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ROOM NAME:
BIOM9420CARDIAC

Cardiac Monitoring

BIOM9420 - T2 2019

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UNSW SYDNEY

Learning outcomes

- Identify the main functions of the circulatory system
- Understand the electrical activity of the heart
- Understand techniques used to diagnose cardiac diseases.

Contents

- Cardiovascular physiology
- Electrical activity of the heart
- Blood pressure measurement
- Cardiac output measurement and estimation

But first, about me

Education

- BEng (Medical Engineering) QUT 2010
- PhD Biomedical Engineering UQ 2014
- UNSW since 2015

Work

- Innovative Cardiovascular Engineering Technology (ICET) Laboratory, Brisbane – Researcher.
- BiVACOR (Artificial Heart Startup) - consultant

First activity…

Imagine that you're a doctor. A patient comes in, saying they think they've got heart problems.

What do you do?

Think about

What do I measure?

How do I measure it?

One minute to discuss with your neighbour, then put your two best answers (one each) up on Socrative

Cardiovascular Physiology

Main functions of the circulatory system

Transportation

• brings oxygen to body cells and takes away carbon dioxide (a waste product)

• carries nutrients from the gastrointestinal tract (gut) to body cells

• carries hormones from endocrine glands to body cells

Regulation

• helps regulate the pH of body fluid

• helps regulate body temperature

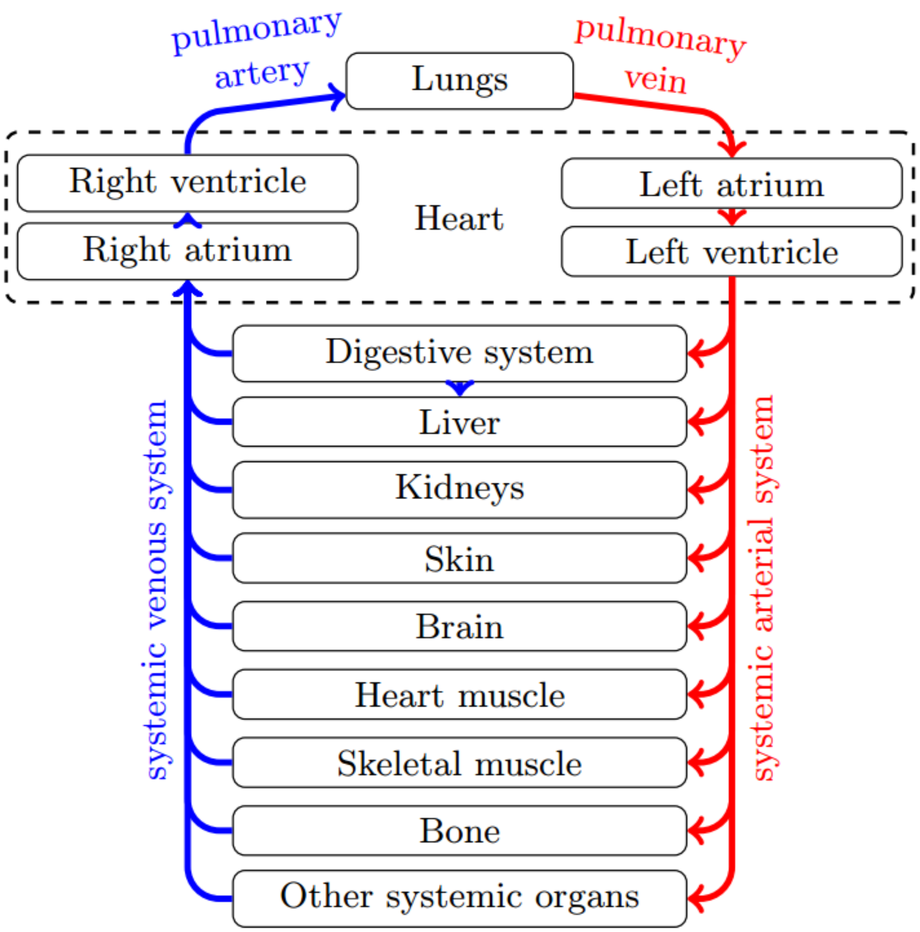
• regulates water content of cells

Protection

• carries white blood cells, antibodies, and interferons that protect against disease

