Pulmonary Artery Catheterization & Cardiogenic Shock: Part 1

BWH Housestaff Noon Conference

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Disclosures

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Shock

"State of cellular and tissue hypoxia due to either ↓ O_2 delivery, ↑ O_2 consumption, inadequate O_2 utilization, or a combination of these processes."

Types of Shock

Type	PCWP	CO	SVR
Hypovolemic			
Cardiogenic			
Distributive			

Types of Shock

Type	PCWP	CO	SVR
Hypovolemic	↓↓	↓	↑
Cardiogenic			
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Cardiogenic	↑	↓↓	↑
Distributive			

Types of Shock

Type	PCWP	CO	SVR
Hypovolemic	↓↓	↓	↑
Cardiogenic	↑	↓↓	↑
Distributive	↔ or ↓	Var	↓↓

Types of Shock (2.0)

Type		RA	PCWP	CO	SVR
Hypovolemic		↓↓	↓↓	↓	↑
Cardiogen.	Left-sided	↔ or ↑	↑	↓↓	↑
	Right-sided	↑	↔ or ↓		
	Biventricular	↑	↑		
Mixed		↑	↑	↓↓	↓↓
Distributive		↔ or ↓	↔ or ↓	Var	↓↓
Obstruct.	Tension PTX	↓↓	↓	↓↓	↑
	PE	↑	↓		
	Tamponade	↑	↑		

Definition of Cardiogenic Shock

- **Complex clinical syndrome characterized by clinical triad of:**
  1) **Tissue and organ hypoperfusion** → Δ mental status, cool or mottled extremities, oliguria, ischemic liver or kidney injury, lactic acidosis
  2) **Ineffective cardiac output** (clinical assessment or invasive hemodynamics)
  3) **Normal or elevated cardiac filling pressures** (pulmonary congestion seen in ~2/3)

- Clinical trial entry criteria generally include sustained HoTN, but "normotensive CS" can occur (~5%) in setting of intense vasoconstriction

- **Hemodynamic criteria:**
  – CI <2.2 L/min/m^2
  – PCWP >15 mmHg

Assessing Shock

Type	Invasive	Non-Invasive
Perfusion pressure	Arterial line	
Filling Pressures	Left-sided: PCWP from PAC Right-sided: RA (or CVP from CVC)	
Cardiac Output	Thermodilution or Fick CO from PAC (can approx. w/ $S_{cv}O_2$ from CVC)	
SVR	Calculated from MAP, CVP & CO	

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Cardiac Output	Thermodilution or Fick CO from PAC (can approx. w/ $S_{cv}O_2$ from CVC)	UOP (not if other cause of AKI); LFTs, lactate; pulse pressure; mental status
SVR	Calculated from MAP, CVP & CO	

Assessing Shock

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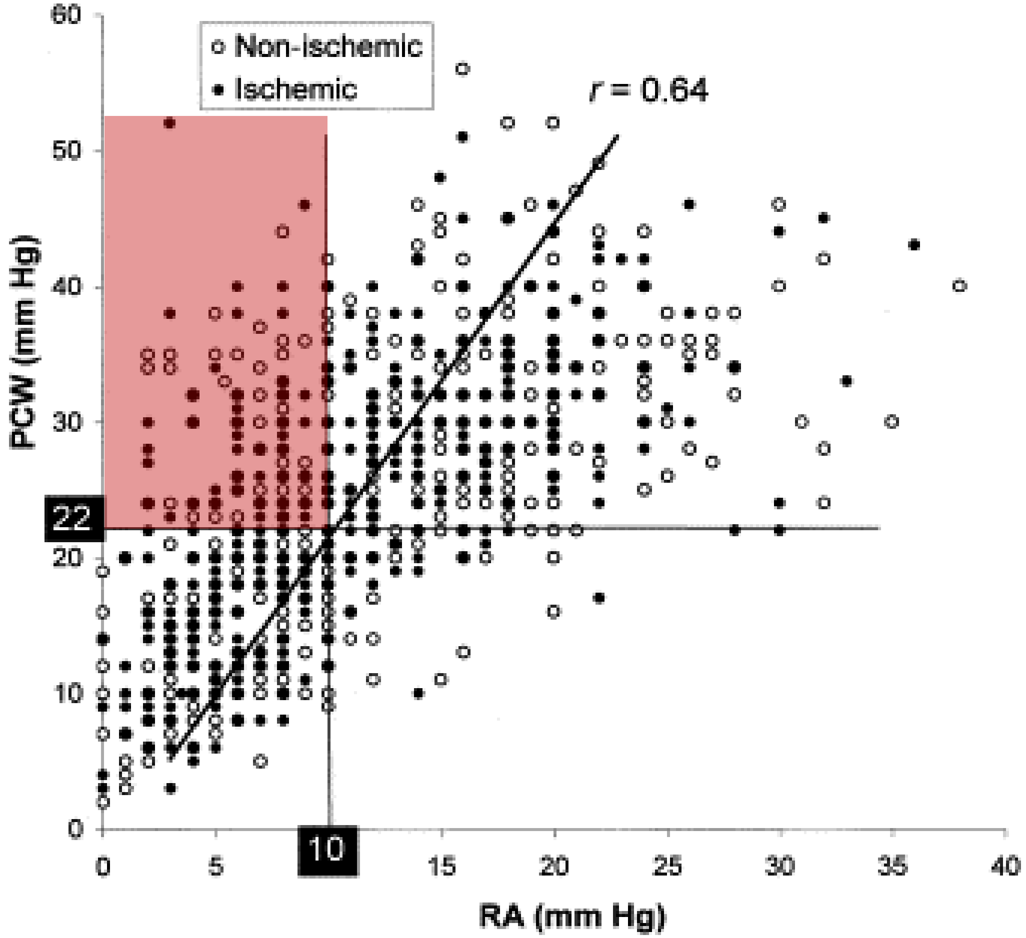
SVR	Calculated from MAP, CVP & CO	Capillary refill; forearm & leg temperature

