

Hemodynamic Waveforms Questions

Direct blood pressure monitoring and arterial pressure waveforms

- what information can be obtained from arterial pressure waveforms inc. normal values
- normal and abnormal waveforms (technical problems and patient problems)
- Systolic pressure and pulse pressure variation (calculations, how these relate to volume-responsiveness)

Central venous pressure

- Normal and abnormal CVP waveforms inc. normal values
- Clinical interpretation of changes in CVP / Limitations i.e. fluid-responsiveness

Pulmonary artery pressure and pulmonary artery occlusion pressure waveforms

Mixed venous and central venous oxygen saturation

Arterial pressure waveforms

Label the following diagram of an arterial pressure waveform

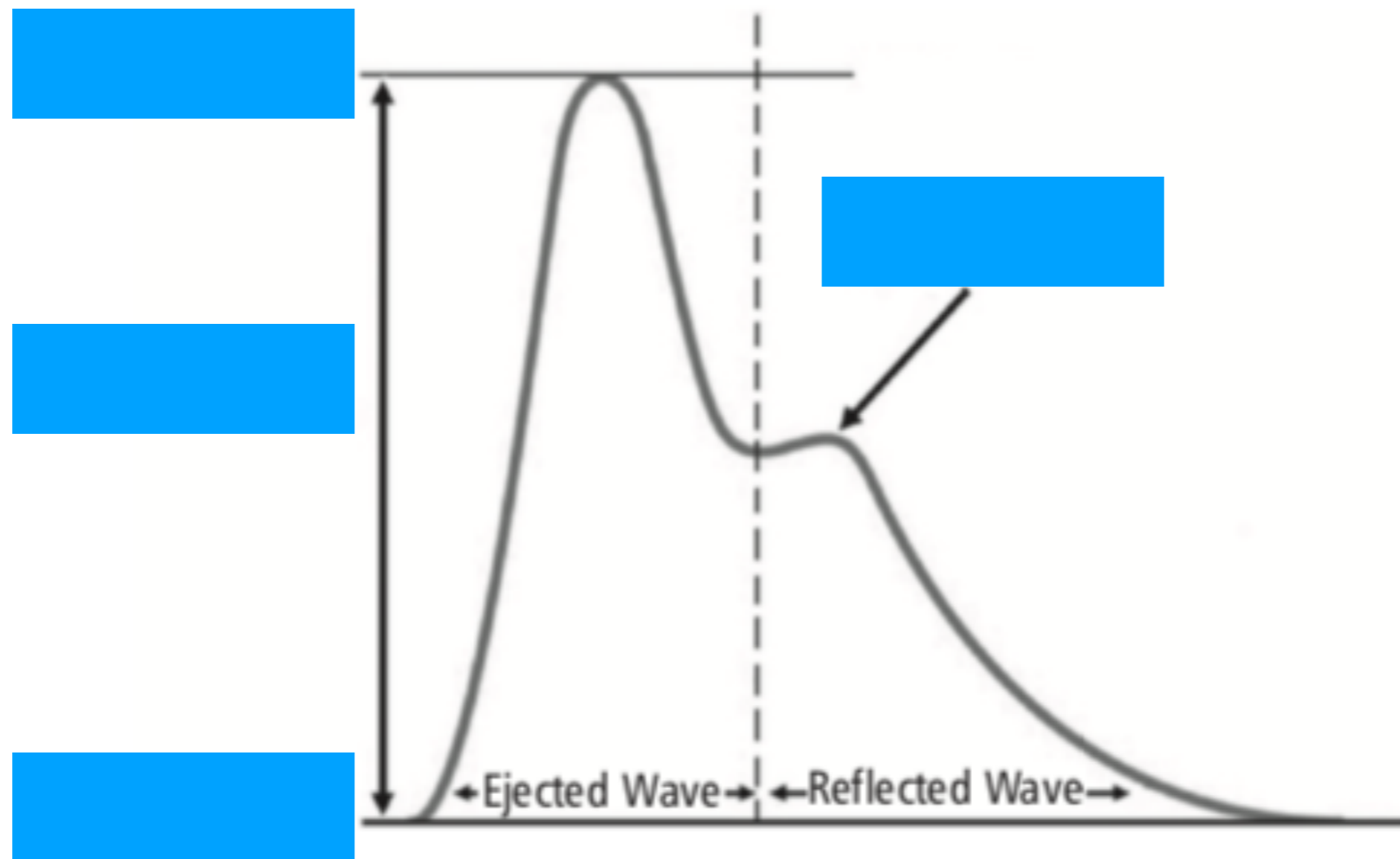


Figure 9.3 Idealized arterial pressure waveform.

Label the following diagram of an arterial pressure waveform

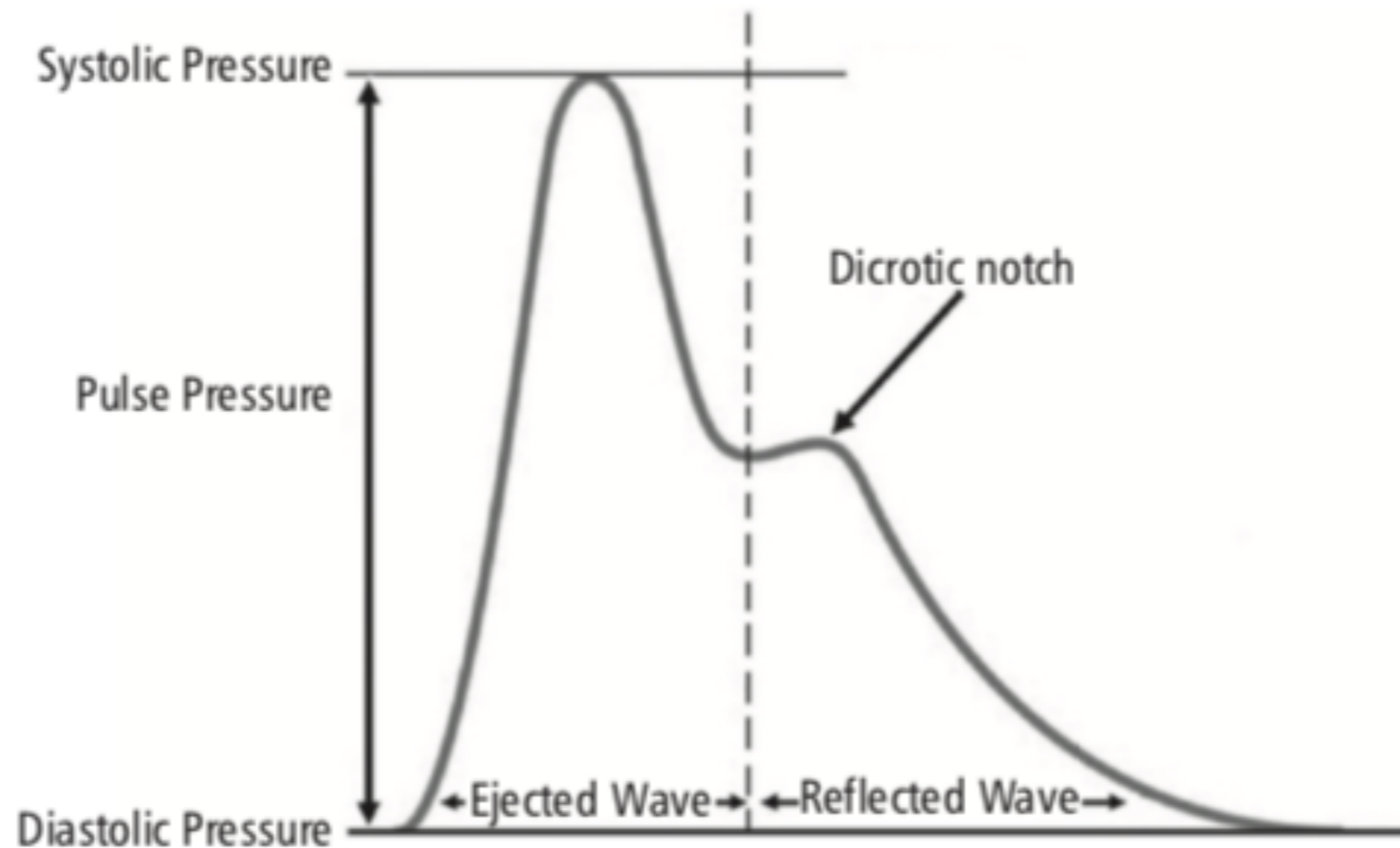


Figure 9.3 Idealized arterial pressure waveform.

Dicrotic notch occurs due to closing of the aortic valve
Elastic recoil in the presence of a closed aortic valve causes a slight rebound, and elevation in pressure. The dicrotic notch is largely a function of arterial elasticity and can be significantly diminished in the face of vasoconstriction.

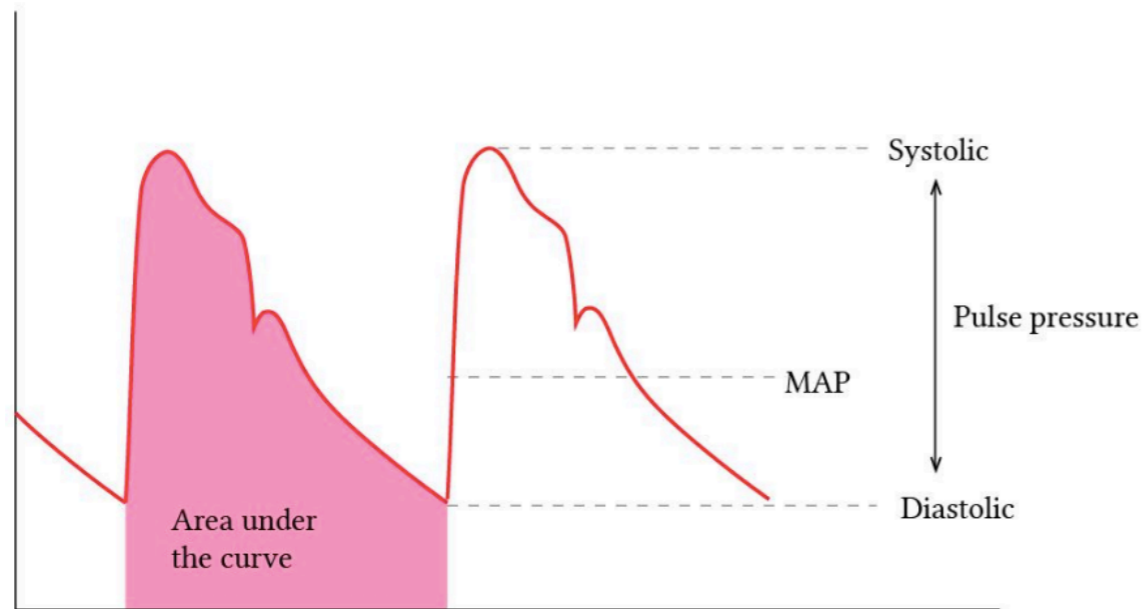
List the important pieces of the information that can be obtained from an arterial waveform tracing

List the important pieces of the information that could be obtained from an arterial waveform tracing

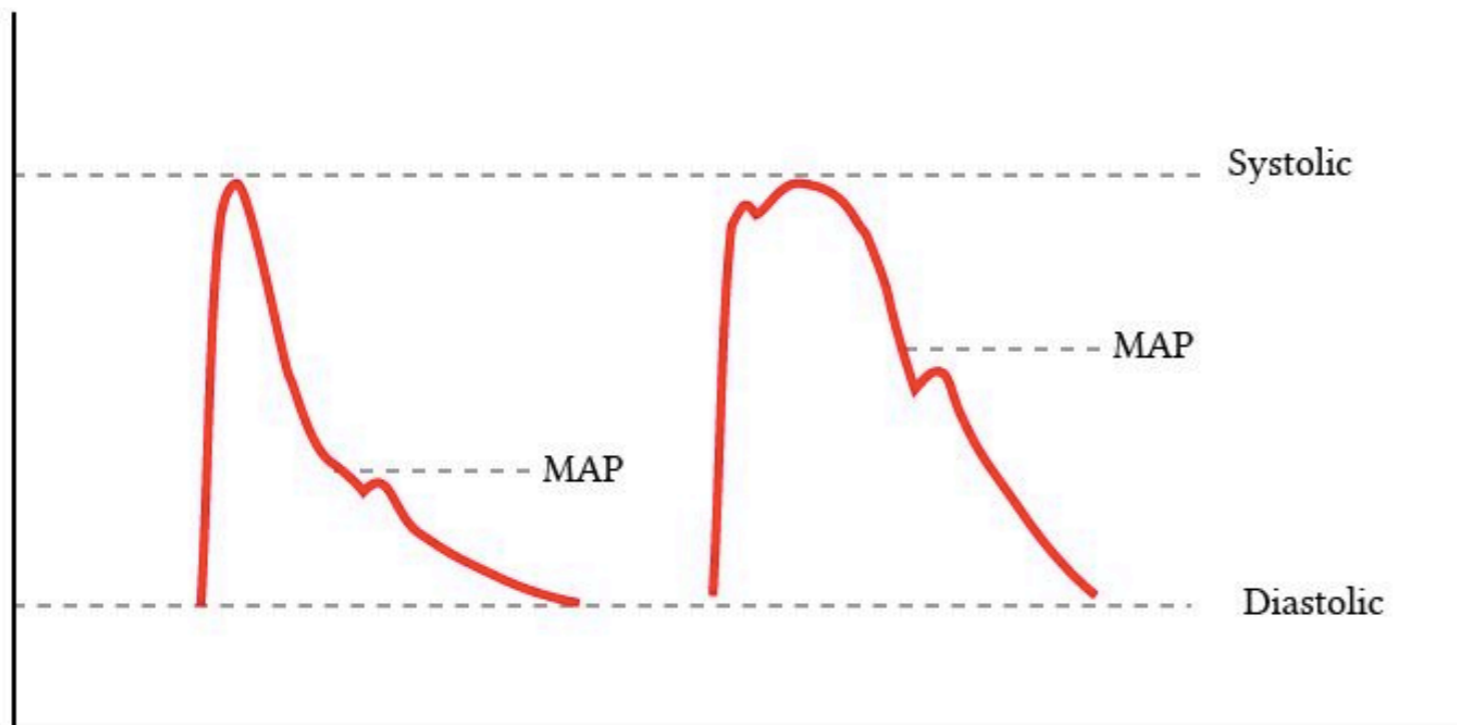
- Systolic, diastolic, mean and pulse pressures
- Heart rate and rhythm
- Effect of dysrhythmias on perfusion
- ECG lead disconnect
- Continuous cardiac output using pulse contour analysis
- Specific waveforms might be diagnostic - eg. slow rising pulse in AS, pulses paradoxes in tamponade
- Systolic pressure variation or pulse pressure variation may be useful in predicting fluid responsiveness

How is MAP calculated from the arterial pressure waveform?