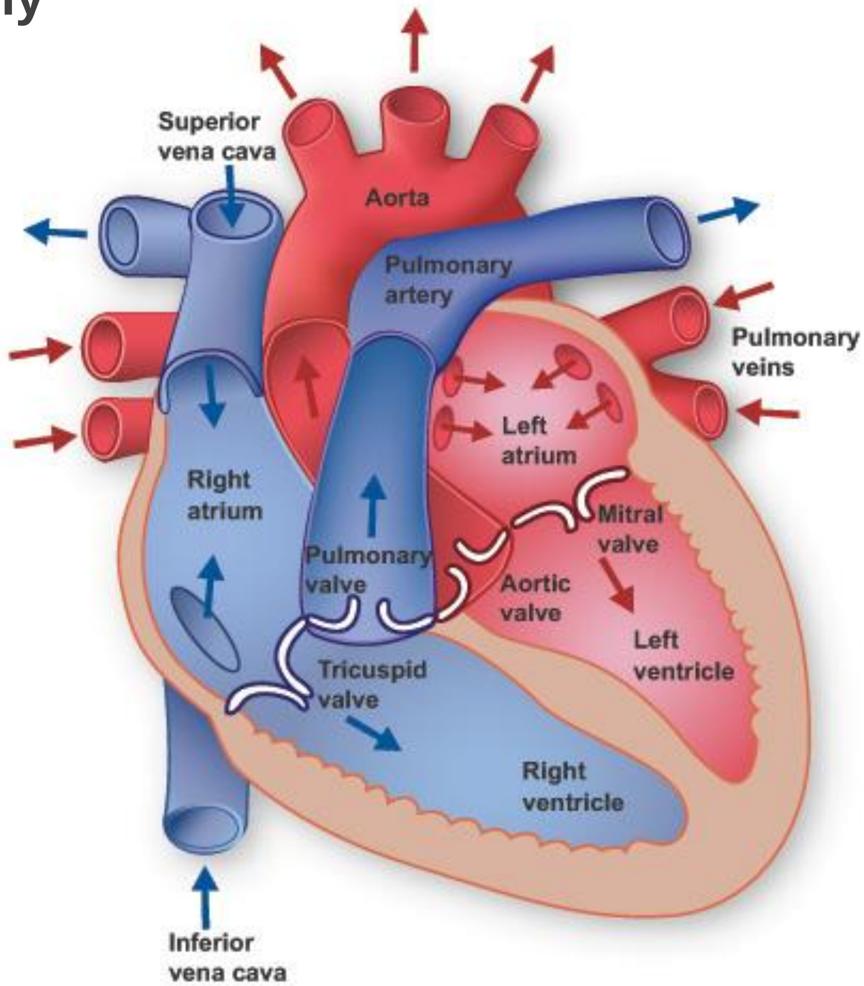
Cardiovascular Physiology

The Circulation



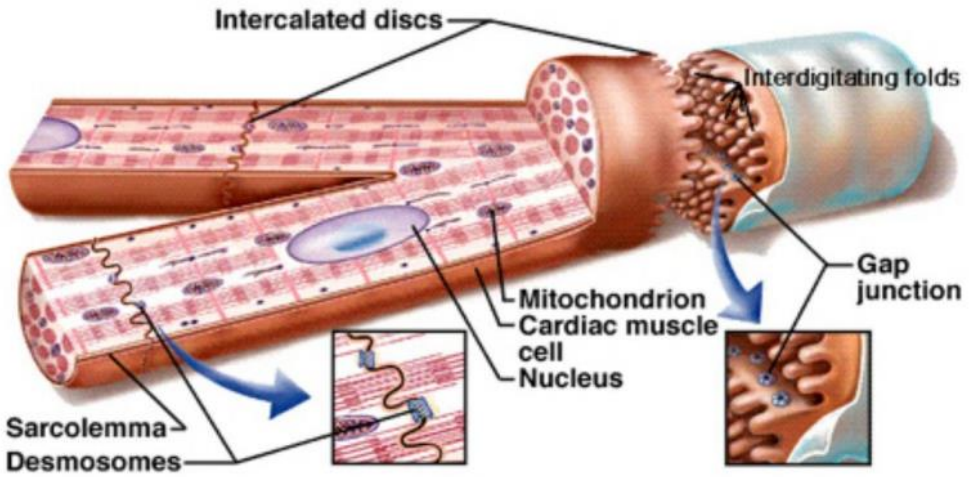
Cardiovascular Physiology

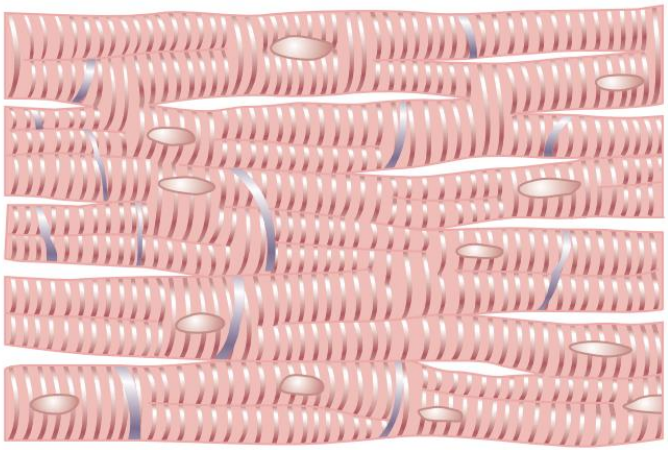
Functional Anatomy



Cardiovascular Physiology

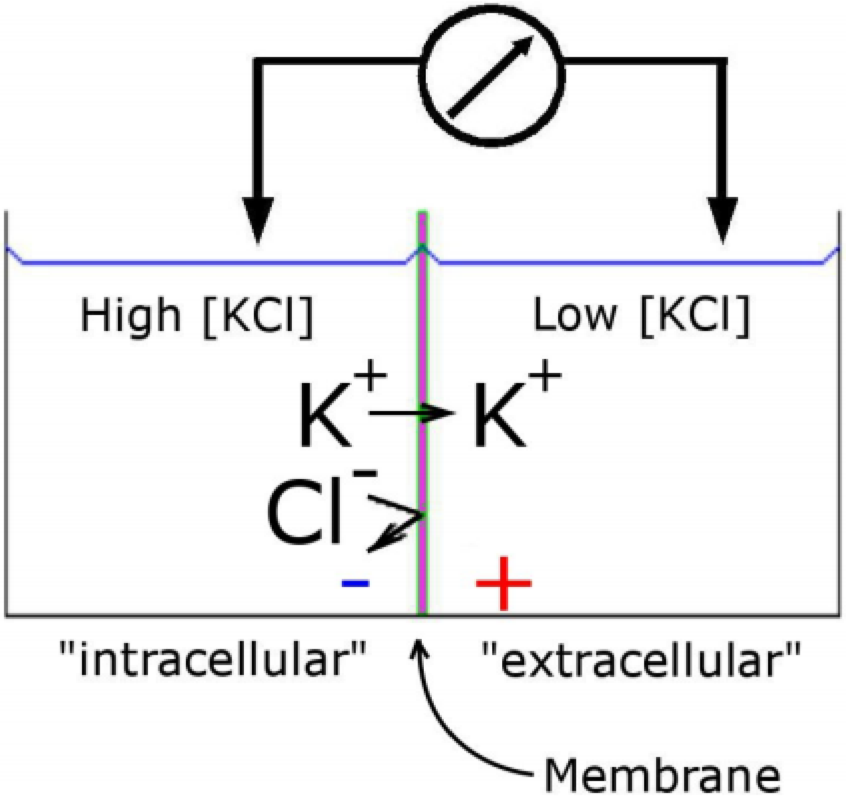
The cardiomyocyte – “Heart Muscle Cell”





Electrical Activity of the Heart

Where does the energy come from?



