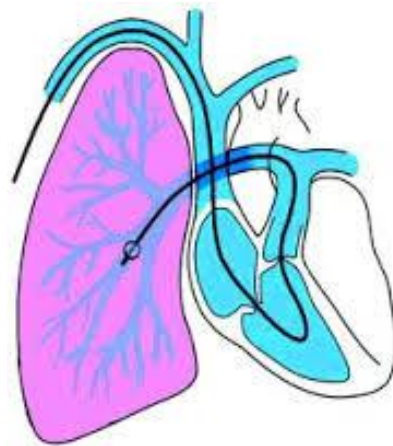
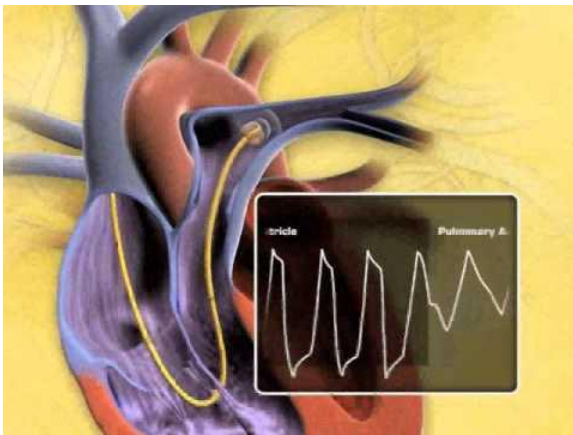


**PULMONARY ARTERY PRESSURE MONITORING
USING THERMODILUTION CATHETER (SWAN GANZ)**

A LEARNING RESOURCE FOR INTENSIVE CARE NURSING STAFF



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Contents of Pulmonary artery pressure monitoring learning resource

Indications and contra-indications for PA catheter	Page 4
PA catheter lumens	Page 5
Monitoring sites and insertion procedure	Page 6
Preparation for PA catheter insertion	Page 7
How to connect the various components	Page 8
Typical waveform progression during insertion	Page 9
Right atrial waveform	Page 10
Right ventricular waveform	Page 11
Pulmonary artery waveform	Page 12
Pulmonary artery wedge waveform	Page 13
How to start the wedge procedure	Page 14
Waveform analysis	Page 15
Wedge pressure summary of safety points	Page 16
Precautions for operating gate valve	Page 17
Wedge position and associated problems	Page 18
Cardiac output and the thermodilution curve	Page 19

Contents of Pulmonary artery pressure monitoring learning resource

Performing cardiac output measurements	Page 20
Performing haemodynamic calcs and review	Page 21
Curves for low and high CO and poor technique	Page 22
Tricuspid regurgitation and summary of CO curves	Page 23/24
Problems associated with measuring CO	Page 25
Complications of a PA catheter	Page 26/27
Summary of PA catheter complications & troubleshooting advice	Page 28
PA catheter measurements and what they represent	Page 29
Removing the PA catheter and percutaneous introducer	Page 30

Learning objectives:

- State the indications and contra-indications of a pulmonary artery catheter.
- Identify the associated risks and complications when a pulmonary artery catheter is inserted.
- Correctly identify the lumens.
- Perform all routine safety checks.
- Be able to identify the position and waveforms of the pulmonary artery catheter.
- Be able to recognise abnormal waveforms.
- Perform a wedge procedure safely.
- Perform cardiac output trials.
- Interpret cardiac output trials.
- Identify normal ranges for haemodynamic values measured from a pulmonary artery catheter.
- Reflect on the nursing management of a pulmonary artery catheter.

Introduction:

In 1970, Swan et al described a modified catheter that incorporated an inflatable balloon at its tip. This “balloon flotation catheter” allowed prompt and reliable catheterisation of the pulmonary artery (PA) without the need for screening, and minimising the risk of arrhythmias.

In many critically ill patients, particularly those with pulmonary disease or isolated right heart or left heart dysfunction, the measurement of right atrial pressure gives no indication of the function of the left side of the heart. If the determinants of cardiac function can be known, more effective treatment strategies can be instituted. This can be achieved using a pulmonary artery catheter.

Assessment data that may be obtained from this catheter include – right atrial pressure; right ventricular pressure; including systolic, diastolic and mean pressures; pulmonary artery pressure, cardiac output/index, systemic vascular resistance, mixed venous oxygen saturation and core body temperature.

Indications and uses:

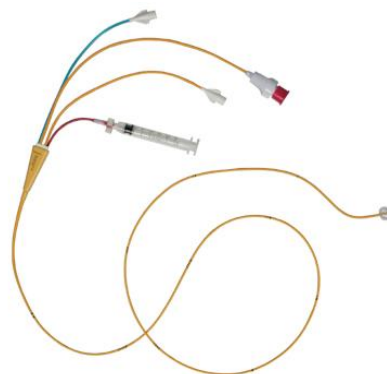
- Monitoring of pulmonary artery pressures and pulmonary artery wedge pressures.
- Administration of fluids and medication through a central line.
- Cardiac output determination via the thermodilution technique.
- Evaluation of the patient’s response to nursing and medical therapeutics.

Contra-indications:

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

The basic pulmonary artery consists of :

1. A distal lumen
2. A proximal lumen
3. A thermistor connector
4. A balloon inflation lumen



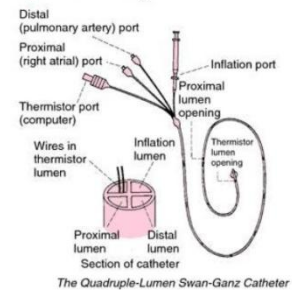
Distal lumen:

The distal lumen which exits into the pulmonary artery, monitors pulmonary artery pressures. Its hub is marked "PA distal" or is colour-coded yellow. Blood gases can be taken from this lumen for measurement of mixed venous oxygen saturation. NEVER inject drugs or connect infusions through this lumen. Routine blood samples must **not** be taken from this lumen.

Proximal lumen:

The proximal lumen exits in the right atrium or vena cava, depending on the size of the patient's heart. It monitors right atrial pressure and can be used as the injected solution lumen for cardiac output determination and infusing solutions. The proximal hub usually is marked "proximal" or is colour-coded blue.

+ Swan-Ganz Catheter/Pulmonary Artery Catheter



Thermistor:

The thermistor, located about 4cm from the distal tip measures temperature (aiding core temperature evaluation) and allows cardiac output measurement. Two insulated wires run the length of the lumen to end at the thermistor connection. The thermistor connector attaches to a cardiac output connector cable, then to a cardiac monitor.

Balloon-inflation:

The balloon inflation gate valve is used for inflating the balloon tip with air.

Catheter length:

The thermodilution catheter is 110cm length long, marked at increments of 10cm, and is available in diameters of no.5 and no.7 French. Due to its length, the catheter needs to be safely secured to the skin using tape. The catheter is at risk of migration therefore the depth of insertion (recorded in cm) should be documented.

Depths of insertion from marks on the catheter are as follows:

- One narrow mark indicates 10cm; two together, 20cm etc.
- 50cm is designated by a heavier line.
- One heavy line and one smaller line indicate 60cm, one heavy line with two small lines is 70cm, etc.

Monitoring sites:

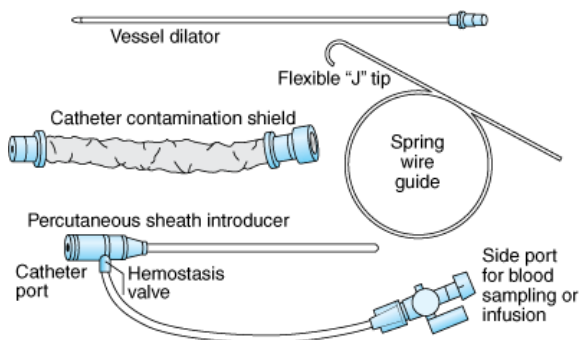
- Internal jugular vein.
- Subclavian vein (may result in kinking in the catheter due to anatomical reasons and may cause a dampened waveform).
- External jugular, antecubital, and femoral veins can also be used.

Techniques of catheter placement:

- All patients should have continuous electrocardiographic monitoring, and all equipment and supplies for cardiopulmonary resuscitation should be available.
- The catheter is inserted under aseptic conditions.
- A larger size introducer cannula (referred to as a percutaneous sheath introducer) is first inserted into the vessel and the pulmonary artery catheter is then passed through a self-sealing valve (prevents the risk of air embolism) at the top of the introducer and into the vessel itself.
- The introducer should be left in situ and also provides an extra central venous access point.



