Hemodynamic Monitoring in the ICU

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- None

Objectives

- **Review** common invasive and non-invasive devices for hemodynamic monitoring in the ICU
- Troubleshoot common problems with hemodynamic devices
- Discuss ways to evaluate if a patient is fluid responsive
- Apply different hemodynamic values to differentiate shock and effect treatment decisions

Hemodynamic Monitoring

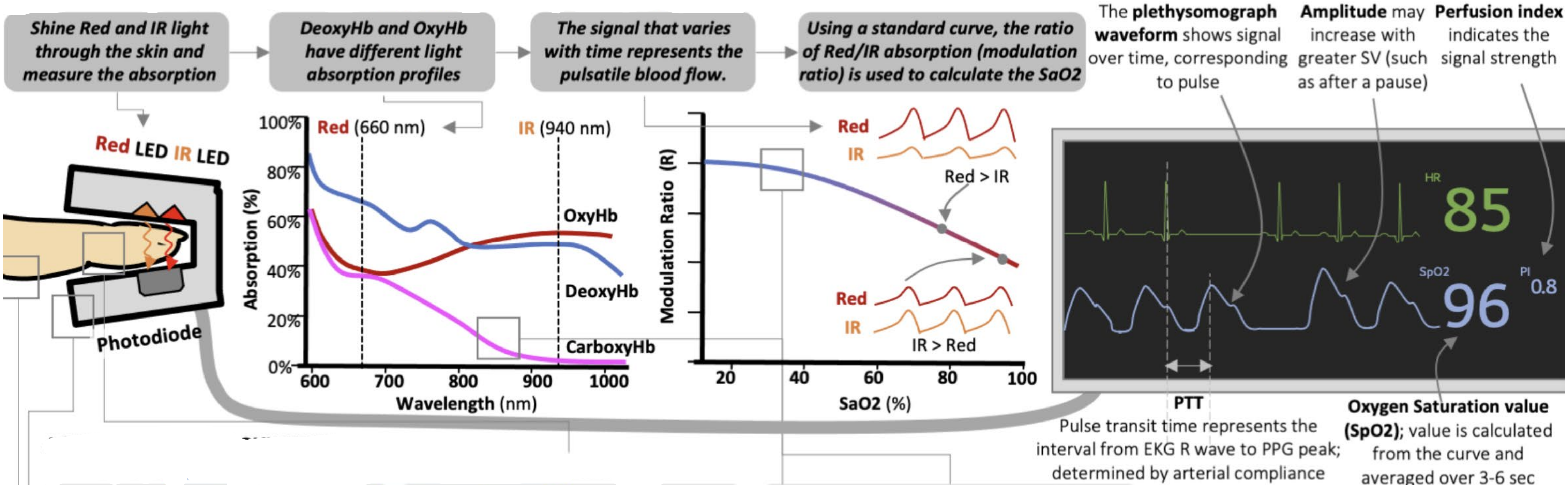
- Noninvasive measures
  - Physical Exam
  - Blood pressure-
  - Pulse oximetry-
  - EKG tracing
  - POCUS
- Invasive measures
  - Catheters
    - Arterial lines
    - PA Catheters
    - CVP monitors, FloTrac
- Lab work/Biomarkers
- Static vs dynamic measures

Common Non-Invasive Measures

- Blood pressure measurement
  - Oscillometric method is most common
  - In this method mean ABP is measured and systolic and diastolic pressures are derived
  - Reliable for detecting hypotension (MAP < 65 mm Hg or systolic < 90 mm Hg) and hypertension (MAP > 140 mm Hg)
  - Less reliable in extremes
  - Cuff size is critical for accuracy
  - Reliable with vasopressor use, obesity, arrhythmias and hypotension

Lakhal K, Ehrmann S, Boulain T. Chest 2018; 153(4):1023-1039. Lakhal et al. Crit Care Med 2012;40(4):1207-1213. Singer et al. JAMA 2016;315(8):801-810.

Plethysomography



ICU One Pager. (n.d.). ICU One Pager. https://onepagericu.com/

Other Common Non-Invasive Measures

- EKG
- POCUS
- End tidal CO_2

Invasive techniques- Arterial Lines

- Permit continuous blood pressure monitoring
    - Beat-to-beat analysis of arterial pressure
    - Estimates of cardiac output, predict volume responsiveness
    - Allow frequent arterial blood sampling
    - Waveform analysis possible
    - Not free of error and artifacts

McGhee B and Bridges M. Crit Care Nurse 2002; 22(2):60-79.
Garland A. Chest 2014; 146(5):1155-1158

Indications

- Accurate measurement of intra-arterial blood pressure.
- Accurate measurement of mean arterial pressure.
- Frequent arterial blood sampling for laboratory analysis, such as arterial blood gas.
- Facilitate titration of vasoactive medications.
- Inability to obtain noninvasive blood pressure monitoring, as in patients with burns, severe hypotension, multiple fractures, or morbid obesity.
- Utilize arterial pulse pressure as a surrogate of stroke volume [5].
- Usefulness in determining fluid responsiveness utilizing changes in arterial pressure waveform during positive pressure ventilation

