Update in
Anaesthesia

# Pressure and Blood Pressure Measurement

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**Summary**

This article describes the basic science of pressure, its relevance to anaesthesia and critical care, and its measurement. Adequate blood pressure is essential to maintain the blood supply and function of vital organs. Measurement of blood pressure is therefore a key part of the monitoring of patients during anaesthesia and critical care.

## FORCE AND PRESSURE

Force causes an object to move in a certain direction. The SI (Systeme International d'Unites) of force is the newton, one newton (N) being the force which, when applied to a mass of 1kg, will give the mass an acceleration of 1 metre per second squared ($m.s^{-2}$).

Pressure is defined as force per unit area. The SI unit of pressure is the pascal, one pascal (Pa) being equal to 1 newton, distributed over an area of $1m^2$ ($1N.m^{-2}$). One newton is a small force and one $m^2$ is a relatively large area, so a pascal is a small amount of pressure. Pressure is therefore commonly expressed in kilopascals (kPa).

$$\textbf{Pressure} = \frac{\textbf{Force}}{\textbf{Area}}$$

This equation can be rearranged to give:

$$\textbf{Force} = \textbf{Pressure x Area}$$

showing that for a given force, pressure and area have a reciprocal relationship.

Using an everyday example, when a constant and equal force is applied to two syringes of differing sizes, it is much harder to inject from the larger (e.g. 20ml) syringe compared to a smaller syringe (e.g. 2ml). This is due to the larger area of the plunger in the 20ml syringe. As already discussed, pressure and area have a reciprocal relationship so in the larger syringe, with the larger area, the pressure generated will be less. This reduced pressure results in the relative difficulty in injecting from a 20ml syringe.

Although the pascal is the SI unit of pressure, many other units of pressure measurement exist. Table 1 provides a comparison.

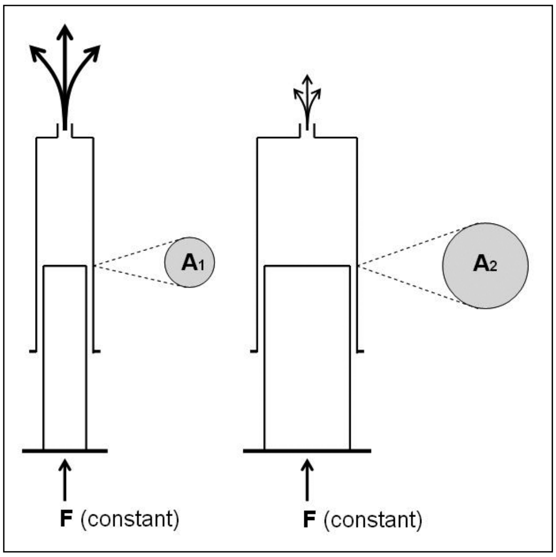


**Figure 1.** *Injection from small and large syringes. Force = force, A = area*

## GAUGE PRESSURE AND ABSOLUTE PRESSURE

Absolute pressure = gauge pressure + atmospheric pressure.

A full oxygen cylinder has a gauge which will read a pressure of 13700kPa. As the oxygen is used the pressure will fall until the gauge reads a pressure of 0kPa. However, at this point, unless a vacuum has been used to 'suck' oxygen out of the cylinder, it will still contain oxygen at the ambient atmospheric pressure (100kPa).

Therefore gauge pressures measure the pressure in a system above or below ambient atmospheric pressure. The majority of pressures measured by anaesthetists are gauge pressures and examples include gas cylinder pressures, blood pressure and ventilator pressures.

**Table 1.** *Units of pressure*

| Unit of pressure | Amount equating to 1 atmosphere | Example of use |
|---|---|---|
| kPa | 101.3 | Gas cylinder pressure |
| pounds per square inch | 14.69 | Car tyre pressure |
| centimetres of water ($cmH_2O$) | 1033 | Airway pressure |
| bar | 1.013 | Gas cylinder pressure |
| millimeters of mercury (mmHg) | 760 | Blood pressure |

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Given the above equation the absolute pressure of an oxygen cylinder is 13800kPa when full.

## PRESSURE MEASUREMENT

Many different systems can be used to measure pressures, some of which are outlined below. Each has advantages and disadvantages.

### Manometers

Manometers are columns of liquid used to measure pressure, usually limited to pressures near to that of the atmosphere. Pressure is measured by its ability to displace the column of liquid in the manometer. The column will rise or fall until its weight is in equilibrium with the pressure difference between the two ends of the tube. A simple version is a U-shaped tube (Figure 2), half filled with liquid, one end of which is exposed to atmospheric pressure and the other exposed to the pressure to be measured.