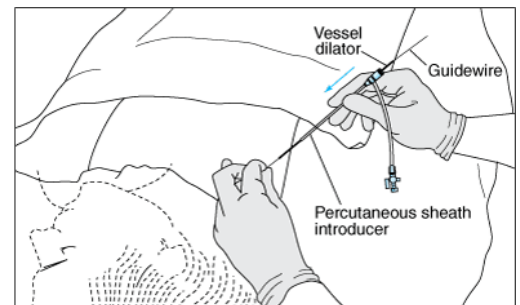
Percutaneous sheath introducer:



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Sterile plastic sleeve luer locks in place on sheath and keeps covered part of PA catheter sterile.

Apply tape after insertion is complete to prevent movement of sheath.



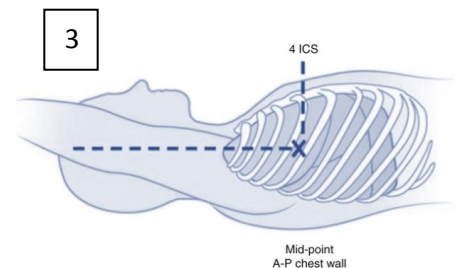
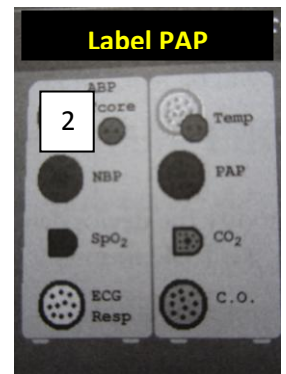
Sheath introducer inserted into vessel

Equipment needed for the procedure:

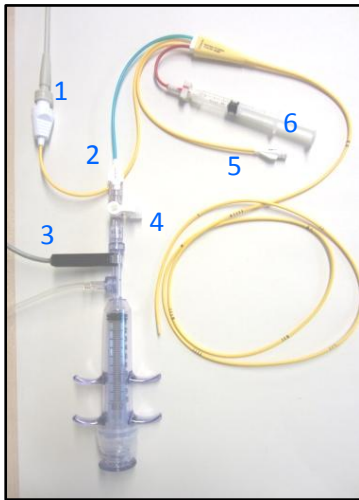
- Procedure is as per central venous catheter (CVC) insertion.
- Cardiac output module (orange colour): includes cardiac output cable and thermistor.
- Injectate set for cardiac output: a 500ml bag of glucose 5% is connected.
- Double transducer kit: PA (yellow colour) and CVP (blue colour).
- CVC insertion pack.
- PA catheter.
- Percutaneous sheath introducer.

Preparation for PA catheter insertion:

- Insert cardiac output module (orange colour) in to the cardiac monitor. This includes the cardiac output cable and the thermistor.
- Prime double kit transducer PA (yellow colour) and CVP (blue colour) with 0.9% sodium chloride using a 500ml bag. Ensure that there are no air bubbles in the transducer, transducer ports and extension lines.
- Place the 0.9% sodium chloride in the pressure infuser bag and inflate to 300 mmHg.
- Label blue transducer CVP and label the yellow transducer PA and connect to transducer mount. Measurements for cardiac pressures will be displayed in yellow on the monitor screen.
- The transducer mount is placed level with the 4th intercostal space in the mid-axillary line.
- Both the CVP and PA transducers need to be “zero-ed”.
- The yellow PA transducer line is connected to the yellow or distal port. This needs to be connected to allow visualisation of the pressure waveform.
- The CVP lumen and the PA lumen of the PA catheter are primed with 0.9% sodium chloride under aseptic technique.
- The cardiac output injectate set is primed with 5% glucose.
- Once primed the injectate set is then connected to the blue-coloured lumen labelled “injectate”.
- The thermistor needs to be connected to the discreet side-port mid-way between the 10ml syringe and the 3-way tap.
- Check that the thermistor is functioning – connect to the cardiac output computer to test the integrity of the thermistor wires. If the wires are not intact, the computer will indicate a defective catheter.
- Medical staff prime the PA catheter with normal saline under aseptic conditions.
- Medical staff check integrity of the PA catheter balloon by inflating slowly no more than 1.5ml of air (the bursting volume of the balloon is about 3ml). The balloon should appear symmetrical when inflated.
- Once balloon integrity has been confirmed, the balloon is deflated, and the catheter is passed through the introducer and into the vein. The balloon is then inflated with 1 to 1.5 ml of air and the catheter is advanced until the tip is in or near the right atrium, and at the same time, pressures and waveforms are noted.



Connecting the parts:

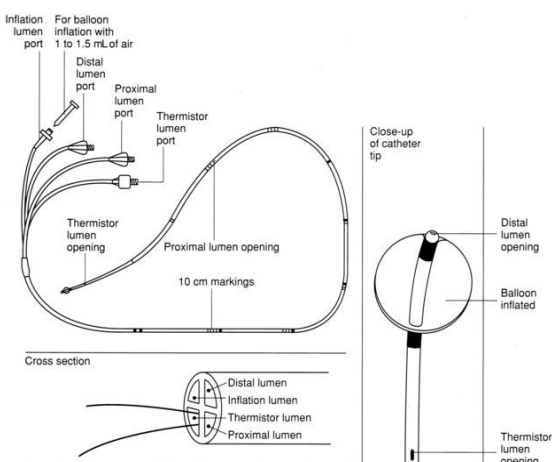


1. After inserting the cardiac output module in to position, connect the cardiac output cable to the chunky white connection on the PA catheter. The chunky connection has an arrow to guide direction of the cardiac output cable.
2. Prime the injectate system with glucose 5% and connect the injectate system to the blue-coloured port (labelled “prox injectate”).
3. Attach the thermistor cable to the side port mid-way between syringe and the 3-way tap.
4. The CVP transducer line can be connected to the 3-way tap.
5. The PA transducer line can be connected to the hub marked “PA distal”.
6. The syringe for balloon inflation is connected to the red-coloured line on the PA catheter. After ensuring that the balloon is deflated, the gate clamp should be in closed position.



After connecting the CO module and cables:

- The computation constant needs to be programmed: this enables the computer to identify which catheter is being used.
- This constant depends on the make and model of the catheter i.e. Edwards/thermodilution; the volume of the injectate fluid used i.e. 10ml of 5% glucose; and the temperature of the injectate.
- The patient’s height and weight/BSA will also need to be programmed into the cardiac monitor.
- Inject temp: select IN-LINE.



The catheter is designed to be flow-directed when the balloon is inflated.

During insertion, the inflated balloon allows the catheter to follow the venous blood flow from the right heart into the pulmonary artery.

Correct position of the catheter tip depends on the insertion site:

- 10cm from the subclavian vein
- 10 to 15cm from the right internal jugular vein
- 35 to 45cm from the femoral vein
- 35 to 40cm from the right antecubital fossa
- 45 to 50cm from the left antecubital fossa