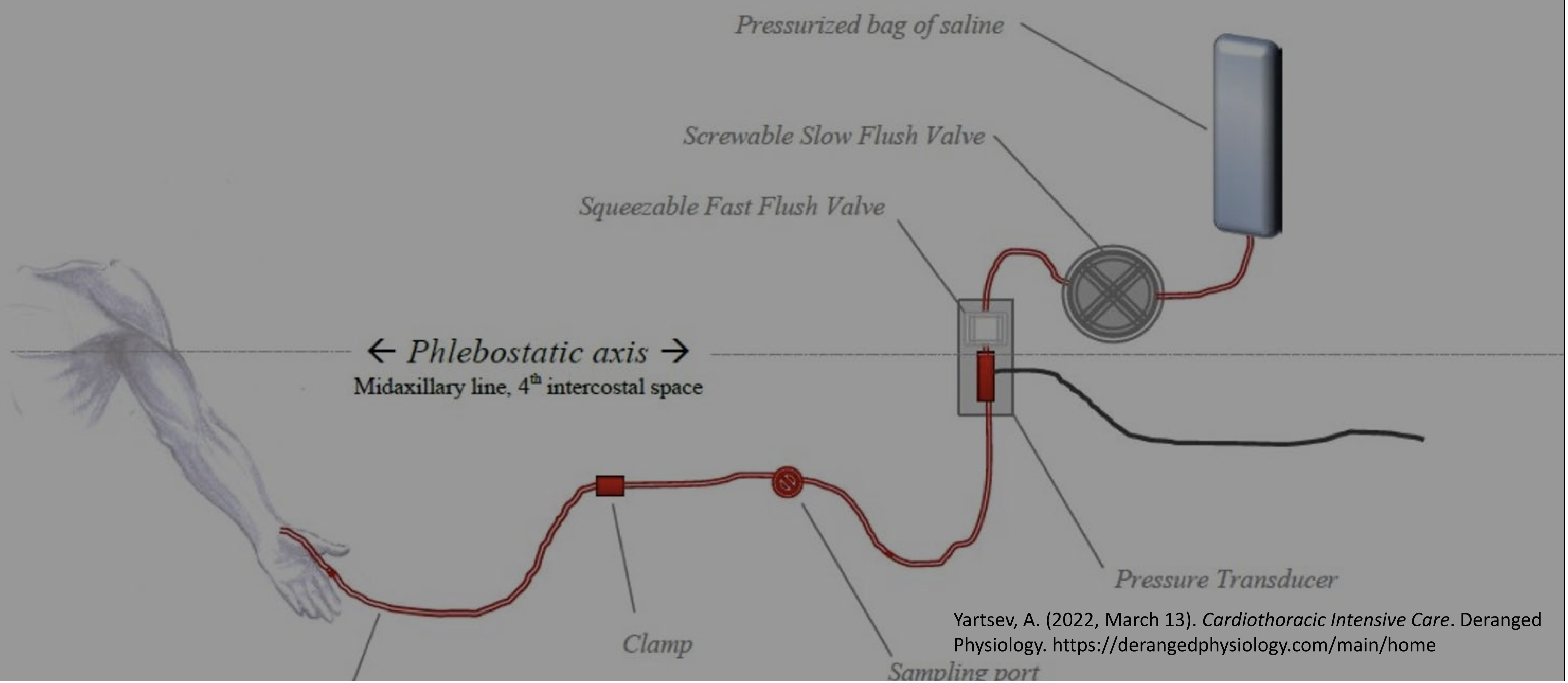
Contraindications

- Absolute contraindications:
  - Inadequate or interrupted collateral circulation
  - Absent pulse
  - Thromboangiitis obliterans (Buerger's disease)
  - Full-thickness burns over the cannulation site
  - Raynaud's syndrome
- Relative contraindications:
  - Recent TPA administration, coagulopathy
  - Arterial atherosclerosis
  - Synthetic arterial or vascular graft
  - Insufficient (reduced but not absent) collateral perfusion
  - Infection at the cannulation site
  - Partial thickness burns at cannulation site
  - Previous surgery in the area

Abide, A.M., Meissen, H.H. (2021). Arterial Line Access and Monitoring. In: Taylor, D.A., Sherry, S.P., Sing, R.F. (eds) Interventional Critical Care.

Arterial Line Transducer Setup

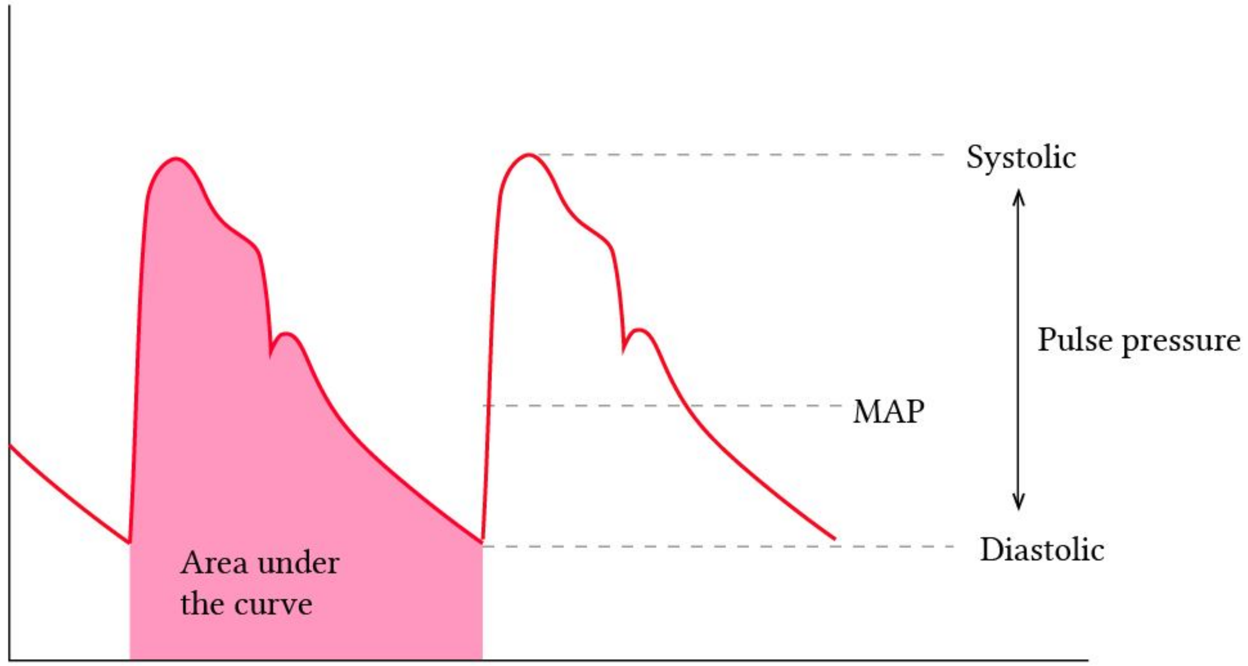
- Principle- A continuous column of fluid between indwelling catheter and a pressure transducer allows for arterial pressure measurement



Yartsev, A. (2022, March 13). *Cardiothoracic Intensive Care*. Deranged Physiology. https://derangedphysiology.com/main/home

Arterial Pulse Waveform Analysis

- Systolic phase- rapid increase in pressure to a peak, then rapid decline. Opening of aortic valve
- Dicrotic notch, closure of aortic valve
- The diastolic phase
- Peak correlates with systolic BP as measured by cuff
- Trough correlates with the diastolic pressure.
- Mean arterial pressure (MAP) is calculated from the area under the pressure curve



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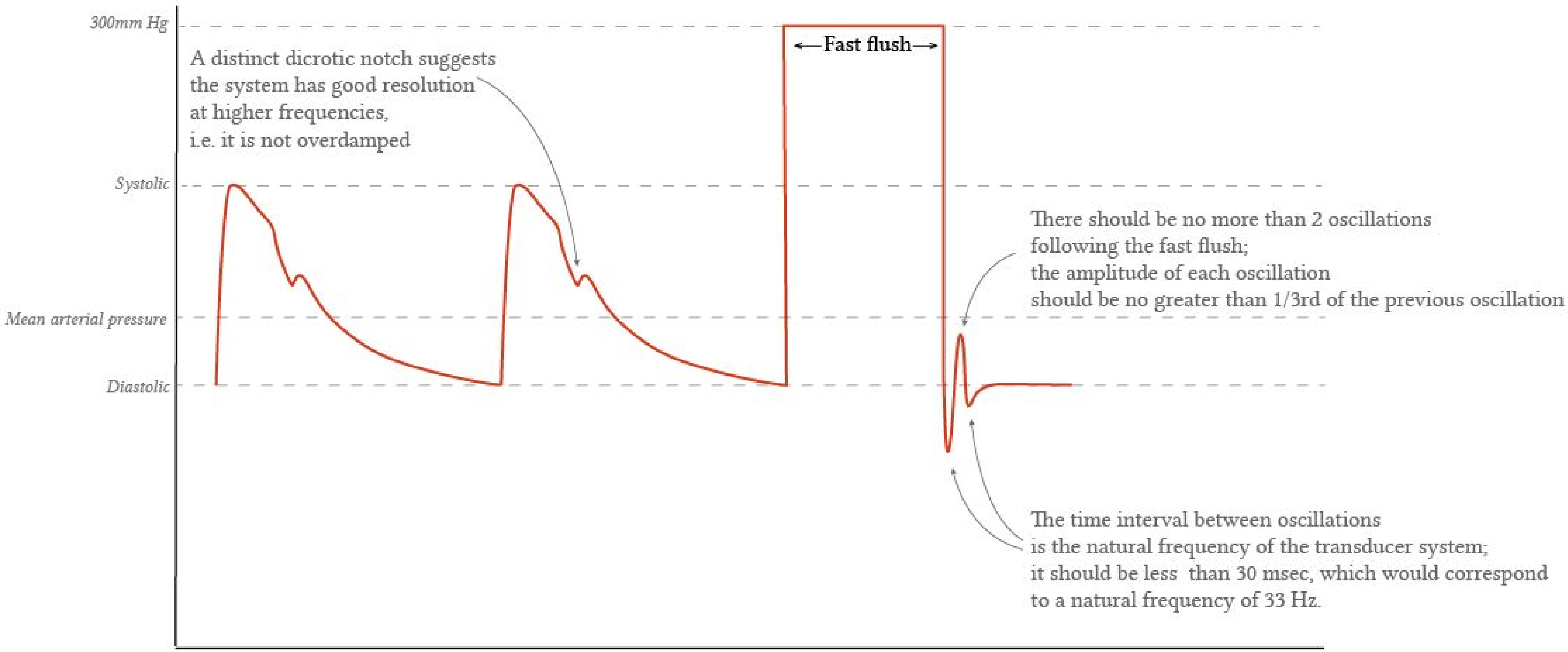
Square Wave Test

