What Do You Know About Cardiac Hemodynamics?

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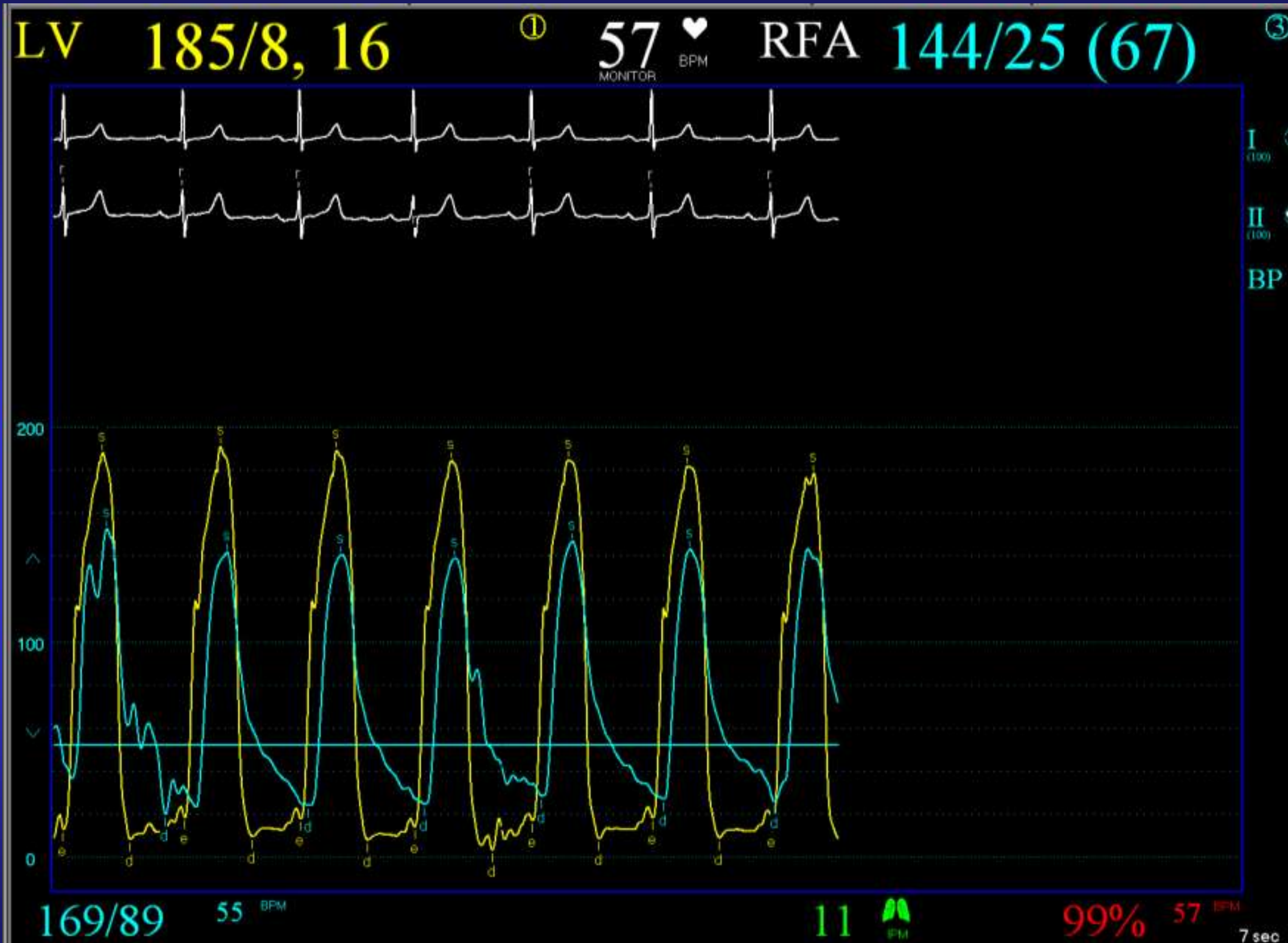
Overview

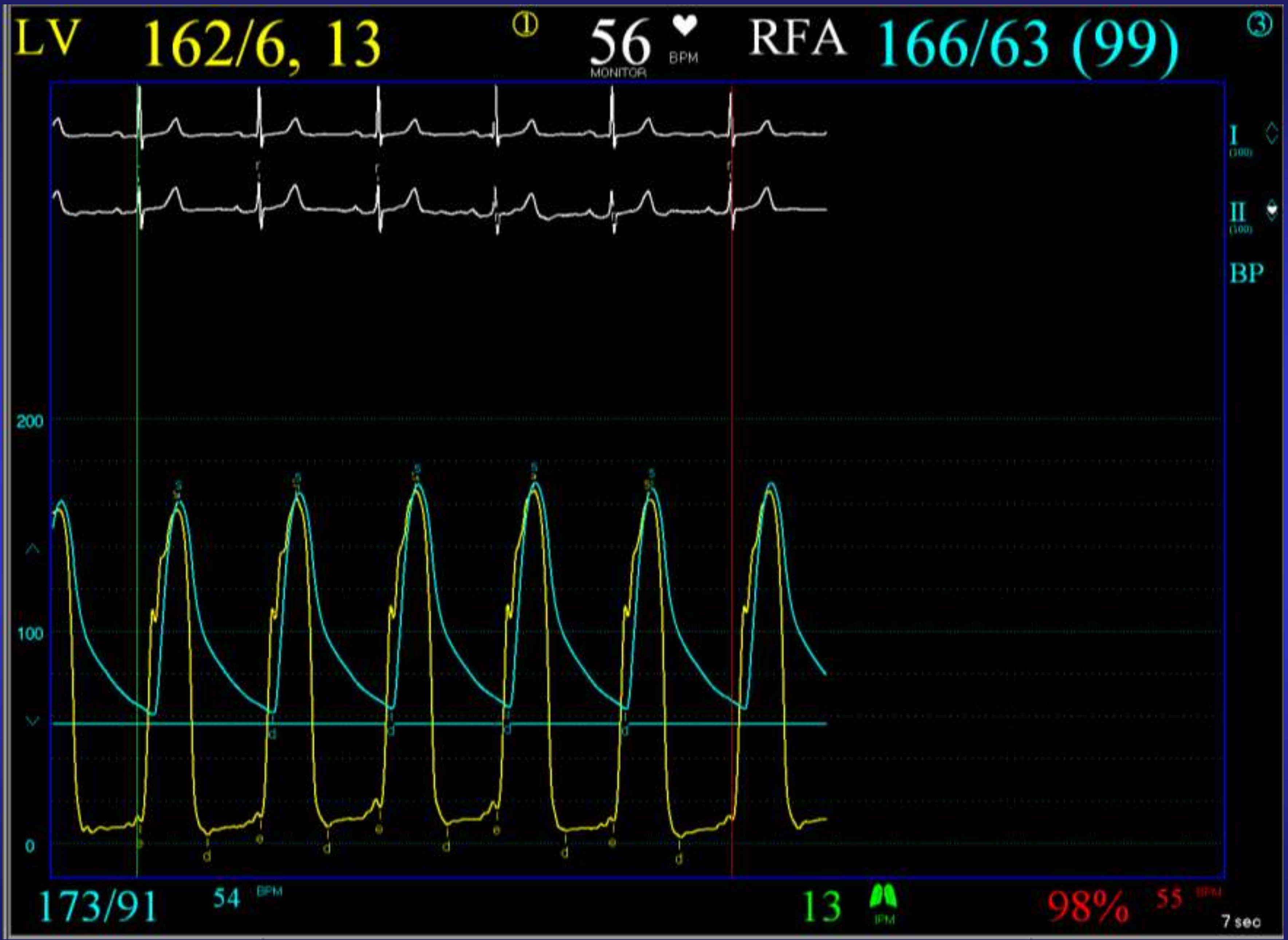
- Hemodynamics
  - Basic principles and definitions
  - Hemodynamic guided therapy
  - Exercise
  - Constriction and Restriction
- Endomyocardial biopsy
- Coronary angiography



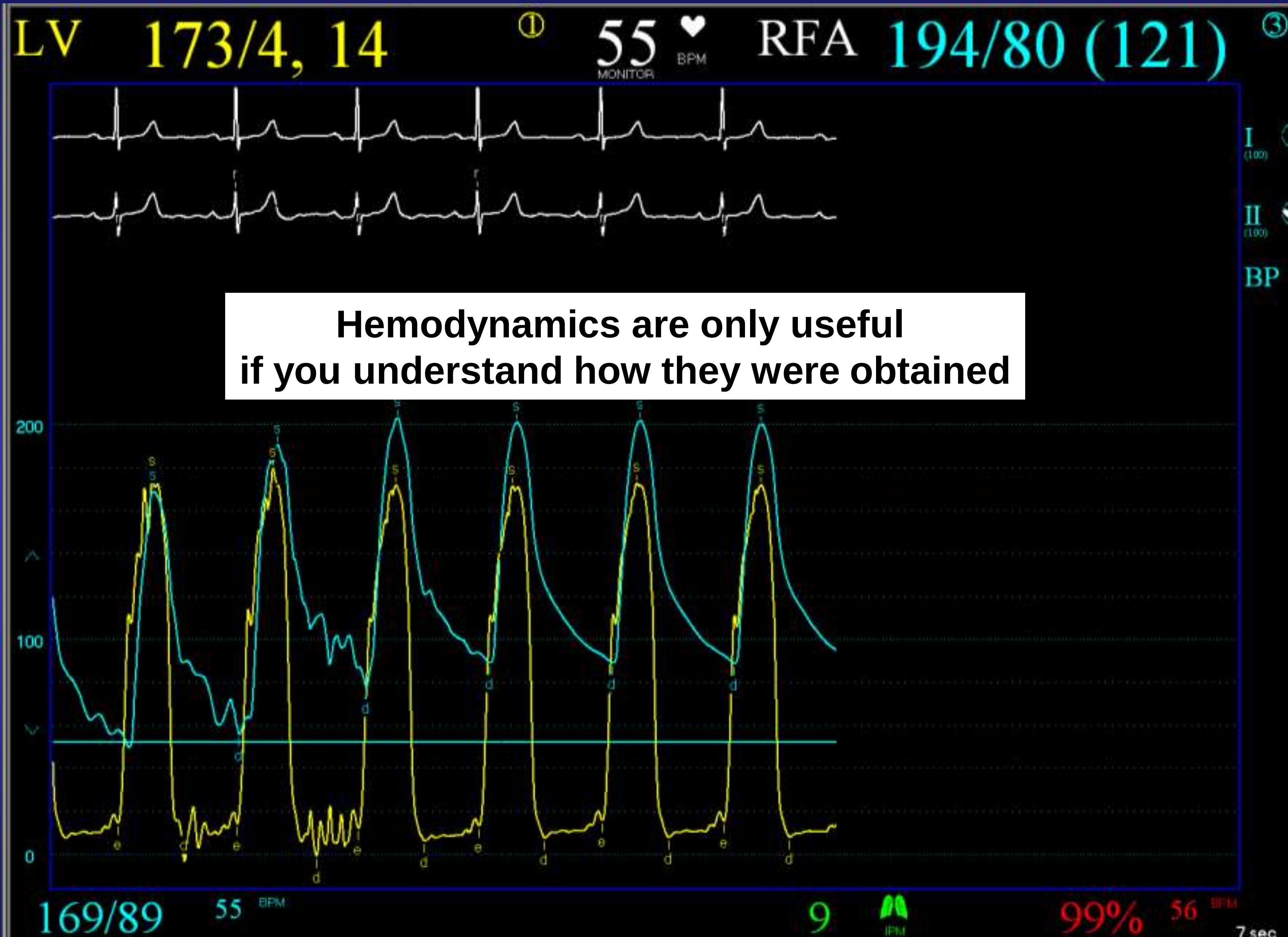
LV 185/8, 16
57 BPM
MONITOR
RFA 144/25 (67)
I
II
BP
200
100
0
169/89
55 BPM
11
99%
57
7 sec

These hemodynamics represent:

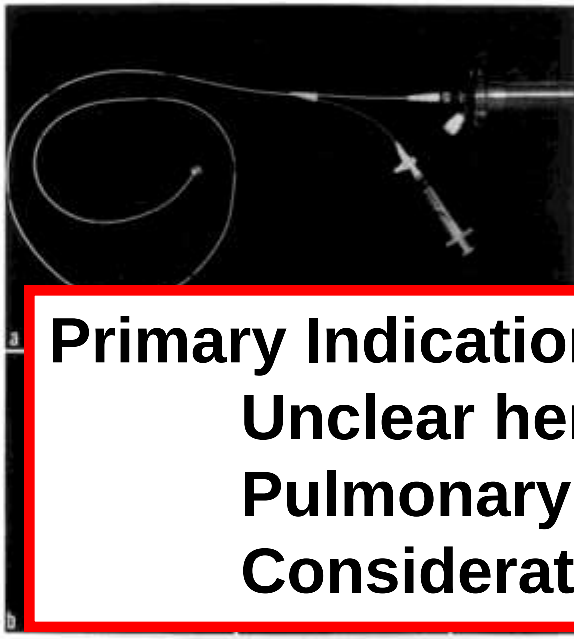
a) Aortic stenosis
b) Aortic regurgitation
c) Hypertension
d) Coarctation
e) Artifact


LV 162/6, 13
56 BPM
MONITOR
RFA 166/63 (99)
I
II
BP
200
100
0
173/91
54 BPM
13
IPM
98%
55
7 sec

Hemodynamics are only useful if you understand how they were obtained

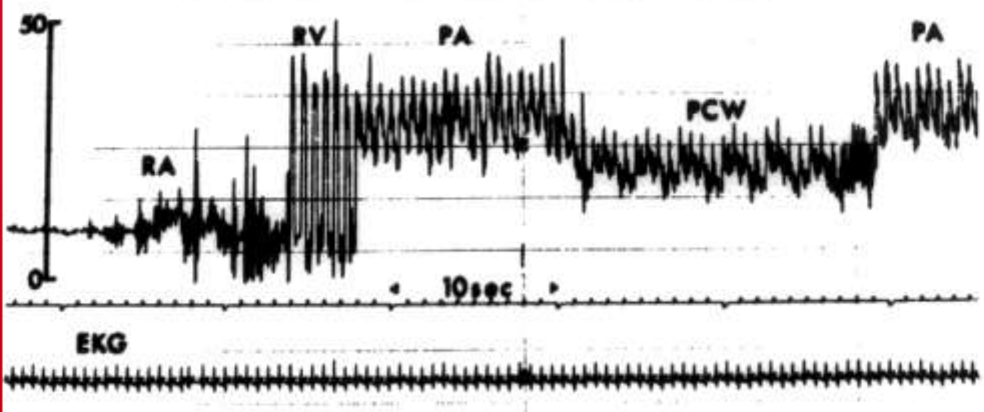


The Pulmonary Artery Catheter



Primary Indications

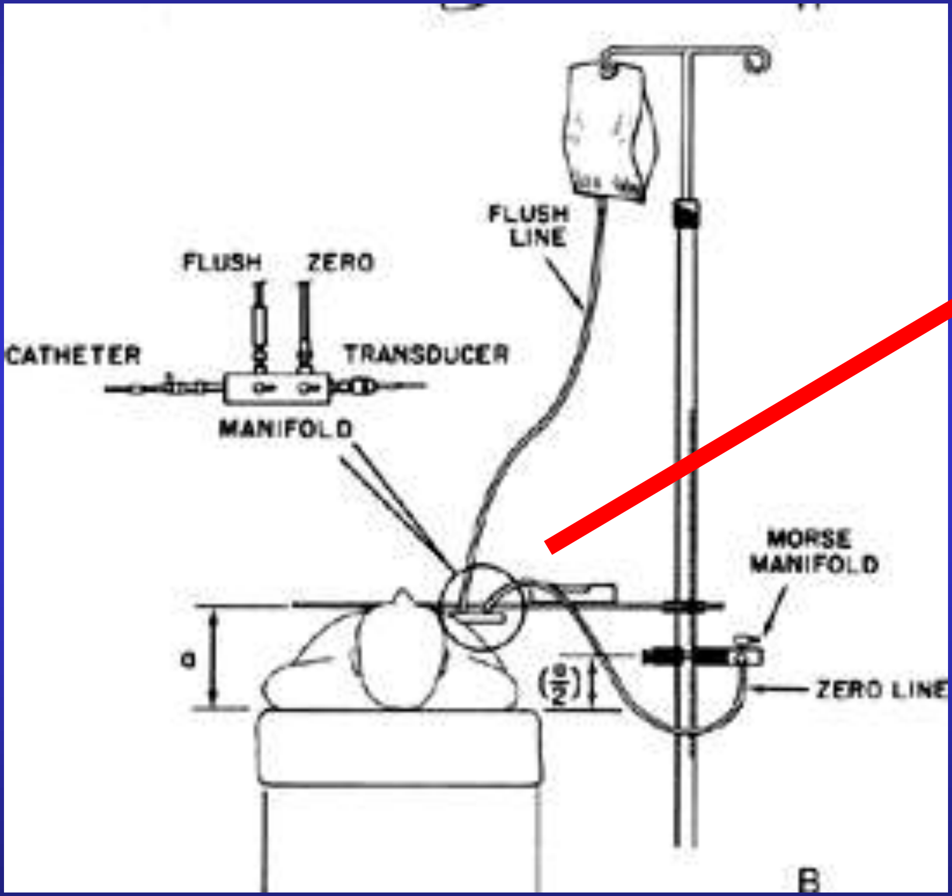
- **Unclear hemodynamic picture**
- **Pulmonary hypertension**
- **Consideration of Advanced Therapies**