Electrical Activity of the Heart

The Nernst Equation: Calculating the membrane potential

$$E_x = \frac{RT}{z_x F} \ln \frac{[X]_o}{[X]_i}$$

E_x Nernst potential for ion X (membrane potentials, inside with respect to outside)

$[X]_o$ concentration of X outside the cell

$[X]_i$ concentration of X inside the cell

z_x valence of ion X

R Universal gas constant (8.3144598 J K^{-1} mol^{-1})

T absolute temperature

F Faraday's constant (9.65 x 10^4 C mol^{-1})

Electrical Activity of the Heart

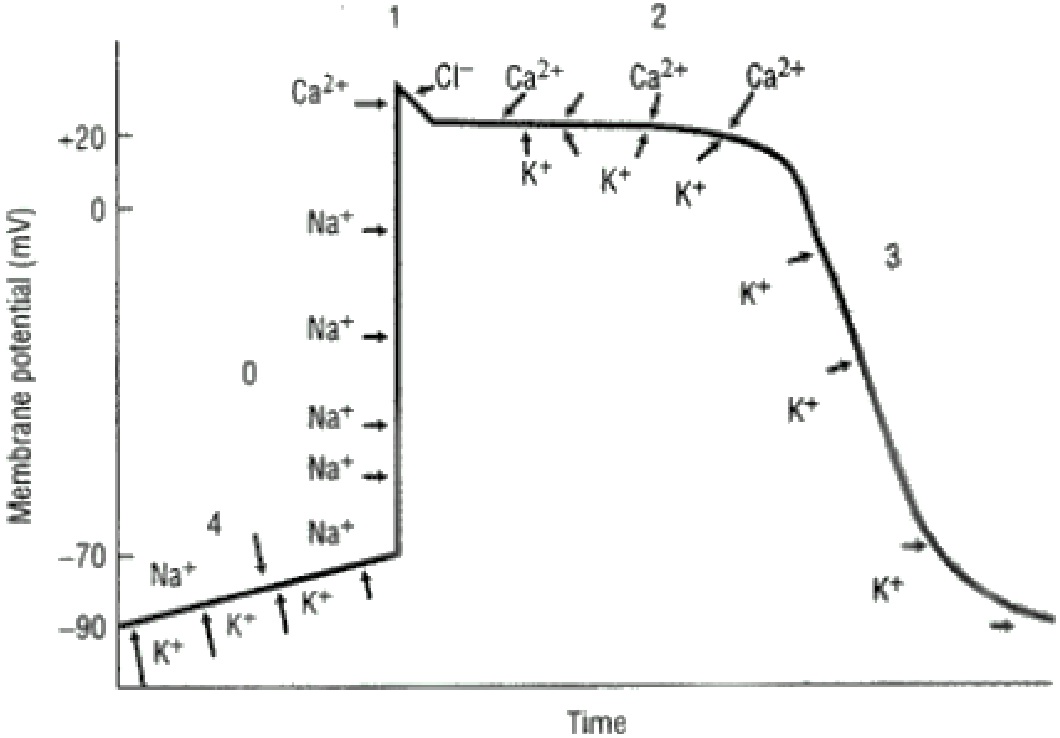
Cardiac cell ionic concentrations

Ion	Intracellular concentration (mm/L)	Extracellular concentration (mm/L)	Equilibrium potential (mV)
Na^+	7	144	+81
K^+	151	4	-97
Cl^-	4	114	-90
		Sum:	-106

Source: Little RC. Physiology of the heart and circulation, Year Book Medical Publishers, Chicago, 1977.

