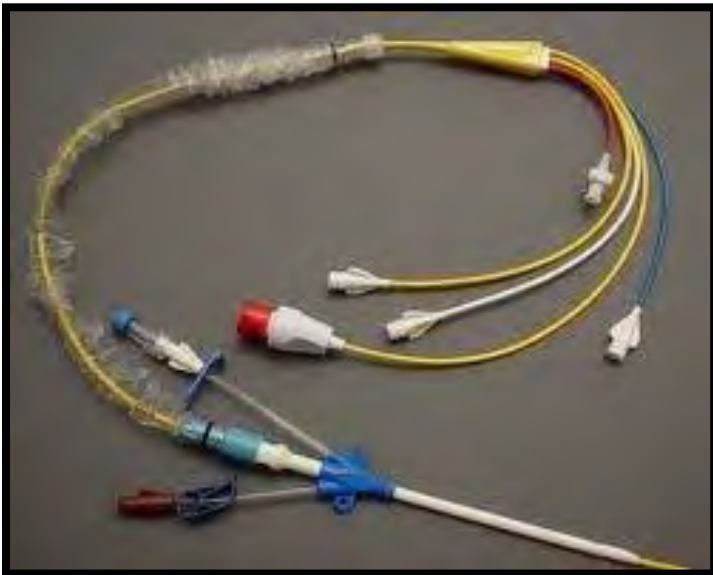


2016

Pulmonary Artery Catheter Learning Package

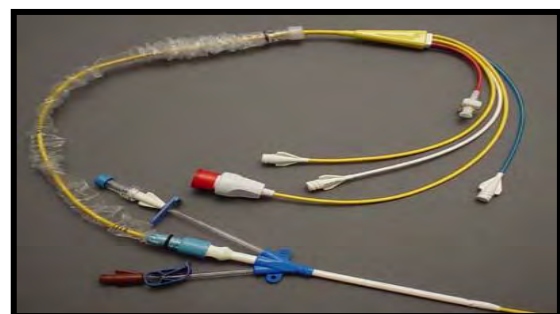


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1/12/2016

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OBJECTIVES

The aim of this package is to provide the nurse with a learning tool which can be used in conjunction with clinical practice under supervision of a CNE and or resource person for the management of a pulmonary artery catheter.

After completion of the package the RN will be able to:

1. State the indications, contraindications and complications of a PA catheter
2. Identify the lumens and their uses
3. Identify normal and abnormal waveforms
4. Perform all routine and safety checks
5. Identify normal ranges for haemodynamic values measured from a PA catheter
6. Identify the position and waveforms of PA catheter
7. Perform a wedge procedure safely
8. Perform cardiac output studies
9. Interpret cardiac output studies
10. Identify the risks and complications associated with the insertion and management of a PA catheter
11. Discuss nursing management of a PA catheter

Pulmonary Artery Catheter History

The first introduction of a catheter into a human pulmonary artery was in 1929 by Forsmann. He inserted a urinary catheter into his own cubital vein and into his right heart.

In 1954 a catheter was developed by Lategola and Rann and used in dogs.

It wasn't until 1970 that Dr Swan was on an outing with his family and noticed how easy it was for a sailboat to move even in the slightest breeze. Up until this point no one had been able to float the catheter into the pulmonary artery. Dr Swan then invented the balloon tipped catheter. Around the same time Dr Ganz was working on thermo dilution methods to calculate cardiac outputs. So the pulmonary artery catheter was named Swan Ganz.

The Pulmonary Artery Catheter

The pulmonary artery catheter (PAC) is a balloon tipped thermo dilution catheter 110cms long, that is inserted via a large vein and floated into the pulmonary artery. It is used to obtain haemodynamic measurements which together with clinical observations indicate how efficiently the heart is functioning.

The PAC directly measures:

- Right pulmonary systolic and diastolic pressures (PAP),
- Pulmonary Artery Wedge Pressure (PAWP),
- Cardiac Index (CI),
- Systemic and Pulmonary Vascular Resistance (SVR & PVR),
- Core body temperature
- Mixed venous oxygen saturation.

These will be discussed later in this package.

Indications

A pulmonary artery catheter is indicated for assessment of:

- Shock states
- Cardiovascular function
- Pulmonary function
- Haemodynamic function peri, intra and post cardiac surgery
- Fluid requirements and the effectiveness of therapy
- Multiorgan failure

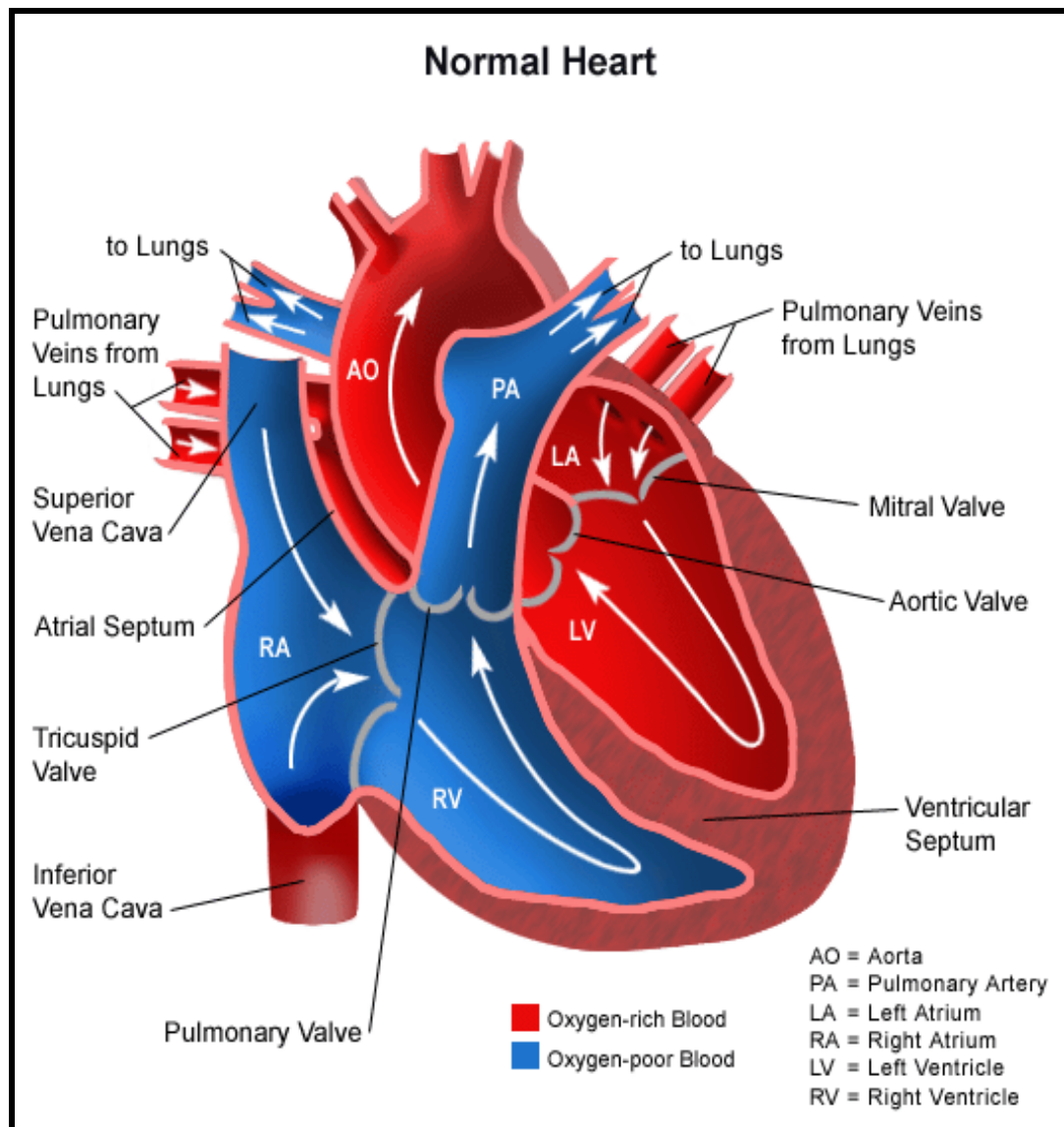
Contraindications

- Coagulation defects
- Tricuspid or pulmonary valve replacements
- Right heart mass / thrombus /tumor
- Tricuspid or pulmonary valve endocarditis
- High risk of dysrhythmias
- Caution with LBBB (5% risk of complete heart block)

Complications

- Atrial and ventricular dysrhythmias
- RBBB (0.1-5%)

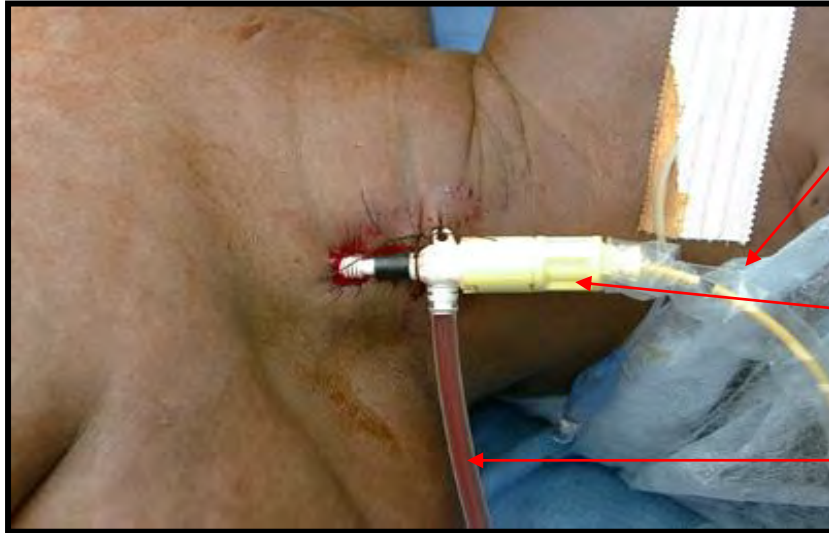
- Pulmonary infarct
- Pulmonary artery rupture
- Infection
- Thrombus
- Insertion of introducer sheath
 - ~ Pneumothorax
 - ~ Arterial puncture
 - ~ Air embolus



www.yalemedicalgroup.org

PULMONARY ARTERY CATHETER

The sheath



Pulmonary artery catheter sealed with plastic to maintain sterility

Sheath

Side arm of sheath for infusion of fluids

The pulmonary artery catheter is inserted via an 8.5F sheath which is usually placed in

- Subclavian vein
- Jugular vein
- Femoral vein

The sheath has a removable seal on the end which allows the PAC to pass through it and forms a water tight seal around it. It also allows the PAC to be removed and the sheath to remain in place. A cap is then placed on the end of the sheath to maintain patency.

A plastic protective sleeve covers the PAC and attaches to the end of the sheath to maintain sterility of the PA while it is being advanced and withdrawn.

The sheath may also have a side arm for infusion of fluids and drugs.

Pulmonary Artery Catheter Learning Package

- This lumen is usually utilised for sedation and low dose GTN not for inotropes.

Temperature port:

- Temperature cable from the cardiac output cable is connected here to obtain patients core temperature and assists in computing cardiac output studies

Insertion of pulmonary artery catheter

The PAC is inserted by a trained Registrar, with an ICU nurse assisting. Post –op cardiothoracic patients will have the PAC inserted in theatres.

