Echo in Pulmonary HTN

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Pulmonary Artery Pressure
Clinical Importance

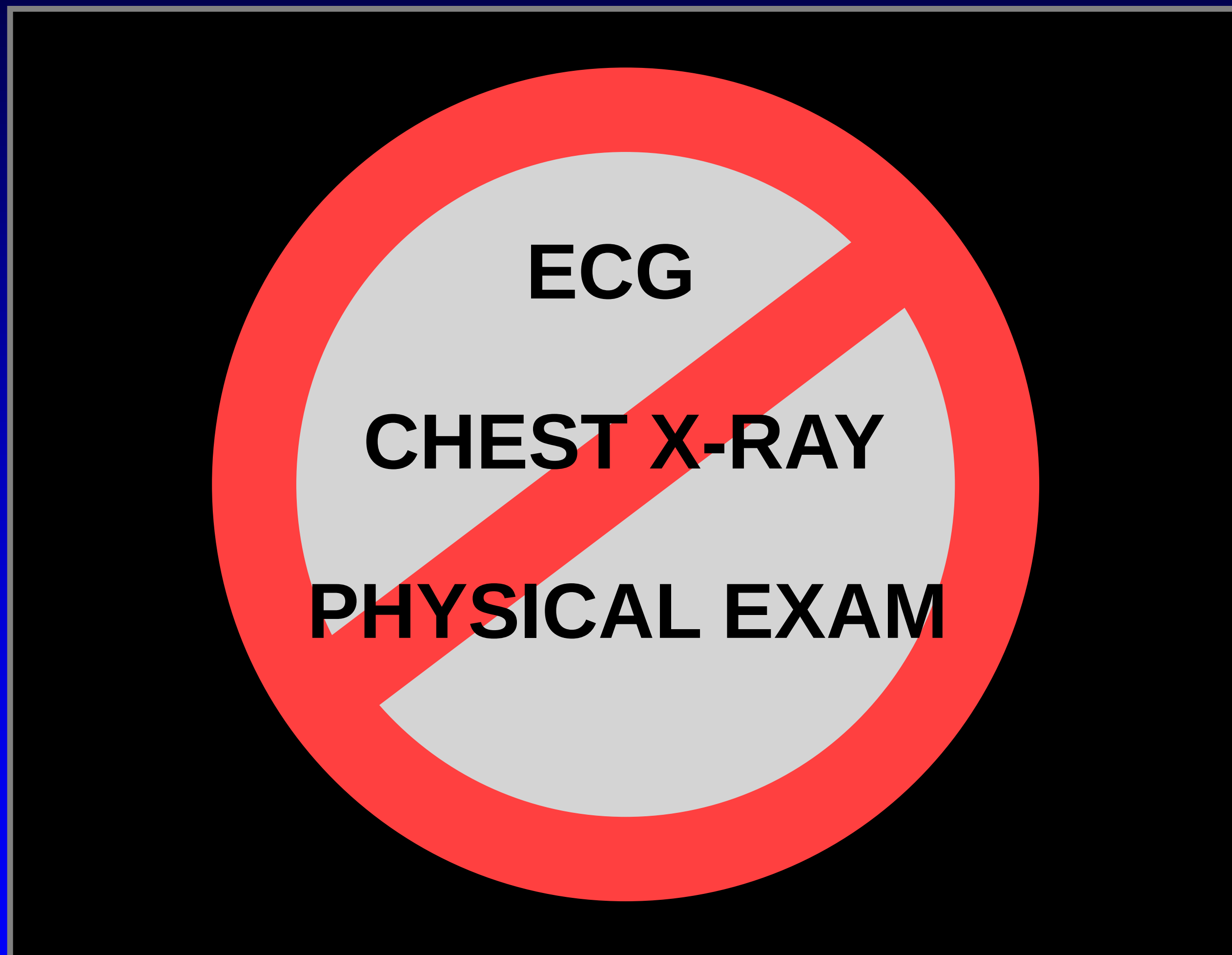
- Responsible for symptoms and disability
  (LV disease, valvular disease, etc)

- Responsible for hemodynamic consequences
  (acute and chronic lung disease; TR; ↑'d CVP)

- Prognostic importance

- Management decisions
  (eg operability in congenital HD, MV disease)

Noninvasive Assessment of PA Pressure



RV – Pulmonary Circulation Unit

- Degree of pulm HTN does not strongly correlate with symptoms or survival

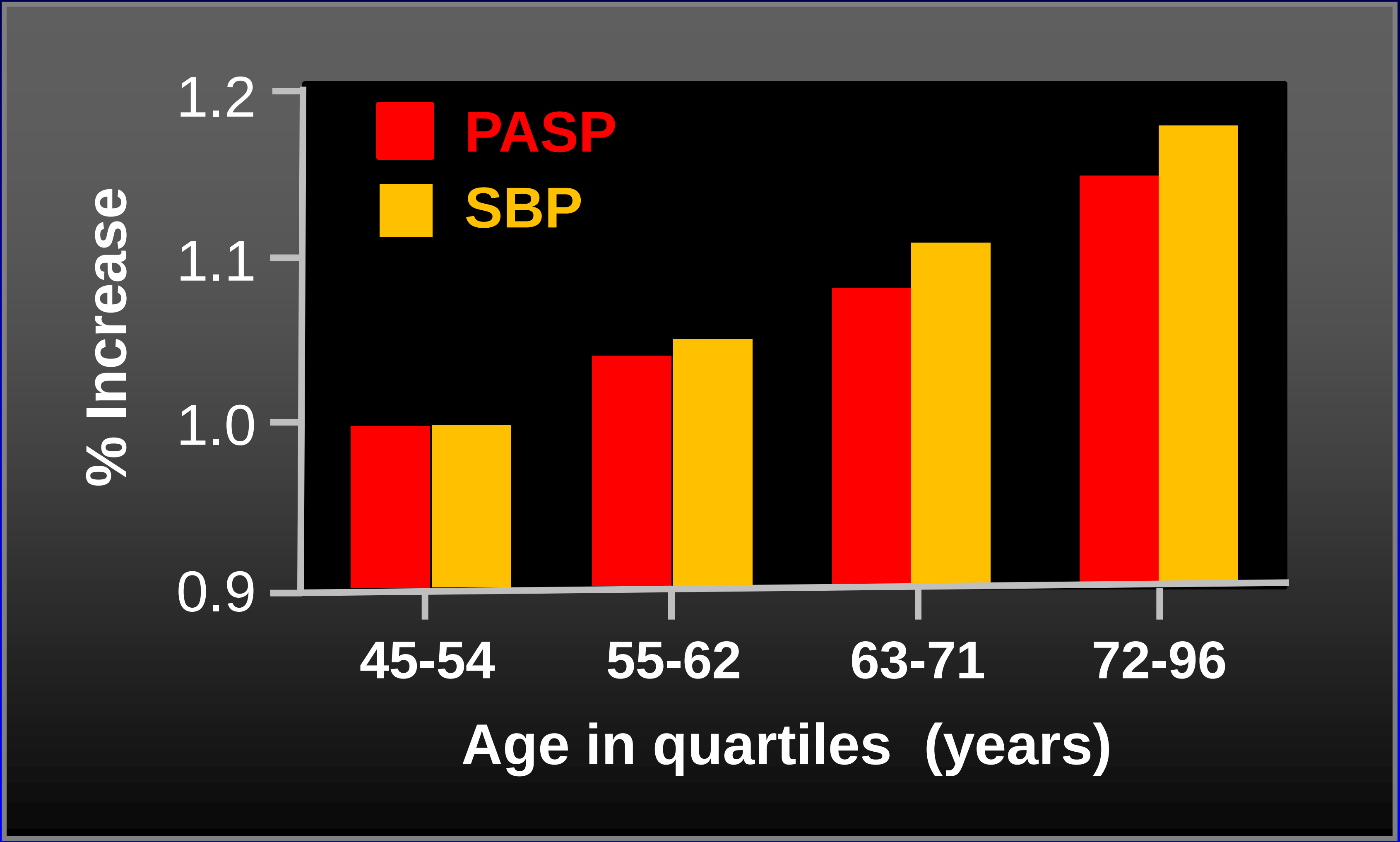
- RV size, RV mass, and RA pressure **do** reflect functional status and are strong predictors of survival

Normal Right Heart Hemodynamics

$RVSP/PASP_{Echo}$	< 36 mm Hg*
Mean PAP	8 – 20 mm Hg
PAEDP	4 – 12 mm Hg
RAP	0 – 5 mm Hg
PVR	< 2.0-3.0 WU

* (up to 40 mm Hg in older and obese patients)

Association of Systemic and PA Pressure with Age



Lam et al. *Circulation* 2009;119:2663-2670

Figure 2. Association of systemic pressure and RASP with age

Normal Resting Values

Guidelines for the Echocardiographic Assessment of the Right Heart in Adults (ASE, EAE, ESC, CSE)

Peak TR velocity	**≤ 2.8 – 2.9 m/s**
Peak systolic pressure	**35 or 36 mm Hg***

(assuming an RA pressure of 3 to 5 mm Hg)

* “This value may increase with age and increasing BSA . . . “

Rudski J Am Soc Echocardiogr 2010;23:685-713

Badesch J Am Coll Cardiol 2009;54:S55-66

Pulmonary Hypertension

- Mean PAP > 25 mm Hg
- PVR > 3 Wood units
- PCWP ≥ 15 mm Hg

Rudski J Am Soc Echocardiogr 2010;23:685-713

Pulmonary Hypertension
Role of Echocardiography

- Diagnose pulmonary HTN
- Determine etiology

  (Left heart disease, MV disease, congenital HD, etc)

- Quantitate PA pressures (PASP, PADP, PA_{mean})
- Evaluate end effects
- Determine prognosis

  (RA pressure, mean PA pressure, large pericardial effusion)

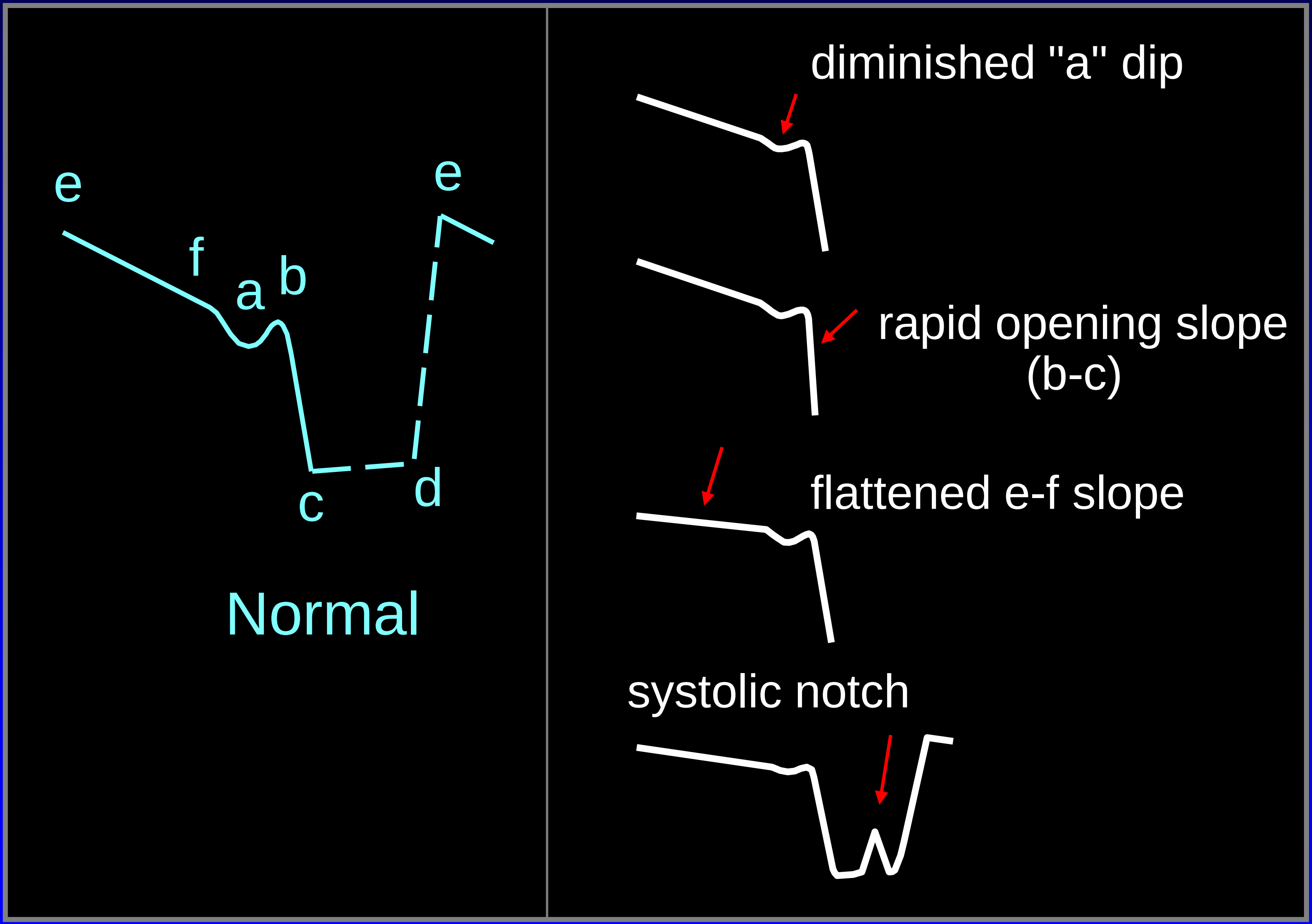
Pulmonary Hypertension
Echo Findings

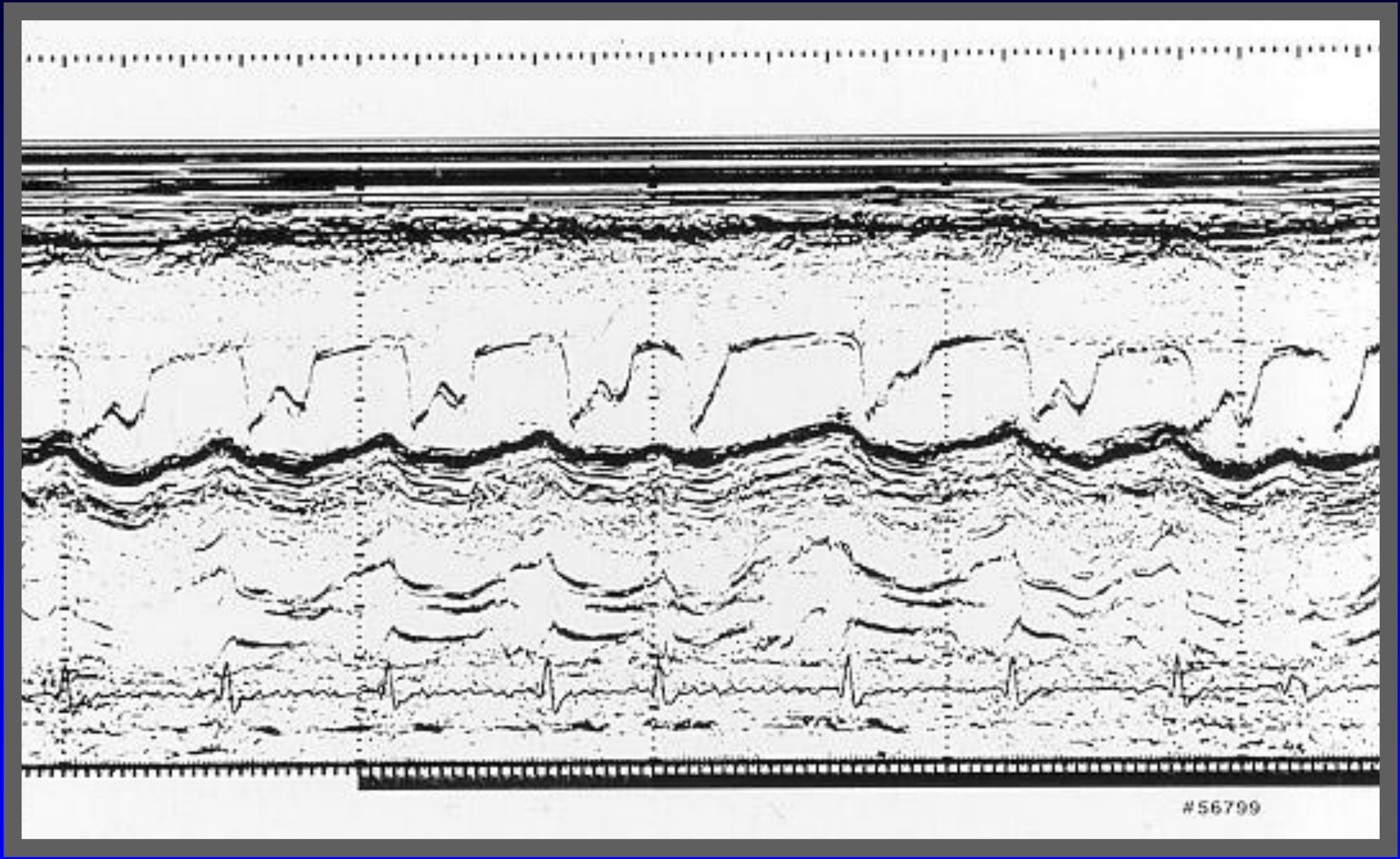
1. Right ventricular hypertrophy and/or dilatation
2. Abnl shape of LV in short axis ("D-shaped")
3. Right atrial dilatation
4. Dilated pulmonary artery
5. Abnormal systolic time intervals
    a. Prolonged RPEP/RVET
    b. Increased PV_c - TV_o interval
6. Abnormal pulmonic valve motion (M-mode)