- **Time between oscillations will be short.**
- **Should be at least one "bounce" oscillation.**
- **Should be no more than two oscillations;**
- **Distinct dicrotic notch.**



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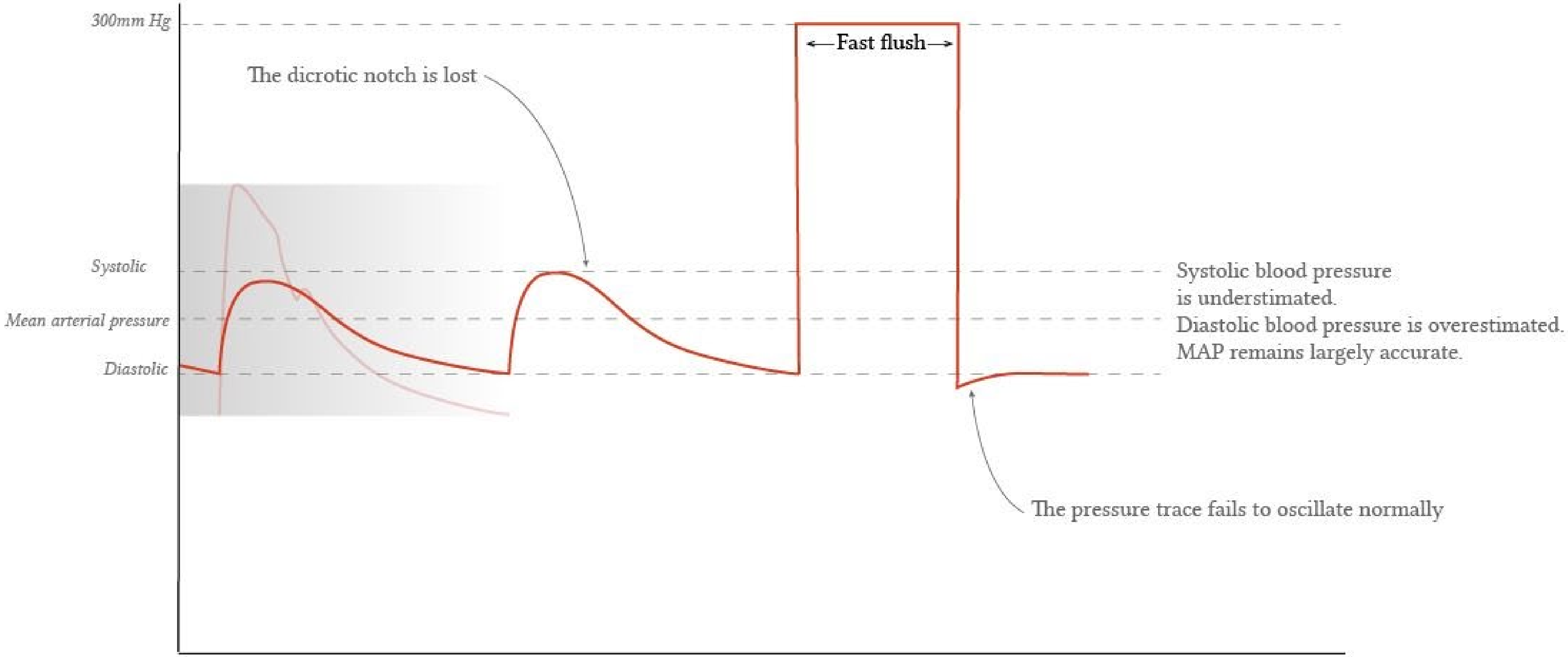
Over-damped Art Line

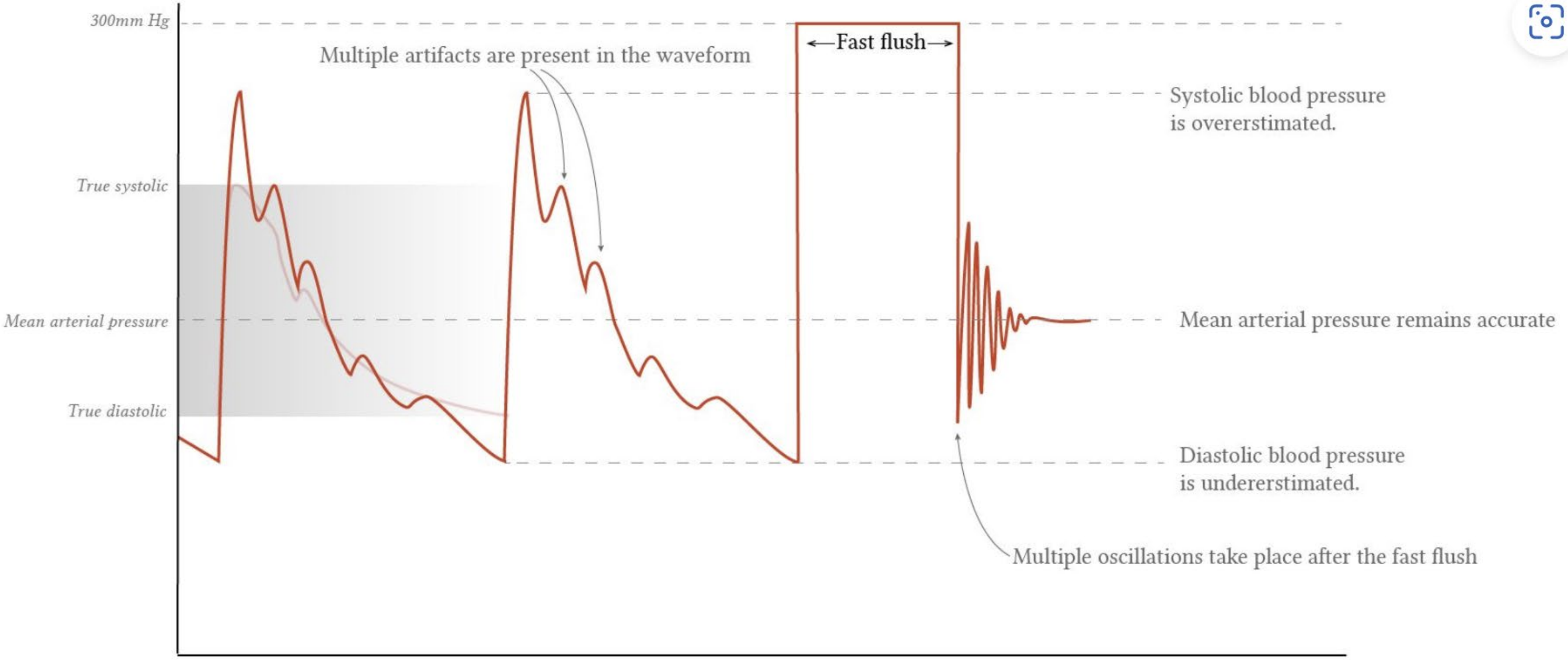
- Underestimate blood pressure
- Loss of dicrotic notch
- Often when air bubble or clot in tubing, too long of tubing