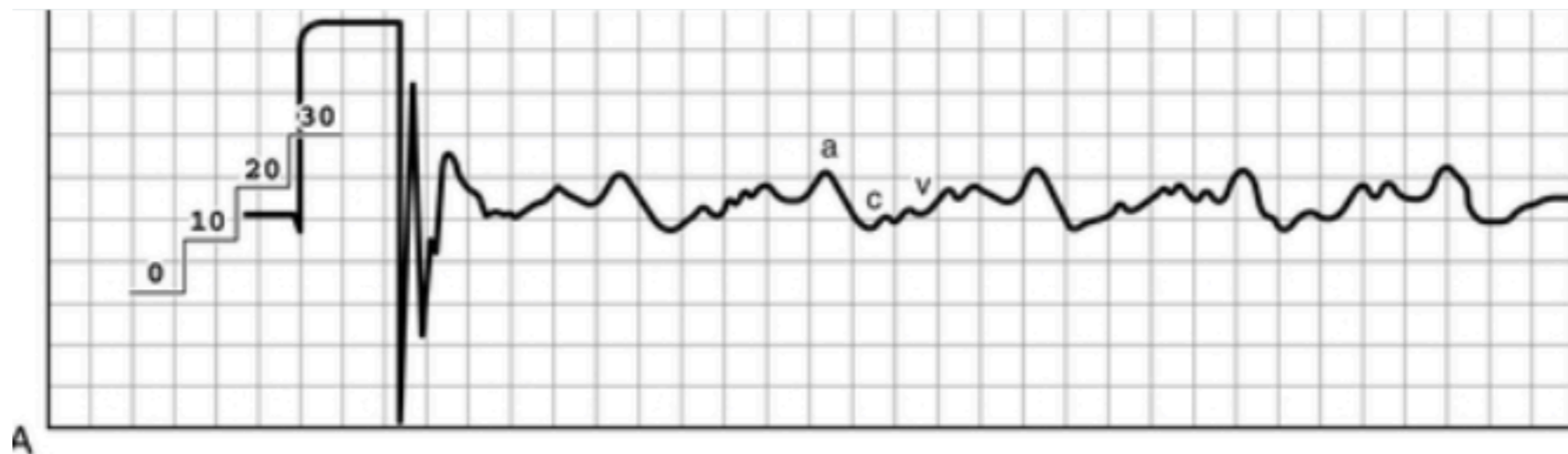
How is MAP calculated from the arterial pressure waveform?



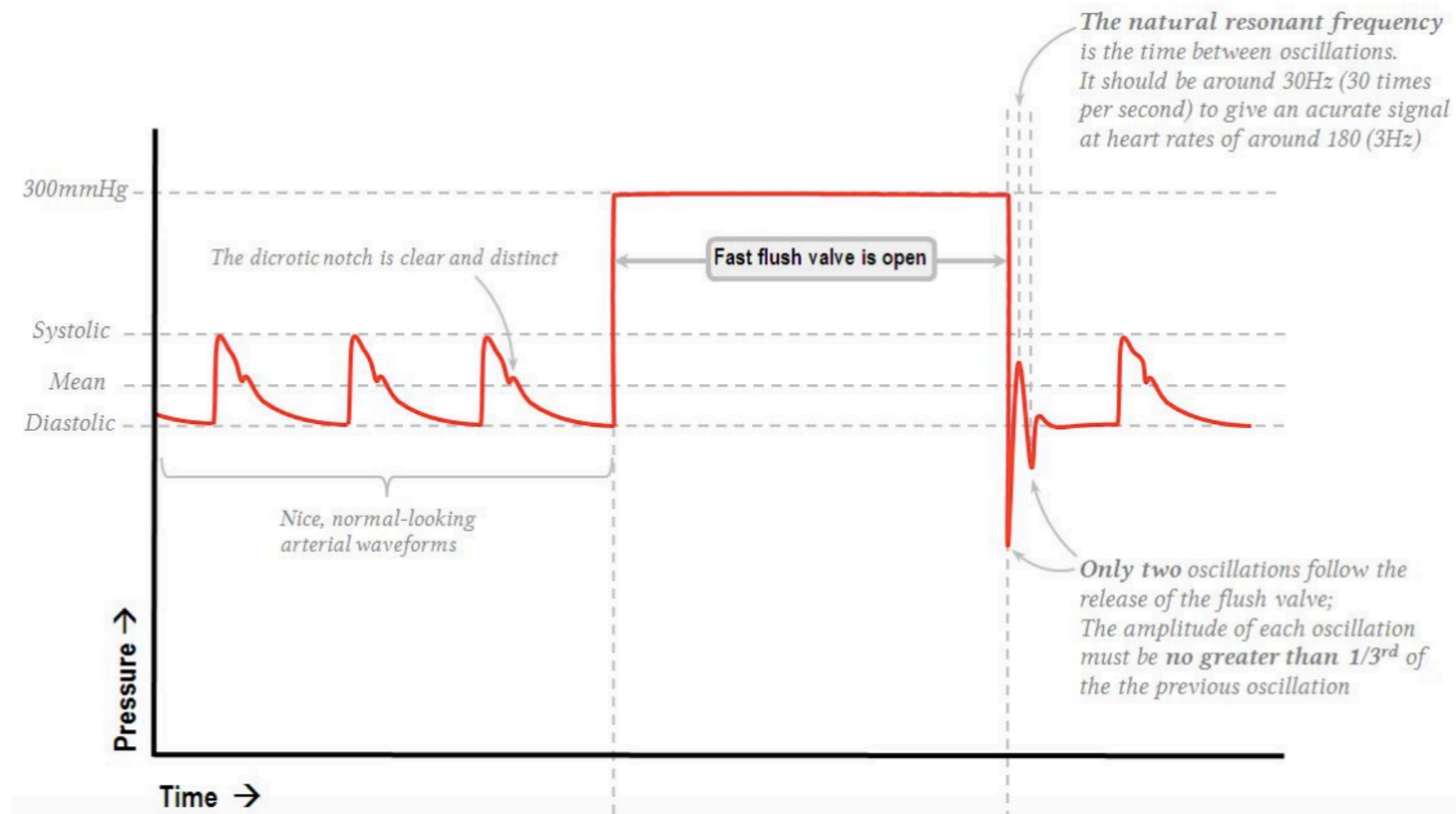
**AUC is more reliable than
 $MAP = DAP + (SAP - DAP)/3$**



Is this system optimally —
over- or under- damped?

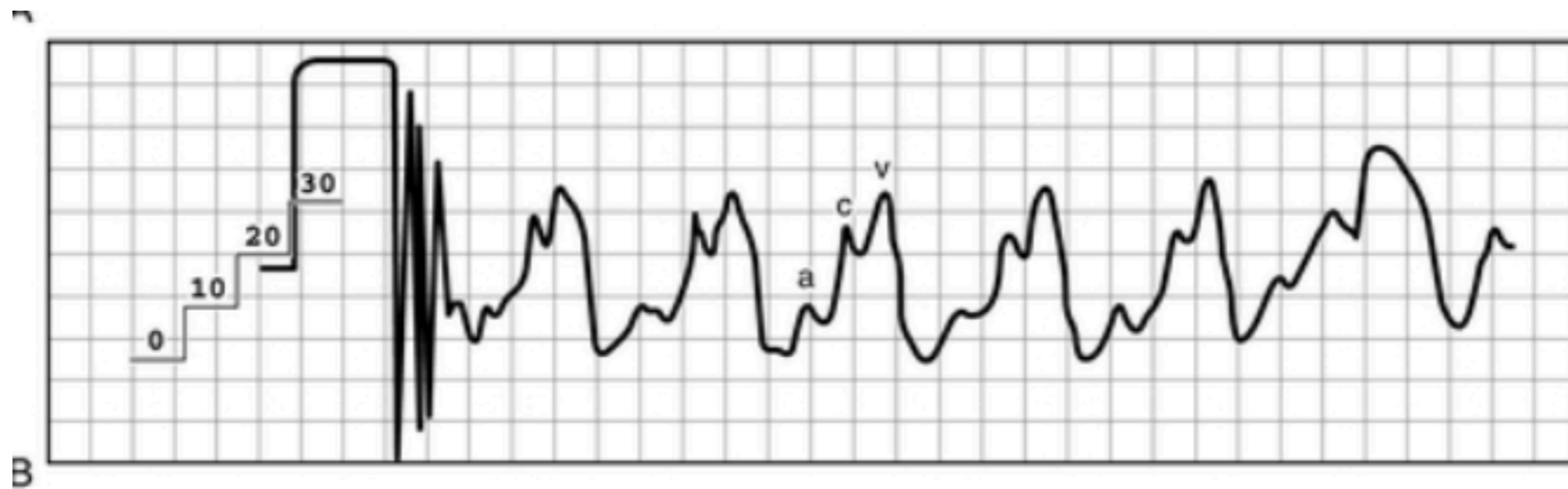


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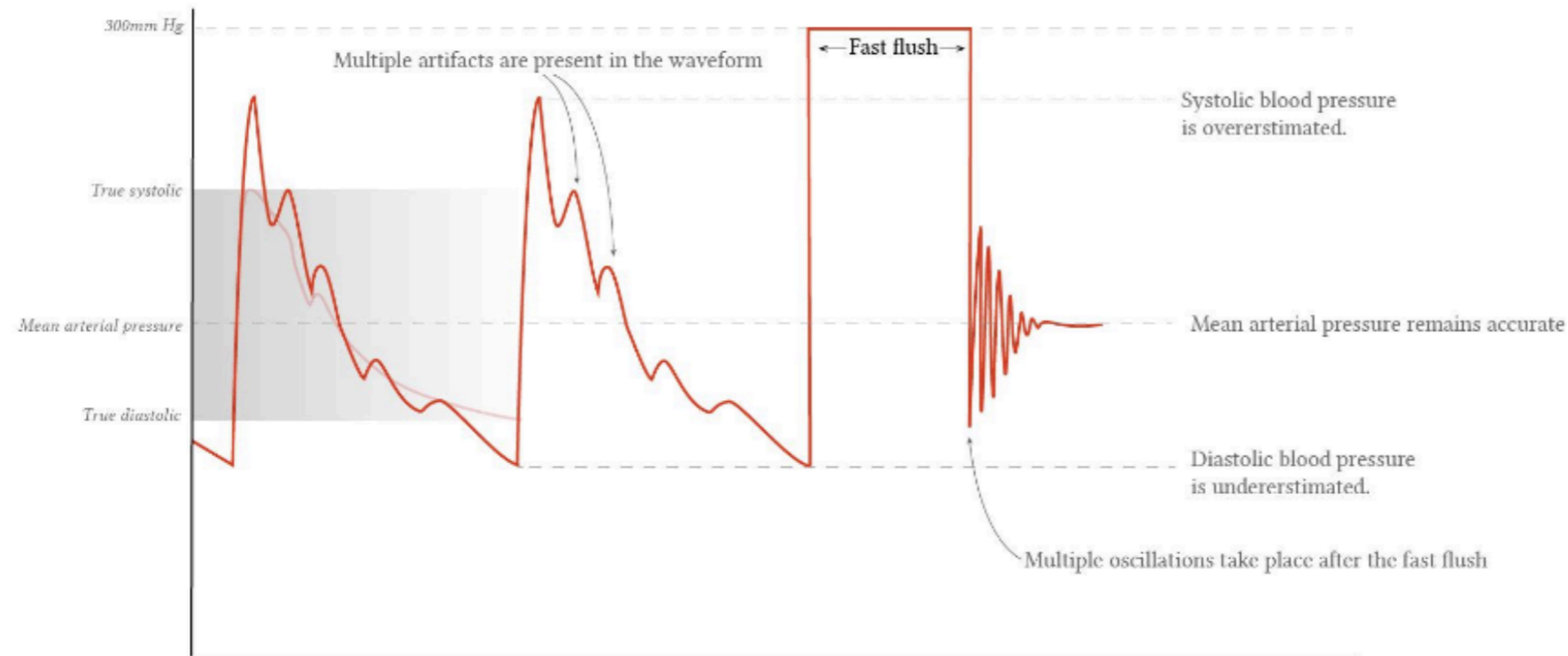


Damping: inherent tendency for the system itself to alter the pressure signal as it is transmitted from the patient to the transducer

Is this system optimally —
over- or under- damped?