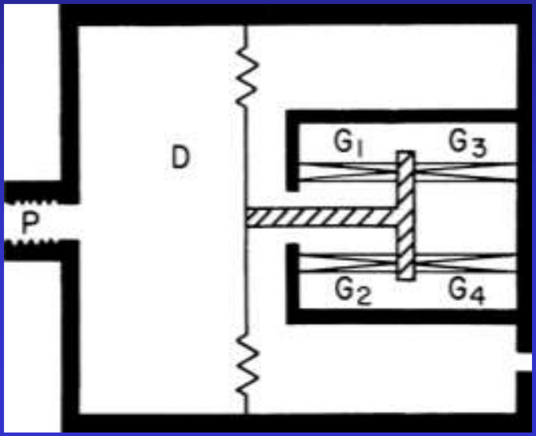


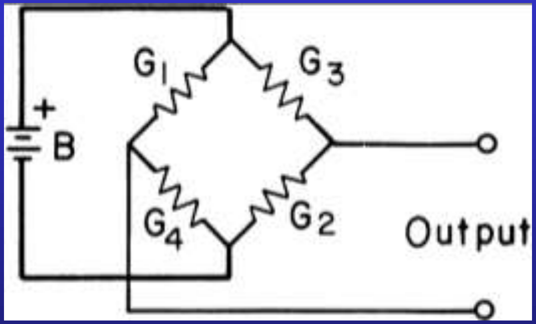
William Ganz and H.J.C. Swan

Chatterjee K, Circ 2009;119:147-152

Hemodynamic Principles



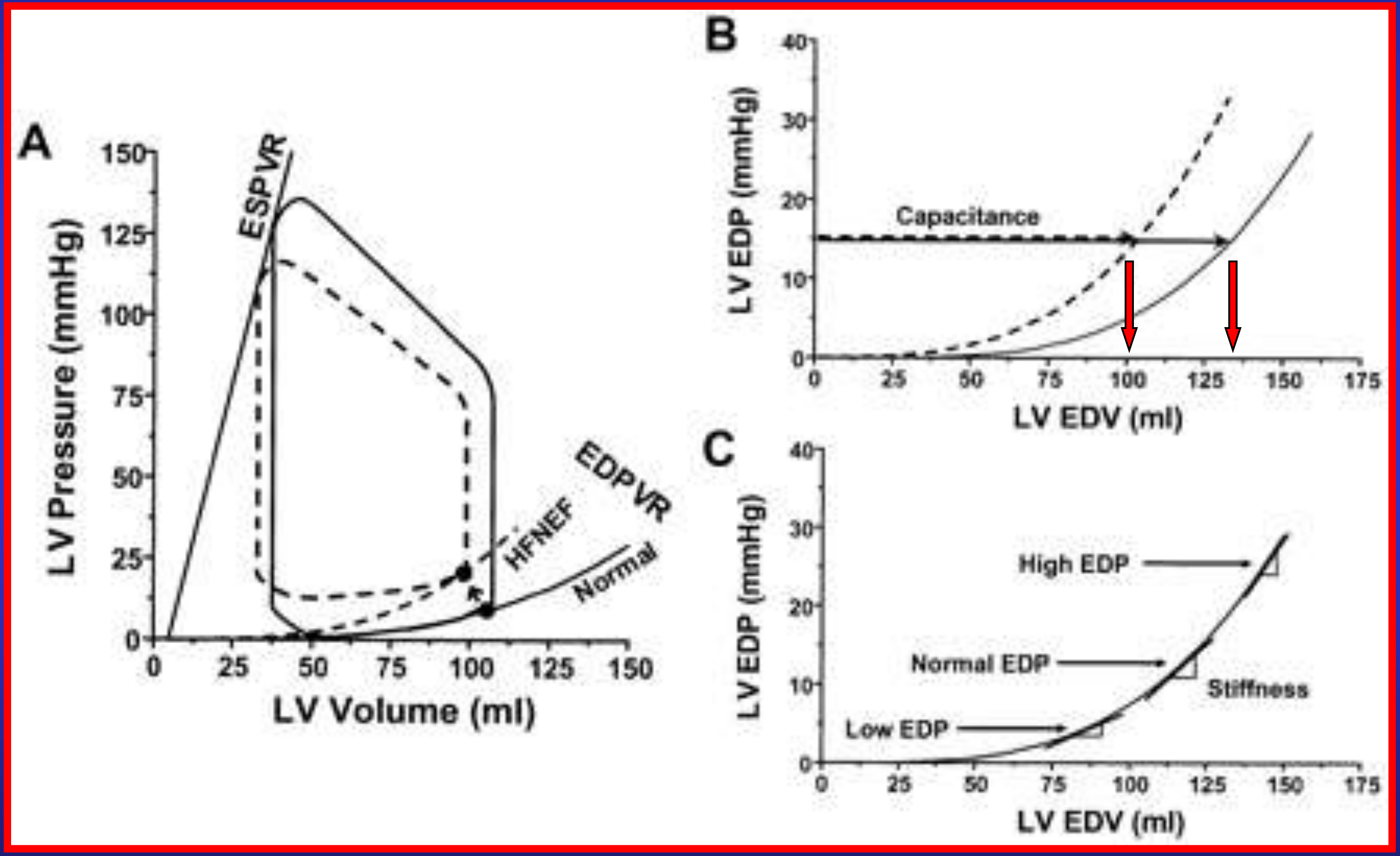




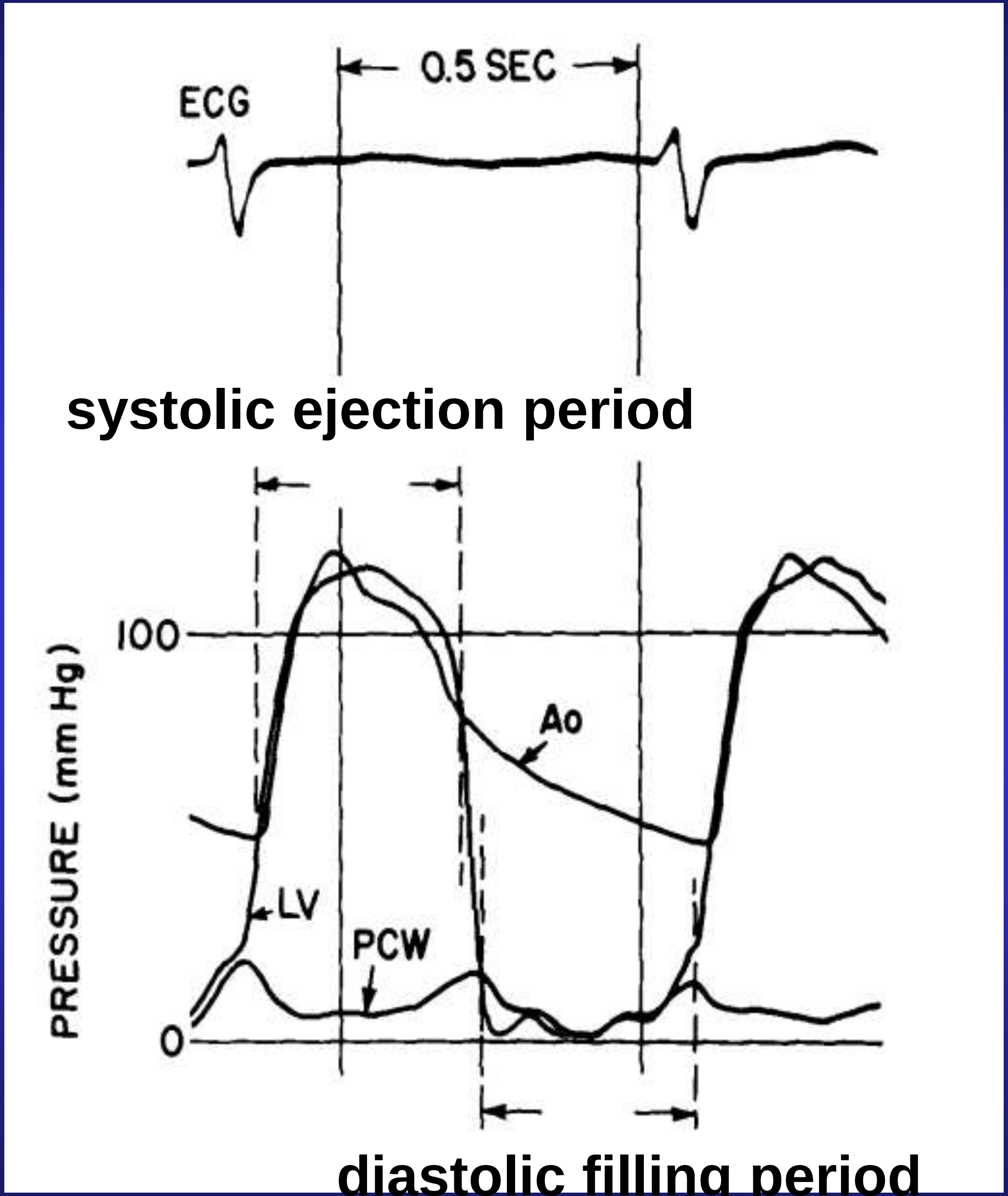
From Grossman's Cardiac Catheterization, Angiography, and Intervention, 7th Edition

Hemodynamic Principles

Pressure is only surrogate for volume



Burkoff, Maurer, Packer. Circulation 2003;107:656

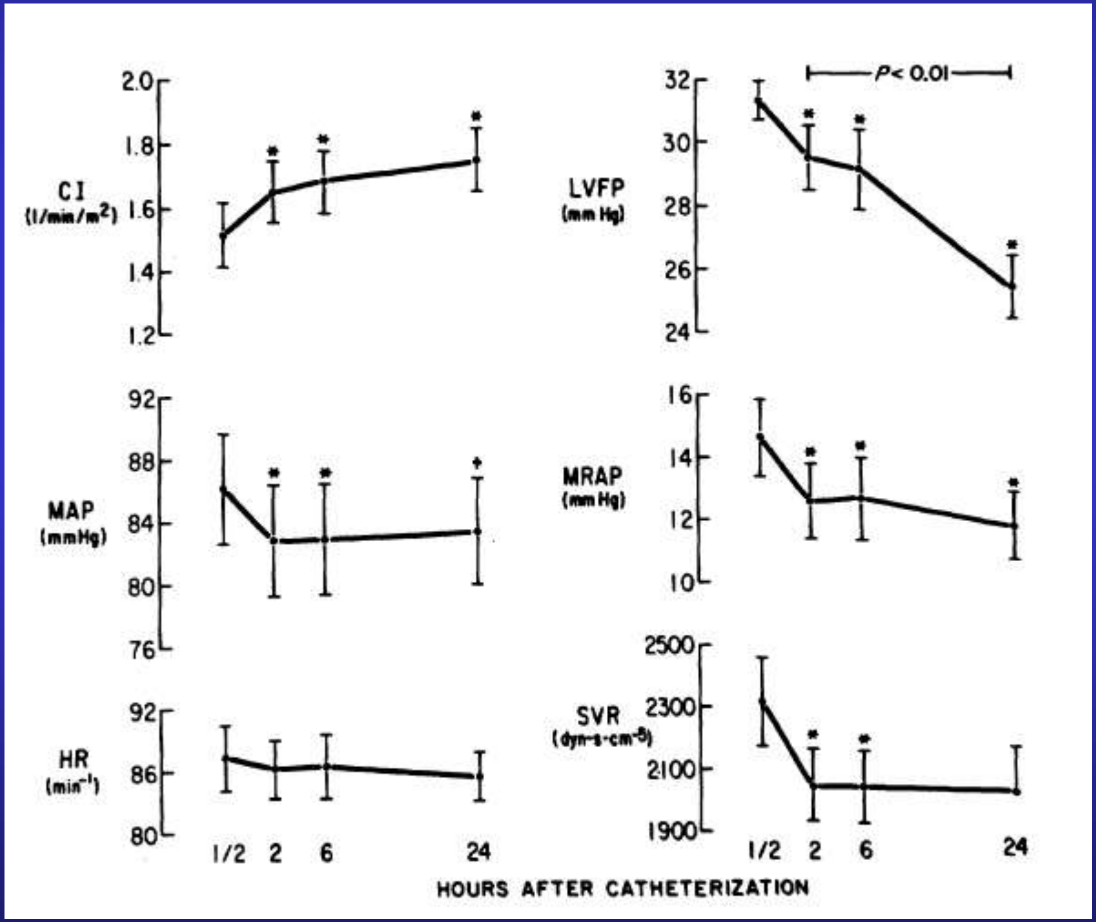


systolic ejection period

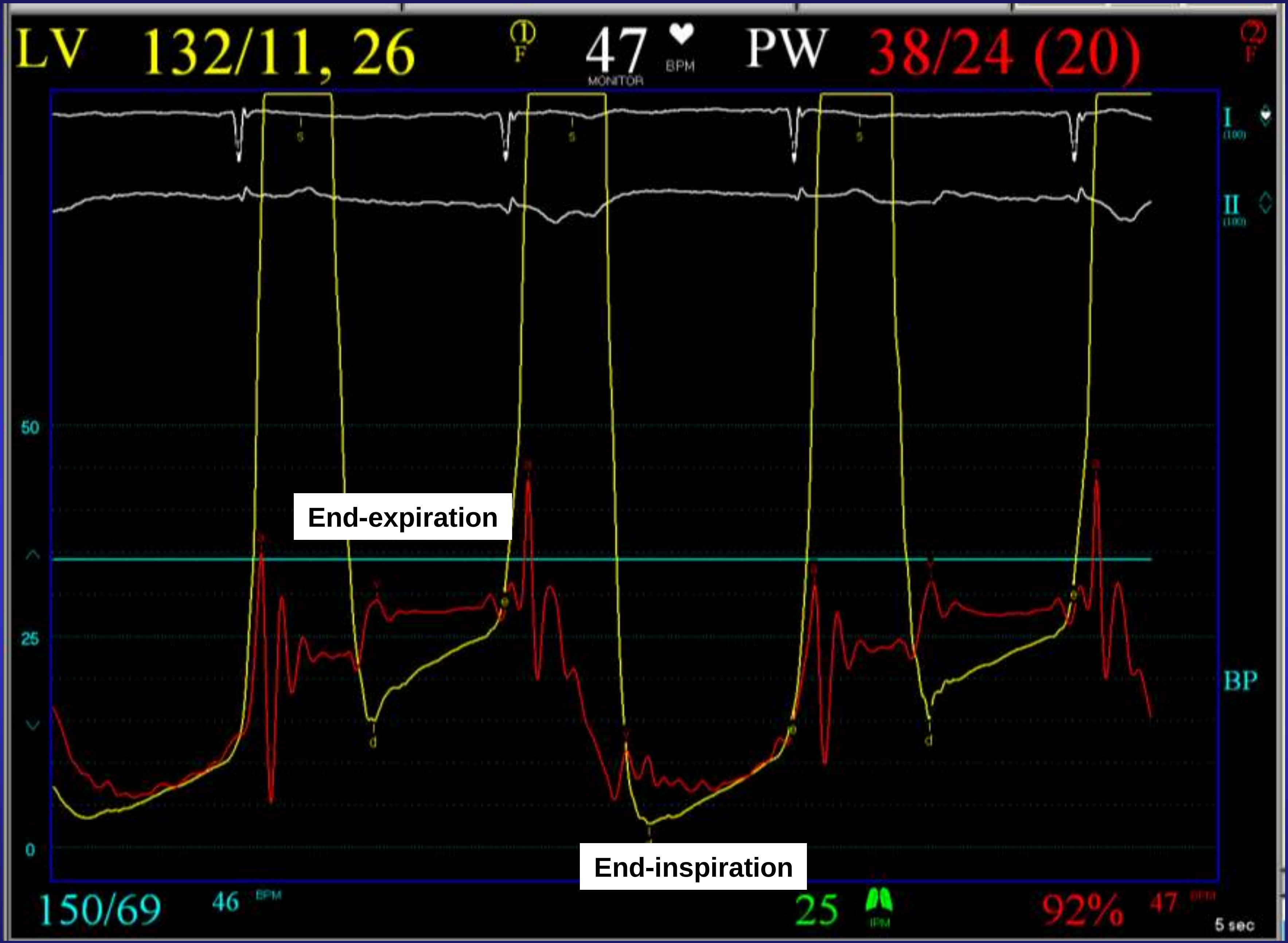
diastolic filling period

Hemodynamics Change Over Time

Limitations of measurements at a single point in time

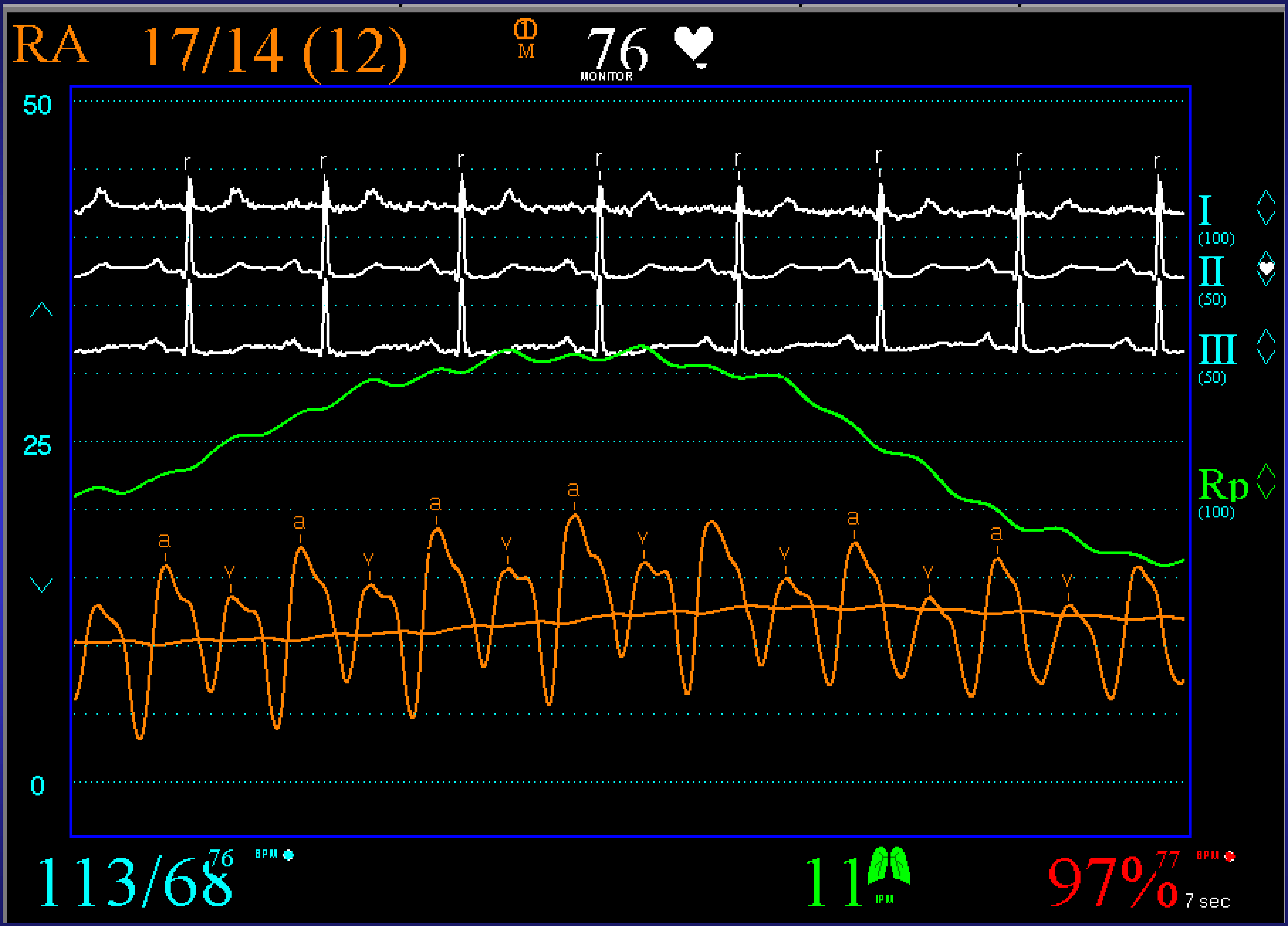


Packer M, et al. Circulation 1985;71:761


LV 132/11, 26
47
BPM
MONITOR
PW 38/24 (20)
I
II
50
25
0
BP
End-expiration
End-inspiration
150/69
46
25
92%
47
5 sec