Equipment

- Large dressing pack
- Sterile gown, drapes, gloves, protective eyewear
- Pulmonary Artery Catheter
- Thermodilution Catheter Introducer Set (Sheath)

Cardiac output injectate set

- 500 ml 5% Glucose
- Cardiac Output module & cable
- ECG and 2 pressure modules & cables
- Inflatable pressure bag
- 2 Pressure Transducers
- 2 Pressure line extension tubing
- 500 ml 0.9% Sodium chloride
- 5ml & 10ml syringes
- 2 x 10 mls 0.9% Sodium chloride
- 5 mls Lignocaine 1%
- Scalpel Blade
- Gauze Sponges
- 2/0 Silk Suture
- Large and Small Opsite Dressing
- 2 Three Way Taps
- 21g,23g,25g, needles
- Transducer holder

Preparation for PA Catheter Insertion:

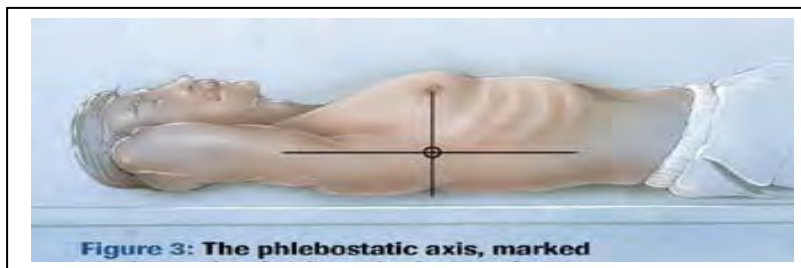
- Observe universal precautions.
- Insert an ECG, Pressure Module and a Cardiac Output Module into the monitor.
- Connect the 2 pressure cables, and the cardiac output cable.
- Prime both transducers & pressure extension lines with 0.9% sodium chloride from the same flask. Ensure that there are no bubbles in the lines or transducers.
- Place the 0.9% sodium chloride in the inflatable pressure bag, and inflate to 300mmHg.
- Label transducer as “CVP” and the other as “PA” & then place them in the transducer holder

- Connect PA transducer line to PA (yellow /distal) port. As seen in picture below. This needs to be connected so as you have a pressure waveform for insertion.



http://intensivecare.hsnet.nsw.gov.au/five/doc/RNSH/PA_Catheter_management_rnsh_2007.pdf

- Connect one of the pressure cables to the “PA” transducer.
- Turn the stopcock on the (PAP) pulmonary artery pressure transducer off to the patient (open to air).
- Transducer holder with transducers should be placed level with the patient’s *4th intercostal space in the midaxillary line*.

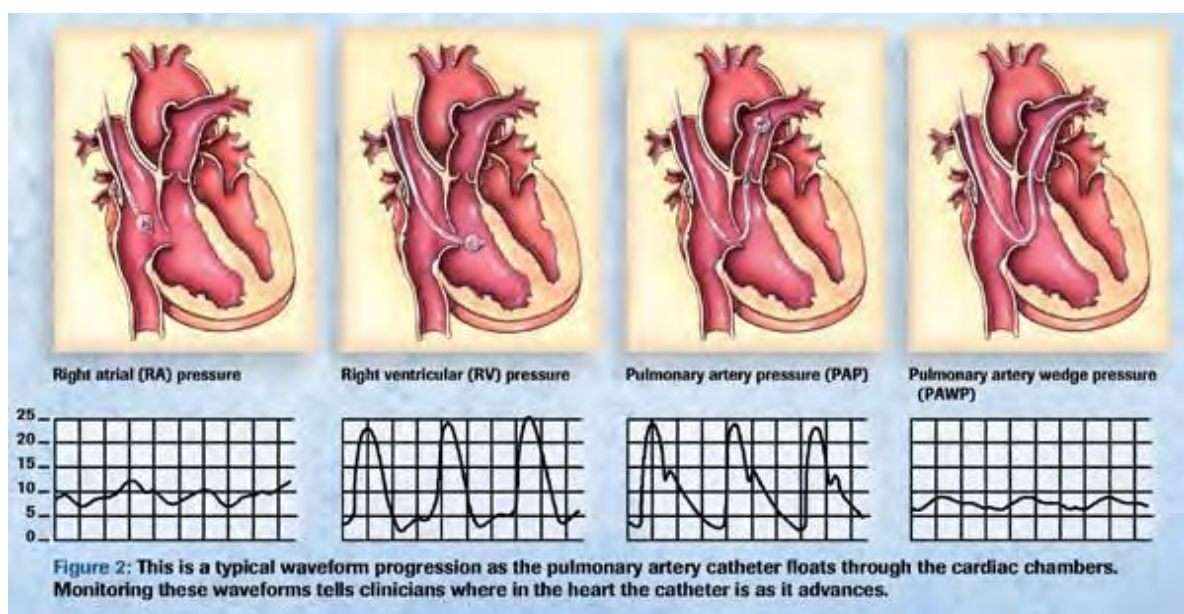


- Select the “0- Zero” soft key. Press “ZERO PAP”
- Once calibrated, turn the PAP transducer stopcock back to the patient and resume tracing.
- Check that the scale of the PAP trace is set at optimal.
- If the PAP trace is dampened, flush the line well.
- Always ensure that the PAP trace is visible at all times and that the alarms are on.
- Check the alarm limits at the beginning of each shift.
- Prime the enclosed injectate delivery system set with 5% Glucose
- Set up the basic tray with the requirements for catheter insertion.

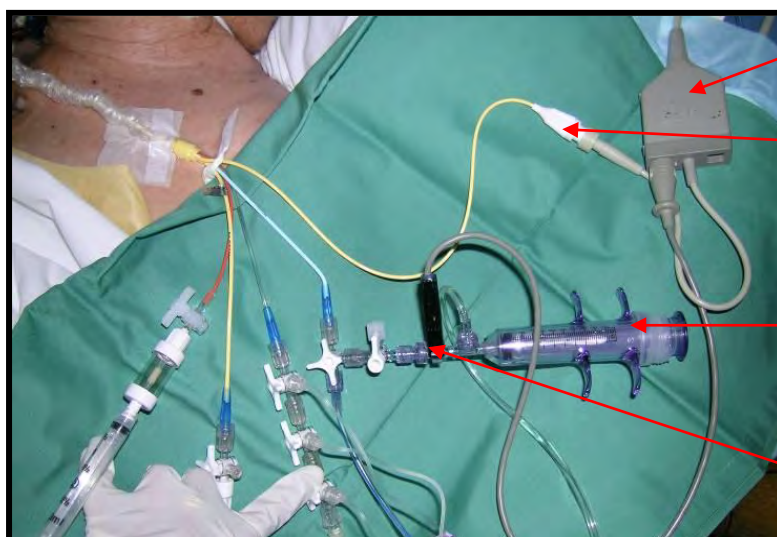
PA Catheter Insertion: (ICU Registrar)

- Observe universal precautions - Surgical scrub. Don gown, gloves and mask.
- Prep and drape the insertion area.
- Position’s patient to maximise access to desired area of insertion i.e. Trendelenberg position if required
- Attaches monitoring (ECG or SpO2) if available
- Flush/prime each lumen with 0.9% normal saline
- Zero, level and Transducer each lumen on monitor for correct waveforms
- Infiltrate the skin with 1% Lignocaine.
- Position the patient as appropriate for the insertion site chosen.
- Attach the long 18G needle to the 10ml syringe, and puncture the desired vein.

- Remove the syringe, and confirm that a free flow of non-pulsatile blood is returned.
- Insert the guide wire through the needle, maintaining control of the proximal end.
- An assistant should observe the monitor for arrhythmia caused by irritation of the myocardium with the wire. If arrhythmias occur, withdraw the wire slightly.
- Remove the needle. Make a small skin incision with the scalpel blade, at the point of entry of the guide wire.
- Insert the dilator through the haemostasis valve, and into the sheath.
- Thread the dilator/sheath/haemostasis valve assembly over the guide wire. Holding skin taut at the insertion site, advance the assembly into the vessel with a slight twisted motion, maintaining control of the proximal end of the guide wire.
- Remove the guide wire.
- Attach a 10ml syringe to the side point of the sheath, and aspirate blood to confirm that the sheath is in position. Flush the port with 10mls N/Saline, and apply the cap.
- Firmly suture the sheath in position.
- Check the balloon on the pulmonary artery catheter by inflating it inside the testing chamber with 1.5mls air. Use only the special syringe supplied for this purpose.
- Allow the balloon to passively deflate.
- Check the patency of each lumen by flushing with 0.9% sodium chloride.
- Taking care not to contaminate the sterile field, pass the "PA (DISTAL) LUMEN" to an assistant, for connection to the already zeroed PA transducer. The transducer is positioned 4th intercostal space in the midaxillary line.
- Insert the catheter through the haemostasis valve on the sheath.
- The balloon is clear of the sheath when the catheter is inserted to 18cm (note the 10cm graduations along its length).
- Inflate the balloon with 1.5mls, and close the red tap on the balloon inflation port.
- Insert the catheter until a CVP waveform appears on the monitor.
- Rapidly feed the catheter through the sheath while observing for the characteristic waveforms which indicate transition from: **CVP → RV → PA → PCWP**



- When a PCWP trace is obtained, deflate the balloon and confirm that a PA trace returns on the monitor.
- If the trace remains wedged, the catheter will need to be withdrawn slightly. Usually, the correct insertion distance is:
 - 50 to 60cm for subclavian or internal jugular approach
- **Note and document on flow chart the cm marking on the sheath at which a PCWP trace is obtained when the balloon is inflated.** *As the catheter warms to body temperature, it lengthens slightly and can spontaneously wedge. If this occurs, it will need to be withdrawn slightly.*
- Place the blue adapter on the Cath Guard over the haemostasis valve on the sheath.
- Clean the insertion site of all blood.
- Apply OpSite dressings to sheath site
- Connect the CVP transducer to the 3 way tap
- Connect the cardiac output injectate syringe to CVP port
- Connect thermistor cable to cardiac output syringe port and temperature cable to red temperature port as shown