RAP vs. PCWP in *Chronic HF*

1000 Patients with Chronic HF Evaluated at Transplant Center w/ PAC

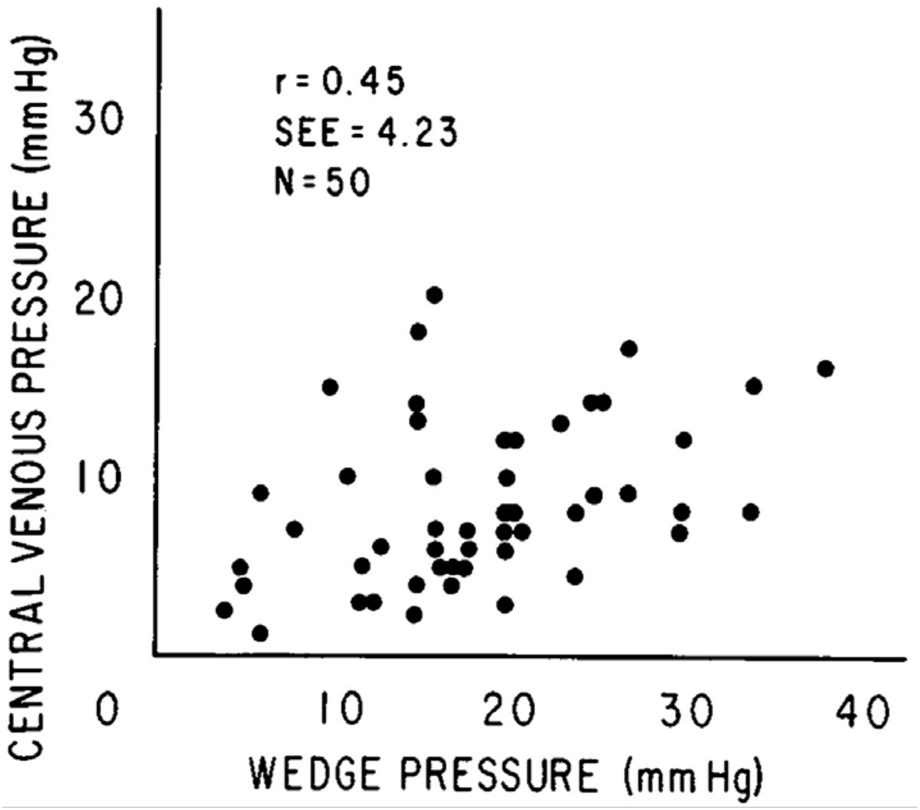


		PCWP	
		<22	≥22
RAP	<10	~30%	~15%
	≥10	~6%	~49%

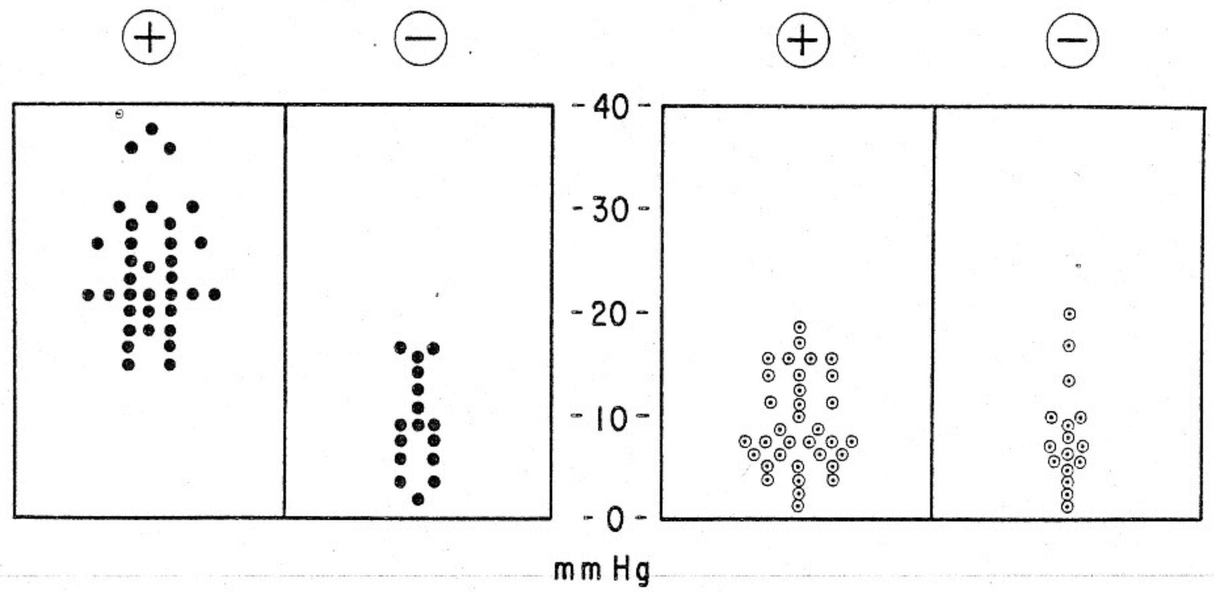
- ***If RAP high, WP very likely high***
- ***If RAP low, WP still high in ~1/3 of cases***

Drazner MH et al. *J Heart & Lung Tx* 1999;18:1126-32

CVP vs. PCWP in *Acute MI*



Pulmonary Edema on CXR



PCWP **CVP**

Forrester et al. *NEJM* 1971;285:190

Oxygen Saturation in Shock

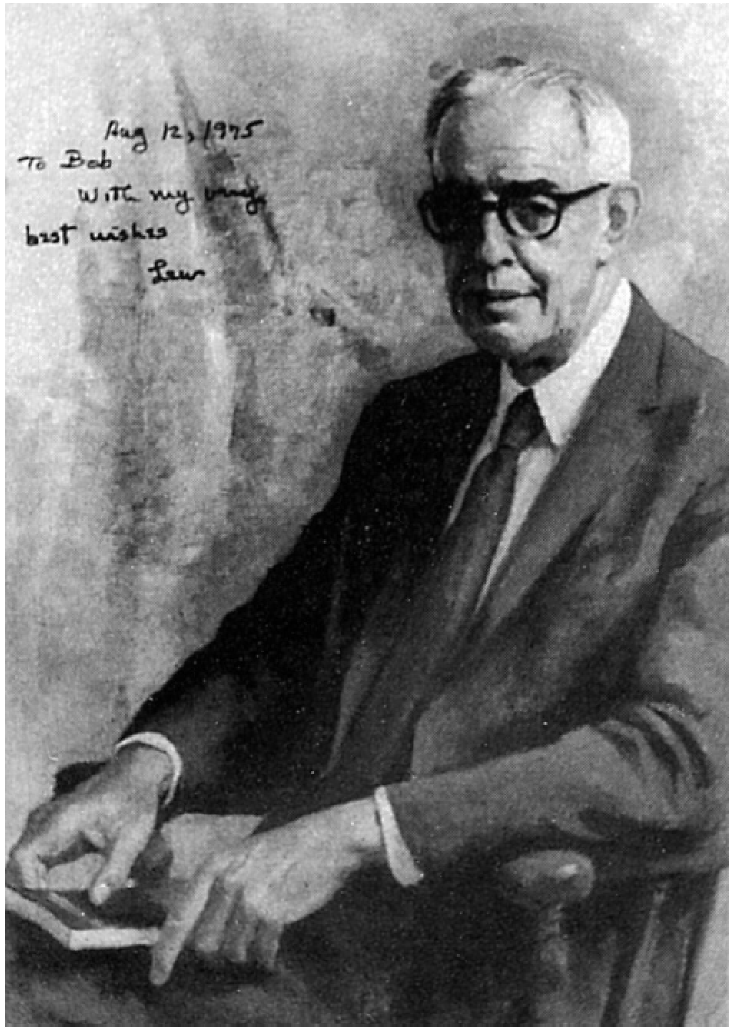
Situation	CVO_2 vs. MVO_2	Correlation: Absolute	Correlation: Δs
Normal	CVO_2 2-3% lower	n/a	n/a
Shock	CVO_2 ~6±6% higher	0.89	n/a
Cardiogenic Shock	CVO_2 ~10±10% higher	0.55	0.92

↓ splanchnic blood flow →
↑ O_2 extraction → ↓ IVC O_2 sat

Int Care Med 2006;32:1336
Circulation 1969;40:165

Lewis Dexter, MD

- Born in Boston
- Harvard (1932), HMS (1936)
- Residency at Presbyterian
- Returned to Boston to study w/ Soma Weiss
- Went to Buenos Aires to study hypertension w/ Bernardo Houssay (who would go on to receive Nobel Prize)
- Returned to Boston, continued his research under Soma Weiss (now at Peter Bent Brigham) to study renin



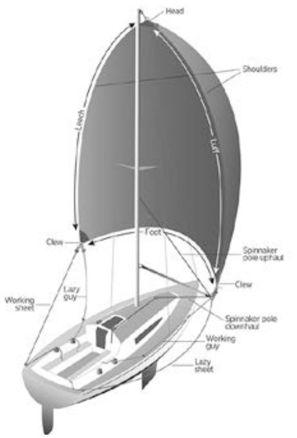
1st Catheterization of Pulmonary Artery

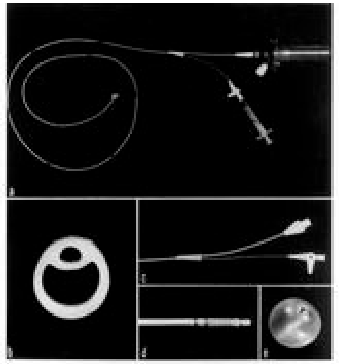
- On Dec 7, 1944, catheterizing renal vein of a patient w/ HTN under fluoro
- "I decided to wander around the heart … Suddenly, this catheter came clear out in the lung field and I was sure I [had] perforated the heart. I didn't have any idea what to do …"
- I turned on the overhead lights and said, "Mr. S____, how are you?"
- He said, "I feel a hell of a lot better than you look."
- "I went and looked up the anatomy of the chest and I figured I had gone into the pulmonary artery."
- Later that day, discussed with HMS Dean Charles Burwell (a cardiologist), who remarked that if he could do it again, could study congenital heart disease, which Dexter went on to do.

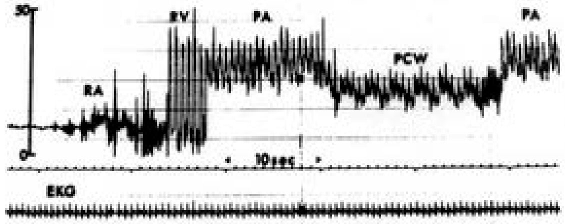
Balloon Flotation PAC

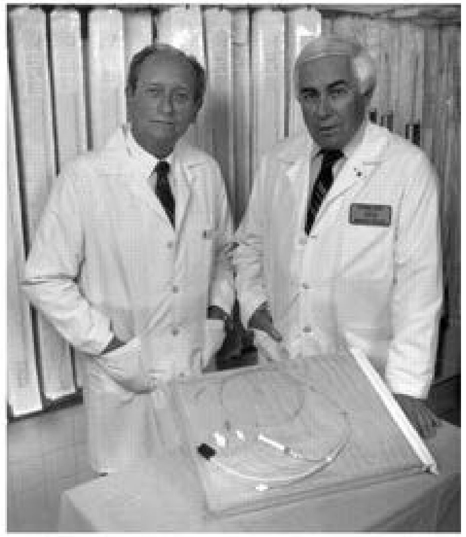
- **“I had had a very difficult evening with a very sick lady and failed completely to advance [the PA] catheter.**
- **The next day I was watching my kids at the beach and there was a sailboat on an apparently calm sea and it had a big spinnaker out in front of it.**
- **So, I thought well now probably the answer is to have a propulsion mechanism. A sail … or something like that ….**
- **And stick that on the end of a flexible catheter and that would work.”**