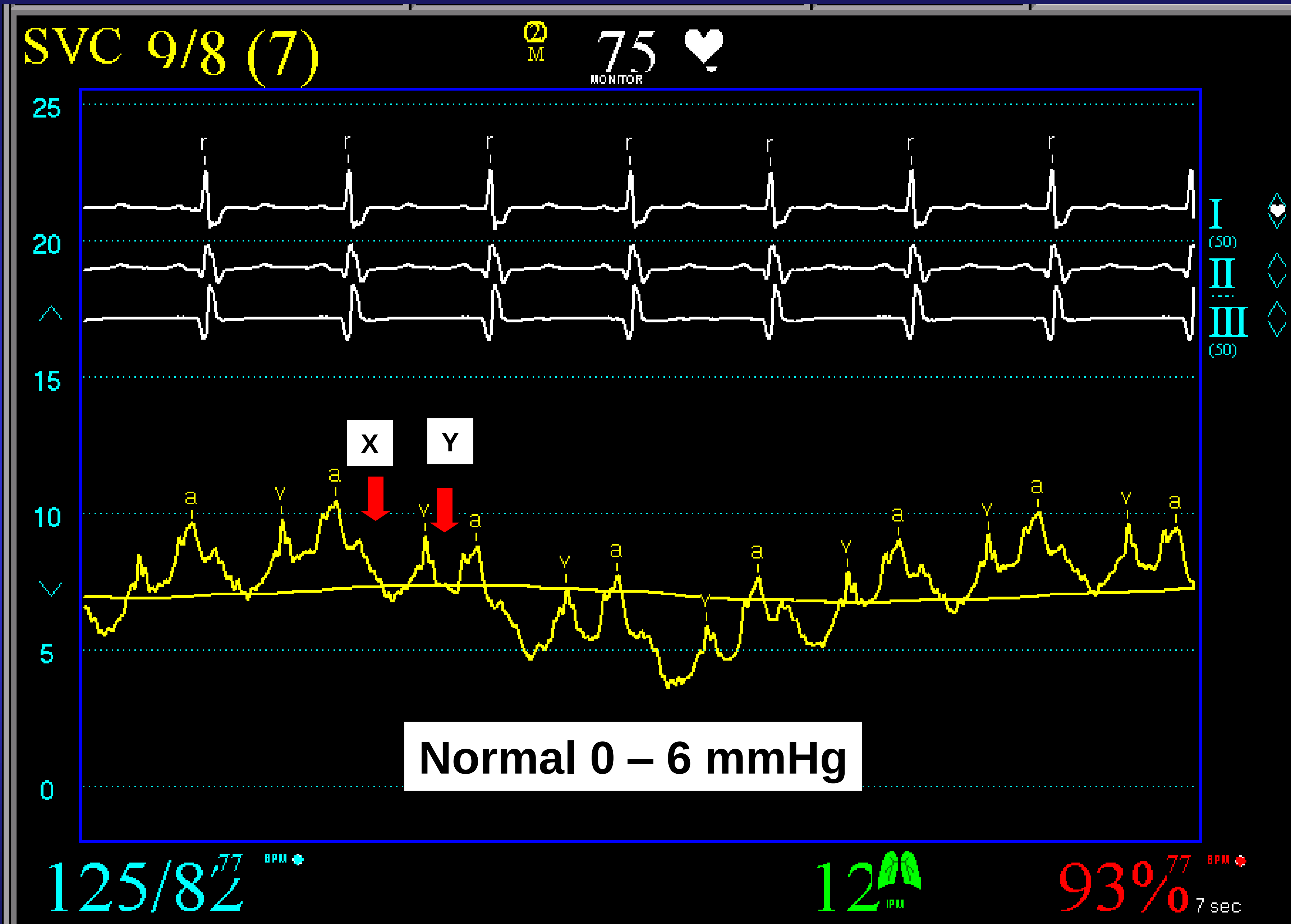
This waveform is consistent with all of the following except:

a) Tamponade
b) Constriction
c) Restriction
d) Transplantation
e) RV infarction



RA 17/14 (12)
M
76
MONITOR
50
25
0
r
a
y
I
(100)
II
(50)
III
(50)
Rp
(100)
113/68
76
BPM
11
IPM
97%
77
BPM
7 sec

50
25
0
a
v
25
0
s
d


SVC 9/8 (7)
75
MONITOR
25
20
15
10
5
0
I
(50)
II
III
(50)
X
Y
Normal 0 – 6 mmHg
125/82
77
BPM
12
IPM
93%
77
BPM
7 sec

Central venous pressure

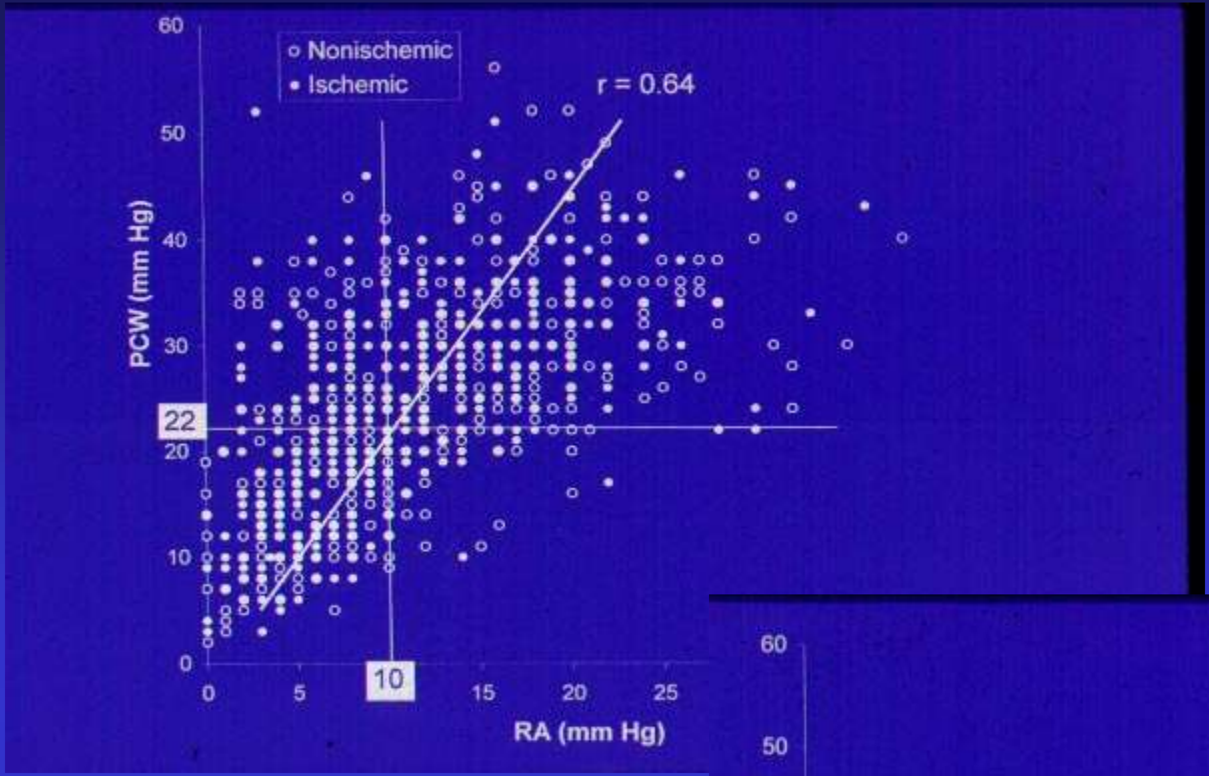
Things to consider

- Inspiratory fall of 2 – 3 mmHg
- Atrial events are “out of phase” from ventricular events
- A wave: late V diastole
  - Reflection of atrial contraction
- X descent: early V systole
  - Usually predominant in normal individuals
- V wave: late V systole
  - Determined by atrial compliance
- Y descent: early V diastole
  - Determined by ventricular compliance

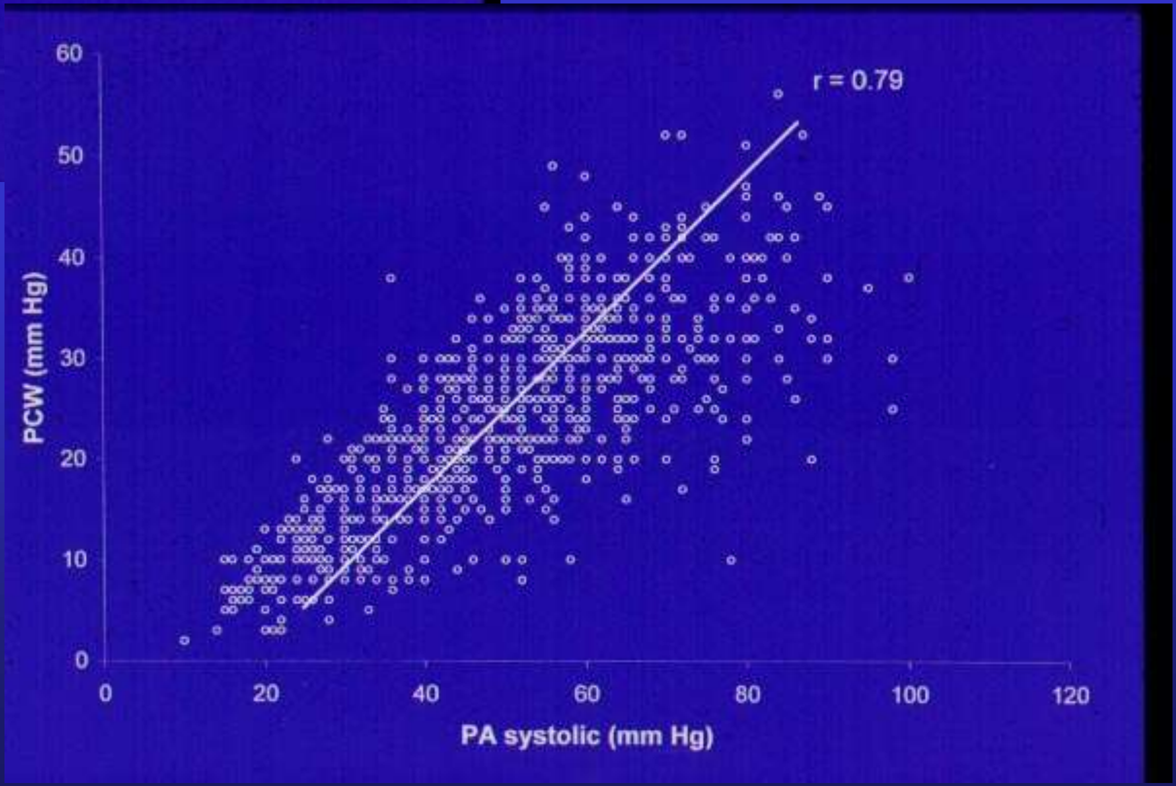
Which hemodynamic parameter is correlated with cardiorenal syndrome?

a) Cardiac index
b) Pulmonary capillary wedge pressure
c) Right atrial pressure
d) Pulmonary arterial pressure
e) Systemic vascular resistance

Nohria A, et al. JACC 2008



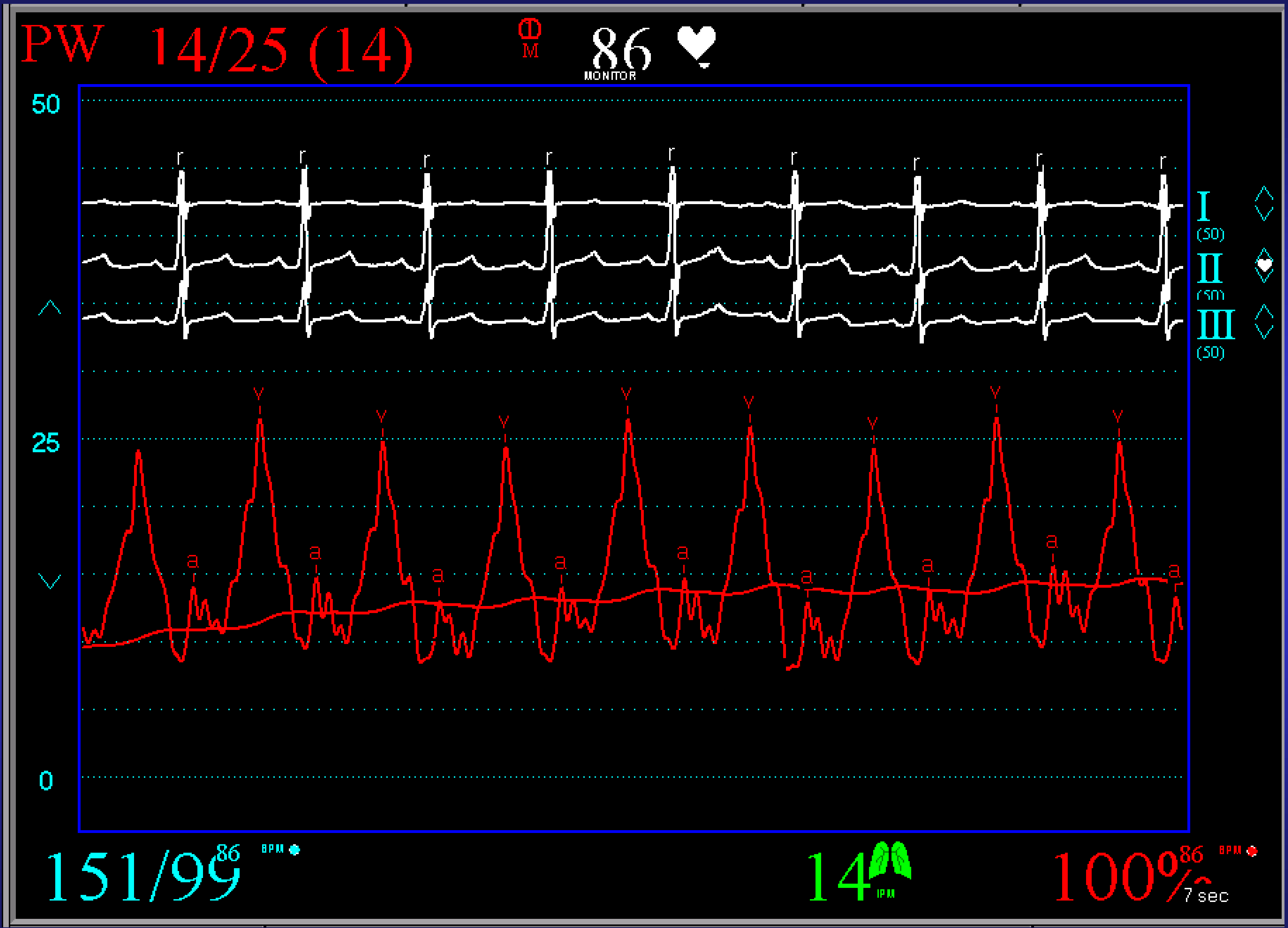
CVP x 2 = PCW
PCW x 2 = PA sys



Drazner M, JHLT 1999

This waveform is most consistent with:

a) Pulmonary artery pressure
b) Right ventricular pressure
c) Pulmonary capillary pressure
d) Left atrial pressure

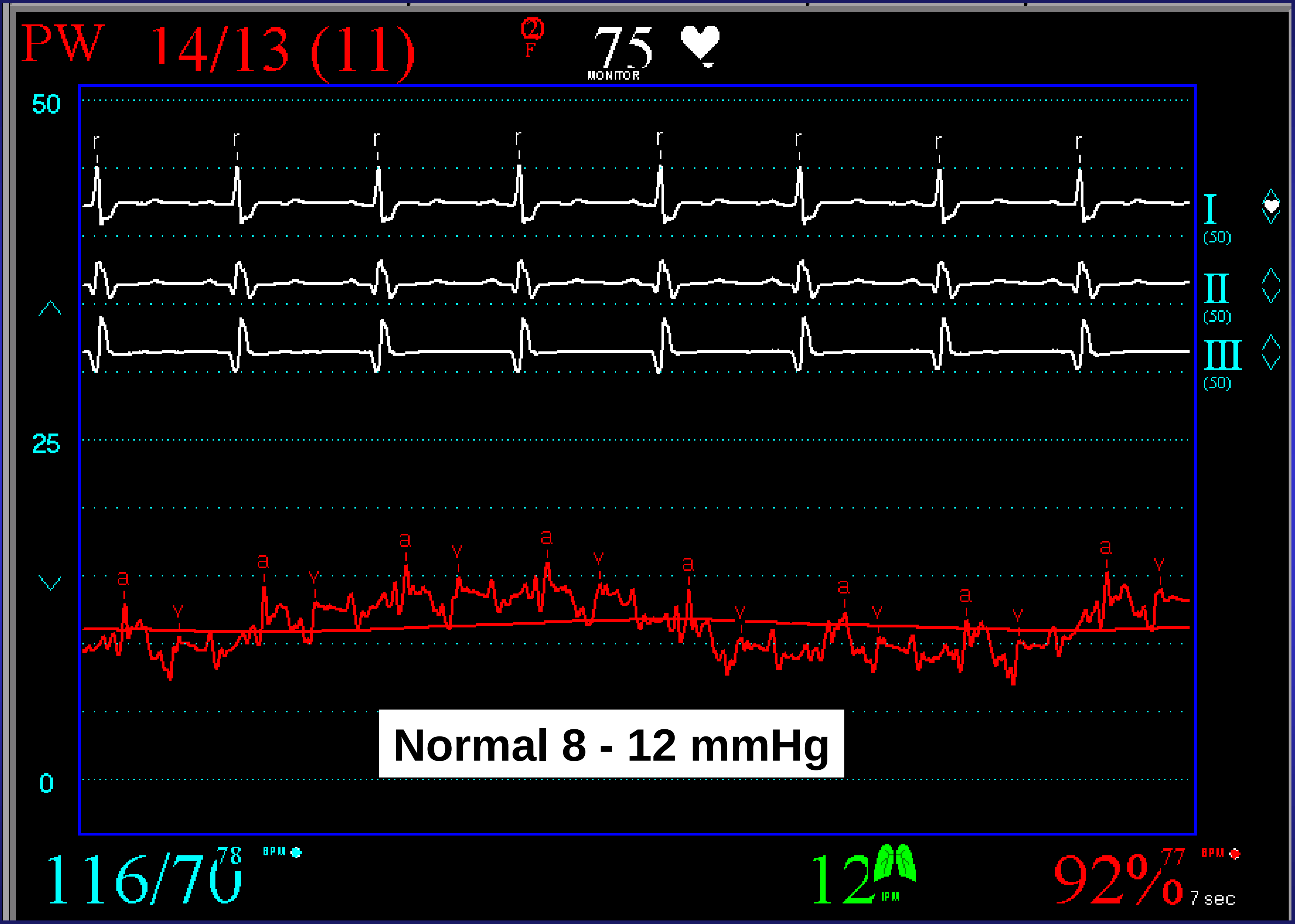


PW 14/25 (14)
M
86
MONITOR
50
25
0
I
(50)
II
III
(50)
151/99
86
BPM
14
IPM
100%
86
BPM
7 sec

Pulmonary capillary wedge pressure

Things to consider

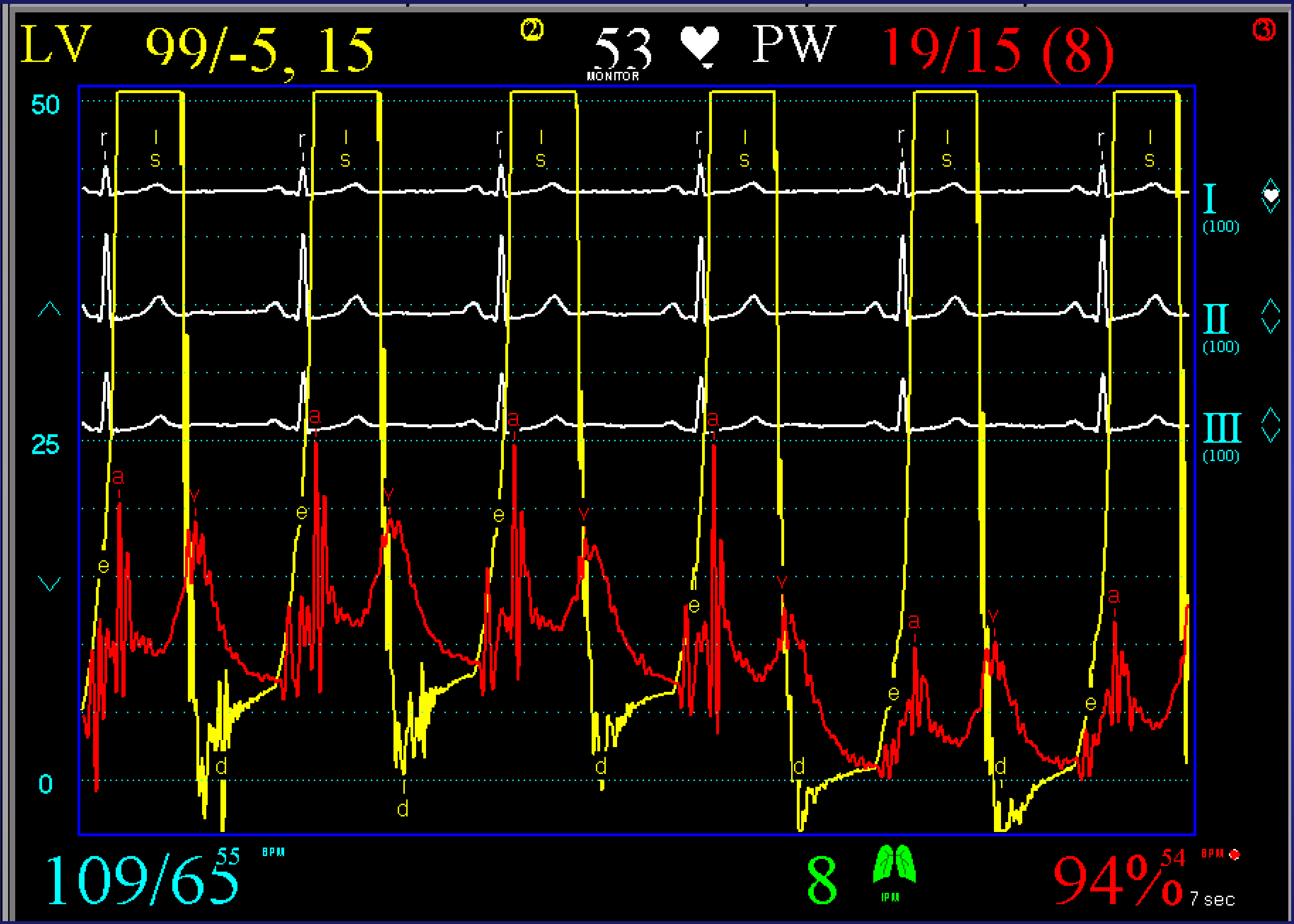
- Do not force balloon inflation to obtain PCW
- If truly “wedged”, blood no longer moving so proximal pressure will equal distal pressure, e.g. left atrial pressure
- At diastasis, in absence of atrial or MV obstruction, PCW = LA = LVEDP (usually)
- Report A wave, V wave, and mean values

