Intra-Arterial Blood Pressure Monitoring

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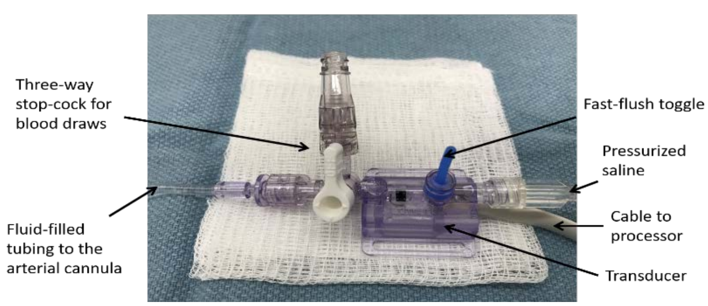
Intra-Arterial Blood Pressure (IABP) measurement has several advantages over a non-invasive blood pressure (NIBP) measurement.

- A continuous beat-to-beat pressure measurement when close monitoring is indicated
- The waveforms can provide further information on the cardiovascular status (pulse contour analysis)
- Useful when NIBP measurement is difficult e.g. burns or obesity
- It allows frequent arterial blood sampling
- More reliable than NIBP in patients with arrhythmias or extreme hypotension

Components of the IABP monitoring system

The arterial pressure monitoring system consists of a transducer connected through saline-filled, low compliant tubing to a 20-22G cannula inserted into the artery. A bag of heparinized saline pressurized to 300 mmHg is attached to the other end of the transducer and infuses saline through the system at 2-4ml/h to maintain the patency of the arterial cannula. A cable connects the transducer to the processor. The arterial pressure wave transmits through the fluid column and vibrates the diaphragm of the transducer which converts it into an electrical signal to be displayed on a monitor. (*Figure 1*)

Figure 1: The components of the Intra-Arterial Blood Pressure monitoring system

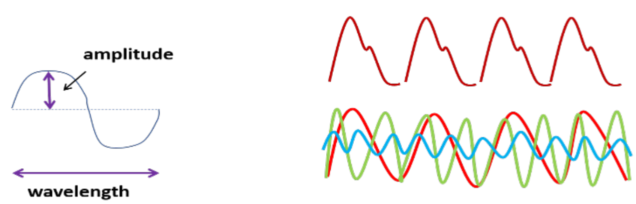


Physical principles

Sine wave

A sine wave is the depiction of movement of energy through a medium. (*Figure 2*) It is described by its 'amplitude' or the maximum displacement, 'wavelength' or distance moved in one cycle and its 'frequency' or the number of cycles it lapses per second, known as 'Hertz' (Hz). Sine waves of differing amplitude and frequency can combine to form a complex wave. Conversely, a complex wave can be broken down into its 'fundamental' wave and a series of 8-10 'harmonic' waves which have frequencies in multiples of the fundamental frequency. Therefore, an arterial pressure wave would have a 'fundamental' wave, with a frequency of 1-3Hz (pulse rate of 60-180/minute or 1-3 per second), and a series of 'harmonic' waves, with frequencies up to 24-30 Hz. The process of analyzing a complex wave by splitting it into its constituent sine waves is known as Fourier analysis. A transducer measuring the arterial pressure should be able to detect all the component waves in order to give an accurate representation of the original waveform.

Figure 2: Sine wave and Fourier analysis-
A complex 'arterial' waveform can be broken down into its component sine waves (fundamental and harmonic)



Natural frequency and Resonance

Every material when struck oscillates at its 'natural' frequency (f_n) and this depends on physical properties of the material, such as density and thickness and also of the adjacent material. If an external force or a waveform, with a frequency similar to the natural frequency, is applied, the material would oscillate at its maximal amplitude and this is known as 'resonance'.

Therefore, if the natural frequency of the IABP monitoring system is close to the frequency of any of the components of an arterial waveform, it would vibrate excessively and distort the signal. Most commercially available arterial pressure transducers have a natural frequency of around 200Hz. However, the addition of 3-way taps and increased length and compliance of the tubing can reduce the natural frequency of the system.