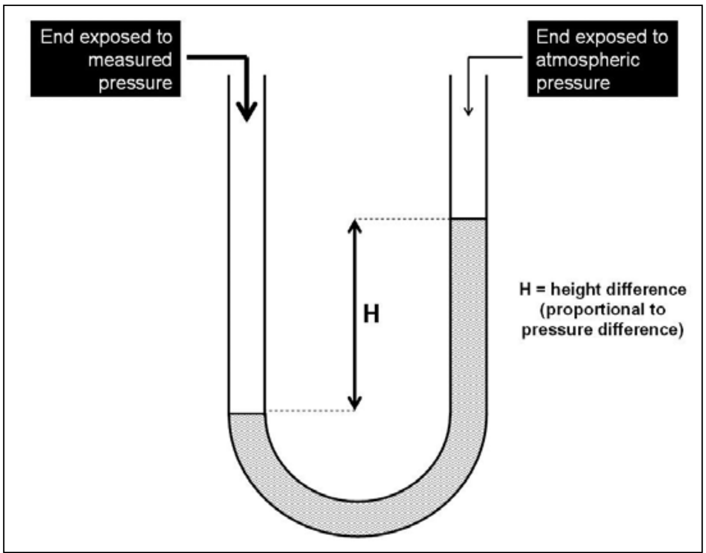


**Figure 2.** *A manometer*

The commonest liquids used are water and mercury, each having their own advantages. Mercury is 13.6 times denser than water and hence can be more easily used to measure higher pressures. The pressure in the column is equal to the product of the height of the column, the liquid's density and the force of gravity. The width, shape or even angulation of the column, have no impact on the pressure reading.

Surface tension has an effect on the meniscus at the top of the liquid column. It will pull water up the walls of the tube causing a slight over-reading, whilst in a mercury manometer the meniscus is convex and the level of the liquid is depressed.

### Bourdon gauge

This pressure measurement device is used for the measurement of high pressures, where the required height of the fluid column in a manometer would be impractical. A Bourdon gauge uses a coiled tube which, as it expands due to increased pressure, moves a pointer over a scale.

A bourdon gauge is an example of an *aneroid* gauge meaning 'without fluid'. Another type of aneroid gauge is based on a bellows mechanism, the bellows expanding with increased pressure. These are useful for the measurement of small pressures and can be open to the atmosphere (and measure gauge pressure) or closed (and measure absolute pressure).

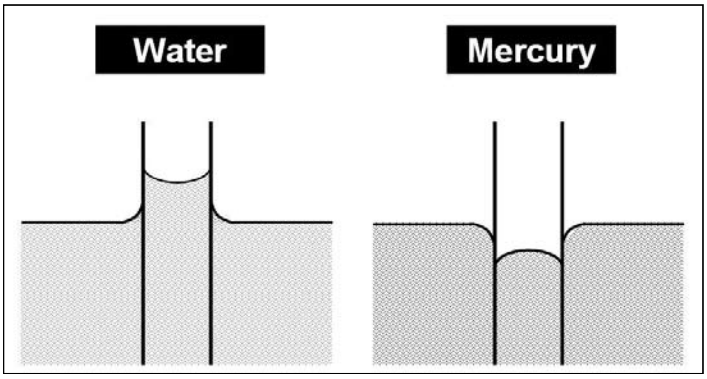


**Figure 3.** *Menisci of water and mercury*

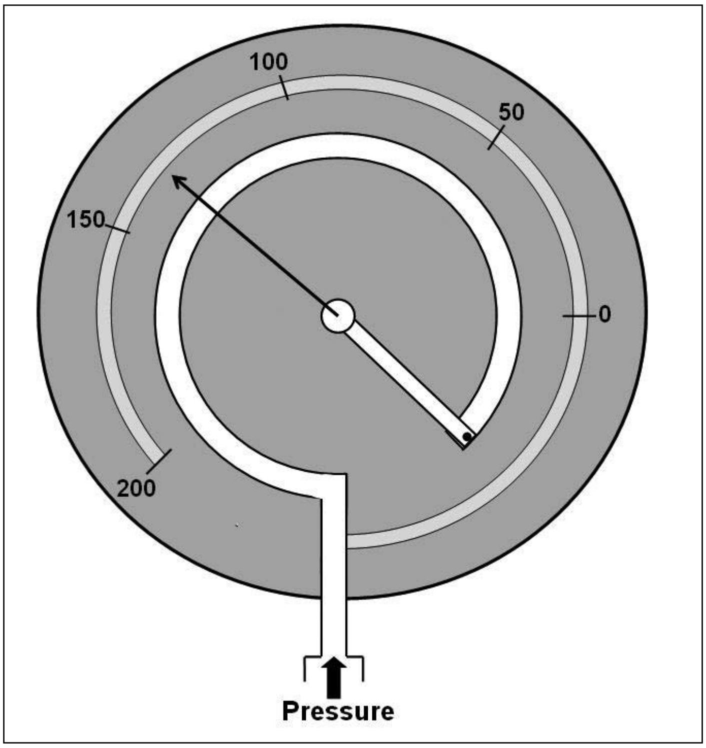


**Figure 4.** *A bourdon gauge; as the pressure increases the coil unravels and indicates the pressure on the calibrated scale. A system of cogs (not shown in this figure) converts uncoiling of the coil into clockwise movement of the needle*