Yartsev, A. (2022, March 13). *Cardiothoracic Intensive Care*. Deranged Physiology. https://derangedphysiology.com/main/home

Underdamped Art Line

- Overestimate blood pressure
- See many post-flush oscillations



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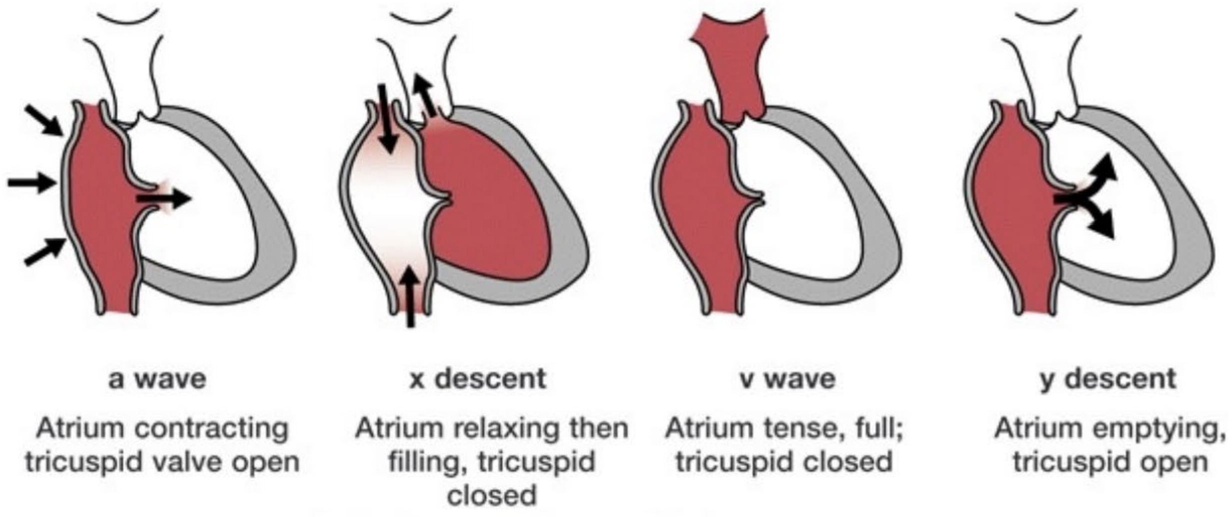
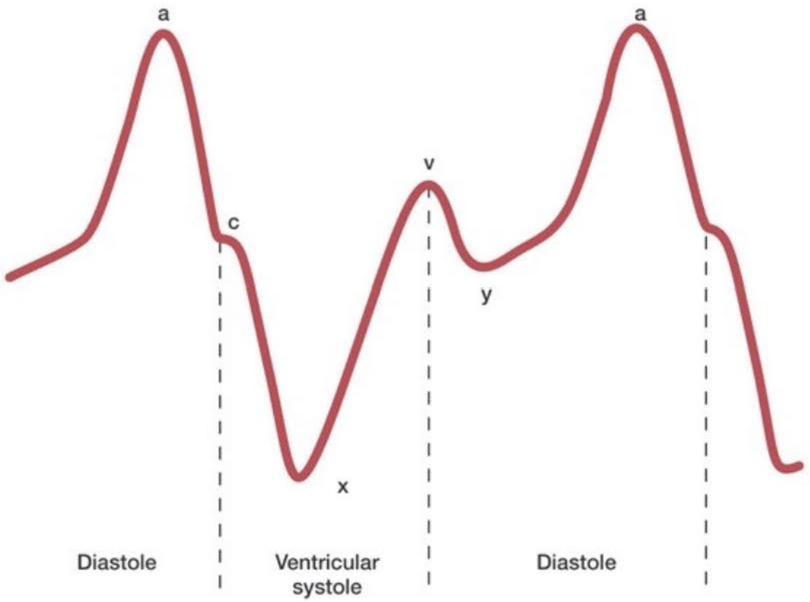