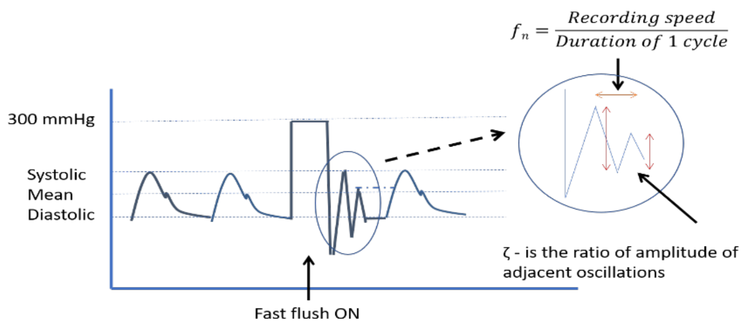
Damping

The arterial pressure monitor, in addition to having a high natural frequency, also needs an appropriate damping coefficient (zeta or ζ). Damping can be construed as the force which brings the transducer system back to its resting stage after the oscillation in order to detect the next wave. Therefore a critical damping is essential for proper functioning of the system, and overdamping or underdamping would adversely affect the measurement. Underdamping leads to large amplitude oscillations and factitiously high systolic and low diastolic pressure readings, while the oscillations are blunted in an overdamped system with erroneously low systolic and a high diastolic pressure. Although in both the situations, the mean arterial pressure may be accurate. In an IABP measuring system, the factors that impede fluid flow such as narrowing (kinks, vasospasm) or obstruction (clots, air bubbles) or a compliant tubing increase damping, that are very similar to the factors that lower the natural frequency. The optimal damping coefficient of 0.7 provides the balance between rapid response and accuracy.

'Fast flush' test

The flushing system can also be used to perform the 'Fast flush' test to calculate the natural frequency and the damping coefficient of the system. A short burst of flush is applied and the pressure waves on the monitor are analyzed. The square wave corresponds to the exposure of the transducer to the 300 mmHg pressure of the flushing system. This is followed by sharp waves oscillating at the natural frequency of the system and it can be calculated by dividing the screen speed by the wavelength of the resonant waves. Therefore, closer the oscillation cycles, higher the natural frequency. Similarly, the ratio of the amplitudes of the second to the first post-flush waves (amplitude ratio) can be used to derive the damping co-efficient from standard nomograms. A low amplitude ratio corresponds to a high damping coefficient, or the system comes to rest quickly. (*Figure 3*)

Figure 3: The ‘Fast flush’ test: This is used to calculate the natural frequency (f_n) and the damping coefficient (ζ) of the system



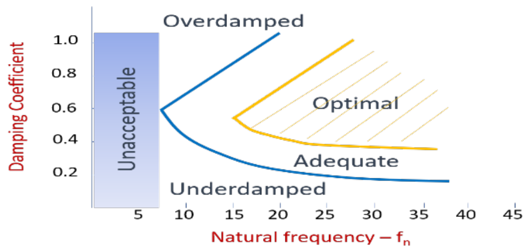
Clinical significance

Although the desired technical requirements for arterial pressure monitoring are a natural frequency greater than 25Hz and a damping coefficient of 0.7, these conditions are rarely met in routine clinical practice. Most catheter-tubing transducer systems are underdamped (damping coefficient of 0.15 to 0.45) and have an acceptable natural frequency of 12-25 Hz, especially if the heart rate is less than 90/min or 1.5Hz. If the f_n of the system is less than 7Hz, it is unacceptable and if the f_n is greater than 24Hz, damping will have minimal effect on the arterial wave recording. Figure 4 shows the relationship between damping coefficient and the natural frequency of arterial pressure monitoring systems. There are five possible situations.

1. Adequate – accurate recording of most pressure waveforms seen clinically
2. Overdamped
3. Underdamped
4. Unacceptable – natural frequency <7Hz
5. Optimal

If the natural frequency is low (10 Hz) then the damping coefficient should be between 0.45-0.6 or the system would resonate and record an erroneous wide pulse pressure.

Figure 4: Relationship between natural frequency and the damping coefficient of the arterial pressure monitoring system



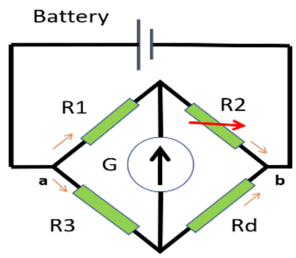
Transducer

The IABP transducers use the physical principle that the electric resistance of a wire varies with its length to convert the pressure of the arterial wave into electrical signal. The arterial pressure wave moves along the fluid column and displaces the diaphragm of the transducer. This displacement compress and stretch the wire attached to the diaphragm and the change in resistance of the wire can be measured precisely by incorporating it as one of the limbs of a 'Wheatstone bridge'.