Cardiac output cable

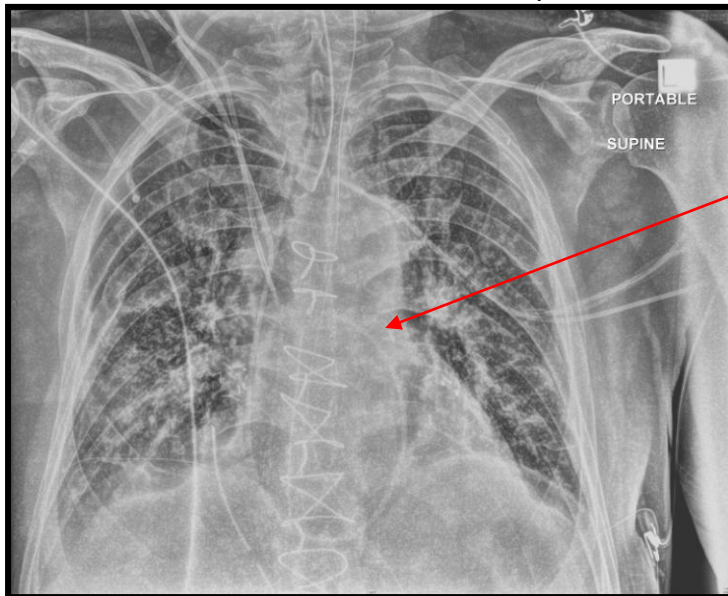
Temperature cable

Cardiac output syringe,
primed with 5% dextrose

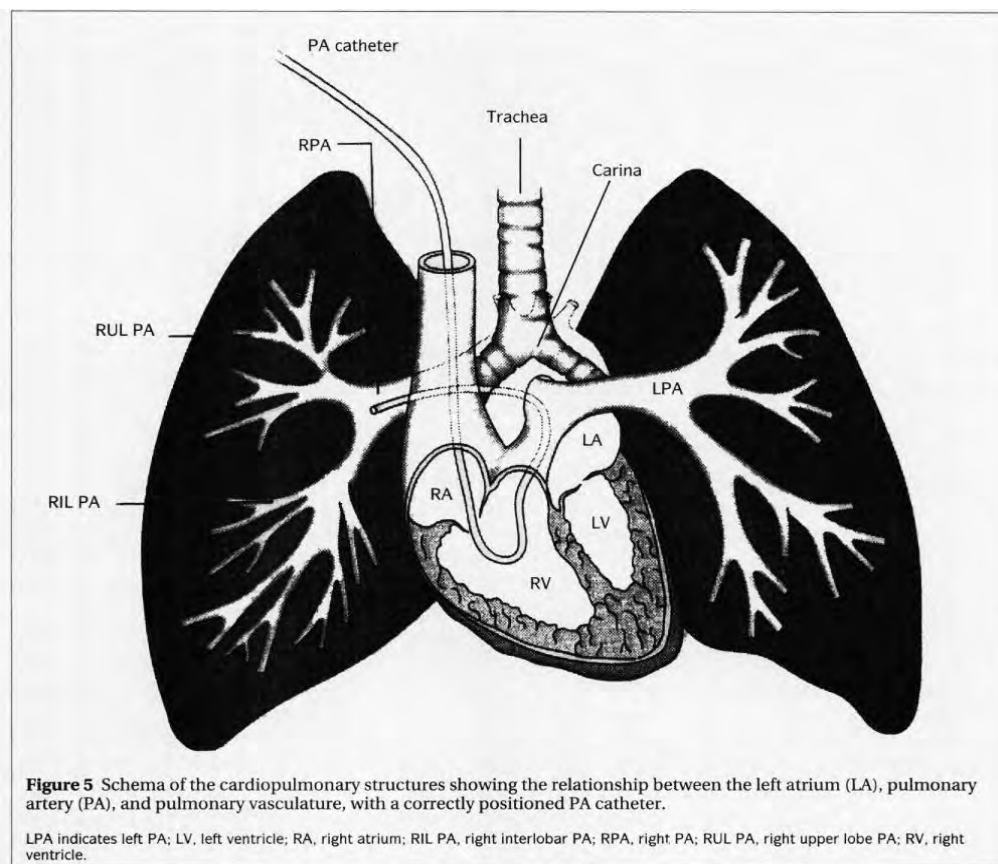
Thermistor cable.

- Confirm the transducer holder with PA and CVP transducers, are level with the *4th intercostal space in the midaxillary line.*
- Turn the tap on the cardiac output injectate set "off" to the syringe.
- Connect a pressure cable to the CVP transducer.
- Turn the stopcock on the CVP transducer off to the patient (open to air).
- Select the "0- Zero" soft key. Press "ZERO CVP"
- Once calibrated, turn the CVP transducer stopcock back to the patient and resume tracing.
- Press the alarms limit key on the Philips monitor.
- Press select parameter to highlight the parameter that you want to adjust e.g. PAP
- Use low limit and high limit keys if you wish to adjust the limits.
- You can alter the systolic, diastolic and mean alarm limits individually.

- Leave the PAP trace displayed on the monitor at all times, so that inadvertent wedging of the catheter can be detected. Set PAP alarm as diastolic to alert inadvertent wedging
- The spare "infusion" lumen can be used for sedation and low dose GTN (no more than 10mls/hr) only.
- Measure the PCWP and attend cardiac output studies.
- Obtain CXR to ensure correct placement – 2cm left of mediastinal border

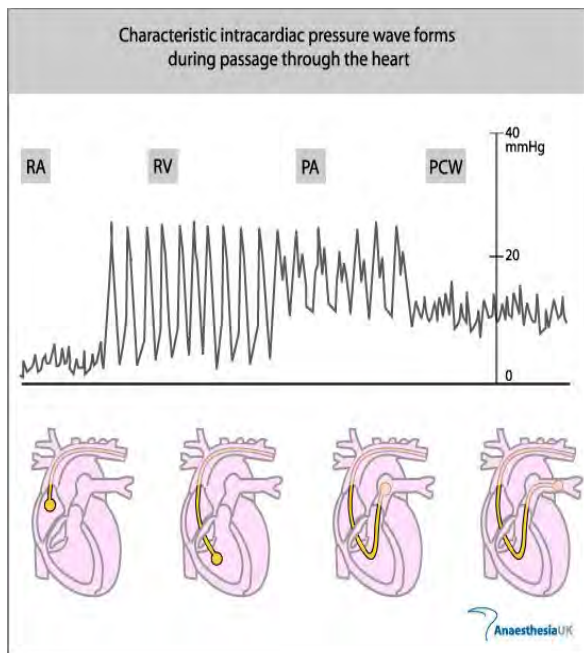


Pulmonary artery catheter



Monitoring pulmonary artery pressures: Just the facts

WAVEFORMS

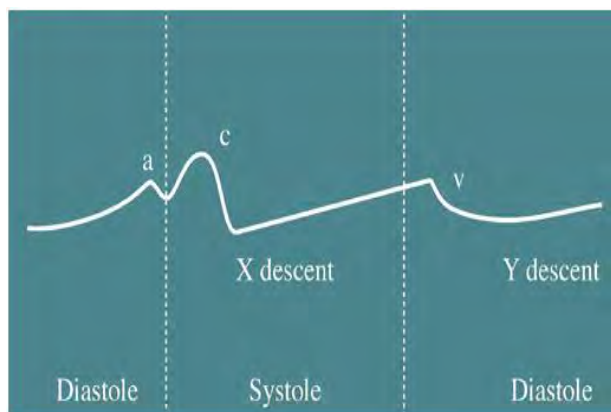


When a right atrial pressure waveform demonstrates that the catheter has reached the right atrium the balloon is inflated.

The catheter will then float through to the right ventricle, then into the pulmonary artery. As the blood flow makes the catheter float through the heart the waveforms will change according to the position of the catheter in the heart. See picture on left.

The normal range for CVP is 5 -15 mmHg.

CVP measures right ventricular function and systemic fluid status.



<http://www.hku.hk/anaesthe/LearNet/index.htm>

a wave = atrial contraction

c wave = bulging of tricuspid valve into atrium at start of ventricular contraction

x descent = atrium relaxes and tricuspid valve is pulled downwards

v wave = passive filling of right atrium and vena cava when tricuspid valve closes

y descent = tricuspid valve opens and blood flows into right ventricle

Right Ventricular Pressure (RVP):

Once the catheter passes through the Right Atrium it then floats into the Right Ventricle. The normal value for RVP is 25/0 mmHg.

Dangers of the catheter being in the ventricle are that the catheter could rupture the ventricle wall or irritate the ventricle causing VT.

Monitor PA waveforms at all times to ensure catheter is not sitting in ventricle.

Pulmonary Artery Pressure (PAP):

The catheter should then float into the pulmonary artery.

The normal range for PAP is 15 - 25 / 5-15 mmHg.

The dicrotic notch is the usual feature of the PA waveform and represents aortic valve closure.

Systolic PA pressure indicates the pressure in the pulmonary artery as blood is being ejected from the right ventricle

Pulmonary artery diastolic pressure (PADP) indicates the pressure in the pulmonary artery as blood moves from the artery into the lungs capillaries. It can be used to assess preload as it is an indirect measurement of Left ventricular end diastolic pressure (LVEDP)

The PADP can be utilised as a wedge pressure if a wedge is not able to be obtained

Mean pulmonary artery pressure is the average pressure in the pulmonary vasculature throughout the cardiac cycle

Once the catheter is inserted and zeroed the CVP and PAP readings will be displayed as seen in picture below:

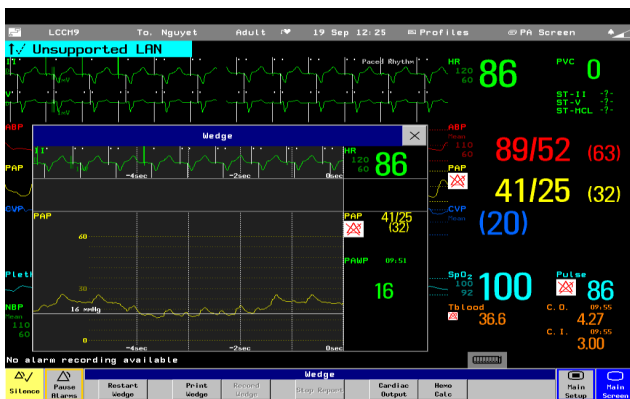
**Pulmonary Artery Wedge Pressure (PAWP):**

When the balloon is inflated, the catheter then floats through the pulmonary circulation until it wedges in a small artery. The balloon is effectively “wedged” against the artery.

When the catheter is wedged, there is no blood flow to this part of the pulmonary artery therefore the balloon should only be wedged long enough to obtain a reading, (usually 15 secs or 2 respiratory cycles) as the pulmonary artery could rupture.

The benefits of measuring PAWP are to optimise filling of the patient without overloading the lungs.

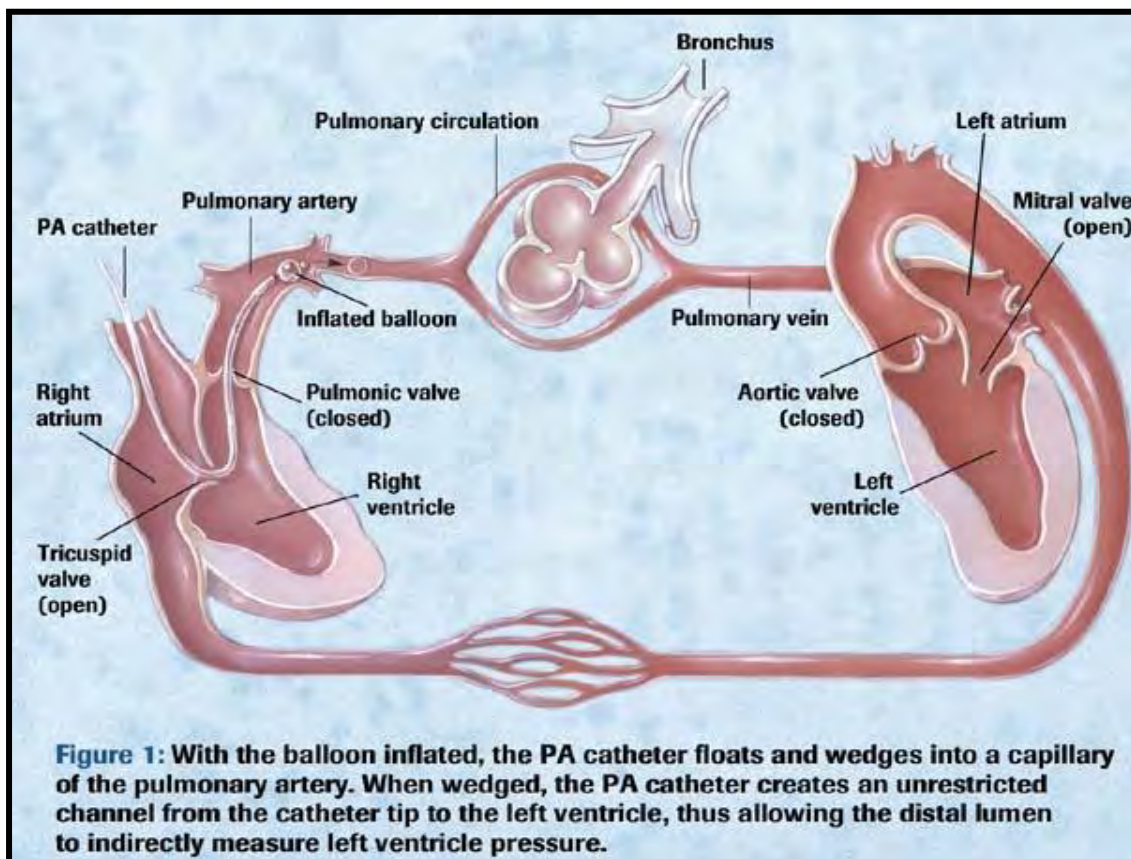
The normal range for PAWP is 8 -12mmHg



Wedge trace: represented by a change in pressure tracing from PA trace to a flattened wedge tracing

PAWP represents LVEDP and is used to assess the function and workload of the left ventricle.