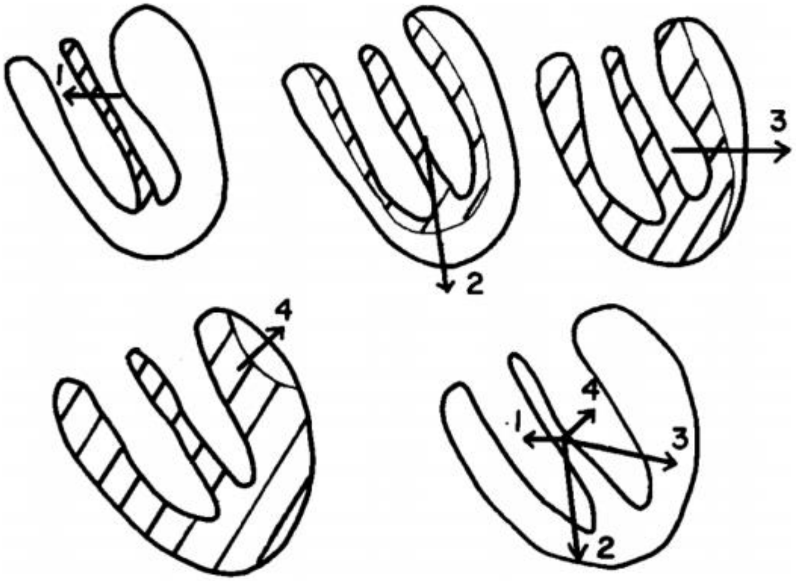
Electrical Activity of the Heart

Movement of ions during the action potential and spontaneous depolarisation



Electrical Activity of the Heart

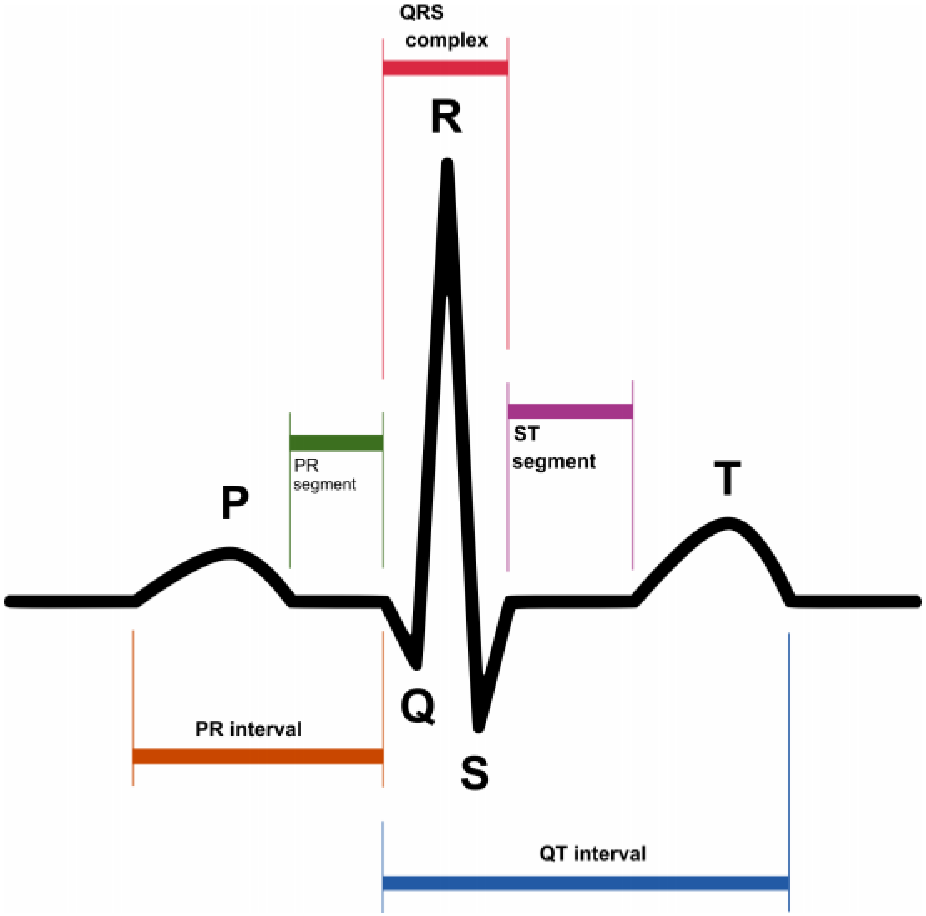
Electrical activity in the heart as a whole



Hashed area represents the part of the muscle which is depolarised at different time points (1,2,3,4).

