Monitoring arterial blood pressure

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Abstract

The accurate measurement of a patient's arterial blood pressure is vital as it enables clinicians to deliver safe and appropriate care. Blood pressure is a key measurement of haemodynamic status and is a marker of adequate organ perfusion and tissue flow. This article reviews the physical principles of both non-invasive and invasive methods of arterial blood pressure measurement. Recent developments in 'continuous' non-invasive monitoring techniques are also outlined.

Keywords Manometer; measurement; oscillometry; Peňáz; plethysmography; pressure; tonometry; ultrasound

Royal College of Anaesthetists CPD Matrix: 1A03

Learning objectives

After reading this article, you should be able to:
- understand the concept of pressure
- outline the methods of non-invasive arterial blood pressure measurement
- list the components of an invasive arterial blood pressure measurement system
- describe the process of signal transduction of an arterial waveform
- summarize the advantages and limitations of blood pressure monitors

Introduction

Arterial blood pressure is a key measurement of haemodynamic status and is a marker of adequate organ perfusion and tissue flow. The monitoring of blood pressure is one of the minimal mandatory standards required in anaesthetic practice.[1]

Units of pressure

Pressure is the force exerted per unit area, with Système International (SI) unit: newton per metre squared ($N \cdot m^{-2}$) and derived SI unit: pascal (Pa). Systemic blood pressure is the force exerted by blood over the arterial wall area and is influenced by cardiac output and systemic vascular resistance. The non-SI unit millimetre of mercury, mmHg (1 kPa = 7.5 mmHg) remains the unit for blood pressure, measured as gauge pressure, i.e. relative to ambient pressure.

Non-invasive intermittent methods

Manometry

A pneumatic cuff connected to a liquid filled manometer is inflated, occluding the arterial flow to a limb and then slowly deflated. The pressure measured is the height of the fluid column when the pulse returns distal to the cuff. It is detected by digital palpation or auscultation for Korotkoff sounds.

The Korotkoff sounds have five phases:
- **Phase 1:** Onset of a high pitched tapping sound in synchrony with the arterial pulse rate as cuff deflated. This represents the systolic blood pressure.
- **Phase 2:** Auscultated sounds become softer and develop a swishing character as the arterial blood flow increases.
- **Phase 3:** Auscultated sounds become more defined and louder.
- **Phase 4:** Muffling of auscultated sounds due to reducing turbulence of arterial blood flow.
- **Phase 5:** Restoration of blood flow to the limb with disappearance of sounds. This represents the diastolic blood pressure.

The cuff may be used on the upper arm, forearm or leg, and the width should be 40% of the mid-circumference of the limb, covering two-thirds of the limb length.

Aneroid gauges or electronic pressure transducers are now commonly used.

Oscillometry

Early oscillotonometers (Von Recklinghausen, 1931) used two cuffs. The proximal cuff with adjustable bleed valve occludes arterial flow. The distal cuff senses when pulsations return by means of two aneroid chambers that are connected to a dial via a mechanical linkage. A rotating valve determines interconnections between the cuffs, inflating mechanism, bleed valves, and aneroids.

Devices employing oscillometric principles include the Dinamap (**d**evice for non-**in**vasive **a**utomatic **m**ean **a**rterial **p**ressure) allow automatic hands-free blood pressure measurement at a user-defined frequency. A pneumatic cuff occludes the arterial flow and a microprocessor controls its step-wise deflation, coupled with the patient's heart rate. As the arterial flow returns, the vessel wall vibrates causing variations in cuff pressure, which are sensed by a pressure transducer. The signal is digitized and a microprocessor presents a numerical display. Mean arterial pressure (MAP) is the point of maximal oscillations and the most accurate measurement. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) are calculated as the fastest rate of increase and decrease in oscillation amplitude respectively (Figure 1). The algorithm for measurement will typically require 10–12 of deflation steps.

The DINAMAP SuperSTAT^{TM} device (GE Healthcare) has an algorithm that has no more than four deflation steps. This has been developed to reduce the cycling time, improve patient