Jeremy Swan, MD









William Ganz and H.J.C. Swan

NEJM 1970;283:447 & *Circulation* 2009;119:147

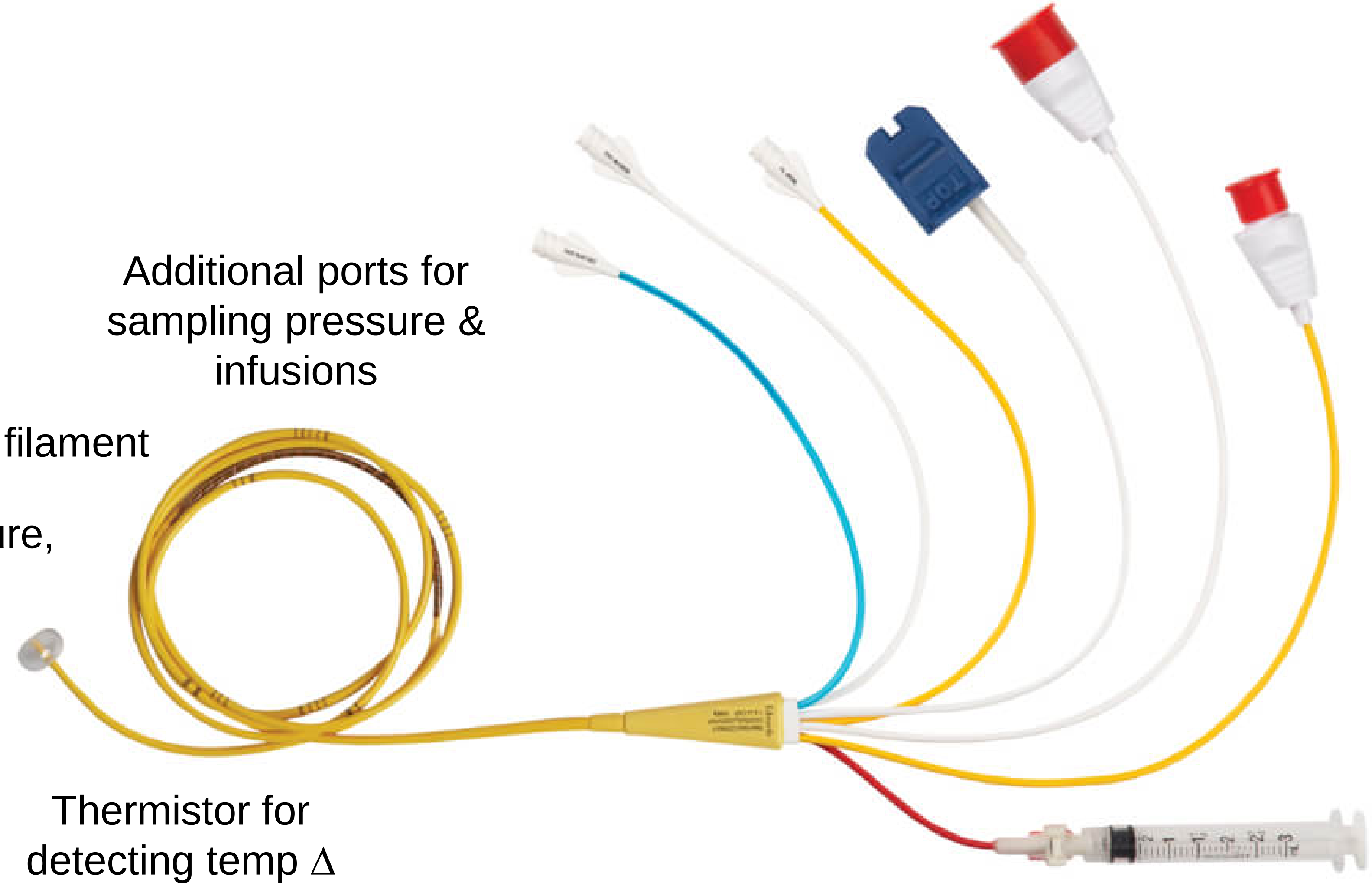
Pulmonary Artery Catheter

Additional ports for sampling pressure & infusions

Thermal filament

Port for measuring PA pressure, sampling blood for MVO_2, fiberoptic O_2 sat sensor

1.5 ml balloon



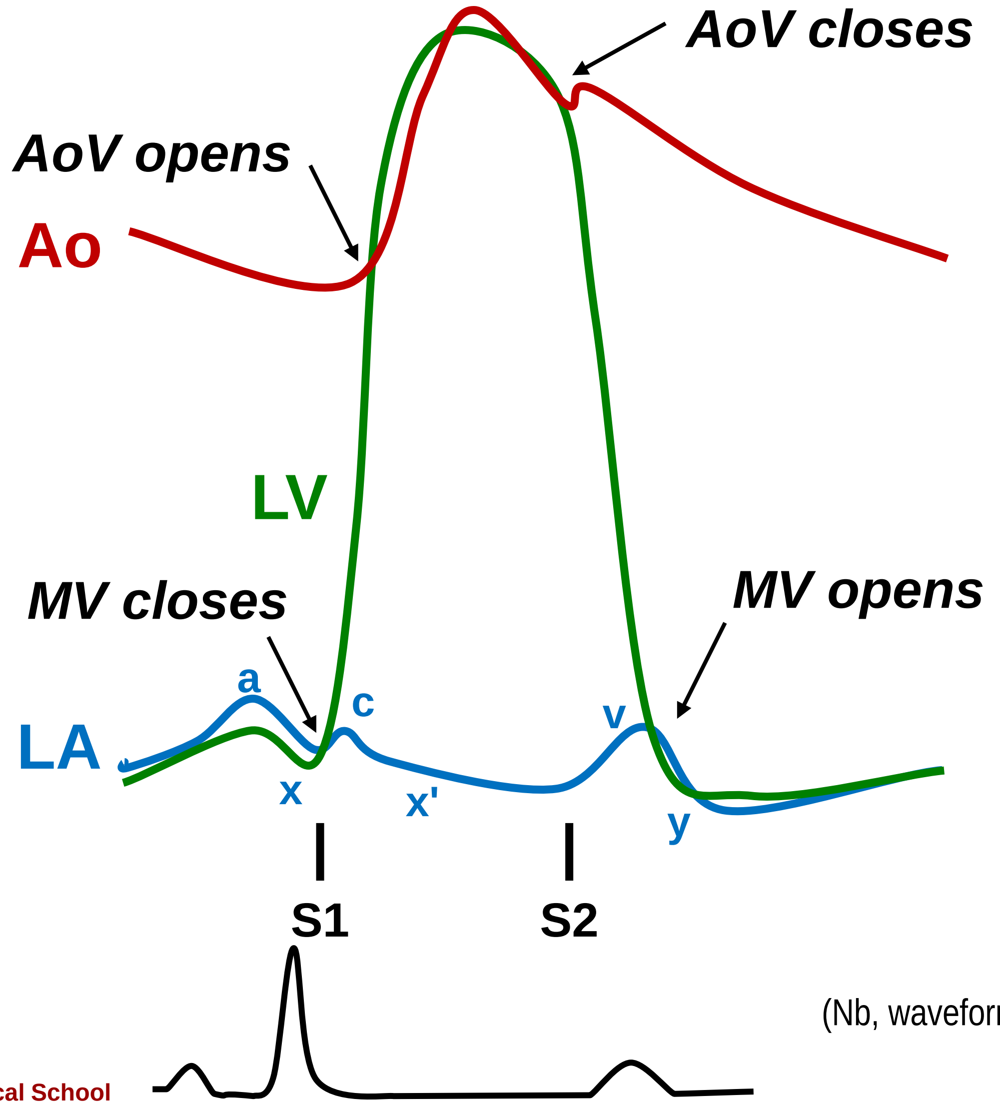
Thermistor for detecting temp Δ

PAC Waveforms

Right Atrium (RA)

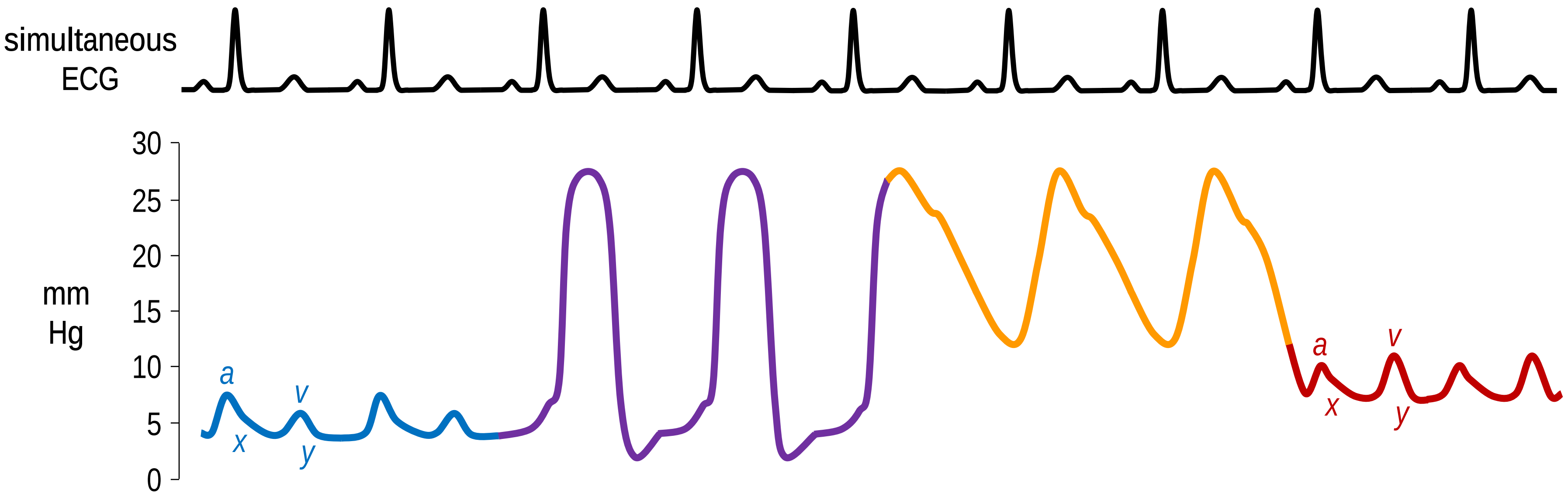
Upper limits of normal (mmHg) **6**

LA, LV, and Aortic pressures



(Nb, waveforms phase-shifted to aid interpretability)