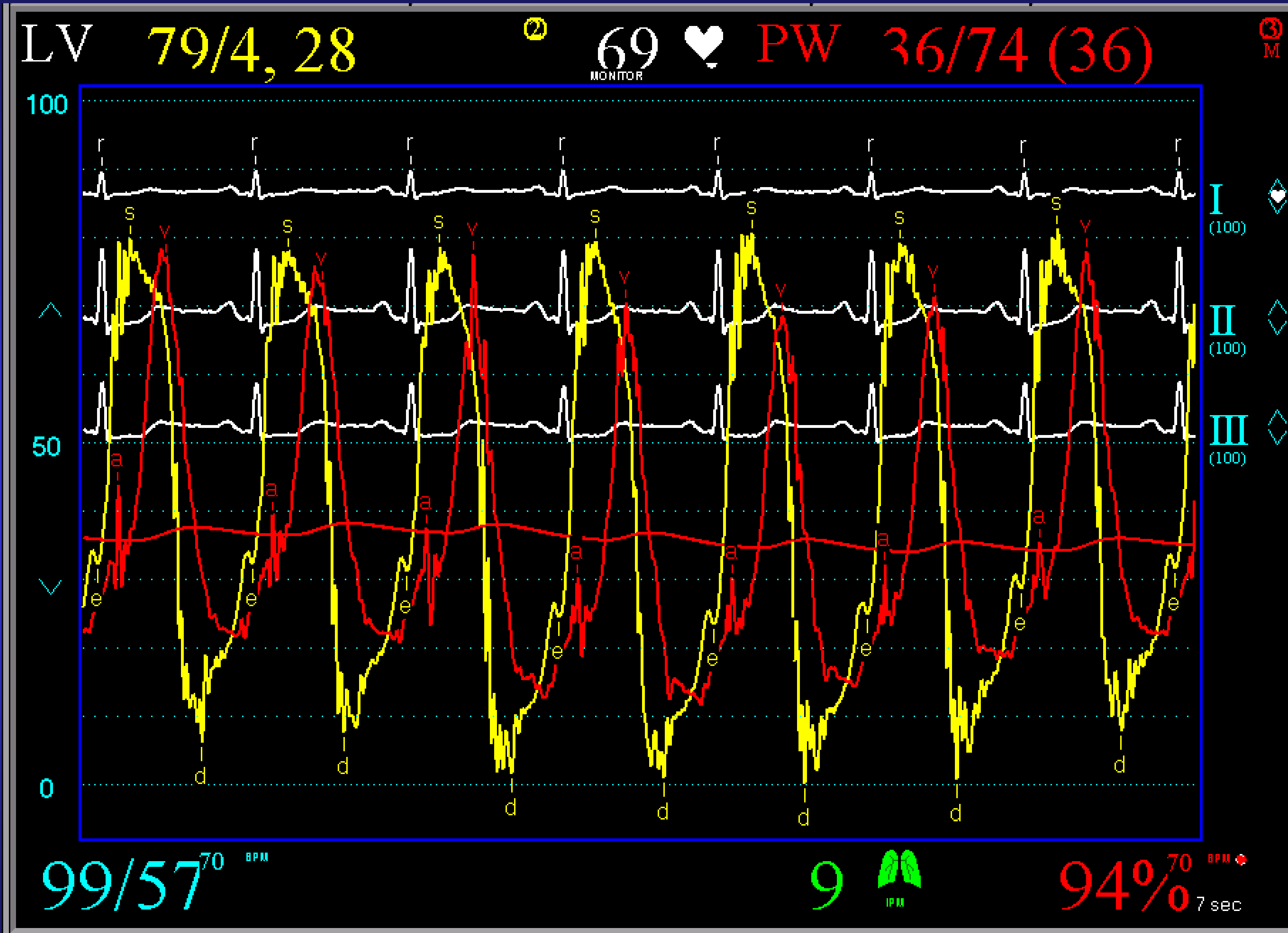

PW 14/13 (11)
75
MONITOR
50
25
0
I (50)
II (50)
III (50)
Normal 8 - 12 mmHg
116/70 78
BPM
12
IPM
92% 77
BPM
7 sec

Pulmonary capillary wedge pressure

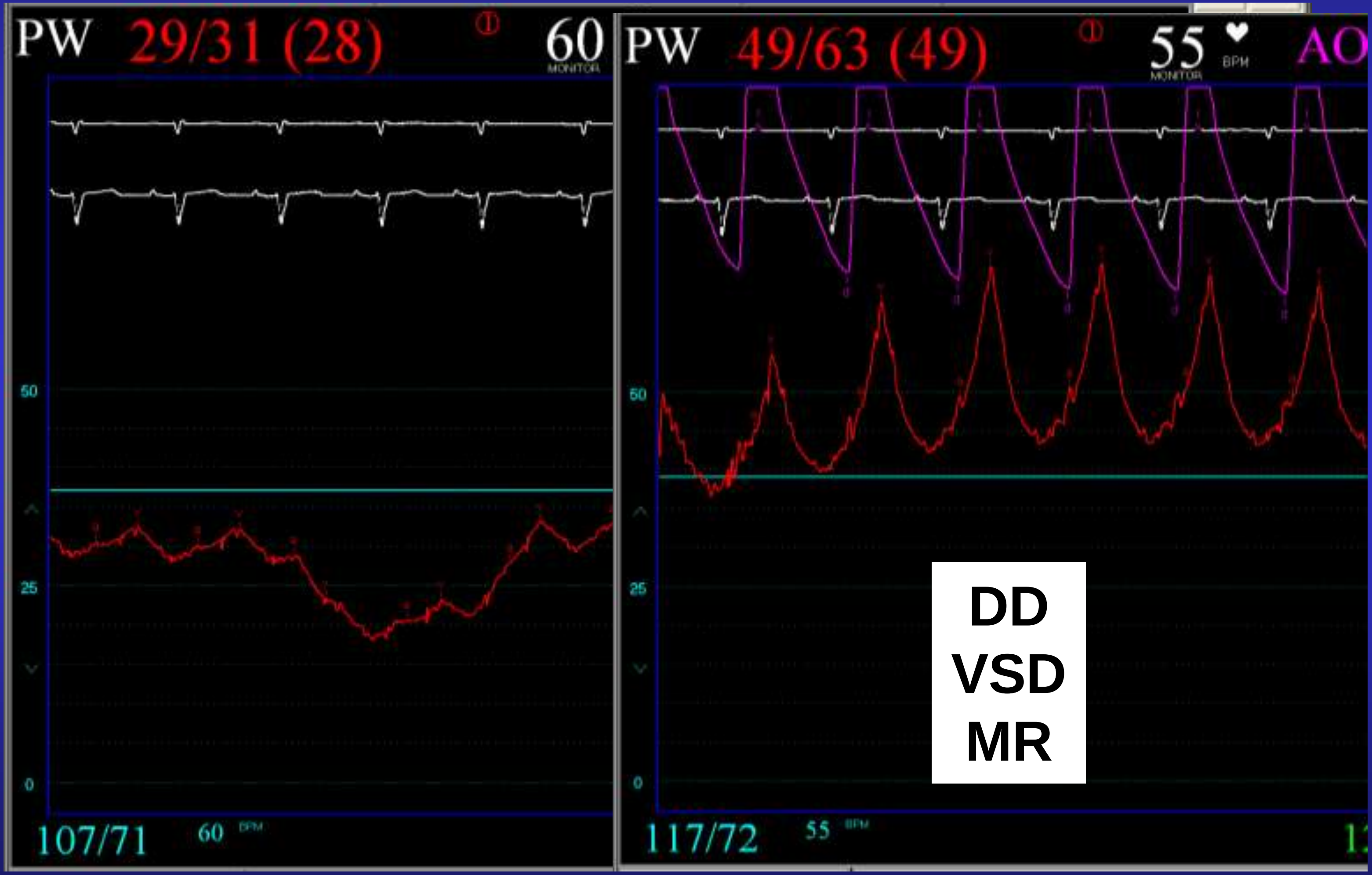
Things to remember

- Thoracic, not intracardiac pressure
- Review the tracings!
- Confirm with saturation >95%
- PAD < 3 mmHg greater than LVEDP
- V wave < 2X A wave
- V wave is reflection of atrial compliance

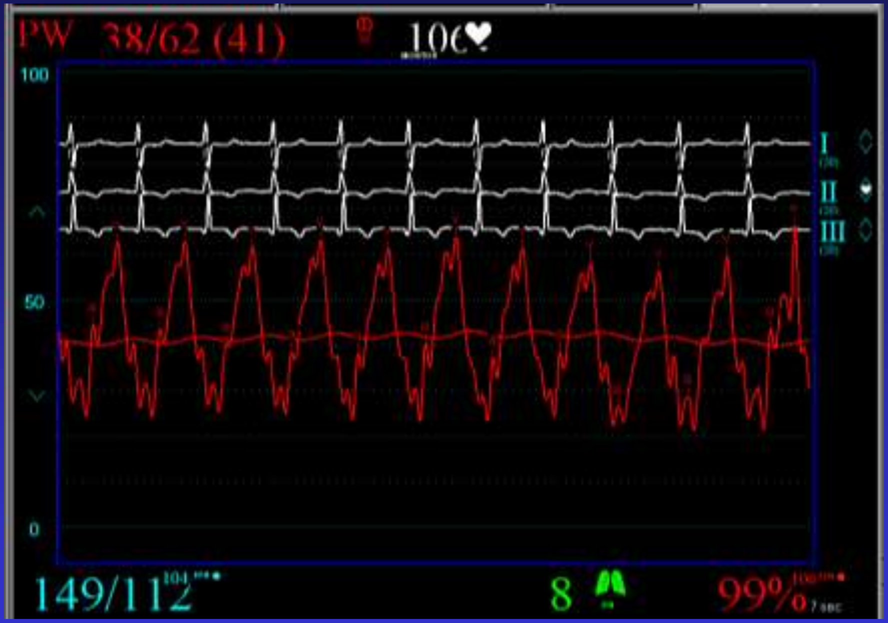

LV 99/-5, 15
53
MONITOR
PW 19/15 (8)
50
25
0
I (100)
II (100)
III (100)
109/65 55 BPM
8
IPM
94% 54 BPM
7 sec

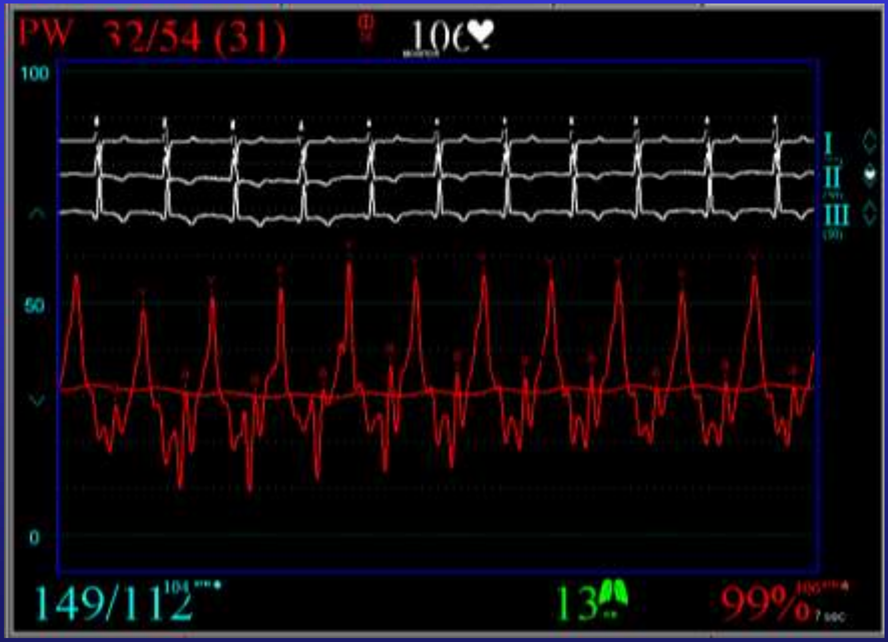

LV 79/4, 28
69
MONITOR
PW 36/74 (36)
M
100
50
0
I
(100)
II
(100)
III
(100)
99/57
70
BPM
9
IPM
94%
70
BPM
7 sec

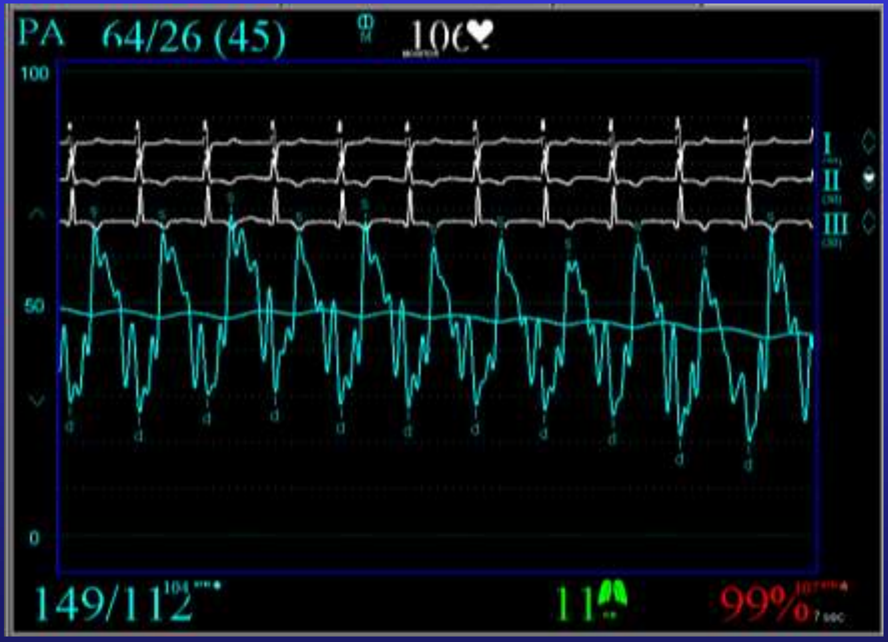
V waves can be very dynamic

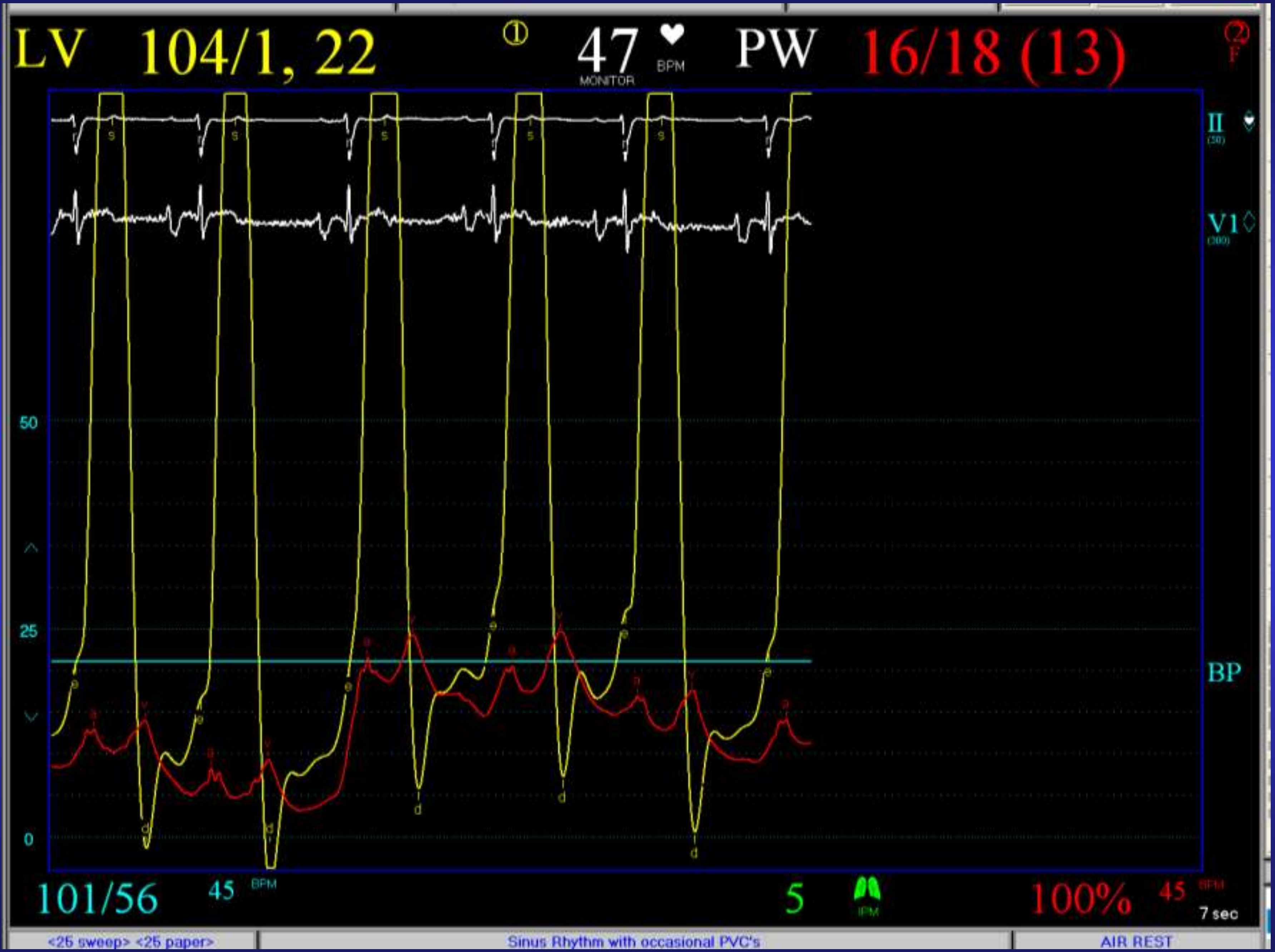


Which one is the Wedge?

