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Invasive arterial blood pressure measurement

Produced by:
The perioperativeCPD team

Introduction

Invasive intra-arterial blood pressure monitoring is commonly used in the operating theatre. It is the gold standard of blood pressure measurement giving accurate beat-to-beat information.

This module covers the basic principles behind setting up, inserting and monitoring intra-arterial blood pressure.

In this module we will use the common abbreviation of arterial blood pressure to refer to invasive intra-arterial blood pressure monitoring; although non-invasive blood pressure cuffs also measures arterial blood pressure.

Why arterial blood pressure measurement?

Arterial blood pressure measurement is more accurate than measurement of a blood pressure BP by a non-invasive cuff, especially in hypotensive patients or patients with heart arrhythmias.

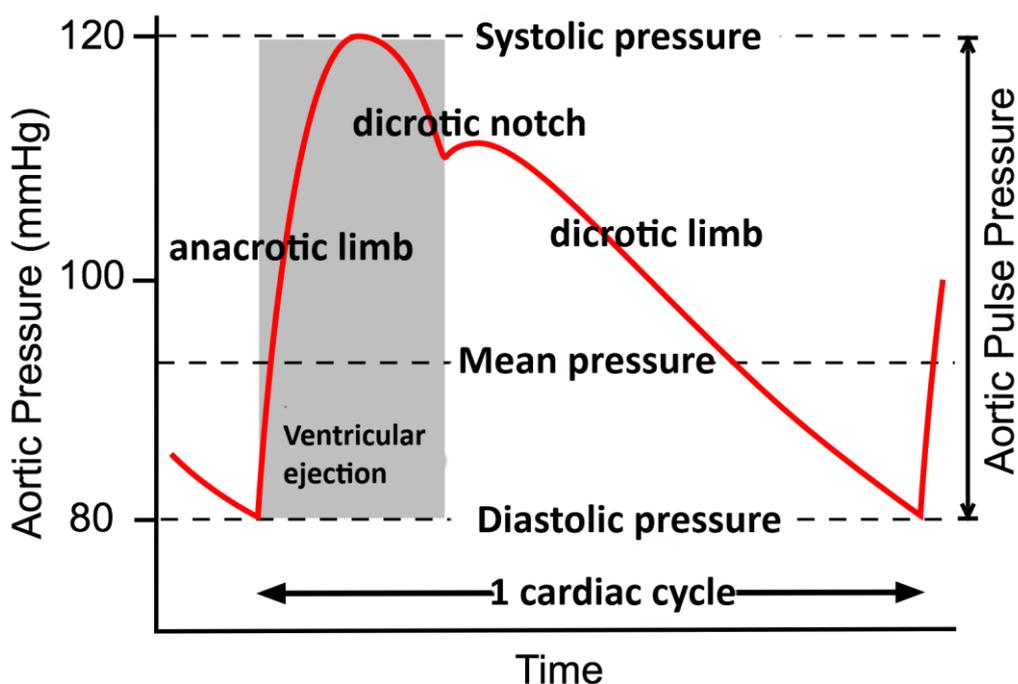
With an arterial BP measurement the systolic pressure will read slightly higher and diastolic pressure slightly lower (5–10 mmHg), when compared to the same non-invasive measurements.

It gives beat by beat near real-time measurement which permits the rapid recognition of blood pressure changes.

Arterial cannulation allows repeated arterial blood gas samples to be drawn.

It can be used where non-invasive cuffs are difficult. Two examples are burns and bariatrics cases.

Finally when used for a long time NIBP cuffs have a risk of nerve and tissue damage.



What does the arterial blood pressure waveform look like?

The arterial pressure wave corresponds with the cardiac cycle.

The systolic upstroke (**the anacrotic limb**) - begins with opening of aortic valve and rapid ejection of blood into the aorta from the left ventricle.

The slope of upstroke of the arterial relates to the myocardial contractility.

The peak of the wave is the **systolic pressure**.

As the left ventricle contraction comes towards an end, the pressure in the aorta falls.

The **dicrotic notch** which is visible on downward stroke which represents closure of the aortic valve signifying the beginning of diastole.