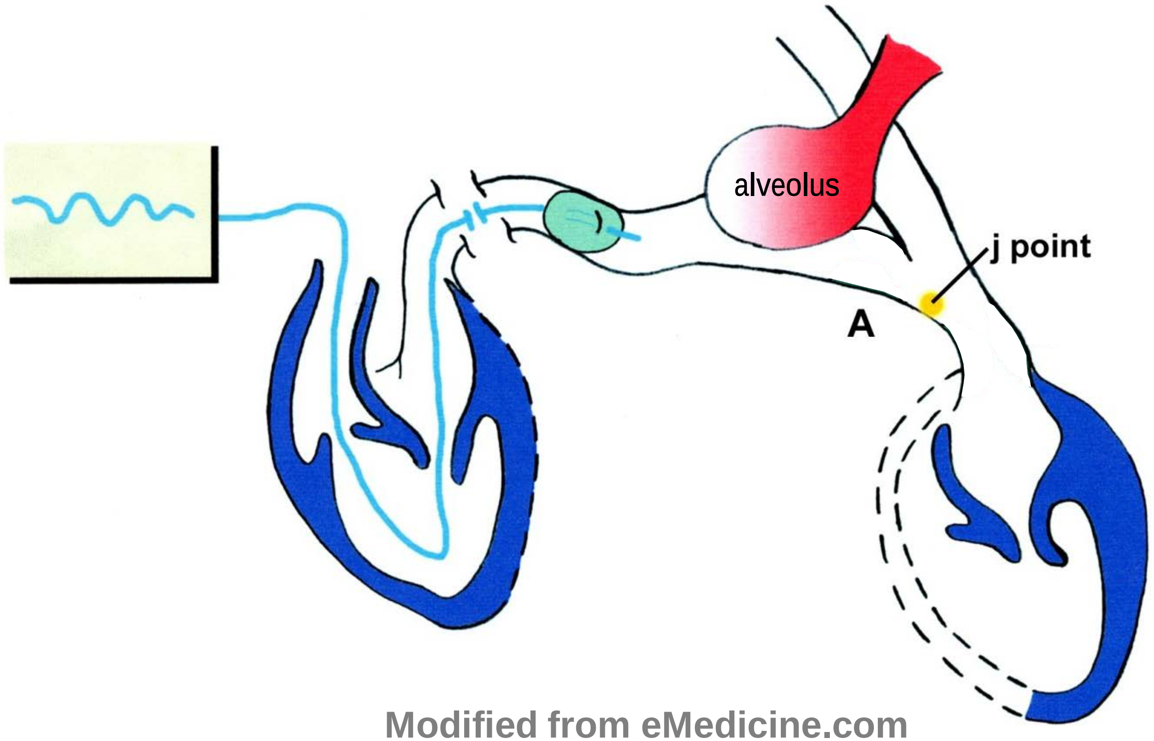
PAC Waveforms



	Right Atrium (RA)	Right Ventricle (RV)	Pulmonary Artery (PA)	Pulmonary Capillary Wedge (PCW)
Upper limits of normal (mmHg)	6	30/6	30/12, 18	12

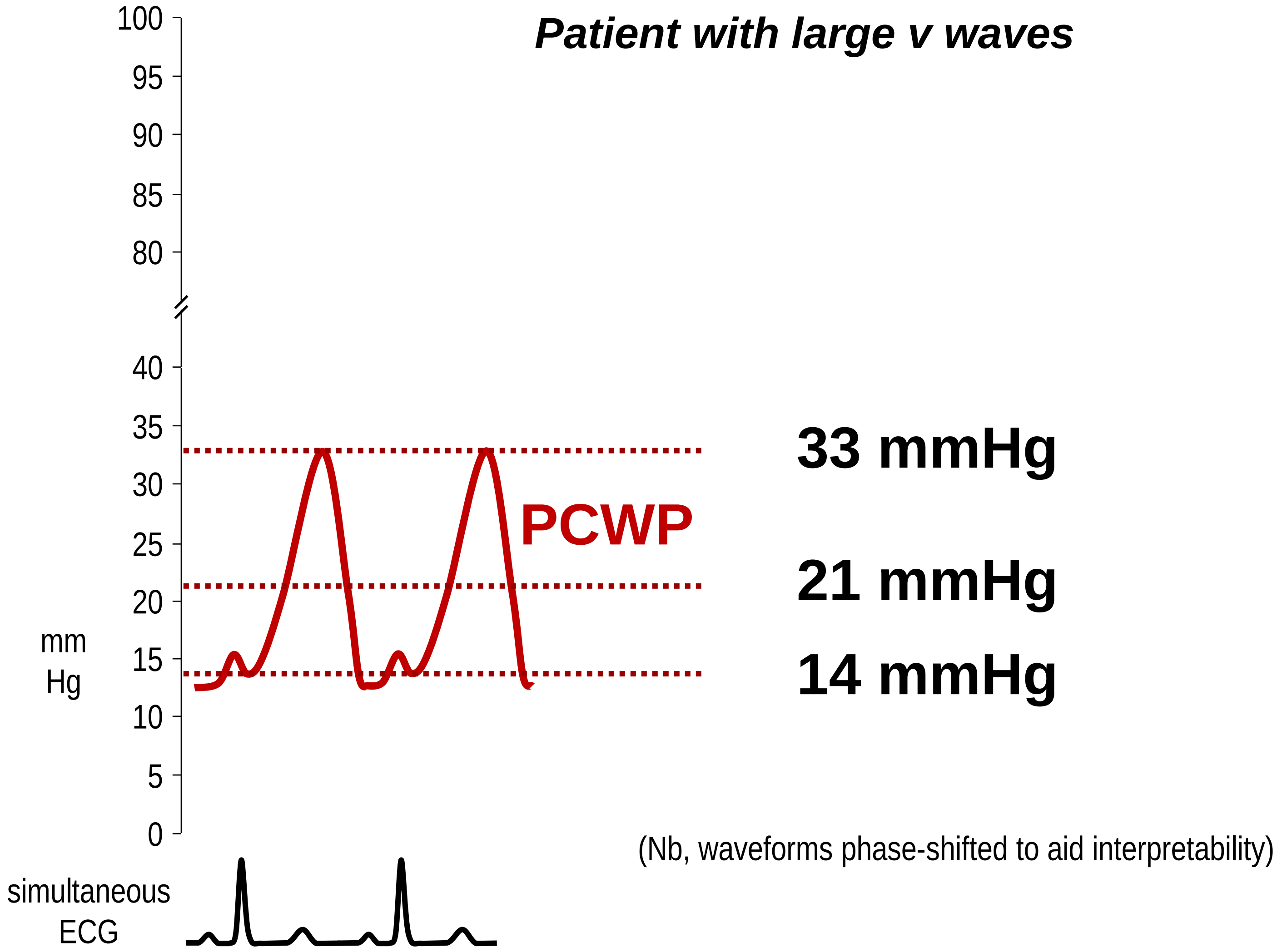
Pulm Capillary Wedge Pressure

When balloon inflated, static column of blood between distal pulmonary artery and distal pulmonary vein.
No flow, ∴ pressures should be equivalent.



