INVASIVE BLOOD PRESSURE MONITORING

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Introduction
Invasive (intra-arterial) blood pressure (IBP) monitoring is a commonly used technique in the Intensive Care Unit (ICU) and is also often used in the operating theatre. The technique involves the insertion of a catheter into a suitable artery and then displaying the measured pressure wave on a monitor. The most common reason for using intra-arterial blood pressure monitoring is to gain a 'beat-to-beat' record of a patient's blood pressure.

Advantages of IBP monitoring
- Continuous 'beat-to-beat' blood pressure monitoring is useful in patients who are likely to display sudden changes in blood pressure (e.g. vascular surgery), in whom close control of blood pressure is required (e.g. head injured patients), or in patients receiving drugs to maintain the blood pressure (e.g. patients receiving inotropes such as epinephrine).
- The technique allows accurate blood pressure readings at low pressures, for example in shocked patients.
- The trauma of repeated cuff inflations is avoided in patients who are likely to need close blood pressure monitoring for a long period of time e.g. ICU patients.
- Intravascular volume status can be estimated from the shape of the arterial pressure trace, either by eye or by waveform analysis by a specific device e.g. a pulse contour analysis system.
- IBP measurement allows accurate assessment of blood pressure in certain patients not suitable for non-invasive blood pressure monitoring, e.g. patients with gross peripheral oedema in ICU or morbidly obese patients.
- The indwelling arterial cannula is convenient for repeated arterial blood sampling, for instance for arterial blood gases. This is not usually the sole reason for insertion of an indwelling arterial catheter.

Disadvantages of IBP monitoring
- The arterial cannula is a potential focus of infection, although arterial lines become infected far less frequently than venous lines, especially central venous lines.
- The arterial catheter can lead to local thrombosis which may result in emboli travelling down the limb or occasionally arterial occlusion – this is rare if the catheter is kept flushed with saline and an appropriate vessel is chosen. The radial, femoral and axillary arteries are commonly used, as are the arteries of the foot, the posterior tibial and dorsalis pedis arteries. Where possible, the brachial artery should be avoided as this is an end artery and has no collateral supply – occlusion of the brachial artery will result in loss of blood supply to the arm.
- Any drug inadvertently administered into the arterial line may form crystals and cause catastrophic ischaemia of the limb. Examples of drugs with which this has been reported are thiopentone and antibiotics. All arterial lines should be clearly labelled and the tubing colour coded (usually with a red stripe) to avoid confusion and drugs should **never** be administered via the arterial line.
- The insertion of an intra-arterial blood pressure monitoring system can be difficult and time consuming, especially in shocked patients. This can potentially distract from other problems that need more urgent attention.
- The monitoring equipment, spare parts and cannulae are expensive when compared to non invasive methods of blood pressure monitoring.
- The arterial monitor requires an electrical supply which will limit its usefulness in some settings.

Components and principles of IBP monitoring
The components of an intra-arterial monitoring system can be considered in three main parts (see Figure 1):

1. the measuring apparatus
2. the transducer
3. the monitor

The measuring apparatus
The measuring apparatus consists of an arterial cannula (20G in adults and 22G in children) connected to tubing containing a continuous column of saline which conducts the pressure wave to the transducer. The arterial line is also connected to a flushing system consisting of a 500ml bag of saline pressurised to 300 mmHg via a flushing device. Formerly 500IU heparin was added to this fluid, but many centres now consider this to be unnecessary. The flush system provides a slow but continual flushing of the system at a rate of approximately 4-5ml per hour. A rapid flush can be delivered by manually opening the flush valve. There is also usually a 3-way tap to allow for arterial blood