M-Mode

Pulmonary Hypertension

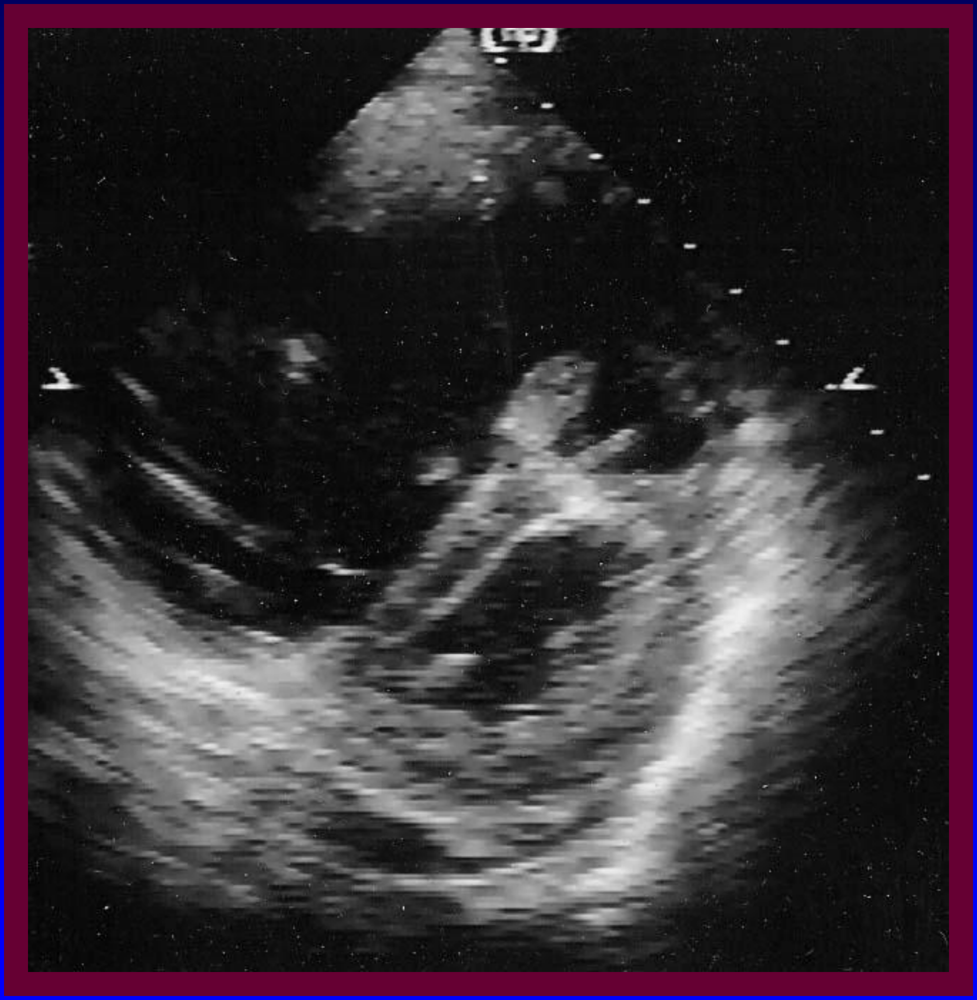
M-Mode Echo Signs

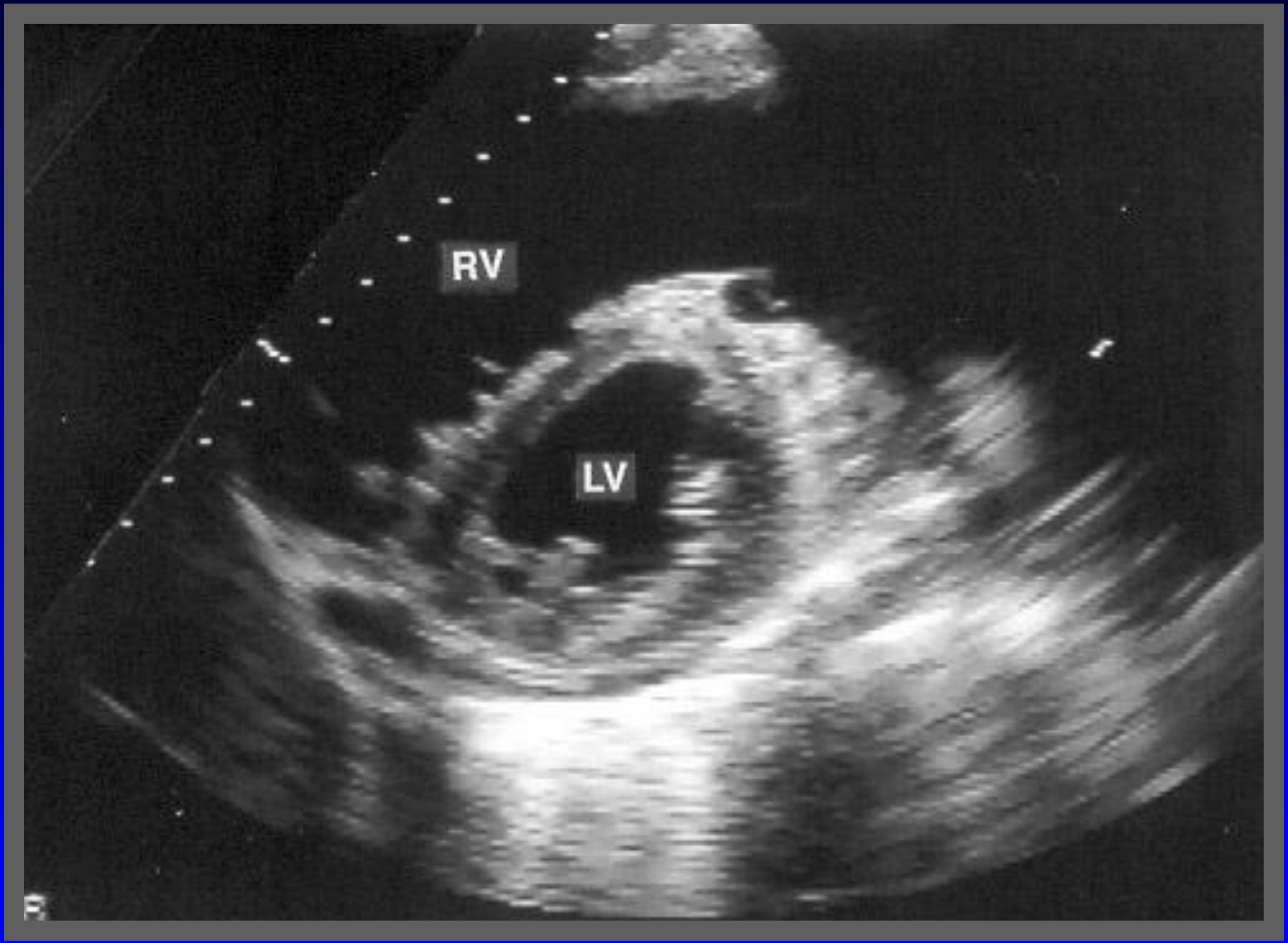



#56799

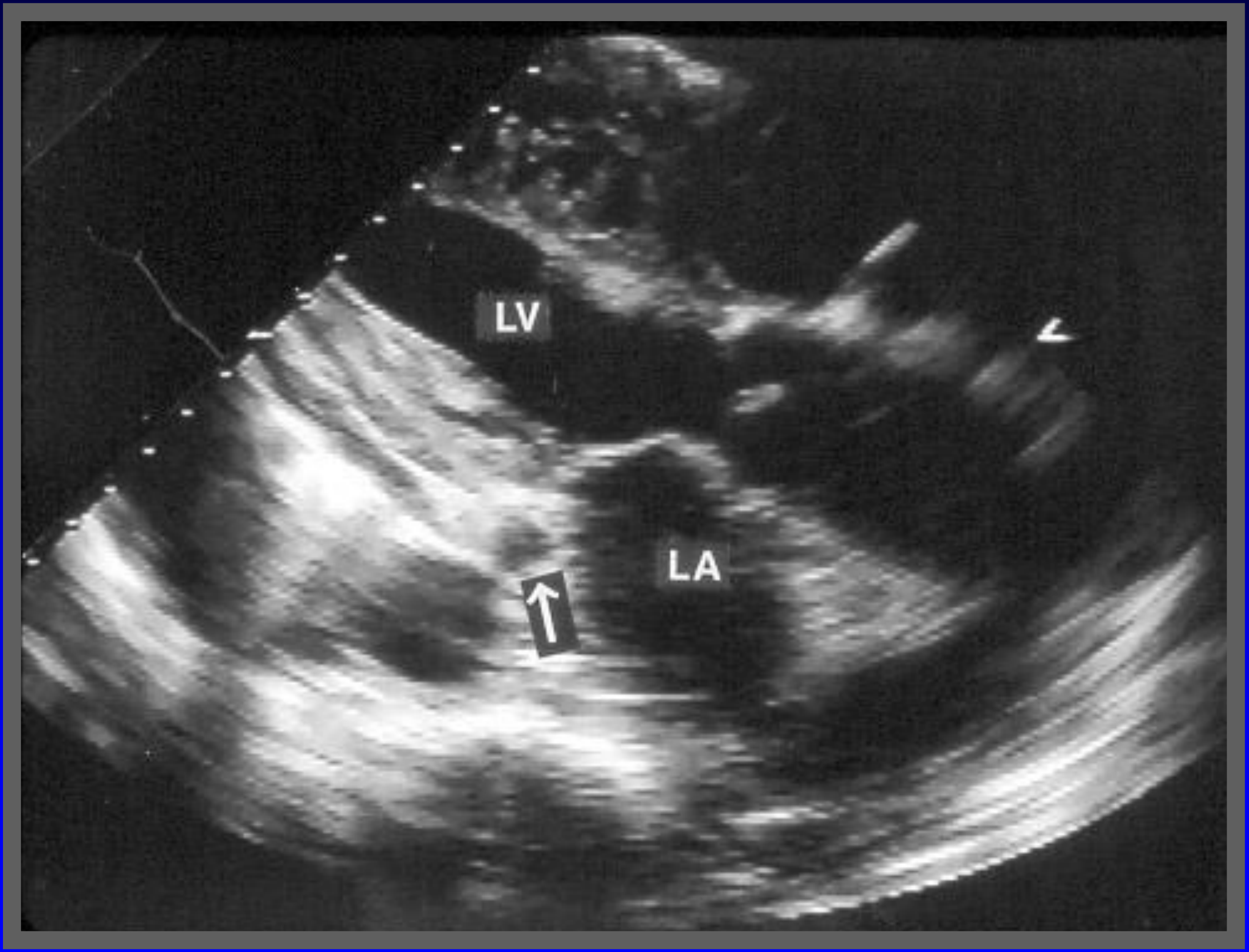
Flattened Ventricular Septum

(D-Shaped)




RV
LV

Dilated coronary sinus → Increased RA pressure



Determination of PA Pressure
Echo-Doppler Methods

1. **TR jet velocity method**

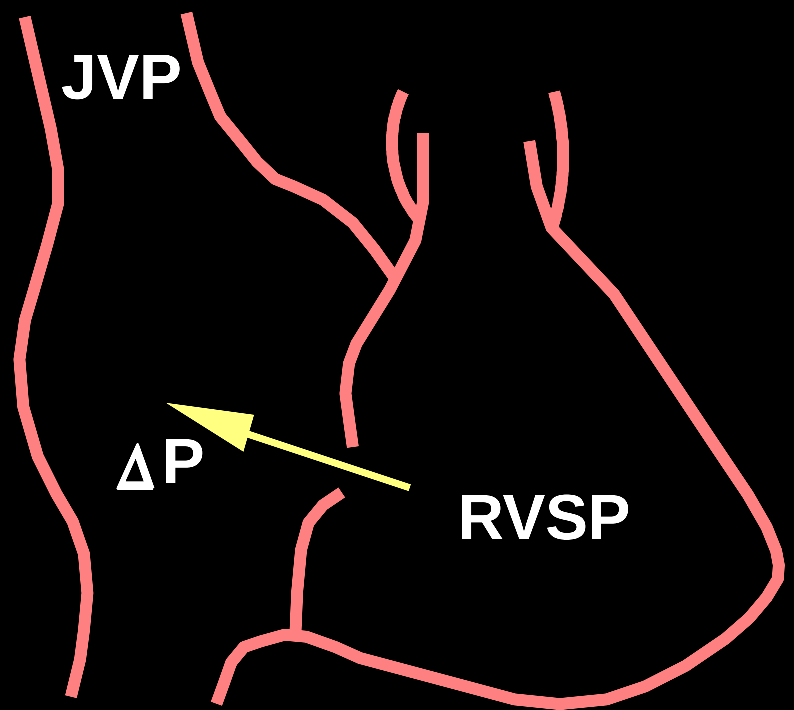
2. Pulmonary acceleration time

3. Pulmonic regurgitant jet method

4. RV isovolumic relaxation time

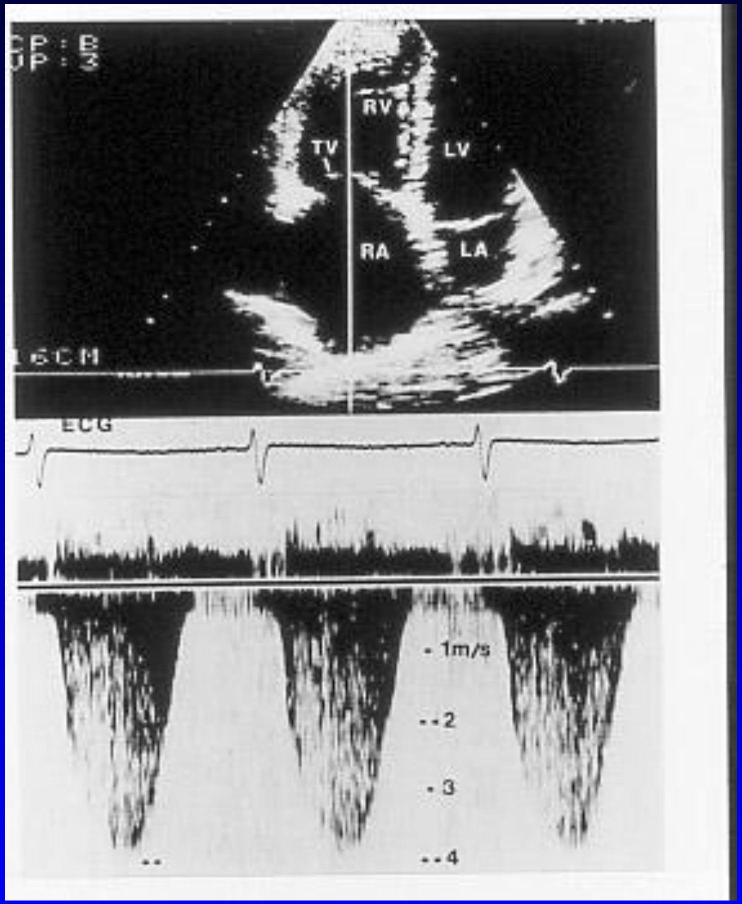
TR Jet

Estimation of RV Systolic Pressure (RVSP) From Maximum Transtricuspid Gradient



$$RVSP = \Delta P + JVP$$

Peak Velocity of Tricuspid Regurgitant Jet

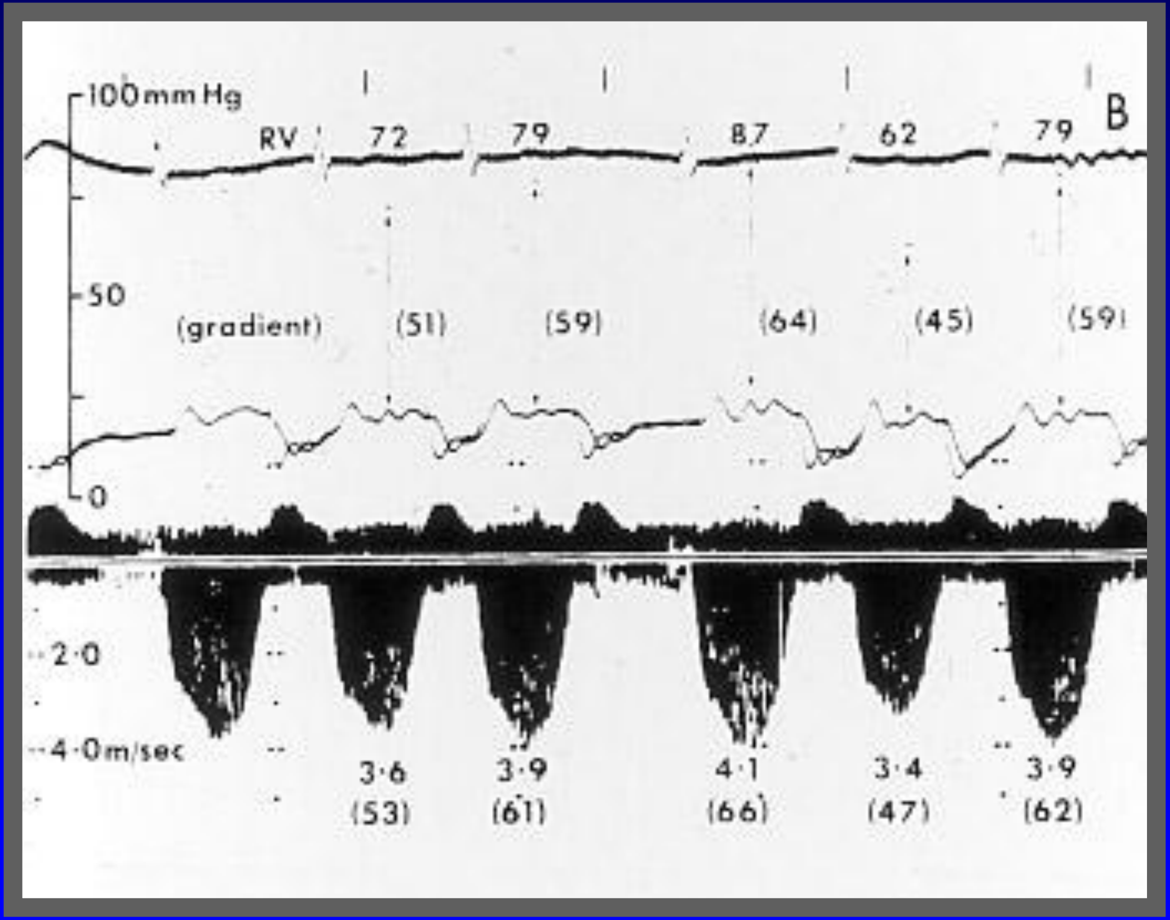


Determination of RV-RA pressure gradient

RV-RA Gradient = 64 mmHg
Est. of RA Pressure = 10 mmHg
Pulm Art Pressure = 74 mmHg

Doppler Estimation of RV Systolic Pressure

Simultaneous Doppler and Cath Tracings

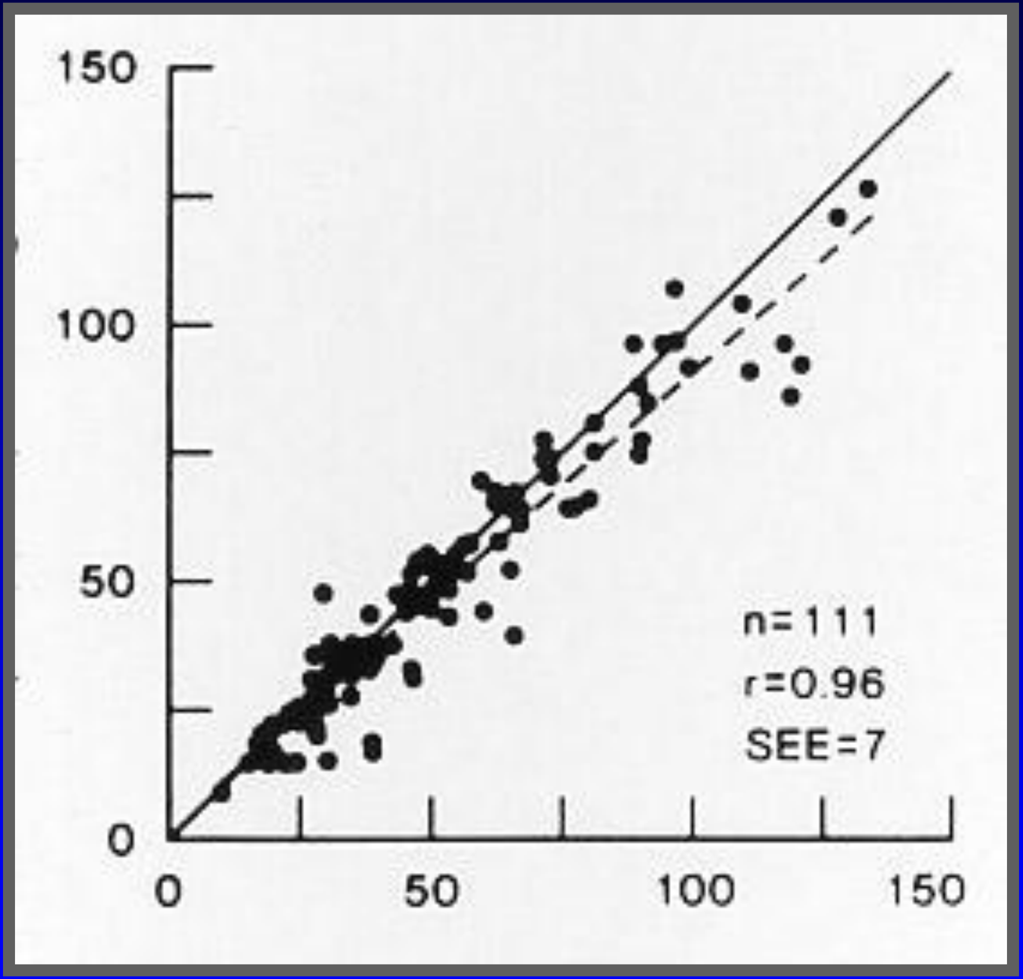


Currie JACC 6:750(1985)