A low dicrotic notch is seen in hypovolaemic patients and the slope of the diastolic decay indicates resistance to outflow. A slow fall is seen in cases of vasoconstriction.

The remainder of the downward stroke represents diastolic run off of blood flow into the arterial tree.

The lowest pressure in the aorta, which occurs just before the ventricle ejects blood again, is termed the **diastolic pressure**.

The difference between the systolic and diastolic pressures is the pulse pressure, which typically is between 40 and 50 mmHg.

The mean aortic pressure (MAP) is the average pressure during the aortic pulse cycle.

$$\text{MAP} = \text{diastolic} + \frac{1}{3} (\text{systolic} - \text{diastolic})$$

The risks of arterial blood pressure monitoring

As well as being painful to insert in a conscious patient there are risks to arterial blood pressure cannulation and its subsequent monitoring.

Haemorrhage - An arterial bleed though any leaks or disconnections is extremely dangerous. All arterial sets must be checked for tightness before using as loose connections are the most common cause of leaking. The cannula site should be in view where ever possible.

Thrombosis or blood clots are common but the risk is less with a smaller cannula (20-22g). Permanent occlusion is rare but the risks are greater the longer the cannula is in. The risk of thrombosis is higher with tapered catheters and/or polyurethane catheters.

Ischaemia - Constant observation of the site distal to the arterial cannula is essential for early identification of ischaemia. The arterial cannula should be removed if there is poor capillary refill, loss of sensation or cold periphery is observed. It is more common after multiple insertion attempts and haematoma formation.

Infection - Local infection is common although systemic sepsis though an arterial line is rare (<5%). Factors that can predispose to infection include infection at the site of insertion, poor aseptic technique, prolonged duration of use and contaminated blood syringes or bungs.

Emboli - During priming or accessing the arterial line the risk of air entraining into the line is high. Arterial air bubbles can cause serious problems for patients and even result in death.

Inadvertent drug administration through an arterial line is always a risk and clear labelling of line is essential.

Intra-arterial injection of drugs

Intra-arterial injection of drugs may cause acute, severe extremity ischaemia and gangrene. The drugs which cause the most severe injury are barbiturates, although 5% thiopental which caused damage by precipitation of crystals which formed when the alkaline drug reached arterial pH is no longer available.

Recognition

The first sign may be that the drug fails to have the expected effect. Patients usually complain of immediate severe discomfort distal to the site of injection although this obviously will not happen in an anaesthetised patient. Pallor, paraesthesia, hyperaemia, and cyanosis of the affected limb develop and severe cases may progress to develop profound oedema and gangrene.

Management

There is no universally accepted treatment protocol; most interventions attempt to maintain perfusion distal to the site of injury.

Initial steps:

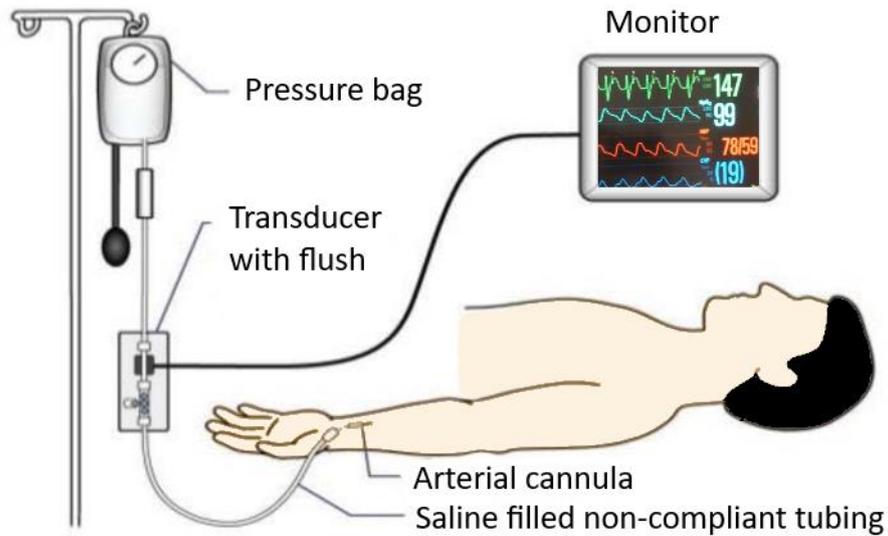
1. The affected extremity should be elevated to improve venous and lymphatic drainage.
2. Maintain catheter in place.
3. Start slow infusion of isotonic solution to keep the cannula patent.
4. Evaluate severity of injury (soft compartments, neuro-vascular exam).
5. Anticoagulation with IV heparin is recommended.
6. Treat pain and symptoms.
7. If there is evidence of vasospasm intra-arterial Papaverine could be considered.