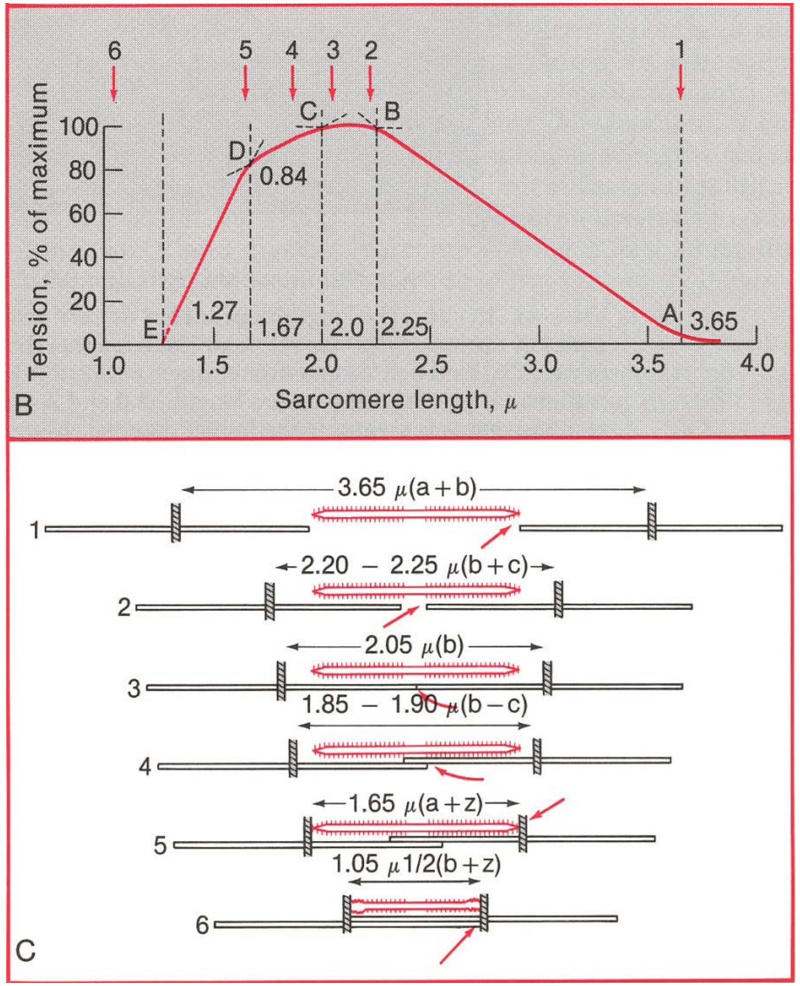
Modified from eMedicine.com

What value best represents LV preload?



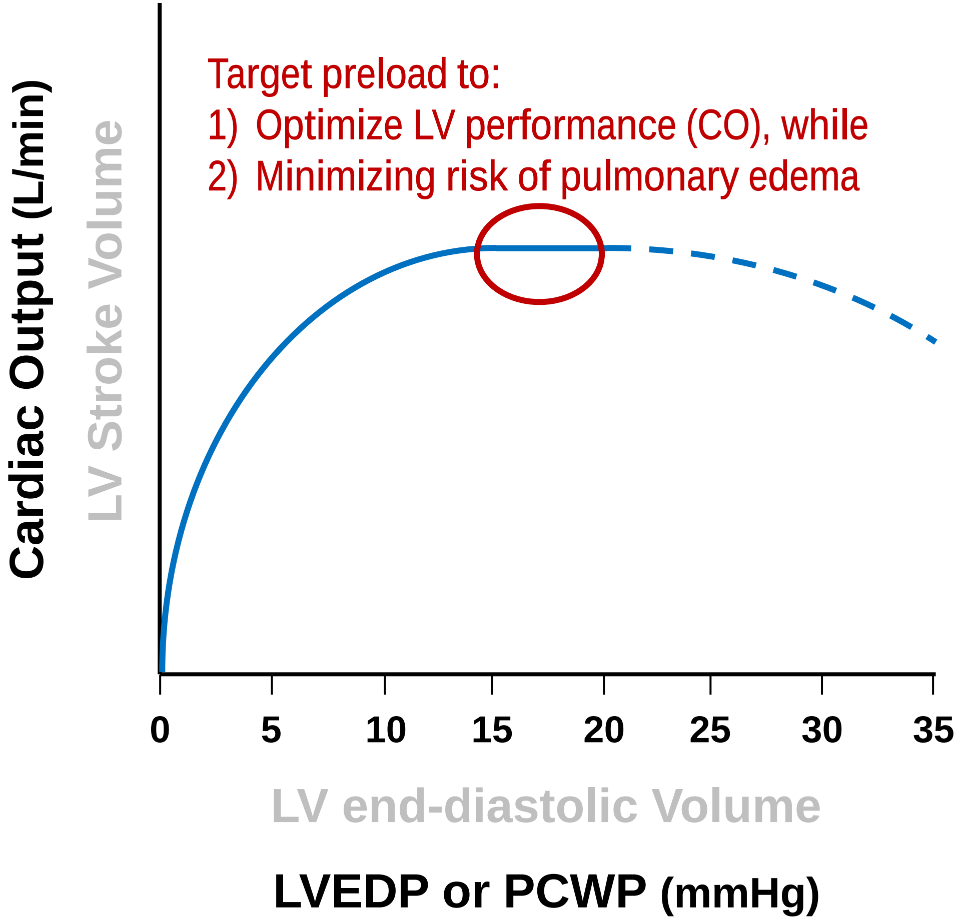
Preload

Length-Tension Relationship in Myocytes



Braunwald's Heart Disease 4/e

Frank-Starling Curve in Heart



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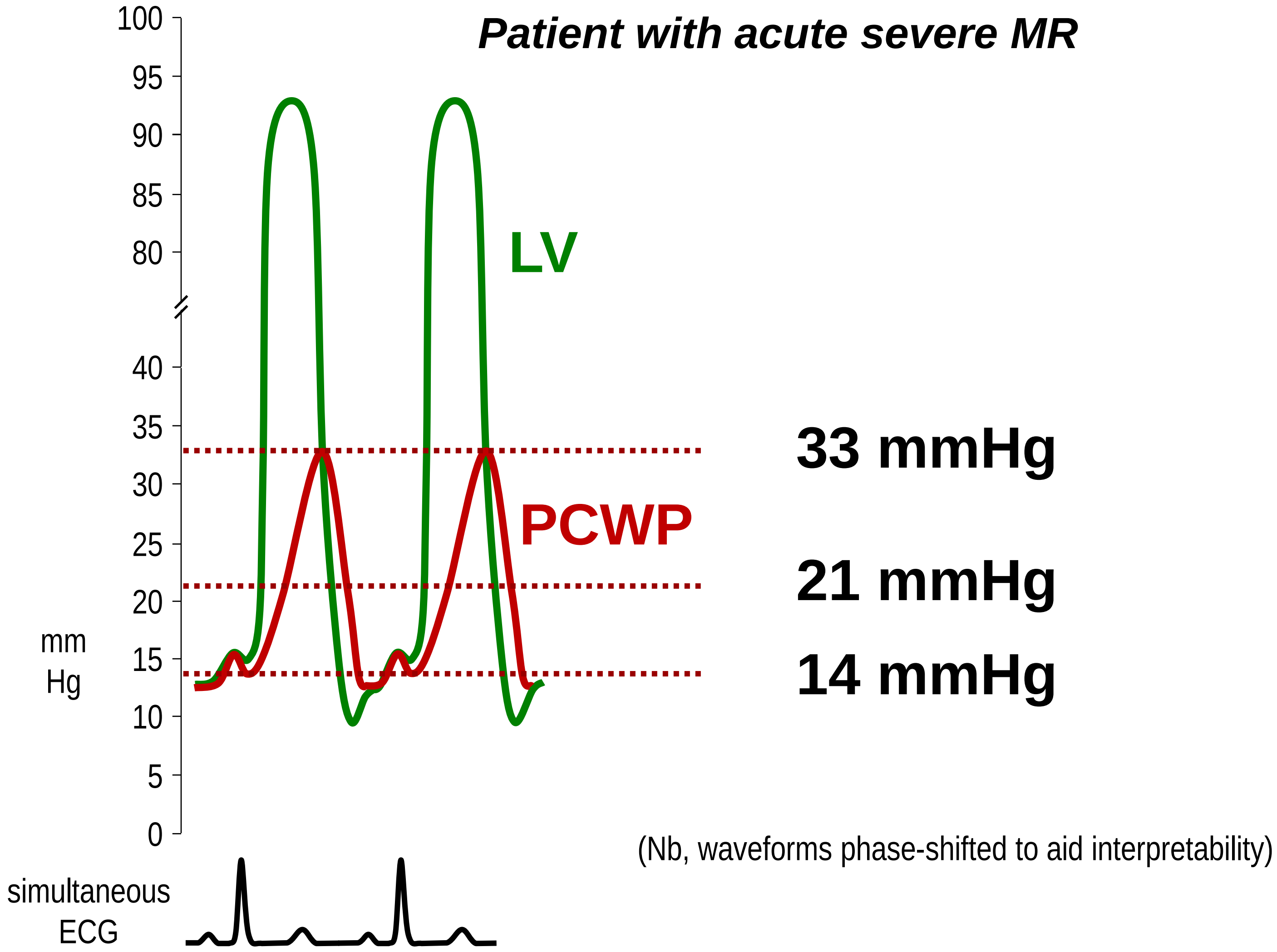