As shown below, the balloon occludes the pulmonary artery creating a back pressure from the right atrium. The transducer on the tip of the catheter only sees what is happening in the left atrium and left ventricle. So the PAWP measures filling pressures on the left side of the heart.



[http://www.ispub.com/ispub/ija/volume 11 number 2 1/paradigm shift in hemodynamic monitoring/hemodynamics](http://www.ispub.com/ispub/ija/volume%2011%20number%202%201/paradigm%20shift%20in%20hemodynamic%20monitoring/hemodynamics)

INTERPRETING PAP WAVEFORM CHARACTERISTICS: a, c, and v WAVES

Waveform interpretation can be simplified by remembering that electrical activity (ECG) comes before mechanical activity (pressure waveform).

The table below summarises the electrical and mechanical events in relation to pressure waveforms.

Electrocardiographic correlate	Mechanical event	Pressures/waveforms
80-100 msec after P wave (Downslope of the a wave) After the QRS (follows the a wave by a time interval = PR interval) Peak of the T wave (Downslope of the v wave)	Right atrial systole Right atrial relaxation Tricuspid valve closure Right atrial filling against a closed tricuspid valve Right atrial emptying with opening of the tricuspid valve (onset of right ventricular diastole)	Right atrial pressure (2-6 mm Hg) a wave x descent c wave v wave y descent
T wave (read at peak of waveform) 0.08 seconds after onset of QRS (Determined by bisecting the waveform)	Right ventricular ejection of blood into pulmonary vasculature Indirect indicator of left ventricular end-diastolic pressure	Pulmonary artery pressures Systolic (PAS; 15-30 mm Hg) End-diastolic (PAEDP; 8-12 mm Hg) Mean (9-18 mm Hg)
Approximately 200 ms after P wave (Downslope of the a wave) T-P interval (Downslope of the v wave)	Left atrial systole Left atrial relaxation Left atrial filling against a closed mitral valve Left atrial emptying associated with opening of the mitral valve (onset of left ventricular diastole)	Pulmonary artery wedge pressure* (6-12 mm Hg) a wave x descent v wave y descent

*The pulmonary artery wedge pressure waveforms are phase delayed relative to right atrial pressure waveforms because of transmission of the waveform from the left side of the heart through the pulmonary vasculature.

Monitoring pulmonary artery pressures: Just the facts *Elizabeth J Bridges*. *Critical Care Nurse*. Alisa Veijo: Dec 2000. Vol. 20, Iss. 6

The LAP or PAWP waveform has the same characteristics as the RAP waveform, with three positive and two negative deflections.

The c wave, however, is often not visible as it may be "hidden" in the x descent of the a wave.

If only two positively deflected waves are seen,

- The first is the a wave, which represents left atrial systole
- The second is the v wave which represents left atrial filling against a closed mitral valve. The peak of the v wave marks the end of ventricular systole" and occurs after the T wave of the ECG

The timing of the PAWP waveform is slightly delayed compared to the timing of the RAP waveform relative to the ECG. This occurs because the left atrial waveform must travel back through the pulmonary vasculature to the distal tip of the PA catheter, whereas the RA pressure is measured directly through the proximal port in the right atrium.

Keep in mind that being able to recognize this time delay in relation to the ECG will help you differentiate the RAP from the PAWP waveform.

The picture below illustrates this difference in timing of the RAP and PAWP waveforms relative to the ECG.

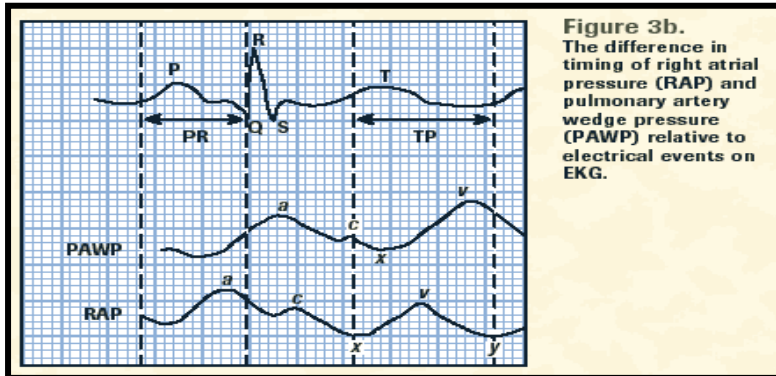


Figure 3b.
 The difference in timing of right atrial pressure (RAP) and pulmonary artery wedge pressure (PAWP) relative to electrical events on EKG.

Identifying a wave in PAWP trace

Align the end of at least two QRS complexes at the point of end-expiration with the PAWP waveform. Draw a vertical line from the end of the QRS down to the PAWP waveform, which identifies the a wave.

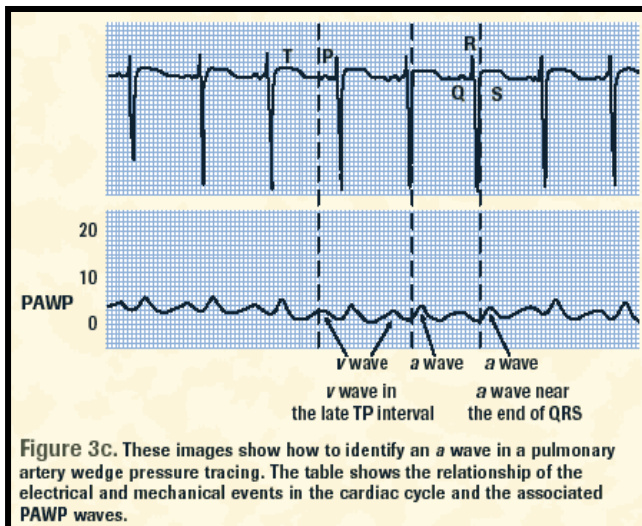


Figure 3c. These images show how to identify an a wave in a pulmonary artery wedge pressure tracing. The table shows the relationship of the electrical and mechanical events in the cardiac cycle and the associated PAWP waves.

Electrical event (ECG)	Mechanical event	Pulmonary artery wedge pressure (normal PAWP is 6 – 12 mm Hg)
Approximately 20 milliseconds after P wave	Left atrial (LA) systole	a wave
	LA diastole	x descent
T-P interval	LA filling/mitral valve closed	v wave
	LA emptying at opening of mitral valve/onset of left ventricle diastole	y descent

PA catheters: What the waveforms reveal. Sally Beattie, RN 2003

It is important to recognise these waves as

- The shape of the v wave is primarily determined by the relationship between pressure and volume in the left atrium; that is, with decreased atrial compliance (e.g., ischemia or hypertrophy), any change in volume is associated with a greater increase in pressure as indicated by increased v wave amplitude.

large influx of blood into the atrium (e.g., mitral valve regurgitation or a ventricular septal defect) may cause a large v wave (known as a V wave)."

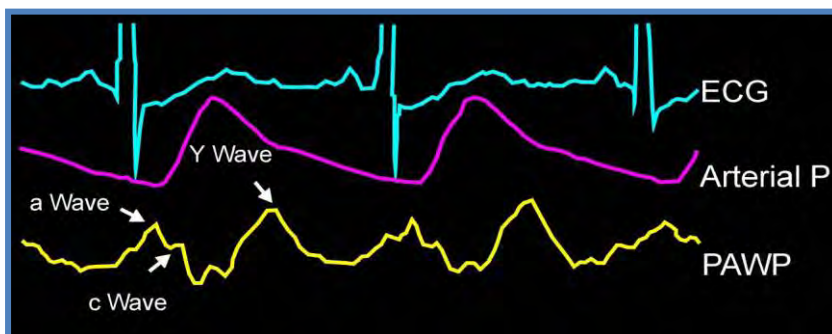
ABNORMAL WAVEFORMS

Altered a waves:

- Large a waves can occur when atria contract against stenotic mitral or tricuspid valves
- Giant a waves (or cannon waves) can occur with junctional and AV dissociative rhythms. The a wave produced by the simultaneous contraction of the atria and ventricle is enlarged and occurs later in the cardiac cycle usually where the v wave would occur
- Cannon waves can also occur with premature ventricular contractions or re-entrant tachycardias.

Large v waves:

- They are produced by the increase in blood volume entering the atria during the cardiac cycle
- The shape of the v wave is determined by the relationship between pressure and volume in the left atrium
- On the monitor the v wave will be taller than the a wave, followed by an exaggerated y descent that reflects the release of atrial pressure with the opening of the tricuspid or mitral valve
- This is the most frequent wave abnormality
- They are commonly caused by tricuspid and mitral insufficiency due to a large influx of blood into the atrium
- Others causes include ventricular failure, increased pulmonary or systemic resistance and ventricular septal defect
- The importance of recognising a large v wave is being able to obtain an accurate PAWP. The large v wave maybe mistaken for the systolic PAP wave. This can be avoided by measuring pressures and waves in relation to the ECG.



Large v waves in a case of mitral regurgitation

Pulmonary Artery Catheterization: Treatment & Medication Author: Bojan Paunovic, MD

Abnormal wedge trace

~ Over wedging is when:

The wedge trace rises dramatically with the balloon inflated. The balloon should be immediately deflated and the catheter withdrawn 1 – 2cms with help from a Registrar, CNE or CNS