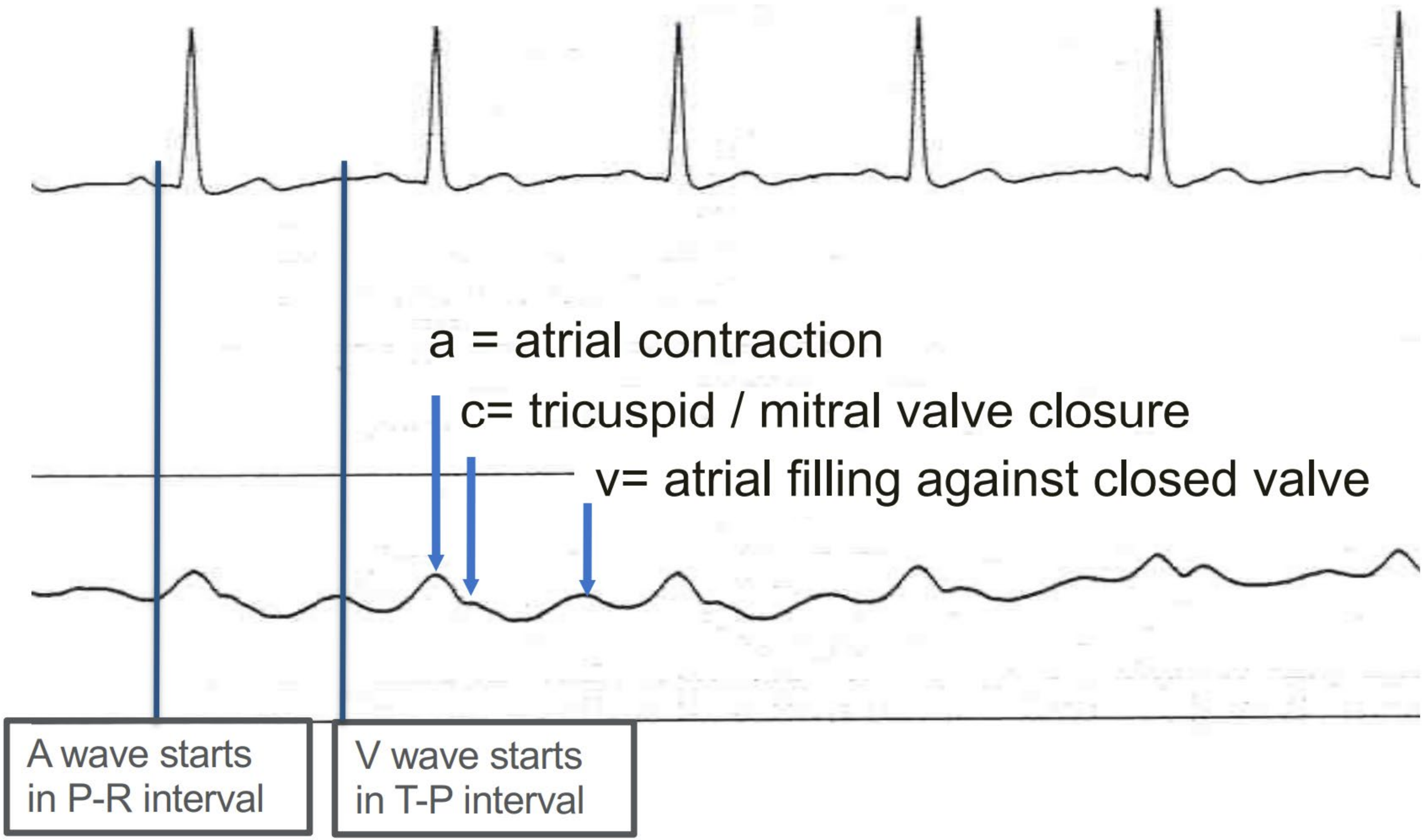
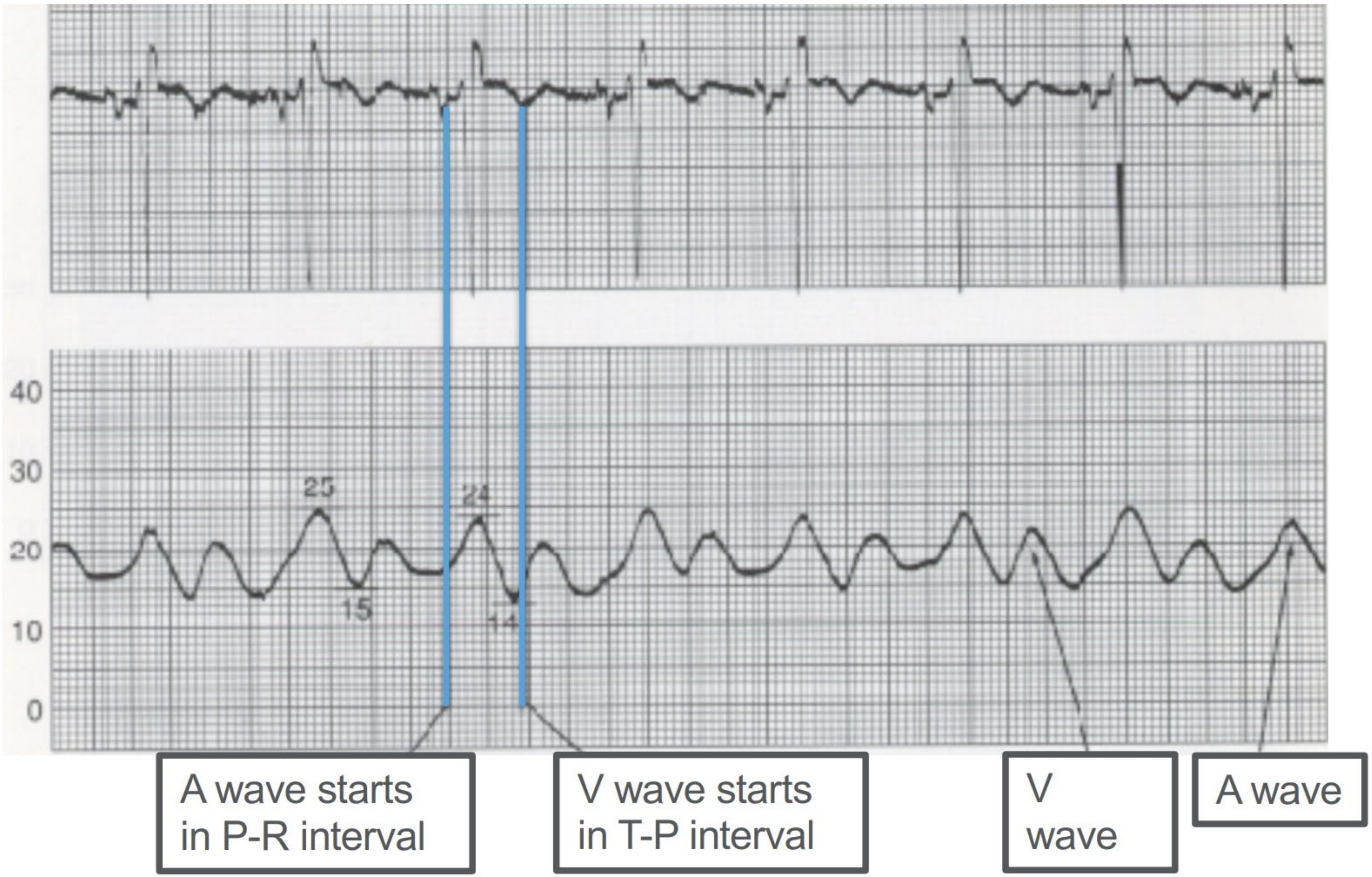
CVP monitoring

- Requires a central venous catheter
- Surrogate for RV filling pressure
- Normal CVP 2-8mmHg
- Measure at end expiration






a = atrial contraction
c= tricuspid / mitral valve closure
v= atrial filling against closed valve
A wave starts in P-R interval
V wave starts in T-P interval