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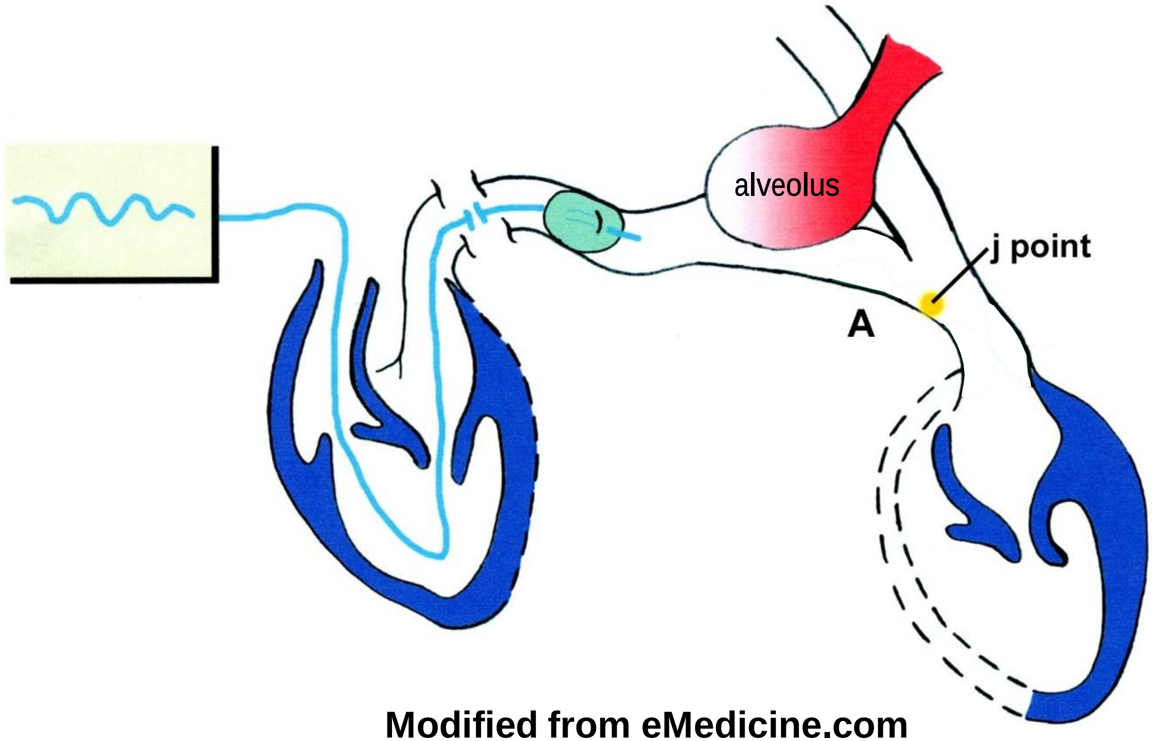


Modified from eMedicine.com

∴ PCWP

≈ pulm vein pressure

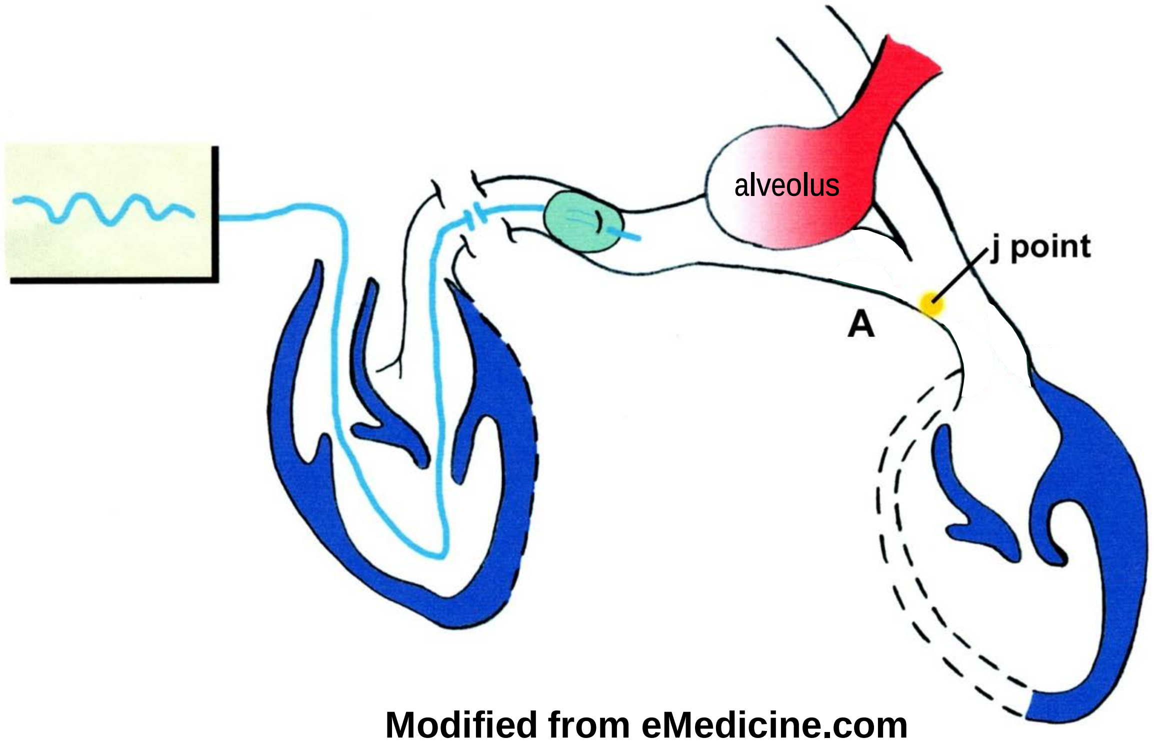
≈ LA pressure

≈ LV EDP

∝ LV EDV or preload

PCWP vs. Preload

When balloon inflated, static column of blood between distal pulmonary artery and distal pulmonary vein.
No flow, ∴ pressures should be equivalent.



