Biomedical Instrumentation

E. Blood Pressure

Dr Gari Clifford
Adapted from slides by Prof. Lionel Tarassenko
Blood pressure

- Blood is pumped around the body by the heart.
- It makes its way around the body through a network of tubes known as the vascular system.
- Together with the heart they form the cardiovascular system.
The vascular system

- Three sub-systems:
  - **Arteries**: high-pressure arterial tubes which carry the blood away from the heart
  - **Capillary network**: fine, thin-walled tubes which allow transfer of nutrients & oxygen into cells and the removal of waste products from the cells
  - **Veins**: low-pressure tubes which return the blood to the heart
Blood pressure is generally recorded using two measurements (in mmHg):

- Systolic Pressure
- Diastolic Pressure

Blood pressure is usually reported as "Systolic over Diastolic"; e.g. 120/70 is a systolic pressure of 120 mmHg and a diastolic pressure of 70 mmHg.
Systolic blood pressure

- Systolic blood pressure (SBP) is the arterial pressure when the heart is beating (during systole).

- It is, broadly speaking, the highest pressure present in the arterial (and vascular) system.

- It is a reflection of how hard the heart is pumping.
Diastolic blood pressure (DBP) is the arterial pressure when the heart is not beating (during diastole).

- It is, broadly speaking, the lowest pressure present in the arterial (but not vascular) system.
- It is a reflection of the resistance against which the heart is pumping.
Other measures of blood pressure

- There are two other measures of blood pressure:
  - *Pulse Pressure*, the difference between systolic and diastolic pressures
  - *Mean Arterial Pressure*, the mean over the cardiac cycle. It is usually approximated using the following formula:

    \[ \text{MAP} = \frac{2}{3} \text{DBP} + \frac{1}{3} \text{SBP} \]
Measurement of blood pressure

- Blood pressure is measured invasively (in the Intensive Care Unit) using a catheter and a pressure transducer.

- There are two main methods of non-invasive blood pressure measurements:
  - Korotkoff sounds
  - Oscillometry
Blood flow occlusion

- With both methods, it is necessary to occlude the flow of blood in arteries.
- To achieve this, occlusive pressure is applied evenly around the limb.
- The pressure is transmitted to the underlying blood vessels.
- The pressure difference between the inside of the blood vessel and the surrounding tissue (the *transmural* pressure) is lowered as the occlusive pressure is increased.
Blood flow occlusion

- As the transmural pressure decreases, the radial stress in the vessel decreases.
- It is assumed that when the transmural pressure reaches zero, there is no hoop stress.
- At this point, the vessel is said to be *unloaded*. 
Blood flow occlusion

- Once the vessel has been unloaded, any further increase in pressure will collapse the vessel, occluding the flow completely.
- Vascular unloading is achieved using an *occlusive cuff* which is wrapped around the limb.
Korotkoff sounds

- Introduced by the Russian Army physician N. Korotkoff in 1905.
- Korotkoff discovered that, if a limb is partially occluded, a cardiac-synchronous sound is still present in the limb distal to the occlusion.
- The method therefore relies on occluding the flow of arterial blood for a short period of time.
Korotkoff sounds

- These are the sounds for which clinicians listen out when they take blood pressure using a cuff and a stethoscope.
- They are only present if an artery is partially occluded.
- Different degrees of occlusion result in different types of sound.
Korotkoff sounds

- The cuff is initially inflated to a sufficient pressure to occlude the limb completely.

- Then the pressure is slowly decreased (2-3 mmHg s\(^{-1}\)).

- This gives rise to four or five different “phases” of Korotkoff sounds.
I Initial “tapping” sounds

II The tapping sounds increase in intensity but are less well defined in time

III The loudest phase, more akin to a thump than a tap

IV A much more muffled sound

V Silence – no Korotkoff sounds
Automating the method of Korotkoff sounds

Three-phase process:

1. The cuff cuff is inflated to slightly (20-30 mmHg) above systolic pressure.
2. The cuff is deflated slowly and the audio signal from a microphone placed distal to the cuff is analysed to identify each successive phase of Korotkoff sounds.
3. Once Phase IV has been identified, the cuff is deflated rapidly and the pressures are reported.
Automating the method of Korotkoff sounds
Cuff control

Cuff control is achieved using a pump and a few control valves:
Analysis of Korotkoff sounds

- Automating the analysis of the sounds recorded by the microphone is difficult:
  - The presence of other sounds (e.g. the noise of the heart beating) confuses the analysis.
  - The distinction between the different Korotkoff phases, whilst relatively easy for a trained clinician, is much harder to achieve with signal processing.
Oscillometry

- This method was discovered by the French physiologist Marey in 1885.