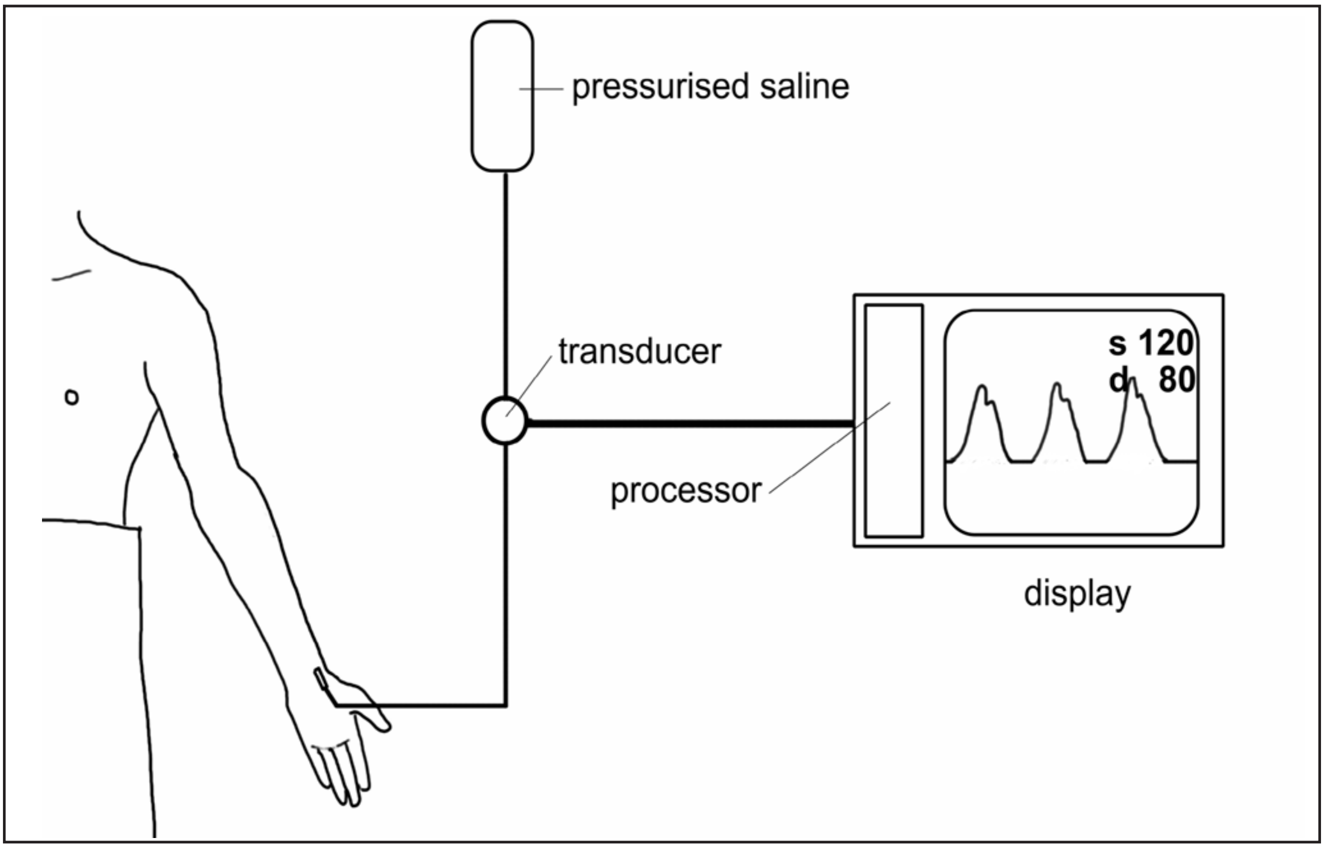


Figure 1: Components of an arterial monitoring system

sampling and the ejection of air from the system if necessary. The three-way tap must also be **clearly labelled** as arterial, to minimise the risk of inadvertent intra-arterial injection of drugs. For small children a smaller volume of flush is administered via a syringe driver, so that it is not possible to over-administer fluid by repeated flushing of the arterial cannula.

The transducer
A transducer is any device that converts one form of energy to another – for example, the larynx is a type of physiological transducer (air flow is converted to sound). The output of transducers is usually in the form of electrical energy. In the case of intra-arterial monitoring the transducer consists of a flexible diaphragm with an electric current applied across it. As pressure is applied to the diaphragm it stretches and its resistance changes, altering the electrical output from the system. The transducers used are differential pressure transducers and so must be calibrated relative to atmospheric pressure before use.

The monitor
It is not necessary for the anaesthetist to have an in-depth understanding of the internal workings of the monitor. Modern monitors **amplify** the input signal; amplification makes the signal stronger. They also **filter** the 'noise' from the signal – unwanted background signal is removed with an electronic filter - and display the arterial waveform in 'real time' on a screen. They also give a digital display of systolic, diastolic and mean blood pressure (see figure 2). Most monitors incorporate various safety features such as high and low mean blood pressure alarms and tachycardia and bradycardia alerts.

