A practical guide to using pulmonary artery catheters


Summary
This article reviews the physiological principles underlying the use of the pulmonary artery (PA) catheter. The procedure for PA catheter insertion, PA pressure monitoring, PA catheter removal and complications associated with the PA catheter are discussed, as are nursing management of the catheter and nursing care of the patient.

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THE PULMONARY ARTERY (PA) flotation catheter is a specialised central venous catheter that is inserted into the right side of the heart and then ‘floated’ into the PA (Scales 1999). These catheters are also known as flow-directed balloon-tipped PA catheters (Morton et al 2005) and are more commonly referred to as PA catheters.

There are several designs of PA catheter ranging from a simple catheter that measures PA pressure to complex multiple lumen catheters that also measure cardiac output and other variables. PA catheters are usually inserted in critical care environments such as the intensive therapy unit (ITU), coronary care unit (CCU), anaesthetic room or cardiac catheter laboratory where full haemodynamic monitoring is available. PA catheters are inserted into (Morton et al 2005):

› Assess right ventricular function.
› Directly measure PA pressure.
› Indirectly measure left heart pressure by PA occlusion.

› Calculate cardiac output and other variables.
› Use the information gained to aid diagnosis and to assess the effect of cardiovascular interventions.

Pulmonary artery catheters
PA catheters were developed in the early half of the 20th century. Bradley, a British physician, first reported the use of a PA catheter in clinical practice in 1964. Branthwaite and Bradley (1968) described the clinical use of the PA catheter to measure cardiac output by the thermodilution method. Branthwaite and Bradley used a rigid, thermistor-tipped catheter placed in the PA under fluoroscopy and a second injection catheter placed in the right atrium (Steel and Bihari 2000). A breakthrough came when Swan and Ganz developed the multiple lumen, balloon-tipped catheter that could be placed without the use of fluoroscopy (Swan et al 1970).

In recent years, alternative, less invasive, technologies have been developed to measure cardiac output, for example, the oesophageal Doppler, and doubts have been raised about the benefits and safety of PA catheters (Connors et al 1996). A recent randomised controlled trial found no clear evidence of benefit or harm from the use of PA catheters (Harvey et al 2005). The clinical decision to use a PA catheter should be made on a case-by-case basis weighing up the risks and the benefits for each individual patient (Reade and Angus 2006).

A PA flotation catheter has an inflatable balloon incorporated into the distal tip of the catheter, which allows the catheter to float within the bloodstream. The PA catheter is inserted through a central vein. When the tip of the catheter is in the right atrium the balloon is inflated and the catheter ‘floats’ through the tricuspid valve into the right ventricle. The catheter then passes through the pulmonary valve and enters the PA. It is further advanced until the balloon is wedged in a small branch of the PA (Morton et al 2005). The wedged balloon isolates a segment of the pulmonary bed and blood flow in that area ceases (Gomez and Palazzo 1998).
The pulmonary arteries divide to form pulmonary capillaries and these converge to form pulmonary veins which ultimately drain into the left atrium. Once the catheter is wedged there is effectively a static column of blood from the end of the catheter through the pulmonary capillary bed to the left atrium (Gomez and Palazzo 1998). When the mitral valve opens, the column of blood extends to the left ventricle. The distal lumen of the catheter records the pressure in this isolated segment of the pulmonary bed. The pressure recorded is an indirect measurement of the pressure in the left atrium because the pressure from the left side of the heart is transmitted through the capillary bed back to the distal tip of the catheter (Figure 1).

The expression pulmonary capillary wedge pressure (PCWP) is sometimes used in clinical practice to describe the pressure recording obtained when the balloon is inflated. This is a misnomer and the terminology is misleading (Weed 1991). The pulmonary capillaries are not wedged, the ‘downstream’ pressure in the occluded segment of PA equilibrates with pulmonary venous pressure (Wiedemann 1986, Gomez and Palazzo 1998) which is influenced by left atrial and left ventricular pressure.

This technique was described by Swan et al (1970) and a device to catheterise the right side of the heart was commercially marketed as a Swan Ganz catheter. Many devices are available for catheterisation of the right heart and the generic name for this type of device is the PA flotation catheter; it should only be referred to as a Swan Ganz catheter if the branded commercial product is specifically used.