### Diaphragm

Another type of aneroid gauge is a diaphragm. This uses a flexible membrane which is deflected by changes in pressure. The amount of deflection is proportional to the pressure and hence the pressure can be determined once the system used has been calibrated. These are commonly found in systems used to measure direct intra-arterial blood pressure.

## MEASUREMENT OF BLOOD PRESSURE

### What is normal blood pressure?

'Normal' or 'acceptable' blood pressure varies with age, state of health and the clinical situation. At birth, a typical blood pressure is 80/50mmHg. It rises steadily throughout childhood, so that in a young adult it might be 120/80mmHg. As we get older, blood pressure continues to rise and a rule of thumb is that normal systolic pressure is [age in years + 100] mmHg. Blood pressure is lower in late pregnancy and during sleep.

Therefore a systolic pressure of 160mmHg for an elderly man or 90mmHg for a pregnant woman may be quite normal. To judge whether any particular reading is too high or too low, it must be compared to the 'normal' blood pressure for that patient.

## TECHNIQUES OF MEASUREMENT OF BLOOD PRESSURE

### Rough estimates (no equipment available)

It is not possible to derive a numerical value for blood pressure without some equipment, but a crude assessment of the circulation can still be obtained. If you can feel a radial pulse, the systolic blood pressure is usually at least 80mmHg. The character of the pulse, i.e. bounding or thready, gives a further clue. In most cases, shocked patients have cold hands and feet - the most important exception to this is a patient who is shocked because of severe sepsis.

Capillary refill time is another simple test of circulatory adequacy: press firmly on the patient's nail bed with your thumb for 3 seconds; release your thumb and see how long it takes for blood to return. A refill time of greater than 2 seconds suggests an inadequate circulation. This test is particularly useful to diagnose shock and monitor the response to fluid therapy in children - the skin over the chest wall is a common site for this.

### Manual non-invasive blood pressure measurement

This requires, at the very least, an inflatable cuff with a pressure gauge (sphygmomanometer). Wrap the cuff round the arm (which should be at about heart level) and inflate it to a pressure higher than the expected blood pressure. Then deflate the cuff slowly. With a stethoscope, listen over the brachial artery. When the cuff reaches systolic pressure, a clear tapping sound is heard in time with the heart beat. As the cuff deflates further, the sounds initially become quieter, but then become louder again before disappearing altogether. The point at which the sounds disappear completely is the diastolic pressure. If you have no stethoscope, the systolic blood pressure can be estimated by palpating the brachial artery and noting the occlusive pressure in the cuff at which it become palpable.

The sounds described above are called the *Korotkoff sounds* and undergo 5 phases:

I initial 'tapping' sound (cuff pressure = systolic pressure)

II sounds increase in intensity

III sounds at maximum intensity

IV sounds become muffled

V sounds disappear (diastolic pressure)

Most inaccuracies result from the use of the wrong size of cuff. A narrow cuff wrapped round a broad arm will give a falsely high reading and vice versa. The World Health Organisation recommends a 14cm width cuff for use in adults. Smaller cuffs for infants and children are available. Occasionally, the reading obtained from one arm may be different from that obtained from the other arm - this is usually of no clinical relevance, but can be an indication of aortic pathology, notably dissection or coarctation.

An appropriate size of cuff can be applied to the calf and pressure estimated by palpation of the posterior tibial pulse. This may be useful during surgery, when the patient's arms are away from the anaesthetist, e.g. shoulder surgery.