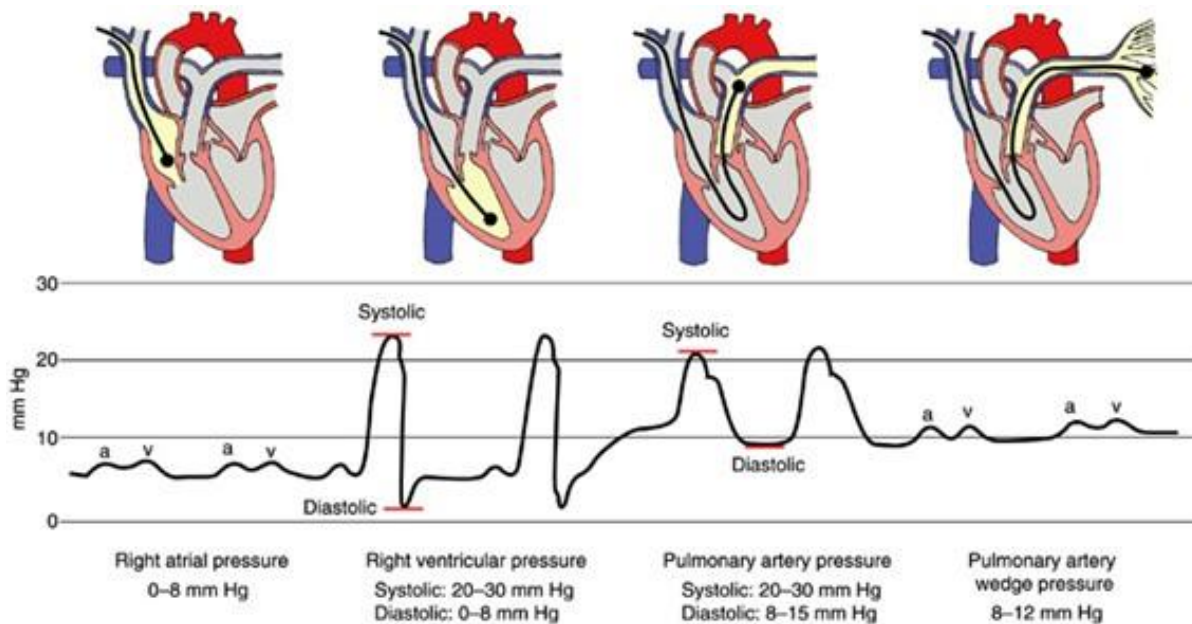


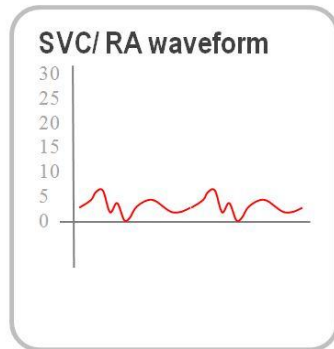
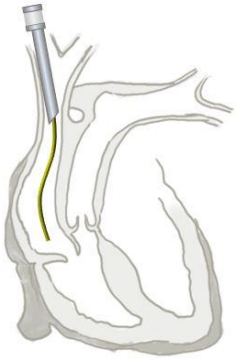
Figure 17-58 Normal values and wave configurations produced by the pulmonary artery catheter.

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The chambers on the right side of the heart have characteristic pressures and waveforms. The pulmonary artery also has typical waveforms and pressures.

Right atrial waveform:

Once the catheter tip has reached the junction of the superior vena cava or inferior vena cava and right atrium, the balloon is inflated with air (not exceeding 1.5ml). From here, the catheter should never be advanced with the balloon deflated. The first chamber reached is the right atrium. Pressures are normally low and will produce two small upright waves.



Normal pressure 4 to 12 mmHg

Right atrial pressure increases in the following conditions:

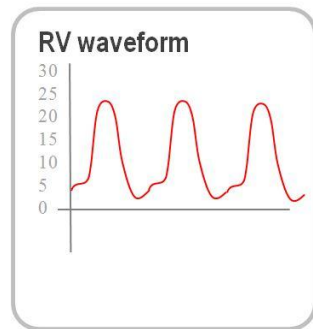
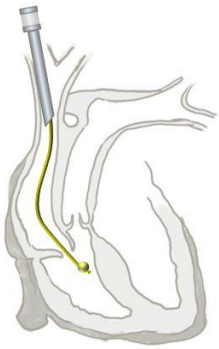
- Right ventricular failure and infarction.
- Increased pulmonary vascular resistance causing increased afterload on the right ventricle and reduced ejection volume.
- Tricuspid or pulmonic stenosis or regurgitation.
- Cardiac tamponade and constrictive pericarditis.
- Right ventricular failure secondary to left ventricular failure (RA pressures are a poor reference for evaluation of left ventricular performance in left ventricular failure).

Right atrial pressure is decreased by:

- Hypovolaemia.
- Inadequate filling as in vasodilation from medications, in early sepsis, and in anaphylaxis.

Right ventricular waveform:

The next chamber is the right ventricle. Waveforms show taller, sharp uprisings as a result of ventricular systole and low diastolic dips and values. The systolic pressure is higher in the right ventricle, with the diastolic value being nearly the same as the right atrial pressure value. When the catheter has passed the tricuspid valve, special attention should be paid to the patient's ECG to identify any ventricular ectopics that may occur.



Normal systolic pressure is 20 to 30 mmHg

Normal diastolic pressure is 0 to 5 mmHg

Right ventricular pressure is increased by all the factors that increase right atrial pressure, and is increased in pulmonic stenosis and ventricular septal defects.

Implications of increased right ventricular pressure:

In acute right ventricular failure and right ventricular infarction, dilation and expansion of right ventricular size are inhibited by the noncompliant restrictive fibrous pericardium.

In this scenario, increases in right ventricular pressure and volume may lead to shift the IVS toward the LV, reducing the space for ventricular filling. Decreased left ventricular end-diastolic volume reduces preload and cardiac output.

In chronic left ventricular failure the most common cause of right ventricular failure, the high pressure in the left ventricle offsets the interventricular shift.

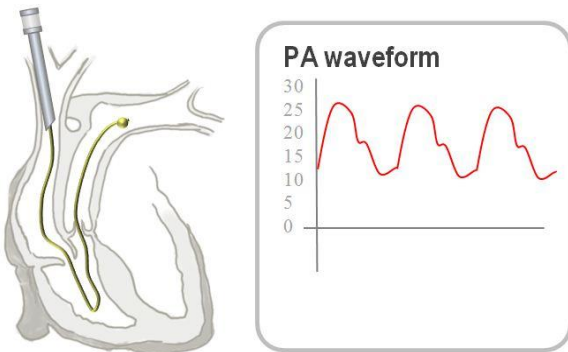
Pulmonary artery waveform:

As the catheter floats into the pulmonary artery (not a wedge position) characteristic waveforms can again be noted.

As a result of right ventricular systole, there is a rise in pressure in the pulmonary artery. This pressure is recorded as being almost the same as right ventricular systolic pressure. The waveform has a large excursion with upward slope being more rounded than the right ventricular tracing.

The onset of diastole begins with closure of the pulmonic valve, which produces a dicrotic notch on the pulmonary artery tracing. Diastole continues in the ventricles. Once the pulmonic valve closes, and since the pulmonary artery does not relax further, the diastolic pressure is higher in the pulmonary artery than in the right ventricle.

Because diastolic pressures will be higher in the pulmonary artery than in the right ventricle, special attention should be paid to observing diastolic pressures during insertion. Right ventricular systolic and pulmonary artery systolic pressures are nearly the same. If monitoring them during insertion, distinguishing catheter tip location between the right ventricle and pulmonary artery may be more difficult. By observing the diastolic pressures, a rise in pressure value will be noted when the pulmonary artery has been reached.



Normal systolic pressure is 20 to 30 mmHg

Normal diastolic pressure is 5 to 10 mmHg

Mean pressure is less than 20 mmHg.

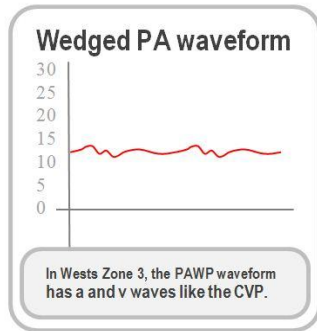
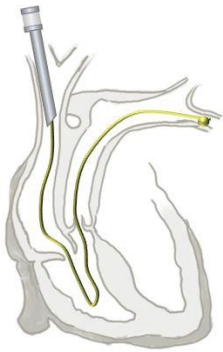
Increased pulmonary artery pressure readings may indicate:

- Pulmonary hypertension from many causes.
- Chronic obstructive airways disease.
- Acute respiratory insufficiency.
- Long-standing congenital heart disease with large shunts.
- Left ventricular failure.
- Mitral stenosis.

Pulmonary artery wedge waveform:

The catheter with the balloon still inflated, is now advanced further until it wedges in a central branch of the pulmonary artery. At this point, right heart pressures and pulmonary influences are occluded. The catheter is “looking” at left heart pressures. The waveform reflected will be that of the right atrium (6mmHg to 12mmHg). The waveform will have two small rounded excursions from systole and diastole.

The value recorded will also be slightly less than the pulmonary diastolic pressure. Pulmonary artery diastolic pressure is higher than pulmonary artery wedge pressure by 1 to 4 mmHg, typically.



The catheter with the inflated balloon is advanced further, until the PA waveform disappears, and a venous-looking waveform appears. This is the **wedge** waveform – it indicates that the pulmonary artery is occluded.

In normal physiology, the pressure should approximate 6 to 12mmHg, like the diastolic PA pressure. Once the wedging point is found, deflate the balloon: **DO NOT KEEP IT INFLATED**. Leaving the balloon wedged might lead to pulmonary infarction.