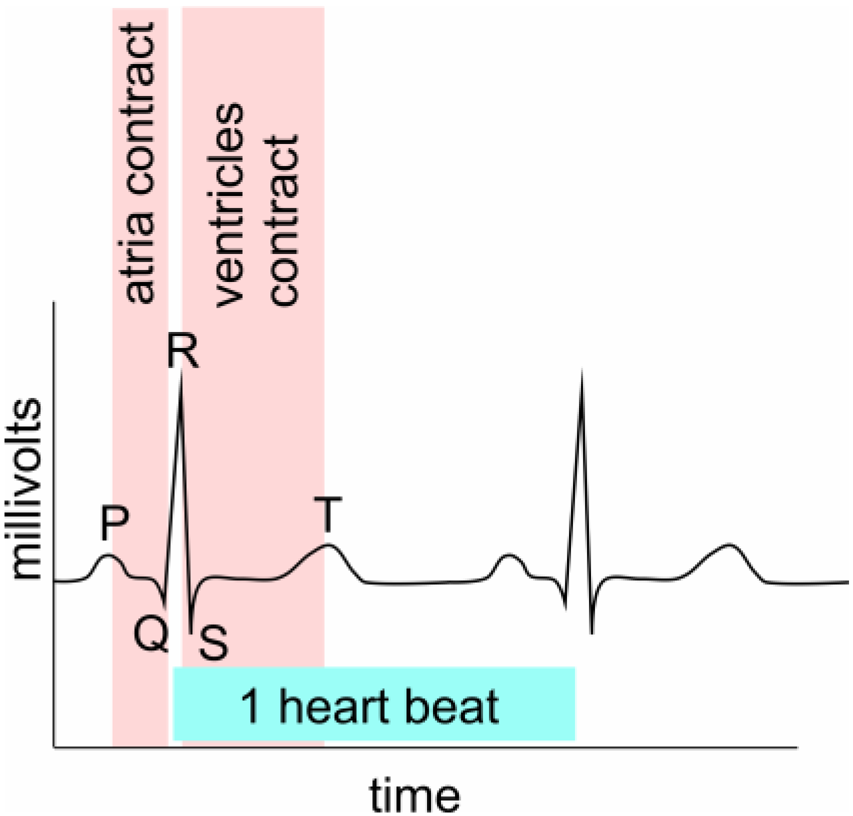
Electrical Activity of the Heart

Features of the electrocardiogram



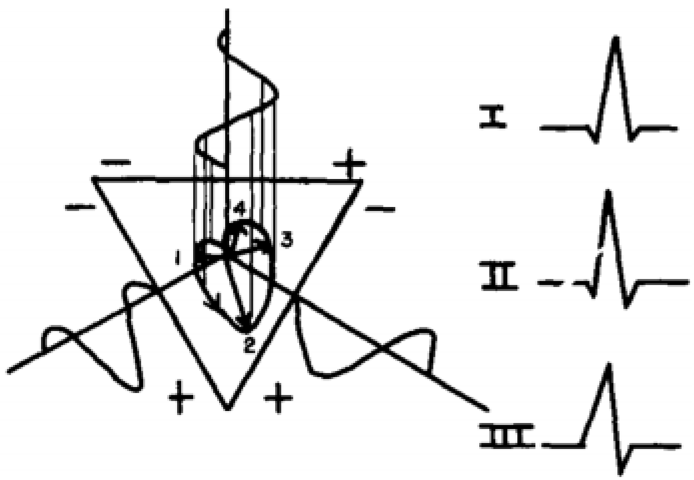
Electrical Activity of the Heart

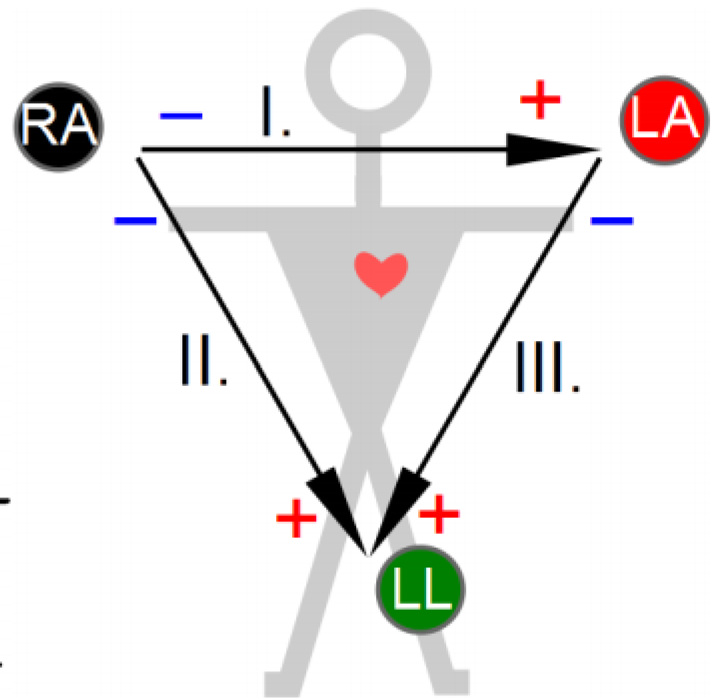
Features of the electrocardiogram



Electrical Activity of the Heart

The electrocardiogram (ECG) and Einthoven's triangle

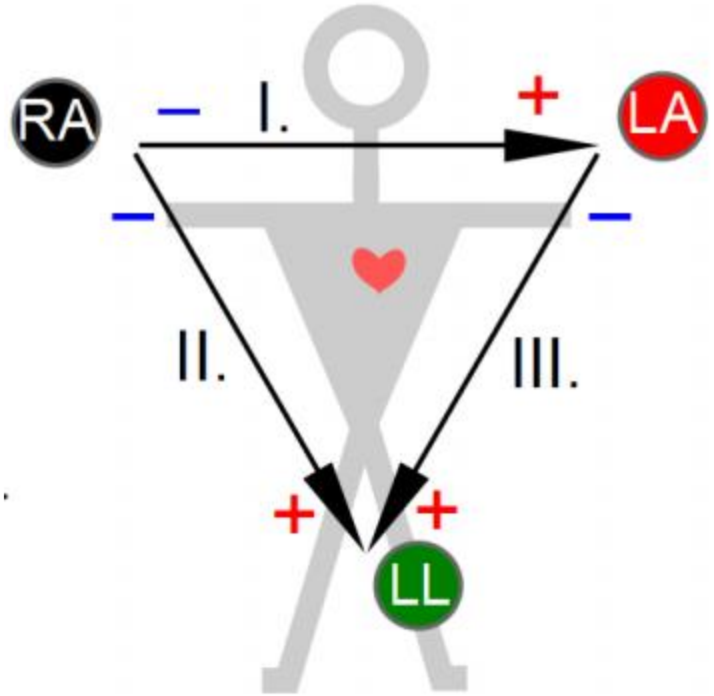




Electrical Activity of the Heart

The electrocardiogram (ECG) and Einthoven's triangle

Einthoven's law
If any two of the three bipolar limb ECG signals is known, the third can be mathematically calculated by summing the two known signals.