Doppler Estimation of RV Pressure

Simultaneous Cath and Doppler

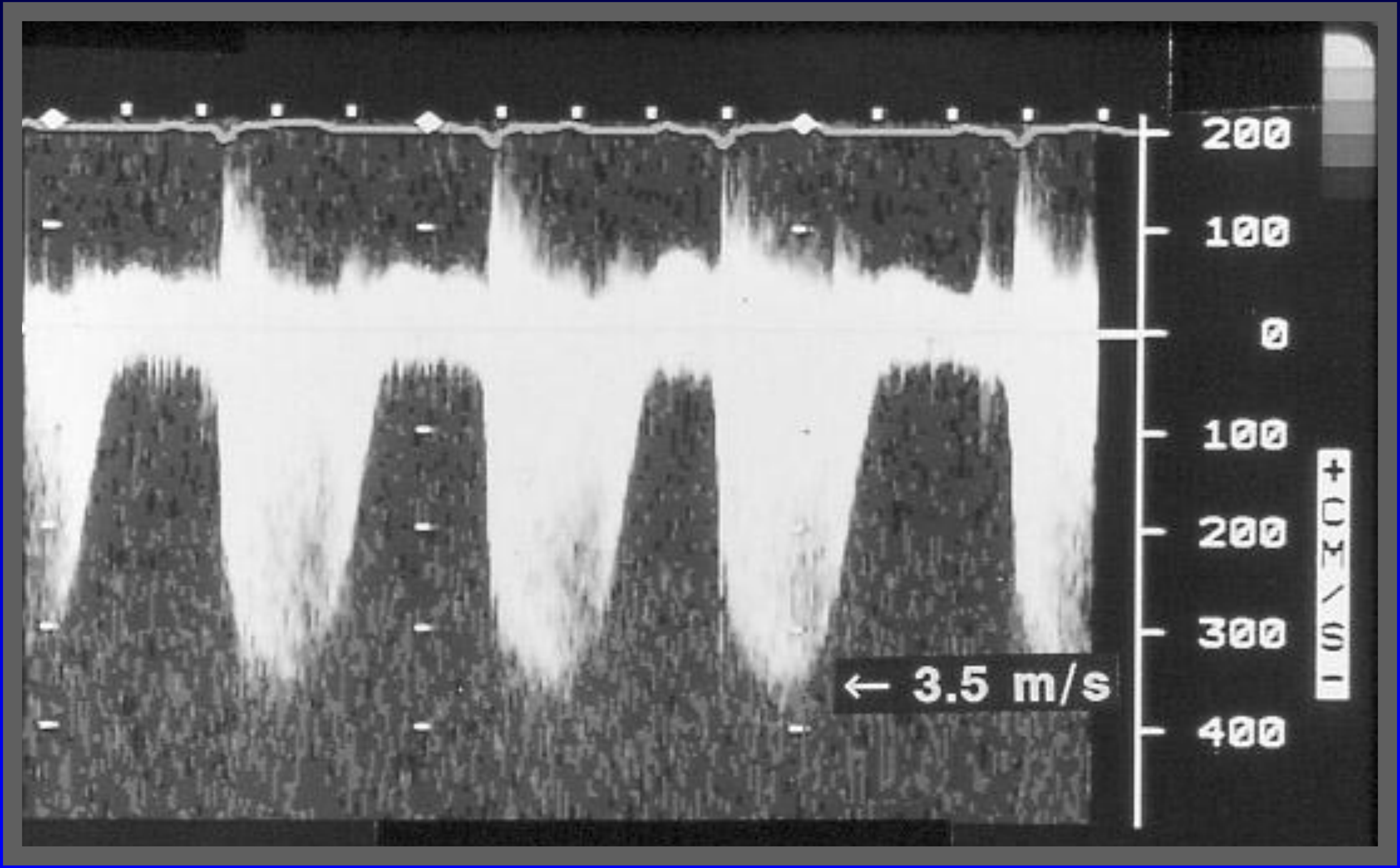
Max Gradient (Doppler), mmHg



Max Gradient (catheter), mmHg

Currie JACC 6:750(1981)

Peak TR Jet Velocity



3 Methods of Estimating Right Atrial Pressure

1. Assume RA pressure of 5, 10, 15, or 20 mmHg
2. **Clinical estimate of RA pressure (JVP)**
3. **IVC "collapsibility index"**

Estimation of Mean RA Pressure

2005

IVC size	Collapsibility Index	RA Pressure
Normal IVC (≤ 1.7 cm)	50% decrease	0 – 5 mm Hg
Dilated IVC (> 1.7 cm)	≥ 50% insp collapse	6 – 10 mm Hg
	< 50% insp collapse	10 – 15 mm Hg
	No collapse	> 15 mm Hg

Lang, et al Quantitation Guidelines
J Am Soc Echocardiogr 2005;17:1155-1160

Estimation of Mean RA Pressure

2015

	Normal RAP (0-5 [3] mm Hg)	**Intermediate** (5-10 [8] mm Hg)		**High RAP** (15 mm Hg)
IVC diameter	≤ 2.1 cm	≤ 2.1 cm	> 2.1 cm	> 2.1 cm
Collapse with sniff	> 50%	< 50%	> 50%	< 50%

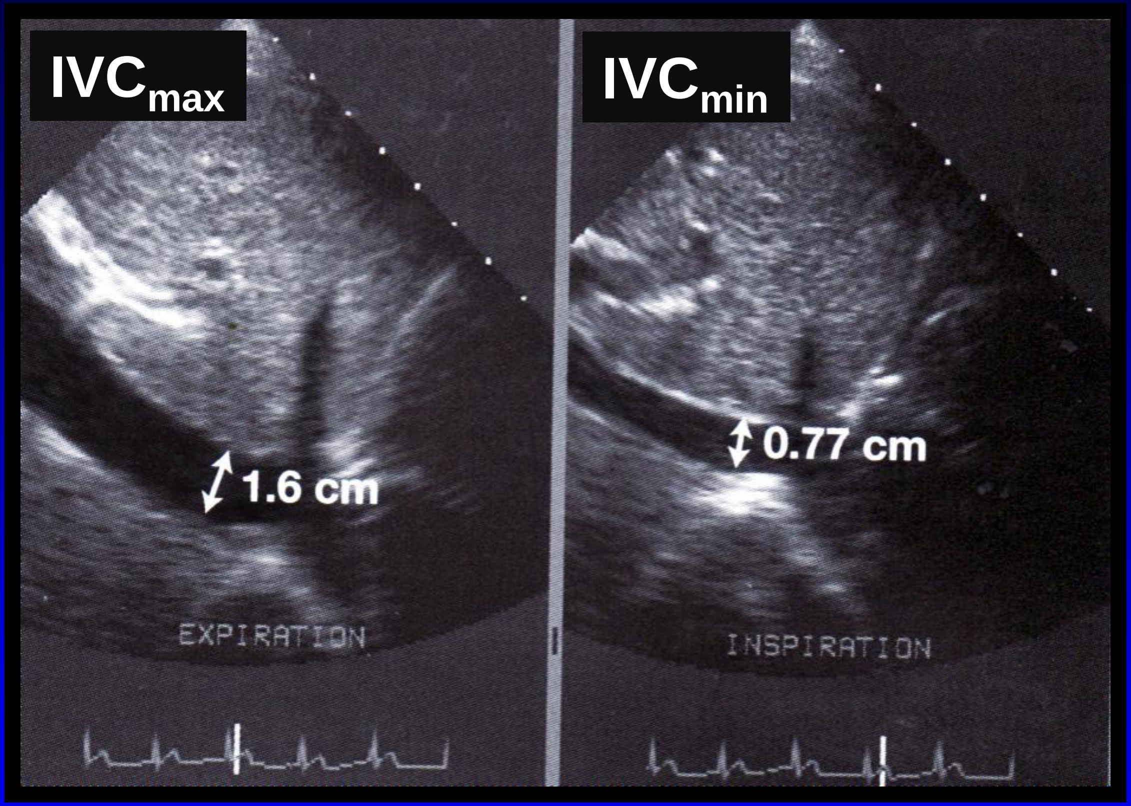
Lang, et al Quantitation Guidelines
J Am Soc Echocardiogr 2015;28(1):1-39

Evaluation of RA Pressure

IVC (cm)	Δ with insp (%)	RA pressure (mm Hg)
<2.1	>50%	0-5 (3)
>2.1	<50%	5-10 (8)
<2.1	>50%	5-10 (8)
>2.1	<50%	10-20 (15)

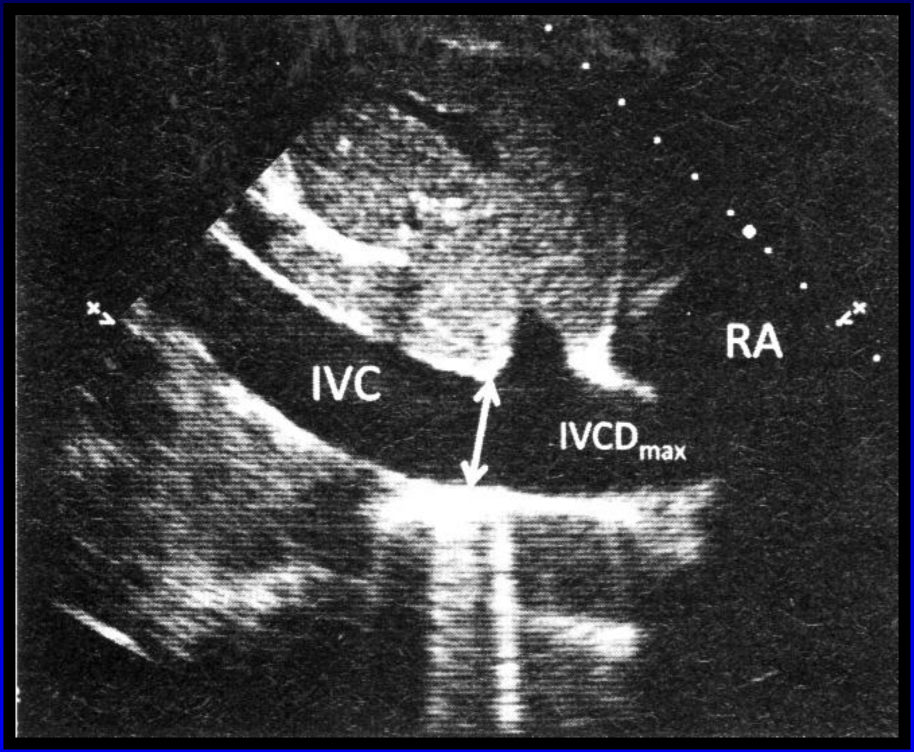
Lang J Am Soc Echocardiogr 2015;28(1):1-39
Cardiac Chamber Quantification Guidelines (ASE/EAC)

IVC from Subcostal Long-AxisView

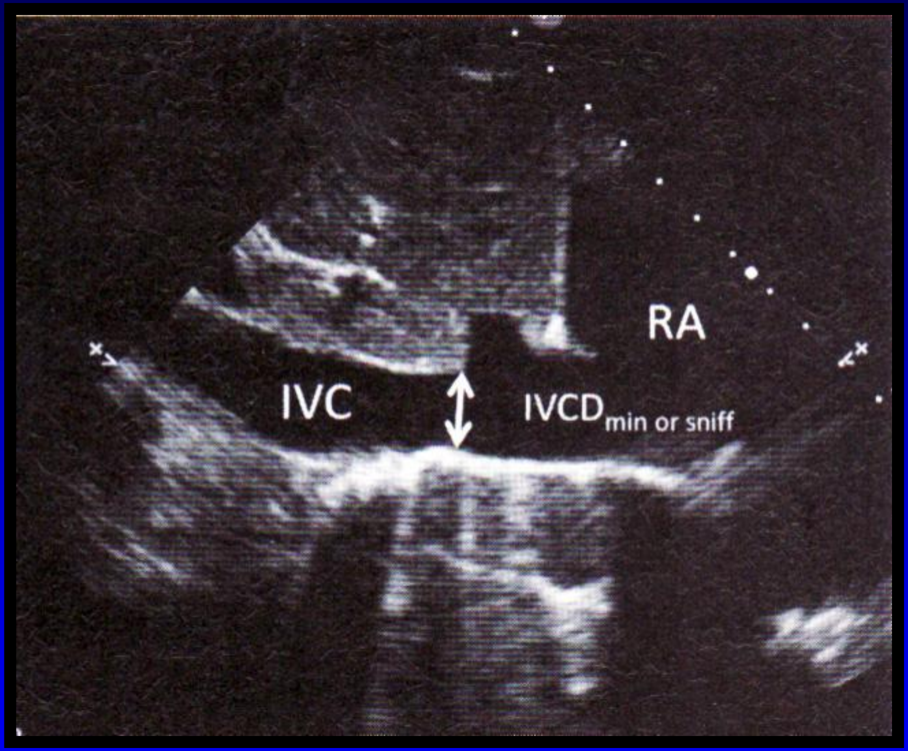


- IVC measured perpendicular to its long-axis
- Inner edge-to-inner edge
- Just proximal to junction of IVC with hepatic vein
- Or 1 – 2 cm proximal to IVC entrance into RA

IVC from Subcostal Long-Axis View



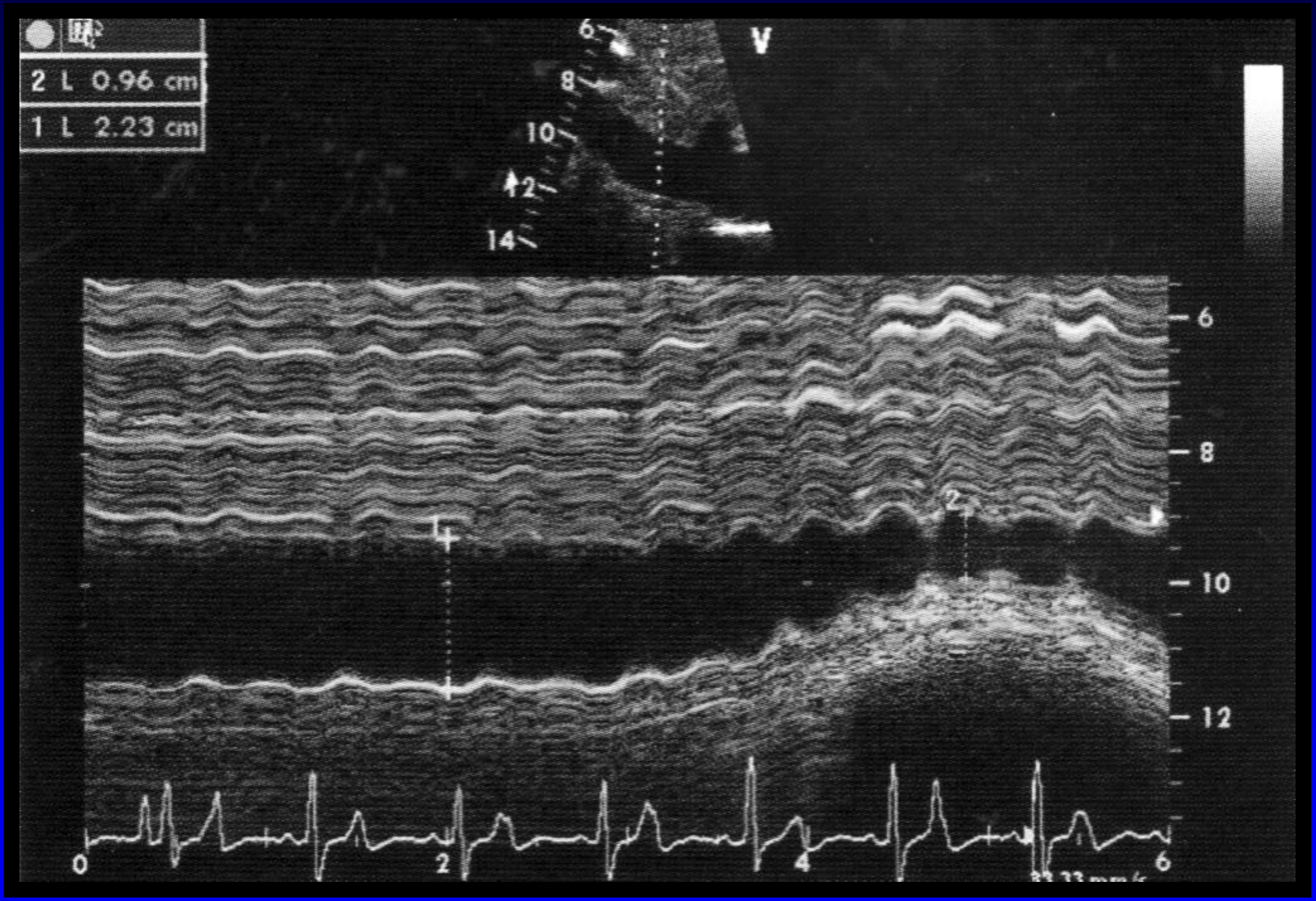
End-expiration



End-inspiration

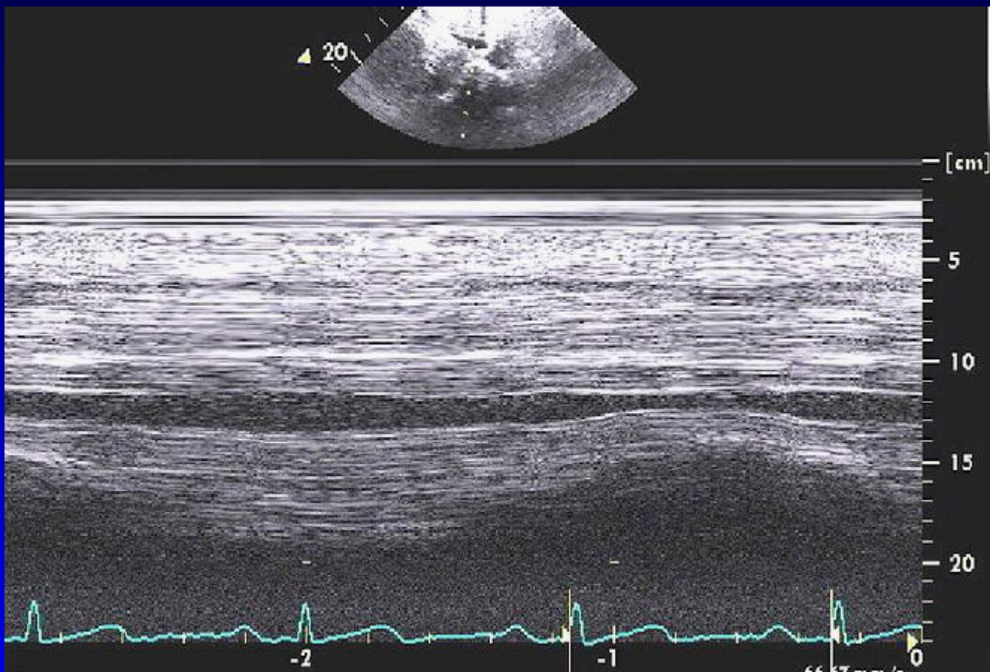
(with or without sniff)