Once the wedge position has been identified, the balloon is deflated by removing the syringe and allowing the back pressure in the pulmonary artery to deflate the balloon. Once the balloon has been deflated, reattach the syringe to the gate valve. To reduce or remove any redundant length or loop in the right atrium or ventricle, slowly pull the catheter back 1 to 2 cm. Then reinflate the balloon to determine the minimum inflation volume necessary to obtain a wedge pressure tracing. The catheter tip should be in a position where the full or near-full inflation volume (1 to 1.5ml) produces a wedge pressure tracing. NEVER inflate the balloon more than the minimum required to obtain a wedge tracing: avoid prolonged manoeuvres to obtain wedge pressure and keep wedge time to a minimum i.e. 2 respiratory cycles or 10 to 15 seconds.

Continuous pulmonary artery tracings and pressures can now be monitored. Since there is always a potential risk of pulmonary artery damage during wedging, in most situations monitoring of the pulmonary artery diastolic will reflect pulmonary artery wedge values. Note and document on ICU chart the cm marking on the catheter at which wedged waveform is obtained.

CONSEQUENCES OF ABNORMAL PRESSURES	
Normal wedge pressure is less than 12 mmHg	
PAWP 18 to 20 mmHg	Mild pulmonary congestion
PAWP 20 to 25 mmHg	Moderate pulmonary congestion
PAWP 25 to 30 mmHg	Severe congestion
PAWP over 30 mmHg	Acute fulminating pulmonary oedema

Continuous monitoring of the PA pressure is important for several reasons. First, therapy will depend upon the values obtained from the pulmonary artery and intermittent wedge recordings. Second, catheter tip position changes can present **potential risks** to the patient.

How to start the wedge procedure:

- In the **Main Setup** menu, select **Wedge** to display the wedge procedures window.
- Inflate the balloon when the monitor prompts you – this will appear as **“Ready for balloon inflation”**. The waveform changes from the PAP to the PAWP wave. The measurement takes approximately 12 seconds. On completion, the monitor stores the PAWP waveform display and prompts you to deflate the balloon. If the monitor cannot detect a wedging waveform you must use **Store Trace** to store the wedge and two reference waves manually.
- Deflate the balloon when the monitor prompts you: the message **“Ready for balloon inflation”** will appear. Verify that the waveform returns to pulmonary artery shape.
- If you need to start a new measurement, select **Restart Wedge**.



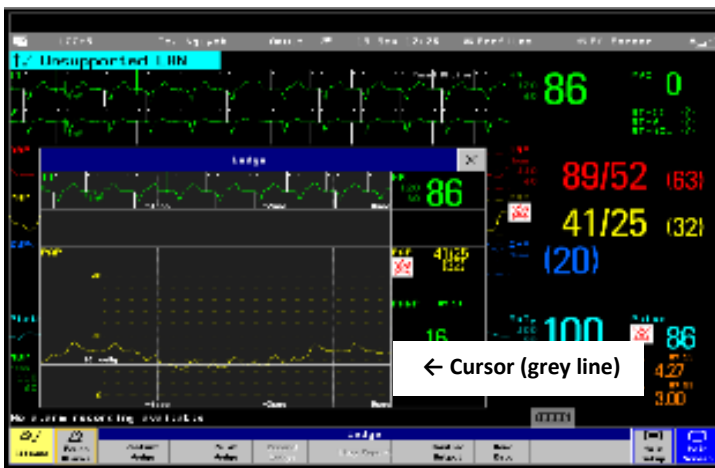
The balloon is inflated, and as the balloon wedges in the pulmonary artery, the waveform changes from PA trace to a flattened wedge tracing.

Never flush the catheter when the balloon is wedged in the PA.

Editing the wedge:

- Select the **Edit Wedge** pop-up key to see the stored waveforms.
- The monitor displays a cursor in the waveform at the PAWP mean value. It also displays any previously stored value and the time it was stored.
- Select **Change Speed** if you want to change the speed (resolution) of the displayed wave.
- Move the cursors up, down, right and left to set them on the correct wedge position.
- Select **Store Wedge** to store the PAWP value.

Balloon inflation is usually associated with a feeling of resistance. If no resistance is encountered, it should be assumed that the balloon has ruptured. Discontinue attempts of inflation and inform medical staff immediately



Reviewing/editing the wedged waveform:

Cursor is moved down to the level of end-expiration using the cursor soft keys.

Respiratory Cycle and Wedging:

All pressures are interpreted at the **end-expiration** phase of respiration, whether or not the patient is spontaneously breathing or on assisted mechanical ventilation.

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.

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.

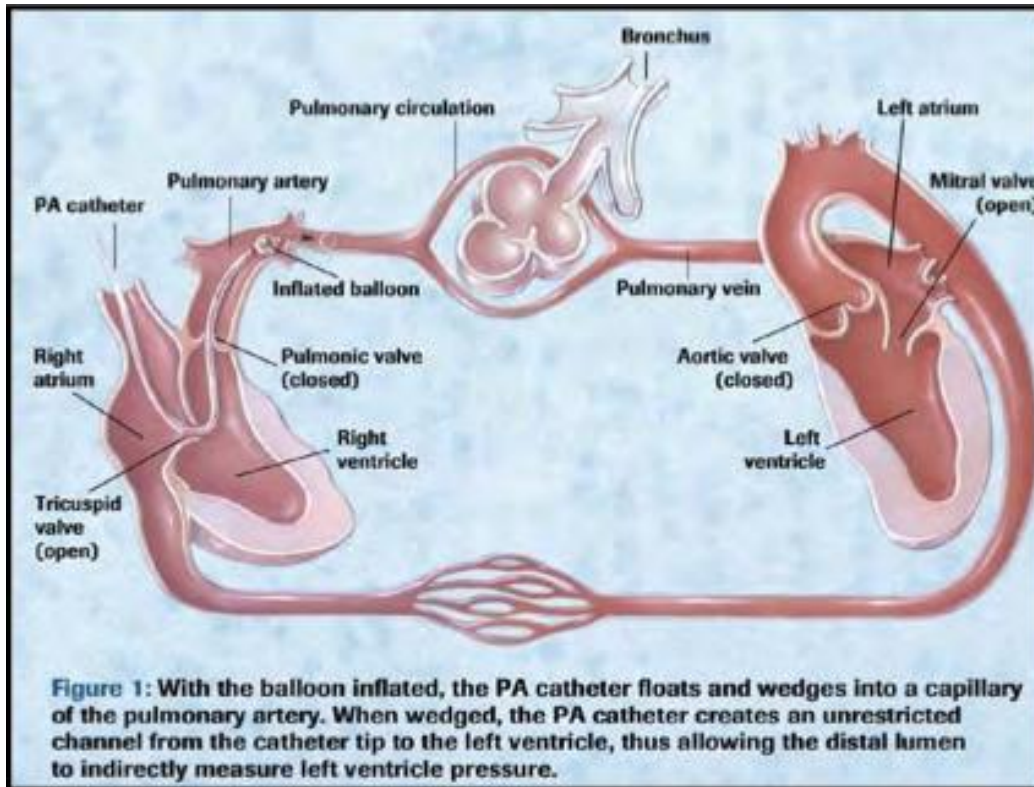
Press the hard key “confirm” when the cursor is in the correct position. This will be at end expiration. The chosen value is then stored as PAWP. The numerical value is displayed.

Waveform analysis:

- As with CVP, analysis of the pulmonary artery wedge waveform may give some indication of cardiac pathology.
- Constrictive pericarditis and pericardial tamponade show the same abnormalities (but less clearly) as in the CVP trace.
- Mitral regurgitation may cause a large v-wave, which may be confused with the PA waveform.
- The two can be distinguished by examining the timing of the waves relative to the T-wave of the ECG.
- The peak of the PA systolic wave occurs before and the v-wave appears after the T-wave.
- Large v-waves may also be associated with mitral stenosis, congestive heart failure or ventricular septal defect.

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.



Summary of safety points relating to the wedge pressure procedure:

- Once the wedging point is found and measurement obtained, always deflate the balloon: DO NOT KEEP IT INFLATED.
- Do not use more than 1.5ml of air to inflate the balloon.
- Avoid prolonged inflation time: keep wedge time to a minimum i.e. 2 respiratory cycles or 10 to 15 seconds.
- Balloon inflation is usually associated with a feeling of resistance. If no resistance is encountered, it should be assumed that the balloon has ruptured. Discontinue attempts to inflate the balloon and inform medical staff immediately.
- Never flush the catheter when the balloon is inflated.