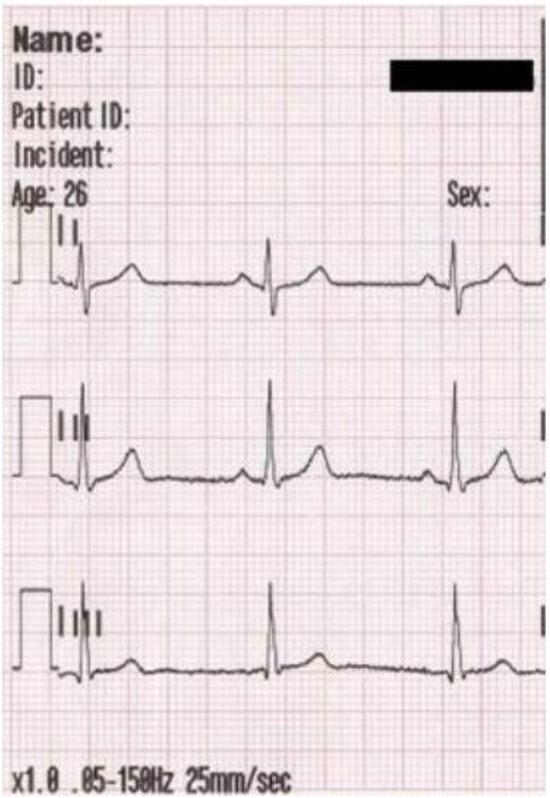


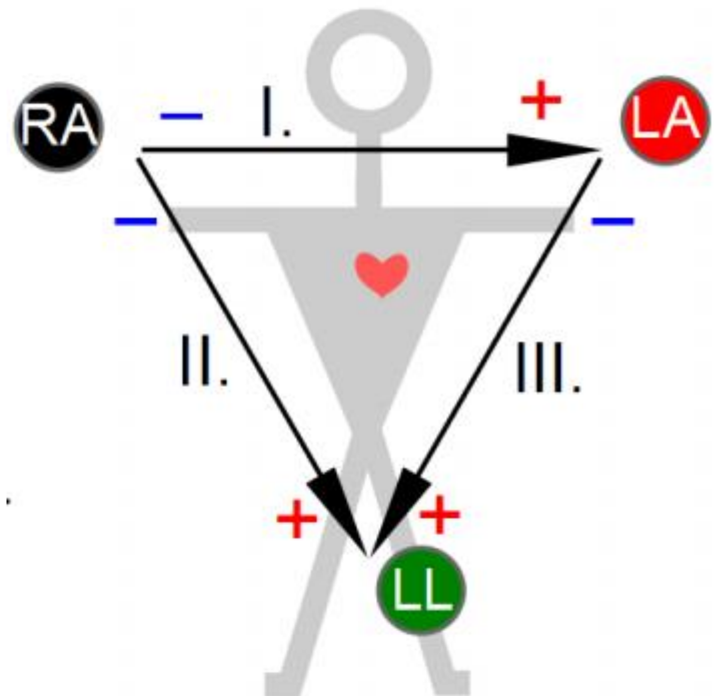
RA = -0.2 mV
LA = +0.3 mV
LL = +1.0 mV

Lead I = 0.5 mV
Lead II = 1.2 mV
Lead III = 0.7mV

Electrical Activity of the Heart

The electrocardiogram (ECG) – Bipolar Leads



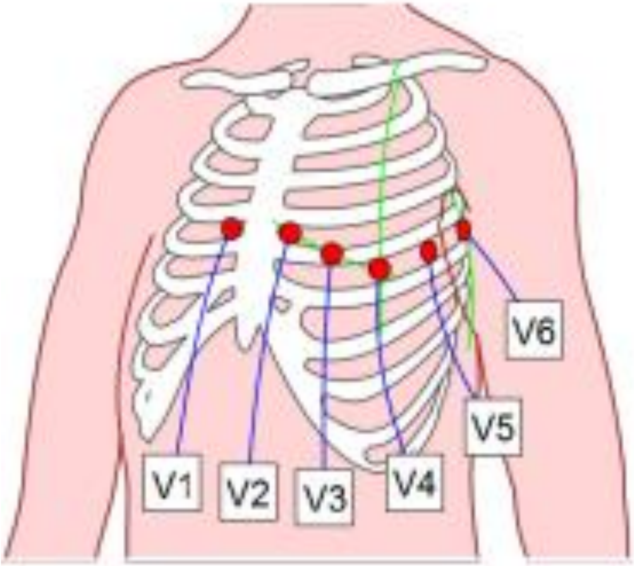


Electrical Activity of the Heart

The electrocardiogram (ECG) – Precordial leads (Chest leads)

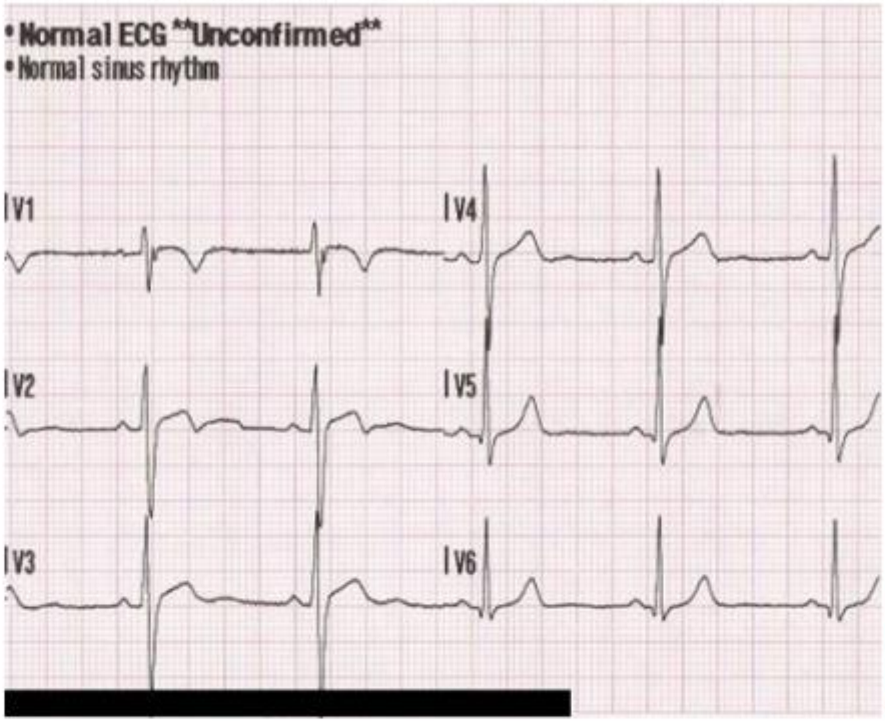
Positive Lead Vx

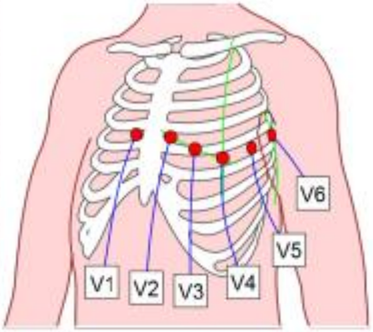
Negative Combined RA, LA, LL



Electrical Activity of the Heart

The electrocardiogram (ECG) – Precordial leads (Chest leads)