Accuracy of IBP monitoring
The accuracy of intra-arterial monitoring is affected by several important physical principles - the *oscillation, natural frequency, damping* and *resonance* of the system

Oscillation
A swinging pendulum is an example of a system that oscillates. When a pendulum is pushed (energy is put into the system), it moves away from its resting position, then returns to it. The resting position for a pendulum is at the bottom of its arc of swing and is dictated by gravity. However, the pendulum doesn't usually just return to the resting position, but tends to overshoot, swinging past the resting point in the opposite direction to the original push. This cycle continues until all the energy put into the system has been dissipated. The tendency of a system to move either side of set point is referred to as its tendency to **oscillate**.

Damping
Imagine you have two identical pendulums. One has recently been well greased at its point of rotation (fulcrum) and the other is stiff from rust. When an equal sized force is applied to each, the well greased one will oscillate freely around the set point but the

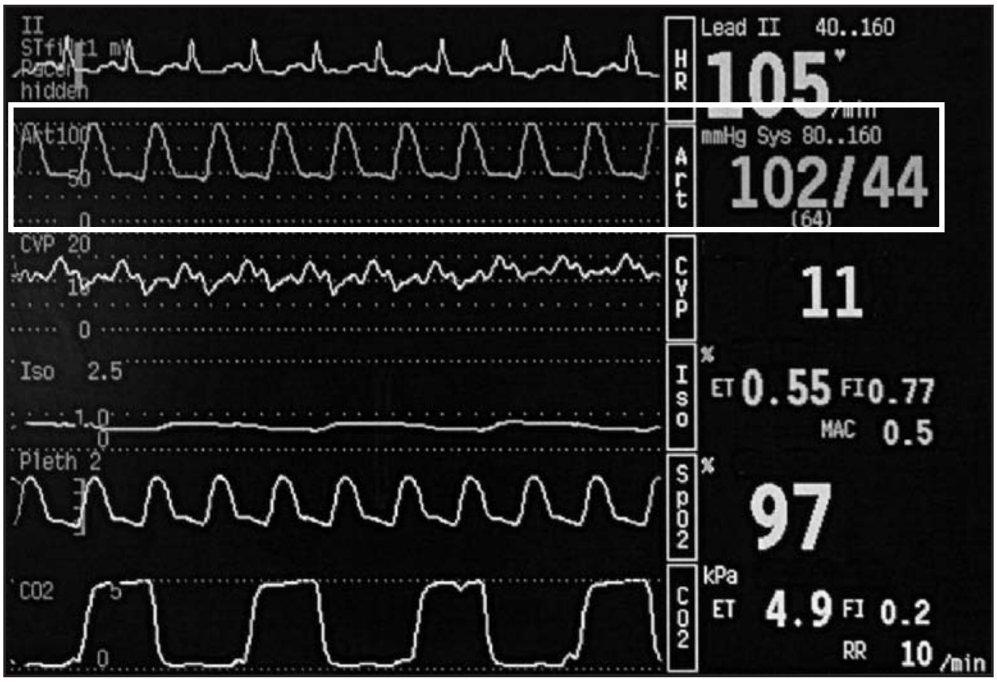


Figure 2: Invasive blood pressure monitoring (boxed). The waveforms are usually colour coded (red for the arterial trace) and the monitor displays the systolic/diastolic BP, with the mean arterial BP in brackets below.

old rusty pendulum may barely move. This is because much of the energy put into the system will be used up or 'damped' in overcoming the frictional force of the rusty axis. The rusty pendulum will tend to oscillate at smaller amplitude (i.e smaller swings) and for a shorter period of time than the well greased one. How freely a system oscillates following an input of energy is dependant on the degree of **damping** in the system.

A 'well damped' system tends not to oscillate freely whereas a 'poorly damped' system may oscillate wildly. The amount of damping inherent in a system can be described by the **damping coefficient (D)** which usually lies between 0 and 1 (but can be greater than 1). A system with a D value greater than 1 describes a system that is over-damped, will not oscillate freely, that takes a long time to initially move away from and to return to its resting point, but does not oscillate (a high friction pendulum). A D value less than 1 and approaching 0 describes a system that is under-damped, that oscillates freely, moving rapidly away from its resting point and back again, but tends to overshoot and then oscillate around the resting point (a low friction pendulum). A D value of exactly 1 is known as **critical damping.**

Oscillations are un-desirable in physiological measuring systems. These systems require accurate measurement of a maximum amplitude (for instance, that caused by the arterial pulsation, the systolic blood pressure), with a rapid response time and rapid return to the set point, ready for the next measurement. The ideal level of damping applied to a measuring system is a compromise between achieving a rapid response time and accurate reflection of maximum amplitude by designing a system with D close to 0, and needing a system that returns to the resting point without excess oscillation (D around 1). In the case of an IBP monitoring system this would represent the difference between using very compliant measuring apparatus (compliant catheters, tubing) i.e. D approaches 0, and very stiff or non-compliant equipment i.e. D is closer to 1. The value of D chosen for physiological measuring systems such as IBP monitoring equipment lies between 0.6 and 0.7 – it is known as **optimal damping** (see Figure 3).