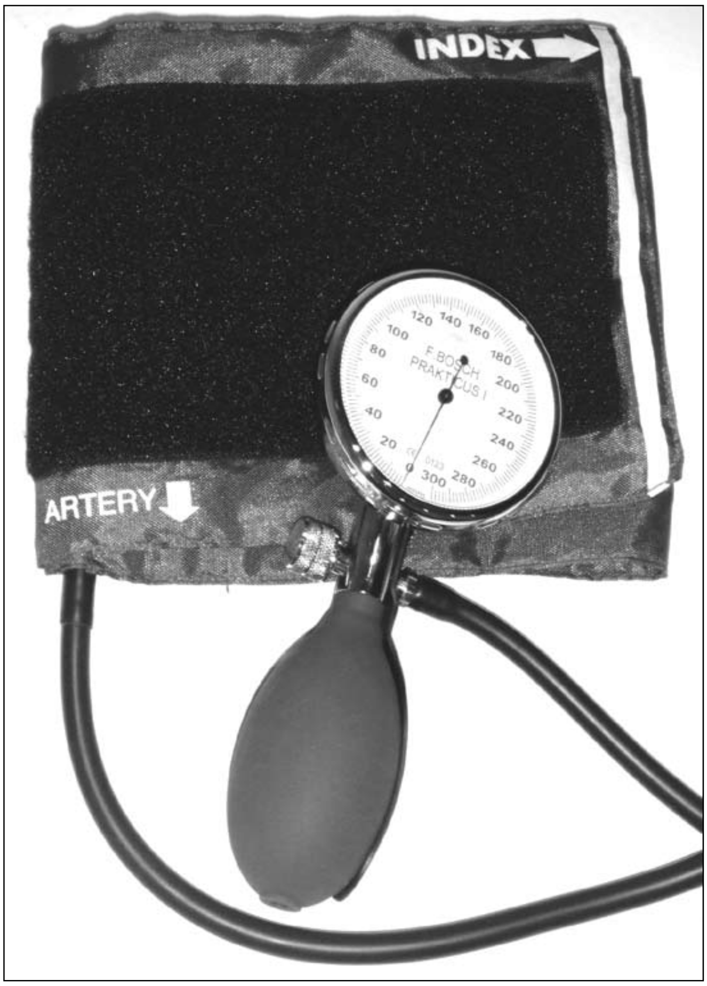


**Figure 5.** *A simple non-invasive blood pressure device*

### Oscillotonometry

The Von Recklinghausen oscillotonometer is a device that allows both systolic and diastolic blood pressure to be read without a stethoscope. It consists of two overlapping cuffs (one large, one small), a large dial for reading pressure, a bleed valve and a control lever. The large cuff performs the usual function of the sphygmomanometer cuff. The job of the smaller cuff is to amplify the pulsations which occur as the larger cuff is deflated, so that instead of listening for the Korotkoff sounds, they are seen as oscillations of the needle on the pressure dial. The lever simply switches the dial between the two cuffs.

*Technique of use for an oscillotonometer*

- Wrap the cuff round the arm in the usual way, and inflate it.
- Adjust the bleed valve so that the pressure falls slowly.

- Pull the control lever towards you. The needle will jump slightly in time with the pulse.
- As the cuff pressure approaches systolic, the needle suddenly starts to jump more vigorously. At this point, let go of the lever, and the needle will display systolic pressure.
- Pull the lever forward again. As the pressure is reduced, the needle jumps more vigorously.
- If the lever is released at the point of maximum needle oscillations, the dial will read the mean arterial pressure.
- If it is released at the point when the needle jumps get suddenly smaller, the dial reads diastolic pressure.

**Automatic non-invasive blood pressure measurement**

Automatic devices, which essentially apply the same principle as the oscillotonometer, have been produced (e.g. the 'Dinamap' made by Critikon). They require a supply of electricity.

*Technique of use*

- A single cuff is applied to the patients arm, and the machine inflates it to a level assumed to be greater than systolic pressure.
- The cuff is deflated gradually. A sensor then measures the tiny oscillations in the pressure of the cuff caused by the pulse.
- Systolic blood pressure is taken to be when the pulsations start, mean pressure is when they are maximal, and diastolic is when they disappear.
- Readings are fairly accurate and a major advantage is that they free the hands of the anaesthetist for other tasks.
- There are important sources of inaccuracy:
    - Such devices tend to over-read at low blood pressure, and under-read very high blood pressures.
    - The cuff should be an appropriate size.
    - The patient should be still during measurement.
    - The technique relies heavily on a constant pulse volume, so in a patient with an irregular heart beat (especially atrial fibrillation) readings can be inaccurate.
    - Sometimes an automatic blood pressure measuring device inflates and deflates repeatedly 'hunting', without displaying the blood pressure successfully. If the pulse is palpated as the cuff is being inflated and deflated the blood pressure may be estimated by palpation and reading the cuff pressure on the display.

**Invasive arterial pressure measurement**

This technique involves direct measurement of arterial pressure by placing a cannula in an artery (usually radial, femoral, dorsalis pedis or brachial). The cannula must be connected to a sterile, fluid-filled system, which is connected to an electronic monitor via a transducer. The advantage of this system is that pressure is constantly monitored beat-by-beat, and a waveform (a graph of pressure against time) can be displayed. Patients with invasive arterial monitoring require very close supervision, as there is a danger of severe bleeding if the line becomes disconnected. It is generally reserved for critically ill patients or those undergoing major surgery, where rapid variations in blood pressure are anticipated. The basic science principles behind this technique of blood pressure measurement are described in the article, *Biological signals and their measurements*.