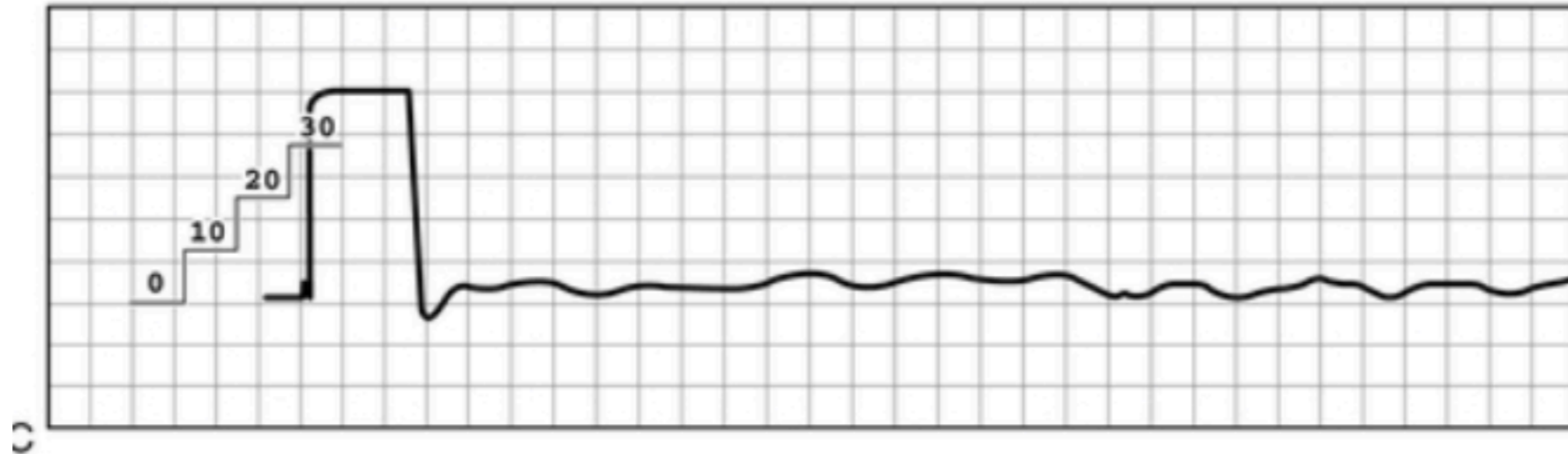
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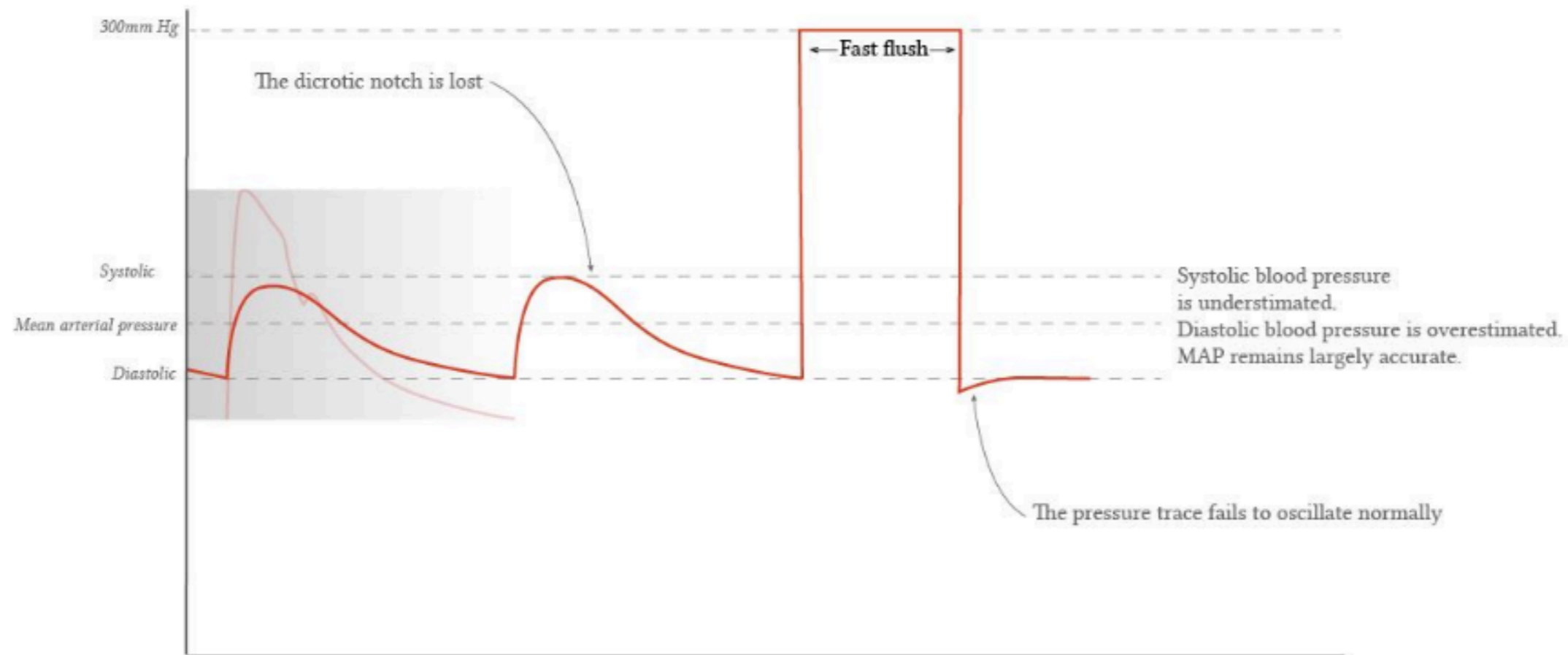
Underdamping: resonant frequency of the monitoring system too closely matches the frequency of the pressure waveform. The result is a summation or resonance of the two frequencies, amplification of the signal, overestimation of the SAP, and underestimation of the DAP

- All dABP monitoring systems will have some inherent underdamping effects
- Results in waveforms with sharp peaks or points
- Increasing the length of the tubing proportionally worsens the underdamping

**Is this system optimally —
over- or under- damped?**



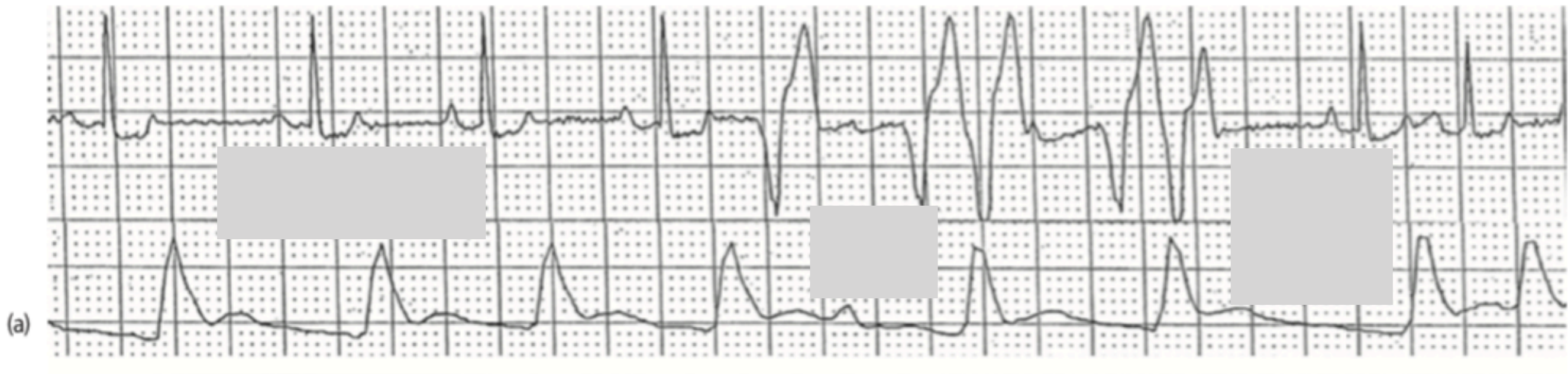
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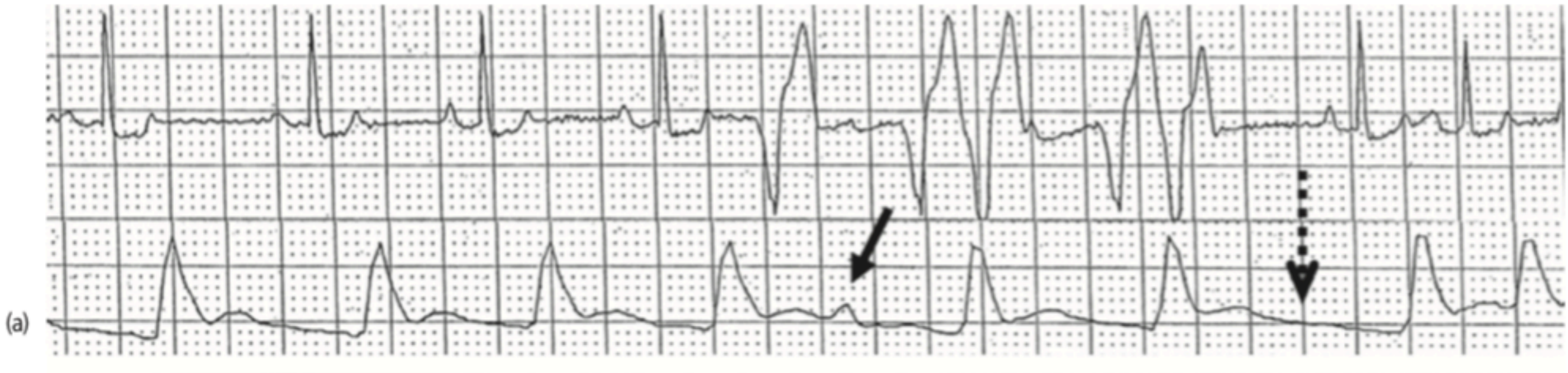
Overdampened: results in attenuation or muting of the arterial pressure waveform, leading to a falsely low SAP and falsely elevated DAP

- results in smooth waveform with loss of many of the defining characteristics
- potential causes of overdamping include bubbles in the line, line occlusion, use of overly compliant tubing

Describe the abnormal arterial pressure waveform

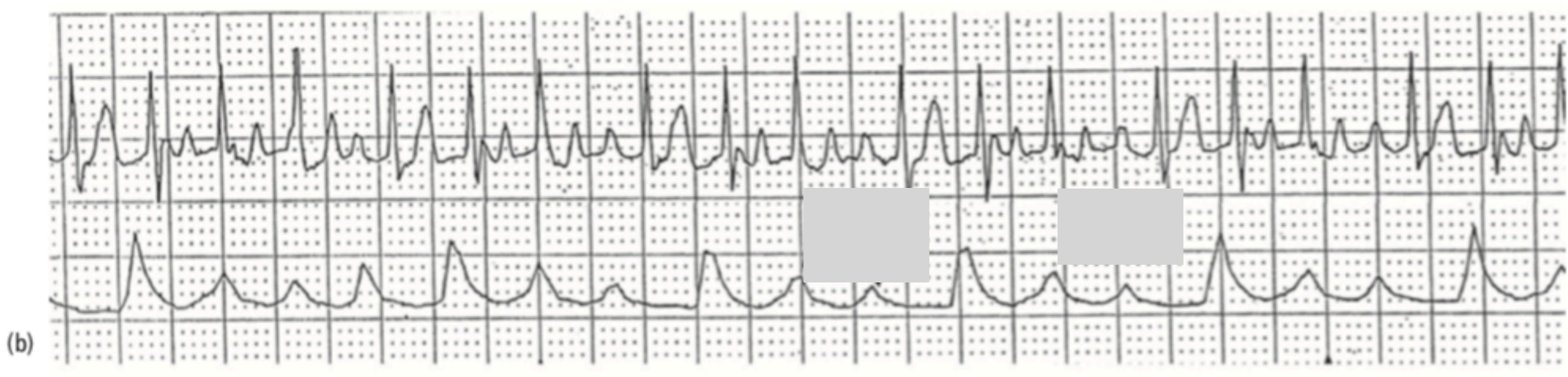


Describe the abnormal arterial pressure waveform



- VPCs associated with diminished to absent pressure tracings

Describe the abnormal arterial pressure waveform

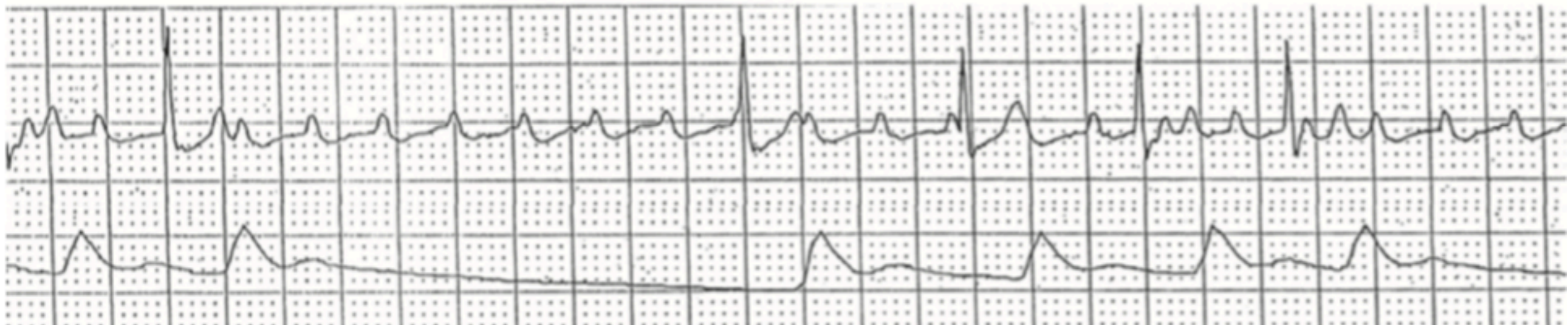


- Marked tachycardia resulting in progressively diminished waveforms and blood pressure

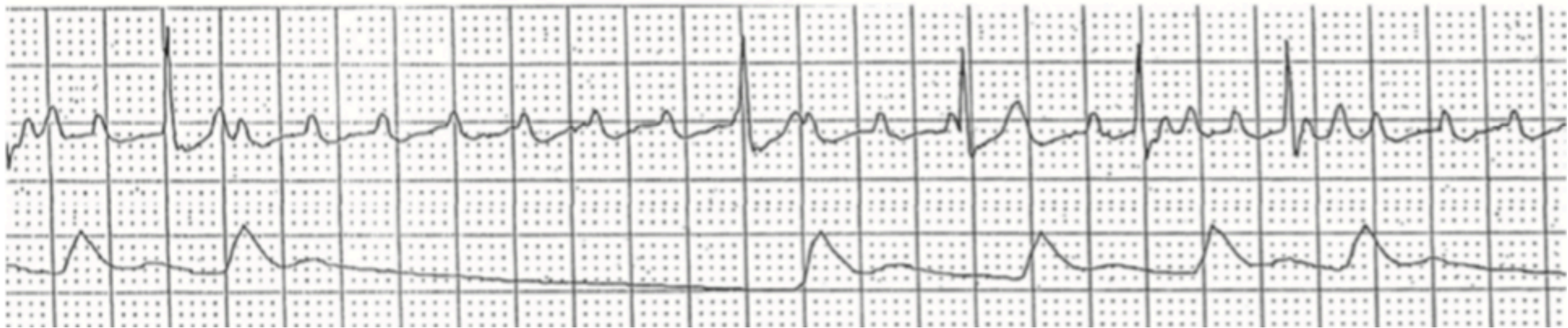
Describe the abnormal arterial pressure waveform



Describe the abnormal arterial pressure waveform



Describe the abnormal arterial pressure waveform



- Atrial flutter with prolonged periods of absent ventricular contraction resulting in absent arterial waveforms

What is systolic pressure variation (SPV) and how is it clinically useful?