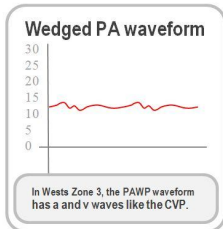
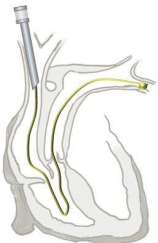
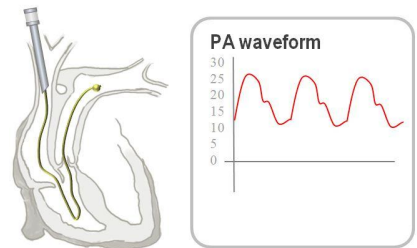
Balloon inflation port:



- Syringe for inflation is connected to the red-coloured line on the PA.
- Syringe is connected to a gate valve to allow for open or closed position.
- After obtaining wedge position, always check that the balloon is completely deflated and that the gate valve is in the closed position.
- On deflating the balloon, always check that the pulmonary artery pressure waveform (see picture below) appears on the monitor screen.
- Always keep the syringe attached to the balloon lumen of the catheter to prevent accidental injection of liquids into the balloon.
- Picture on left demonstrates closed position.



After performing wedge pressure, deflate the balloon and check the correct pressure waveform appears i.e. pulmonary artery pressure waveform (on right). On deflating the balloon, close the gate valve.



After deflating the balloon and closing the gate valve always check that the PA waveform appears on the monitor screen.

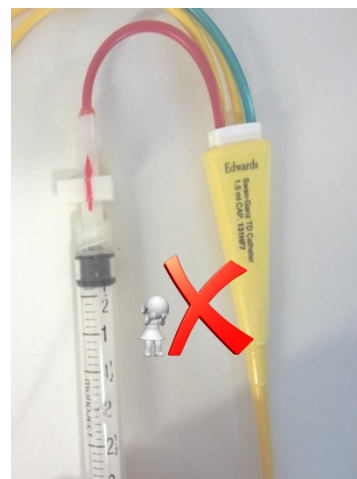
The balloon must be deflated otherwise the wedged waveform (on left) will continue to be displayed on the monitor screen.

NEVER accept this waveform (other than when performing wedge pressure assessment)

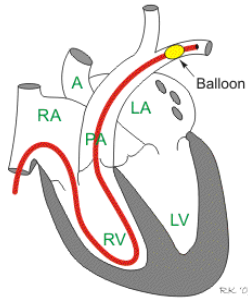
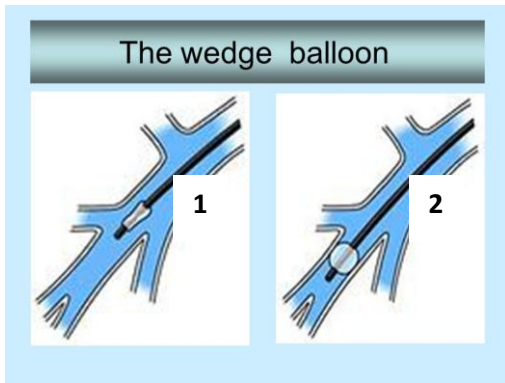


Left: image shows correct position for closing the valve. The balloon must be fully deflated prior to closing the valve.

Right: image shows that the valve has been left in the open position. The valve should only be open for the wedge procedure. The balloon needs to be deflated once the wedge is

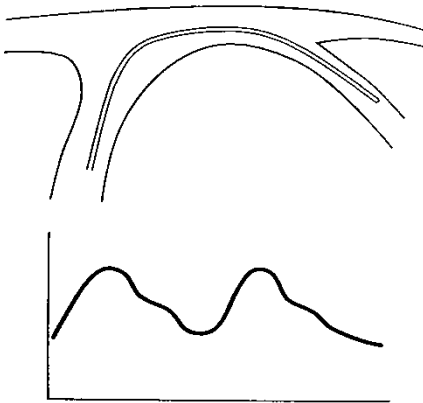


Wedge position and associated problems:

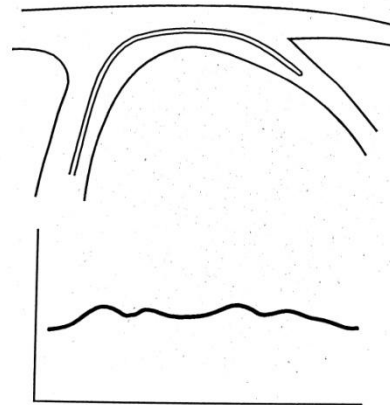


Balloon-tipped, Swan-Ganz catheter for measuring pulmonary capillary wedge pressure (PCWP).

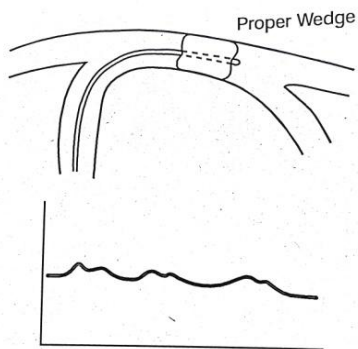
1. Balloon is deflated.
2. Balloon is inflated and wedged into position.
3. Catheter in position with balloon inflated (wedged).



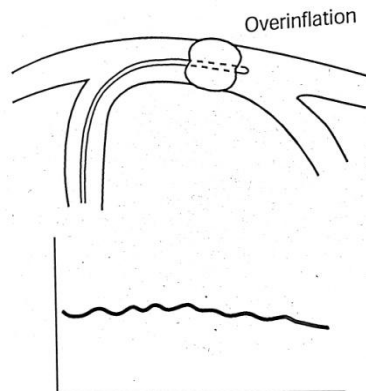
3. Proper PA position



4. Catheter migration



5. Proper wedge



6. Overinflated balloon

Cardiac output measurement and the thermodilution curve:

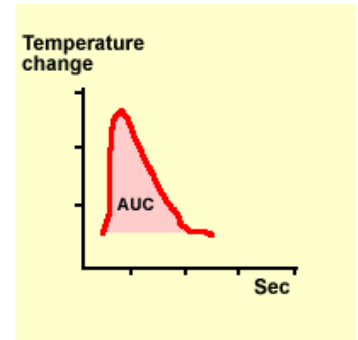
Cardiac output is determined by injecting a 10ml bolus of dextrose 5% into the patient's bloodstream through a Swan Ganz catheter.

A thermistor near the distal end of the catheter senses the change in temperature as the injectate passes the catheter tip located in the pulmonary artery.

A temperature curve is created by the room temperature injectate passing the thermistor, which of course changes its resistance as the temperature changes.

The cardiac output is inversely proportional to the area under the curve (AUC). Therefore, a good cardiac output will produce a curve with a small area. A patient with a poor cardiac output would produce a large area under the curve. This is because the catheter thermistor sees temperature changes over a longer period of time, creating a larger area under the curve.

As you can see by the thermodilution curve below, the upward slope is very steep while the downslope is gradual. This reflects the cold bolus solution passing the thermistor rapidly and the thermistor returning more gradually to the normal core temperature of the blood.



A series of cardiac output trials is initiated:

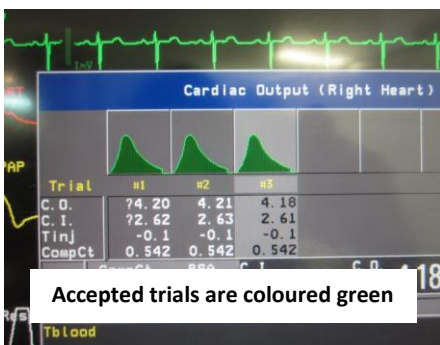
- It is recommended that at least **3 cardiac output measurements** should be made and these are averaged to give a final value.
- The outputs averaged should be within 10% of each other and selected measurements can be rejected (deleted) if they are beyond the range.
- Observation should be made of any recordings with irregular, uneven injection patterns or distorted by artifact.
- The timing of measurements should be varied across the inspiratory and expiratory phase to prevent distortion of data by changes in venous return.



Performing the cardiac output measurements:

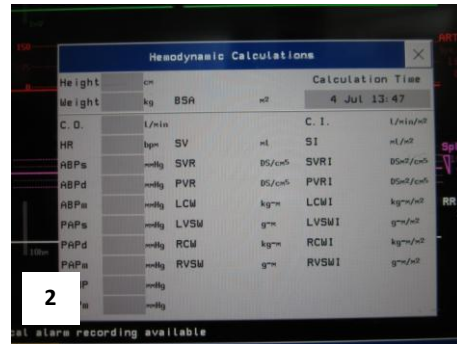
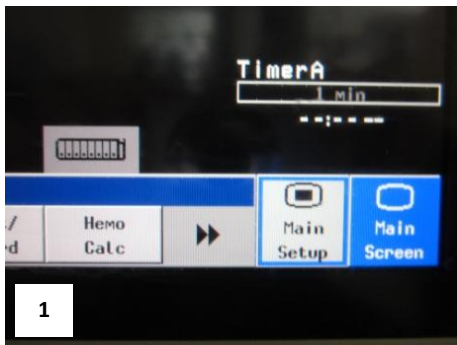
Press the **Main Set-up** key.