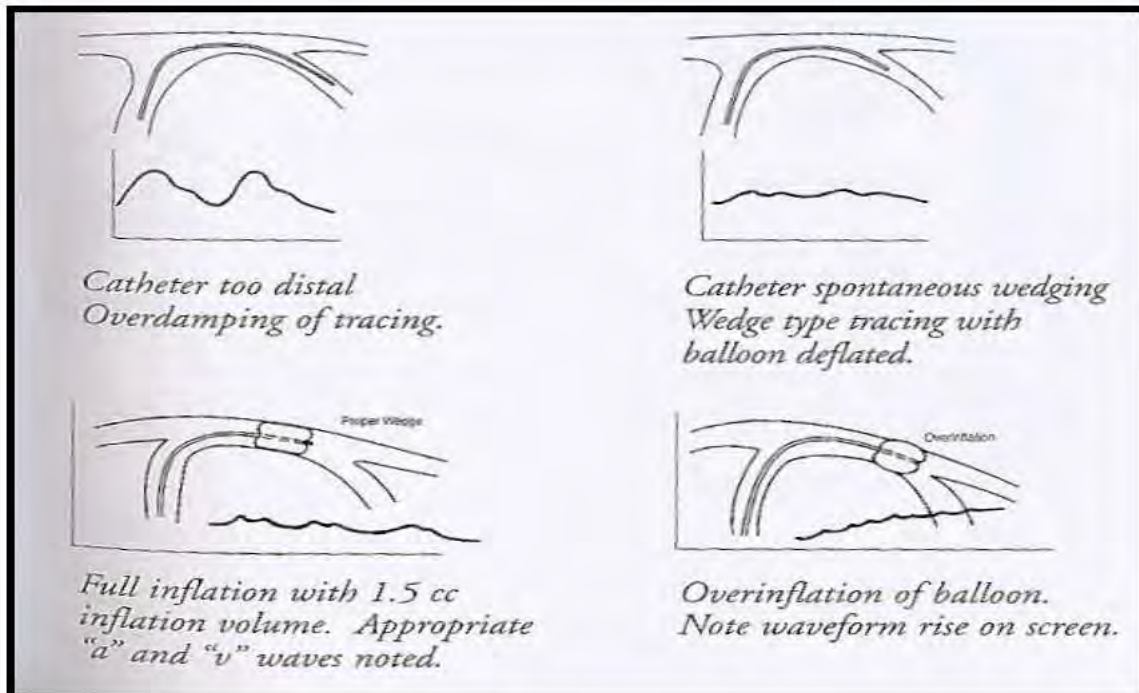
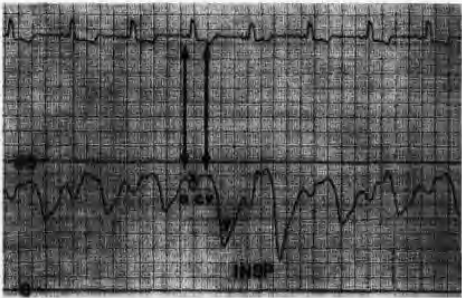
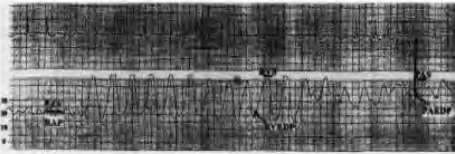
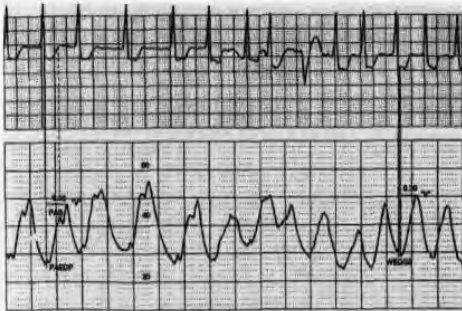
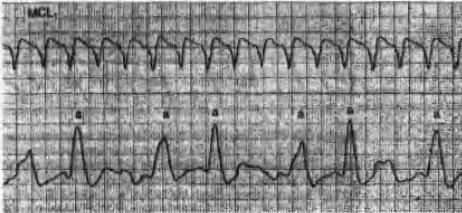
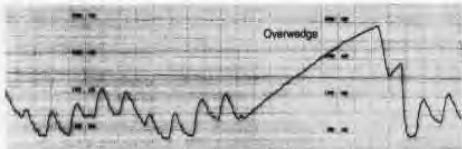


Table 3 Examples of abnormal waveforms

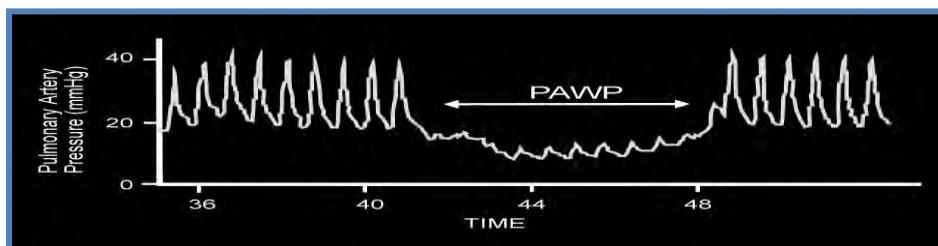
Condition	Diagnostic cues/interpretation	Example
Tricuspid regurgitation (from a patient with long-standing pulmonary hypertension)	<p>The A wave (a) and the x descent (x) are normal. The X-prime wave, which is the downslope of the a wave after the c wave, is obliterated. The result is a broad positive CV wave (cv) that is higher than the A wave.</p> <p>Note that inspiration (INSP) magnifies the nadir of the y descent and the peak of the CV wave, so there is little change in the mean right atrial pressure.</p> <p>An exaggerated Y descent is the key diagnostic feature.</p> <p>Interpretation: The mean right atrial pressure is elevated at 22 mm Hg.</p>	 <p>Figure reprinted from Sharkey,¹⁸ with permission.</p>
Right ventricular pressure versus pulmonary artery (PA) pressure tracing	<p>At end-diastole, when the tricuspid valve is open, the mean right atrial pressure (RAP) is approximately equal to the right ventricular end-diastolic pressure (RVEDP).</p> <p>As the catheter is advanced from the right ventricle into the PA, the end-diastolic pressure increases. The right ventricular systolic (RVS) pressure is equal to the PA systolic (PAS) pressure.</p> <p>Interpretation: If the waveform visualized from the distal port has an end-diastolic pressure (measured 0.08 seconds after the onset of the QRS) that is equal to the RAP and RVS pressure = PAS pressure, catheter malposition should be suspected.</p>	 <p>PAEDP indicates PA end-diastolic pressure.</p>
PA pressure or PA wedge (PAW) pressure?	<p>Comparison of the PA pressure and the PAW pressure relative to electrocardiographic findings: The v wave of the PAW pressure waveform occurs during the TP interval, whereas the initial systolic upstroke of the PA pressure waveform is closely related to the end of the QRS complex, with the PAS peak occurring during the T wave.</p> <p>The regurgitant V wave can be observed as a second peak or on the downslope, and has the same temporal relation to the QRS as the V wave in the PAW pressure tracing.</p> <p>Interpretation: PAW pressure = 30 mm Hg (read at the nadir of the waveform).</p>	
Cannon A waves	<p>Central venous pressure tracing and electrocardiogram of a patient in ventricular tachycardia.</p> <p>No P waves can be seen for certain on the electrocardiogram.</p> <p>Central venous pressure tracing shows exaggerated A waves when the right atrium contracts against the closed tricuspid valve during atrioventricular dissociation.</p> <p>Interpretation: Cannon A waves; supports diagnosis of ventricular tachycardia.</p>	 <p>Figure reprinted from Jacobson,¹⁶ with permission.</p>
Overwedge	<p>Interpretation: Overwedge as indicated by (1) progressive increase in pressure off the screen and (2) loss of waveform components (a and v waves).</p> <p>IN THIS SITUATION, STOP INFLATION IMMEDIATELY AND DEFLATE THE BALLOON.</p>	

Monitoring Pulmonary Artery Pressures: Just the Facts. CCN Vol20, No6, Dec 2000

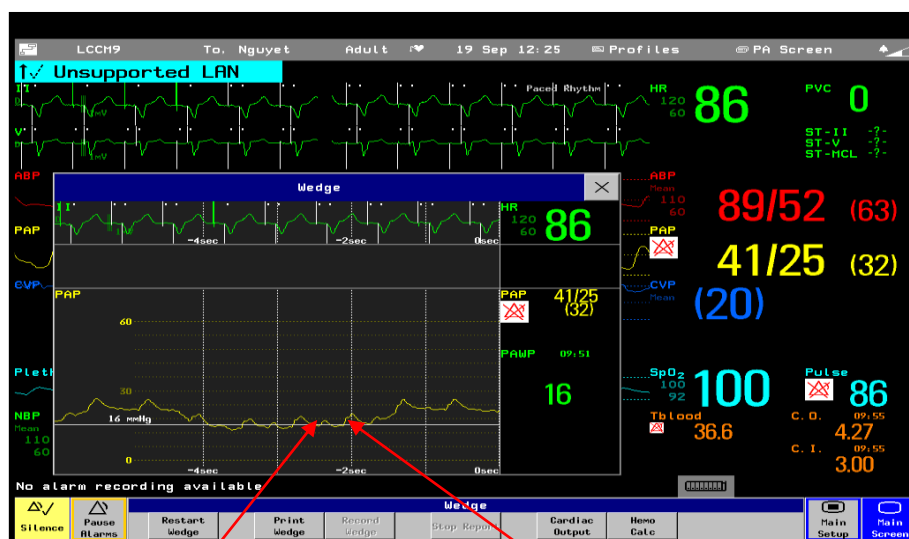
PULMONARY ARTERY WEDGE PROCEDURE

(Adapted from Pulmonary Artery Catheter Guideline LHS ICU 2014)

- Ensure the configuration of the PA trace appears normal.
- Ensure the SaO₂ is greater than 90%,
- Position the patient supine with the backrest elevated to 45°, unless contraindicated. Whatever position is used, the same position should be adopted for each reading.
- Ensure the PA transducer is positioned level with 4th ICS, midaxillary line, and has been zeroed.
- In the main screen window inflate the balloon and ensure that catheter wedges and large v waves are not seen (see above explanation on v waves
- Go to wedge screen then press Wedge to get into the “required wedge task window”.
- Inflate the balloon slowly and carefully watching the screen for a wedge trace
- The waveform changes from PAP to PAWP and the message “wedging” will appear. Inflate the balloon only for the time required to see end expiration on the screen. Usually 2 respiratory cycles.
- Press store trace.
- Deflate the balloon once a wedge trace is stored. Allow the balloon to deflate passively.
- Disconnect wedge syringe from balloon port, expel air and reattach syringe to port with tap open to the syringe. This prevents any accidental wedging of the catheter
- See below for examples of a wedge trace.



Normal wedge trace

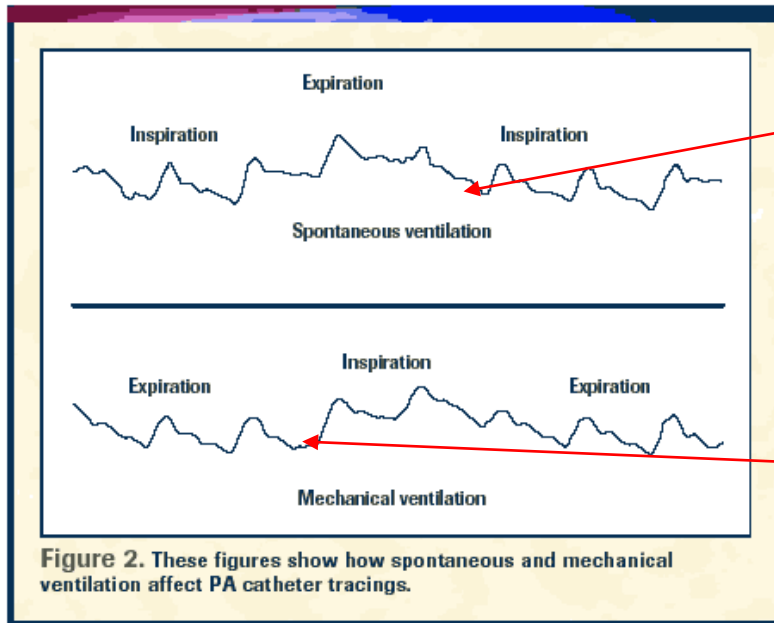


a wave: 20 milliseconds after p wave

v wave : T-P interval

Respiratory Cycle and Wedging

The effect of the respiratory cycle on PCWP measurements is important in obtaining an accurate PAWP. The timing of PCWP measurement is critical because intrathoracic pressures can vary widely with inspiration and expiration and are transmitted to the pulmonary vasculature. During spontaneous inspiration, the intrathoracic pressures decrease (more negative); during expiration, intrathoracic pressures increase (more positive). Positive pressure ventilation (e.g., in an intubated patient) reverses this situation. To minimize the effect of the respiratory cycle on intrathoracic pressures, measurements are obtained at end-expiration, when intrathoracic pressure is closest to zero.