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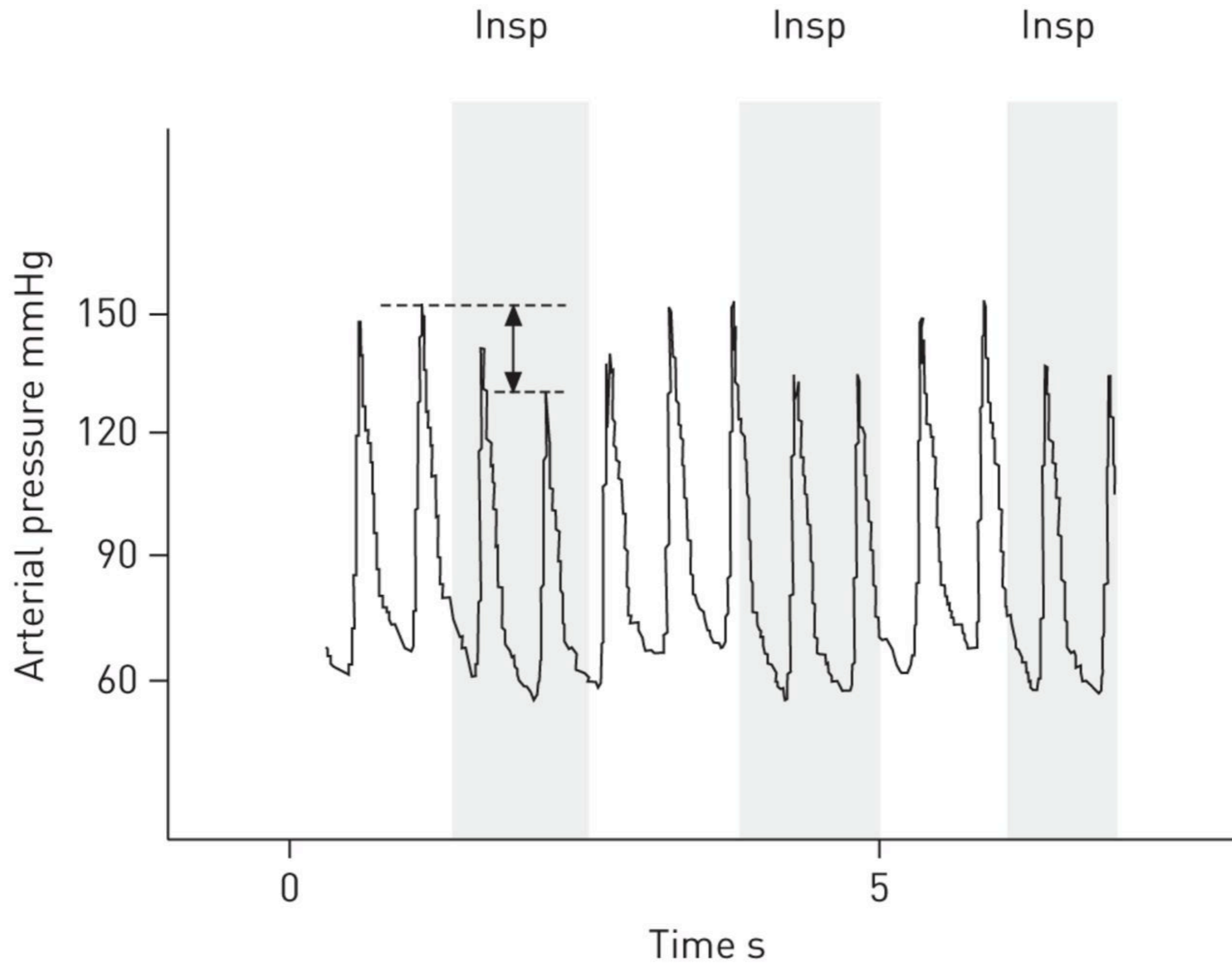
- Systolic pressure variation: difference between the maximum systolic pressure present during inspiration and the minimum systolic pressure present during exhalation
- $SPV > 10$ mmHg has been shown to correlate fairly well to hypovolemia in human patients

What is pulse pressure variation (PPV) and how is it clinically useful?

What is pulse pressure variation (PPV) and how is it clinically useful?

- Obtained by dividing the difference between the minimum and maximum pulse pressures per a single breath by the mean of the two values. The result is expressed as a percentage.
- PPV appears to have the strongest correlation to hypovolemia and volume responsiveness, with higher PPVs correlating to greater degrees of volume-responsiveness
- A PPV of 10-15% is likely to indicate potential for fluid responsiveness. The higher the PPV the more likely the patient is to be fluid responsive.
- The lower you are on the Frank-Starling curve, the more stroke volume will vary depending on the phase of ventilation
 - decrease in preload due to mechanical inspiration results in a decrease in ventricular wall stretch -> decreased stroke volume -> greater difference inspiration and expiration stroke volumes

Calculate the SPV & PPV



Calculate the SPV & PPV

- $SPV = 150 - 130$

$$SPV = SP_{\max} - SP_{\min}$$

- $SPV = 20$

- $PPV\% = 100 \times (PP_{\max} - PP_{\min}) / [(PP_{\max} + PP_{\min}) / 2]$

- $= 100 \times (90 - 70) / [(90 + 70) / 2] = 25\%$

- $= 25\%$

$$PPV\% = \frac{PP_{\max} - PP_{\min}}{\text{Mean of the 2 PP}} \times 100$$

**What are limitations of
pulse pressure variation?**

What are limitations of pulse pressure variation?

- Patient must be on PPV
- Accuracy is affected by arrhythmias, changes in chest wall compliance or with right or left ventricular failure

Central Venous Pressure (CVP)

Fill in the blanks

Central venous pressure is a close approximation of _____, which is in turn is a determinant of _____.

Fill in the blanks

Central venous pressure is a close approximation of right atrial pressure, which is in turn is a determinant of right ventricular preload.

Right atrial pressure is a major determinant of right ventricular end-diastolic pressure. Right ventricular end-diastolic pressure is related to right ventricular end-diastolic volume, which determines end-diastolic myocardial wall stretch, or preload. (Assumes right ventricular compliance is normal)

What is a normal CVP?

What is a normal CVP?

- 0 - 5 cmH₂O, although up to 10 cmH₂O can be normal
- The wider reference range reflects inherent variability in normal resting CVP due to the impact of many factors on venous tone (blood volume, venous tone, cardiac function)
- $\text{CVP in cmH}_2\text{O} = \text{CVP in mmHg} \times 1.36$
- Trends are more important than individual numbers

**What are differentials for a
low or falling CVP?**

What are differentials for a low or falling CVP?

- Shock
- Vasodilation
- Transducer is above the level of the right atrium

**What are differentials for a
normal CVP?**

What are differentials for a normal CVP?

- Normovolemia
- Compensated hypovolemia
- Compensated hypervolemia

**What are differentials for a
high or rising CVP?**

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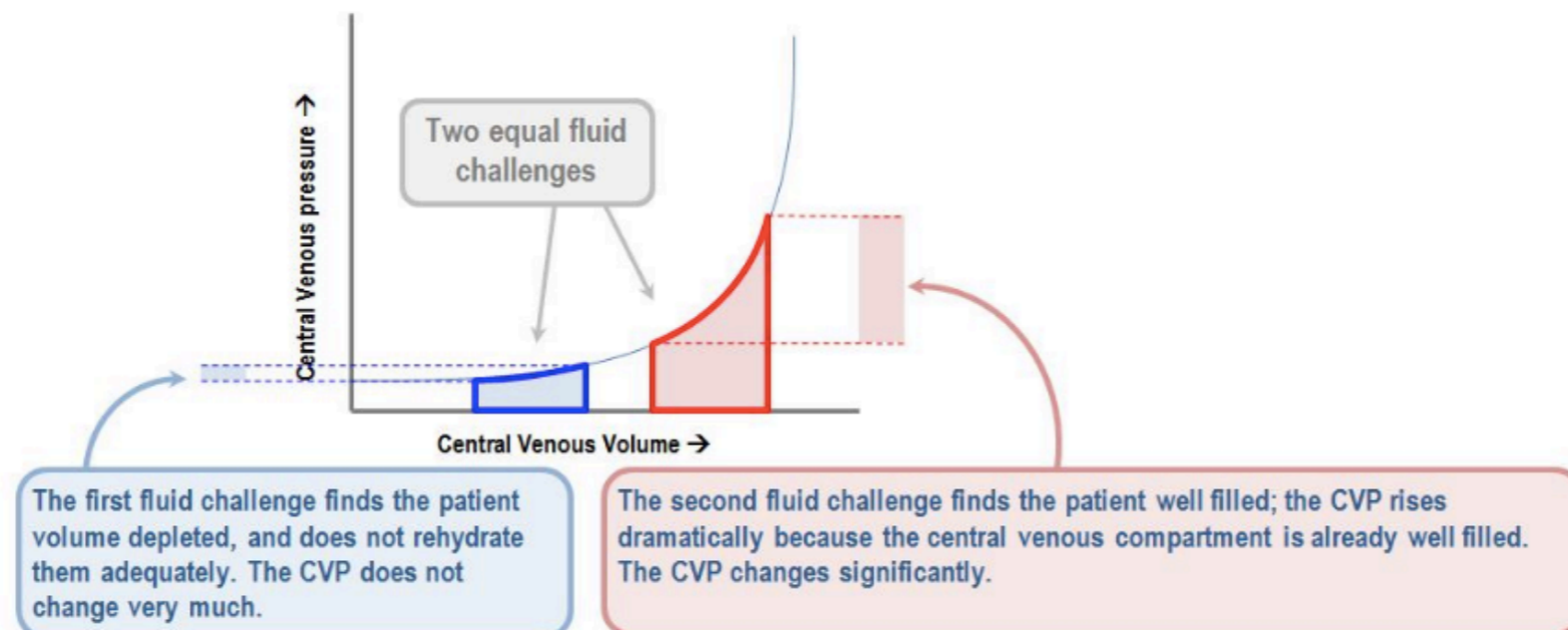
- Volume overload
- Vasoconstriction or systemic hypertension
- Right-sided heart disease
 - tricuspid regurgitation
 - tricuspid stenosis
- Pericardial disease
 - pericardial effusion
 - constrictive pericarditis
- Vena caval obstruction
- Pulmonary disease
 - pulmonary hypertension
 - pulmonary thromboembolism
- Increased intrathoracic pressure
 - pleural effusion
 - intrathoracic mass
 - PEEP
 - Positive-pressure ventilation in the presence of hypovolemia
 - pneumothorax
- Increased intra-abdominal pressure
- Occlusion of the catheter, fluid line or stopcock
- Transducer is below the level of the right atrium

What is the anticipated response to a fluid challenge in a hypovolemic, euvolemic, and volume-overloaded patient?

- what is the baseline CVP?**
- how much does CVP rise?**
- does it return/ how quickly does it return to baseline?**

Does the following response to a fluid challenge best describe a hypovolemic, euvolemic, or volume-overloaded patient?

1. **Euvolemic animal:** Rise in CVP of 2-4 cm H₂O, followed by rapid return to the original value within 15 minutes
2. **Hypovolemic animal:** Starting CVP is low, rises minimally or rapidly returns to baseline (within 5-15 minutes)
3. **Volume-overload, decreased cardiac performance, restrictive pericardial disease:** persistent, marked elevation in CVP, and prolonged return to baseline (greater than 30 minutes)

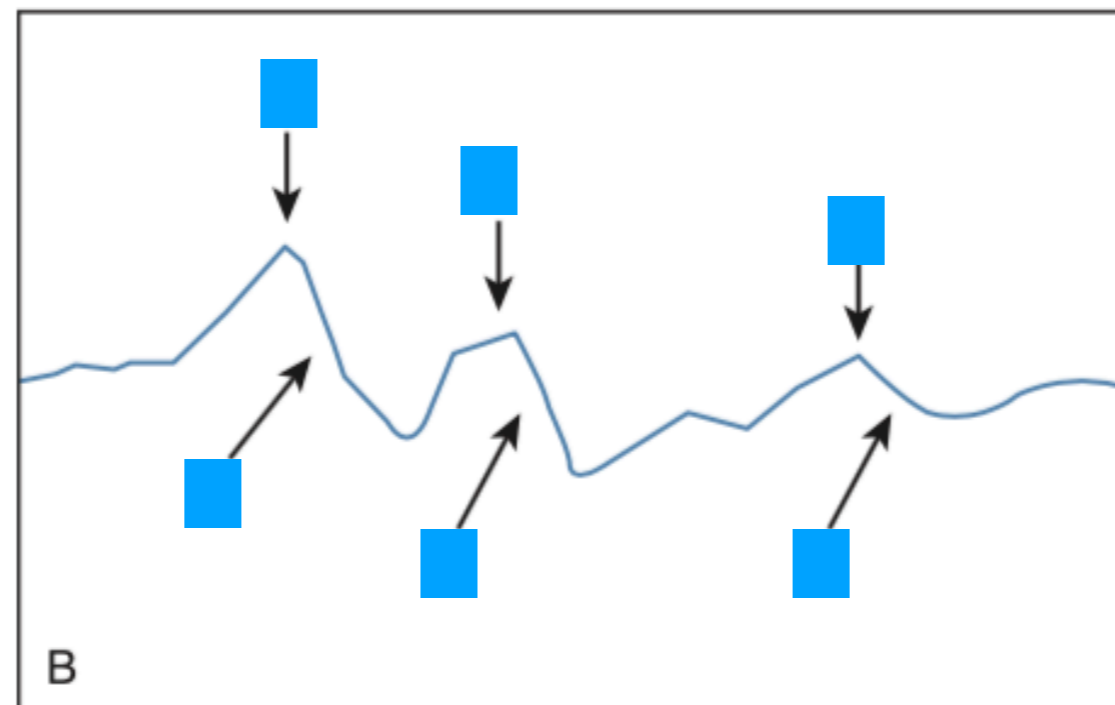
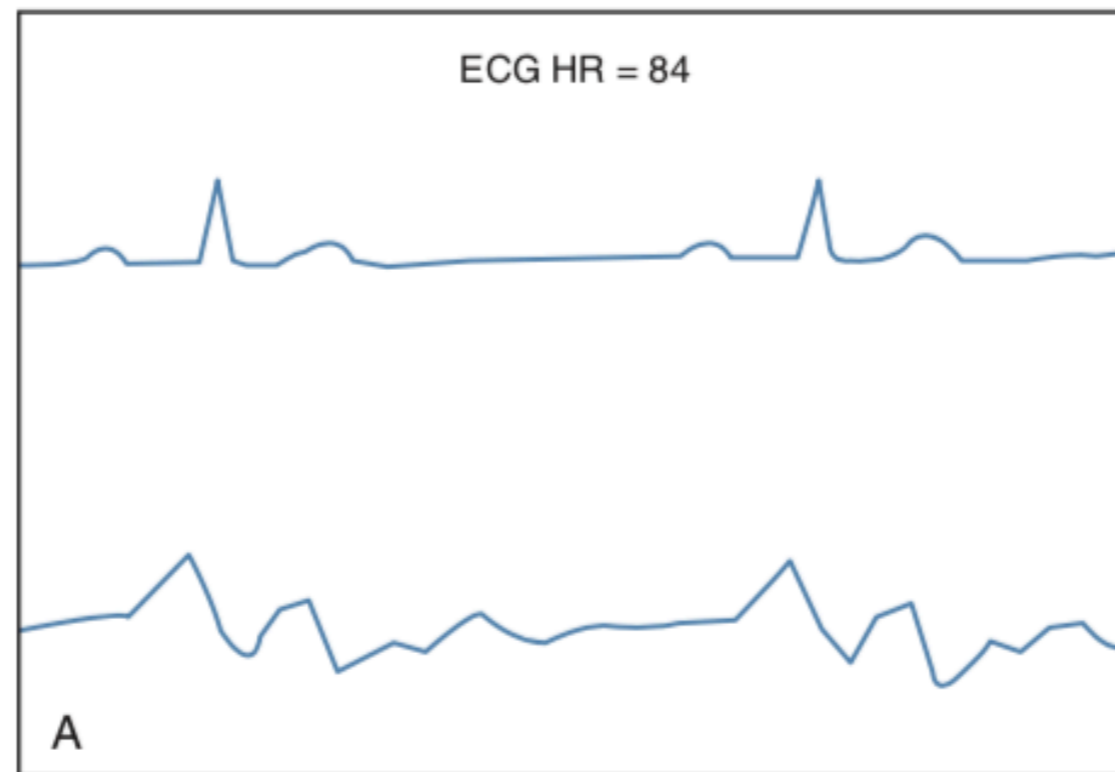


Does CVP predict volume status? Why/ why not?