Natural frequency and resonance

A pendulum of set length and with a set weight at the end will always oscillate at exactly the same frequency, no matter what the initial starting point of the oscillation. In other words, whether you give the pendulum a small push or a really hard shove it will make the same number of oscillations per unit time (although the amplitude of the oscillations will differ). This is why pendulums can be used to keep time. Any system such as this will have a frequency at which it 'naturally' oscillates. This frequency is known as the **natural frequency**.

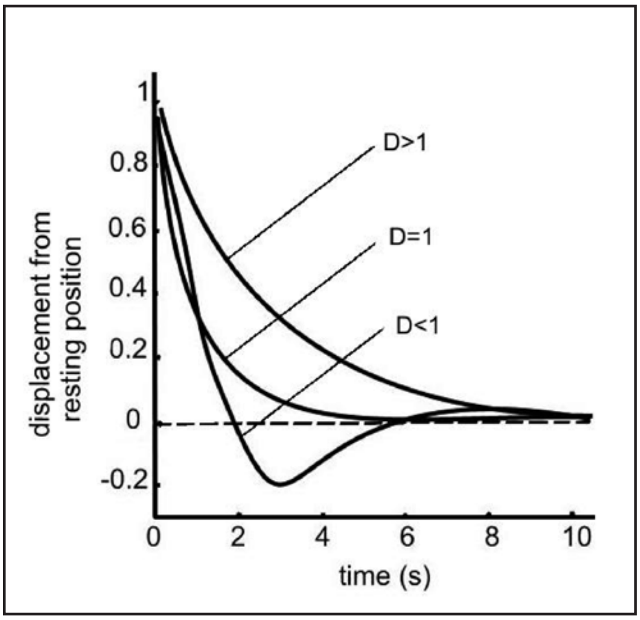


Figure 3: Graph showing the effect of different levels of damping on the oscillation of a measuring system

If the input of energy into a system is occurring at the same frequency (or close to) the natural frequency, a phenomenon called **resonance** occurs and the output amplitude of the oscillations is greatly magnified. In the case of intra-arterial blood pressure monitoring this could lead to over-reading of the systolic blood pressure. Arterial pulsation is a complex sine wave and is composed of many individual sine waves. It is therefore important that the natural frequency of the measuring equipment (the catheter and column of saline etc) does not correspond to any of the component frequencies of the arterial pulsation input. This is achieved by making sure that the natural frequency of the measuring system is raised above any of the component frequencies of the arterial sine waveform.

The characteristics of the measuring equipment that will ensure that the natural frequency of the system is higher than that of the arterial pulsation are:

- Arterial catheter must be short and with the maximum gauge possible
- Column of saline must be as short as possible
- The catheter and tubing must be stiff walled
- The transducer diaphragm must be a rigid as possible