Spontaneous ventilation:
 cursor would be on end expiration

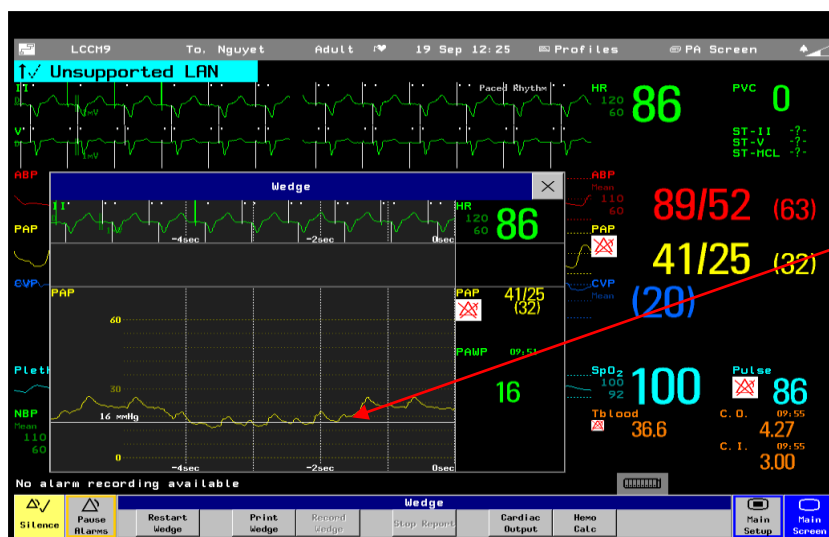
Mechanical ventilation:
 cursor would be on end expiration

Figure 2. These figures show how spontaneous and mechanical ventilation affect PA catheter tracings.

Editing wedge trace.

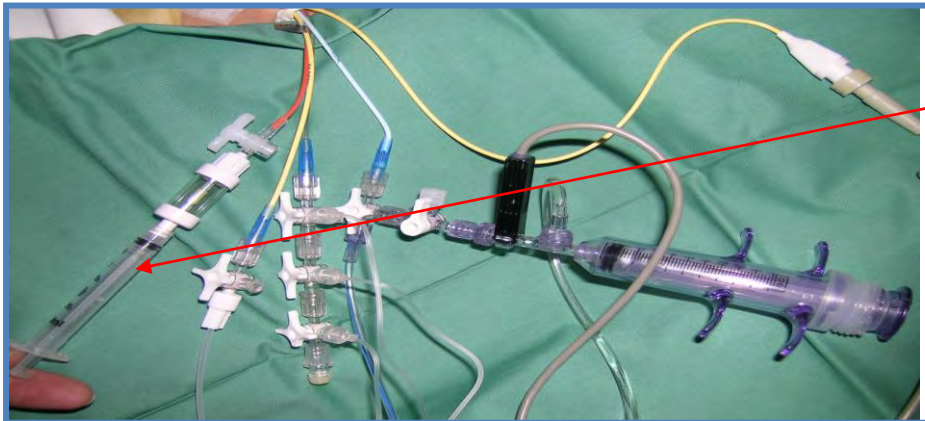
Press “edit wedge” soft key to open the next task window.

A horizontal line (cursor) appears in the PAWP waveform in the position of the mean value for PAWP. A numerical value for PAWP appears on the screen, entitled cursor. If a previous value is stored, it is also shown along with the time.



Positive pressure ventilation;
 cursor on end expiration

- Move the cursor up and down using the “cursor” soft keys if you want to alter the position of the cursor within the PAWP waveform.
- Press the hard key “confirm” when the cursor is in the correct position. This will be at end expiration. The chosen value is then stored as PAWP. The numerical value is displayed.
- Ensure that the PAP trace has returned to normal.
- Press “main screen” hard key to return to the main screen.
- Make absolutely certain that the balloon is DEFLATED. Remove the syringe and fully depress the plunger. Reattach the syringe. This will prevent accidental inflation of the balloon and demonstrate that the balloon is deflated.



Syringe left with all air expelled & tap open

PERFORMING CARDIAC OUTPUT STUDIES

- Cardiac output studies can obtain the following advanced hemodynamic values:
 - Cardiac index
 - Systemic vascular resistance (SVR)
 - Pulmonary vascular resistance (PVR)
 - Systemic vascular resistance index (SVRI)
 - Pulmonary vascular resistance index (PVRI)
 - Pulmonary artery wedge pressure (PAWP)
- As the fluid (mixed with blood) passes through the right atrium, right ventricle and then into the pulmonary artery, its temperature changes
- The temperature probe on the end of the PA catheter measures this temperature change. The change in temperature is then plotted on a time – temperature curve.
- A bolus of 5-10ml cold 5% dextrose into the right atrium should decrease the temperature in the pulmonary artery.
- The rate of blood flow is inversely proportional to the change in temperature over time
- Thus, the mean decrease in temperature is inversely proportional to the cardiac output.
- The Stewart-Hamilton Equation describes this relationship

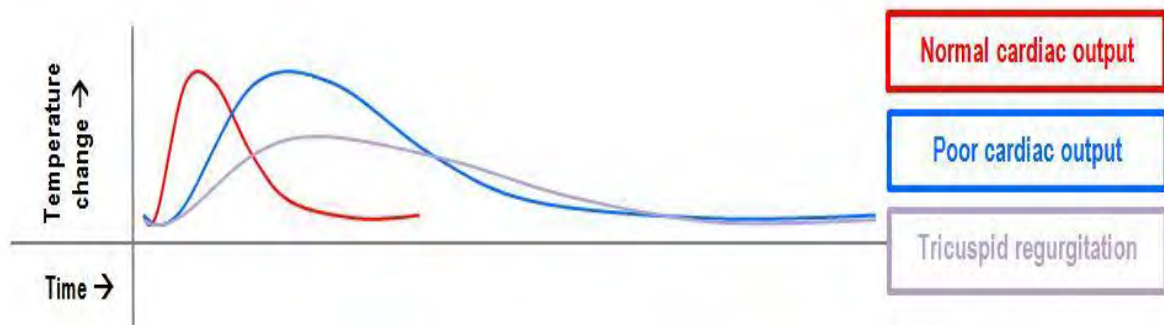
The Stewart- Hamilton Equation:

$$Q = \frac{V \times (T_b - T_i) K_1 \times K_2}{T_b(t) dt}$$

Q = cardiac output
 V = injected volume
 T_b = blood temperature
 T_i = injectate temperature
 K₁ and K₂ = corrections for specific heat and density of the injectate and for blood and dead space volume
 T_b(t)dt = change in blood temperature as a function of time

These variables are derived from the measured thermodilution curves.

These curves are visibly different in different cardiovascular pathological states:



Method

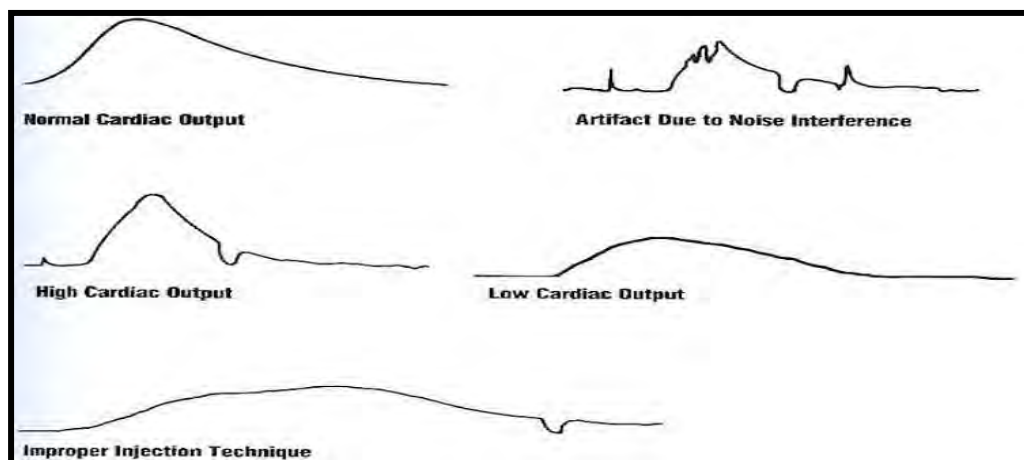
- Observe universal precautions.
- Position the patient supine with the backrest at 45°, unless contraindicated. Whatever position is used, the same position should be adopted for all measurements.
- Ensure the injectate delivery set is connected to the CVP proximal lumen, as described under heading PA Catheter Insertion
- Ensure the monitor is in the PA display screen
- Press the soft key labelled “CO” to enter the measurement task window.
- Draw 10ml 5% glucose into the CO injectate syringe
- Press “Start C O” soft key and wait for the prompt message “Inject now!” to appear on the screen. To ensure the greatest accuracy, use an injectate volume of 10ml.
- At the end of the measurement the thermodilution curve, cardiac output and index are displayed and a message will appear “Wait before starting new measurement”.
- A prompt message “Ready for new measurement!” will then appear on the screen. Press “start C.O” for the next measurement.
- Perform 3 measurements ensuring that at least two of them appear accurate curves with similar results for cardiac output.
- Edit the curves / measurements (to accept or reject them) by pressing on the waveform. If the waveform turns RED this means it has been deleted. If it is GREEN this means it has been accepted)



Assessing the measurements (CO Studies)

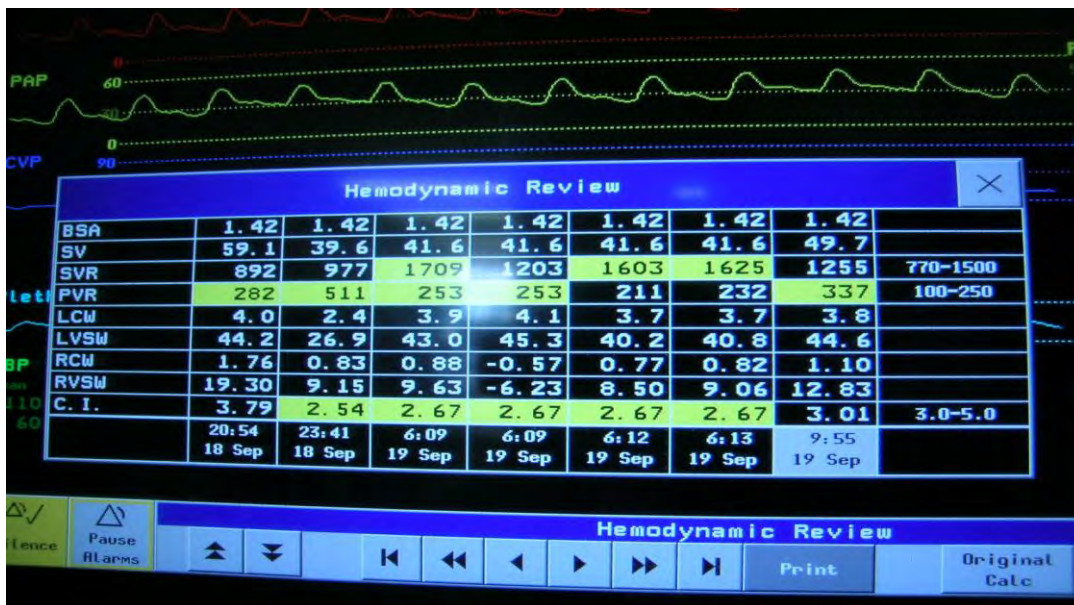
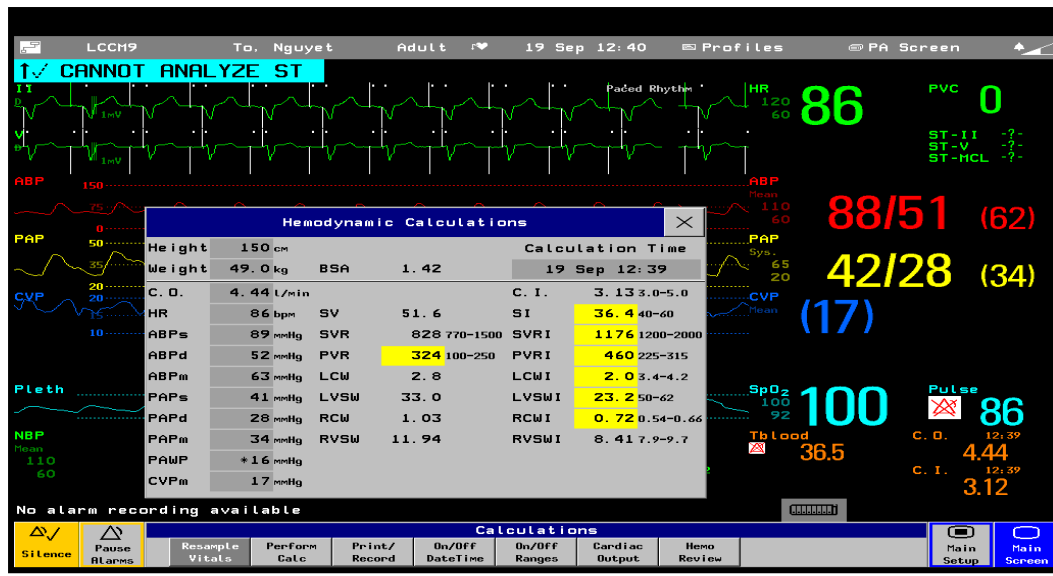
When assessing the accuracy of the measurements for editing consider:-

- The similarity of the values. If most of the values are similar, but one is different (i.e. outside a .5L difference), it should not be included in the average. If all values are different, they are uncontrolled error curves or true haemodynamic instability (e.g. arrhythmias).
- Whether the C.O. curve is normal.
The normal curve has:
 - A smooth, rapid injection
 - A single peak,
 - A stable baseline, indicating the return of the blood temperature to near the original. If the curve is irregular, a “curve alter” message will be displayed.