Modified from eMedicine.com

∴ PCWP

≈ pulm vein pressure — *but not if pulm vv stenosis*

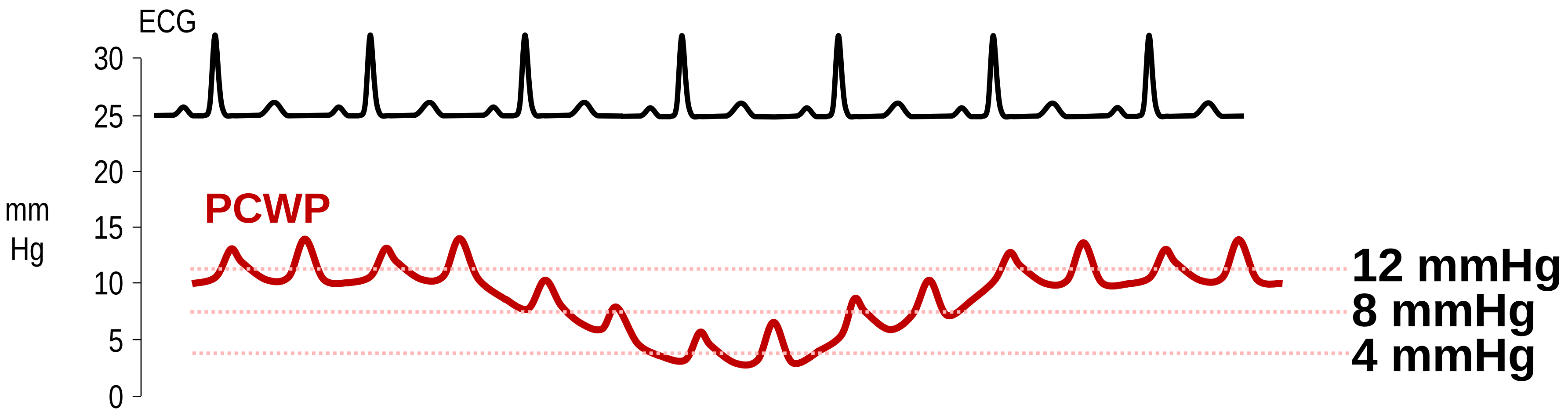
≈ LA pressure — *but not if MV disease*

≈ LV EDP — *Δ'd if LV less compliant*

∝ LV EDV or preload

What is the Wedge

Spontaneously breathing patient w/o pulmonary disease



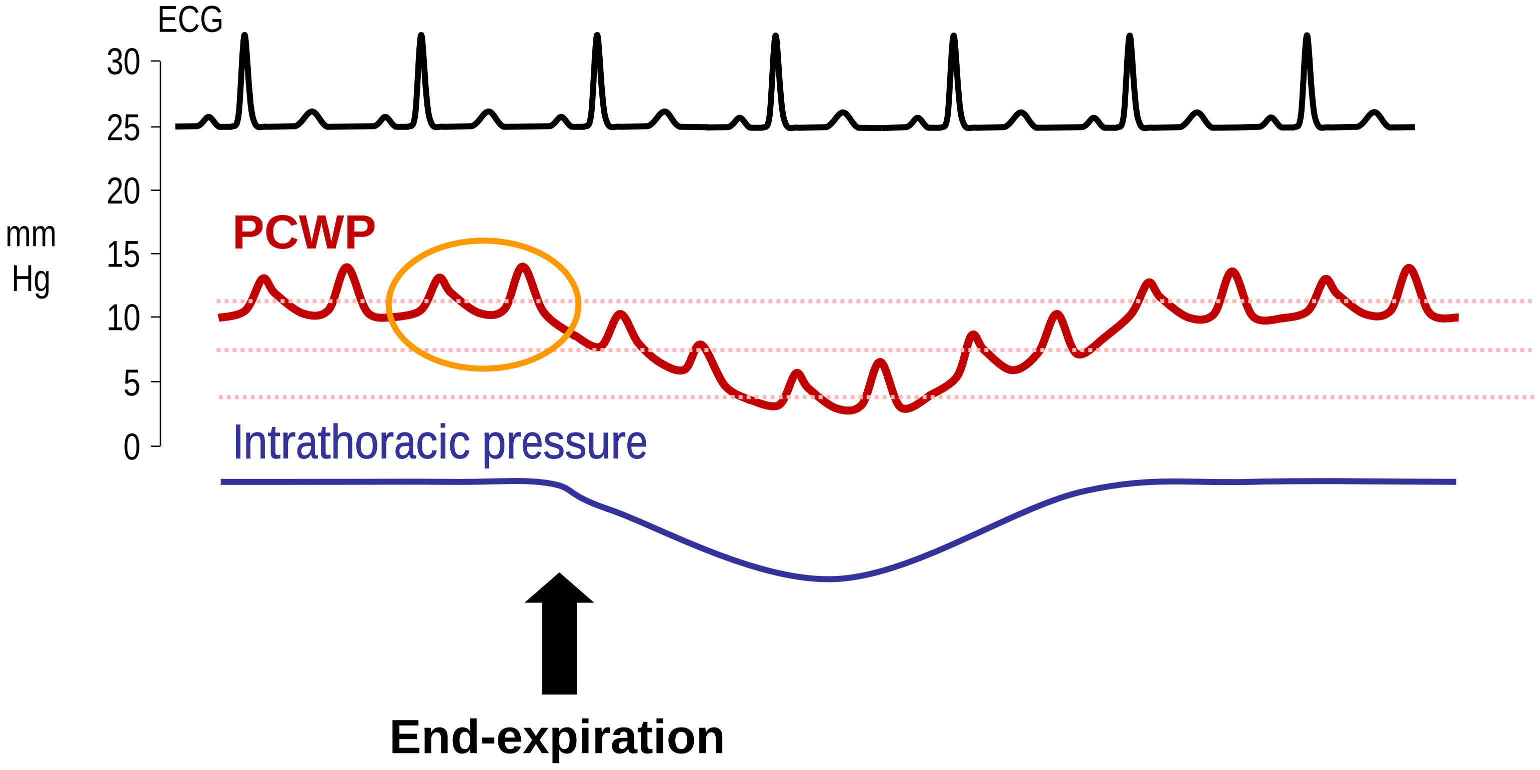
Intracardiac Pressures & Phases of Respiration

Inspiration, Expiration, or Average?

- **Measured pressure relative to atmospheric pressure**
- **Heart sits inside pericardium within the thoracic cavity**
- **Want to read pressures when intrathoracic pressure closest to 0**
- **By convention, use end-expiration**
- **Spont breathing Pts: PCWP expiration > inspiration**
- **Ventilated Pts: PCWP expiration *usually* < inspiration**

Read PCWP at End-Expiration

Spontaneously breathing patient w/o pulmonary disease



Calculating Cardiac Output

Thermodilution

- Application of indicator-dilution method
- Inject cold solution into RA (or heating element on PAC for CCO)
- Measure temperature at PA
- Generate a thermodilution curve
- CO inversely proportion to AUC

Fick

- O_2 consumption = CO × AV O_2 difference

$$CO = \frac{O_2 \text{ consumption}}{AV\ O_2 \text{ diff}}$$

Estimated using this # for every Pt in ICU …

$$CO = \frac{125 \text{ mL/min/m}^2}{Hb \times 10 \times 1.36 \times [\text{arterial } O_2 \text{ sat} - \text{mixed venous } O_2 \text{ sat}]}$$

Usually only value that is significantly Δ'ing

Mixed Venous O_2 Sat

Value (%)	Status
65-80	Normal; $DO_2 \geq VO_2$

DO_2 = oxygen delivery
VO_2 = oxygen consumption

Mixed Venous O_2 Sat

Value (%)	Status
65-80	Normal; $DO_2 \geq VO_2$
50-65	↑ O_2 extraction to compensate for ↓ DO_2 or ↑ VO_2
30-50	Exceeding max O_2 extraction; VO_2 > DO_2; beginning of anaerobic metabolism & lactic acidosis
<30	Severe lactic acidosis & cellular death

DO_2 = oxygen delivery
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Mixed Venous O_2 Sat

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DO_2 = oxygen delivery
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Mixed Venous O_2 Sat

Value (%)	Status
>80	↓↓ VO_2 (eg, sepsis w/ impaired extraction, hypothermia, cyanide) Shunt: L→R intracardiac shunt; large peripheral AV fistula Wedged sat (sampling pulm vv blood); ? torrential MR ↑↑ DO_2
65-80	Normal; $DO_2 \geq VO_2$
50-65	↑ O_2 extraction to compensate for ↓ DO_2 or ↑ VO_2
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Afterload or Vascular Resistance

- Ohm's law: V (voltage) = I (current) × R (resistance)
- Applied to the heart: Pressure gradient = CO × Vascular Resistance
  Vascular Resistance = Pressure gradient / CO
- Not directly measured, but calculated
- For systemic circulation: SVR = (MAP – RA) / CO
- For pulmonary circulation: PVR = (mean PA – WP) / CO

Utility of SVR & PVR

- <u>SVR</u>: usually obvious in isolated septic shock (patient warm, CO high, MAP low, ∴ SVR low)

  Can be useful to clarify mixed picture (low CO with concomitant vasoplegia)

- <u>PVR</u>: can differentiate ↑ pulm pressures due to intrinsic pulm vasc disease (1° PHT or PAH) vs. backward transmission of left-sided heart failure
  - PVR = (mean PA – WP) / CO
  - If transpulmonary gradient (mean PA – WP) ≤12 mmHg, or diastolic gradient (PA diastolic – WP) <7 mmHg, then numerator will be small, and ∴ PVR unlikely to be elevated

Measurement Error

Parameter	Error
PCWP	± 4 mmHg
Thermodilution CO	± 0.5 L/min
MVO_2	± 2 %

Indications of PAC

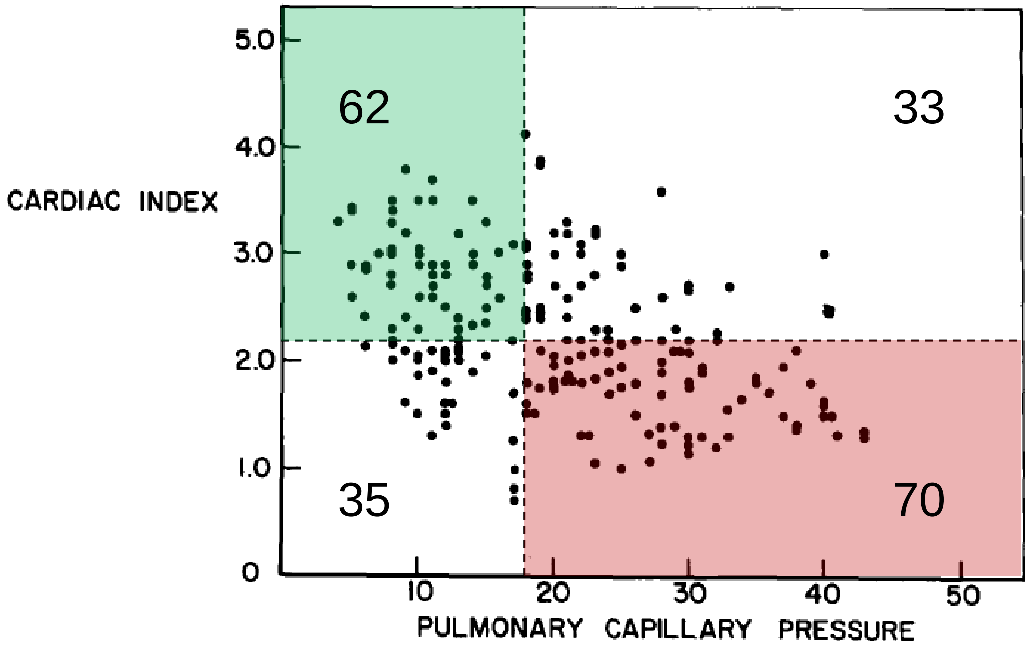
- **Diagnosis & evaluation**
  - Ddx shock (especially if empiric therapy failed or high risk)
  - Quantify cardiac filling pressures or aid in Ddx pulmonary edema (especially if trial of diuretic failed)
  - Assess mechanical complications of acute MI
  - Quantify CO, degree of pulmonary hypertension
- **Treatment**
  - Tailored Rx in cardiogenic shock to optimize cardiac parameters
  - Guide vasodilator Rx in PHT