The Basic principles:

The arterial BP waveform is transmitted through a cannula to a transducer via a fluid filled column.

The transducer converts the pressure to an electrical signal.

A computer module processes the electrical signal into a waveform which is displayed on the screen in near real-time.

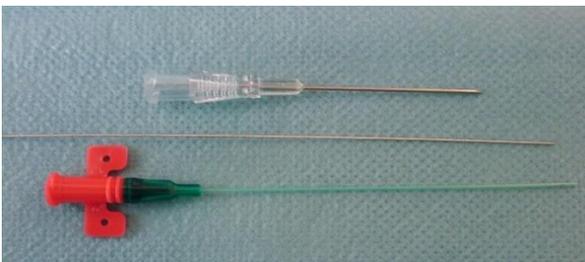


Components:

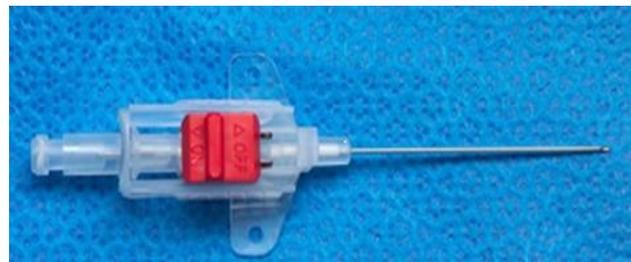
Intra-arterial cannula

The cannula detects the flow of blood and the pressures exerted with each contraction of the heart. A narrow parallel sided Teflon (preferred) or polyurethane cannula is used. 20-22G is most common (24G in paed).

- The larger the cannula the higher the risk of thrombosis.
- The smaller the cannula the more risk of damping the trace.



An arterial cannula with guidewire



A floswitch arterial cannula

Some designs have an on-and- off switch to prevent bleeding while connecting and disconnecting the cannula, as seen in the picture above.

Fluid filled tubing

The purpose of the fluid filled tubing system is to provide a means of transmitting the pressure generated in the artery to the transducer.

It is attached to the cannula and is water filled as this provides a column of non-compressible fluid. Any air in the line increases damping as air is highly compressible.

Air bubbles are more likely to form if the line is primed under pressure so it is recommended to prime first then pressurise.

The tubing is also as stiff (non-compliant) and short as practicable to reduce damping.

All tubing should also be colour coded or clearly labelled to assist easy recognition and reduce the risk of intra-arterial injection of drugs.

A 3-way tap is incorporated to allow the system to be zeroed and blood samples to be taken. However extra 3-way taps increase damping and should be removed.

Pressurised bag of fluid

A 500ml bag of 0.9% saline is attached to the fluid filled tubing via a flush system. It is pressurised to 300mmHg to prevent backflow and allow a slow continuous flush of 2-4 mls per hour.

Recent studies show that is the constant slow flush that keeps the artery open so heparinised fluids are not needed.

Note: Alternative fluids such as glucose solutions are not allowed as they contaminate arterial blood gas results leading to dangerous misreading of blood test results.