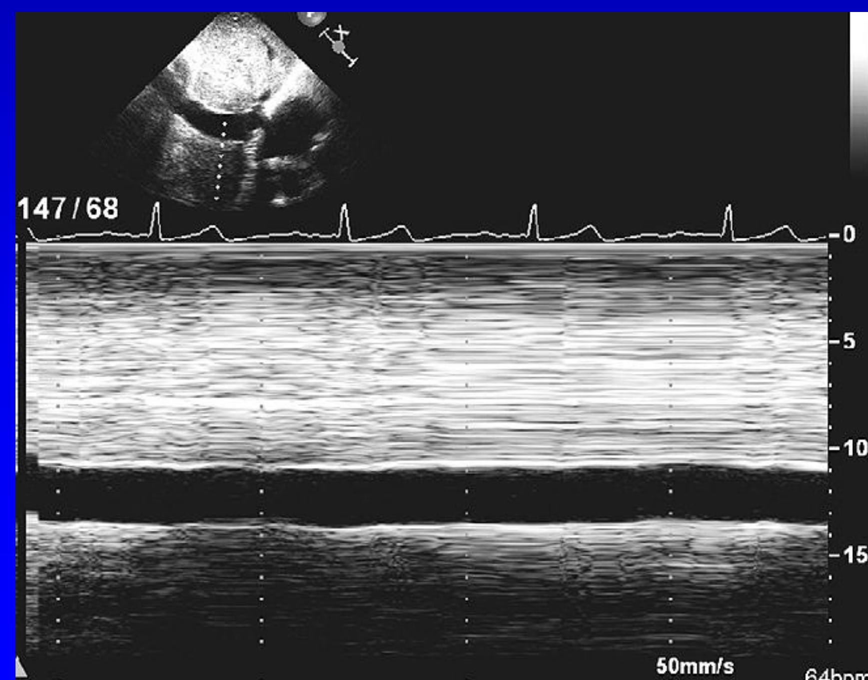
Subcostal View – M-mode

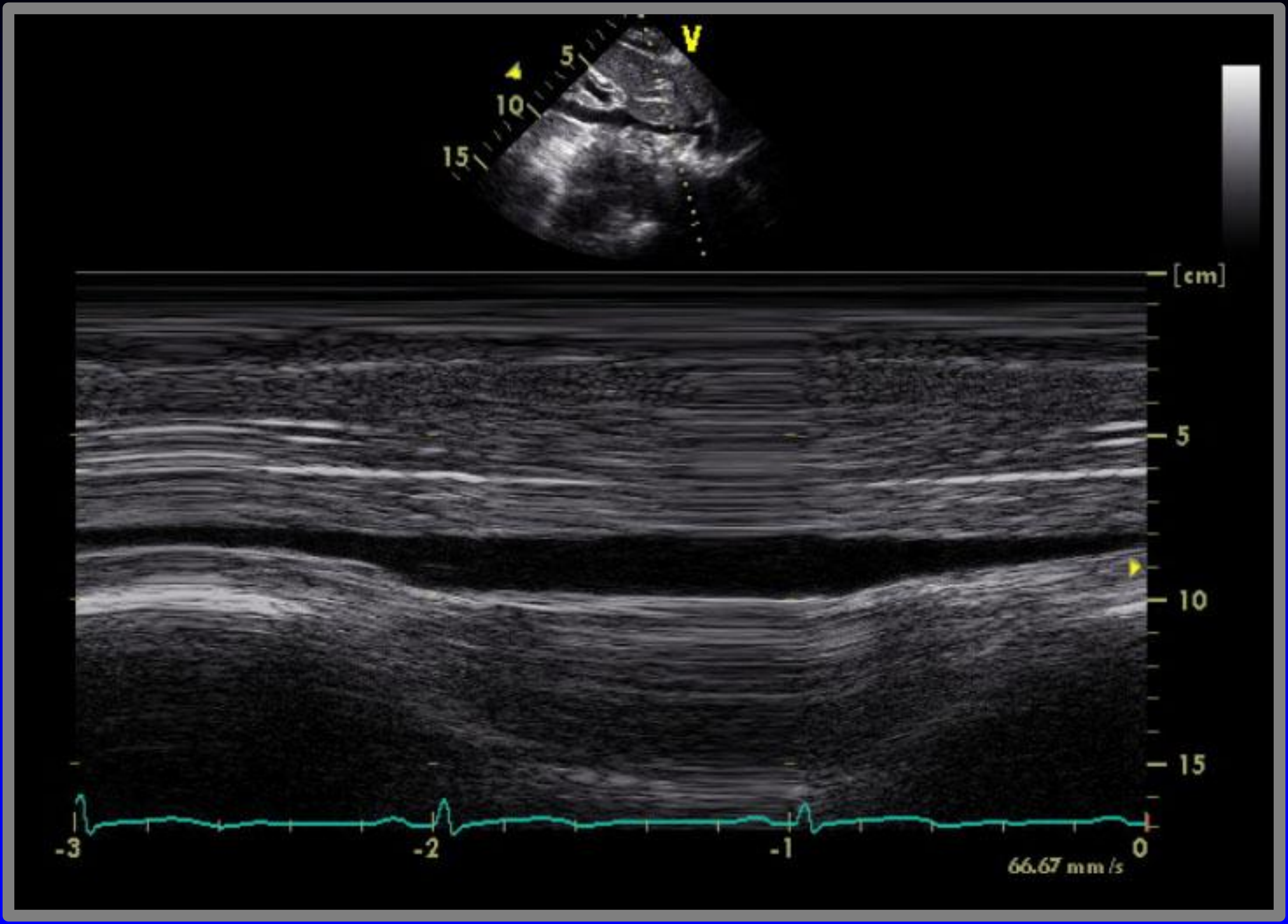


Place cursor perpendicular to IVC
Just proximal to junction b/w IVC and hepatic vein
Use slow sweep speed to include 1 or 2 respirations

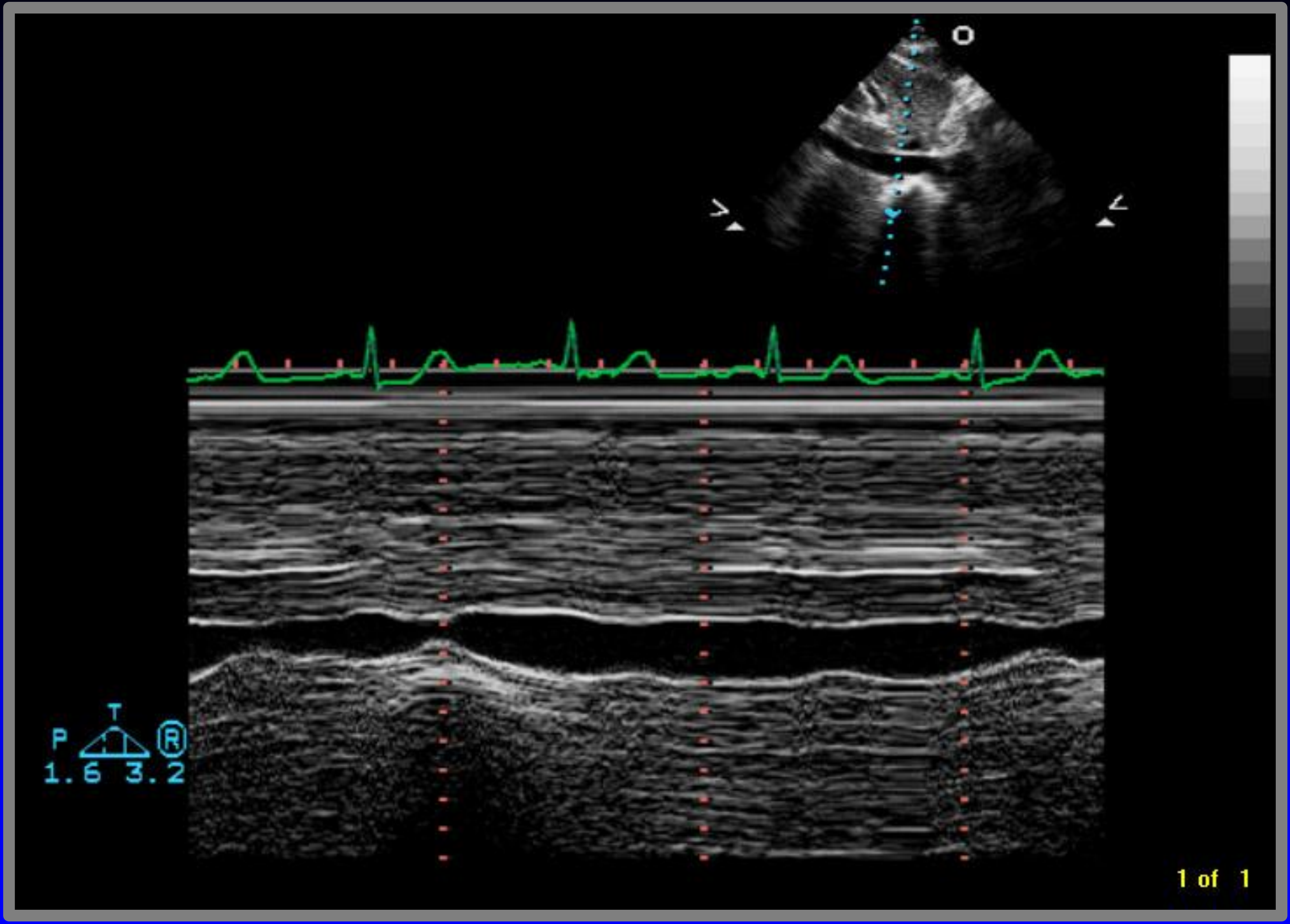
IVC Collapse



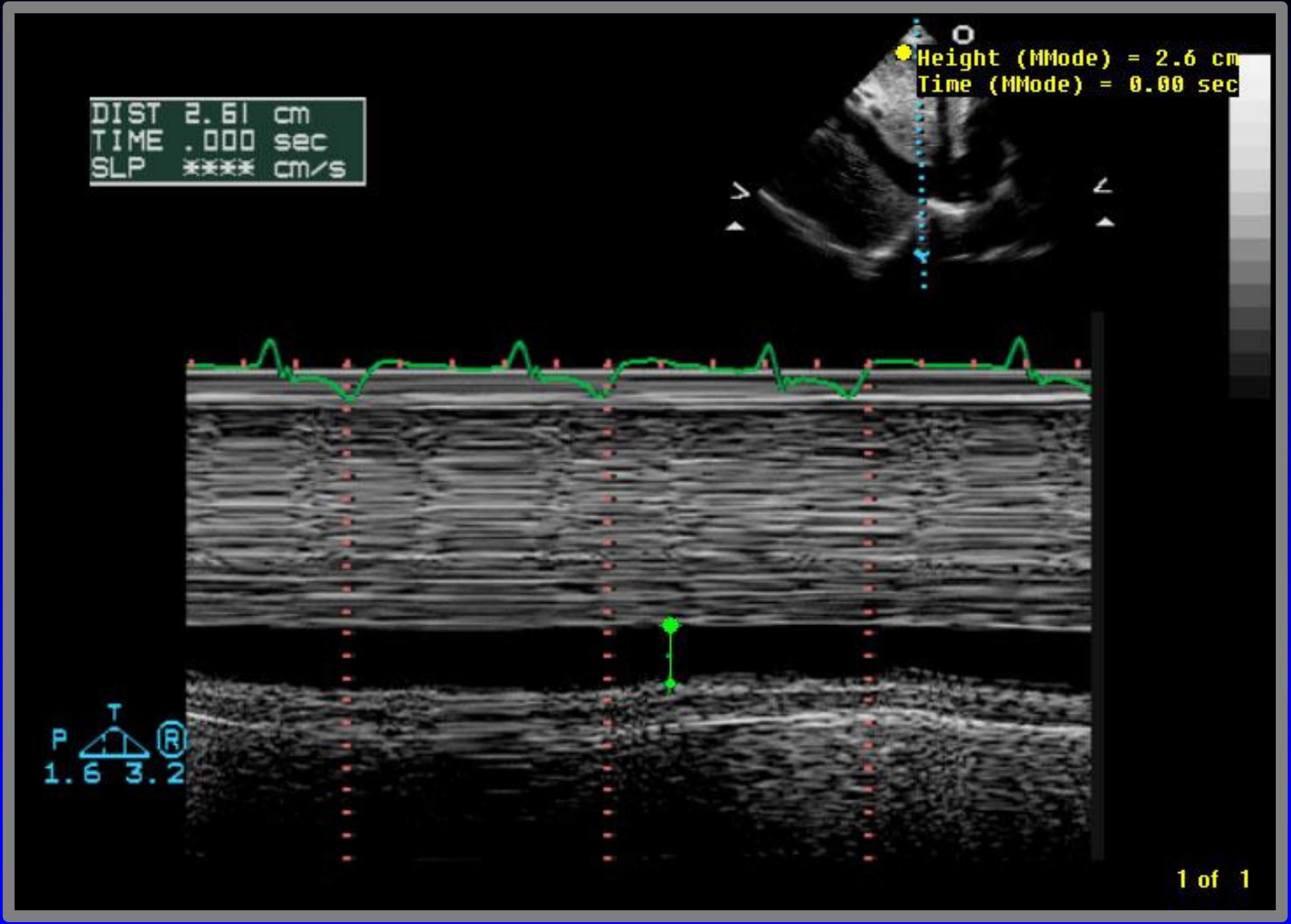




Normal size, normal collapse → RA pressure ≈ 3 mm Hg



Mildly dilated, normal collapse → RA pressure ≈ 8 mm Hg



Dilated, minimal or no collapse → RA pressure ≥ 15 mm Hg

Limitations of "Sniff" Test

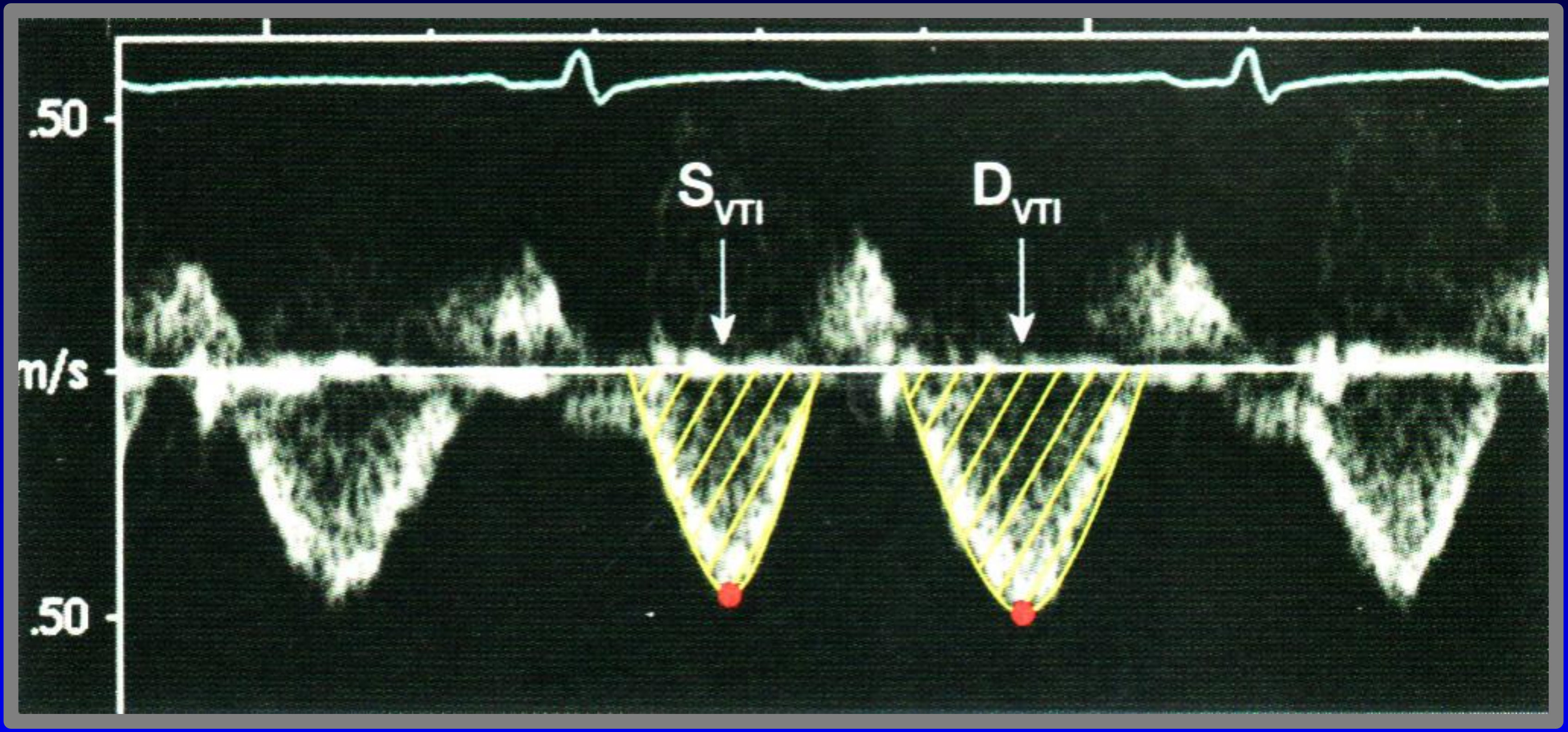
- Requires patient cooperation
- Tachypneic patients
- Mechanical ventilation
- Lack of standardization of insp effort

Decrease sweep speed to include 1 or more resp cycles

Secondary Indices for RA Pressure

- Restrictive filling (TV inflow pattern)
- Tricuspid E/e’ > 6
- Diastolic flow predominance in hepatic veins

PW Doppler from Hepatic Vein



$$SFF = \text{systolic filling fraction (\%)} = \frac{S_{VTI}}{S_{VTI} + D_{VTI}} \times 100$$

S_{VTI} = Systolic velocity time integral (or peak velocity)

D_{VTI} = Diastolic velocity time integral (or peak velocity)

Impact of Body Size on Inferior Vena Cava Parameters for Estimating Right Atrial Pressure: A Need for Standardization?

Tatsunori Taniguchi, MD, Tomohito Ohtani, MD, PhD, Satoshi Nakatani, MD, PhD, Kenichi Hayashi, PhD, Osamu Yamaguchi, MD, PhD, Issei Komuro, MD, PhD, and Yasushi Sakata, MD, PhD, *Suita and Tokyo, Japan*

Background: Inferior vena cava (IVC) diameter and its respiratory change, as determined using echocardiography, are commonly used to assess right atrial pressure (RAP). Despite the widespread use of the IVC approach for RAP assessment, the relations among body surface area (BSA), IVC diameter, and respirophasic change remain unclear. The aim of this study was to investigate the impact of BSA on IVC parameters for predicting elevated RAP.

Methods: Ninety consecutive patients undergoing right-heart catheterization or central venous catheter insertion were prospectively included. To investigate the impact of BSA on IVC parameters, patients were divided into higher and lower BSA groups by comparing individual BSA measurements with the median value. Optimal cutoff points of IVC parameters for detecting RAP of ≥10 mm Hg were defined using receiver operating characteristic curves.

Results: The median RAP and BSA were 8 mm Hg (range, 1–25 mm Hg) and 1.61 m^2 (range, 1.23–2.22 m^2), respectively. In all patients, the optimal cutoff point for maximal IVC diameter ($IVCD_{max}$) and IVC collapsibility for the detection of RAP ≥ 10 mm Hg were 20 mm and 49.0%, respectively. The optimal cutoff point of $IVCD_{max}$ for predicting RAP of ≥10 mm Hg was significantly larger in patients with higher BSAs than in those with lower BSAs (21 vs 17 mm, $P = .0342$). No differences in collapsibility indices were detected between the two groups. $IVCD_{max}$ was larger in men (19 ± 5 vs 17 ± 5 mm in women, $P = .0347$) and weakly correlated with BSA ($r = 0.35$, $P = .0007$), whereas no relation was found between $IVCD_{max}$ and age. However, the partial correlation coefficient of the entire cohort demonstrated that only BSA was still associated with $IVCD_{max}$ after adjusting for age and gender (partial correlation coefficient = 0.32, $P = .0020$).

Conclusions: Body size, measured as BSA, is important to consider when IVC diameter is used to assess RAP. The optimal cutoff point of $IVCD_{max}$ was 21 mm for patients with larger BSAs and 17 mm for those with smaller BSAs. However, the cutoff point of IVC collapsibility was not influenced by the difference of BSA. (J Am Soc Echocardiogr 2015;28:1420-7.)

J Am Soc Echocardiogr 2015;28:1420-7

Impact of Body Size on IVC Parameters

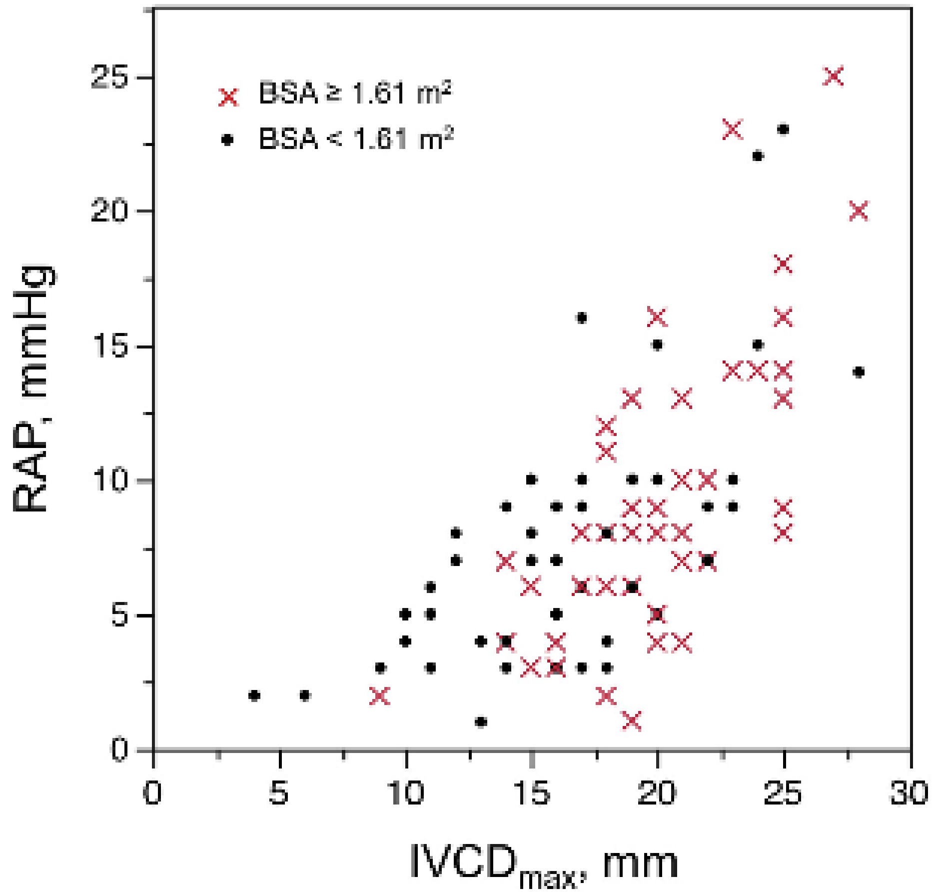


Figure 3 Scatterplot of the relation between IVCD$_{max}$ and RAP, differentiating patients with BSAs of ≥1.61 m^2 (*red crosses*) and those with BSAs of <1.61 m^2 (*black circles*).