There are several designs of PA catheter (Scales 1999):

- **Simple**: a balloon at the tip and a distal lumen through which pulmonary pressure is measured.
- **Intermediate**: a balloon, a distal lumen and a proximal lumen opening into the right atrium through which central venous pressure can be measured.
- **Complex**: a balloon, distal and proximal lumens, plus a thermistor and electronic connections for cardiac output studies.

Complex catheters can be used to measure PA pressure, pulmonary occlusion pressure, cardiac output and mixed venous oxygenation. Additional variables such as stroke volume, systemic vascular resistance (SVR), pulmonary vascular resistance (PVR), coronary perfusion pressure, oxygen delivery and oxygen uptake can also be calculated (Steel and Bihari 2000). These variables can only be calculated if the catheter is connected to a cardiac output computer or to a cardiac output module that can be inserted into the patient’s haemodynamic monitoring system. The complexity of the catheter selected will depend on the amount of haemodynamic information that is needed and the patient’s clinical condition (Morton et al 2005).

After measuring the PA occlusion pressure (or PA wedge pressure) the balloon must be deflated to restore blood flow to the isolated segment of the pulmonary bed.

Because the PA catheter sits within the heart it is subject to the rhythmical contractions produced by the systolic and diastolic phases of the cardiac cycle, consequently the position of the catheter tip can move. The catheter may need to be repositioned to obtain a wedged pressure. To prevent contamination of the catheter and to allow it to be advanced and withdrawn the catheter is enclosed in a plastic sleeve (Figure 2).

**Insertion procedure**

The internal jugular is usually the preferred site for PA catheter insertion as the subclavian vein is associated with a higher risk of pneumothorax and the femoral vein is a difficult site from which to ‘float’ the catheter (Gomez and Palazzo 1998).
The use of two-dimensional ultrasound is recommended for the placement of central venous catheters in the internal jugular vein (National Institute for Clinical Excellence 2002).

The procedure should be explained to the patient and informed consent obtained wherever possible (Scales 1999). The environment is prepared to ensure that the electrocardiogram (ECG) monitor can be easily observed and resuscitation equipment is readily available. Once the equipment has been assembled (Box 1), the patient is positioned flat or head down in the Trendelenburg position, which increases the pressure within the vein and reduces the risk of air embolism during the insertion procedure (Scales 1999).

The catheter should be inserted under strict asepsis following the epic2 guidelines (Pratt et al 2007):

- Full surgical scrub, sterile gown and gloves.
- Skin antisepsis using 2% chlorhexidine gluconate (unless the patient is allergic to chlorhexidine). Clean the skin for a full minute and allow to air dry.
- Full barrier precautions using large, sterile drapes.

To insert a PA catheter a wide bore percutaneous introducer sheath must first be placed in a central vein. The introducer sheath is often a two-part device composed of a relatively short, wide bore catheter to which a self-sealing diaphragm with side arm is attached (Figure 3).

Once the introducer sheath is in place the clinician flushes all the lumens of the PA catheter with 0.9% sodium chloride to expel air and to reduce the risk of air embolism. The balloon at the tip of the catheter is tested to ensure that it inflates correctly and has no leaks (Morton et al 2005). A self-limiting syringe is provided in the PA catheter kit, which prevents the balloon from being over inflated: the volume limit of the balloon is 1.5ml. The dedicated syringe should be retained and used to inflate the balloon once the catheter is in situ in the PA. Having checked the balloon the air is withdrawn and the sterile plastic sleeve is placed over the catheter. The catheter is then fed through the self-sealing diaphragm of the introducer sheath and the plastic sleeve connected to the introducer sheath to protect the catheter.

The port for the distal lumen of the catheter is connected to transduced haemodynamic monitoring so that the pressure waveforms can be displayed as the catheter passes through the chambers of the right heart and into the PA.