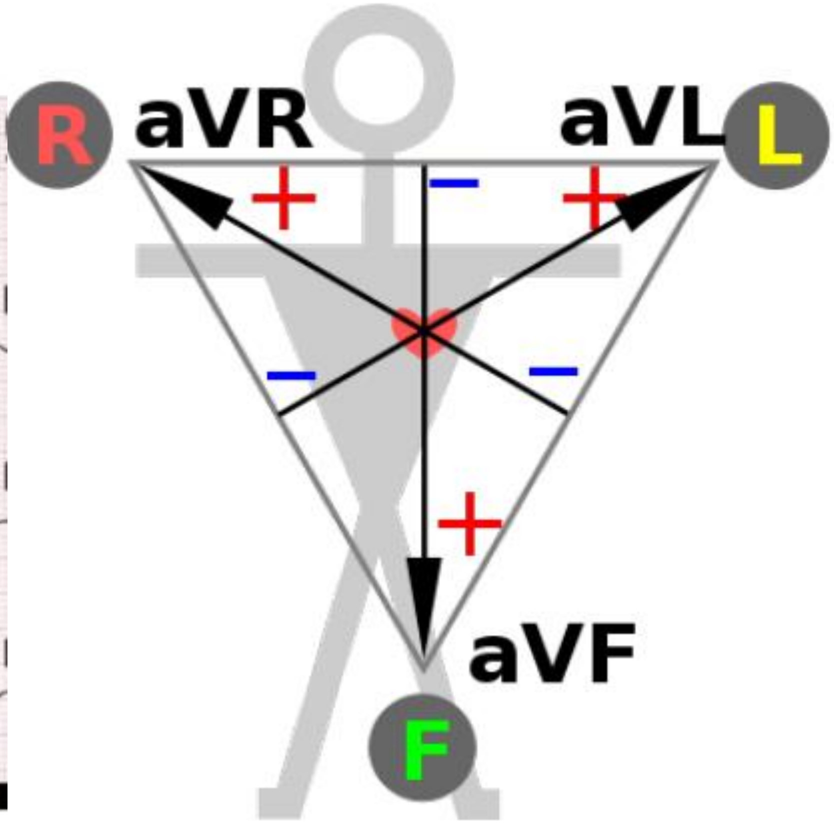


Positive Lead Vx

Negative Combined RA, LA, LL

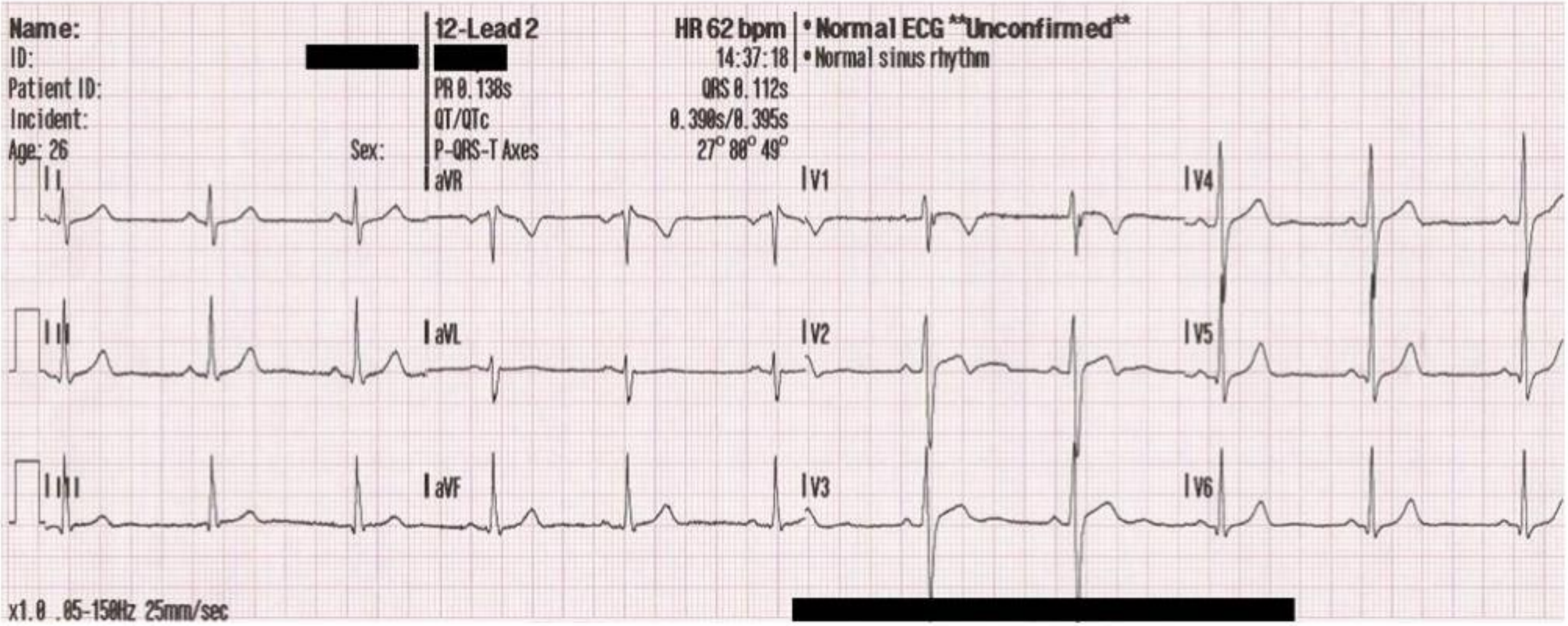
Electrical Activity of the Heart

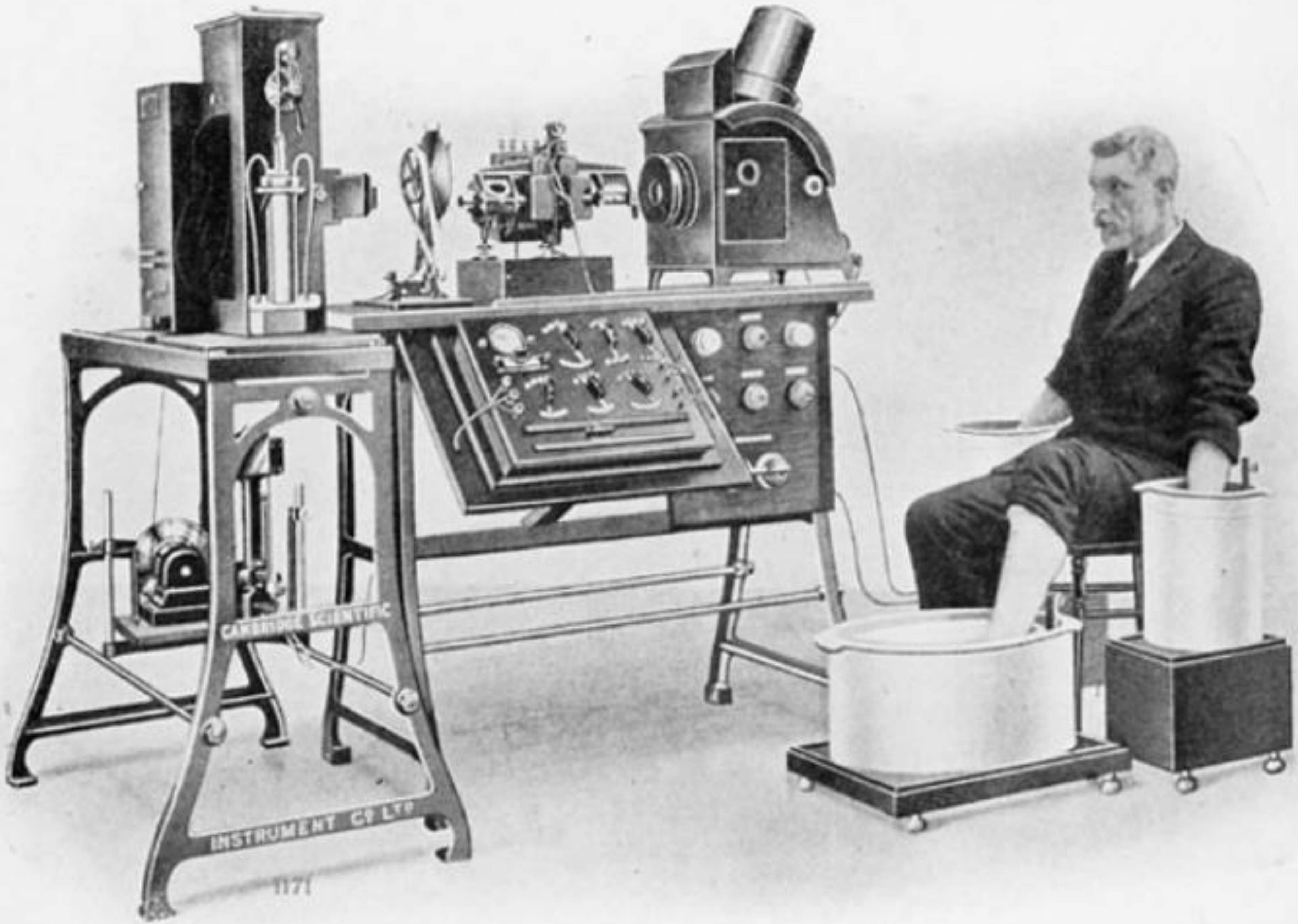
The electrocardiogram (ECG) – Augmented unipolar limb leads



Electrical Activity of the Heart

The 12-lead ECG

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Electrical Activity of the Heart

Biomaterials in ECG Measurement