J Am Soc Echocardiogr 2015;28:1420-7

Limitations of "Sniff" Test

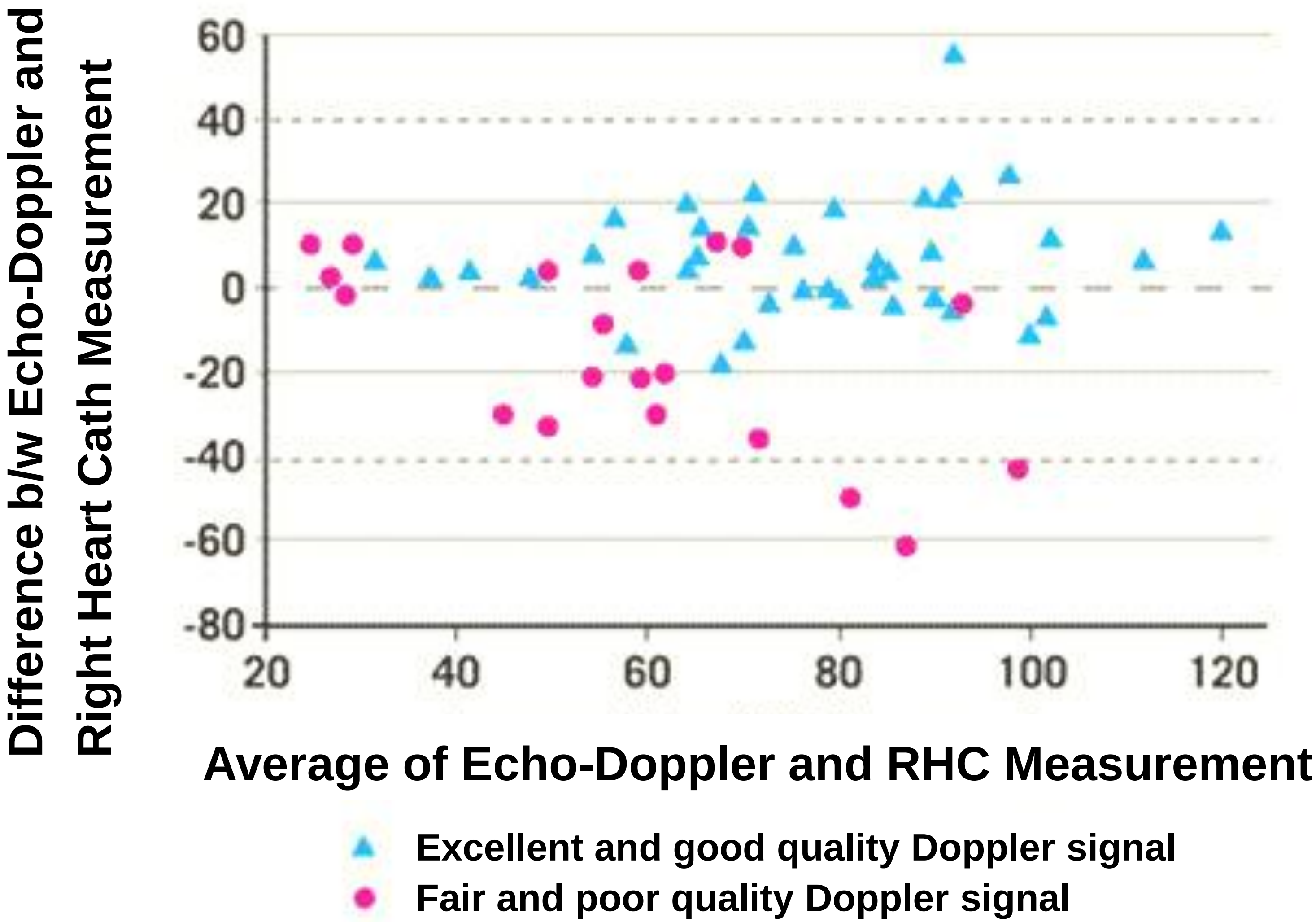
- Requires patient cooperation
- Tachypneic patients
- Mechanical ventilation
- Lack of standardization of insp effort

Decrease sweep speed to include 1 or more resp cycles

Estimation of PA Pressure
Limitations of TR Jet Method

- Absence of detectable TR (10%)
- Nonparallel intercept angle of TR jet
- Misidentification of jet signal (AS, MR)
- RA pressure estimate in ventilated patients
- Presence of pulmonic stenosis
- Inadequate signal in COPD patients
- Wide-open TR ("free TR")

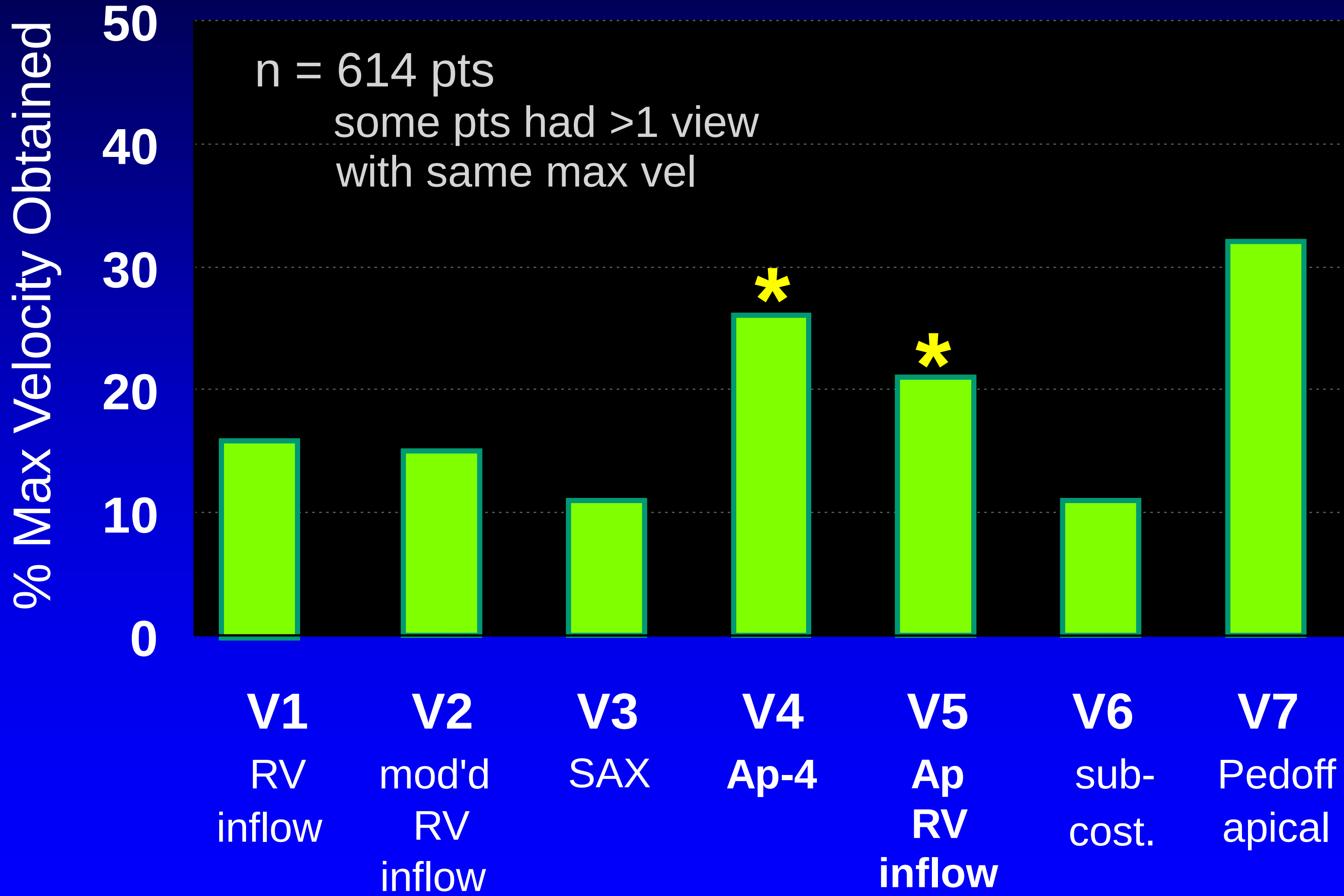
Pulmonary Artery Systolic Pressure



Mathai *Advances in Pulm Hypertension* 2008;7:1-7

Case

Doppler Assessment of PA Systolic Pressure
Importance of Using Multiple Views



Abramson J Am Soc Echocard 8:55(1995)

Case

Adequate Spectral Doppler Signals

	Feasibility Without Contrast	Feasibility With Contrast
TR jet	**94%**	**98%**
PR jet	**80%**	**85%**

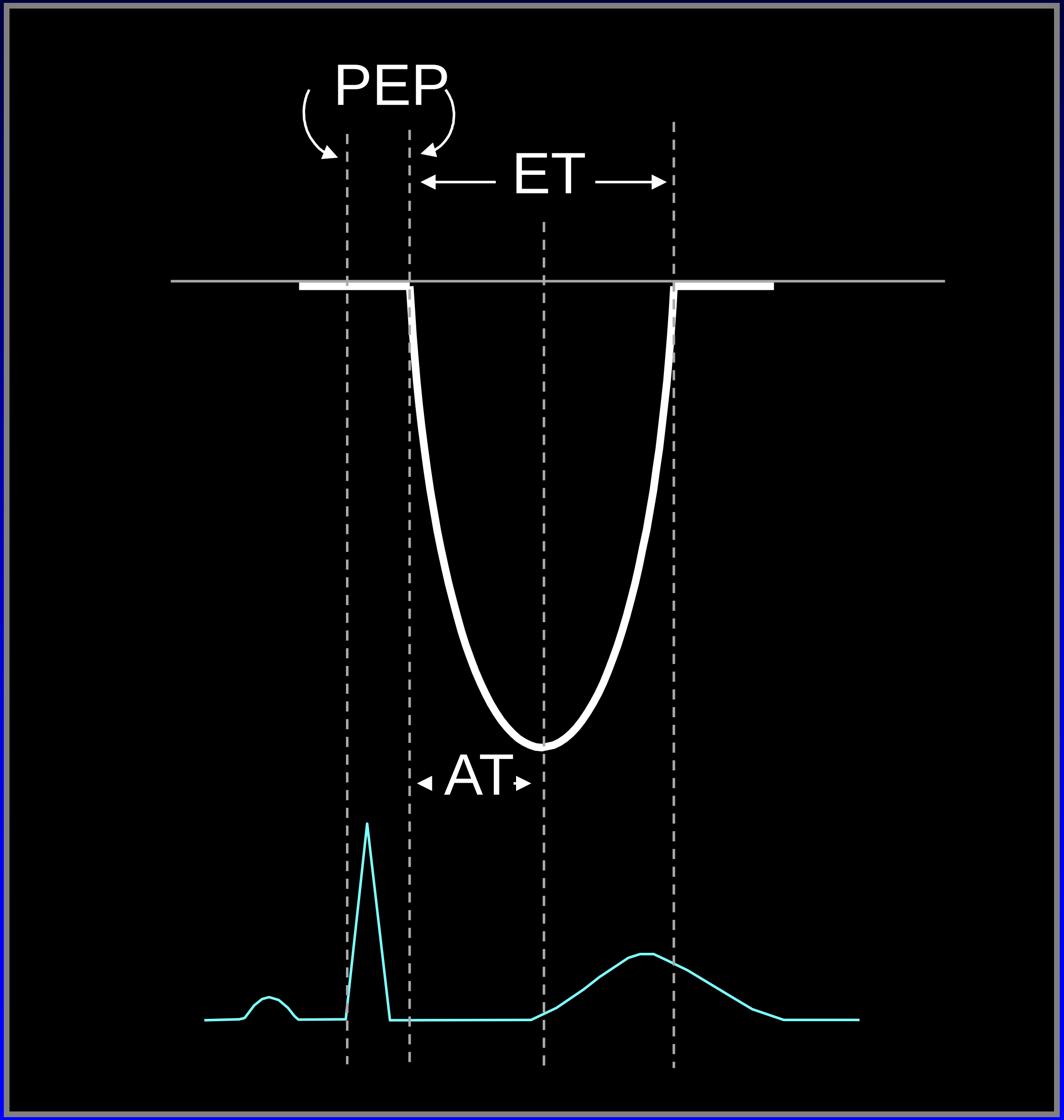
Tramarin *Eur Heart J* 1991;12:102-112

PA Systolic Pressure
TR Jet Method

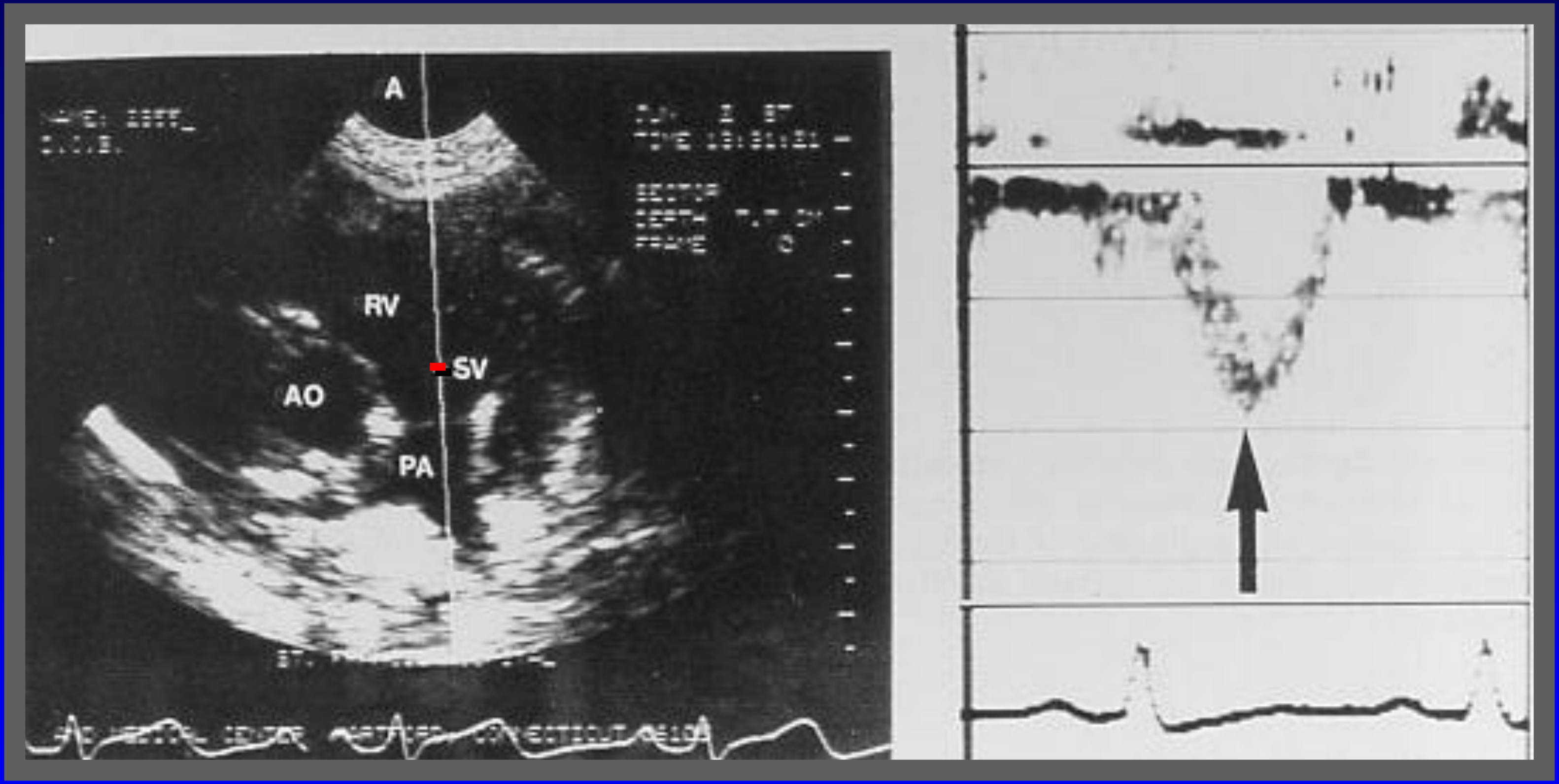
- Feasibility high – TR present in >85% normals
- Incidence higher in pulmonary hypertension
- If TR jet trivial or absent, can enhance TR velocity signal with agitated saline or echo-contrast agents (eg Definity, Optison)
- Or use alternative methods . . .