Forward vs. Backward Failure

200 Pts w/ Acute Q-wave MI

Congestion

Hypoperfusion	No	Yes	
No	75	36	111
Yes	22	67	89
	97	103	200



AJC 1977;39:137-45

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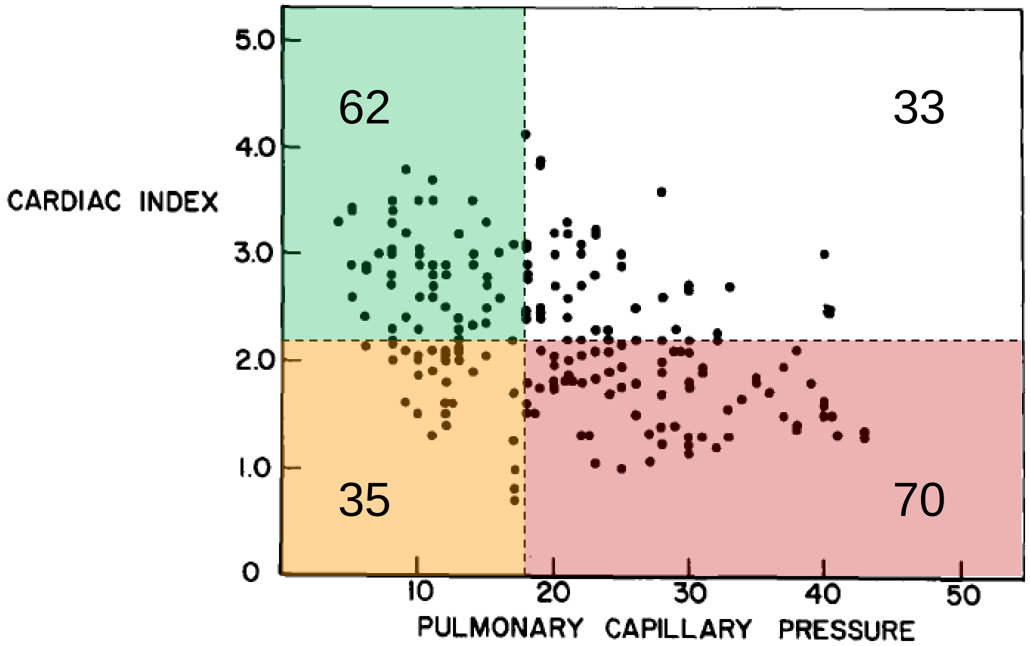

25-33% of Pts with hypoperfusion / low CI do not have congestion / high WP

AJC 1977;39:137-45

Major Randomized Trials of PAC

Trial				Result
SVO_2 Collab (NEJM '95)				
Canadian Crit Care (NEJM '03)				
French PAC (JAMA '03)				
PAC-Man (JAMA '03)				
FACTT (NEJM '06)				

Major Randomized Trials of PAC

Trial				Result
SVO_2 Collab (NEJM '95)				No Δ in mortality
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French PAC (JAMA '03)				No Δ in mortality
PAC-Man (JAMA '03)				No Δ in mortality
FACTT (NEJM '06)				No Δ in mortality

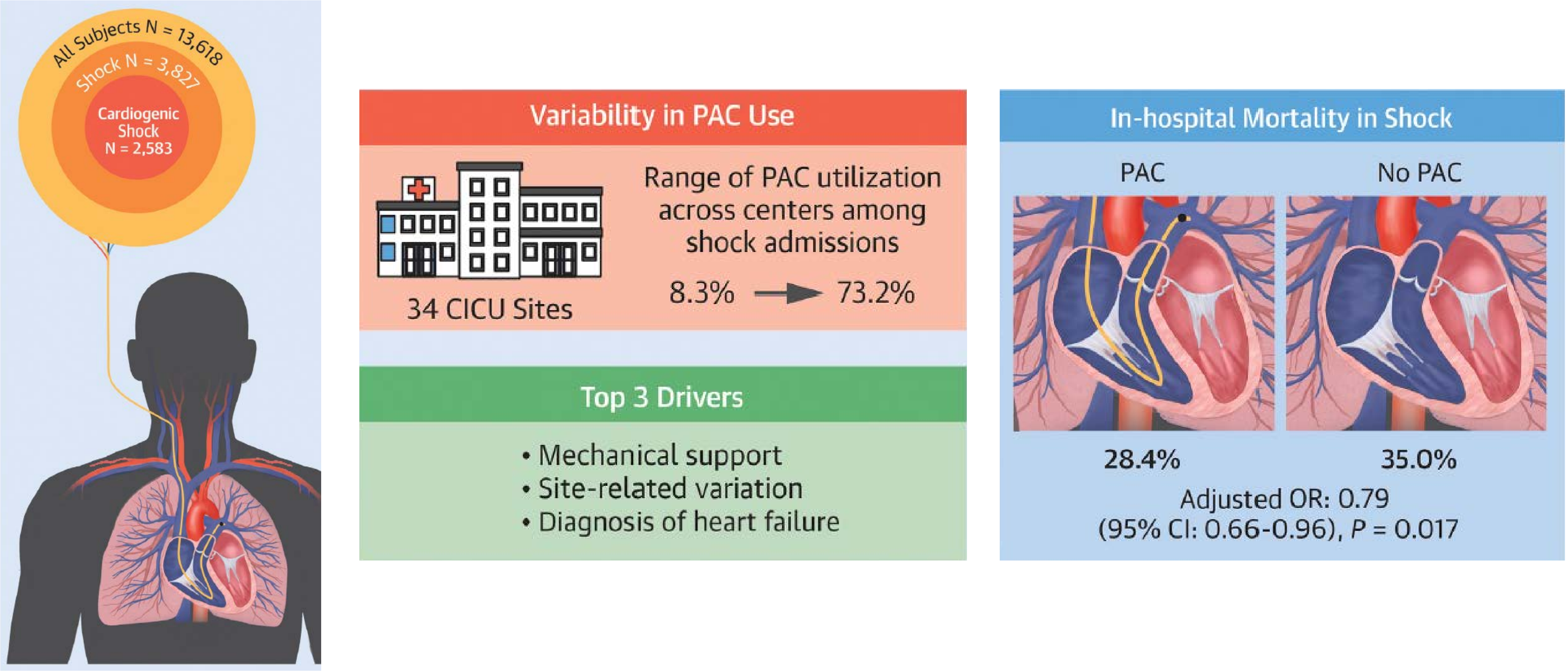
Major Randomized Trials of PAC

Trial	Subjects	Baseline Char	Intervention	Result
SVO_2 Collab (NEJM '95)	Surgery, trauma, sepsis, bleed	PCWP 14 CI 3.7 MVO_2 68%	All PAC; CI >4.5 vs. MVO_2 **≥70% vs.** stnd care	No Δ in mortality
Canadian Crit Care (NEJM '03)	Surgery	CVP ~10 CI ~2.8	Routine PAC w/ goal CI 3.5-4.5 vs. ∅ PAC; ~1/2 got colloid or PRBCs	No Δ in mortality
French PAC (JAMA '03)	Shock, ARDS; ∅ AMI, ~6% cardiogenic	n/a	PAC vs. ∅ PAC; no therapeutic protocol	No Δ in mortality
PAC-Man (JAMA '03)	ICU; ~11% decomp HF	n/a	PAC vs. ∅ PAC; no therapeutic protocol; most common Δ after PAC was IVF	No Δ in mortality
FACTT (NEJM '06)	ALI 5L fluid pre-rand	CVP ~12 PCWP ~15	PAC vs. CVC; therapeutic protocol; net +3 L; dobuta <10%	No Δ in mortality

Major Randomized Trials of PAC

Trial	Subjects	Baseline Char	Intervention	Result
ESCAPE (JAMA '05)	Decomp HF; but not cardio shock, excluded if: dopa (>3 µg//kg/min), dobuta (>3), or milrinone	PCWP 25 CI 1.9 SBP 106 SVR 1500	PAC vs. ∅ PAC; **goal RAP ≤8 & PCWP ≤15;** inotropes discouraged; vasodil 37 vs 19% inotropes 44 vs 39%	No Δ in mortality

Critical Care Cardiology Trial Network



Kadosh BS, Berg DD, et al. *JACC* 2023;11:903-14

Take Home Points

- **Consider if Pt in cardiogenic shock (can be normotensive)**
- **Use clues from physical exam**
- **Consider PAC for patients w/ acute MI or decompensated HF in cardiogenic shock or not responding to initial Rx for hypotension/congestion**
- **Study the waveforms carefully**
- **Filling pressures (PCWP)**
  - Ensure assumptions linking PCWP to LV preload are true
  - Think about what you want to learn from PCWP (preload; pulmonary edema)
- **Cardiac output: thermodilution vs. Fick** (assumptions for each)
- **Trends are more valuable than isolated data points**