- He investigated the effect of putting a patient's arm in a pressure vessel.

- He noted that the pressure in the vessel fluctuated with the beating of the heart.

- The magnitude of these pressure fluctuations varied with the applied pressure.
Pressure fluctuations

- First assumption:
  - The start of the pressure fluctuations occurs at systolic pressure.
  - The end of the pressure fluctuations occurs at diastolic pressure.
- It turns out, however, that this is not the case.
Pressure fluctuations

- Empirical studies have shown that:
  - The onset of the oscillations occurs well above systolic pressure.
  - The oscillations do not disappear until well below diastolic pressure.
The pressure at which the oscillations have their maximum amplitude is the Mean Arterial Pressure (MAP).
Empirical determination of systolic and diastolic pressures

Systolic pressure = cuff pressure when the oscillation amplitude is 55% of the maximum amplitude
Diastolic pressure = cuff pressure when the oscillation amplitude is 85% of the maximum amplitude
Oscillometry – system overview

- It is possible to design a system for measuring blood pressure non-invasively using oscillometry.
- The cuff control system developed for the method of Korotkoff sounds can be used and combined with a pressure measurement system.
Oscillometry – system overview

- The signal from the pressure transducer has two components:
  - the underlying pressure of the cuff
  - the cardiac-synchronous oscillations
Pressure measurement system

- The pressure measurement system consists of the following:
  - A pressure transducer to sense the cuff pressure (including the cardiac-synchronous oscillations)
  - Amplification and filtering
  - Analogue-to-digital conversion
Pressure measurement system

- Pressure transducers typically employ the piezo-resistive principle to convert pressure into an electrical signal.
- A silicon chip is micro-machined to give a diaphragm around which four resistors are diffused in a bridge configuration.
- Application of pressure to the diaphragm results in a change in the value of the resistors.
- Typically these transducers have an output impedance of 5 kΩ and generate differential outputs with a dynamic range of 200 mV.
Amplification and filtering

- Instrumentation amplifier (as with ECG or EEG measurement) is used to amplify the differential pressure transducer output.

- Amplifier output is low-pass filtered to derive the cuff pressure signal and high-pass filtered to extract the cardiac-synchronous fluctuations.
Analogue-to-digital conversion

- **Sampling frequency:**
  - Accurate peak detection requires 10 samples per cycle of cardiac-synchronous fluctuations $\rightarrow$ choose a sampling frequency of 50 Hz or above for that channel.

- **Amplitude resolution:**
  - 8-bit accuracy should be sufficient for A-D conversion:
    - Low-pass filtered cuff pressure signal needs to be resolved to 1 or 2 mmHg in a range of 0 to 300 mmHg
    - High-pass filtered cardiac-synchronous fluctuations will be digitised with 0.5% accuracy.
A simple (low-cost) BP monitor

- Pressure sensor, A/D & USB
- No battery or UI needed
- All work done by phone
Signal processing

• Software will perform the following functions:
  • Initiating the measurement cycle and driving the cuff controller (or telling the user to pump’)
  • Reading in the digitised data
  • Recording the amplitude of the cardiac-synchronous fluctuations at the different cuff pressures
  • Computing mean, systolic and diastolic pressures
  • Computing pulse rate, if required

• (It is of course possible for the low-pass and high-pass filtering of the overall cuff pressure signal also to be performed in software after A-D conversion of the amplifier output.)
Errors

- Cuff size & fitting
- Arm position
- Measurement error
- Patient demographics (calibration)
- Movement artefact
- Quantisation
- ...

B18/BME2 Biomedical Instrumentation
Safety issues

1. Over-inflation of the cuff can lead to bruising (particularly in the elderly):

2. If blood flow is occluded for too long, oxygen depletion can occur.
Safety issues

Patient safety can be enhanced by introducing:

1. An over-pressure control:
   - Pressure is monitored such that if the pressure or its integration over time exceeds certain thresholds, the cuff is automatically deflated.

2. A default action:
   - Deflate the cuff when there has been no change in control inputs for a set time or when there are conflicts between input signals.
Combined with pulse oximetry?

- How could we estimate blood pressure more reliably by using the pulse oximeter too?
  - (Type of data fusion)

- Which blood pressures can’t be measure this way? Why?
Combined with pulse oximetry
Summary: vital sign measurement

Oscillometry has become a safe and reliable method to measure blood pressure non-invasively.

- It is possible to measure non-invasively:
  - **Blood pressure** (using oscillometry) and **core temperature** (using an or tympanic thermometer) *periodically*;
  - **Heart rate** (from the ECG), **breathing rate** (using electrical impedance plethysmography) and **oxygen saturation** (with pulse oximetry) *continuously*.