PAcT

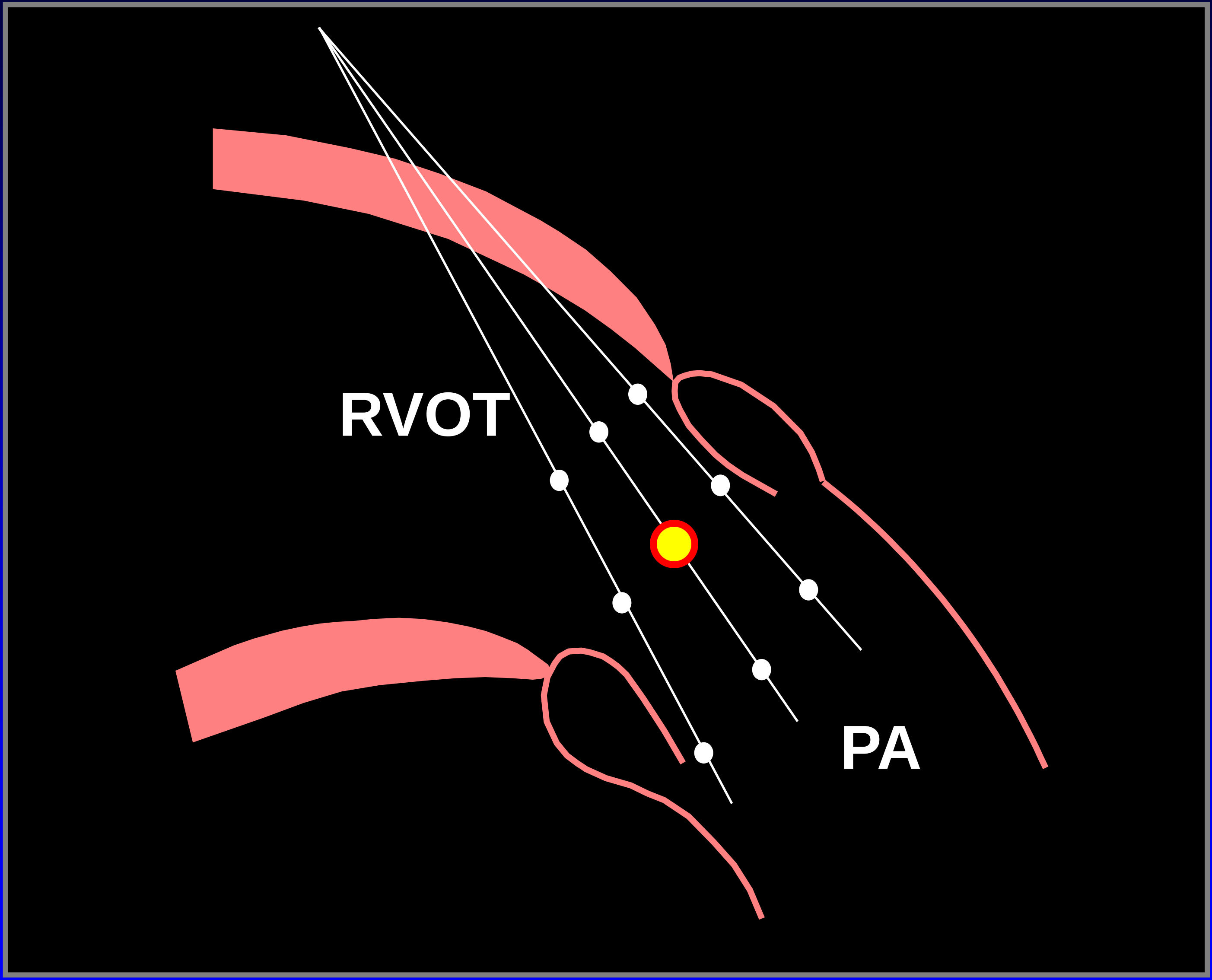
Pulmonary Systolic Flow Velocity Pattern



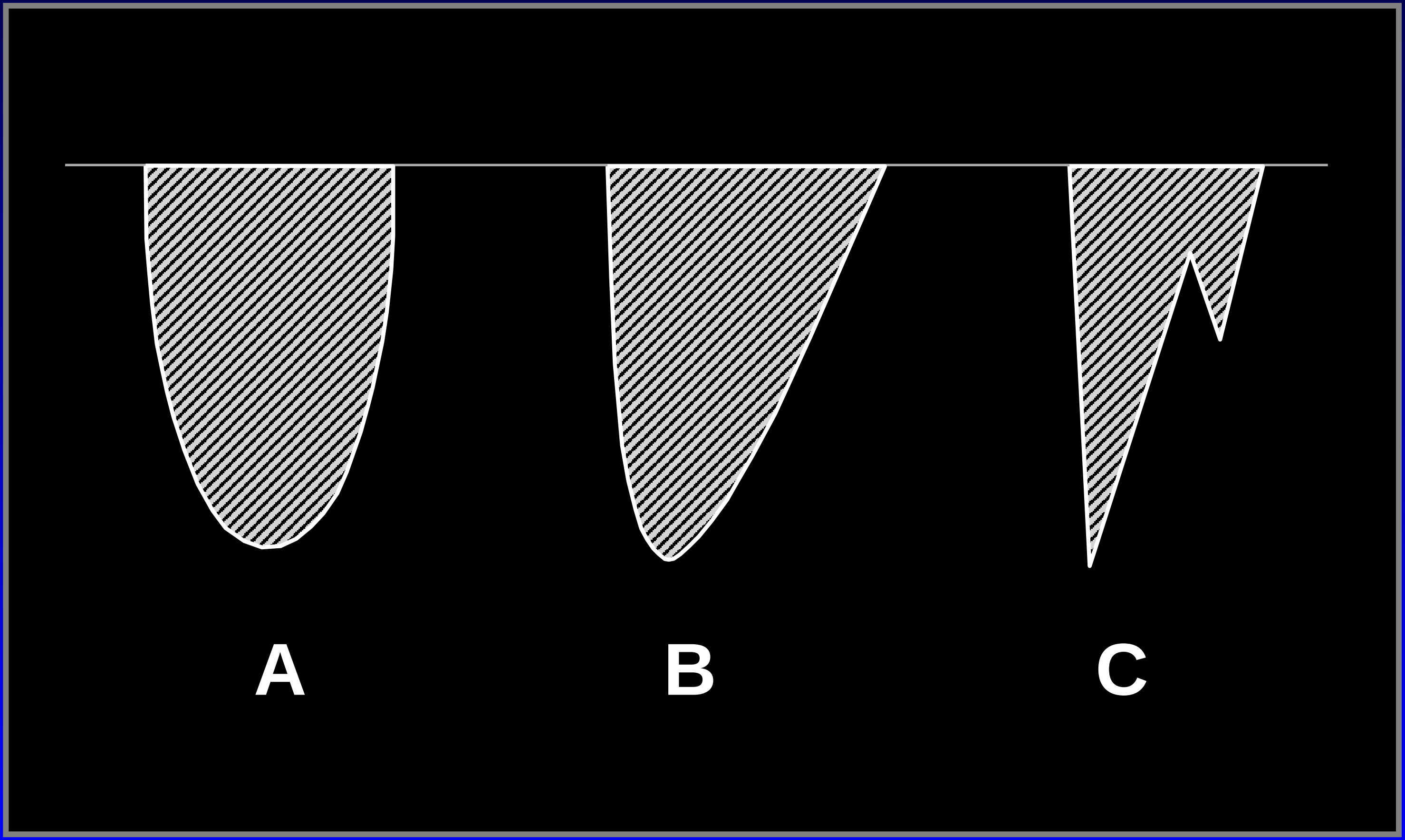
Position of Sample Volume in Short-Axis View For Obtaining Pulmonary Flow-Velocity Profile



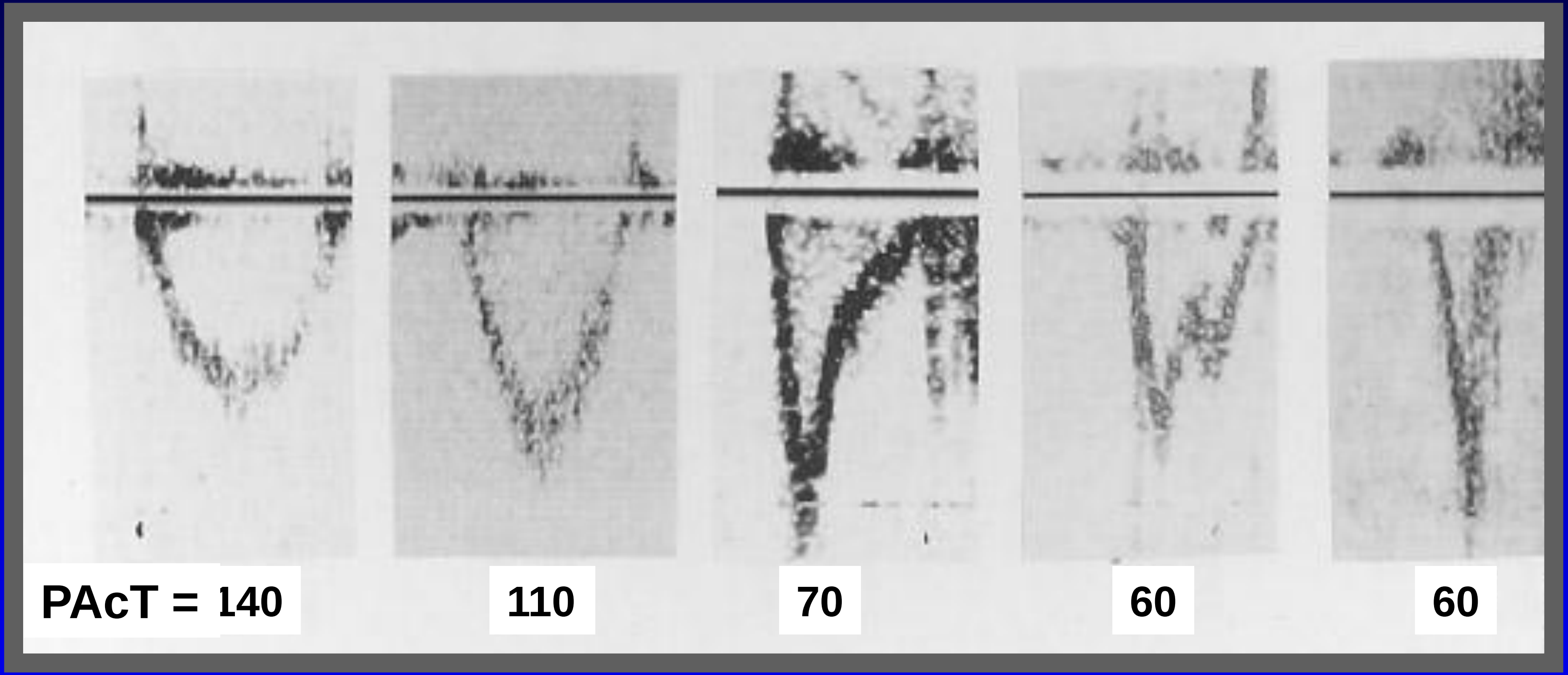
Sampling Sites in RVOT and PA



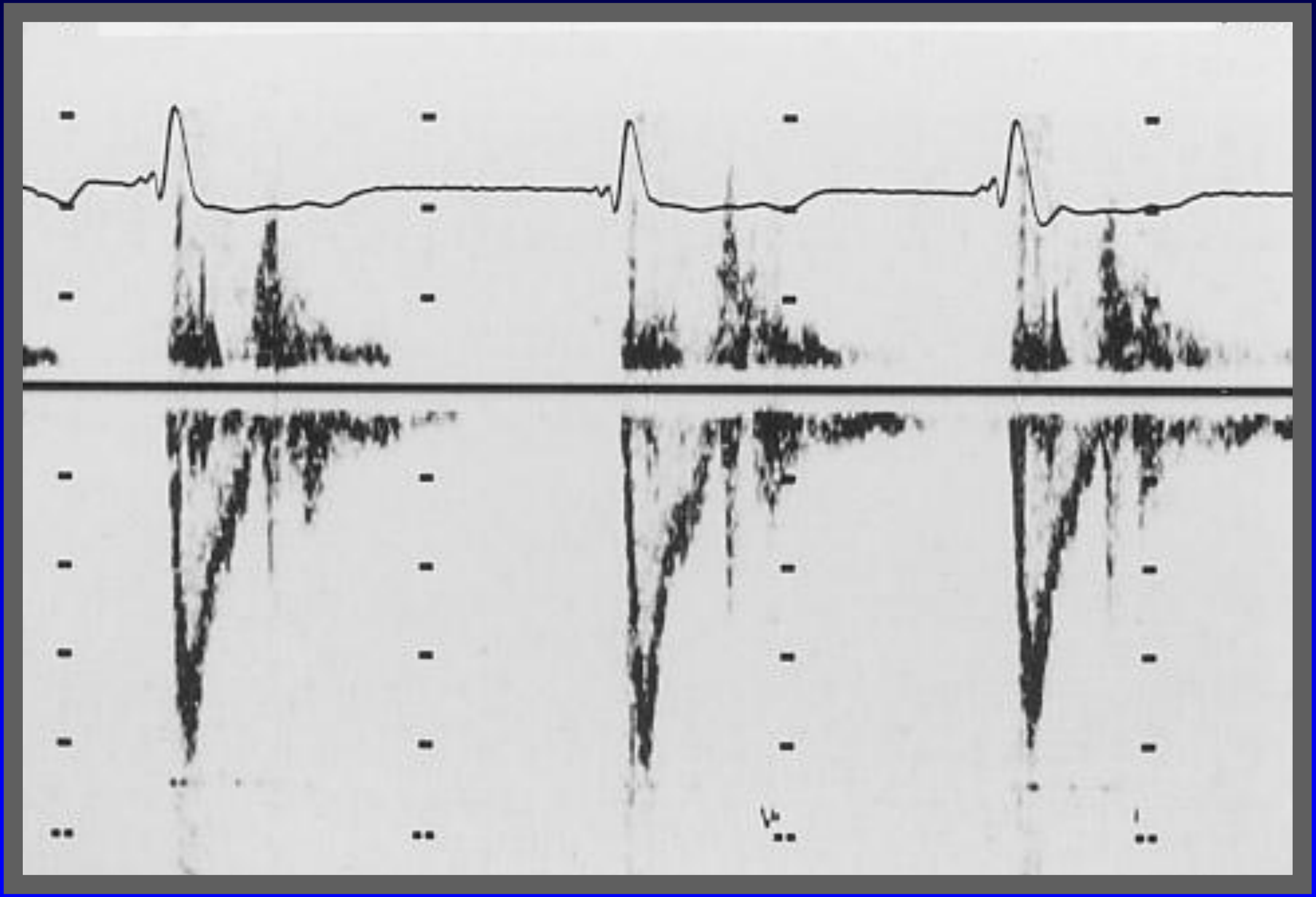
Pulmonary Flow-Velocity Patterns



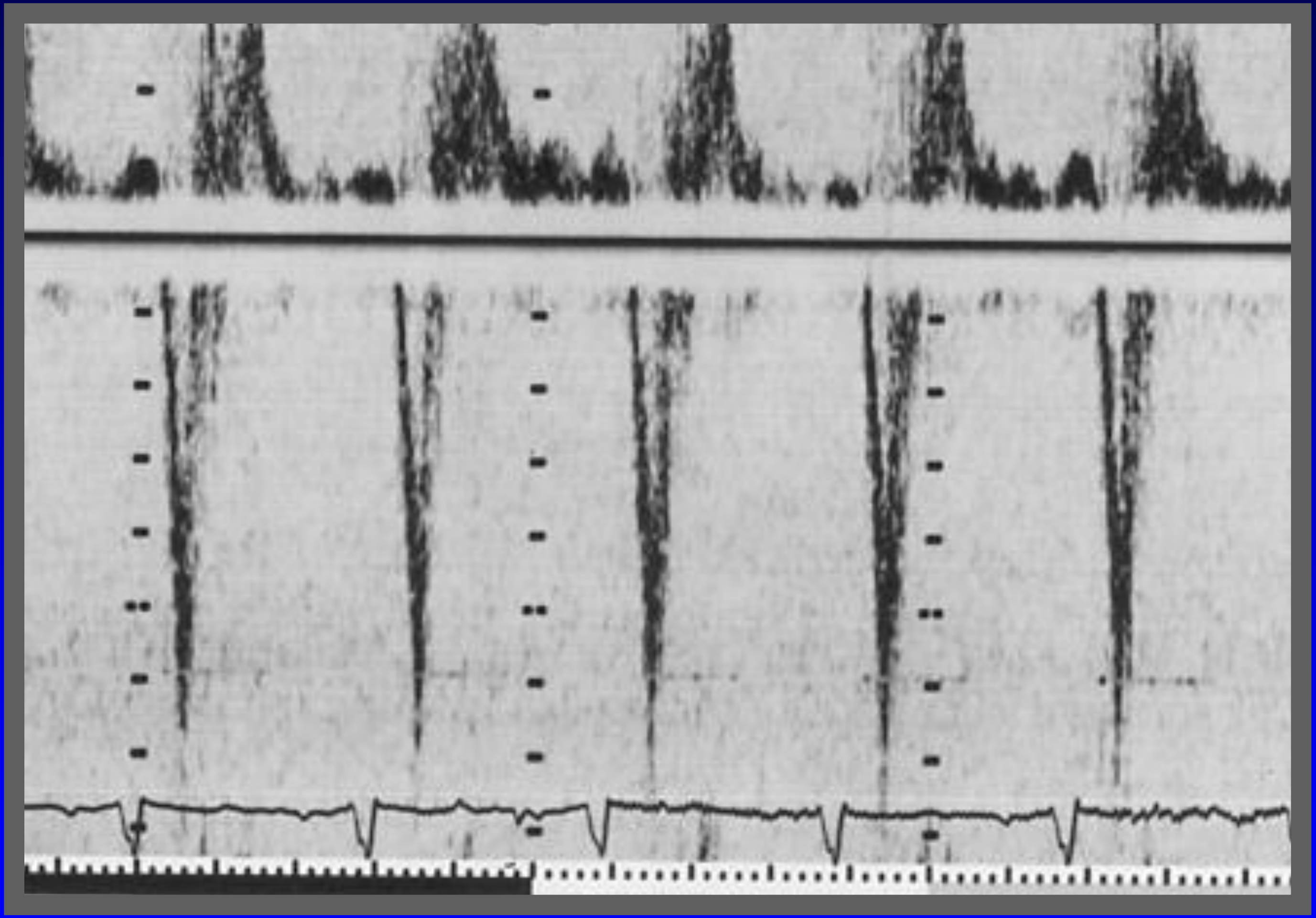
Pulmonary Flow Velocity Profiles



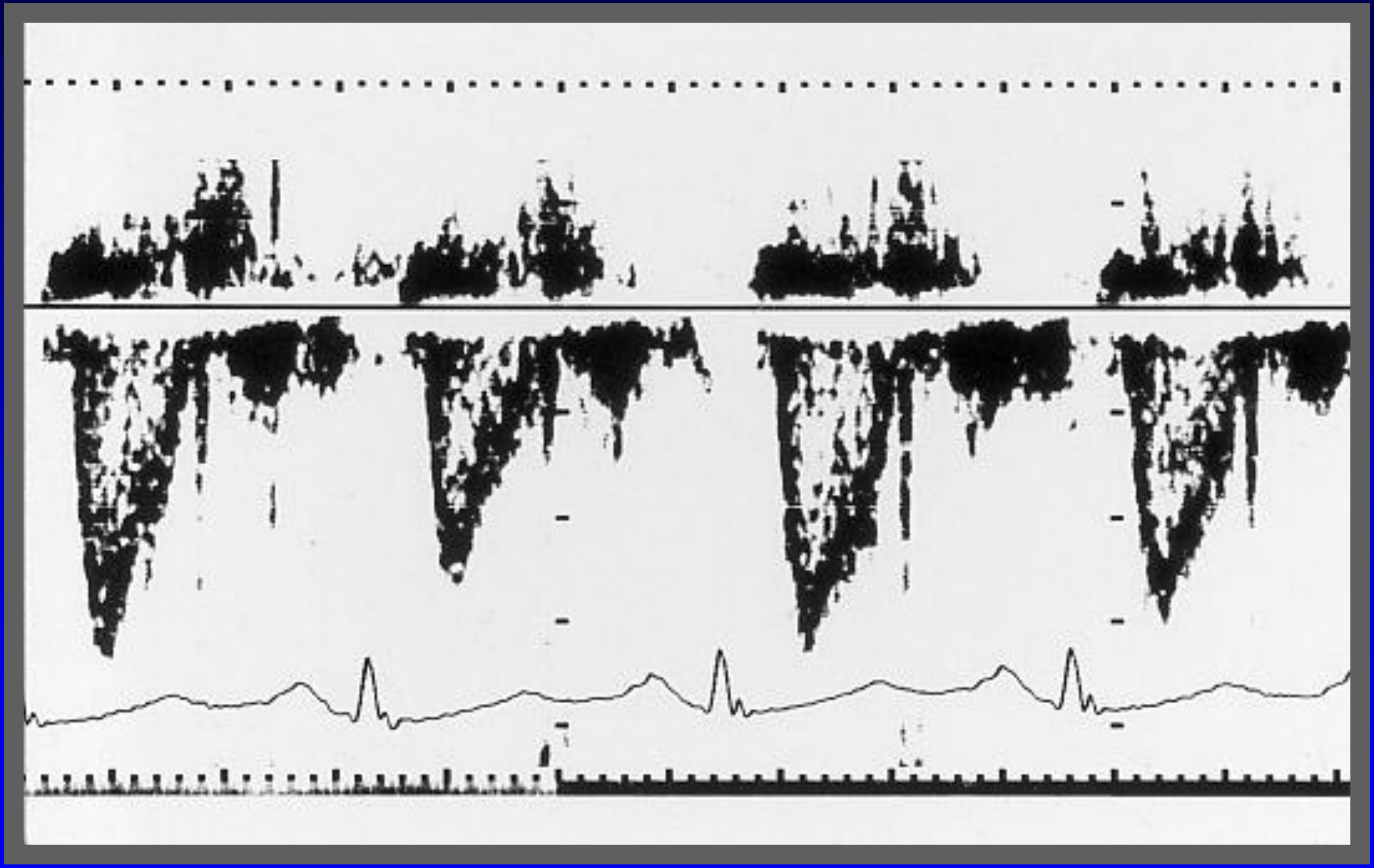
Pulmonary Flow Velocity Profile



Pulmonary Flow Velocity Profile



Pulmonary Flow Velocity Profile



Pulmonary Acceleration Time

Normal	**120 - 140** ms
Borderline	**100** ms
Usually PHTN	**< 80** ms
Severe PHTN	**< 60** ms