Wheatstone bridge

Wheatstone bridge is a circuit designed to measure an unknown resistance. (*Figure 5*) Current is passed through two parallel circuits, each with two resistances in series. A galvanometer connects the two circuits in the middle to detect any flow of current between the circuits. When no current flows through the galvanometer and the bridge is said to be balanced, and at this stage the ratio of the resistances R1/R2= R3/Rd. So if Rx is the resistance attached to the diaphragm and it changes with oscillation of the diaphragm, the adjustable resistance R2 can be electronically tuned to balance the bridge and the changes in R2 would reflect the change in pressure and can be electronically displayed.

Figure 5: The Wheatstone Bridge: If Rd (resistance attached to the diaphragm) changes, the adjustable resistance R2 can be electronically tuned to balance the bridge, which would indicate the change in Rd (R- resistances; G galvanometer)



Clinical Points

Practical Points about Transducer setup

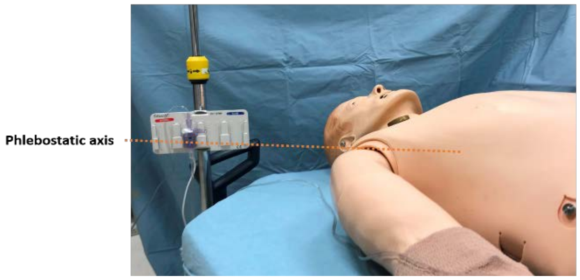
It is crucial that all air bubbles are meticulous removed from the flushing system and the tubing before it is connected to the arterial cannula. The flushing system, pressurized to 300 mmHg, provides a continuous infusion of heparinized saline at 2-4ml/h, which can also be used to flush the system after blood sampling.

Zeroing and Levelling of Transducer

Zeroing – The transducer must be exposed to the atmosphere and calibrated to read zero before it is exposed to the arterial pressure. This is done by turning the three-way stop-cock adjacent to the transducer. Note that the level of the transducer in relation to the patient is not crucial for zeroing.

Levelling – The transducer must be set at the level of the heart (4^{th} intercostal space, mid-axillary line) to measure the blood pressure accurately. This is the ‘phlebostatic’ axis. (*Figure 6*) If not, the hydrostatic pressure of the column of fluid would cause error. If the transducer is 10cm lower than the phlebostatic axis, the pressure would read higher, than actual, by 10 cm H_2O or 7.5 mmHg.

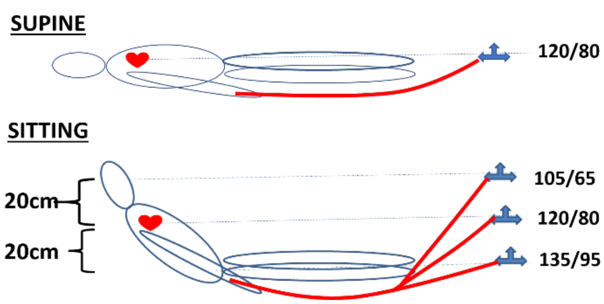
Figure 6: The transducer should be levelled to the '*Phlebostatic*' axis



Effect of change in position of the patient

If the position of the patient is changed for surgical access, the transducer should be re-positioned to the phlebostatic axis to obtain the correct blood pressure. (*Figure 7*) However, if one is interested in monitoring the pressure of the cerebral circulation (e.g. in a patient undergoing shoulder surgery in 'beach-chair' position), the transducer should be placed at the level of the tragus.

Figure 7: The transducer position should be changed with change in patient position



Summary

Close monitoring of blood pressure especially when non-invasive mode is unreliable, analysis of the arterial waveform, and ease to perform arterial blood gas analysis as required are some of the advantages of an IABP measuring system. However, an understanding of the working principles of the system, and knowledge of the common causes of error and ways to trouble-shoot it are essential to avail the maximum benefit of this extremely crucial monitoring mode.

References

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