To ensure accuracy of the recordings the haemodynamic monitoring system must be zeroed to atmospheric pressure and levelled with the patient’s right atrium (McGhee and Bridges 2002).
To interpret the waveforms as the PA catheter is directed through the heart, the nurse should be familiar with normal cardiac anatomy and physiology including the normal pressures within the heart and arteries (Figure 4).

With the balloon deflated the PA catheter is advanced through the superior vena cava until it enters the right atrium. A right atrial pressure wave (or central venous pressure) will be displayed on the monitor (Figure 5a).

Once the tip of the catheter is in the right atrium the balloon is inflated and the catheter gently advanced. The air-filled balloon makes the tip of the catheter lightweight and buoyant and the catheter is carried along in the blood flow into the right ventricle. The ECG monitor should be observed as dysrhythmias may occur as the catheter passes through the tricuspid valve. Atrial and ventricular ectopics and salvos of ventricular tachycardia are not uncommon and usually resolve without treatment when catheter manipulation ceases (Iberti et al 1985). The position of the catheter within the right ventricle is confirmed by the change in pressure which is recorded on the monitor (Figure 5b).

The balloon remains inflated and the catheter is further advanced. With gentle manipulation the catheter will turn and float upwards through the pulmonary valve and into the PA. The position in the PA is confirmed by the change in pressure seen on the monitor (Figure 5c).

Once PA pressure has been recorded the catheter is further advanced with the balloon inflated. The PA divides and the branches become progressively smaller. The PA catheter is advanced until the inflated balloon becomes ‘weddged’ in a branch of the PA. This occludes the artery and prevents further blood flow past the catheter. The distal tip of the catheter is now exposed to the pressure in the pulmonary vascular bed, which is continuous with the left side of the heart. The pressure recorded is the pulmonary occlusion pressure or pulmonary wedge pressure and is an indirect measurement of the pressure in the left side of the heart. The wedged position is confirmed by the change in pressure on the monitor (Figure 5d).

After the wedged pressure has been recorded the balloon is deflated and the waveform on the monitor is checked to ensure that the PA pressure is displayed (Morton et al 2005), indicating that blood flow has been restored to the section of the pulmonary bed that had been occluded.

The pressure changes as the catheter is advanced from the right atrium, through the right ventricle, into the PA and finally wedged can be seen in Figure 6.

Once the correct position of the catheter has been confirmed the device should be secured. Traditionally sutures are used to secure central venous catheters but there is growing evidence to suggest that sutures contribute to catheter-related bloodstream infection (Maki and Crnich 2003). Sutureless devices such as StatLock® have been shown to reduce catheter-related bloodstream infection (Crnich and Maki 2002). The entry site should be covered with a sterile transparent dressing to increase security and make inspection of the entry site easier (Royal College of Nursing (RCN) 2005). The proximal end of the plastic sheath should be locked onto the PA catheter to ensure that the catheter does not become dislodged and to maintain the sterility of the catheter within the sheath. The nurse should note the position of the PA catheter by reading the catheter depth.
should also be recorded if the nurse has been trained to do so. Before recording the PA wedge pressure the nurse should ensure that the transducers have been zeroed to atmosphere and levelled to the patient’s right atrium (Morton et al 2005). The position of the patient should be consistent with previous recordings.

The PA balloon should be inflated gently while observing the monitor. When the waveform changes from the pulsatile PA pressure with clear systolic and diastolic values to a waveform that is similar to a central venous pressure waveform, the PA catheter is considered to be wedged successfully. The mean value is recorded. The balloon is deflated and the nurse must check to ensure that a pulsatile PA pressure wave is again displayed on the monitor. There is usually a gate device or a tap on the balloon lumen of the PA catheter and it is standard practice to close the lumen after the balloon has been allowed to deflate. This prevents accidental inflation of the balloon. If the nurse has not been trained to perform wedge pressures, this haemodynamic indicator will only be recorded intermittently when a member of the medical team performs the procedure.

Complications of pulmonary artery catheter insertion

Complications of PA catheter insertion include arterial puncture, pneumothorax, air embolism and infection, which are general complications of central venous catheter insertion (Scales 1999). The post-insertion chest X-ray will reveal or exclude the presence of a pneumothorax.