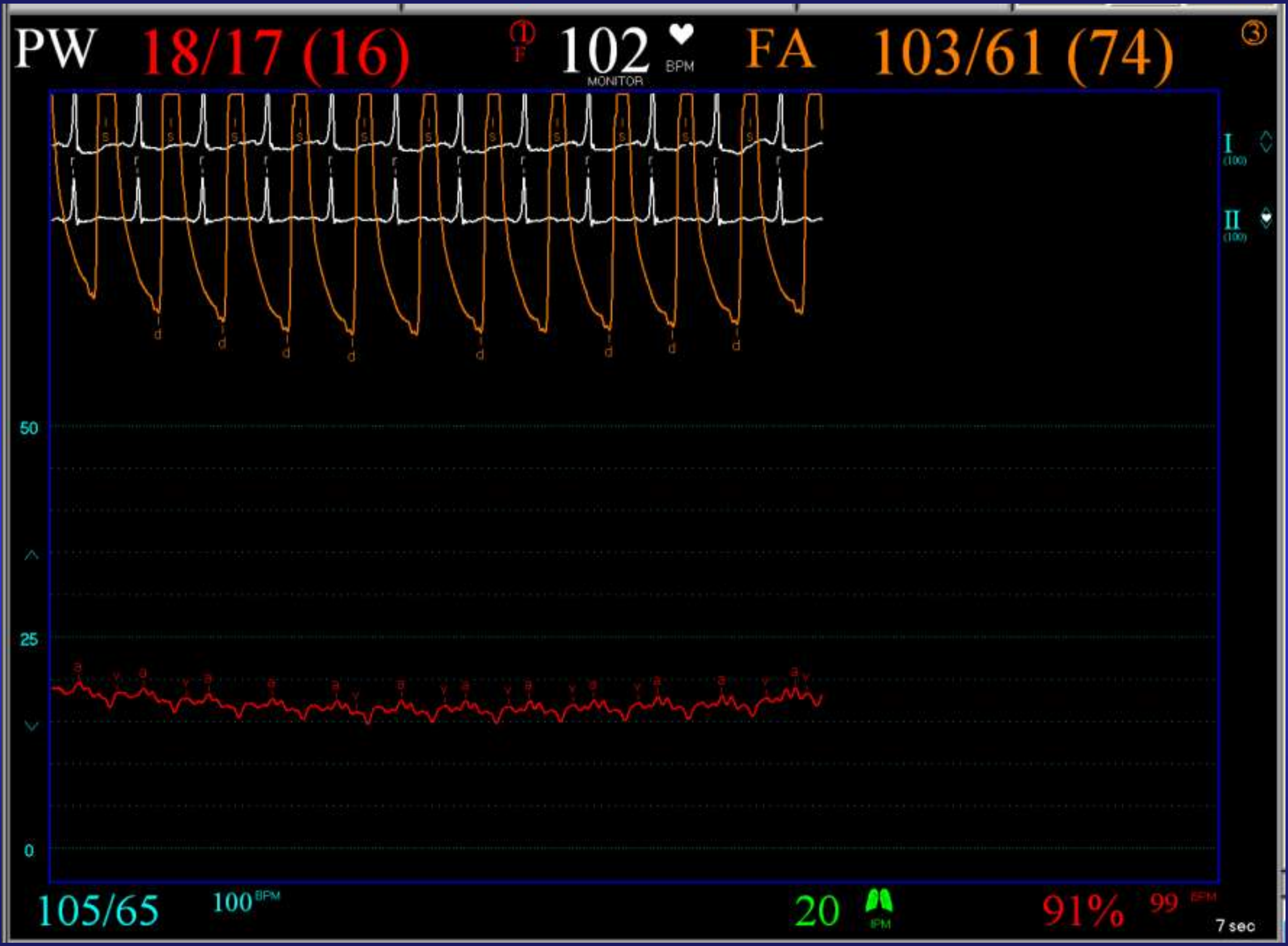


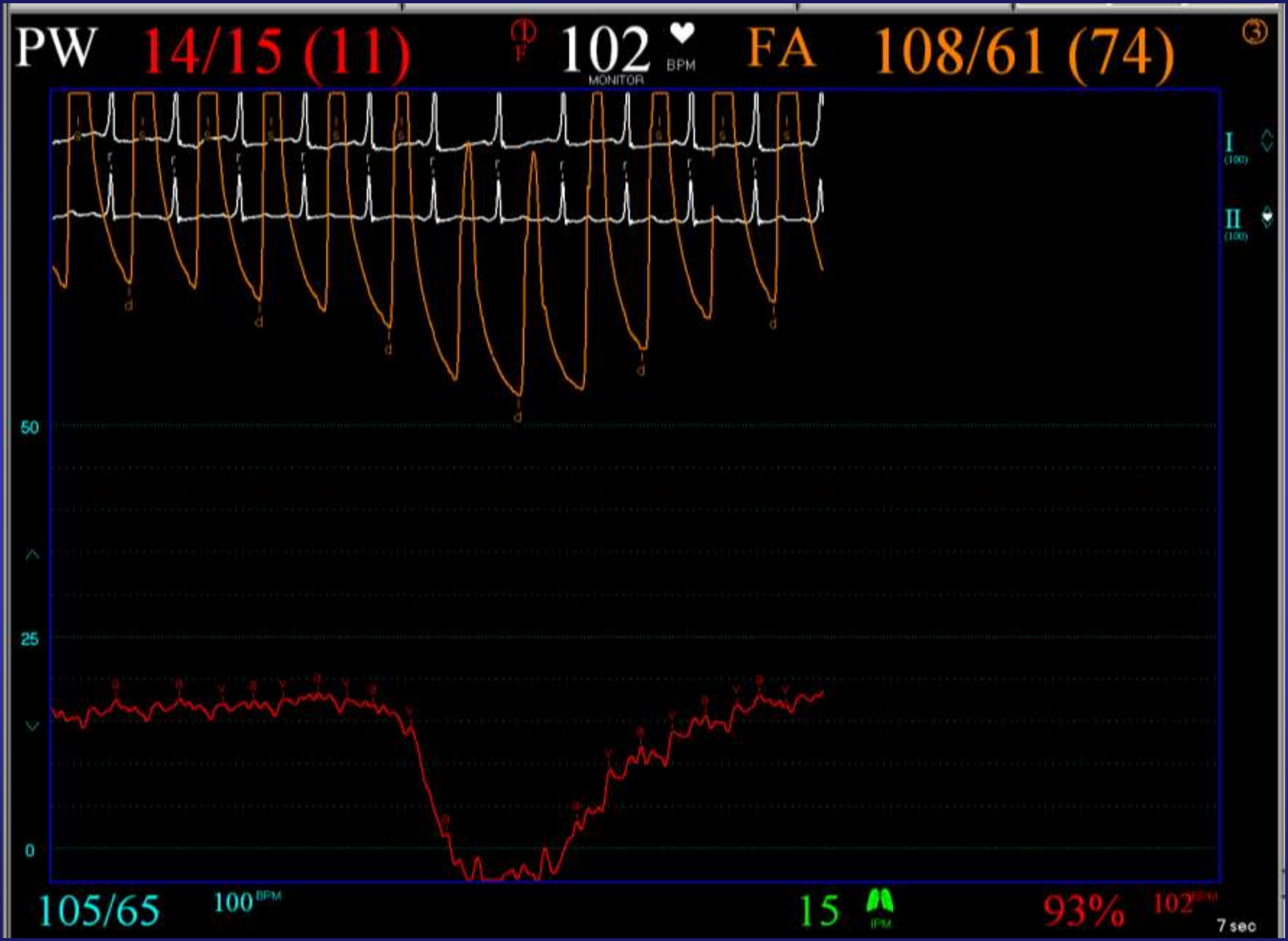


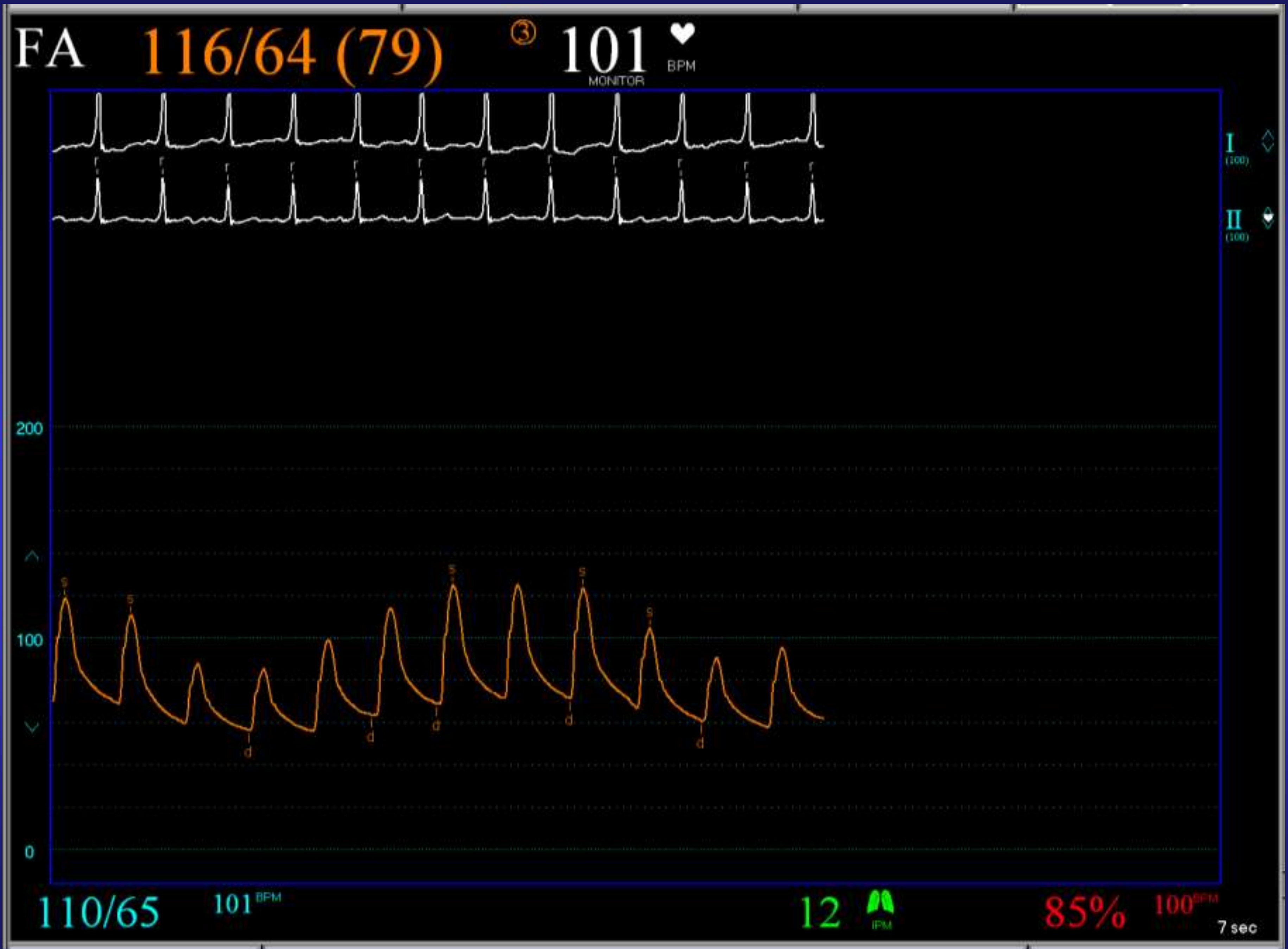



LV 104/1, 22
47
BPM
MONITOR
PW 16/18 (13)
II
V1
BP
50
25
0
101/56
45 BPM
5
IPM
100%
45
7 sec
<25 sweep> <25 paper>
Sinus Rhythm with occasional PVC's
AIR REST


PW 21/22 (15)
100 BPM MONITOR
FA 124/69 (86)
I (100)
II (100)
50
25
0
105/65
100 BPM
16 IPM
92%
100 BPM
7 sec


PW 18/17 (16)
102 BPM
MONITOR
FA 103/61 (74)
I (100)
II (100)
50
25
0
105/65
100 BPM
20
IPM
91%
99 BPM
7 sec


PW 14/15 (11)
102 BPM
MONITOR
FA 108/61 (74)
I
II
50
25
0
105/65
100 BPM
15
IPM
93%
102 BPM
7 sec

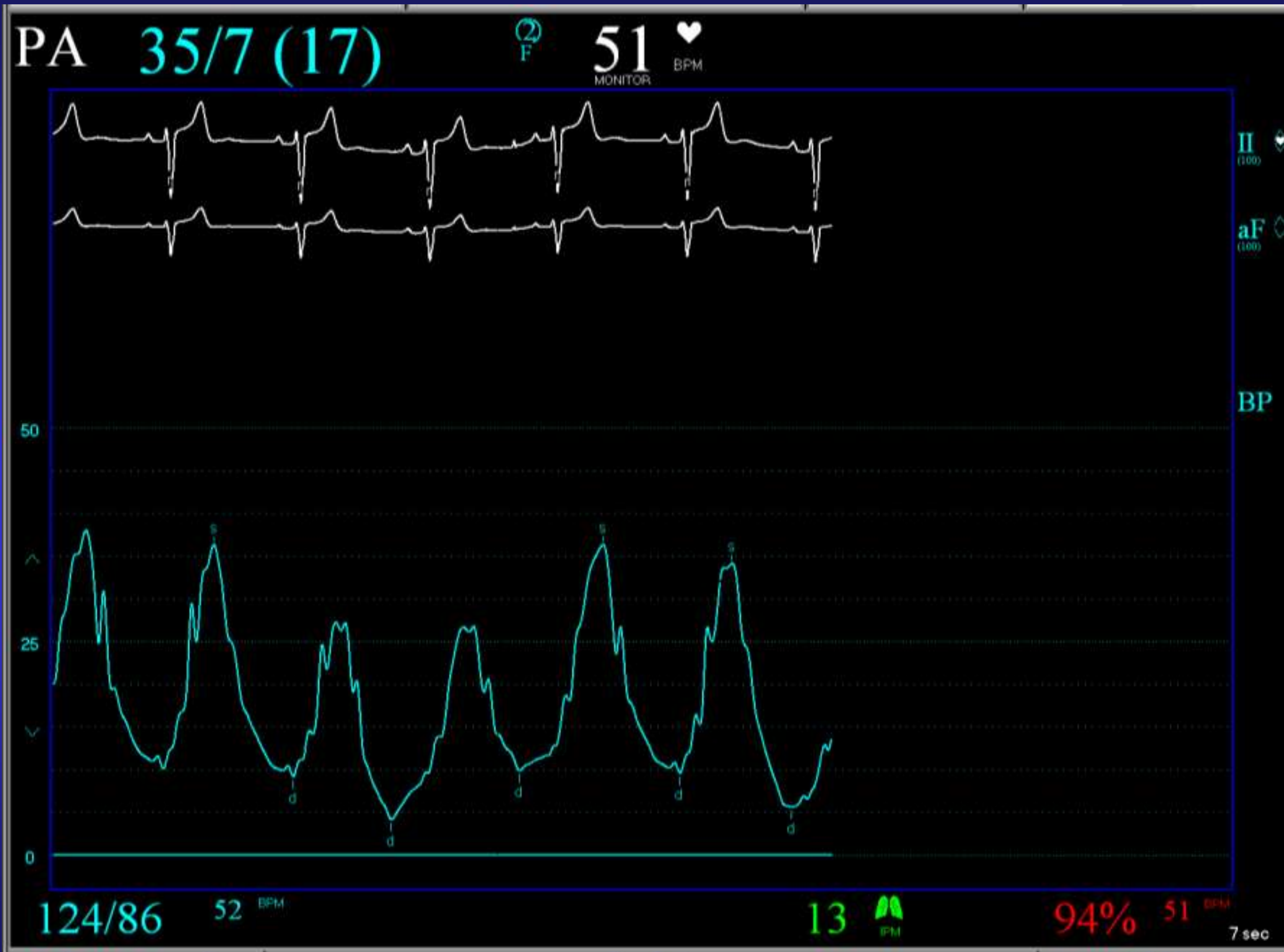

FA
116/64 (79)
③
101
BPM
MONITOR
I
(100)
II
(100)
200
100
0
s
d
110/65
101 BPM
12
IPM
85%
100 BPM
7 sec

The capillary wedge pressure and left ventricular end-diastolic pressure

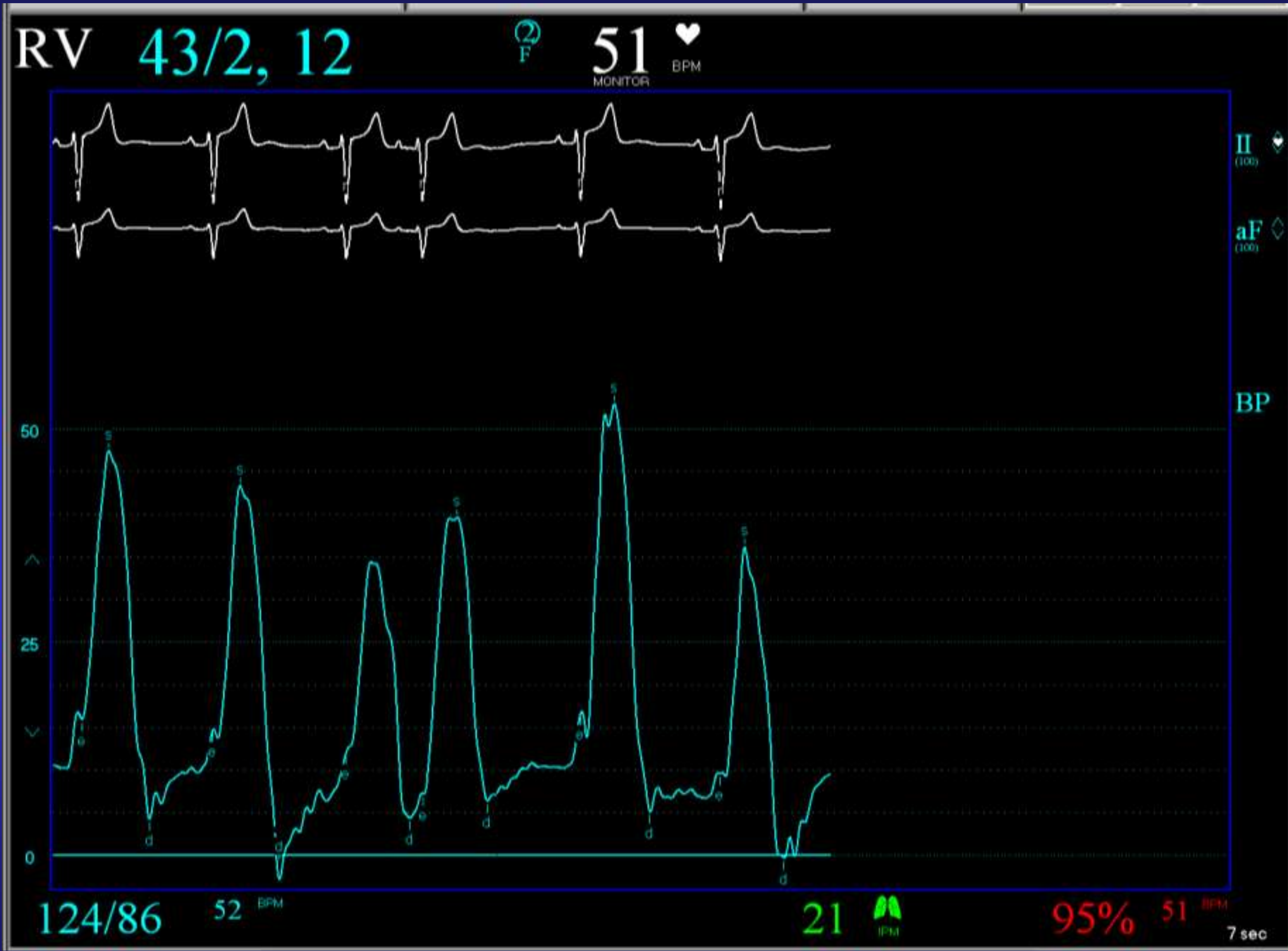
- 472 pts with simultaneous right and left heart catheterization
- 43 without heart disease
- 429 with primarily CAD, HTN, AS