Setting up the arterial line and trouble shooting

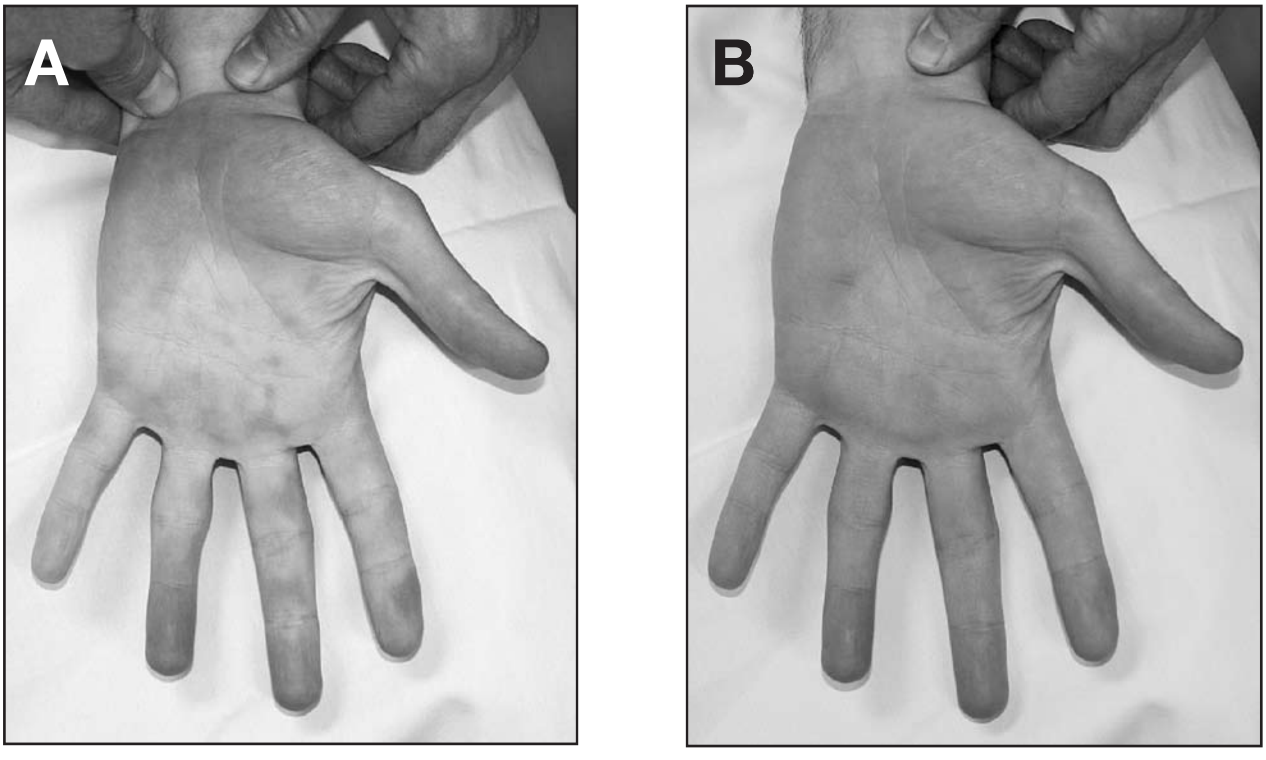
The usual location for insertion of the arterial catheter is the radial artery. The advantage of the radial artery is that it is superficial, easily accessible, and there is a collateral blood supply to the hand from the ulnar artery. It is advisable to perform **Allen's test** to detect adequacy of collateral supply to the hand via the ulnar artery, although the test is not infallible and can only be performed in conscious patients (see figure 4).

The brachial artery should be avoided if at all possible (no collateral supply); the femoral artery, the ulnar artery, arteries of the foot and ankle, and even the axillary artery should be used in preference if necessary. Whichever location of artery is used, the distal limb should be monitored regularly for signs of emboli or distal ischaemia.

Insertion of a radial arterial line

This should be performed as an aseptic technique. The wrist should be cleaned with alcoholic chlorhexidine solution prior to cannulation and in conscious patients the skin should be infiltrated with 1% plain lignocaine. The arm should be abducted in the anatomical position and the wrist should be hyper-extended to aid cannulation (the radial artery is brought closer to the skin surface and the hand moved out of the way). This is most conveniently done by an assistant. If an assistant is not available use tape to secure the patients hand fingers extended over a bag of fluid (see figure 5).

There are various types of stiff, short arterial catheter available. Some feature a simple cannula over needle design similar to an intravenous cannula and some incorporate a guide-wire as part of a Seldinger technique – the needle is inserted, a wire passed through the centre if the needle, the cannula threaded over the wire. The correct cannula to use is the type



Figures 4A and 4B: Allen's test. Ask the patient to make a fist, use your thumbs to occlude the patient's radial and ulnar arteries. Ask the patient to unclench their fist – the palm will remain pale (A), whilst the blood supply is still occluded. When you remove the thumb that is occluding the ulnar artery, the palm will flush red if the ulnar artery is functional (B).

Figure 5: A technique for securing the patient's wrist extended using adhesive tape and a fluid bag.

with which you are most comfortable. Ideally a cannula with injection port should not be used as this may be confused with an intravenous cannula - if such a cannula is used, the injection port should be taped over and the cannula clearly labelled as arterial.