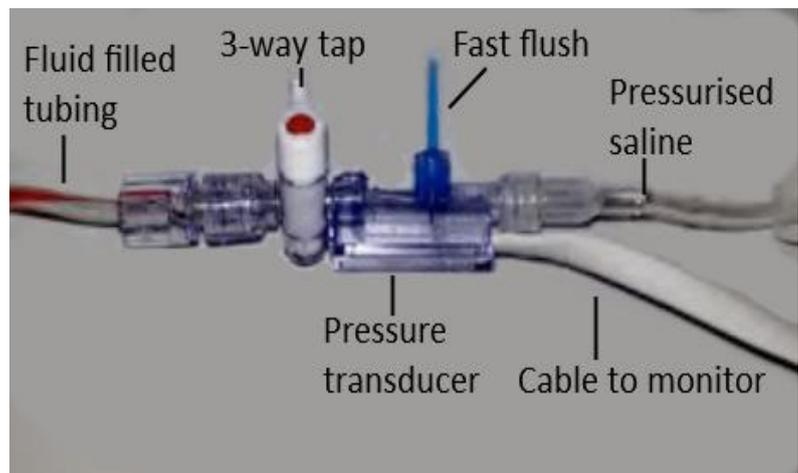
Transducer

A pressure transducer is a device that converts the mechanical impulse of a pressure wave into an electrical signal. A microphone is another example of a transducer as it converts sound energy into electrical energy.

The transducer consists of a diaphragm (a very thin membrane) that stretches in response to pressure changes within the column of fluid.

The flexible diagram is attached to strain gauges in such a way that the movement of the diaphragm means the gauges are stretched or compressed, altering their resistance.

There are four strain gauges that are setup in a Wheatstone Bridge arrangement to maximise sensitivity and accuracy.



These changes in resistance and the dependent changes in current are measured and displayed as the systolic, diastolic and mean pressure.

A flush system is also incorporated to allow a high-pressure flush of fluid. This is used to keep the tubing clear as well as checking the damping and natural frequency of the system.

Sites of insertion

Arterial lines are commonly inserted into the radial artery however the femoral, brachial and dorsalis pedis arteries can be used.

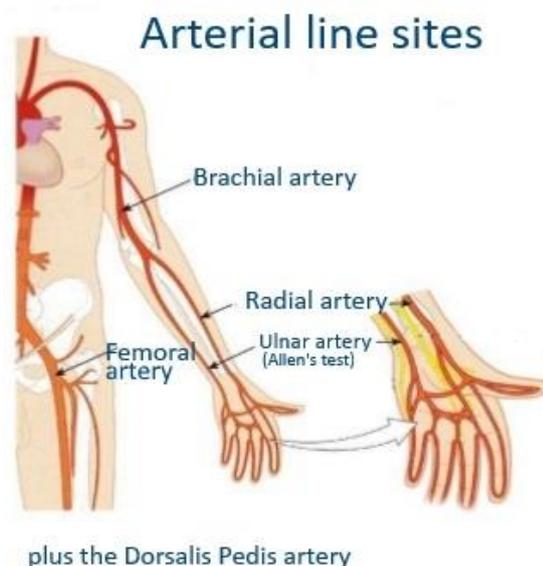
The radial artery is usually the preferred site as it is superficial, easily palpated, easily accessed and it doesn't limit the patient's mobility. It normally has good collateral flow from the ulnar artery via the palmar arch. (See Allen's test later).

Additional advantages of the radial artery include the consistency of the anatomy and a low complication rate.

After the radial artery, the femoral artery is the second most common site. The main advantage of femoral artery cannulation is that the vessel is larger than the radial artery and has stronger pulsation.

The brachial and dorsalis pedis are least preferred due to an increased chance of complications.

Whichever site is selected, arterial line insertion should be a sterile procedure following hospital guidelines.



Allen's test

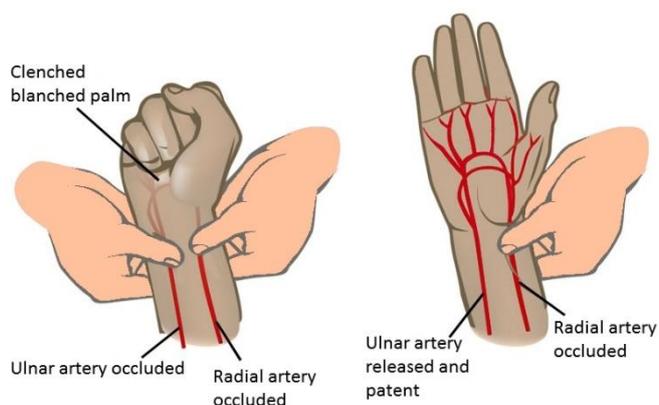
If cannulating the radial artery the Allen's test can be performed to assess if there is sufficient flow in the ulnar artery through the palmar arch. This is normally the case in 95% of people.