- When you have completed accepting / rejecting the measured curves, press “Save CO” to store the average.
- Press the soft key labelled “Hemo Calc” to get into the Haemodynamic measurement task window.
- If you have pressed the “hemo calc” key, the task window will display all the parameters
- Ensure that all displayed parameters in the task window are accurate as it can greatly alter the cardiac output studies.
- Press “Perform calc” for the monitor to do cardiac output calculations.
- Press “Print / Record” soft key to obtain a print out of the performed studies.
- The “Hemo Review” screen will give a tabular summary of all previous results and can be used for comparison.
- On the bottom of the printout sheet ensure that all inotropes and vasodilator / vasopressor agent infusion rates are documented to enable accurate interpretation of the cardiac output calculations.
- Close the “Hemo Cal” screen to return to the main screen.
- Record C.O. boluses on the ICU flowchart. Ensure that C.O. injectate lines is to be left attached to the CVP line at all times to maintain a closed system to minimise the risk of direct intra-cardiac injection of pathogens.

Haemocalculation & Haemo review screens



Troubleshooting - Errors in Measurement

1. Physiological reasons
 - Patient movement during the procedure.
 - Anxious patient.
 - Variations in cardiac rhythm and rate.
 - Shock.
 - Cardiac abnormalities.

2. Catheter-related errors.
 - Balloon inflated during measurement.
 - Catheter not positioned properly.
 - Damaged catheter.

3. Injection errors.

- Use of the wrong injection port.
- Poor timing of the injection.
- Incorrect volume of injectate.
- Inaccurate/over-range injectate temperature.

4. Instrument errors.

- Incorrect computational constant.
- Instrument failure.

Patient Position

Ideally, to achieve accurate and reproducible measurements, the patient's position should be the same for all measurements. The recommended position is supine with a head elevation of 30 - 40 degrees. If a patient is unstable then in accordance with standard procedure the haemodynamic measurements are to be done in the flat position.

PAC HAEMODYNAMIC VALUES & WHAT THEY REVEAL

Parameter	Normal range	Clinical relevance
Central venous pressure (CVP)	0 – 6 mm Hg	Used to determine volume status and right ventricle (RV) function; correlates with right ventricular end-diastolic pressure (RVEDP)
Right ventricular pressure (RVP)	20 – 30/0 – 6 mm Hg	Used to determine RV function and volume
Pulmonary artery pressure (PAP)	20 – 30/6 – 10 mm Hg	Used to determine state of resistance in pulmonary vasculature and RV function
Pulmonary artery wedge pressure (PAWP)	4 – 12 mm Hg	Used to determine left ventricle (LV) function; correlates with left ventricular end-diastolic pressure (LVEDP)
Stroke volume (SV)	60 – 80 ml/beat	Amount of blood ejected during systole; decreased SV indicates ventricular dysfunction
Cardiac output (CO)* (SV x heart rate)	4 – 8 L/min	Describes blood flow through tissues; reflects adequacy of overall cardiac function
Stroke volume index (SVI)	33 – 47 ml/beat/m ²	SV adjusted for patient's body surface area (BSA)
Cardiac index (CI)	2.5 – 4 L/min/m ²	CO adjusted for patient's BSA
Pulmonary vascular resistance (PVR)	20 – 120 dynes/sec/cm ⁵	Describes state of resistance in pulmonary vasculature
Systemic vascular resistance (SVR)	770 – 1,500 dynes/sec/cm ⁵	Describes state of resistance in systemic vasculature
Right ventricular stroke work (RVSW)	10 – 15 g-m/beat	Defines how hard right ventricle is working to pump blood
Left ventricular stroke work (LVSW)	60 – 80 g-m/beat	Defines how hard left ventricle is working to pump blood
Mixed venous oxygen saturation (SvO ₂)	60% – 75%	Index of oxygenation status that measures the relationship between O ₂ delivery and O ₂ demand; reflects cardiovascular tissue perfusion

Schell, H. M., & Puntillo, K. A. (2001). Critical care nursing secrets. Philadelphia: Hanley & Belfus, Inc.
Ahrens, T. (1999). Hemodynamic monitoring. Crit Care Nurs Clin North Am, 11(1), 19.

INTERPRETING CARDIAC OUTPUT STUDIES

To understand whether to fill or use inotropes when your patient has a low blood pressure is dependent on your interpretation of the patient's haemodynamic status.

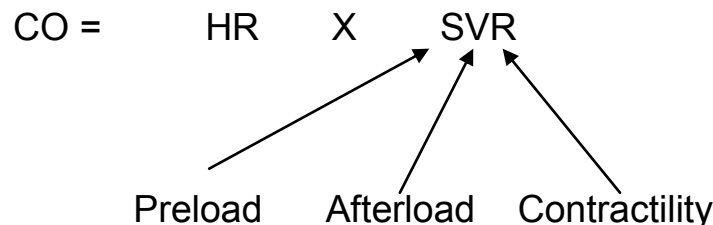
The most important haemodynamic indicator in the early postoperative period is cardiac output. No one parameter, however, should be considered or treated in isolation. Rather, all are evaluated in combination to determine appropriate therapeutic interventions. The goal is to maintain adequate systemic perfusion to protect cerebral, myocardial, and visceral function.

Cardiac Output (CO)

- Is defined as the amount of blood ejected from the ventricle per minute.
- Normal value is 3 -5 l/min
- Determinants are Heart Rate x Stroke volume (mls/beat)

Cardiac Index (CI)

- Determined by HR, SV, Height and Weight
- This is a more accurate determinant of heart function as it takes into account the patient's body surface area (m²)
- Heart Rate and Systemic Vascular Resistance can be manipulated to increase Cardiac Index



(Hudak, C. M., Gallo, B. M., Benz, J. J. 1990)

- The heart rate can be increased by initiating temporary epicardial pacing
- The optimal heart rate balances coronary blood flow (which takes place mainly during diastole) with cardiac output and is usually between 80 and 100 beats per minute. Normal sinus rhythm ensures atrioventricular synchrony and maximises cardiac efficiency (Salenger et al 2003)
- Stroke volume can be manipulated by fluids, inotropes vasopressors and dilators

Stroke volume is the amount of blood which is ejected from the heart with each beat. It is determined by three factors.

~ **Preload** of the ventricle

~ **Afterload** of the ventricle

~**Myocardial contractility**

Preload

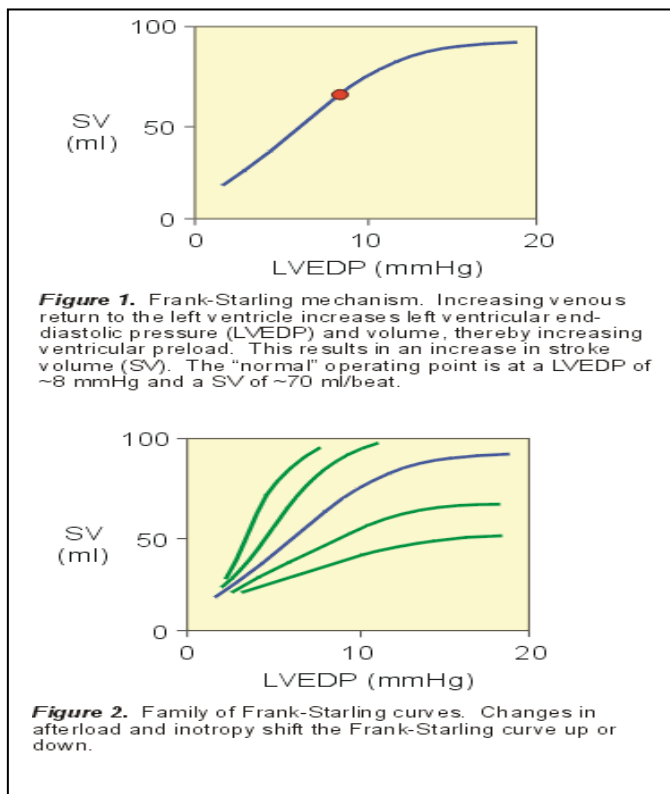
Is the pressure or stretching of the ventricle. It is the end-diastolic volume in the ventricle and serves as an estimation of average diastolic fibre length.

“The heart will pump what it receives” Starling’s law of the heart

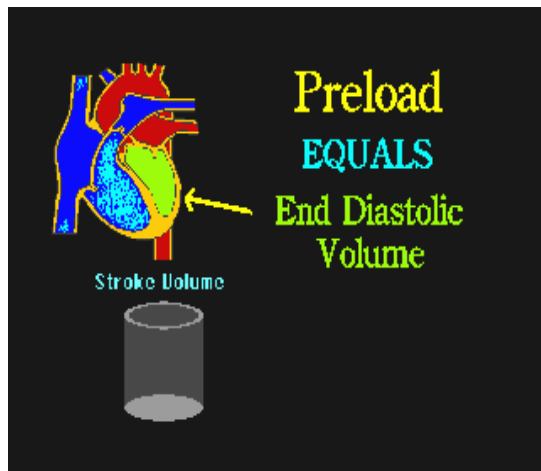
The Frank-Starling mechanism describes the ability of the heart to change its force of contraction (and hence stroke volume) in response to changes in venous return. In other words, if the end diastolic volume increases, there is a corresponding increase in stroke volume.

The Frank-Starling mechanism can be explained on the basis of preload. As the heart fills with more blood than usual, there is an increase in the load experienced by each muscle fibre. This stretches the muscle fibres, increasing the affinity of troponin C to Ca^{2+} ions causing a greater number of cross-bridges to form within the muscle fibres. This increases the contractile force of the cardiac muscle, resulting in increased stroke volume.

Frank Starling curves can be used as an indicator of muscle contractility (inotropy). However, there is no single Frank-Starling curve on which the ventricle operates, but rather a family of curves, each of which is defined by the afterload and inotropic state of the heart. Increased afterload or decreased inotropy shifts the curve down and to the right. Decreased afterload and increased inotropy shifts the curve up and to the left.