The usual insertion technique is to palpate the artery with the fingers of one hand and locate the artery with the cannula at an angle of about 30 degrees (figure 6A). For practical reasons the catheters are inserted against the flow of blood. Once a 'flashback' has been obtained the cannula should be brought level with the skin and then advanced 2-3mm further (figure 6B). This should ensure that the entire tip of the cannula, rather than just the needle is within the arterial lumen. At this stage either the cannula can be advanced over the needle or the guide-wire introduced. Make sure that you tape the cannula securely in position, and take care not to kink the cannula as you do so. Sometimes it is advisable to suture the arterial line in place.

The arterial catheter should be connected to the tubing, the transducer secured in a position approximately level with the heart and transducer 'zeroed' - that is, closed to the patient and opened to atmosphere to obtain a reading of atmospheric pressure. It is often convenient to tape the transducer to the patient's upper arm to ensure it is level with the heart.

Practical Tips and Trouble Shooting

- The radial artery is very superficial at the wrist. Often when you think you can't find it, you have in fact transfixed it (a technique some people use preferentially). Remove the needle and then slowly withdraw the cannula, aspirating using a 5ml syringe attached to the hub all the time. As the tip of the cannula re-enters the artery, blood will flow into the syringe briskly. From this point slowly advance the cannula whilst rotating the cannula in a twisting motion about its long axis. This technique will salvage the cannulation more often than not.
- If you hit the artery but fail to cannulate it a couple of times, it is often wise to move to the other wrist; the artery will go into spasm following repeated trauma making cannulation progressively more difficult.
- Inserting an arterial catheter in shocked patients is very difficult. Do not waste time making repeated attempts to do so; resuscitation of the patient is more important!

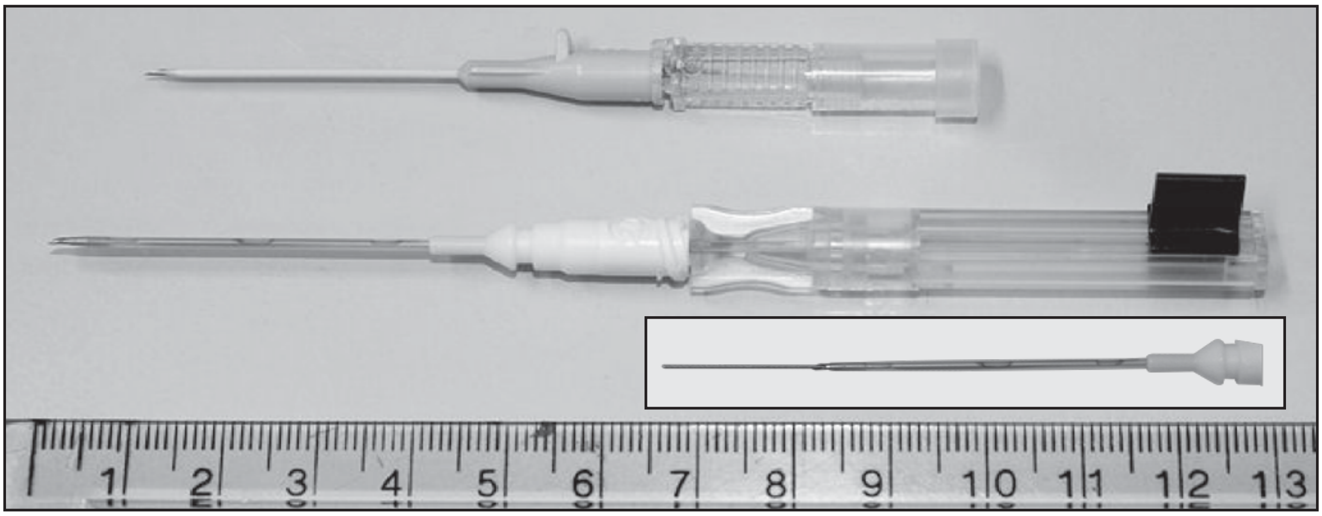
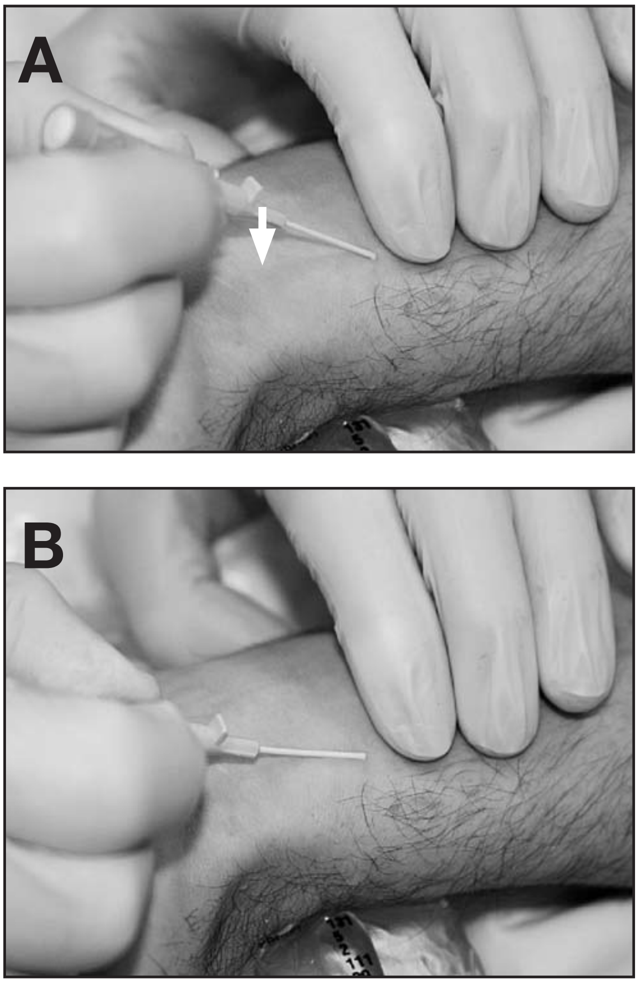