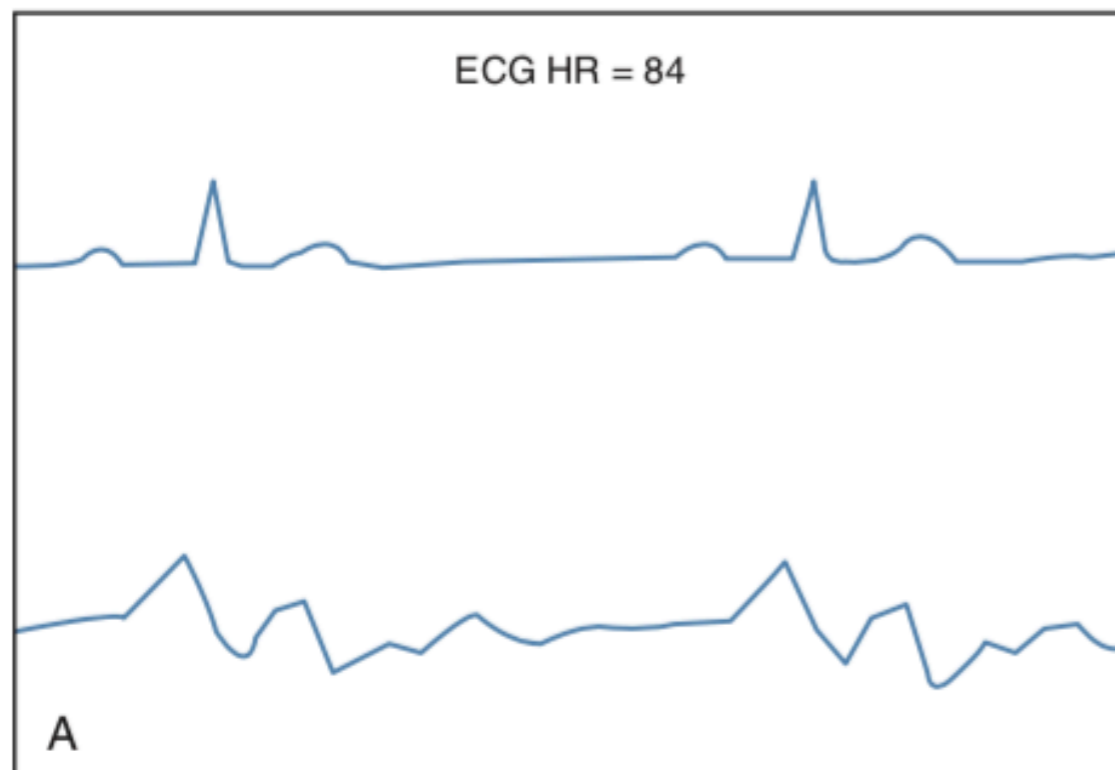
Does CVP predict volume status? Why/ why not?

- Simply, low values of CVP should correspond to hypovolemia and high volume should correlate to volume overload, but in reality, the association between CVP and preload is not always so straightforward. Critics note that CVP does not correlate well with intravascular blood volume, nor can CVP be used to predict stroke volume or cardiac output following a fluid challenge.
- Studies have consistently failed to find a threshold CVP pressure below which fluid loading will always improve cardiac output. This is likely due to the complex hemostatic mechanisms in place that maintain an adequate pressure gradient for venous return.
 - Venous return is dependent on an adequate driving pressure; i.e. the pressure in the peripheral venous circulation is about 5-10 mmHg greater than the pressure within the central veins
 - The venous system serves as a blood reservoir, containing ~65% of the systemic blood volume. When ECV is low, constriction of the splanchnic veins increases the circulating pool of blood to support adequate venous return. CVP may change minimally during this time, but once the blood reservoir has been depleted, the CVP will fall
 - Due to compensatory mechanisms, CVP cannot distinguish between compensated hypovolemia or hypervolemia. A severely elevated CVP may be due to normovolemia in the presence of severe cardiac dysfunction, or hypervolemia with normal cardiac performance.
- Still generally considered that in patient with normal cardiac function and a low CVP, that are more like to respond to volume than patients with a normal or high CVP.
 - CVP < 5 mmHg are likely to be volume responders
 - CVP >10-12 mmHg are unlikely to benefit from a fluid bolus
- Trends are more important than individual readings, and should be interpreted in light of patient's other perfusion parameters

Label and describe the events on a normal CVP waveform



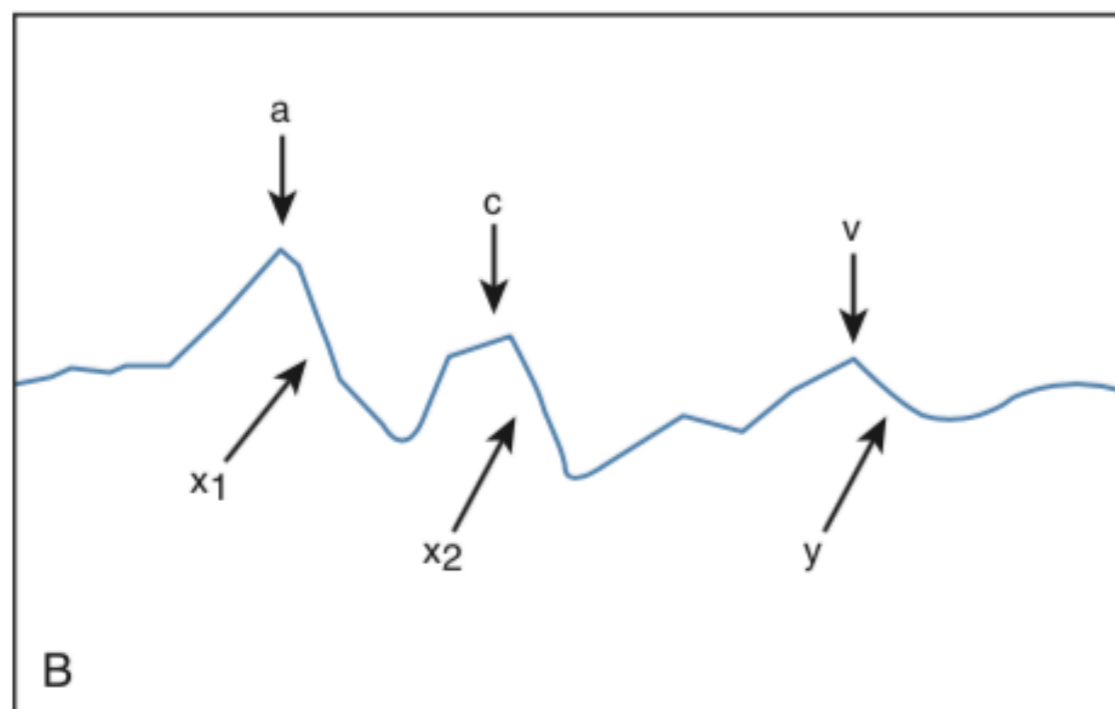
Label and describe the events on a normal CVP waveform



a wave: right atrial contraction
(appears shortly after P wave)

c wave: bulging of the tricuspid valve into the right atrium during early right ventricular systole

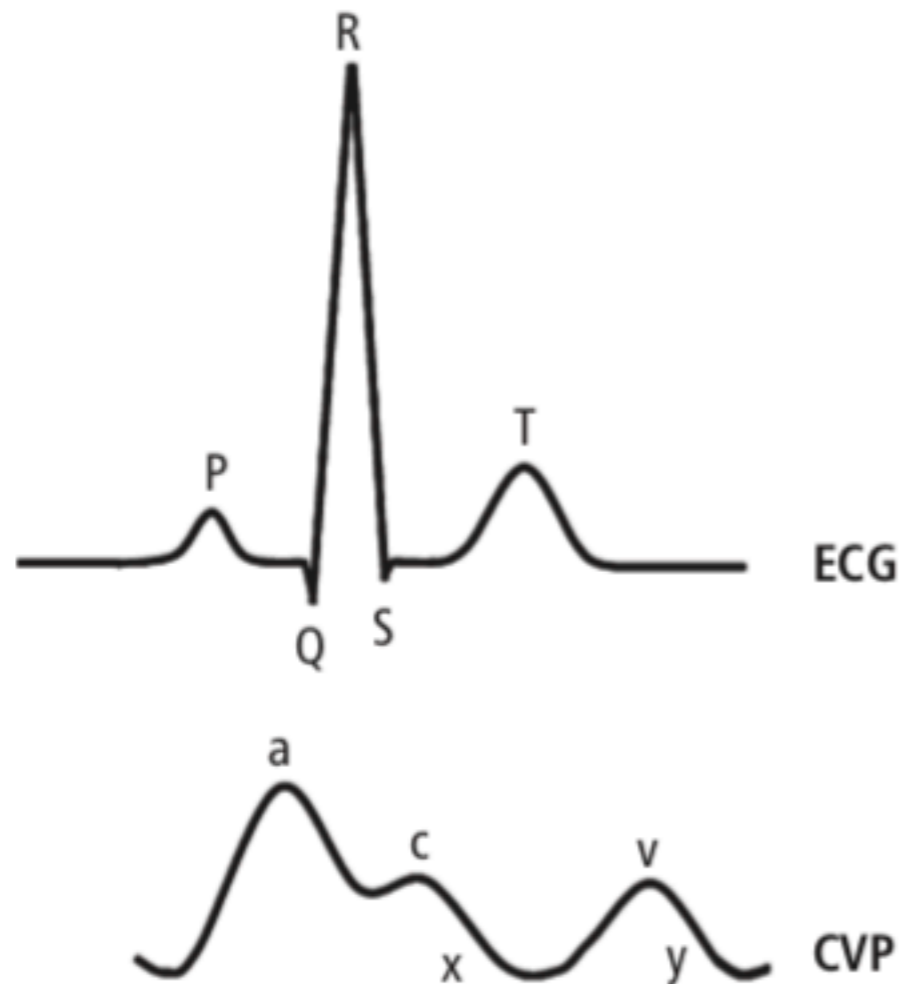
x descent: right atrial relaxation,
ventricular ejection



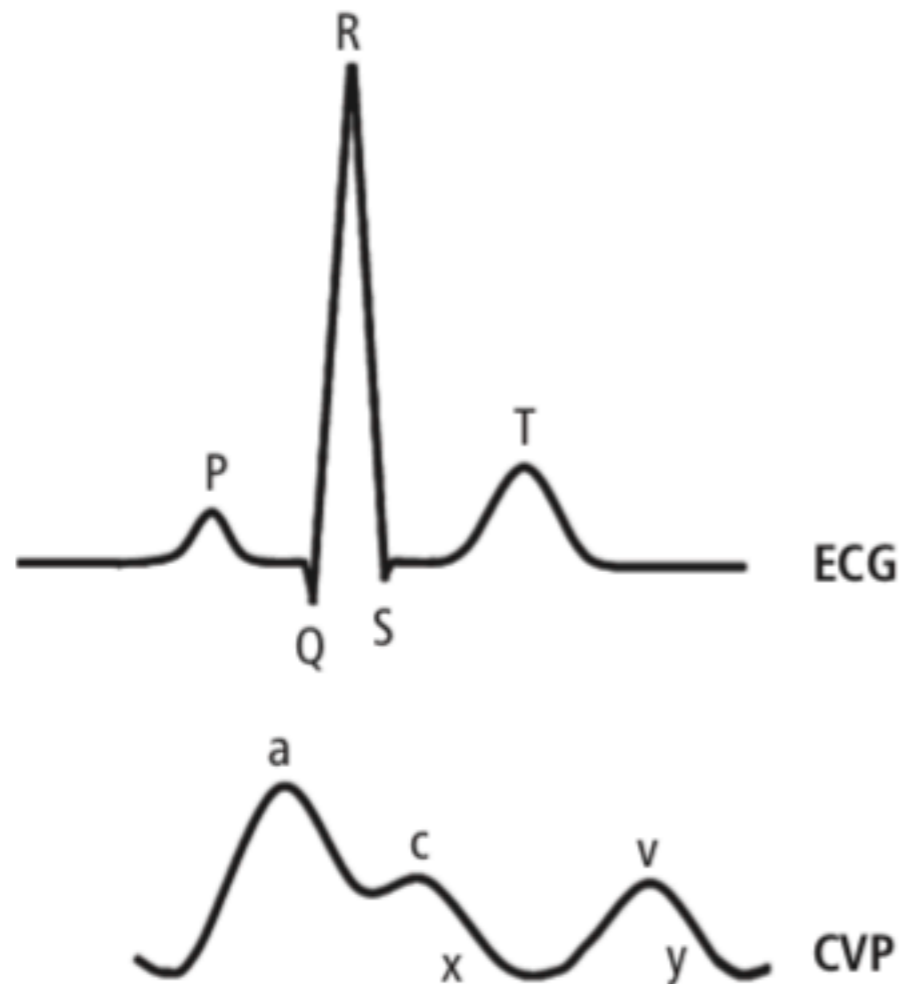
v wave: blood flowing into the right atrium before the tricuspid valve opens (appears shortly after T wave)

y descent: rapid emptying of the right atrium as the tricuspid valve opens, allowing blood to flow into the right ventricle

What pressure is displayed by a continuous CVP monitor? Which pressure on the waveform provides the best estimate of CVP and why?



What pressure is displayed by a continuous CVP monitor? Which pressure on the waveform provides the best estimate of CVP and why?



The monitor displays a continuous pressure reading that represents an average pressure measurement over time

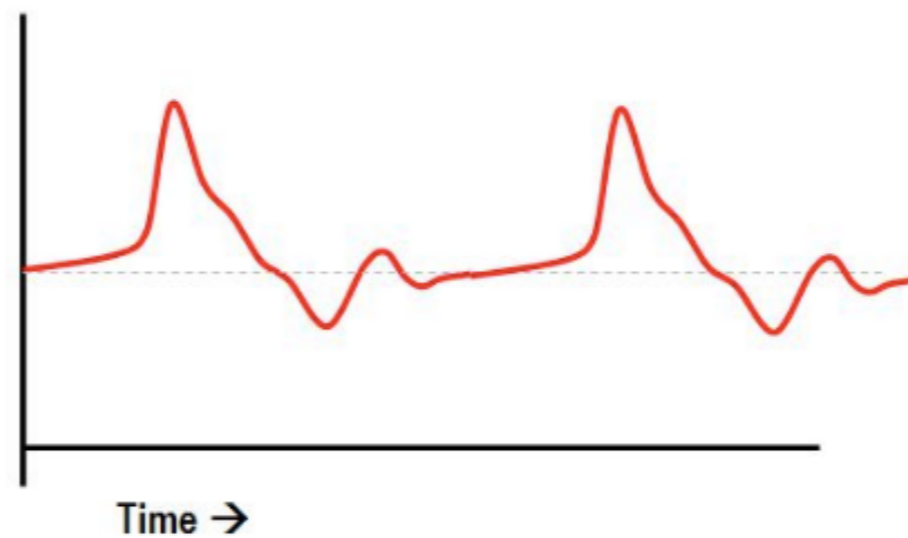
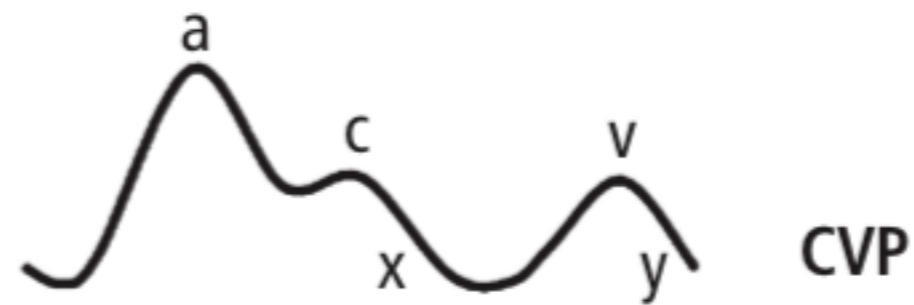
The mean of the a wave provides the best estimate of CVP because it corresponds to venous pressure at the end of diastole.