The hand is elevated and the patient is asked to clench their fist for about 30 seconds. Pressure is applied over the ulnar and the radial arteries so as to occlude both of them. Still elevated, the hand is then opened. It should appear blanched.

Ulnar pressure is released while radial pressure is maintained, and the colour should return within 5 to 15 seconds.

If colour fails to return, the test is considered abnormal and it suggests that the ulnar artery supply to the hand is not sufficient. This indicates that it may not be safe to cannulate the radial artery.

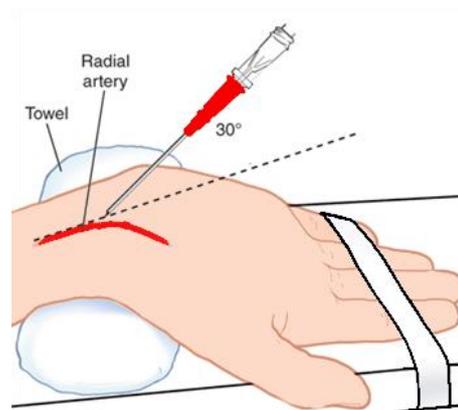
It is not universally used as studies show it may not be 100% reliable at predicting ischemic damage after cannulation and may not even correlate with abnormal flow.



Methods of cannulation:

Direct cannulation

This is similar to IV cannula insertion. The wrist is extended to bring the artery closer to the surface. Stabilising the wrist in this position either with tape or with the aid of an assistant makes insertion easier. The needle is inserted aiming to hit the middle of the artery at an angle of approximately 30° to the skin. When there is free flow of arterial blood back into the hub of the cannula, the cannula sheath is advanced over the needle into the artery.



Transfixion

This starts the same as direct cannulation but the needle is advanced through the posterior wall of the artery.

The needle is removed and a syringe attached. The cannula is slowly withdrawn while aspirating.

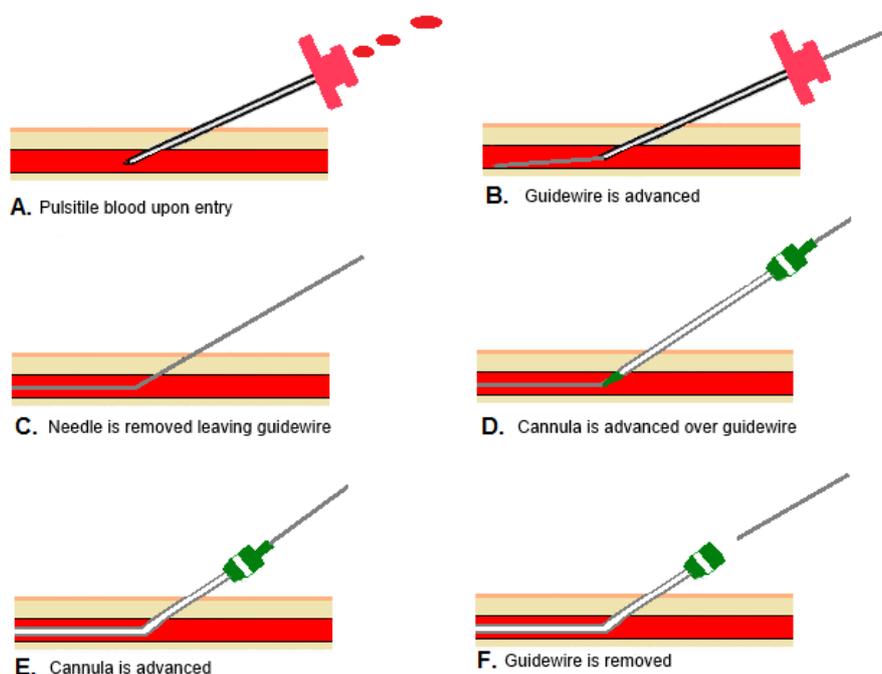
Once free aspiration is achieved, the cannula is advanced proximally along the artery. This is a particularly useful technique in paediatric patients.