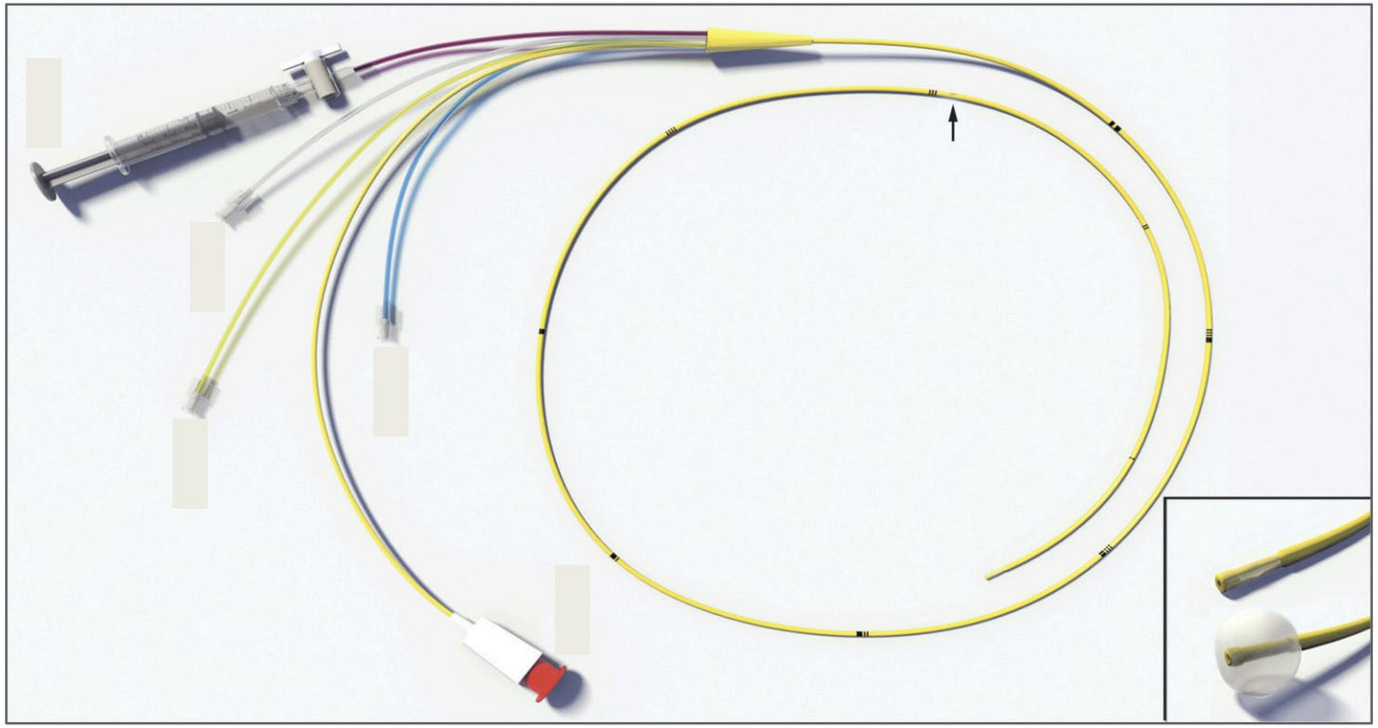
40
30
20
10
0
25
15
24
14
A wave starts in P-R interval
V wave starts in T-P interval
V wave
A wave

CVP Monitoring

- CVP determined by blood volume, PA pressure, RV function, compliance of venous system
- CVP goal no longer part of sepsis guidelines
- Static measure of CVP does not well-predict response to fluid challenge
- Can be helpful at extremes of values and to identify RV dysfunction
- Many limitations
    - Effected by volume status
    - RV function
    - TR function
    - Requires central access

Pulmonary Artery Catheter Utility

- Guide in the diagnosis of:
  - Shock
  - Pulmonary hypertension
  - Pericardial constriction
  - Tamponade
  - Shunt
  - Lymphatic carcinoma



Pulmonary Artery Catheter Utility

- Helpful to guide management
  - Assess fluid responsiveness
  - Titration of vasopressors / inotropes in shock
  - Severe heart failure / cardiogenic shock
  - Assess response to pulmonary vasodilators

Pulmonary Artery Catheter Utility

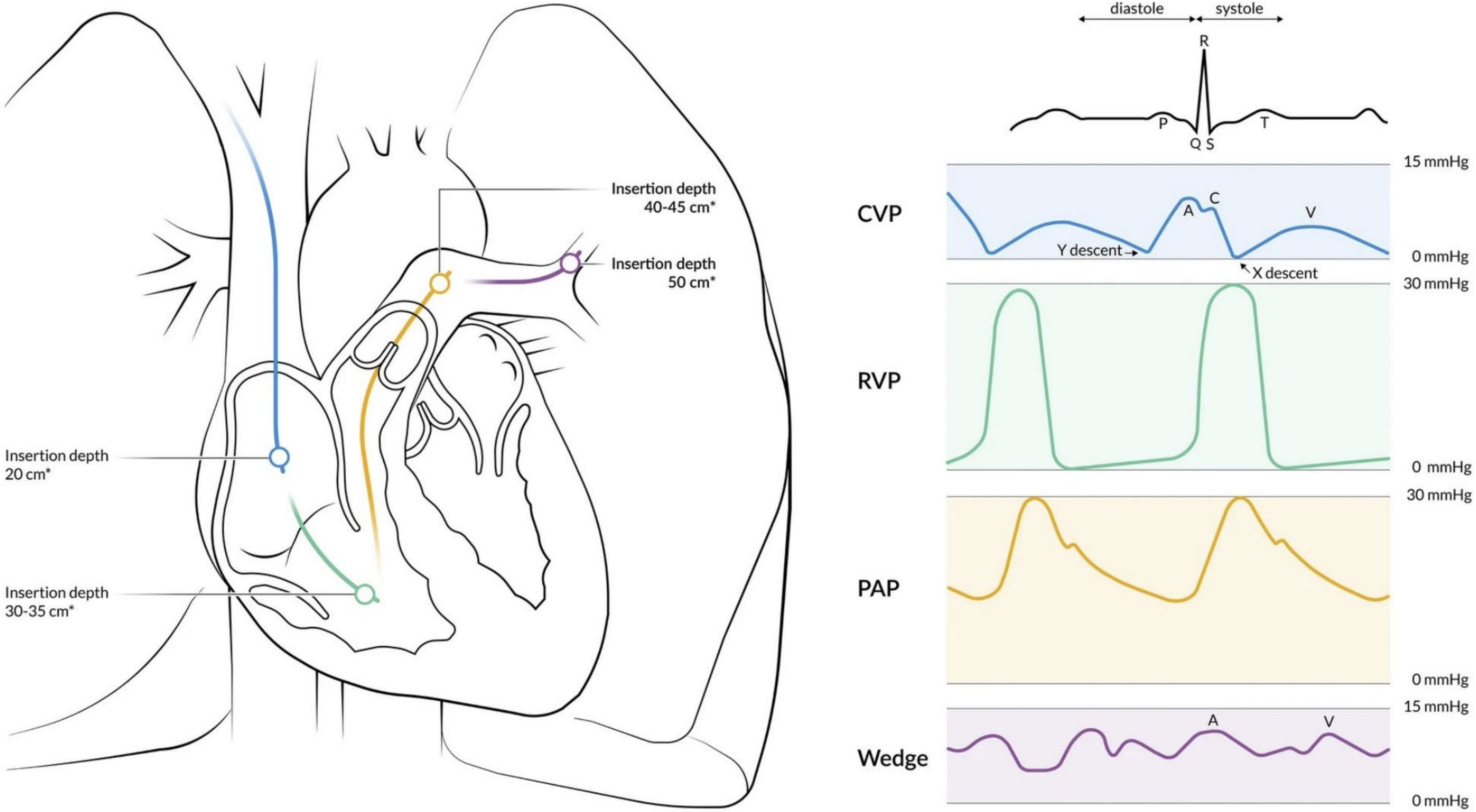
- Obtain directly measured values
  - CVP
  - RV
  - Wedge pressure
  - CO
  - Mixed venous saturation (SvO2)
- Calculated variables
  - SVR
  - PVR
  - CI