Figure 6: Two 20G arterial cannulae. The lower cannula has a guidewire that can be slid into the artery through the needle to allow smooth placement of the cannula (inset).



Figures 6a and 6b.: See text on page 40 for explanation of technique

- After attaching the catheter to the saline column take great care to ensure there are no air bubbles in the system before flushing it.
- If you suddenly obtain a very high blood pressure reading, check the position of the transducer; it may have fallen on the floor!
- If you lose the waveform on the monitor or it decreases in amplitude, the catheter may be kinked or blocked with a blood clot, or there may be an air bubble damping the trace. After checking that your patient has a pulse, you can try making sure the wrist is extended, aspirate any air bubbles and then flush the catheter, or withdraw the catheter slightly to check it is not kinked.
- Note that over or under-damped traces will give false blood pressure values. An under-damped trace will overestimate systolic pressure and underestimate diastolic pressure as the system 'over oscillates'. A low amplitude, over-damped trace will underestimate the systolic blood pressure and overestimate the diastolic blood pressure. Fortunately, the value for the mean arterial blood pressure is little affected and can usually be taken as accurate.

Figure 7: If location of the artery is difficult an alternative method involves positioning your thumb so that the radial pulse is running directly under the centre of your thumb. Then advance the cannula at 30 degrees under the centre point of your thumb.

Pulse Contour Analysis

Useful clinical information can be obtained by looking at the pattern of the arterial waveform on the monitor.

- A large 'swing' or variation in peak amplitude of the systolic pressure that coincides with the ventilatory cycle often indicates that the patient is hypovolaemic.
- Conscious patients who are in respiratory distress may also have a large swing on the arterial pressure trace, due to large swings in intrathoracic pressure.
- A narrow width, high amplitude pulse combined with tachycardia tends to indicate hypovolaemia.
- The angle of the upstroke of the arterial waveform may give an estimate of myocardial contractility; a steeper upstroke indicates greater change in pressure per unit time and higher myocardial contractility. In practice, this only provides a rough assessment of myocardial contractility.

Analysis of the arterial waveform has been developed mathematically to calculate cardiac output. The term 'pulse contour analysis' is usually used to refer to the cardiac output monitoring systems employed in the PiCCO™ (Pulsation Medical Systems, Germany) and LiDCO™ Plus (LiDCO Ltd, UK) monitors.

The PiCCO™ and LiDCO™ systems both measure cardiac output using both the shape and the area under the arterial pulsation curve. For both techniques a haemodilution method is used to calculate the cardiac output and calibrate the pulse contour analyser. Note that this means that both systems require central venous access. By knowing the exact shape and area under the arterial pulsation curve at the time of calibration, future arterial pulsation curves can be compared and the cardiac output at that point in time extrapolated.