PA Pressure Using PAcT Regression Equations

$$PA_{mean} = 79 - (0.45)(PAcT)$$

$$PA_{mean} = 80 - 1/2(PAcT)$$

$$PA_{mean} = 90 - 0.62(PAcT)$$

$$PCW = 57 - 0.39(PAcT)$$

Mean Pulmonary Artery Pressure

$$PA_{mean} = \frac{PA_s + 2 \times PA_d}{3}$$

$$PA_{mean} = 79 - 0.45 \times PAcT$$

Normal cutoff value for invasively measured mean PA pressure = 25 mm Hg

Estimation of PA Mean Pressure

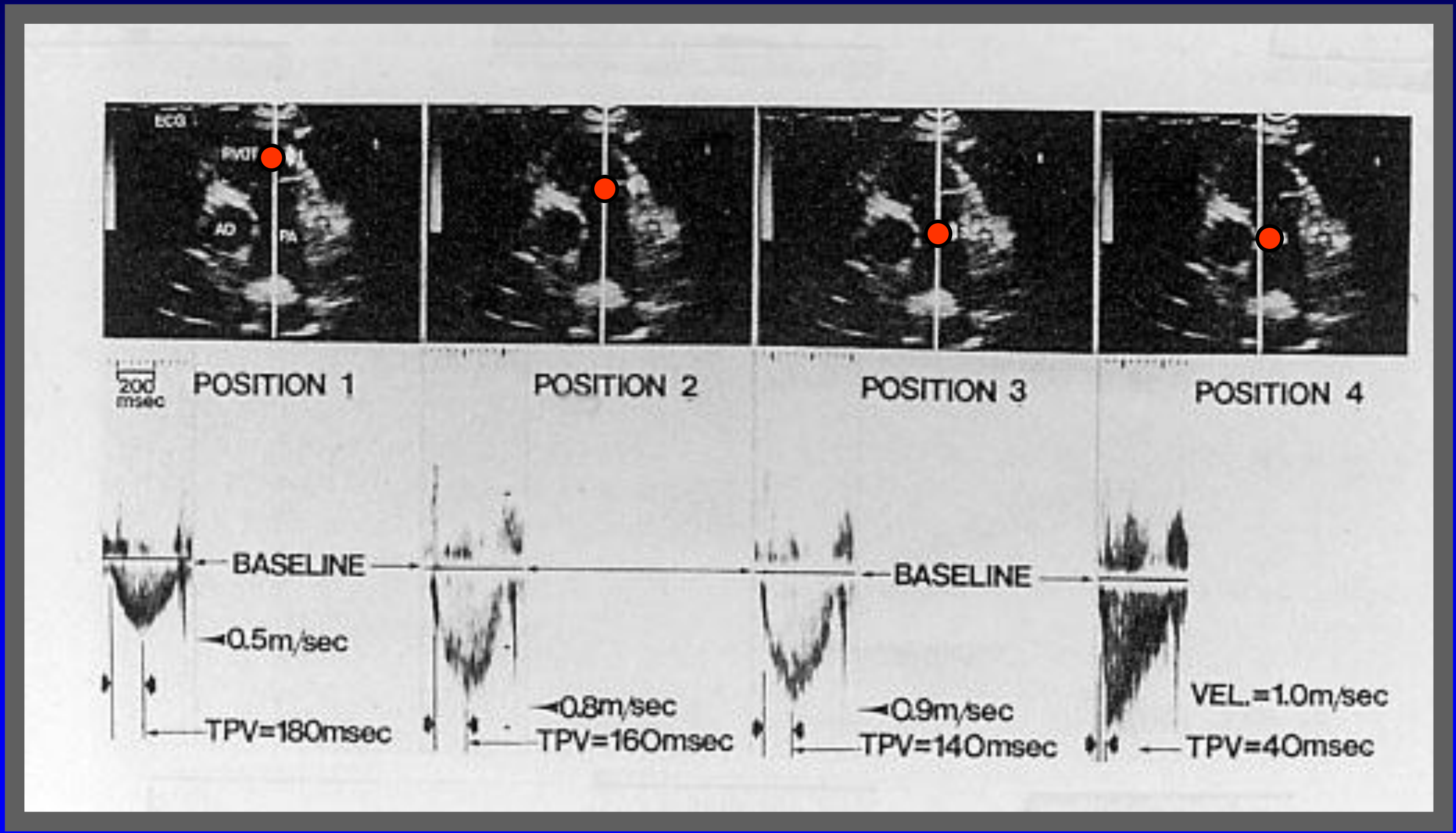
$$PA_{mean} = 0.6 \times PA_{SP} + 2 \text{ mm Hg}$$

Chemla Chest 2004;126:1313-17

Pulmonary Acceleration Time
Limitations/Pitfalls

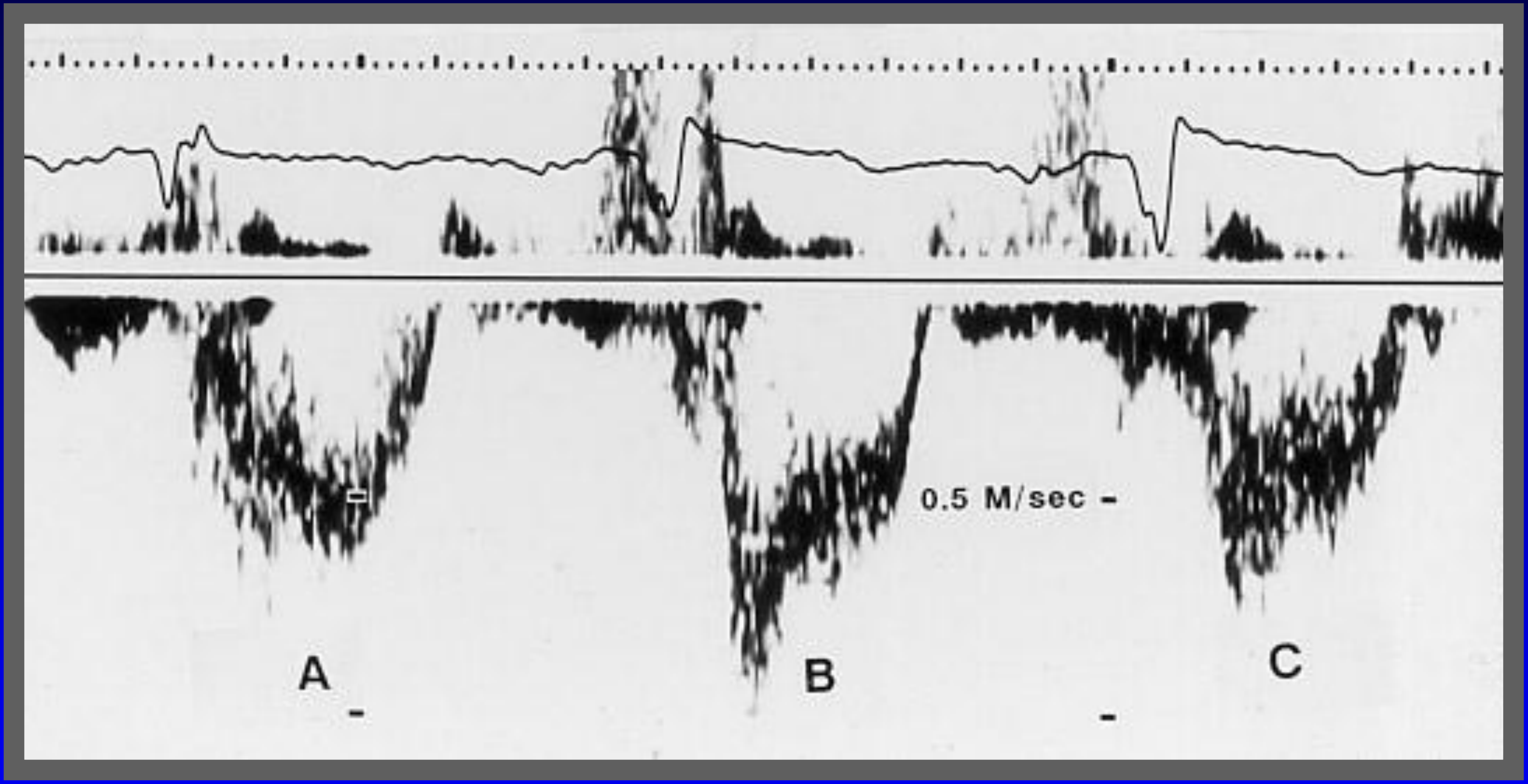
- Waveform varies in different parts of PA
- Peak not always clearcut
- Poor RV function may decrease PAcT
- Inversely related to heart rate

Time to Peak Velocity (TPV)
in
4 Sites in Pulmonary Artery



Panidis Am J Cardiol 58:1145(1986)

Pulmonary Artery Flow Velocity Profile

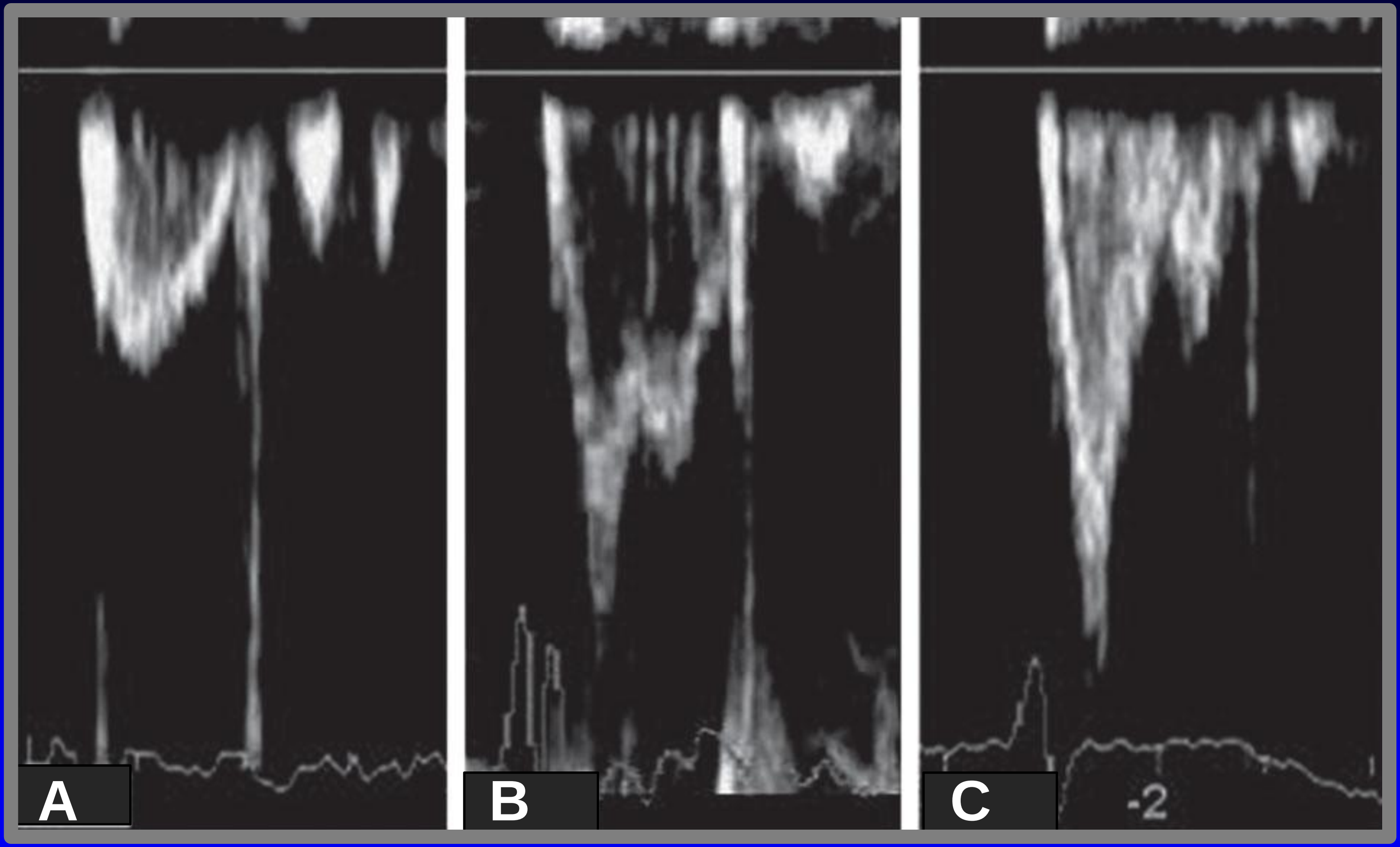


Pulmonary Artery Acceleration Time Correction for Heart Rate

$$PAcT_c = PAcT \times 75/HR$$

Simple visual assessment of the RV outflow tract Doppler pattern provides powerful insight into the hemodynamic basis of PHTN !

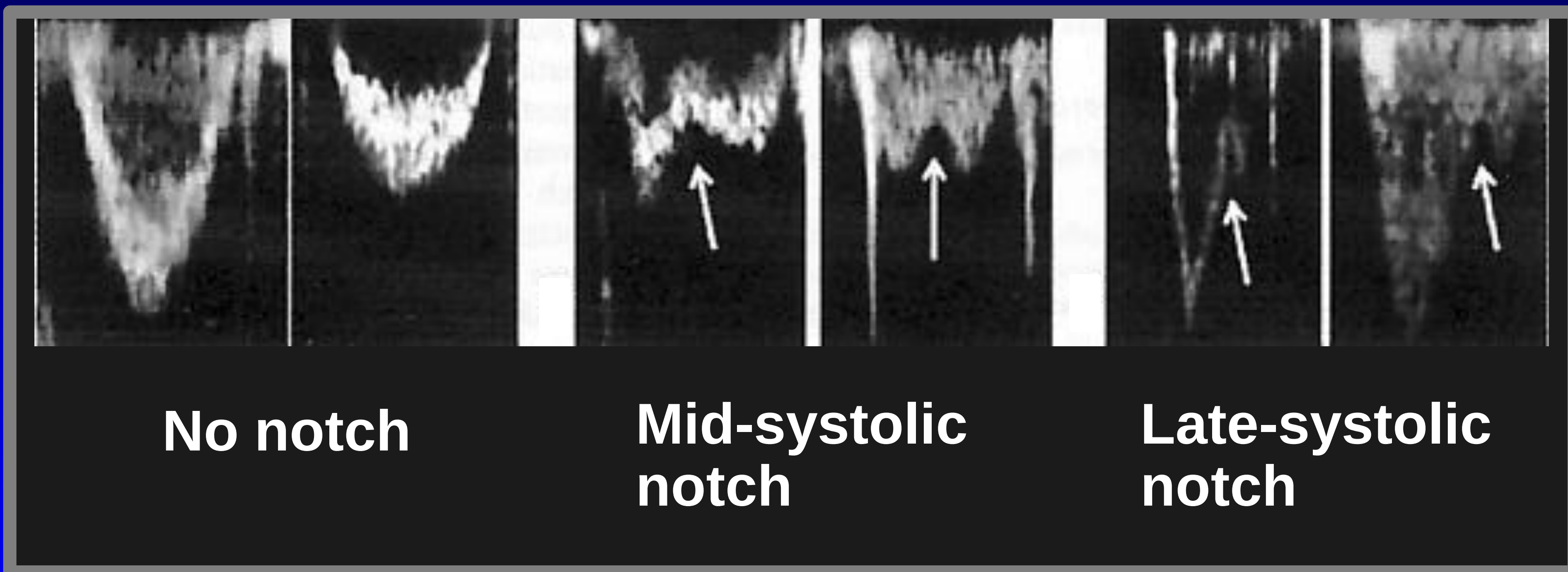
3 Patterns of Pulmonary Flow-Velocity Curves



A. Dome-like, max velocity in mid-systole, no notching
B. Distinct notch in mid portion
C. Triangular contour, sharp peak in early systole, late systolic notch

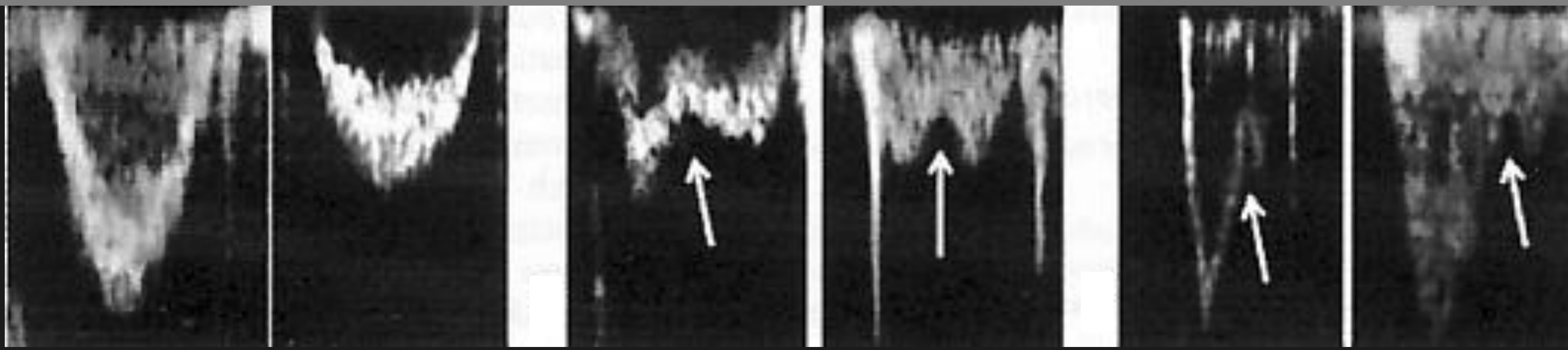
RV Outflow Tract Flow Velocity

3 Distinct Patterns



Courtesy of Forfia - Hospital of the University of Pennsylvania

RV Outflow Tract Flow Velocity
3 Distinct Patterns



No notch | **Mid-systolic notch** | **Late-systolic notch**

- L-heart congestion
- PH largely 2º ↑PCW
- Absence of significant pulm vasc disease

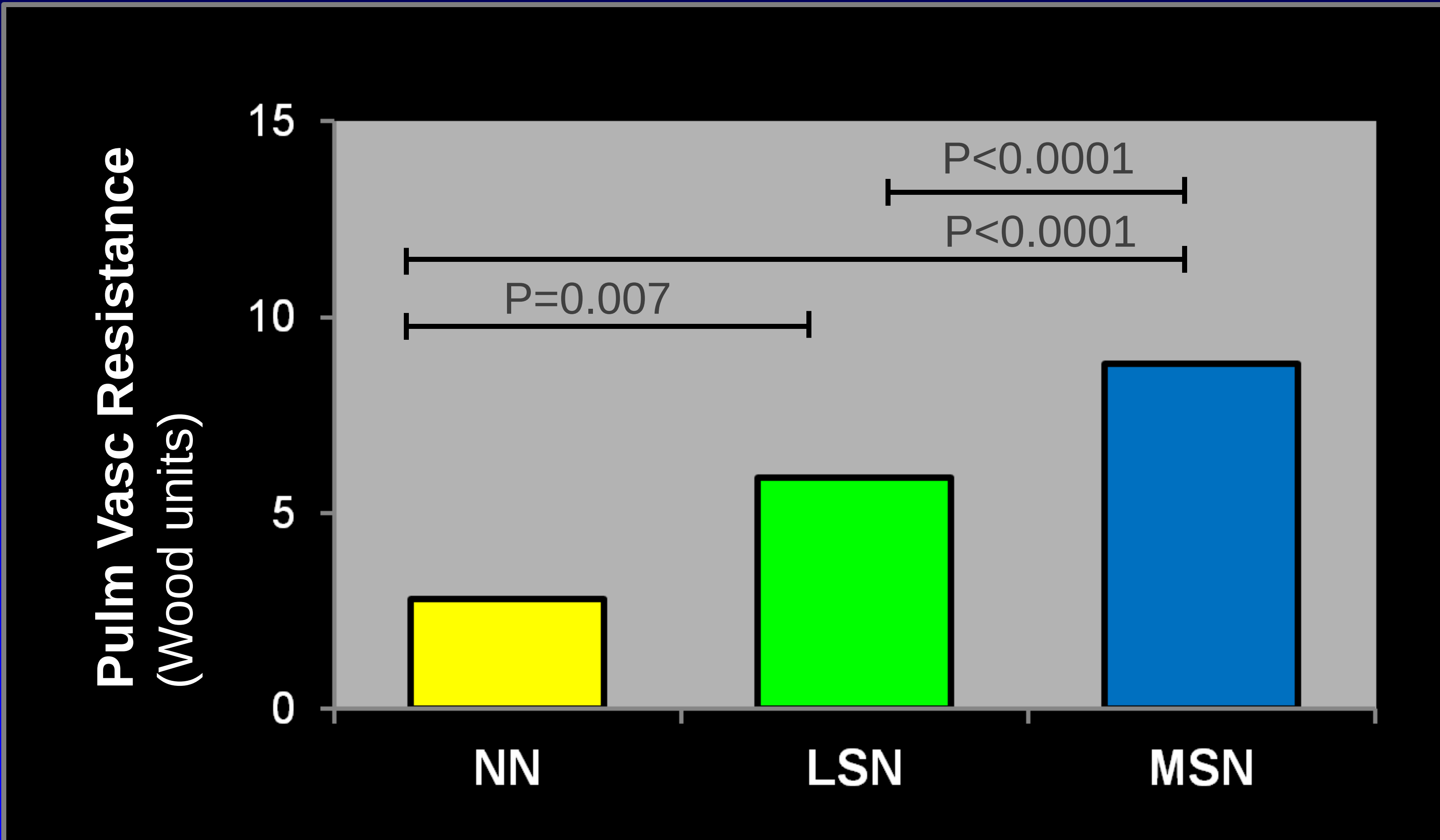
- Markedly elevated PVR
- Low PA compliance
- RV dysfunction