- Enter the **CO procedure** window.
- When you see the message **“Ready for new measurement”**, select the pop-up key Start CO. If the measuring mode is set to **Auto** the **Start CO** key will also enable the automatic start of consecutive measurements.
- When you hear a ready tone and see the message **“Inject now!”** draw 10ml of 5% glucose into the CO injectate syringe and inject via the right atrial port (blue) of the PA catheter: good injection technique involves a smooth, consistent injection that’s completed in less than 4 seconds. The resulting temperature curve will indicate whether injection technique was adequately performed. If good technique is used, then the shape of each curve will indicate whether injection technique was adequately performed.
- At the end of the measurement the thermodilution curve, cardiac output, index values and curve alerts (if necessary) are displayed and a message will appear **“Wait before starting new measurement”** or in Auto mode **Prepare for next injection** or press Stop.
- When you see the **“Inject now!”** message, repeat the procedure until you have completed the **three** measurements you want to perform.
- It is important to identify and reject erroneous measurements (called ‘trials’) as the monitor uses all the measurement trial values you do not reject to calculate the averaged cardiac output.
- Review the trials. Irregular trials or trials marked with a **“?”** should be reviewed carefully. Consider the similarity of the values and the shape of the CO curve. A normal CO curve has one smooth peak and returns to the temperature baseline level after the peak.
- Reject unsatisfactory trials: use the **Select Trial** pop-up key to move between trials, the select the **Accept** **Reject** pop-up key to accept or reject trials. Discard conspicuously different values. The background of rejected trials is red and the background of accepted trials is green. The monitor recalculates the average values after you reject or accept trials. If all values are widely different from each other, there may be true haemodynamic instability caused, for example, by severe cardiac arrhythmia. CO values should be within **10%** of each other.
- **Save average CO values** – to close a measurement series, you must save the average values by selecting the pop-up key **Save CO**. This sends the average CO numeric to be displayed on the main screen, and stores the averaged values in the trends and calculations databases.



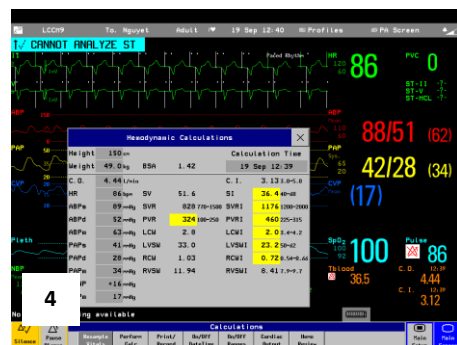
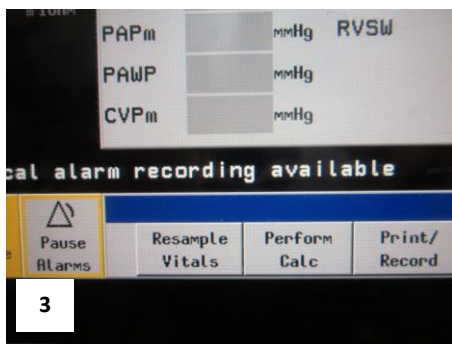
After saving the series of 3 cardiac output measurements, it is now appropriate to check the 'Haemo Calc' screen:

- Press the soft key labelled **"Haemo Calc"** to get into the haemodynamic measurement window: refer to image no.1.
- On pressing the haemo calc key, the task window will display all the parameters: refer to image no.2.
- Ensure that all displayed parameters in the task window are accurate as it can significantly alter the cardiac output studies e.g. check that the current CVP, MAP and wedge values are correctly entered.
- Press **"Perform Calc"** for the monitor to do cardiac output calculations: refer to image no.3.
- The **"Haemo Review"** screen will give a tabular summary of all previous results and can be used for comparison: refer to image no.4
- Close the "Haemo Calc" screen to return to the main screen.
- Remember to record the cardiac output boluses e.g. 30ml on the ICU fluid balance chart.



Haemodynamic calculations:

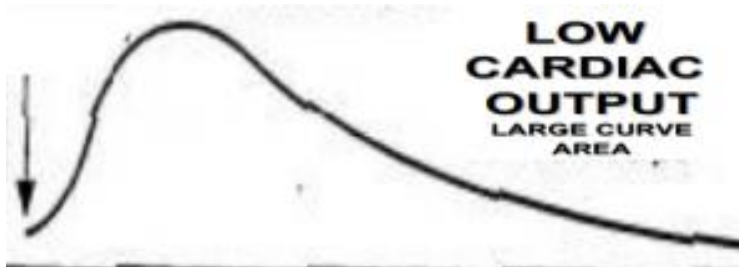
Above: ensure height, weight, CVP, MAP and wedge values are entered.



Ensure height, weight, CVP, MAP and wedge values are entered before pressing PERFORM CALC.

Low cardiac output curve:

The dilution curve below displays a sharp change in temperature at the beginning of the waveform. The gradual downslope and the large area under the thermodilution curve indicate low cardiac output, a result of the cold injectate passing by the thermistor for a longer period of time than with higher cardiac output.



High cardiac output curve:

In the next dilution curve, below, we see the rapid rise at the beginning of the curve, representing the cold injectate passing the thermistor. We then see a steep downslope, which indicates a rapid return of the thermistor to the core blood temperature. This rapidly returning temperature reflects higher blood flow, and thus higher cardiac output.

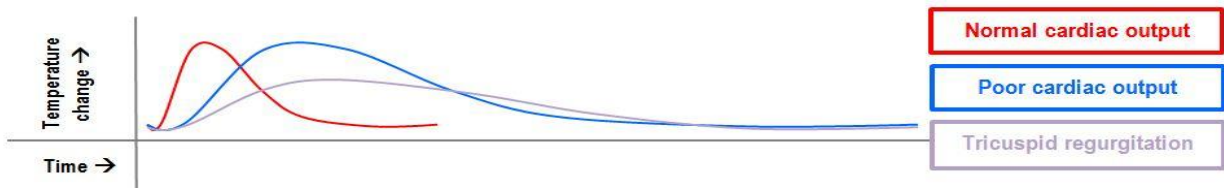


Poor injection technique:

A common problem with cardiac output measurements is improperly administering the injectate. The dilution curve below shows how an improper injection technique may show up on the cardiac output thermodilution curve. The dip in the upward slope indicates a non-continuous injection of the solution. This user error will produce a large area under the curve, but does not necessarily indicate a lower cardiac output or a problem with the heart.

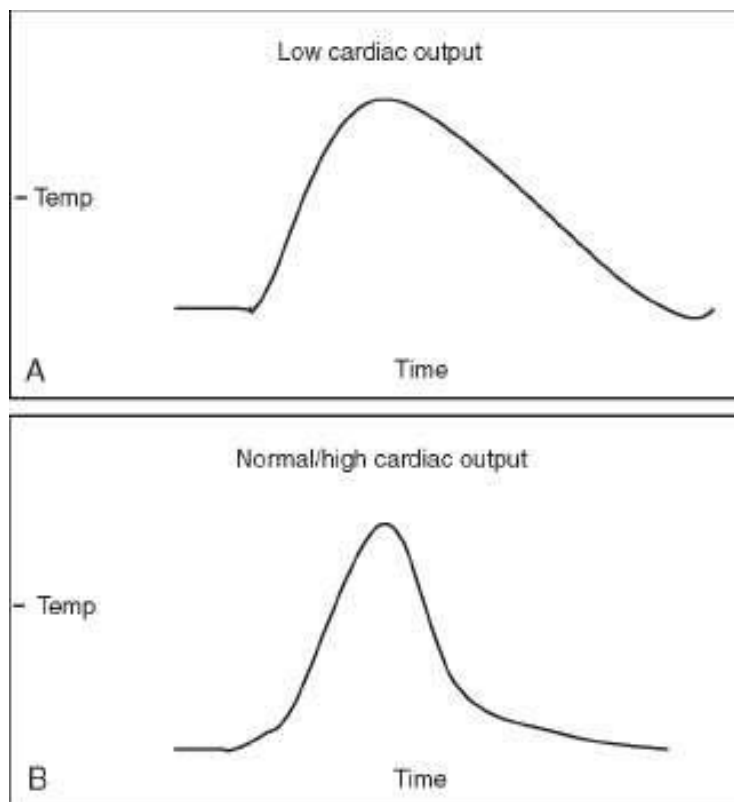


These curves are visibly different in different cardiovascular pathological states:

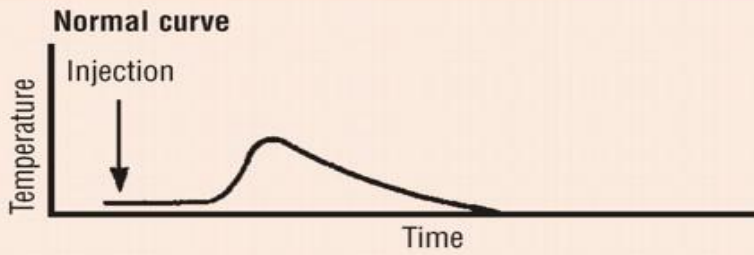


The higher the cardiac output, the faster the blood flow and the shorter and steeper the thermodilution curve. In low cardiac output, the curve is slurred and lazy. Even more so in tricuspid regurgitation.

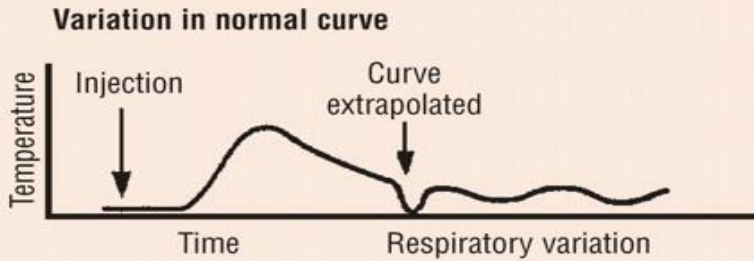
With thermodilution, 10 ml of 5% glucose is injected rapidly via the proximal port into the right atrium. The injectate mixes completely with blood and causes a drop in temperature that is measured continuously by a thermocouple near the catheter tip. The area under the curve is calculated and is inversely related to cardiac output. This method of measurement is not reliable in patients with low cardiac output or significant tricuspid regurgitation.



Area under the curve is inversely proportional to cardiac output. (A) illustration depicts larger area under the curve in patient with low cardiac output. (B) illustration - temperature equilibrates faster in a patient with a higher cardiac output, resulting in a smaller area under the curve.



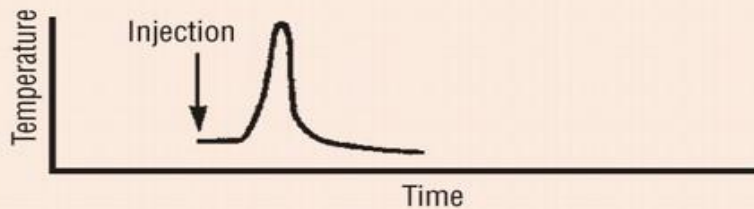
Smooth upstroke to peak, then gradual downstroke to baseline
Computer looks for a smooth curve



Computer extrapolates downstroke to calculate area under curve
Respiratory variation
Increase baseline from recirculation of injectate

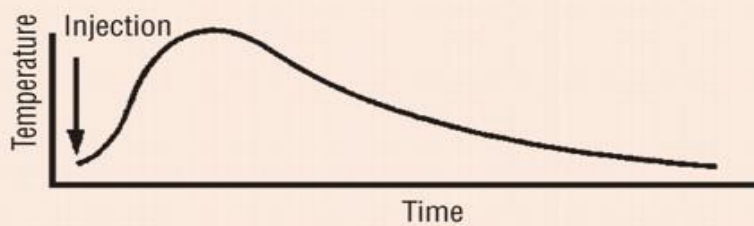
A

Normal high cardiac output



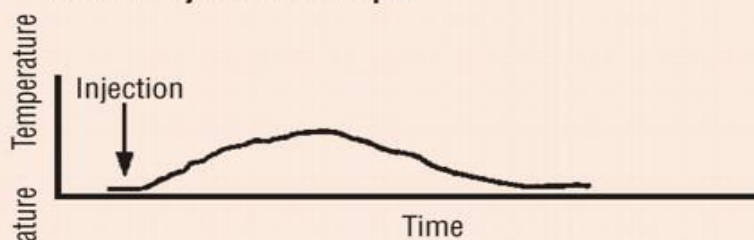
Small area under the curve is typical of a high cardiac output (small change in injectate temperature over time)

Normal low cardiac output



Large area under the curve seen in patients with low cardiac output (greater change in temperature over time)

Uneven injection technique



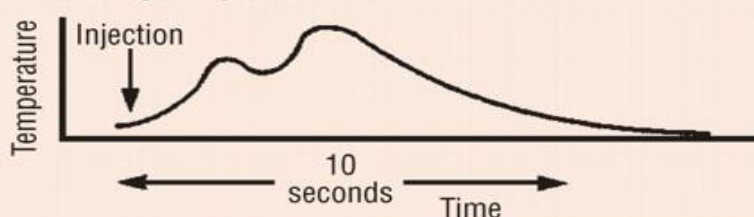
Uneven upstroke on curve



Severe artifact on both upstroke and downstroke of curve

B

Prolonged injection time



Injectate delivered in over 4 seconds

SUMMARY OF PROBLEMS ASSOCIATED WITH MEASURING CARDIAC OUTPUT

Problem	Potential cause	Action
Difficulty injecting solution via proximal lumen.	<ul style="list-style-type: none"> • Proximal lumen occluded or kinked. • Catheter tip against wall of vessel. 	Inform medical staff. Unkink/replace catheter. Reposition catheter.
Blood temperature not displayed.	<ul style="list-style-type: none"> • Faulty thermistor. • Fibrin growth on thermistor. 	Replace catheter.
Injectate temperature not displayed.	<ul style="list-style-type: none"> • Faulty injectate temperature probe. 	Replace probe.
Inappropriately high levels for cardiac output.	<ul style="list-style-type: none"> • Incorrect injectate volume (usually too low or leaking connection). • Injectate temperature too low. • Incorrect computer constant. • Poor injection technique. 	Check correct volume to be used. Check temperature of injectate. Check computer constant. Inject evenly within 4 seconds.
Inappropriately low values for cardiac output.	<ul style="list-style-type: none"> • Incorrect injectate (usually too low or leaking connection). • Injectate temperature too high. • Incorrect computation constant. • Delivery of injectate longer than 4 seconds. • Concomitant infusions at high flow rates (>150ml/hr) through the distal lumen. 	Ensure correct injectate volume. Check temperature of injectate; do not hold barrel of syringe when injecting. Check computer constant. Ensure injection is within 4 seconds. If possible, turn off concomitant infusions during measurements.
Wide discrepancies in serial cardiac output recordings.	<ul style="list-style-type: none"> • Inaccurate amounts of injectate drawn up. • Poor technique (lumen injection). • Arrhythmias (atrial fibrillation or ventricular ectopics). • Valvular disease (tricuspid insufficiency) causing turbulent flow. • Patient moving during recordings. • Malfunction of cardiac computer. 	Exact injectate volume must be drawn up. Inject evenly and within 4 seconds. Observe ECG, avoid injection during arrhythmias. Use alternative method for obtaining cardiac output. Limit patient movement during measurements. Replace cardiac computer.

Complications of PA catheter:

A variety of complications have been reported as a consequence of pulmonary artery catheterisation. Many of these can be avoided or minimised by attentive preparation and care in catheter placement and use.

Balloon rupture –

This can occur because of multiple inflations and deflations over an extended period of time. Even detachment of a portion could become a pulmonary embolus. Rupture can be prevented by careful use of the balloon.

1. Never inflate the balloon with fluid: to prevent unintentional injection of fluid into the balloon, the inflation syringe should always be attached to the balloon port continuously.
2. Stop inflation as soon as a wedge pattern appears on the monitor.
3. Never inflate the balloon above its capacity.
4. Document the air it takes to wedge the catheter. If it is taking more air, the catheter has possibly drifted back to the ventricle. If it is taking less air, there may be forward migration and the potential for a spontaneous wedge position.