Guidewire or Seldinger

Again the needle is inserted aiming to hit the middle of the artery at an angle of approx. 30° to the skin. After flashback a guidewire is inserted through the needle.

The guidewire should advance freely along the artery. The needle is removed leaving the guidewire. The cannula is then advanced along the artery, and the guidewire is removed.

Now taught as standard method in a lot of hospitals.



Typical Equipment needed:

- Transducer set
- Transducer cable & suitable monitor
- 500ml 0.9% NaCl
- 500 ml pressure bag
- Arterial cannula of choice
- Sterile gloves and personal protective equipment
- Alcoholic Chlorhexidine 2% or Cholaprep
- Local anaesthetic (lidocaine)
- Dressings of choice (see below)
- 2x2 ml syringes, needle for local anaesthetic
- Silk sutures if needed
- Dressing pack with drape

Fixing and dressing the catheter

There are two main ways to dress an arterial catheter. Usually if it is intended to be long term (ICU) it is stitched in with silk sutures, then covered with clear Tegaderm type dressings.

If intended to be a short term catheter then dressings alone are considered appropriate. One common method is two Tegaderm I.V dressings, one each way with the option of a larger dressing over both.

Removing the arterial line

The arterial line should be removed when:

- limb circulation is compromised
- the cannula is misplaced
- it is no longer required for monitoring and frequent blood sampling
- there are signs of an infection

When removing the arterial line loosen all dressings, cut retaining suture if present and withdraw the line from the artery without applying pressure. The application of pressure during removal can cause pain. Using the sterile gauze, immediately apply pressure for up to five minutes or until bleeding has stopped.

Make sure to observe the site regularly for bleeding.

Priming an arterial system

Every manufacturer has their own procedure for priming arterial line sets but some principles are generally universal:

Air-free priming starts with removal of all air from the flush solution to prevent air from going into the line as a result of the pressure applied by the pressure bag.

All connections must be checked for tightness then the entire tubing system should be primed. 3-way taps, Luer-Lok connections, ports and the transducer are common locations of air entrapment.

If vented caps are put on the set by the manufacturer to enable sterilisation these must be replaced with non-vented caps to prevent entrainment of air into the system.

With gravity only (no pressure in pressure bag), flush the translator holding the pressure tubing in upright position as the column of fluid rises through the tubing, pushing air out of the tubing until the fluid reaches the end.

Priming while under pressure results in microbubbles that cannot be seen. After priming pressurise the pressure bag until it reaches 300 mmHg.

Arterial Transducer zeroing

Zeroing and levelling are occasionally used interchangeably, but they are not the same thing. They tend to occur together in the clinical setting, but are different processes.

All arterial lines must be zeroed several times a day to equilibrate them to atmospheric pressure and to remove any calibration drift.

It should also be re-zeroed after disconnection from the monitor and/or transducer cable, after redressing the arterial site, after accessing the arterial line for blood sample, after troubleshooting the line, etc.

The level of the transducer in relation to the patient is not important for this.

The zeroing takes place at the transducer.

1. **Turn the 3-way tap off to the patient.** This prevents air from getting into the line while zeroing.
2. Next, take off the cap on the transducer. **Open to air.**
3. Press the "**zero**" button on your monitor. Wait for it to zero the line. This can take up to five seconds.
4. Place the cap back on the transducer.
5. Turn the 3-way tap back to the neutral position.