ORIGINAL ARTICLE

Pulmonary-Artery versus Central Venous Catheter to Guide Treatment of Acute Lung Injury

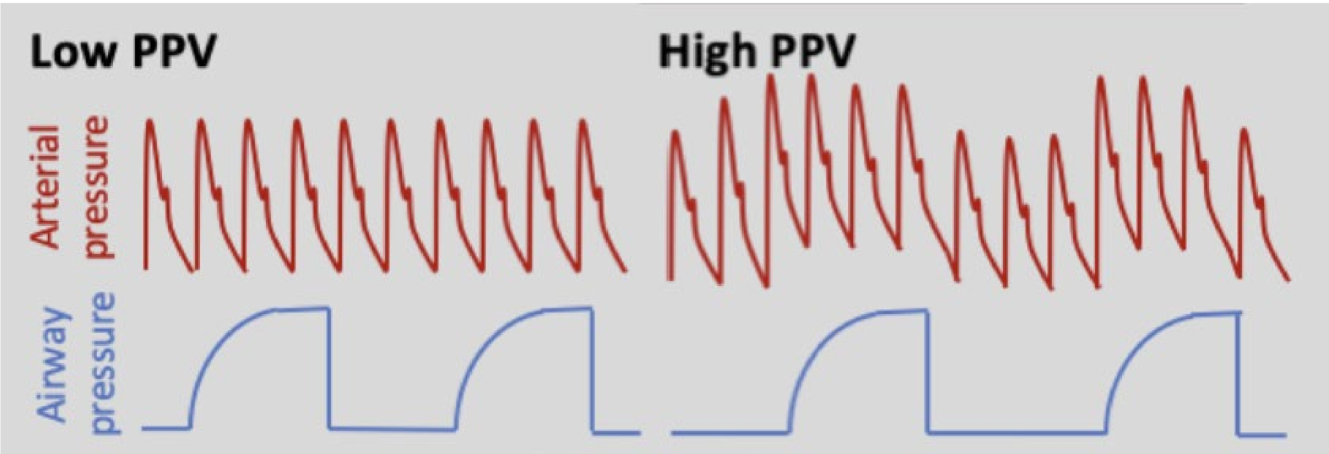
The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network*

Normal PA catheter pressure waveforms



Pulse pressure Variation

- **Pulse pressure** is defined as the difference between the systolic and diastolic blood pressure, and is usually 40 mmHg.
  - Main determinants are stroke volume and arterial compliance
- Pulse pressure is proportional to stroke volume
- Pulse Pressure variation (PPV) is the change in pulse pressure which occurs over time.
- Requirements for interpretation:
  1. SInus rhythm
  2. Mechanically ventilated w/o spontaneous respirations (8cc/kg TV)
  3. No open chest
- **PPV> 12% is suggestive that patient is fluid responsive**



$$PPV = \frac{PP_{max} - PP_{min}}{PP_{mean}}$$

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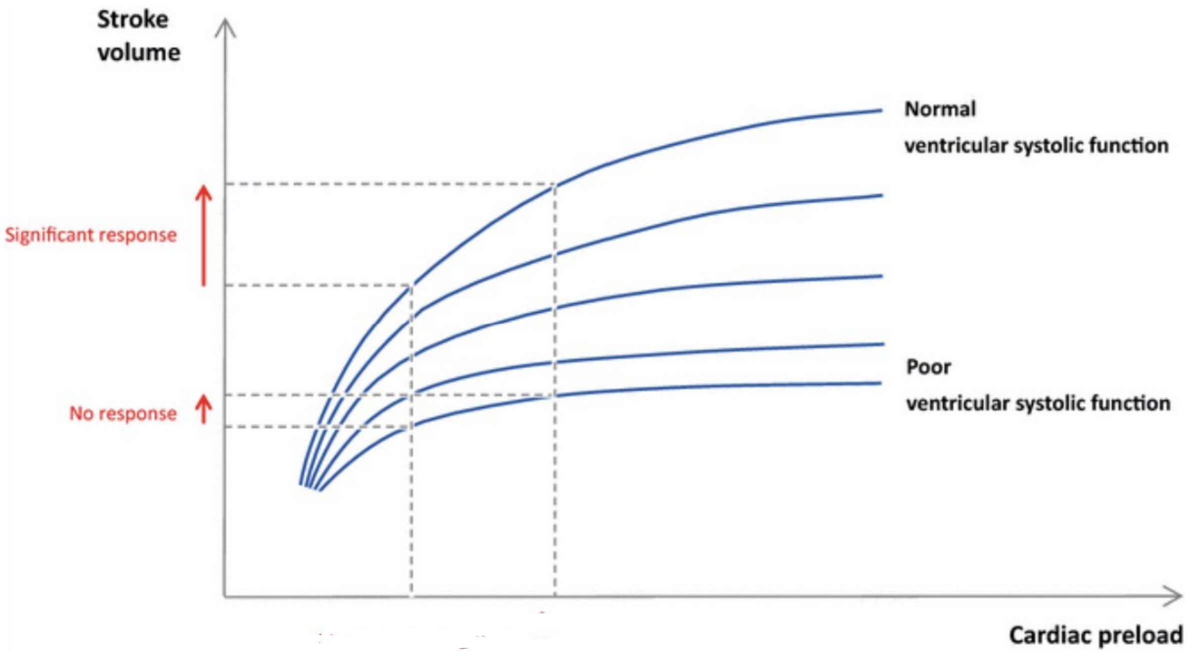
Pulse pressure variation

- Hemodynamic response with breathing may identify patient's response to fluid (or preload)
- Mechanical ventilation ↑'s preload and ↓'s afterload of LV
- Mechanical ventilation ↓'s preload and ↑'s afterload of RV
- After a delay (transit through the lungs), LV stroke volume ↓'s
- Net effect is a variation in PP that is larger when patient is on steep portion of F-S curve

Hemodynamic profiles in shock

Shock etiology	CVP / RA	PAOP	CO	SVR	SvO_2
Cardiogenic	↑	↑	↓	↑	↓
Hypovolemic	↓	↓	↓	↑	↓
Septic	varies	varies	= / ↑	↓	varies
Cardiac tamponade	↑ Equalization: RA/CVP, PAOP, PA diastolic	↑	↓	↑	↓
Increased PVR (pulmonary embolus)	↑	=	↓	↑	↓