How can you calculate CVP from a printed venous pressure tracing?

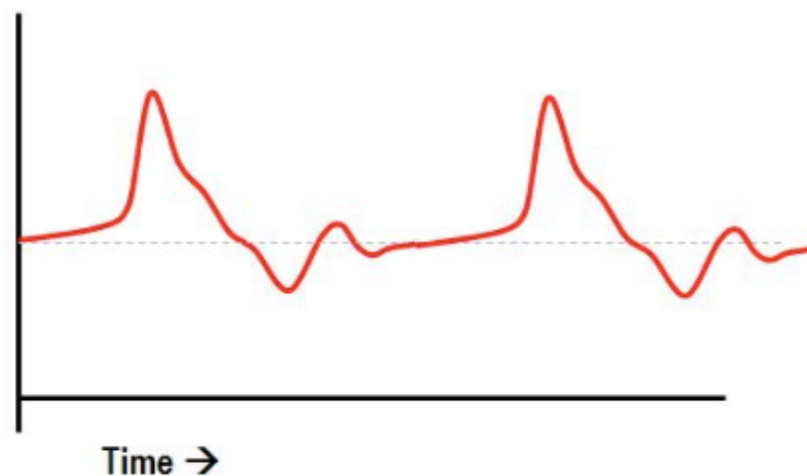
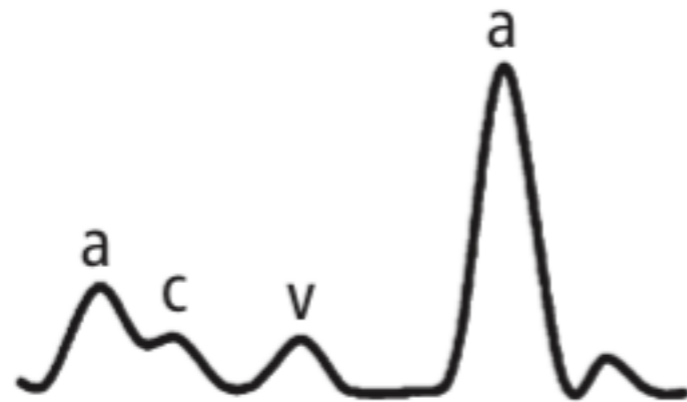
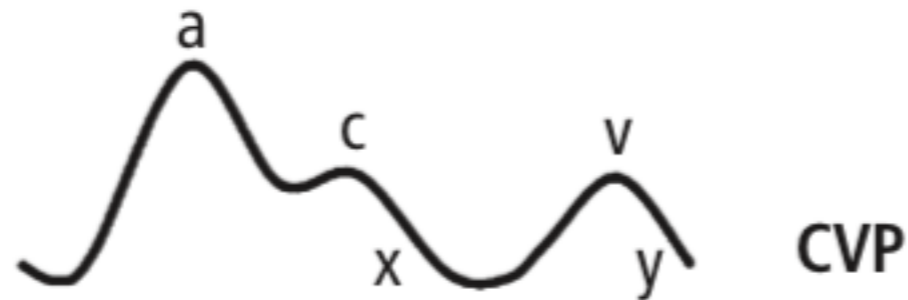
How can you calculate CVP from a printed venous pressure tracing?

- Determine the location of the 'a wave'
 - the 'a wave' begins in the PR interval
 - the 'c wave' begins in the RT interval
 - the 'v wave' occurs after the T wave
- Determine the pressure at the top of the 'a wave' and bottom of the 'x descent', and calculate the average
- The mean of the a wave is used to calculate CVP because it peaks at ventricular end-diastole
- Alternatively - locate the R wave, draw a perpendicular line down to the CVP waveform, where they intersect in the CVP.

**Describe the the abnormal CVP tracing.
What cardiac abnormality is present?**



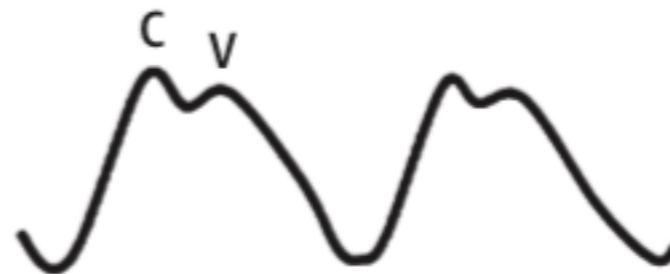
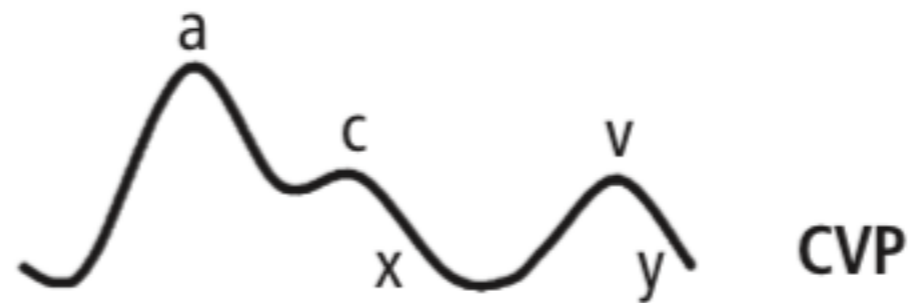
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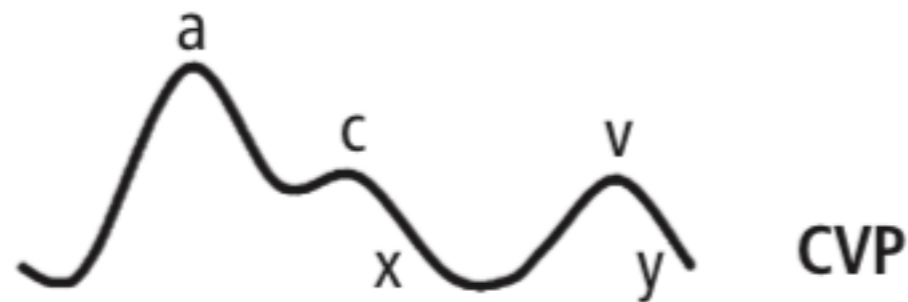
Junctional rhythm, VPCs or complete heart block:

- can intermittently produce large **(cannon) a-waves** due to AV dissociation, where there is transient increase in atrial pressure caused by contraction of the atrium against a close tricuspid valve during ventricular systole
- atrial contraction can also occur concurrently with ventricular contraction, causing fusion of the a and c waves

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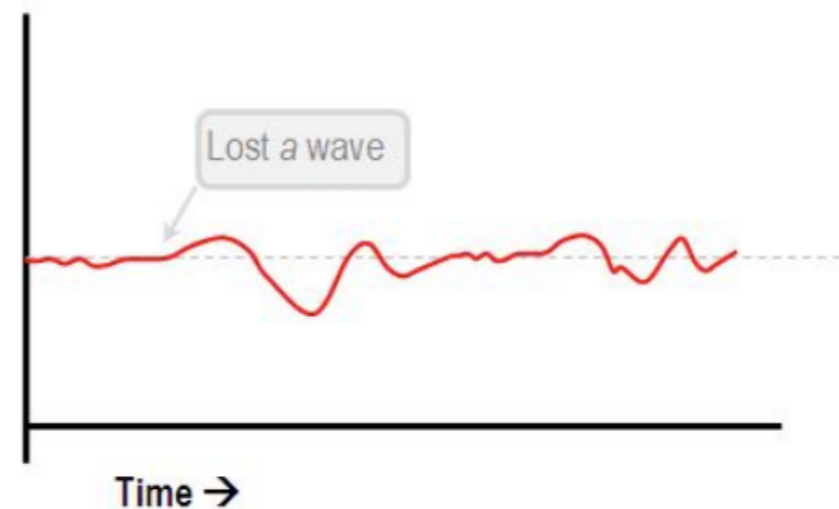
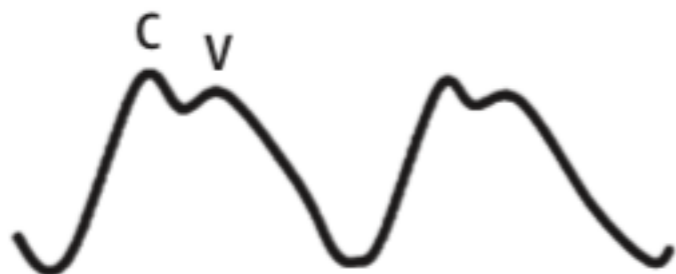


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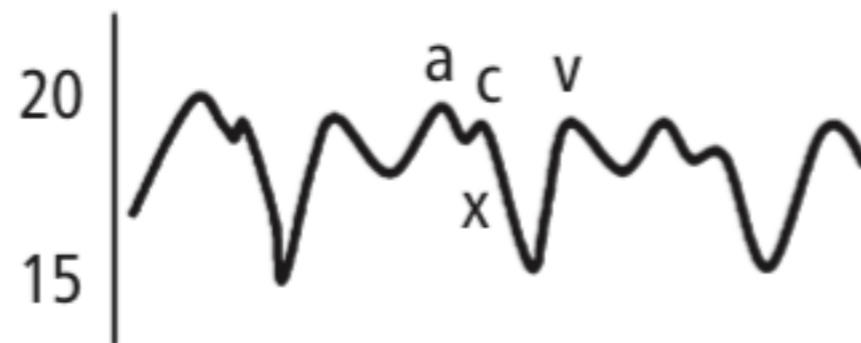
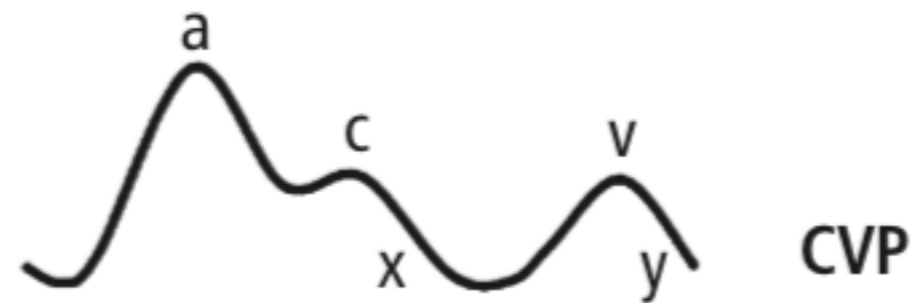


Atrial fibrillation:

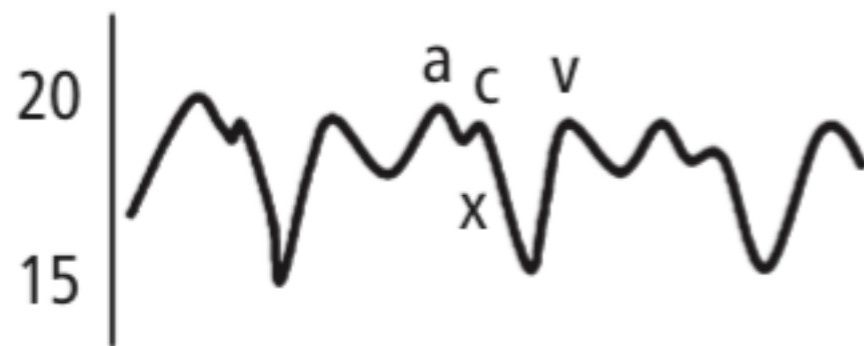
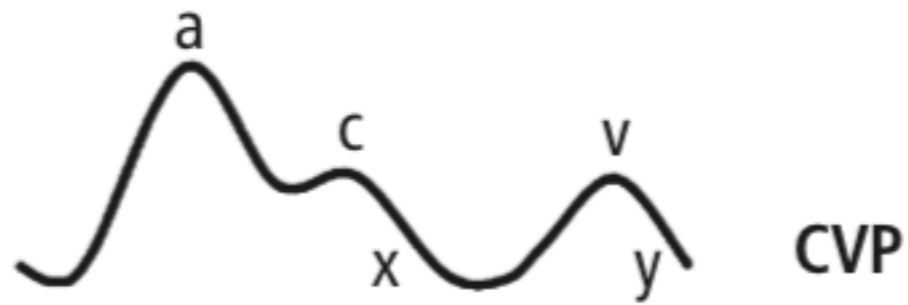
- loss of atrial contraction results in **loss of the a wave**
- prominent c wave resulting from overfilling of the right atrium