Arterial Transducer levelling

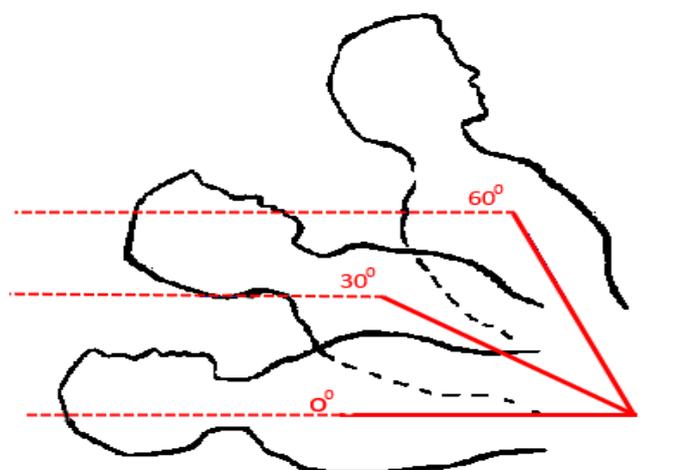
The transducer will only read accurately if it is at the correct level.

The system is conventionally "levelled" at the phlebostatic axis. The phlebostatic axis corresponds roughly with the position of the right atrium.

It is located by drawing an imaginary line from the fourth intercostal space at the sternum and finding its intersection with an imaginary line drawn down the centre of the chest below the axillae.

Every 10cm wrong will put the ABP out by approx. 7.5mmHg so maintaining the correct level is important.

Therefore every time the patient position is changed in relation to the transducer it should be realigned.



This does not necessarily require re-zeroing but in practice it often is done at the same time.

Dampening

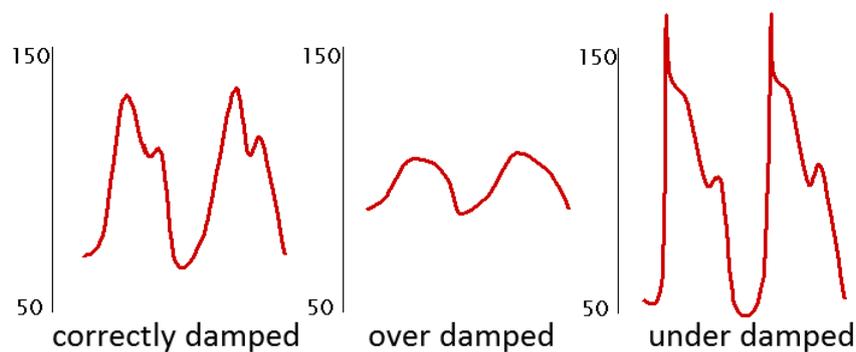
Anything that reduces energy in an oscillating system will reduce the amplitude of the oscillations. This is called damping.

Some damping is inherent in any system and acts to slow down the rate of change of signal between the patient and pressure transducer, but if there is excessive (overdamping) or insufficient (underdamping) the output will be adversely effected.

There are a number of other factors that will cause overdamping including:

- Extra three way taps
- Bubbles and clots
- Vasospasm
- Narrow, long or compliant tubing
- Kinks in the cannula or tubing

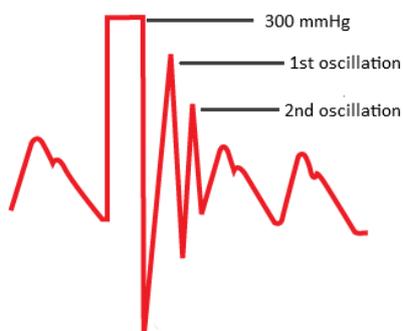
Note: a loss of pressure in the system will result in a damped trace and should be checked first.



The damping on a system can be checked using a fast flush or square wave test.

When you activate the fast flush valve, this produces a waveform that rises sharply, plateaus, and drops off sharply when the flush valve is released.

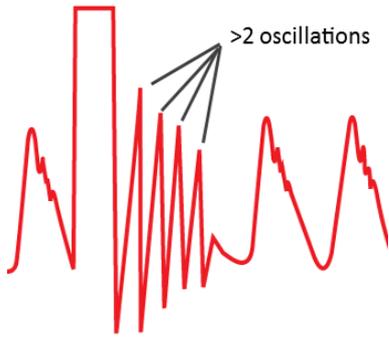
Watching how the waveform reacts after the flush gives an indication how effectively the system is dampened.