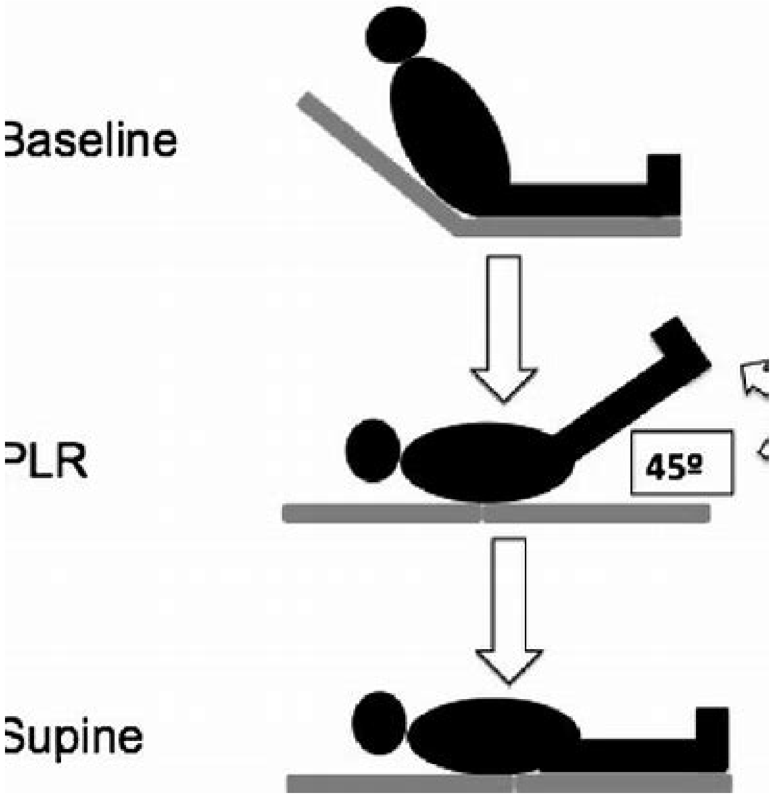
Fluid Responsiveness



- Dynamic assessment of stroke volume or cardiac output after a fluid challenge is easy and feasible
- 10-15% increase in cardiac output after giving fluid
  - Directly observed by assessing CO before and after fluid
  - Surrogate measures such end expiratory occlusion (EEO), bioreactance, IVC measurements, end tidal CO2
- Static measures like CVP and PAOP poorly predict fluid responsiveness
- Clinical parameters like UOP, MAP tend to lag behind and do not reliably predict fluid responsiveness
  - Some exceptions with extreme values

Monnet X, Marik P, Teboul J. Ann Intensive Care 2016; 6:111.

Passive Leg Raise

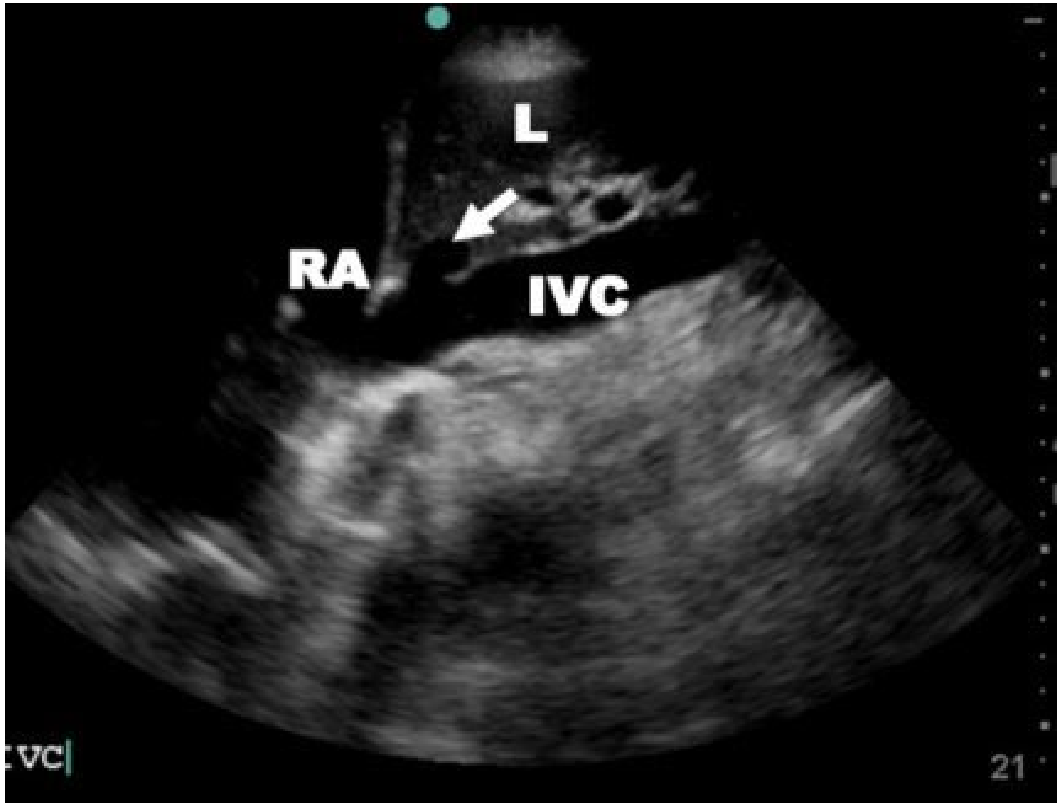


- Position patient with head of bed at 45 degrees
- Lower head of bed to 0 degrees.
- Raise legs quickly to 45 degrees for 30-90 seconds
- This should return a reservoir of blood (~300cc) to the central circulation
- PLR increase in cardiac output by 10% predicts fluid responsiveness with high sensitivity and specificity
- Advantage- Can be used in ventilated and non-ventilated patients, not confounded by arrhythmia

Marik PE. Ann Intensive Care. 2011;1:1 - 9. Monnet X, Marick P, Teboul J-L. Intensive Care Med 2016;42(12):1935-47

IVC Size and Distensibility

- IVC size reflects RA pressure, similar to CVP so measuring IVC size and phasic variation with respiration is a tool to predict fluid responsiveness
- Distensibility- Change in IVC size with respiration
- Mechanical ventilator: ↑ IVC diameter
- Spont breath:↓ IVC diameter



Bentzer P. JAMA 2016;316:1298 – 1309.

Collapsibility index = [IVCmax – IVCmin)/IVCmax] x 100

Variations > 12% suggest fluid responsiveness

IVC (cm)	Respiratory Change	CVP (cm H2O)
<1.5	Total collapse	0-5
1.5-2.5	>50% collapse	6-10
1.5-2.5	<50% collapse	11-15
>2.5	<50% collapse	16-20
>2.5	No change	>20

Measure 2cm from IVC/RA junction or 1cm from IVC/hepatic vein ju

(*IVC Ultrasound - WikEM*, n.d.)

Diagnostic accuracy of tests for FR in hypotension

	Studies (# pts)	Cutoff (mean)	Sensitivity %	Specificity %
CVP	7 (356)	8 mmHg	62	76
PPV > 7 ml/kg Vt	17 (768)	11%	84	84
PPV < 7 ml/kg Vt	5 (219)	8%	72	91
SV variation, mech ventilation	9 (343)	13%	79	84
ΔCO with PLR, mech ventilation	**6 (294)**	**10% ↑ in CO**	**92**	**92**
ΔCO with PLR, Spont breathe	**5 (181)**	**12% ↑ in CO**	**88**	**88**
Change in IVC, mech ventilation	4 (137)	15% distensibility index	77	85

Adapted from Bentzer P. *JAMA*, 2016;316:1298 – 1309.

Review

- There is no perfect tool – use what you are familiar with in the most challenging patients
- PAC is a useful tool to differentiate types of shock but there are other tools that help you do this. Never been proven to have a mortality benefit
- Assessing preload responsiveness should guide management and there are different ways to assess this:
  - Dynamic variables (i.e. changes in CO or PPV) are more accurate than static variables (i.e. CVP)
  - Change in cardiac output with passive leg raise may be best marker of volume responsiveness

Thank you for your time and attention

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