Monitoring arterial, central venous and pulmonary capillary wedge pressure

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Abstract

Arterial blood pressure can be monitored non-invasively by mercury manometer, automated oscillotonometer or continuously by a Finapres based on the Penaz technique. Insertion of a cannula into an artery allows continuous beat-to-beat blood pressure monitoring with pressure transmitted along a column of saline to a piezo-resistive strain gauge transducer. Continuously monitoring blood pressure aids optimization of adequate organ perfusion and further information gained from the waveform can be used to guide treatments. Central venous pressure is the pressure within the right atrium and great veins of the thorax. In a healthy adult, it is between 0 and 8 cm H_2O, varying with respiration. It is measured via a cannula inserted into the superior vena cava (usually via internal jugular or subclavian veins) and uses a pressurized transducer set to produce a reading of central venous pressure and venous waveform. Venous bloods and central venous gases can also be taken and drugs and infusions (particularly if irritant) can be administered. Serial readings are useful for assessing progress and response to treatment. Pulmonary capillary wedge pressure represents left atrial filling pressure and therefore left ventricular end-diastolic pressure and allows more accurate assessment of left-sided heart function. It is measured by floating a pulmonary artery catheter and wedging a balloon into a pulmonary artery branch. It has a complication rate of 10% and, as studies have shown it to have no clear evidence of benefit, alternative less invasive methods such as oesophageal Doppler or arterial pulse contour analysis are now common alternatives.

Keywords arterial blood pressure; central venous catheter; central venous pressure; oscillotonometer; pulmonary artery catheter; pulmonary capillary wedge pressure

Monitoring arterial, central venous and pulmonary capillary wedge pressures provides information regarding a patient's cardiovascular status that allows clinicians to monitor anaesthetized and critically ill patients. Each can be used in isolation or in combination to guide treatments and review responses to interventions.

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Arterial blood pressure

Maintenance of organ perfusion pressure in seriously ill and anaesthetized patients in whom autoregulation is impaired is essential. This can be undertaken using non-invasive methods. However, for those experiencing or at risk of cardiovascular instability and inadequate organ perfusion (Table 1), direct continuous arterial pressure monitoring showing beat-to-beat variation should be employed.

Indirect non-continuous methods of arterial pressure measurement

The simplest method of measuring blood pressure is by a mercury manometer or aneroid gauge system whereby a cuff around the upper arm is inflated to cease distal blood flow and then deflated slowly. The systolic blood pressure is the pressure at which the radial pulse returns on palpation or when flow is heard to return on auscultation over the brachial artery (first-phase Korotkoff sound), and diastolic pressure is when all sound is lost (fifth-phase Korotkoff sound). In practice, these methods are rarely used owing to concerns over the environmental and safety implications of mercury and the significant errors occurring in both zeroing and calibration of aneroid gauges.[1]

The standard non-invasive blood pressure measurement method in current clinical practice is the automated oscillometric technique. A single pneumatic cuff is used to apply pressure to the upper arm (25–30 mm Hg above previous systolic pressure) and ablate arterial blood flow. The pressure is reduced via a bleed valve at a rate of 2–3 mm Hg per second and, as blood flow returns, vibrations of the arterial wall cause oscillations of pressure to occur in the cuff that are sensed by a processing unit. The onset of rapidly increasing oscillations represents systolic blood pressure, with the point of maximal oscillation being the mean pressure. The diastolic pressure is taken as the onset of rapidly decreasing oscillations or can be calculated (mean arterial pressure (MAP) = diastolic + 1/3 pulse pressure). The readings can then be displayed electronically. Readings can be taken as a one-off snapshot or can be set to automatically read at set time intervals. The portability and ease of use of this technique with

Indications for direct continuous arterial pressure monitoring

- Patients at risk of rapidly changing cardiovascular physiology
  - Major surgery, including vascular clamping, cardiopulmonary bypass
  - Inotropic support (e.g. in sepsis, ventricular dysfunction)
  - Haemorrhage (or potential)
  - Cardiac arrhythmias (or potential)
  - Hypotensive anaesthesia
- Patients requiring respiratory support and frequent blood gas monitoring
- Patients requiring multiple/frequent blood tests

Table 1

minimal skill or training make it very popular. However, the technique is inaccurate in certain conditions. These include patients with arrhythmias, owing to the lack of regular pulse, or those with pre-eclampsia, owing to changes in the vascular system. They are less accurate at extremes of blood pressure. It also relies on an appropriately sized cuff, which should be 20% greater than the diameter of the arm with large cuffs under-reading and small cuffs over-reading. Potential complications include nerve entrapment[2] and petechial haemorrhages from repeated inflations.

Indirect continuous arterial blood pressure measurement

The Finapres (*fin*ger *a*rterial *pres*sure) is a continuous non-invasive blood pressure monitor based on a technique described by the Czech physiologist Penaz in 1973. Infrared plethysmography is used to measure the volume of blood in the digital artery. A pneumatic finger cuff is then pressurized to maintain a constant digital artery diameter and therefore plethysmograph reading via a rapid servo-controlled system. This transducer pressure gives a continuous arterial pressure trace that can be digitally displayed. The Finapres is mainly used as a research tool and is rarely used in clinical practice as it needs frequent calibration because of tissue fluid relocation, it eventually causes discomfort and it can be unreliable in certain patient groups (e.g. those with peripheral vascular disease).