Correctly damped

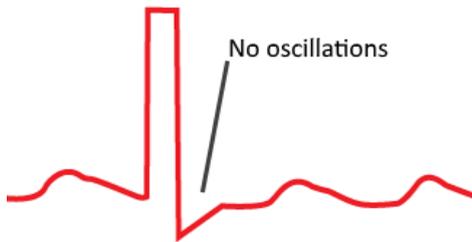
The system responds rapidly to a change in signal by allowing a small amount of overshoot.

An optimally damped system will return to baseline after 1-2 oscillations following a fast flush.



Under damped

An underdamped system is one with more than 2 oscillations before returning to baseline. It will be quick to respond but will tend to overshoot over-reading blood pressure.



Over damped

Less than 1 ½ oscillations. An over damped system will tend to underestimate blood pressure. It will be slow to respond to change due to the frictional drag in the system.

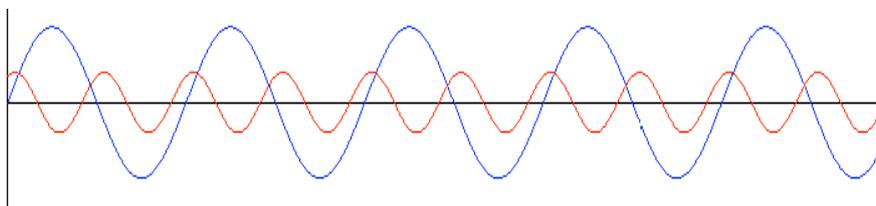
Damping also causes a reduction in the natural frequency of the system, allowing resonance and the distortion of the signal.

Natural Frequency & Resonance

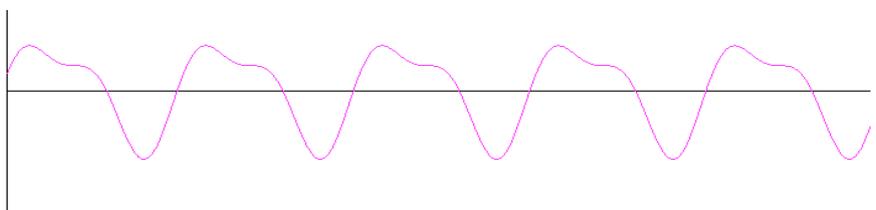
The arterial pressure waveform is made up of many different sine waves with each wave having a specific frequency.

In the monitor, the complex pressure waveform is broken down by a microprocessor into its component sine waves, then reconstructed from the fundamental and **eight** or more waves of higher frequency to give an accurate representation of the original waveform.

The process of analysing a complex waveform in terms of its constituent sine waves is called *Fourier Analysis*. The pictures below demonstrate how just two sine waves may be combined together to form a more complex wave that begins to resemble the arterial pressure wave.



Two sine waves of differing frequency, amplitude & phase become the sum of the sine waves below



Every patient's blood pressure waveform oscillates at its own natural frequency, and if the resonant frequency of the transducer set coincides with one of the frequencies making up the arterial waveform, resonance and therefore distortion of the signal will occur.

Arterial cannulae and commercial transducer sets used in invasive arterial pressure monitoring are designed have a natural resonant frequency of around 200Hz. This keeps it well above 40Hz, which is the maximum frequency of a patients' arterial waveform, thus minimizing the chances of interference due to resonance.

The resonant frequency of the transducer set can be lowered by adding extra 3-way taps, air bubbles, clots or non-standard tubing or cannula. Many of the same issues that cause dampening and increase the risk of complications.

This used to be more of an issue before the advent of commercial transducer sets. When arterial sets were often hand-made of I.V. cannulae, drip extension tubing etc. they had a natural frequency as low as 50Hz so the chances of resonance and interference was a lot greater.

For more advanced learning on the scientific principles behind intra-arterial blood pressure measurement see:

<http://www.periopcpd.com/wp-content/uploads/ABP.pdf>

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