Dysrhythmias are commonly associated with PA catheter insertion because the catheter passes through the heart. While most dysrhythmias resolve spontaneously, 1-3% of dysrhythmias require treatment (Boyd et al 1983).

PA rupture is an important and often fatal complication and is associated with over inflation of the PA balloon (Hardy et al 1993), but can also be caused by erosion of the wall of the PA (Gomez and Palazzo 1998). PA rupture is more common in patients with pulmonary hypertension, patients on anticoagulants and patients aged over 60 years (Hardy et al 1993).

The PA catheter can become accidentally wedged, without balloon inflation, due to the forward movement of the catheter into a narrower section of artery. Distal (forward) migration of the PA catheter occurs in approximately 1% of patients and may result in pulmonary infarction if not recognised (Boyd et al 1983). This may also occur when patients are repositioned. If a wedged waveform can be achieved using less than 1 ml of air to inflate the balloon it is likely that the catheter has migrated
from the correct position (Morton et al. 2005). The nurse should routinely observe the PA waveform on the monitor, particularly when the patient is repositioned, and should be able to recognise the wedged trace and take action to rectify the problem (Scales 1999). In some ITUs nurses who have been trained to use PA catheters will manipulate the catheter into a safe position, in other units this will be a medical responsibility.

Pulmonary artery catheter removal

When the PA catheter is no longer required it should be removed (RCN 2005). Removal of the PA catheter is similar to removal of other central venous catheters, however, the catheter is significantly longer and less easy to handle. It is necessary to place the catheter on a surface when it has been removed such as a disposable, absorbent waterproof sheet (Scales 1999).

Before removal of the PA catheter the nurse must check that the balloon is completely deflated. Significant damage could occur to the pulmonary and tricuspid valves if the catheter is withdrawn with the balloon inflated (Scales 1999). The catheter is withdrawn through the right ventricle and it is important to remember that the ventricle contains papillary muscles which are connected to the tricuspid valve by chordae tendineae. There are reports of PA catheters becoming entangled in the chordae tendineae leading to chordae rupture (Arnaout et al. 2001) and of catheters becoming knotted around the chordae (Tremblay et al. 1992, Ismail et al. 1998). If resistance is felt during the removal of a PA catheter the procedure should be stopped and medical advice sought.

Ideally the introducer sheath should be removed at the same time as the PA catheter. Introducer sheaths are wide-bore devices that carry a significant risk of air embolism and haemorrhage and should not be left in situ as routine vascular access (Darovic 2002).

The procedure for removal of a PA catheter is outlined in Box 2.

Dysrhythmias may occur as the PA catheter is removed. Atrial ectopics, ventricular ectopics and small runs of ventricular tachycardia are not uncommon. If dysrhythmias occur it is prudent to continue to remove the catheter rather than stopping, which may risk leaving the catheter tip positioned in a valve, thus causing further and more severe dysrhythmias (Scales 1999). If dysrhythmias persist after the catheter has been removed from the heart, medical assistance should be sought immediately.

If catheter-related bloodstream infection is suspected the tip of the catheter should be sent to microbiology to be cultured. If this is required the catheter must be placed on a sterile surface when it has been removed. The tip should be cut off using sterile scissors and the tip placed in a sterile specimen container which should be labelled with the patient’s details.

Conclusion

PA catheters have provided valuable haemodynamic information for more than 40 years, however, they are not without...
complications and the benefit of the information obtained should be balanced against the risks of their use. Alternative methods of cardiac output assessment have been developed and many units prefer to use less invasive methods such as the oesophageal Doppler to measure cardiac output, although most units have at least two methods of cardiac output measurement at their disposal (Esdaile and Raobaikady 2005). Management of the PA catheter and performance of haemodynamic measurements are important aspects of the care of critically ill patients. Interpretation of PA occlusion pressure requires experience and an understanding of the clinical situations that can induce errors in interpretation (Steel and Bihari 2000). To expand practice to include PA catheter management it is essential that nurses have a thorough knowledge of cardiac anatomy and physiology as well as a practical understanding of haemodynamic monitoring to care safely for the patient NS

References