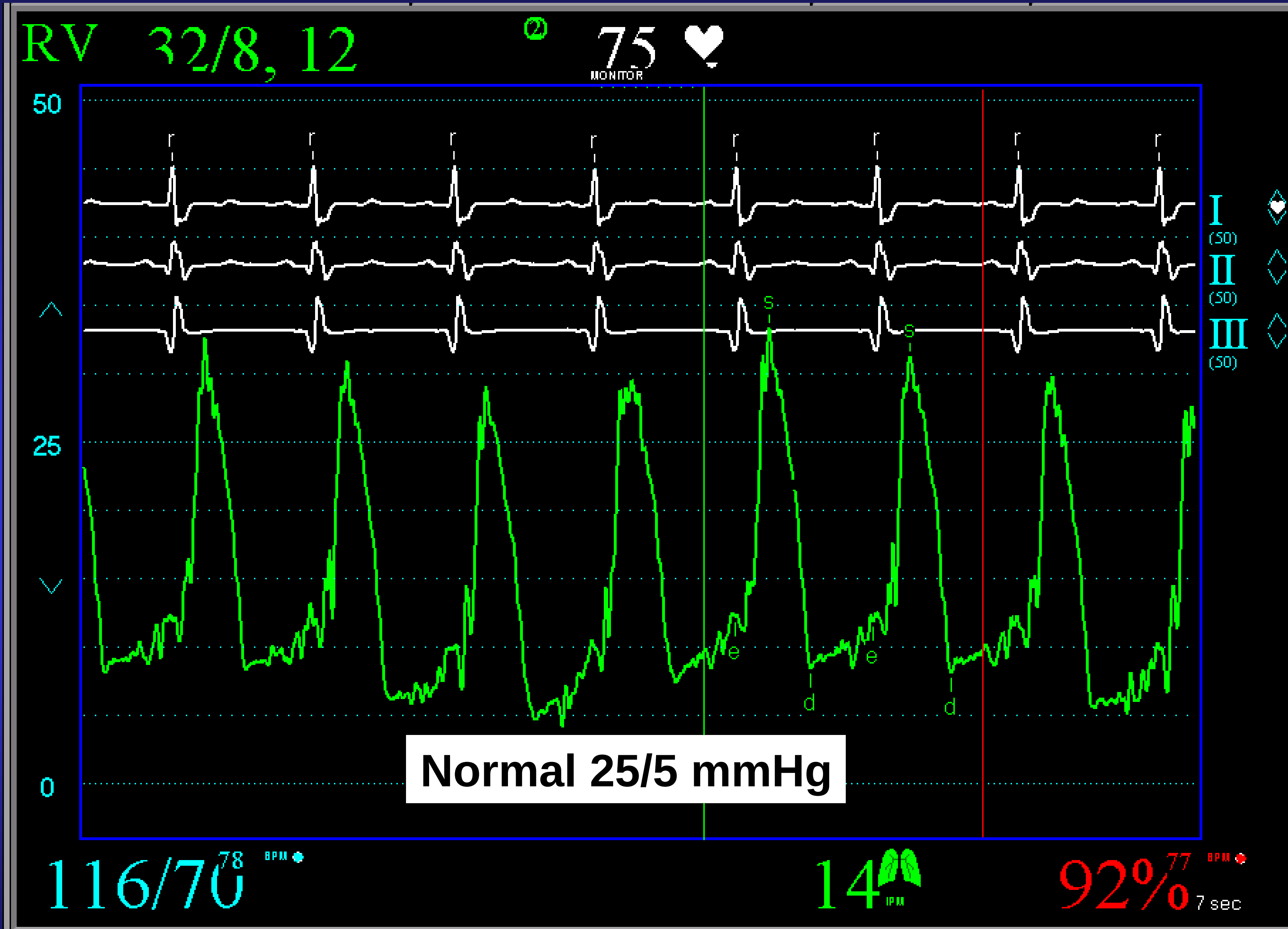
- Overall, mPCW = LVEDP p=0.88
- However, in 133 (28%), LVEDP > PCW by >5 mmHg
  - mPCW 13.0 ± 5.2
  - mLVEDP 20.4 ± 6.6
- 42/43 "normals" difference < 5 mmHg

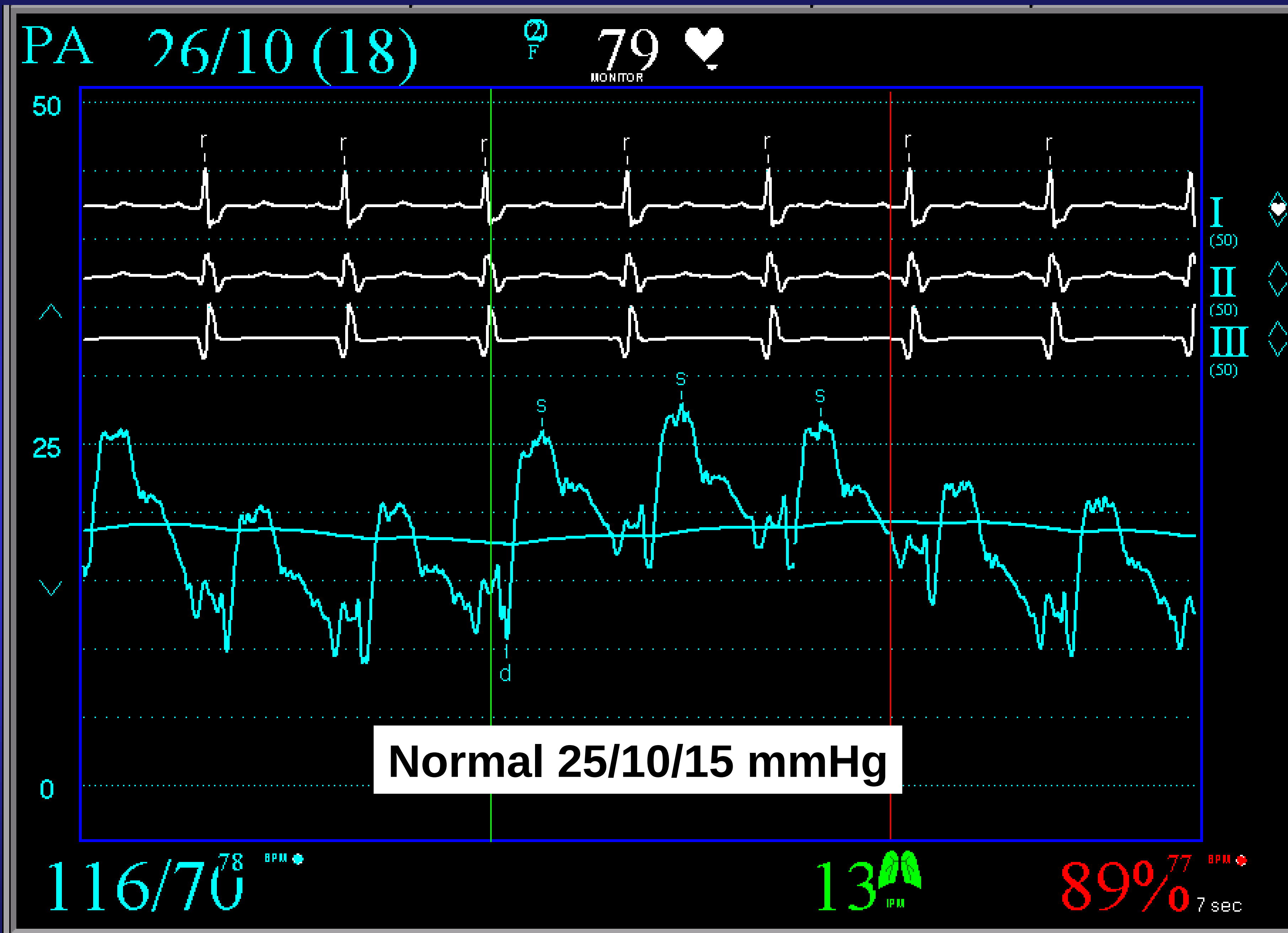
Flores ED, et al. AJC 1990;66:1532-1533



PA 35/7 (17)
F
51
MONITOR
BPM
II
(100)
aF
(100)
BP
50
25
0
124/86
52 BPM
13
RPM
94%
51
7 sec


RV 43/2, 12
51 MONITOR BPM
II
aF
BP
50
25
0
124/86
52 BPM
21
95%
51 BPM
7 sec


RV 32/8, 12
75
MONITOR
50
25
0
I
(50)
II
(50)
III
(50)
116/70
78
BPM
14
IPM
92%
77
BPM
7 sec
Normal 25/5 mmHg


PA 26/10 (18)
79
MONITOR
50
25
0
I
(50)
II
(50)
III
(50)
S
S
S
d
Normal 25/10/15 mmHg
116/70
78
BPM
13
IPM
89%
77
BPM
7 sec

Measuring Cardiac Output

- Cardiac output = Stroke volume x Heart rate
  - Ventriculography, echo, MRI, nuclear
  - Volume measurement difficult in clinical practice
- Fick principle
  - Oxygen consumption ($V0_2$) = oxygen delivery (CO) x oxygen extraction
  - Can also use other substances (e.g. green dye) or even temperature (e.g. “cold”) as the indicator

- **Cardiac output = $V0_2$ / [A-V 0_2 difference]**
- **$V0_2$ = A-V 0_2 diff x CO**
- **$V0_2$ = A-V 0_2 diff x (HR x SV) = 3 x 3 x 2 = 18x**
- **$V0_2$ = 125 cc/min/m^2 [BSA 2.0 m^2]**
- **A – V 0_2 difference =**
  (0.99 – 0.75) x
  (14.0 gm Hgb/dL)(1.36 cc 0_2 / gm Hgb) x
  10 (dL/L blood)

5.47 Liters per minute

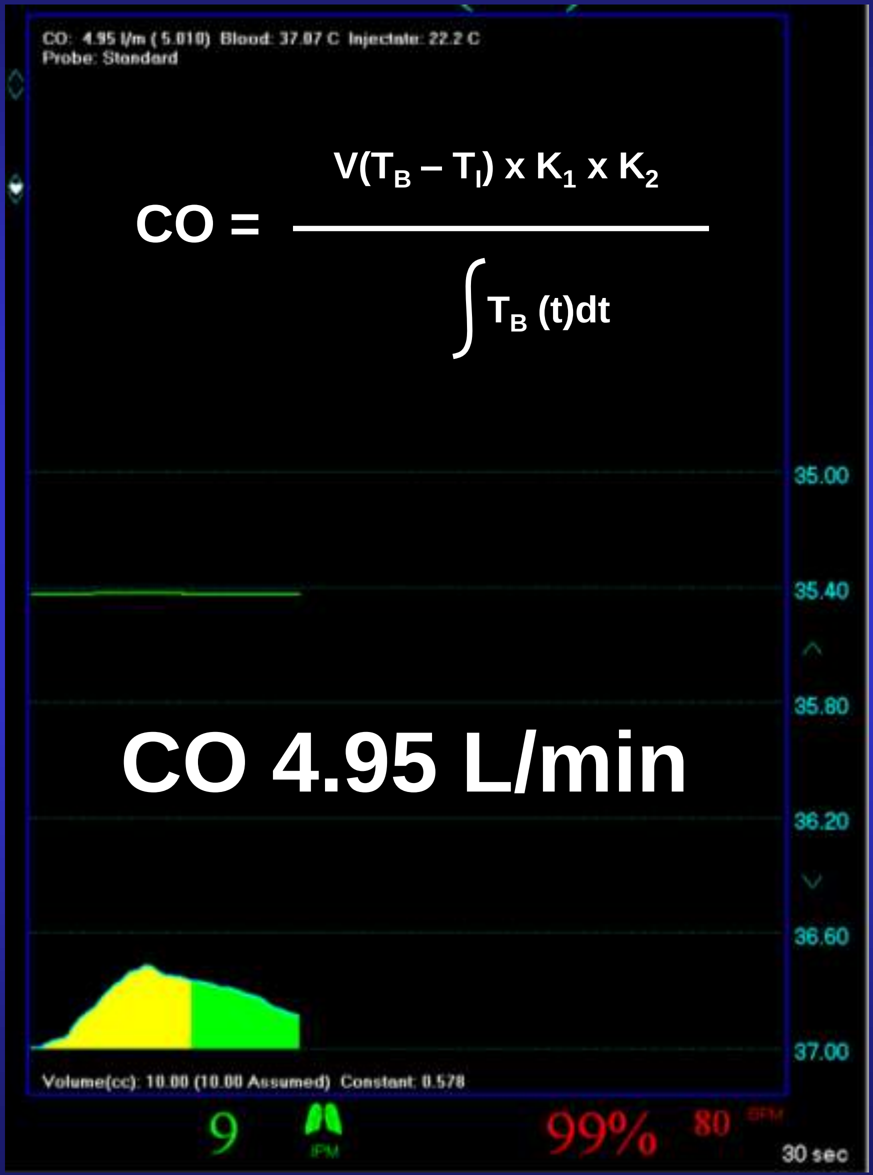
(divide by BSA to get cardiac index)

The Fick Cardiac Output

Sources of Error

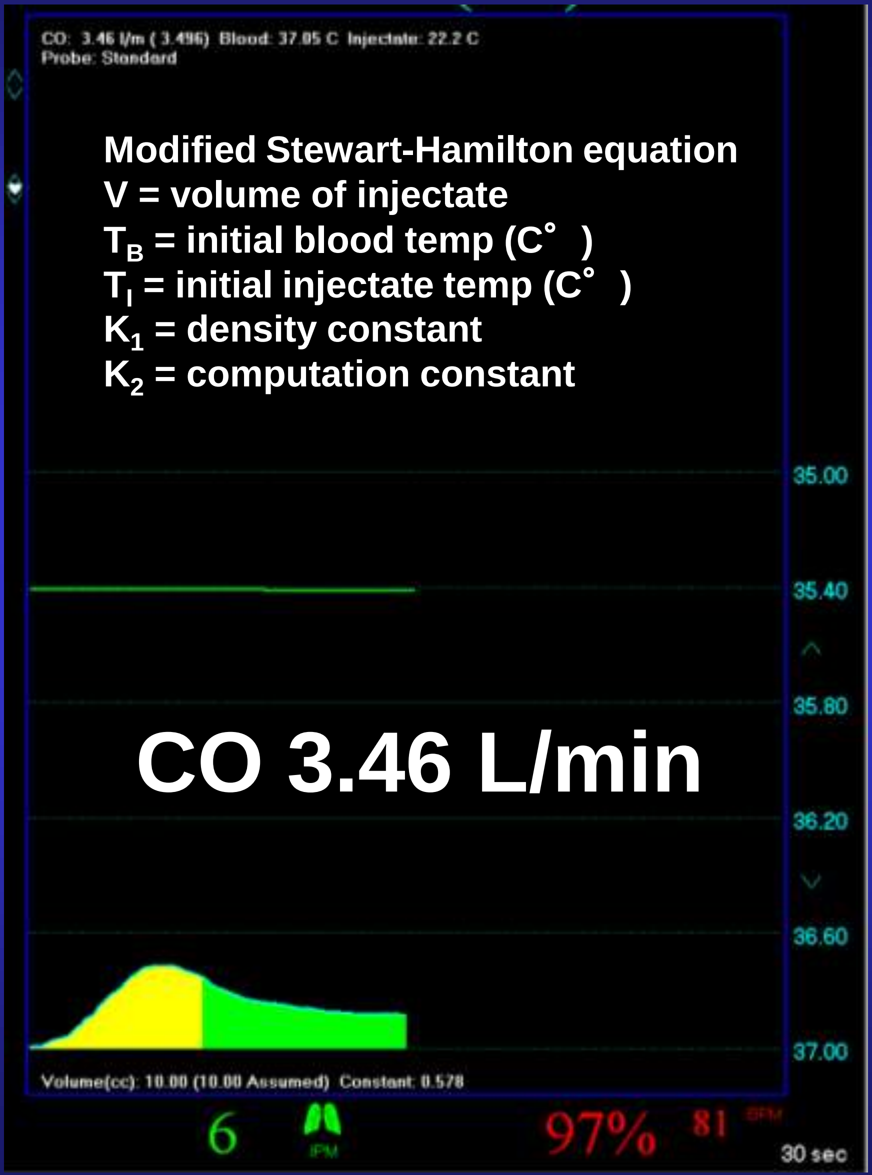
- **Oxygen consumption measurement (6% error)**
  - **125 cc/min/m2 vs 110 cc/min/m2 (>70 yrs)**
  - **126 ± 26 cc/min/m2** (Dehmer GJ, Clin Card 1982;5:436)
  - **Half off by >10%, some off by >25%** (Kendrick AH, EHJ 1988;9:337)
- **Oxygen saturation (5% error)**
  - **Accurate generally when >40%**
  - **Air bubbles, heparin dilution, site "contamination"**
  - **Less error with large A-V 02 differences, e.g. low output**
- **Total error 10%** (Visscher MB, J Appl Phys 1953;5:635)

Thermodilution Cardiac Output



$$CO = \frac{V(T_B - T_I) \times K_1 \times K_2}{\int T_B(t)dt}$$

CO 4.95 L/min



Modified Stewart-Hamilton equation
- V = volume of injectate
- T_B = initial blood temp (C°)
- T_I = initial injectate temp (C°)
- K_1 = density constant
- K_2 = computation constant