Cardiovascular Physiology Concepts, Richard E Klabunde 2007

**PRELOAD = VOLUME COMING IN**

- ↑ ~ hypervolaemia
- ~regurgitation of valves
- ↓ ~ hypovolaemia
- ~ vasodilatation
- ~ post op bleeding

Preload reflects the volume status of the patient and is measured by the PAWP via the thermodilution catheter or PA Catheter.

The preload that provides optimal cardiac output varies from each patient and is dependent on ventricular size.

Afterload

Is the impedance to left ventricular contraction, is assessed by measuring systemic vascular resistance (SVR). It is the degree of constriction or dilatation of the arterial circulation.

**AFTERLOAD = RESISTANCE LEFT VENTRICLE MUST OVERCOME TO CIRCULATE BLOOD**

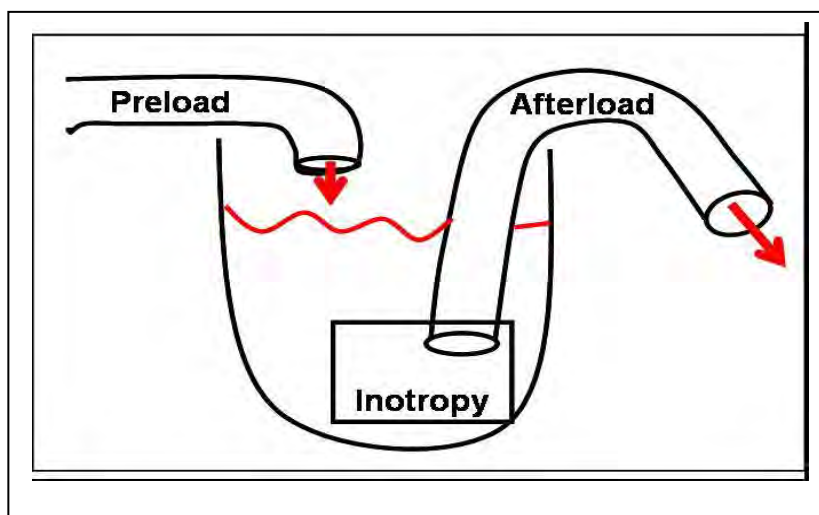
- hypothermia
- history of hypertension
- vasoconstriction
- aortic valve stenosis
- increase in SVR
- ventricular dilatation

High afterload increases myocardial work load and oxygen demand and decreases cardiac output

Contractility

- Is the ability of the myocardial muscle fibres to shorten independent of preload and afterload. It is the ability of the heart to contract and the force it needs to does so.
- The force of contraction is determined by the concentration of calcium ions in the cells
 - Increase contractility by flooding cell with more calcium (beta agonist) or by keeping more calcium in the cell and not letting it escape.
- Mechanism that regulates cardiac output is
 - The autonomic nervous system by altering the heart rate, contractility, preload and afterload.
 - The parasympathetic nervous system slows the heart rate

- The sympathetic nervous system innervates the conduction system of the heart, the arterioles and veins
 - Stimulation produces an increase in heart rate, contractility, preload (venous constriction) and afterload (arterial vasoconstriction)
- Ejection fraction is often used to evaluate the ability of the heart to contract
 - Ejection fraction is the fraction of blood pumped out of the ventricles with each heart beat
 - Normal value for a healthy person is 55-65%
 - End-diastolic volume (EDV) is the volume of blood within a ventricle immediately before a contraction.
 - End-systolic volume the volume of blood left in a ventricle at the end of contraction.
 - Stroke volume(SV) is the difference between end-diastolic and end-systolic volumes
 - Ejection fraction (E_f) is the fraction of the end-diastolic volume that is ejected with each beat; that is, it is stroke volume (SV) divided by end-diastolic volume (EDV) (Richard E Klabunde 2007)
 - **Poor contractility may be due to:**
 - Surgical manipulation of the myocardium
 - Post - Cardiopulmonary bypass myocardial depression
 - Cardioplegia
 - Ischaemia during the aortic cross-clamping
 - Myocardial infarction
 - Changes in the ventricular muscle as a result of valve disease
 - Myocardial contractility is enhanced if necessary by using inotrope pharmacological agents, such as milronone, dobutamine and levosimendan. The choice of agent is individualised to the specific clinical situation.



Summary

Preload = tap filling the heart.
The faster it turned on = more constriction ↑ preload

Contractility / Inotropy = Pump

Afterload = diameter of hose or resistance

CARDIAC OUTPUT INTERPRETATION MADE EASY

- These values as well as a clinical assessment are useful in determining the fluid and inotrope requirements of the patient:
- Below is a interpretation of Cardiac output studies in a simplified form

Cardiac Output

- HR x SV
- Amount of blood ejected from left ventricle in litres/min
- Preload, afterload and contractility regulate SV
- Normal level 4-8litres/min

Cardiac index (CI)

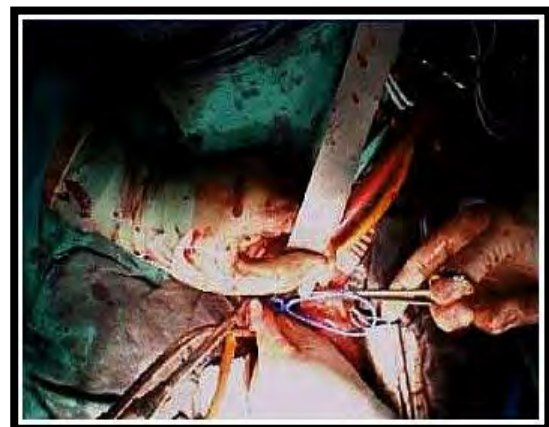
- HR x SV + HT & WT therefore more accurate than CO
- Normal Level 3-5 litres/min/m²
- Low CI can be managed by:
 - ↑ HR e.g. pacing if patient bradycardic
 - manipulate contractility with milrinone, dobutamine
 - manipulate SV with fluids

Systemic vascular resistance (SVR) is

- How dilated or constricted the patient
- Normal level 770-1500 DS/cm⁵
- Low SVR can be managed by filling with fluid bolus or by using inotropes
- High SVR can be managed by antihypertensives and vasodilators such as sodium nitroprusside

PAWP

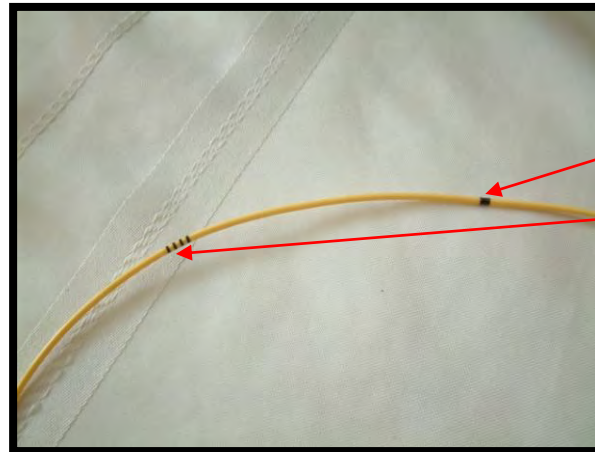
- Wedge pressure is reflection of the filling of left ventricle
- Preload of the left side of the heart
- Normal level 8-12 mmHg
- Normal value depends on size of pts ventricle. A hypertrophied ventricle will need more filling than a normal size ventricle
- Affected by fluid, contractility and valve and pulmonary circulation integrity

**X-ray shows PAC curled up in right ventricle which needed to be removed surgically**

http://www.ispub.com/journal/the_internet_journal_of_radiology/volume_1_number_1_61/article/case_of_the_month_1.html

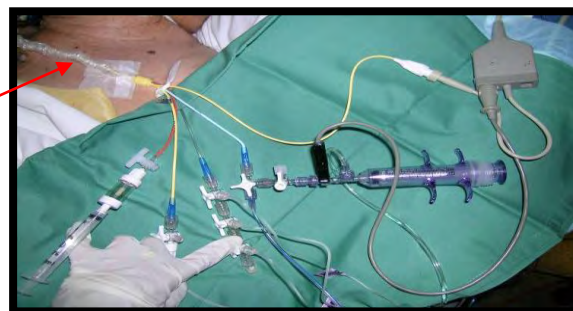
NURSING MANAGEMENT OF PULMONARY ARTERY CATHETER

- Full physical assessment
- Zero and level transducers after repositioning
- Ensure correct waveform, scale and values are monitored
- Monitor PA trace AT ALL TIMES
- Document on flow chart catheter length at sheath site. Thick band is 50cm, line band 10cm



Thick band = 50cm
Thin band = 10cms
each

- Secure catheter to patients chest at lumen site



Secure to chest
with dressing

- Review CXR to check catheter position - 2cm left of mediastinal border
- Document PAP's hourly
- Set alarms appropriately. Set PAP systolic alarm to a value above the patients wedge value so that spontaneous wedging will be notified
- Never inflate balloon longer than 15 seconds
- Leave balloon syringe with no air and tap open to syringe
- Perform cardiac output studies post op and then 6 hourly or as per Registrar according to titration of inotropes and fluids
- Inspect sheath insertion site for infection and change dressing if oozing or loose otherwise as per protocol

REMOVAL OF PAC

- Routinely removed Day 1 or as per Registrar's orders
- Ensure there are no inotropes or fluids running through medication port
- Ensure balloon is deflated
- Position patient supine
- Unlock sheath from PA catheter
- Ask patient to take a deep breath and hold

Pulmonary Artery Catheter Learning Package

- Remove catheter gently while watching monitor for arrhythmias. If arrhythmias seen continue to remove catheter as removal can irritate the heart
- Place cap on end of sheath
- Check end of PAC to ensure all intact
- Redress sheath

TROUBLESHOOTING and COMPLICATIONS OF PULMONARY ARTERY CATHETER***Catheter not wedging***

- Report to Senior Registrar, educator or competent cardiothoracic RN
- Catheter may need to be re floated

Spontaneous wedging of balloon is a life threatening complication and requires **immediate** action by a registrar, CNE or a experienced RN who has completed the Pulmonary Artery Catheter competency

- Ensure that the wedging syringe has not been left full of air and accidentally been inflated
- Do not attempt to inflate or flush a wedged balloon
- Check pressure scale and waveform
- Check pressure bag and transducer
- Pressures of PA, if systolic and diastolic are similar the catheter is likely to have wedged
- If catheter is wedged ensure balloon is deflated and pull catheter back 1 -2 cms
- Reassess trace
- If still appears wedged withdraw blood from PA distal lumen, if no blood catheter is still wedged. Pull catheter back into right atrium and an experienced Registrar or RN will re-float catheter

Balloon rupture

- There should be slight resistance when inflating balloon
- If there is no resistance and no wedge trace assume that the balloon has ruptured and alert Registrar for removal and re-insertion

Arrhythmias

- Catheter may have migrated to ventricle
- Notify Registrar catheter may need to be re floated

Pulmonary infarction

- Catheter tip wedged for prolonged period or formation of thromboemboli

Pulmonary artery rupture:

- Over inflation of balloon while in wedge position

LEARNING QUESTIONS

1. State the indications, contraindications and complications of a PA catheter
2. State the colours and uses for each of the PA lumens
3. Write about the difference between normal and abnormal waveforms
4. State all routine and safety checks required when managing a PAC
5. Identify normal ranges for haemodynamic values measured from a PA catheter
6. What is the correct position and waveforms of PA catheter
7. How do you perform a wedge procedure safely?
8. What does PAWP represent?
9. Where is the cursor moved to on the wedge trace?
10. List safety precautions when managing a PAC
11. Interpret cardiac output studies
State management for a post op Cardiothoracic patient with ventricular hypertrophy, BP: 100/60, HR 55bpm, CI 2.2, SVR 700, PAWP 10mmHg
12. List the risks and complications associated with the insertion and management of a PA catheter
13. Discuss the nursing management of a PA catheter

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