Lecture 13
Measurement of Blood Volume
Today in PBS&D

✦ Measurement of blood volume
  ✦ Chamber plethysmography
  ✦ Impedance plethysmography
  ✦ Photo plethysmography

✦ Next Week
  ✦ Nervous system

✦ Haven’t had a quiz for some time… 😊
Plethysmography is the determination of blood flow (or other physiological parameters) by measurement of volume changes of the limb.

A typical plethysmograph generates a waveform similar to the arterial pressure waveform.

The advantages include non-invasive nature of measuring blood volume and flow relatively easily. Applications of plethysmography related measurements have wide applications, albeit with limited accuracy.
The chamber has a rigid cylindrical container that houses a bladder filled with liquid (water) or air. As the volume of the limb increases due to arterial flow (venous flow is occluded by the cuff), the volume / pressure of the bladder changes which can be measured using a pressure transducer or simply by the water rising on a calibrated tube (also called *venous occlusion plethysmography*).
Chamber Plethysmography

(for calibrating the volume changes)
After venous-occlusion cuff pressure is turned on, the initial volume-versus-time slope is caused by arterial inflow. After the cuff is released, segment volume rapidly returns to normal (A). If a venous thrombosis blocks the vein, return to normal is slower (B).
The change in volume (blood or air) can easily be obtained by measuring the resistivity changes in the appropriate tissue in response to the volume changes:

- Volume of limb → due to blood pulsations
- Volume of air in lungs → due to respiration

The basic assumption is that the limb is considered to be of cylindrical shape (makes sense for blood vessels, but for lungs?)

The changes in blood volume causes $\Delta A$, which then causes change in resistivity, measured as shunting impedance of blood.
Other Assumptions

1. The expansion of arteries is uniform (probably true on healthy vessels, but not so in diseased vessels)
2. Resistivity of blood, $\rho_b$, does not change (not true!, it decreases with velocity as cells become more streamlined at higher velocities)
3. Lines of current distribution are parallel to the arteries (probably true for most limb segments, but not so for knees!)

$$Z_b = \frac{\rho_b L}{\Delta A}$$

$$\Delta V = L \Delta A = \frac{\rho_b L^2}{Z_b}$$

What’s in the equation

However, we measure $\Delta Z$, not $Z_b$ which is

$$\Delta Z = [Z_b \ || \ Z - Z] = \frac{-Z^2}{Z + Z_b}$$

What’s really measured(!)

$$Z \ll Z_b \Rightarrow \frac{1}{Z_b} \cong \frac{-\Delta Z}{Z^2}$$

$$\Delta V = \frac{-\rho_b L^2 \Delta Z}{Z^2}$$
4-electrode impedance plethysmography: current is injected through two outer electrodes, and voltage is sensed between two inner electrodes. Amplification and demodulation yield $Z + \Delta Z$. Normally, a balancing voltage $v_b$ is applied to produce the desired $\Delta Z$. In the automatic-reset system, when saturation of $v_o$ occurs, the comparator commands the sample and hold to sample $Z + \Delta Z$ and hold it as $v_b$. This resets the input to the final amplifier and $v_o$ zero. Further changes in $\Delta Z$ cause change in $v_b$ without saturation.
Applications

- Volume measurements on legs
- Occlusion in one or both limb vessels (venous thrombosis)

- Transthoracic E.P.
- Rate of ventilation, volume of ventilation (infant apnea monitoring, SIDS)

- Body water and body fat measurements (most body fat analyzers sold in stores use a similar approach)

- Ring electrodes on neck and waist
- Impedance cardiography for cardiac output estimation
Photoplethysmography

- Light transmitted through a capillary bed whose absorption and reflection properties change in response to changes in volume of the vessels.
- Light source used today is typically an IR LED, the sensor is typically a phototransistor used along with a optical filter to pass lights of relevant wavelength
- Also used in oximetry measurements for measuring blood $O_2$ content, as well as heart rate (not affected from electrosurgical equipment that kills ECG).
Photoplethysmography