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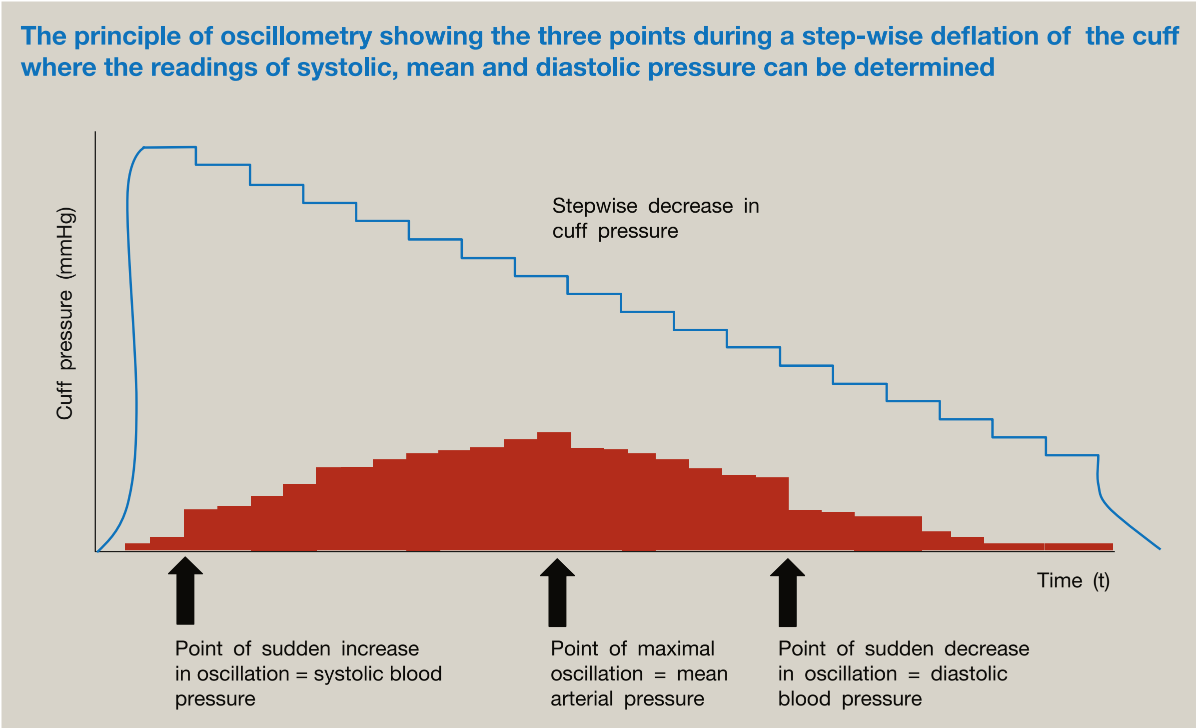

Figure 1

comfort and enhance artifact rejection, whilst retaining the accuracy of the classic DINAMAP system.

These devices are simple to operate and require minimal user training. However, inaccuracies may arise from:

- inappropriate cuff size (over-reading with a small cuff and under-reading with a large cuff)
- limb movement
- external compression
- hypotension
- arrhythmias (atrial fibrillation).

The cuff may cause tissue or nerve damage and patient discomfort. Delay between readings is the major drawback inherent with intermittent techniques and can be overcome by using continuous monitoring devices.

Non-invasive continuous methods

Photoplethysmography (PPT)

Monitors using the Peňáz[2] technique to provide 'raw' continuous pressure readings include the Finapres™ (**fin**ger **a**rterial **pres**sure) and the CNAP™. Finger infrared plethysmography detects changes in blood volume, and is used in conjunction with a finger cuff and servo-controlled pump which adjusts cuff pressure to maintain a constant finger blood volume (the 'vascular unloading' technique).[3]

The Finapres™ uses a single finger cuff that can lead to venous congestion distally, affecting the accuracy of measurements. The CNAP™ overcomes this by alternating the readings between two adjacent finger cuffs.[3] In patients undergoing general anaesthesia, the CNAP™ has comparable accuracy to invasive intra-arterial pressure measurements,[4] however, the device is less accurate during episodes of hypotension or where there are rapid changes in vascular tone.[5] Other limitations of this technique include the need for repeated calibration with the brachial artery pressure using a proximal oscillometric cuff, the potential for patient discomfort and digital damage. Optical plethysmography can be unreliable in patients who are vasoconstricted, hypothermic, have peripheral vascular disease or oedema.

The Nexfin™ monitor (BMEYE B.V, Amsterdam, The Netherlands) uses similar vascular unloading techniques to produce a brachial arterial pressure waveform. It employs modern optical components, microprocessor and mathematical algorithms, along with an inflatable finger cuff, from which pressure readings are derived. The Nexfin™ reliably and rapidly detects acute changes in arterial pressure, but reduced precision during periods of haemodynamic instability makes it an unsuitable alternative to direct pressure monitoring.[6]

Recently, advances have been made with optical PPT blood pressure measurement using cuffless technologies. The amplitudes and phases of the measured waveforms are processed using fast Fourier transformation (FFT), which are then used to estimate blood pressure.[7] This method avoids the risk of digital ischaemia from a finger cuff; however, as with the Peňáz techniques and the Nexfin™, its level of accuracy is dependent on adequacy of digital perfusion.

Applanation tonometry

A pressure transducer is applied directly over and partially flattens the radial artery.[8] The resultant waveform is used to calculate systolic, diastolic and mean arterial pressures. An algorithm allows the accurate calculation of pressure values such as central systolic pressure, pulse wave velocity and ejection time.

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