**Describe the the abnormal CVP tracing.
What cardiac abnormality is present?**



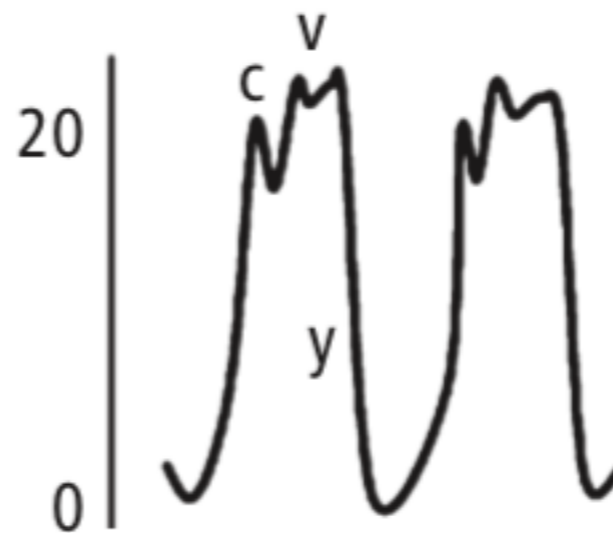
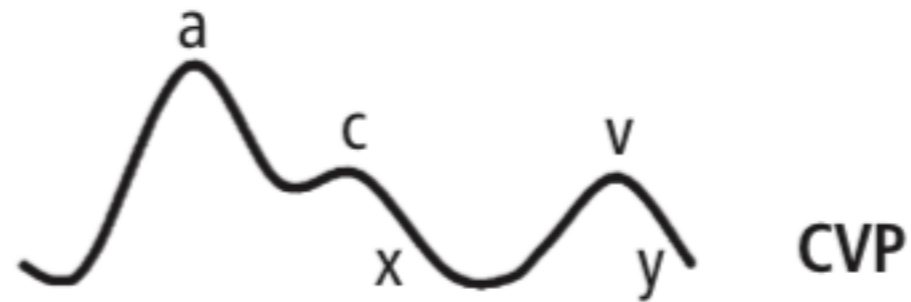
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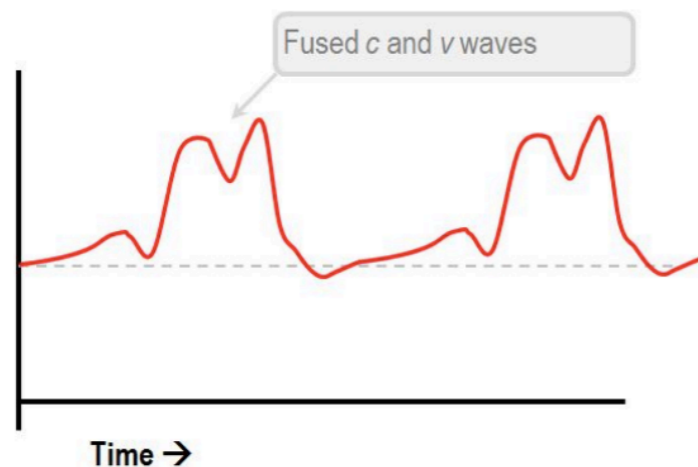
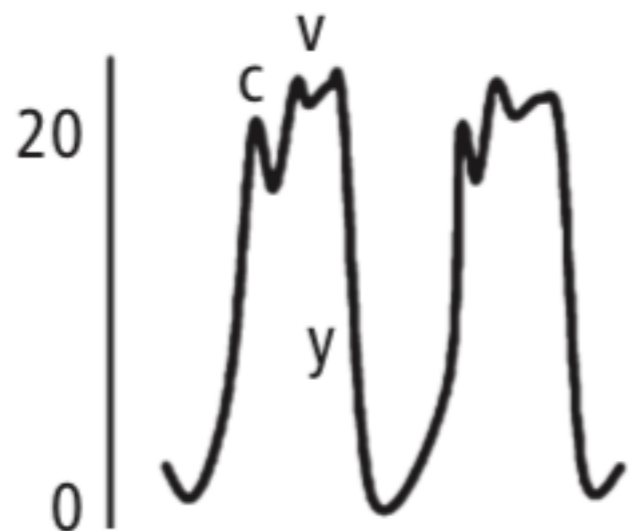
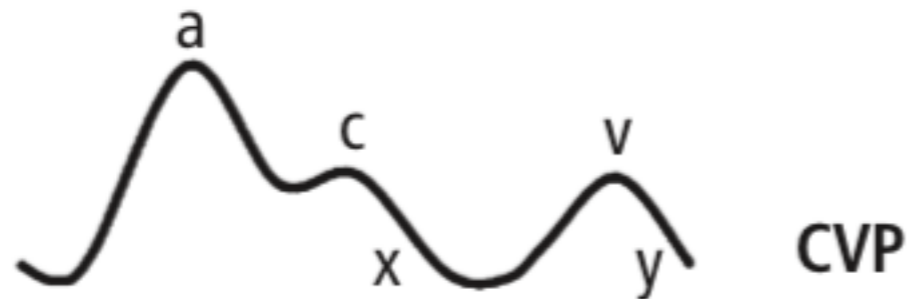
Pericardial effusion with cardiac tamponade:

- inhibits diastolic filling of the heart, resulting in an **increase in the mean CVP** and flattening of the CVP due to a greater equalization of the pressures within the atria and the ventricles
- **prominent x-descent** due to a rapid reduction in atrial pressure during ventricular systole
- **y descent is small or absent**

**Describe the the abnormal CVP tracing.
What cardiac abnormality is present?**



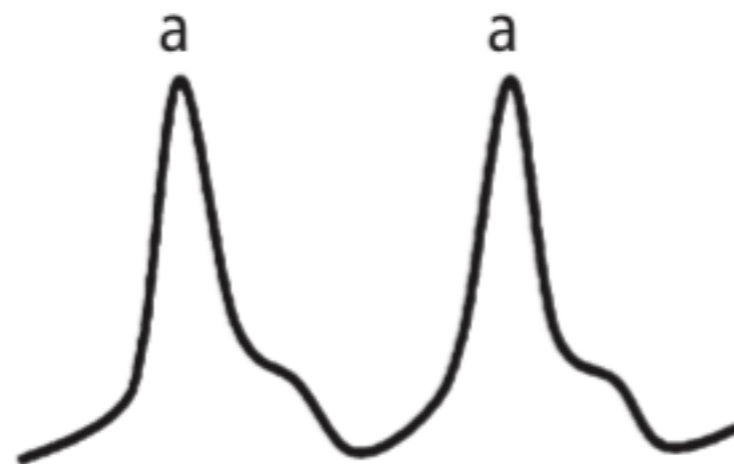
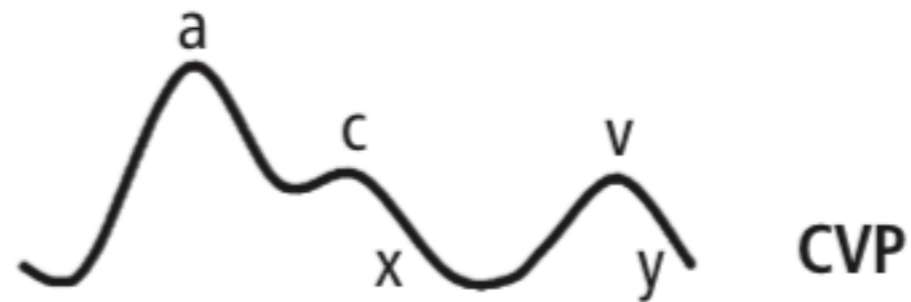
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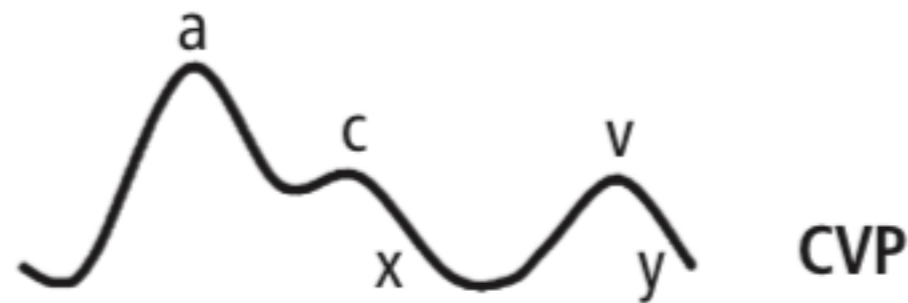
Tricuspid regurgitation:

- **Obliteration of the x descent** during ventricular systole by a large wave created by the backward flow of blood through an incompetent valve
- **merging of the c wave and v wave**, as both are the result of right ventricular contraction
- Both may be visible when there is mild insufficiency, but they combine to form a broad wave with a single peak when severe insufficiency is present.

**Describe the the abnormal CVP tracing.
What cardiac abnormality is present?**

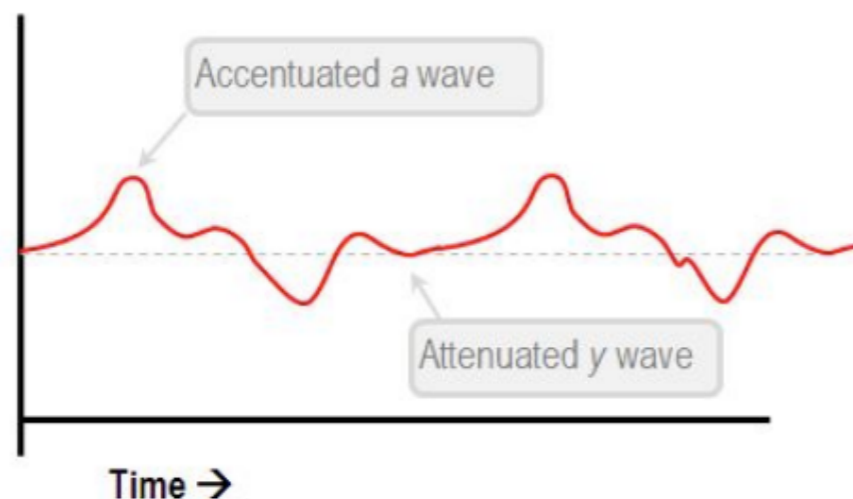
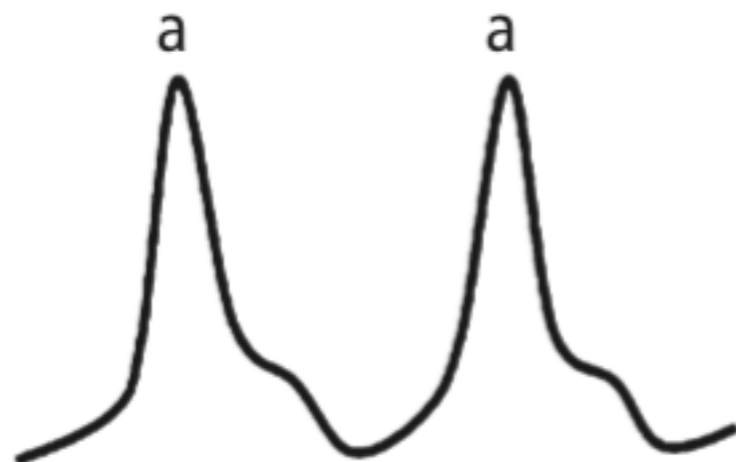


Describe the the abnormal CVP tracing. What cardiac abnormality is present?



Tricuspid stenosis, pulmonic stenosis and pulmonary hypertension:

- “reduced right ventricular compliance”
- can result in **large a waves** as the right atrium contracts against the elevated right ventricular pressure
- **y wave may be attenuated** (longer duration, lower amplitude) because right atrial filling is slow and ‘lazy’



Pulmonary Arterial Catheters

What information can be obtained from pulmonary artery catheters?

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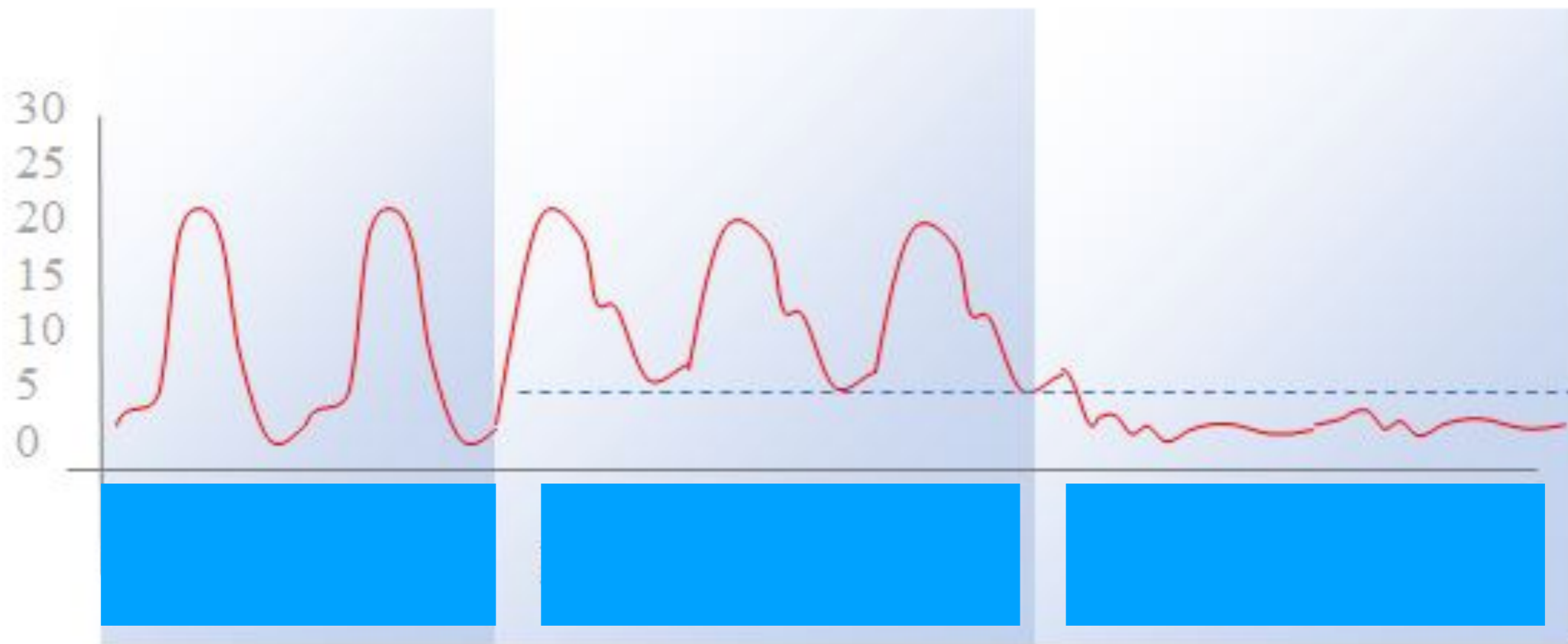
- Right atrial pressures (typically identical to CVP)
- Diastolic, systolic and mean pulmonary arterial pressure
- Pulmonary artery occlusion pressure (PAOP)
- Cardiac output (usually via thermodilution technique - discussed later)

What is meant by pulmonary artery occlusion pressure (PAOP)? What is a normal PAOP?

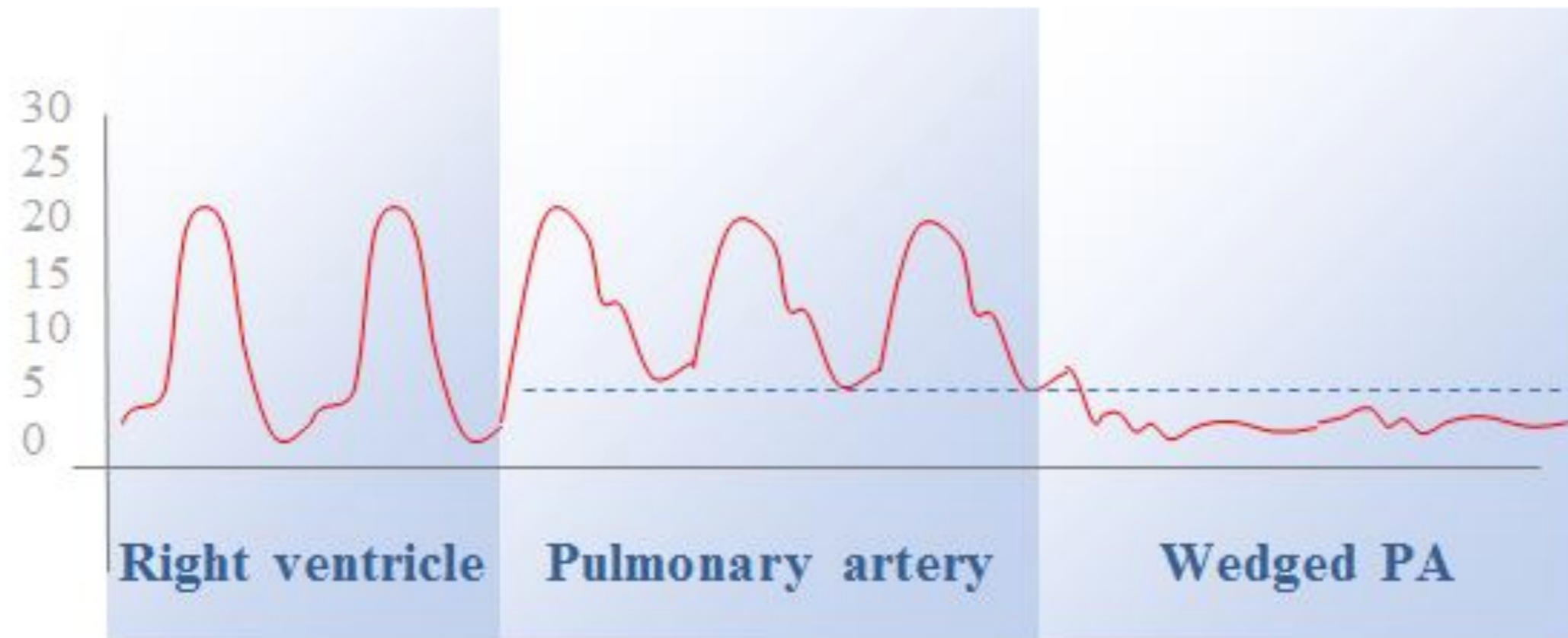
What is meant by pulmonary artery occlusion pressure (PAOP)? What is a normal PAOP?