- Intermediate PVR
- Mod pulm vasc disease
- Mod L-heart congestion

Courtesy of Forfia - Hospital of the University of Pennsylvania

Pulmonary Hypertension Cohort

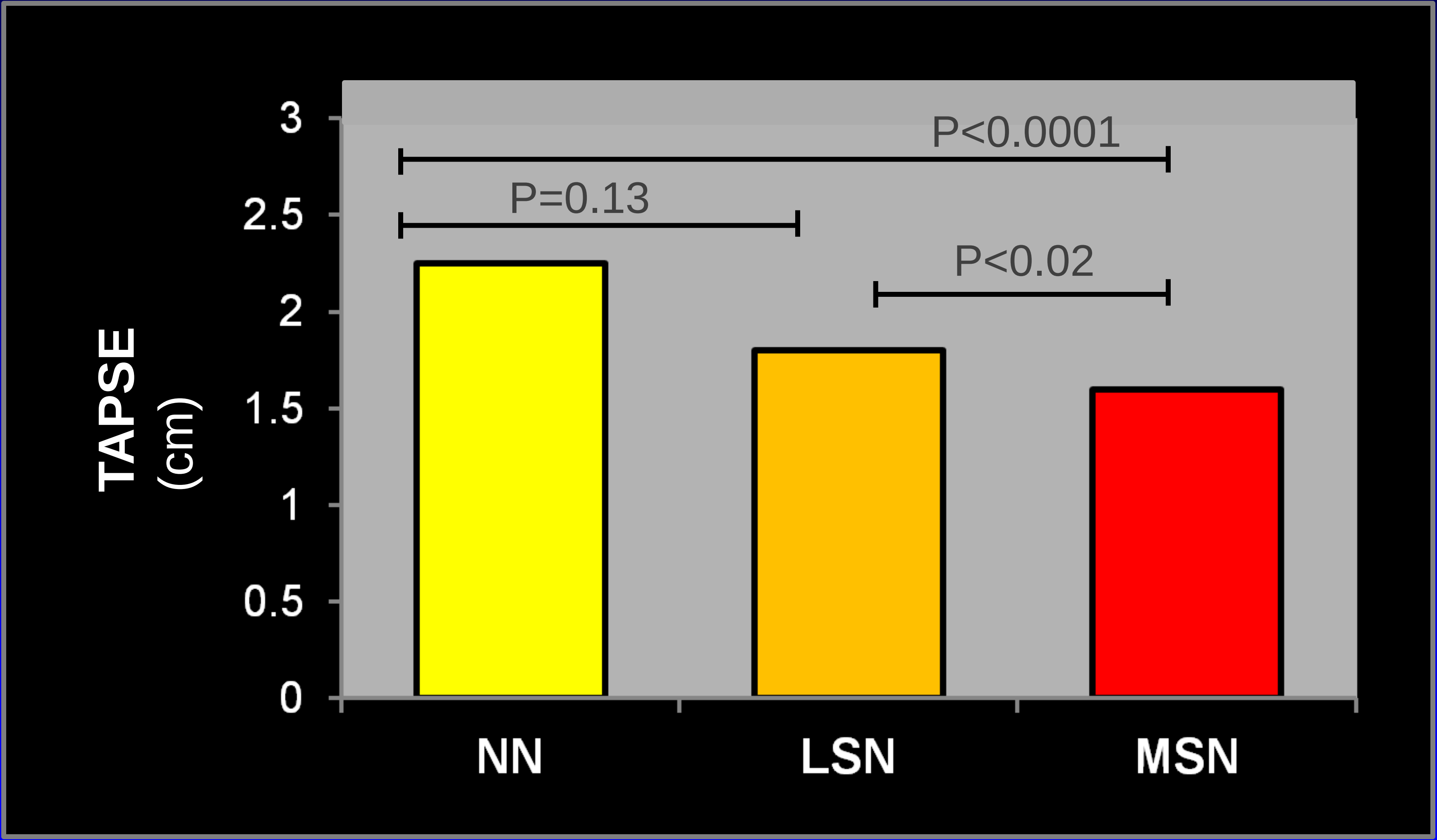
Differences among 3 RVOT velocity patterns



Arkles . . . Forfia   Am J Resp Crit Care Med 2011;183:268-276

Pulmonary Hypertension Cohort

Differences among 3 RVOT velocity patterns



Arkles . . . Forfia   Am J Resp Crit Care Med 2011;183:268-276

Hemodynamic and Echo Data for Notch Groups

(Mean ± SD)

Parameter	NN	LSN	MSN
PAPs (mm Hg)	53 ±16	73 ± 19	82 ±17
PAPm (mm Hg)	33 ± 10	46 ± 12	50 ± 9
PVR (WU)	3.3 ± 2.4	5.7 ± 3.1	9.2 ± 3.5
E/A	1.9 ± 1.1	1.1 ± 1.4	1.0 ± 0.9
PAcT (ms)	113 ±29	79 ± 18	67 ± 21
RA (cm)	4 ± 0.8	4.5 ± 1.5	4.9 ± 1.0

Arkles . . . Forfia   Am J Resp Crit Care Med 2011;183:268-276

Differentiate PAH from PVH
Signs Favoring PVH

- LA enlargement (LA size > RA size)
- Atrial septum bows toward RA
- E/A ratio > 1.2
- E/e’ (lateral) > 11; lateral e’ < 8 cm/s
- RVOT notching uncommon

McLaughlin J Am Coll Cardiol 2015;68(18):1976-97

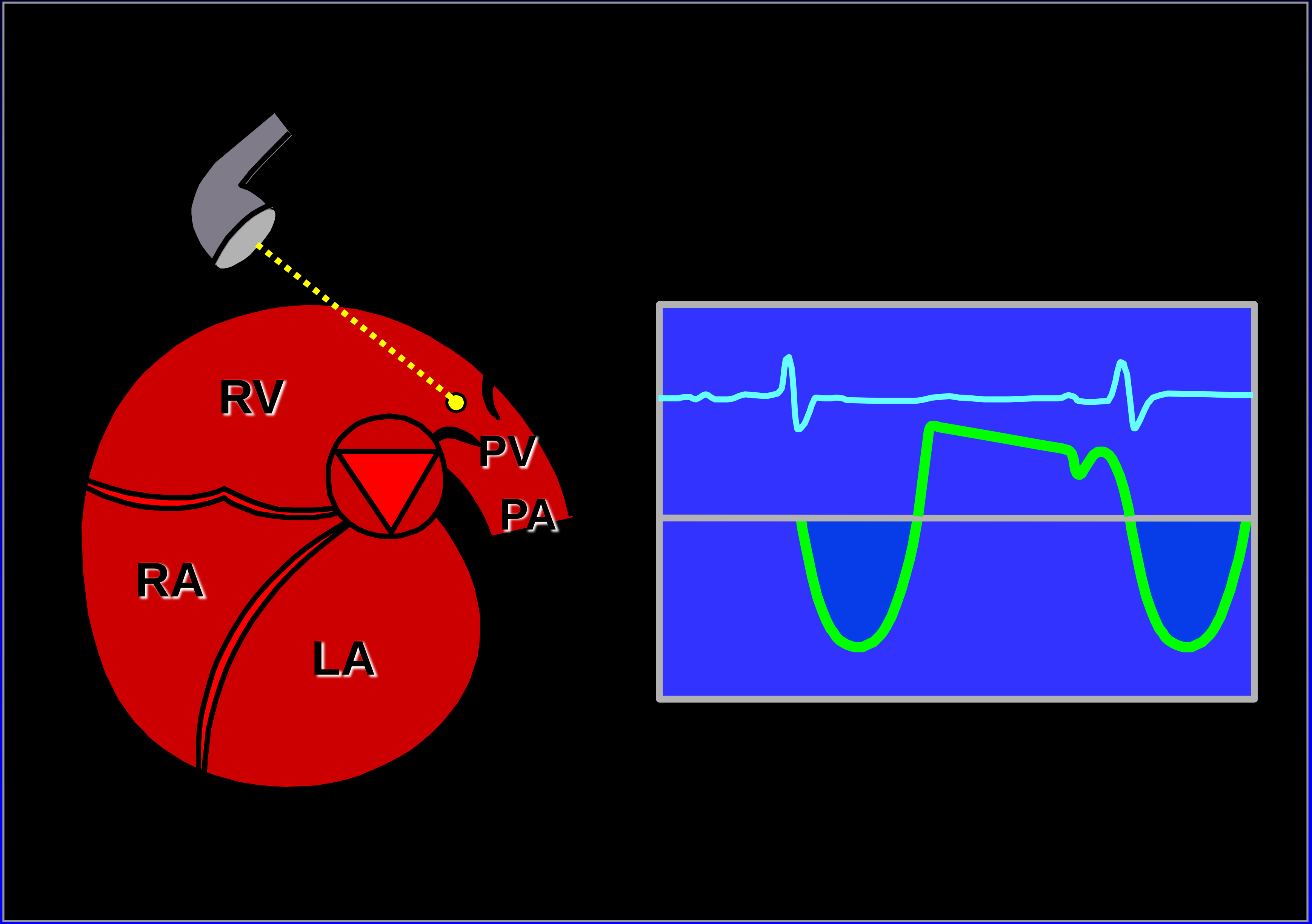
Differentiate PAH from PVH

Signs Favoring PAH

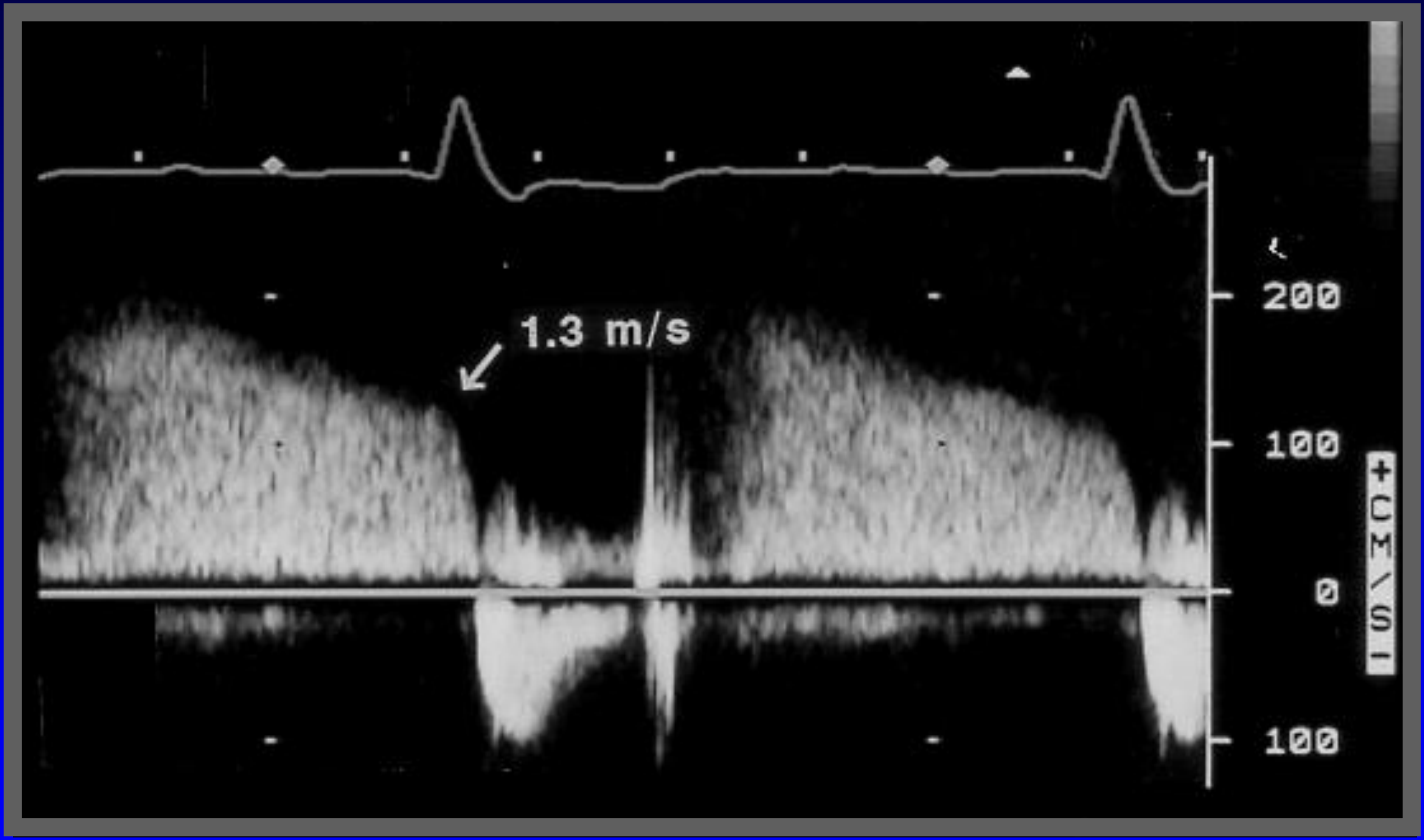
- Marked RV enlargement
- LA size normal or small
- Atrial septum bows toward LA
- RVOT notching
- E/A ratio << 1
- Lateral E/e' < 8

McLaughlin J Am Coll Cardiol 2015;68(18):1976-97

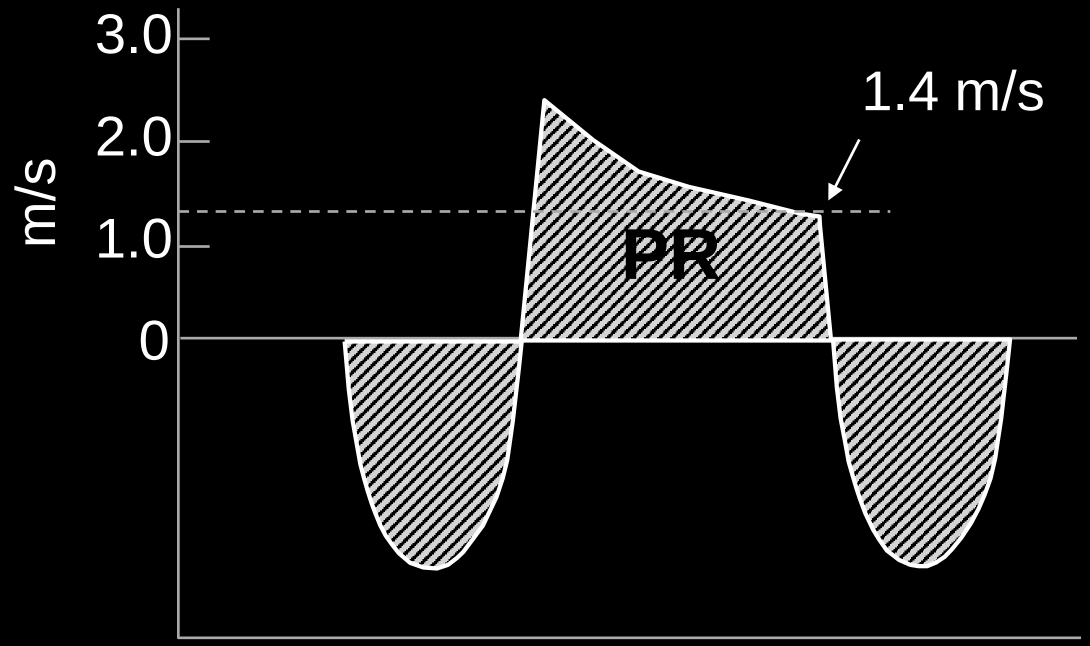
PR Jet

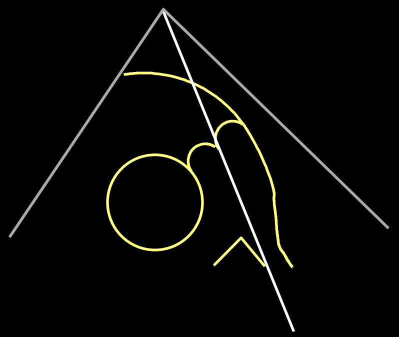

RV
PV
PA
RA
LA

Pulmonic Regurgitant Jet



Doppler Recording of Pulmonic Regurgitant Jet





$$PA_{EDP} - RV_{EDP} = 4V_{PI}^2 = 4(1.4)^2$$

$$PA_{EDP} = 4V_{PI}^2 + RV_{EDP} = 7.8 + 4$$

$$PA_{EDP} = 4V_{PI}^2 + RA_{EDP} = 12\,mmHg$$

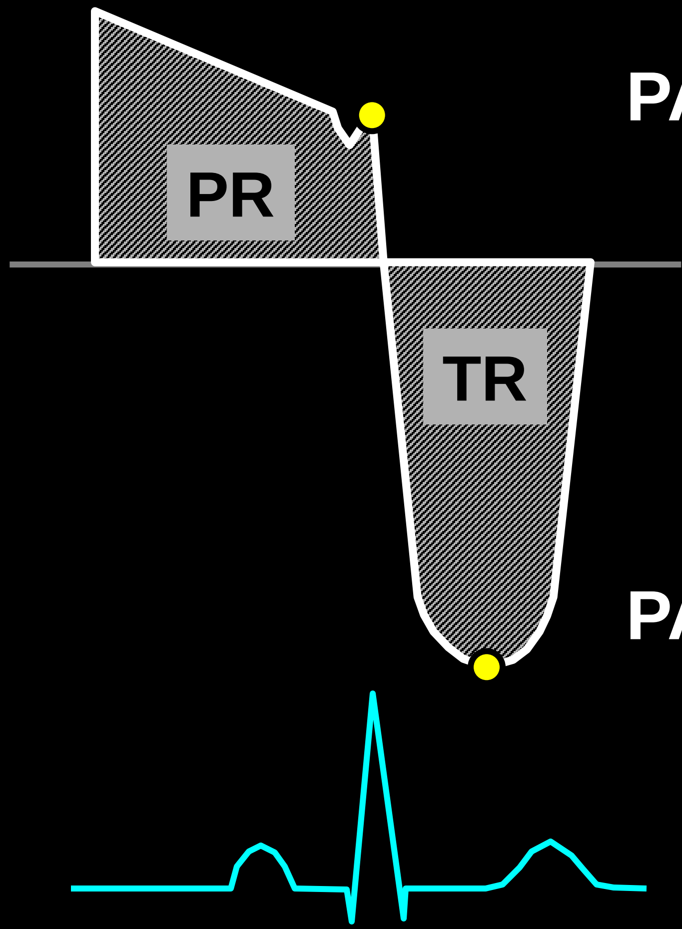
Adequate Spectral Doppler Signals

	Feasibility Without Contrast	Feasibility With Contrast
TR jet	**94%**	**98%**
PR jet	**80%**	**85%**

Tramarin *Eur Heart J* 1991;12:102-112

Case

Pulmonary Artery Pressure



$$\text{PA diast} = 4V^2_{\text{PR end}} + \text{RA}$$

$$\text{PA syst} = 4V^2_{\text{TR}} + \text{RA}$$

$$4V^2$$

The End