical Context



Thanks for Your Attention !