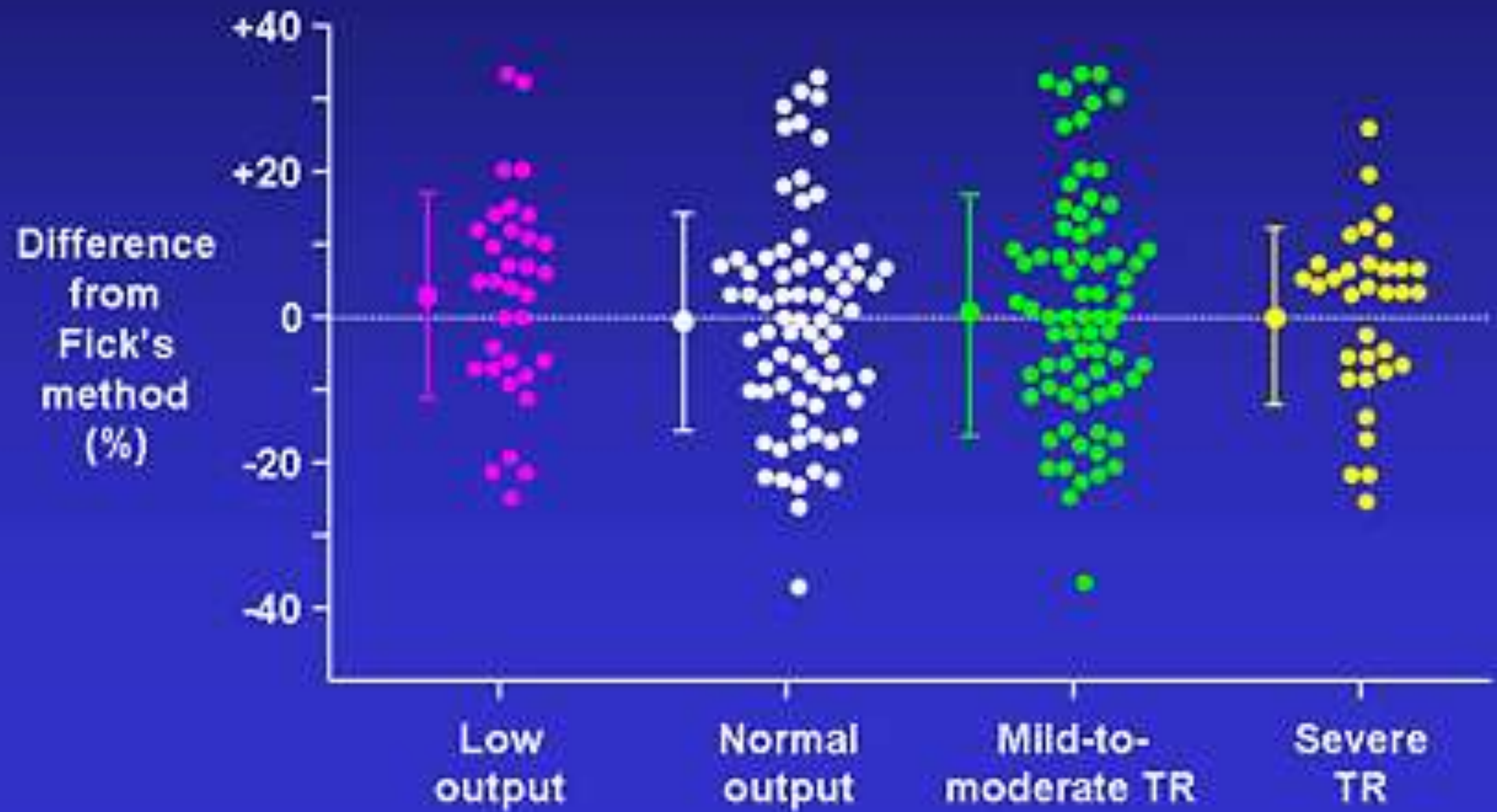
CO 3.46 L/min

Thermodilution Cardiac Output

Sources of Error

- **Tricuspid regurgitation**
  - **TD CO = 0.8 x Fick CO** ***(Hamilton MA, et al. Am J Card 1989;64:945)***
- **Other sources of warming**
  - **PA blood temperature changes with respiration and cardiac cycle**
  - **Empirical correction factor for catheter warming**
- **Reproducibility of injection**
- **Overestimates in low flow states (by as much as 35% when CO <2.5 L/min)**

Cardiac Output
Thermodilution vs Fick



Courtesy of Michael Mathier, MD

Vascular Resistance

- Poiseuille equation [$R = \Delta P/Q = 8\eta l / \pi r^4$]
- Modeled upon continuous flow (not pulsatile, e.g. impedence)
- Dependent upon length, viscosity, cross-sectional area of vessel
- Primarily at level of arterioles (60%) but other contributions (arteries 10%, capillaries 15%, small veins 15%)
- Influenced by autonomic regulation and local metabolic factors

Calculating Vascular Resistance

- **Mean BP = Output x Resistance** ***(Ohm's law, V=IR)***

- **SVR = (mean BP – mean RA) / Qs**
- **PVR = (mean PA – mean PCW / Qp**
- **Generally assume CO = Qs = Qp**

- **Normal values**
  - **SVR = 800 – 1200 dynes-sec-cm-5**
  - **PVR = 80 – 120 dynes-sec-cm-5**
  - **Wood units (x 80) = dynes-sec-cm-5**
  - **SVRI or PVRI obtained by dividing by CI**

Hemodynamic Management

Maximizing CO, decreasing filling pressures…yet maintaining BP

$$CO = \frac{MAP - RA \downarrow}{SVR \downarrow}$$

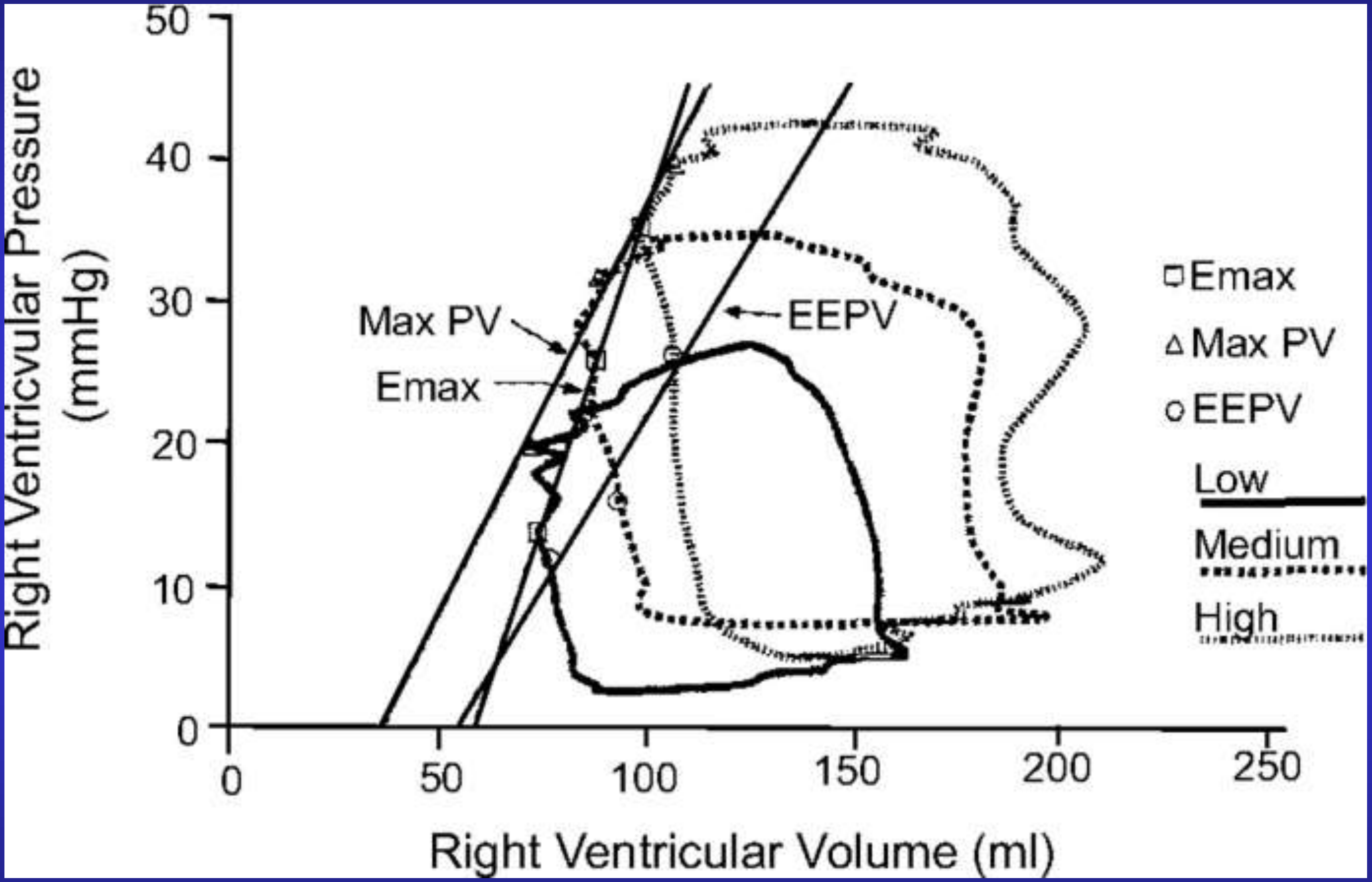
$$MAP - RA = SVR \times CO$$

$$\downarrow \qquad \downarrow$$

Very Bad

Which one of the following provides a measure of load independent RV function:

a) RVEF
b) TAPSE
c) CVP
d) RV width/length ratio
e) RVSWI



Haddad, F. et al. Circulation 2008;117:1436-1448

More equations!

RVSWI = (mPAP – CVP) x [CI/HR] x 0.0136 gm-m/m2

LVSWI = (MAP - PCWP) x [CI/HR] x 0.0136 gm-m/m2

(0.0136 converts mmHg/ml to gm-m)

Stroke Volume	SV	60 – 130 mL
Stroke Volume Index	SVI	30 – 65 mL/beat/m2
Cardiac Index	CI	2.5 – 4.2 L/min/m2
RV Stroke Work Index	RVSWI	5 – 10 g-m/beat/m2
LV Stroke Work Index	LVSWI	45 – 60 g-m/beat/m2
Pulmonary Vascular Resistance	PVR	20 – 120 dynes x sec x cm-5
Systemic Vascular Resistance	SVR	800 – 1500 dynes x sec x cm-5

Assessing RV performance

Parameter	**Desirable Value**
RVSWI	> 300-600 mmHg-ml/m^2
CVP	< 15 mmHg; 5 mmHg < PCWP
Presence of TR	Minimal to Moderate
PVR and TPG	PVR < 4 WU; TPG < 15 mmHg
RV Size	RVEDV < 200 mL; RVESV < 177 mL

Slaughter MS, et al. JHLT 2010;29:S1-S39

LVADs and post RV failure

RV Stroke Work Index (RVSWI)

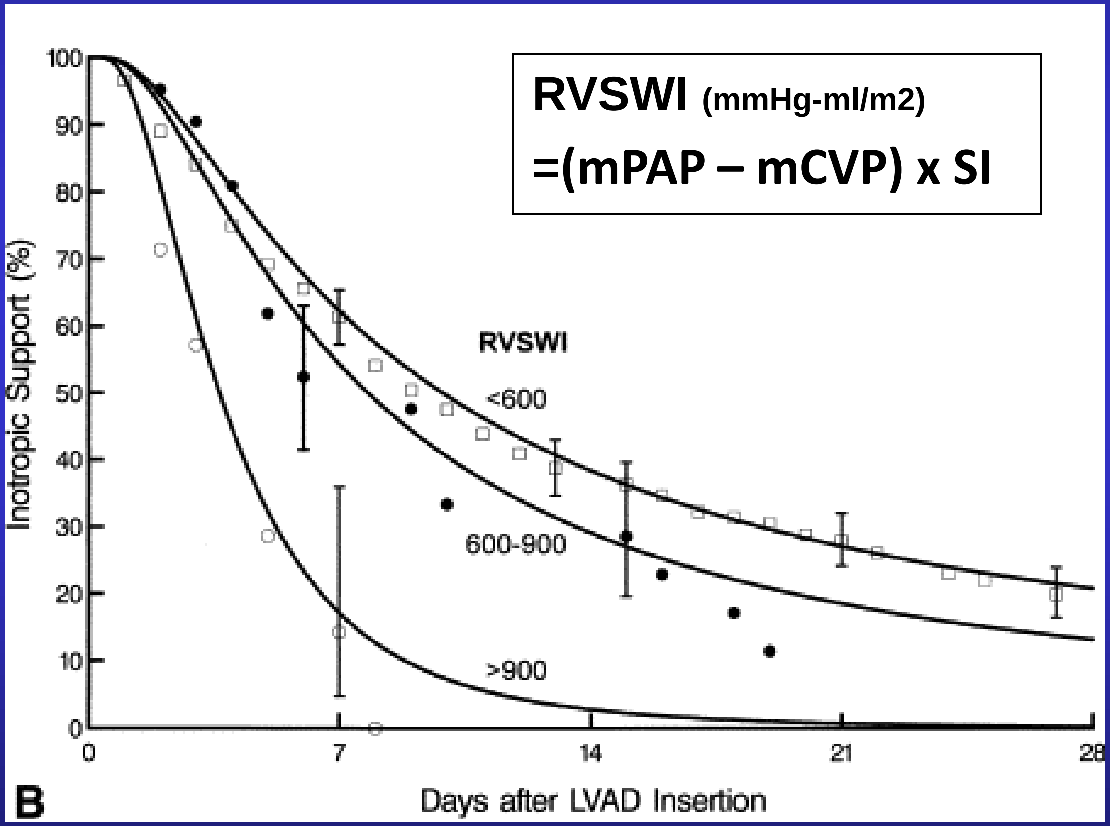
207 pts from 1991-2002
Age 55±11.1, 14% female
All on inotropes, 76% on IABP

mPA 37±8.6, CVP 18±6.0, CI 1.85±0.52

Cr 1.75±0.90; Tbili 1.4 (0.8, 3.1), AST 45 (22, 200)

Duration of inotropic support associated with:

1) **RVSWI, older age, nonischemic**
2) **Associated with poor pre-Tx survival**

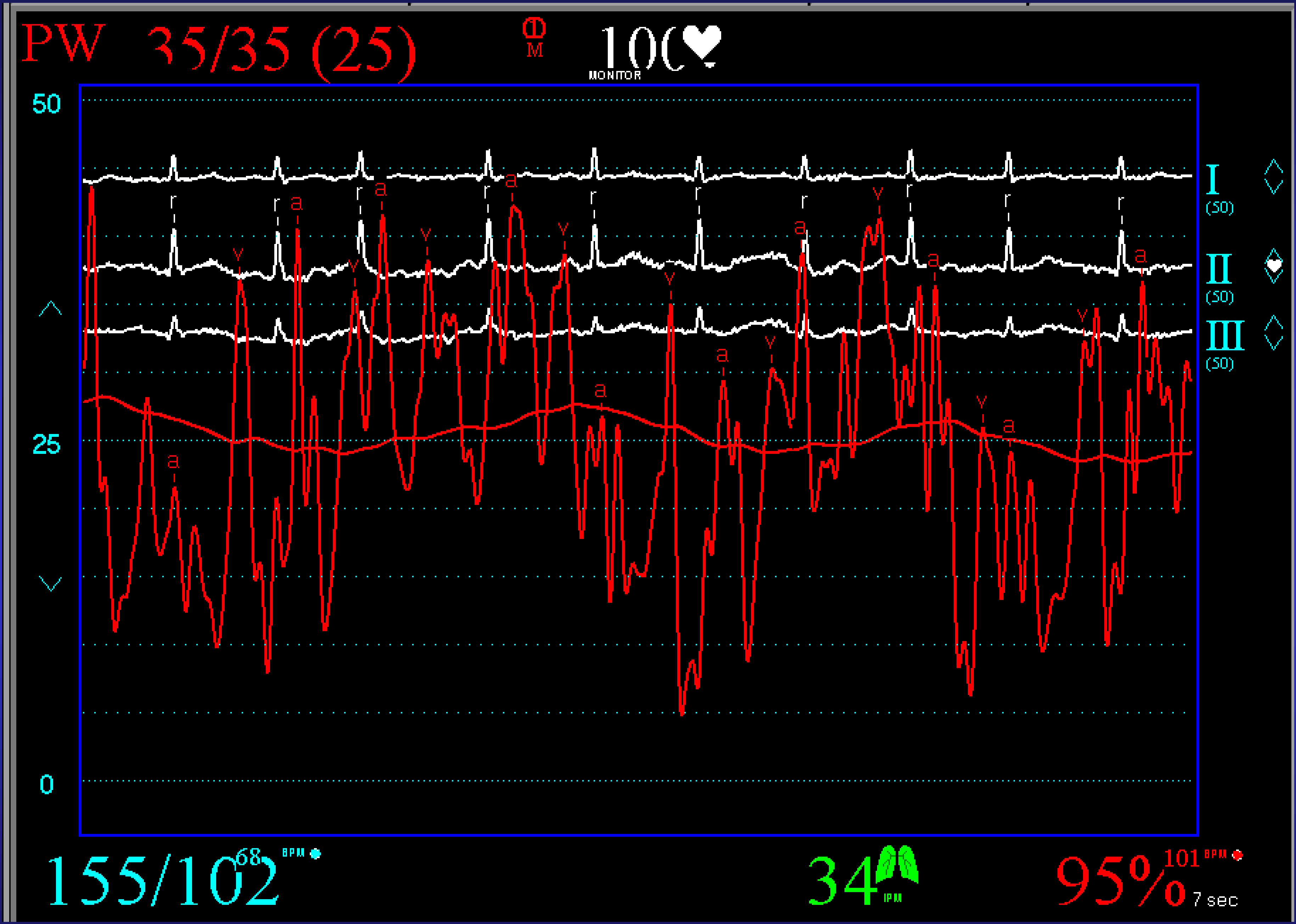


Schenk S, et al. J Thorac Cardiovasc Surg 2006;131:447-54


PW 14/11 (9)
68
MONITOR
50
25
0
I
(100)
II
(100)
III
(100)
Obese man with progressive exertional dyspnea but no history of HF. No PH. BNP normal.
146/102
65
26
96%
68
7 sec

What next?

a) PE protocol chest CT.
b) Pulmonary function tests.
c) Nuclear stress test.
d) Holter monitor.
e) Exercise hemodynamics.