Pulmonary infarction –

This is the most common complication, especially if there has been permanent, undetected wedging. Monitor the tip of the PA catheter continuously to identify a spontaneous wedge pattern. This is more likely to occur with catheters that are placed far into the artery > 50 to 55cm in a 70kg person. Document the insertion depth by checking the catheter markings each shift. A chest x-ray may also be needed.

The catheter material softens with body temperature over time, so the catheter tip with the balloon deflated may migrate further into the smaller branches of the PA and into a wedged position.

If at any time a pressure level tracing other than that characteristic of PA pressure is observed, and flushing of the catheter lumen does not eliminate the distortion, the possibility of permanent wedging should be considered and the catheter pulled back 1 to 2 cm or until the characteristic PA tracing reappears.

Under no circumstances should the catheter be left in pulmonary capillary wedge position or pulmonary infarction may occur.

Infection:

Infection at the entry site, in the cannulated vein, or of the endocardium and tricuspid valve may lead to septicaemia or valve dysfunction. Infections arise when catheters are in place for an extended period. The PA catheter should be removed at the earliest opportunity, and ideally within 72 hours.

Pulmonary artery rupture –

Vessel walls can be damaged by balloon overinflation or by the catheter tip. Rupture of a branch of the pulmonary artery in the main bronchus may lead to haemoptysis.

Over-wedging should be carefully avoided: never inflate the balloon beyond the capacity marked on the balloon port (1.5ml in a 7.5 french catheter).

If the syringe that comes with the catheter is lost, replace it with a 1ml syringe only. Never leave the balloon inflated and locked off.

Exsanguination from rupture of the pulmonary artery branch is most likely to occur in patients > 60 years, and in cases of pulmonary hypertension, anticoagulation and cardiopulmonary bypass surgery. The primary causes are distal migration of the catheter tip, over-inflation of the balloon, eccentric inflation of the balloon.

Knotting of the catheter –

Knotting of the catheter in the right ventricle rarely occurs when excess catheter is inserted at the beginning of the procedure. It is more likely in patients with right atrial or right ventricular enlargement and with prolonged insertion time.

During insertion procedure, once the RV is reached the PA should be entered after no more than 15cm. If PA waveforms are not seen or if there is ectopic activity and persistent RV tracings, the catheter is coiling and should be withdrawn and re-inserted. Twisting the catheter along its long axis or stiffening the catheter by injected cold solution may facilitate entry into the PA.

Arrhythmias –

Short episodes of ventricular tachycardia and fibrillation have been reported, and isolated premature ventricular contractions are common: these can occur in up to 30% of passages of the catheter. They can usually be terminated by withdrawing the catheter.

Thrombi –

Thrombi may form around the catheter, presenting the danger of embolism. This is less common because of the heparin coating that the manufacturers put on the catheters. These clots may still occur along the endothelium, endocardium or valves. Thrombus may also develop at the insertion site. If a port is not monitored continuously, aspirate the port first. After aspiration of 1 to 2ml of blood, gently flush the line with a small volume of normal saline. Pneumothorax, haemothorax or fatal air embolus may also occur (rare).

Cardiac valve damage –

Cardiac valves can be severely damaged if the operator withdraws the catheter without deflating the balloon, while in the longer term, valve cusps can be progressively traumatised by repeated closure against the catheter.

Summary of problems associated with PA catheterisation

Problem	Potential cause	Action
Unable to obtain wedge when balloon inflated.	Catheter tip not in correct position Balloon rupture Pulmonary hypertension	Inform medical staff Catheter needs to be advanced. May not obtain wedge, use other readings.
Overwedged trace when balloon is inflated.	Incorrect positioning of catheter: tip is advanced too far and lies in a small vessel.	Inform medical staff. Catheter needs to be pulled back into larger vessel.
Blood in syringe when air is removed from syringe.	Rupture of balloon.	Inform medical staff. Do not attempt to inflate balloon or air embolism may result. Turn off stopcock to syringe. Catheter must be removed.
Spontaneous wedge trace (see when balloon not inflated)	Catheter has migrated into a small vessel.	Inform medical staff. Catheter must be withdrawn until a waveform is seen otherwise there is a risk of pulmonary infarction.
RV waveform instead of a PA trace.	Catheter has slipped back into the right ventricle.	Inform medical staff. Potential for ventricular arrhythmias. Catheter must be repositioned in the pulmonary artery.
Dampened pressure trace.	Loose connections. Catheter tip against vessel wall. Low pressure in pressure bag. Excessive length of tubing from transducer. Air in bubbles or blood in transducer. Fibrin deposition at tip.	Inform medical staff. Check connections are secure. Reposition catheter. Check pressure bag is inflated to 300mmHg. Check transducer: change if necessary. Flush catheter or replace.

PULMONARY ARTERY CATHETER MEASUREMENTS AND WHAT THEY REPRESENT

Parameter	Normal range	Clinical relevance
Central venous pressure (CVP)	2 to 6 mmHg	Used to determine volume status and RV function; correlates with RVEDP
Right ventricular pressure (RVP)	Systolic 15 to 25 mmHg Diastolic 0 to 8 mmHg	Used to determine RV function and volume.
Pulmonary artery pressure (PAP)	Systolic 15 to 25 mmHg Diastolic 8 to 15 mmHg	Used to determine state of resistance in pulmonary vasculature and RV function.
Pulmonary artery wedge pressure (PAWP)	6 to 12 mmHg	Used to determine LV function; correlates with LVEDP.
Stroke volume (SV)	60 to 100ml/beat	Amount of blood ejected during systole; decreased SV indicates ventricular dysfunction.
Cardiac output (CO)	4 to 8l/min	Describes blood flow through tissues; reflects adequacy of overall cardiac function.
Stroke volume index (SVI)	33 to 47 ml/m ² /beat	SV adjusted for patient's BSA.
Cardiac index (CI)	2.5 to 4l/min/m ²	CO adjusted for patient's BSA.
Pulmonary vascular resistance (PVR)	< 200 dynes . sec/m ⁵	Describes state of resistance in pulmonary vasculature.
Systemic vascular resistance (SVR)	800 to 1200 dynes. sec/cm ²	Describes state of resistance in systemic vasculature.
Right ventricular stroke work (RVSW)	8 to 16 gm-m/beat	Describes how hard RV is working to pump blood.
Left ventricular stroke work (LVSW)	58 to 104 gm-m/beat	Describes how hard LV is working to pump blood.
Mixed venous oxygen saturation (SvO ₂)	60 to 80%	Index of oxygenation status that measures the relationship between O ₂ delivery and O ₂ demand; reflects cardiovascular tissue perfusion.

Removal of the pulmonary artery catheter and introducer:

The PA catheter alone can be removed leaving the introducer in situ – check if only the catheter or both are to be removed.

Infusions via the PA catheter should be transferred to the side arm of the introducer, or other infusion sites and any cardiac output equipment should be disconnected.

The procedure is carried out under strict aseptic conditions:

- Assemble equipment – dressing pack, sterile gloves, stitch cutter, occlusive dressing.
- Explain procedure to the patient.
- Lay patient in supine flat position to reduce the risk of air embolism.
- Ensure the balloon is deflated and that a PA waveform is visible on the monitor screen.
- Remove the sleeve adaptor from the introducer sheath.
- Remove the dressing and cut and release sutures.
- Remove the catheter during expiration in the spontaneously breathing patient or time removal with the inspiratory cycle of the ventilated patient: this helps to reduce the risk of air embolism.
- Whilst observing the ECG monitor, gently withdraw the catheter. As the catheter tip passes from the PA to the RA, the characteristic change in waveforms will be seen. Particular observation of the ECG is necessary as the tip passes through the RV. If ventricular arrhythmias occur, continue withdrawing the catheter as these will often terminate once the catheter is removed.
- If there is any difficulty in withdrawing the catheter, discontinue the procedure immediately and inform medical staff. On **no account** should force be used as this resistance may be due to knotting or kinking of the catheter, or it may be caught on a valve or other structure. If the catheter is in the RV and unable to be withdrawn, and ventricular arrhythmias are occurring, consider inflating the balloon and advancing the catheter forward.
- When the PA catheter has been completely removed, a haemostatic valve will close over the entrance in the introducer. This should prevent air entry and escape of blood but can occasionally be damaged by the passing catheter. A sterile occlusive cap should therefore be placed over the exit site.
- If the introducer is no longer required, clean around the site with chloraprep 2%, remove sutures and gently withdraw the introducer. Ensure haemostasis by firm manual pressure over the site before covering with an occlusive dressing. The site should be checked periodically for bleeding.