The way in which these two systems calculate the initial cardiac output differs in that the PiCCO™ uses haemodilution of cold saline and the LiDCO™ uses haemodilution of lithium. The LiDCO™ cannot be used in patients on lithium therapy or for up to two hours following the administration of non-depolarizing muscle relaxants. Both systems need regular recalibration by re-measuring the cardiac output using haemodilution. All the factors previously mentioned that alter the accuracy of the arterial waveform (air bubbles, kinking etc) will affect the cardiac output value that the system gives. The two systems also alter in terms of the mathematical modelling they use to perform the pulse contour analysis. Further description of these techniques can be found in *Update 21*.

Summary

Invasive arterial monitoring is a highly useful tool, which allows close blood pressure monitoring for patients undergoing major surgery and the critically ill. It is also useful for repeated arterial blood gas analysis and as an access point for obtaining other blood samples. It is important to understand the principles of biological measurement systems in order to optimise their performance and allow trouble-shooting when performance is poor.

Further reading

- J S Gravenstein and David A Paulus. Clinical Monitoring in Practice (2nd edition). Published by J B Lippincott, Philadelphia, 1987
- M K Sykes, M D Vickers, C J Hull. Principles of measurement and monitoring in Anaesthesia (3rd edition). Published by Blackwell Science Publications, 1991.

CORRESPONDENCE

Dr Alex Polishchuk, Oshakati, Namibia

Lateral intubation for difficult intubation

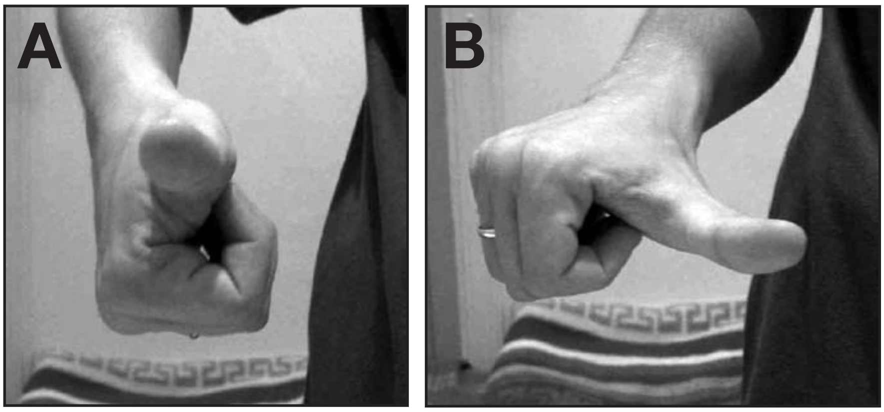
I have received correspondence for Dr Alex Polishchuk, originally from the Ukraine, and now working in Oshakati, Namibia, regarding a potentially useful intubation technique that is widely reported in Russian-language texts, but does not appear in UK textbooks or on the internet. An edited version of Dr Polishchuk's email, with photos, is shown below. Further correspondence of reader's experience with this technique would be welcomed.

Dear Editor, I recently read an Update article about difficult endotracheal intubation (http://www.nda.ox.ac.uk/wfsa/html/u09/u09_025.htm). In this overview article there was no mention of **lateral intubation**. Perhaps Western doctors have never heard of this technique? The technique was shown to me by an old doctor and has helped me many times. I have read about this technique, but only in Russian books. The method is as follows:

- After 3 unsuccessful attempts at conventional intubation turn the patient's head to face to the right side. Insert the laryngoscope in the left corner of the mouth, passing it forward in between the tongue and the upper teeth.
- Keep the laryngoscope handle parallel to the table surface, as during a conventional intubation. Pass the tip of the laryngoscope blade posteriorly, aiming to direct it between the left palatine arch (on the left of the blade) and the base of the tongue (on the right of the blade). Your laryngoscope blade will pass towards the patient's left piriform fossa, with the epiglottis coming into view on the right side of the blade, and the larynx straight ahead. Some anticlockwise rotation of the blade may be necessary to achieve this view.
- Move the larynx with your right hand to improve the view of the vocal cords.

Dr Polishchuk's photographs below demonstrate the lateral approach to the epiglottis and vocal cords.

During this technique, the larynx-mouth distance becomes shorter due to the rightward position of the head and the epiglottis disturbs your view less, because it is to the right of the blade.



The thumb represents the epiglottis and the orifice between the curled fingers, the laryngeal opening, (A) during conventional laryngoscopy and (B) during lateral laryngoscopy.