PW 35/35 (25)
M
100
MONITOR
50
25
0
I (50)
II (50)
III (50)
155/102
68 BPM
34
IPM
95%
101 BPM
7 sec

Exercise hemodynamics to unmask HFPEF

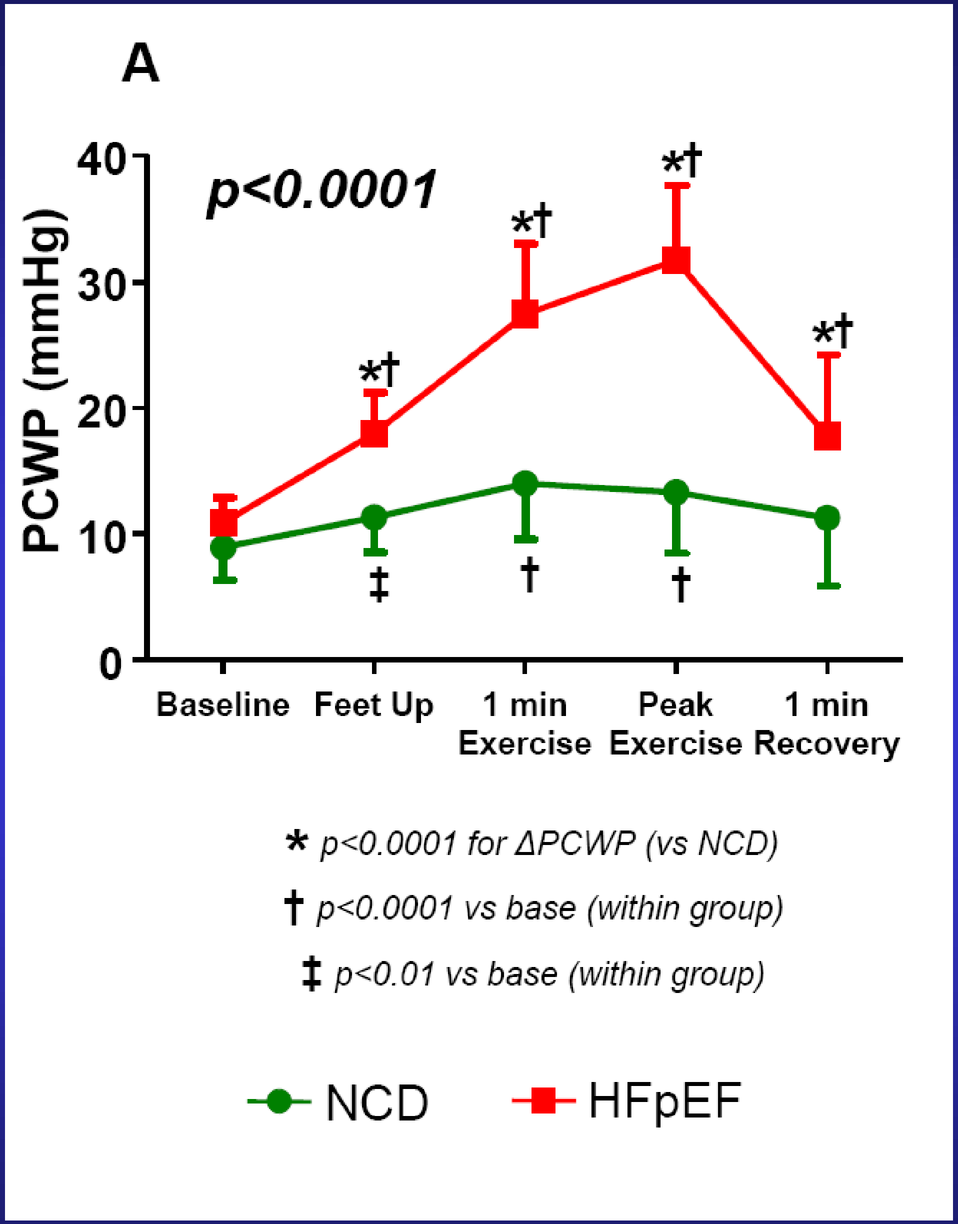
55 pts referred for dyspnea

Normal BNP
No CAD
EF > 50%

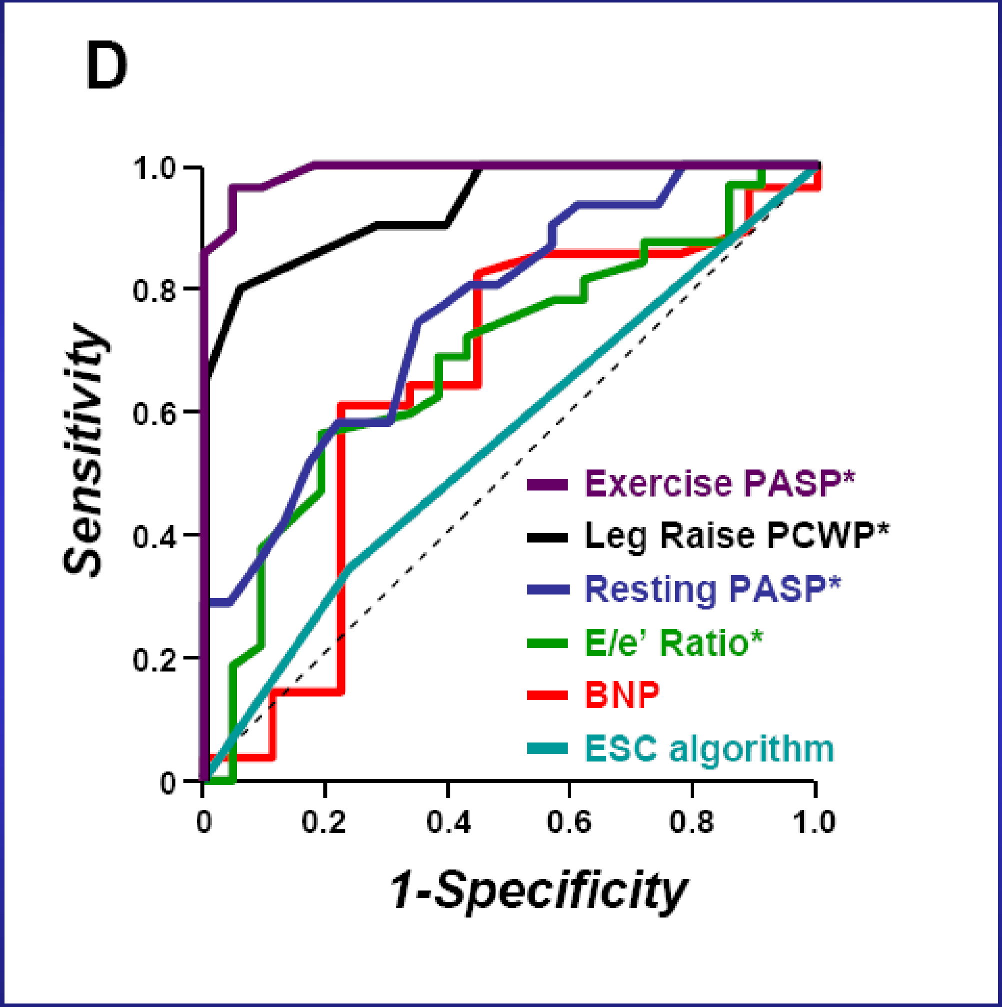
Normal resting hemodynamics
Mean PA < 25 mmHg
Mean PCW <15 mmHg

HFPEF
Exercise PCW > 25 mmHg
Exercise mPA > 30 mmHg

Supine bicycle or arm adduction.
Femoral or internal jugular/radial.

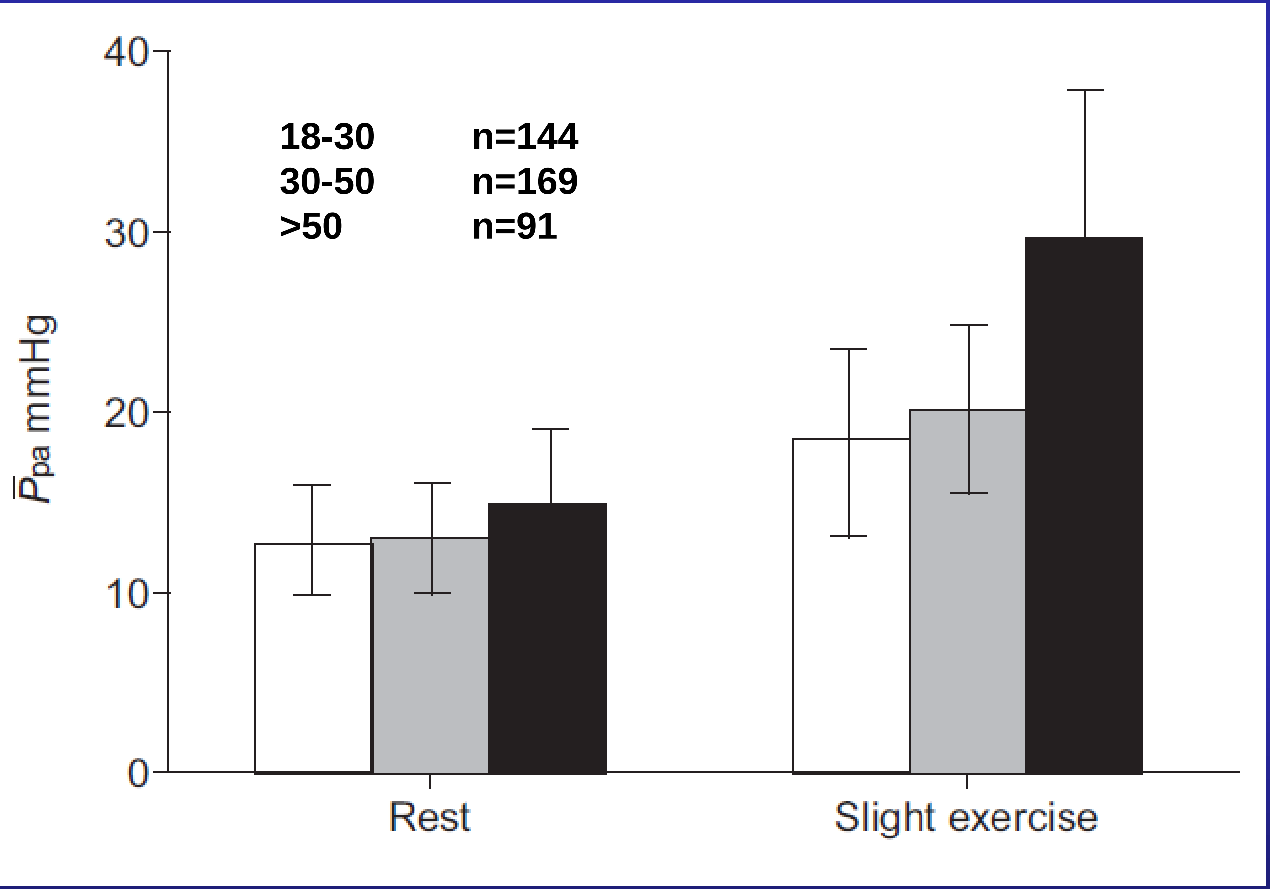


Borlaug BA, et al. Circ HF 2010 (in press)



Borlaug BA, et al. Circ HF 2010 (in press)

Resting but not exertional PA pressures are age independent



Kovacs G, et al. Eur Resp J 2009;34:888-894

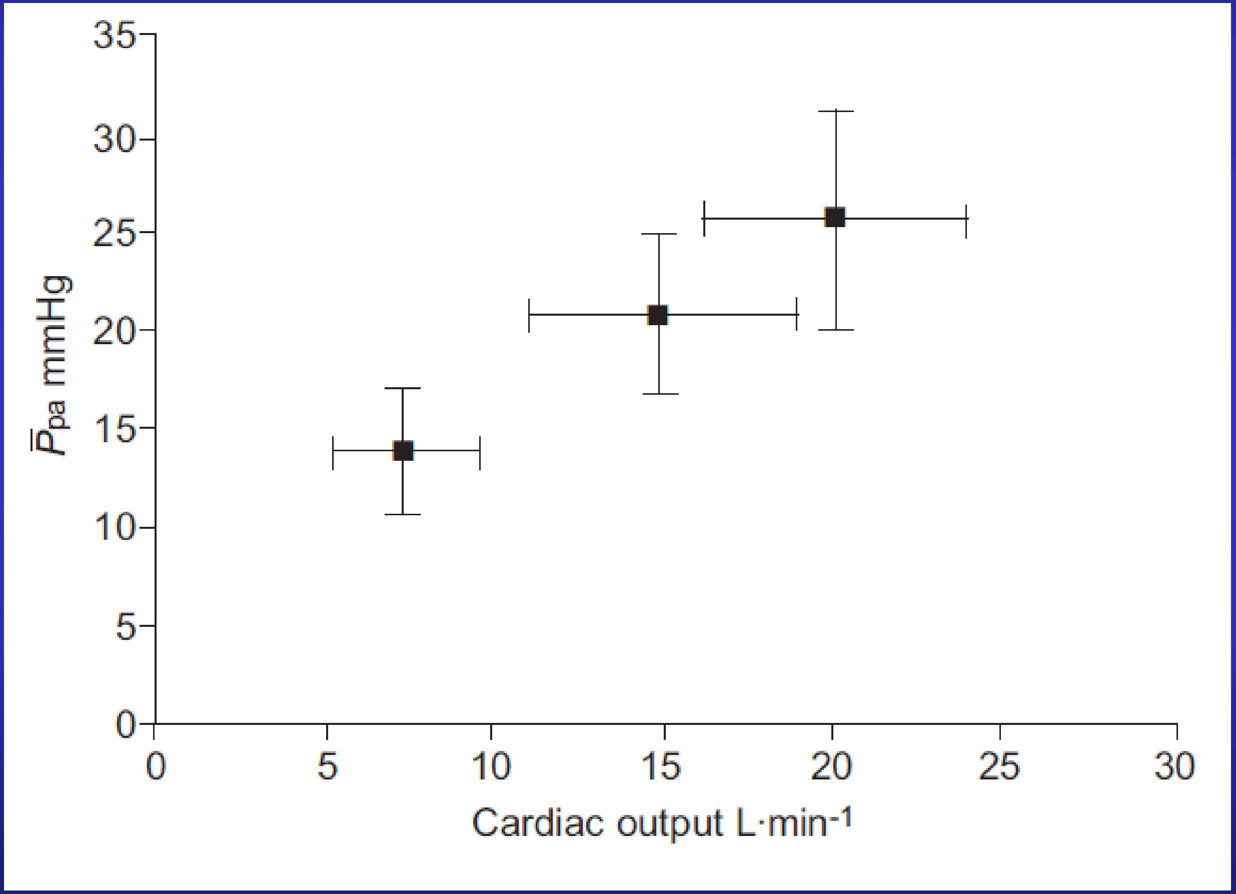
Increases in PA and PCW in normal individuals varies substantially

	Rest	Slight	Maximal
$\bar{P}_{pa}$ mmHg	13.8±3.1	20.8±4.0	25.6±5.6
P_{paw} mmHg	5.9±2.8	9.1±4.2	14.9±7.9
Heart rate min^{-1}	82±16	103±14	170±14
Cardiac output $L \cdot min^{-1}$	7.4±2.2	14.9±3.9	20.0±3.8

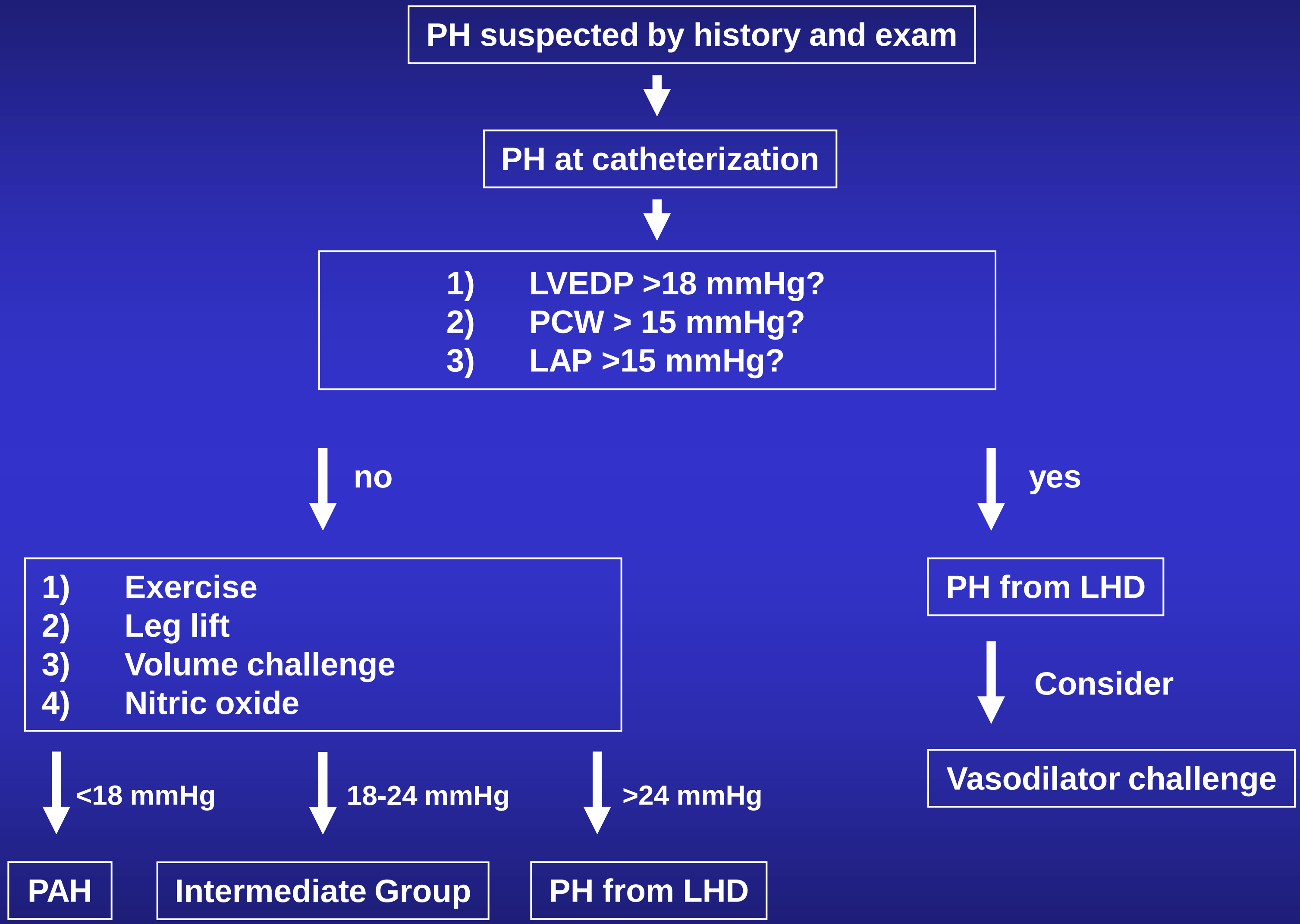
Slight	**HR 100-110 bpm**	**WR 50 watts**	**V02 1000 cc/min**
Maximal	**HR 160-170 bpm**	**WR 150-200 watts**	**V02 2400 cc/min**

Kovacs G, et al. Eur Resp J 2009;34:888-894

The mean PAp rises linearly with increase in CO



Kovacs G, et al. Eur Resp J 2009;34:888-894


PH suspected by history and exam
PH at catheterization
1) LVEDP >18 mmHg?
2) PCW > 15 mmHg?
3) LAP >15 mmHg?
no
yes
1) Exercise
2) Leg lift
3) Volume challenge
4) Nitric oxide
PH from LHD
Consider
Vasodilator challenge
<18 mmHg
18-24 mmHg
>24 mmHg
PAH
Intermediate Group
PH from LHD

Invasive Hemodynamics

Take Home messages

- Phlebostatic axis and the zero reference
  - How was it determined
- Values versus waveforms
  - Patterns not apparent from values
  - Respiratory variability
- Usually obtained at rest and are not static
- Understand how cardiac output and resistance are obtained
- Are you sure it’s the wedge?

Which patient should have an endomyocardial biopsy?

a) 70 year old man with EF 25%, EDD 7.0 cm, EKG qV1-V4, NYHA III
b) 35 y/o AA man with EF 35%, EDD 6.5 cm, EKG LVH, Brother with heart transplant
c) 55 y/o woman with EF 20%, EDD 4.5 cm, EKG low volts,NSVT, NYHA IV, BP 80/65
d) 25 y/o man with EF 55%, TnI 5.0, EKG diffuse ST elevation, pleuritic chest pain

Endomyocardial Biopsy

Few Class I indications

- New onset HF < 2 wks duration
  - normal sized or dilated LV
  - hemodynamic compromise

- New onset HF 2 – 12 wks duration
  - new ventricular arrhythmias
  - advanced AV block
  - or failure to respond to usual care within 1 -2 wks

ACC/AHA EMBx guidelines 2007

Endomyocardial Biopsy

When To Suspect a Specific Diagnosis

Class II (ACC/AHA Biopsy guidelines)

- Failure to respond to usual therapy
- Search for myocarditis or infiltrative disorders
  - Rash, eosinophilia
  - Severe HF, normal EF, no HTN
  - Systemic features (e.g. hilar adenopathy)
  - Autoimmune features
- Unexplained ventricular arrhythmias

Cooper LS, Circ 2007;5:1914

Endomyocardial biopsy

Pros and Cons

- Pros
  - Tissue diagnosis
  - Hemodynamics
  - Safe in experienced hands
  - May be definitive
- Cons
  - Invasive
  - Sampling error
  - Not uniformly available
  - May not change management

Consider Endomyocardial biopsy when specific diagnosis is suspected

Summary

- Look at the Waveforms!
- Routine use of RHC is not necessary in heart failure but useful when the hemos are unclear, assessing PH, and considering advanced therapies.
- Consider hemodynamic challenge when resting hemodynamics are not diagnostic.
- Endomyocardial biopsy is primarily indicated when you suspect inflammatory or infiltrative disease.