- When balloon on the catheter is inflated, it becomes wedged in a small branch of the pulmonary artery, interrupting local blood flow, so that a continuous column of blood is present between the tip of the catheter and the left atrium. PAOP (or pulmonary artery wedge pressure - PAWP) reflects left atrial pressure
- Normal PAOP in dogs is 5-12 mmHg

Where are the following pressure waveforms being measured?

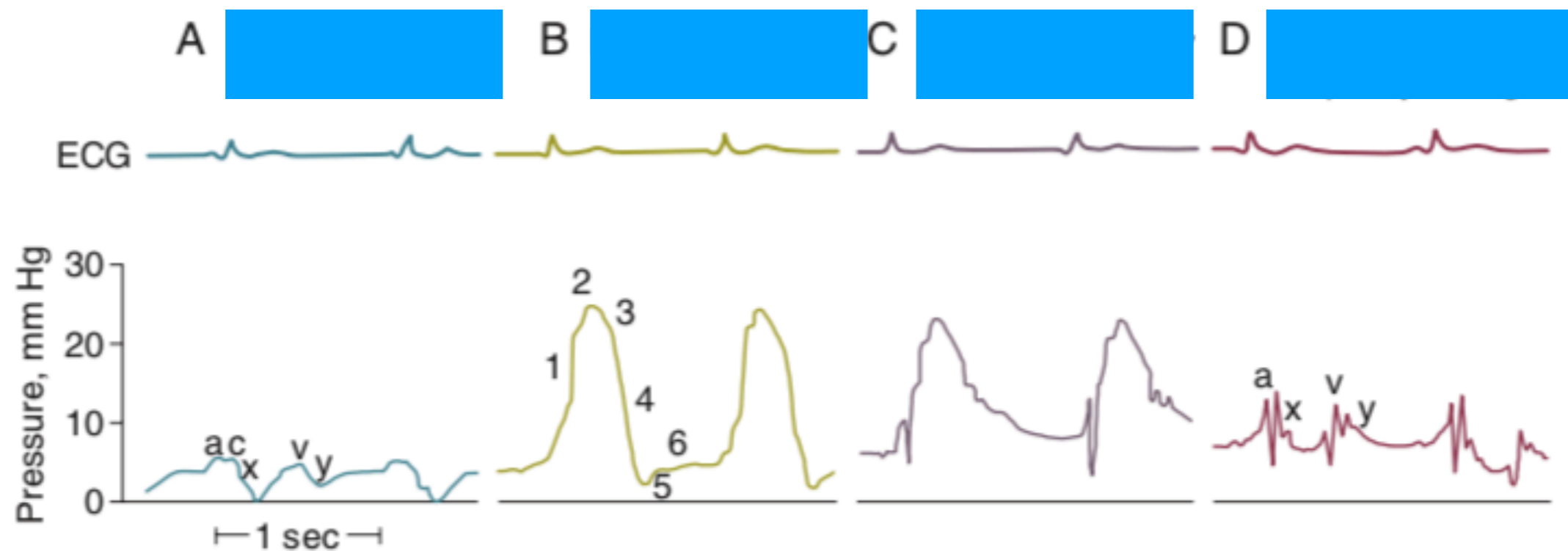


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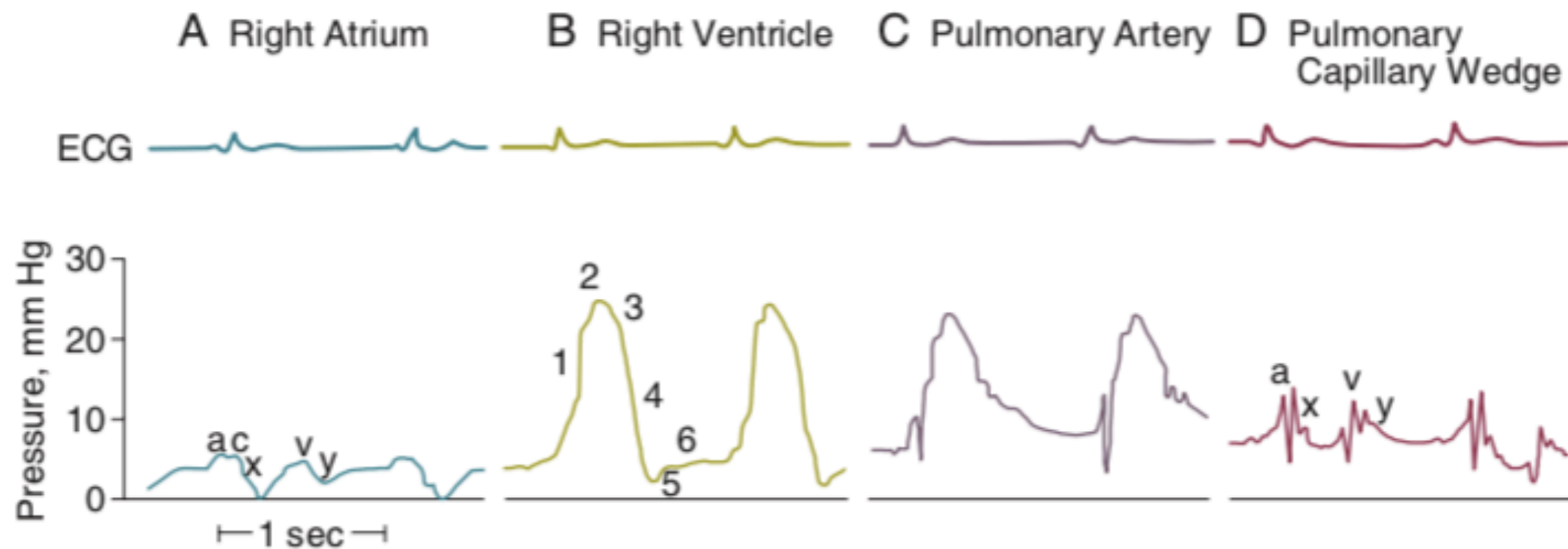


The diastolic pressure in the pulmonary arteries is higher because there is flow (and resistance to flow). With PAOP, flow is stopped and thus the pressure is lower.

In what location were the following waveforms measured?



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Mixed venous and central venous oxygen saturation

Where are mixed venous and central venous oxygen saturation measured from? What are normal values?

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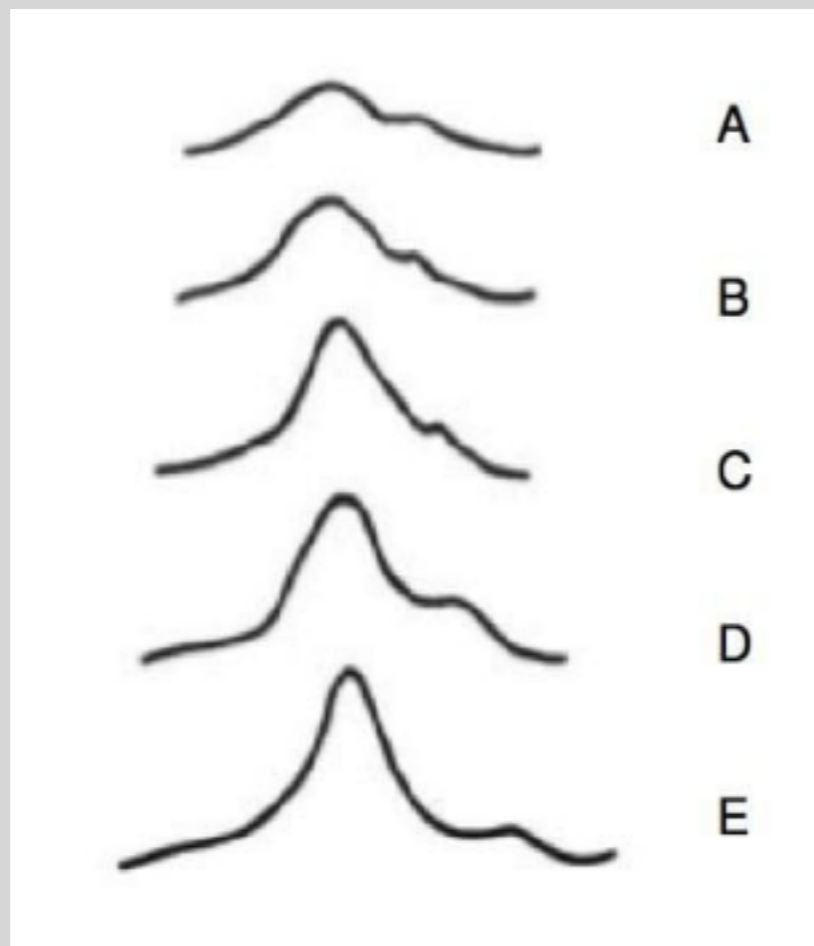
- SvO₂ (mixed venous oxygen saturation) is measured from the pulmonary artery
 - normal = > 75%
- ScvO₂ (central venous oxygen saturation) can be measured from a catheter in the vena cava or the right atrium
 - normal = > 65%

**What does may a high
ScvO₂ indicate?**

What does may a high ScvO₂ indicate?

- >80%
- Cytotoxic dysoxia (e.g. cyanide poisoning, mitochondrial disease, severe sepsis)
- Microcirculatory shunting (e.g. severe sepsis, liver failure, hyperthyroidism)
- Left to right shunts

The above series represents waveforms obtained simultaneously from different arterial sites from the same patient. Match the waveform with the appropriate location.



femoral artery

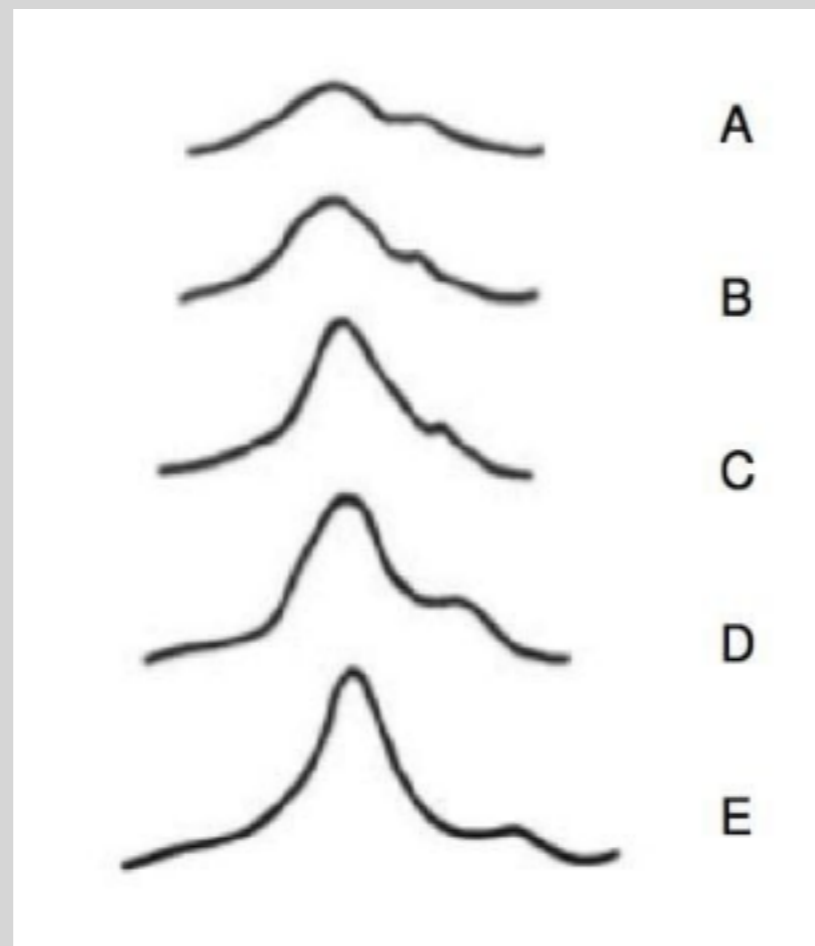
radial artery

dorsal pedalis

Brachial artery

Central aorta

The above series represents waveforms obtained simultaneously from different arterial sites from the same patient. Match the waveform with the appropriate location.



- A - Central aorta**
- B - Brachial artery**
- C - radial artery**
- D - femoral artery**
- E - dorsal pedalis**

“Distal pulse amplification” - occurs due to the action of reflected waves

As the arterial pressure wave is conducted away from the heart, three effects are observed: The wave appears narrower; the dicrotic notch becomes smaller; and the perceived systolic and pulse pressures rise and the perceived diastolic pressure falls.

**What is meant by “zeroing”
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What is meant by “zeroing” in reference to CVP?

- The atmospheric pressure (760 mmHg) is used as the standard reference point to which CVP is compared. The process of correcting for atmospheric pressure is called zeroing. Pressure transducer systems have an integrated stopcock and port that can be opened to the atmosphere to calibrate, or zero, the transducer.

What is meant by “levelling” in reference to CVP?

- The transducer system must be aligned with the vascular structure containing the point of interest, i.e. the zero reference point.
- zero reference point for the bottom of the manometer or pressure transducer should be the manubrium for a patient in lateral recumbency or the point of the shoulder for a patient in sternal recumbency

When measuring CVP, failure to level the transducer to the zero reference point will result in erroneous readings. CVP readings may be falsely [HIGH/ LOW] if the transducer is above the right atrium, and falsely [HIGH/ LOW] if the transducer is below the right atrium

When measuring CVP, failure to measure the transducer will result in erroneous readings. CVP readings may be falsely low if the transducer is above the right atrium, and falsely high if the transducer is below the right atrium