Direct methods of arterial blood pressure measurement

Inserting a cannula directly into an artery allows the arterial blood pressure to be measured by transmitting the pressure along a column of fluid to a pressure transducer. Normal saline (0.9%) is pressurized to 300 mm Hg and non-compliant extension tubing is connected to the arterial cannula via a drip chamber that allows flow at 3–4 ml/h to prevent thrombus formation and can also be used to flush the system when required. Although evidence regarding the use of heparinized or plain 0.9% normal saline is inconclusive to date,[3] most centres now use plain 0.9% saline as flush fluid. The arterial pressure is transmitted via the column of saline to the chamber-mounted pressure transducer across a flexible colloid gel membrane. The transducer uses a piezo-resistive strain gauge in a Wheatstone bridge circuit to convert the arterial pressure into an electrical signal that can then be amplified, processed and displayed.

In order to obtain accurate pressure readings, the pressure of the saline at the transducer must be the same as the arterial pressure. This requires the transducer to be aligned at the same level as either the catheter tip or, more commonly, the level of the right atrium in order to approximate aortic pressure. An error in transducer level of 1.36 cm above or below the reference level produces a pressure error of 1 mm Hg. Also, any restriction in transmission such as an air bubble or very compliant tubing, which absorbs pressure changes, or a blood clot, which restricts fluid movements, will cause a damping of the trace and therefore underestimate systolic pressures and overestimate diastolic pressures (Figure 1). The optimal damping coefficient for the system is 0.64.

Although the aim is to measure the static pressure acting on the vessel wall, there is also a kinetic head of pressure formed by the blood flowing into the arterial cannula. This is related to the square of the blood velocity and will result in a potential overestimation of blood pressure. It could be overcome by placing the cannula perpendicular to the artery, but this would be clinically impractical.

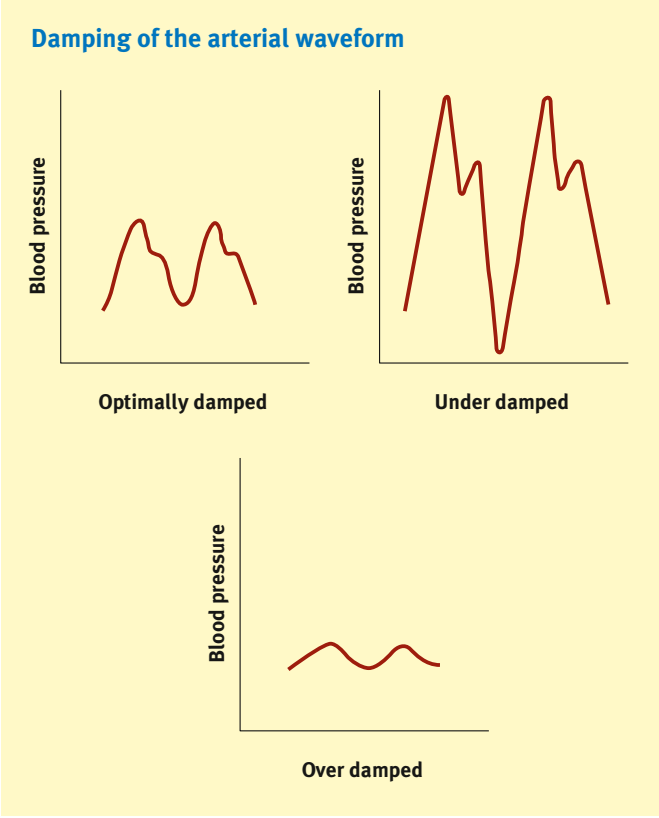

Figure 1

A further potential source of error is resonance within the system. All systems have a tendency to oscillate maximally at a particular frequency (known as the resonant frequency), such as the acoustic resonance of musical instruments. If the resonant frequency of the transduction system falls within the arterial pressure waveform (fundamentally 3–5 Hz but may reach 20 Hz) then oscillations will occur distorting the arterial waveform. In order to prevent this, it is necessary to use a shorter, wider or stiffer catheter to increase the resonant frequency to greater than 40 Hz.

Catheter placement: arterial cannulae should be placed under aseptic conditions in a site that is easily accessible for insertion, sampling, observation and troubleshooting. Most commonly, the radial artery is used following an Allen's test to ensure appropriate collateral circulation.[4] Generalized complications apply to all sites (Table 2). Other potential sites tend to be avoided where possible due to their specific problems; femoral (poor access, tendency to kinking, increased chance of infection), brachial (end artery, over a frequently flexed joint), dorsalis pedis (modified wave pattern, absent in 12% of population), ulnar (supplies 95% of blood supply to the hand).

Information from arterial pressure waveform: detailed examination of the arterial pressure waveform (Figure 2) can provide more information than simply systolic, diastolic and mean pressures. The rate of rise of the upstroke reflects myocardial contractility (gradient a in Figure 2), with the maximal rate of rise related to the speed of ventricular ejection. This can, therefore, be used to guide use of, and assess response to, inotropes. The dicrotic notch is formed as a result of the changes in pressure caused by closure