Electrical Activity of the Heart
Diagnosis from the ECG

- **Increased voltages:** cardiac hypertrophy.

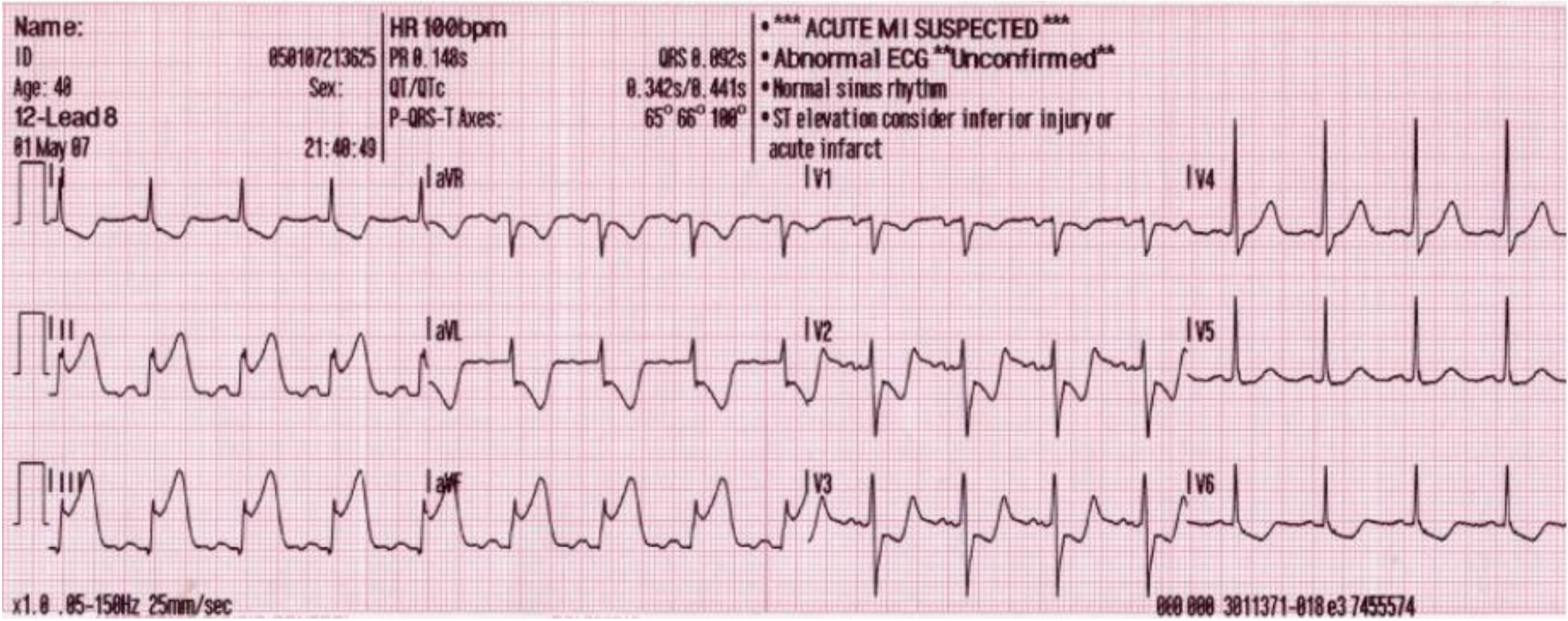
- **Decreased voltages:** cardiac myopathy; or, fluid in the pericardium.

- **Prolonged QRS (>0.09sec):** cardiac hypertrophy; cardiac dilation; or Purkinje system block.

- **Myocardial infarction…..**

Electrical Activity of the Heart

Diagnosis from the ECG



Electrical Activity of the Heart

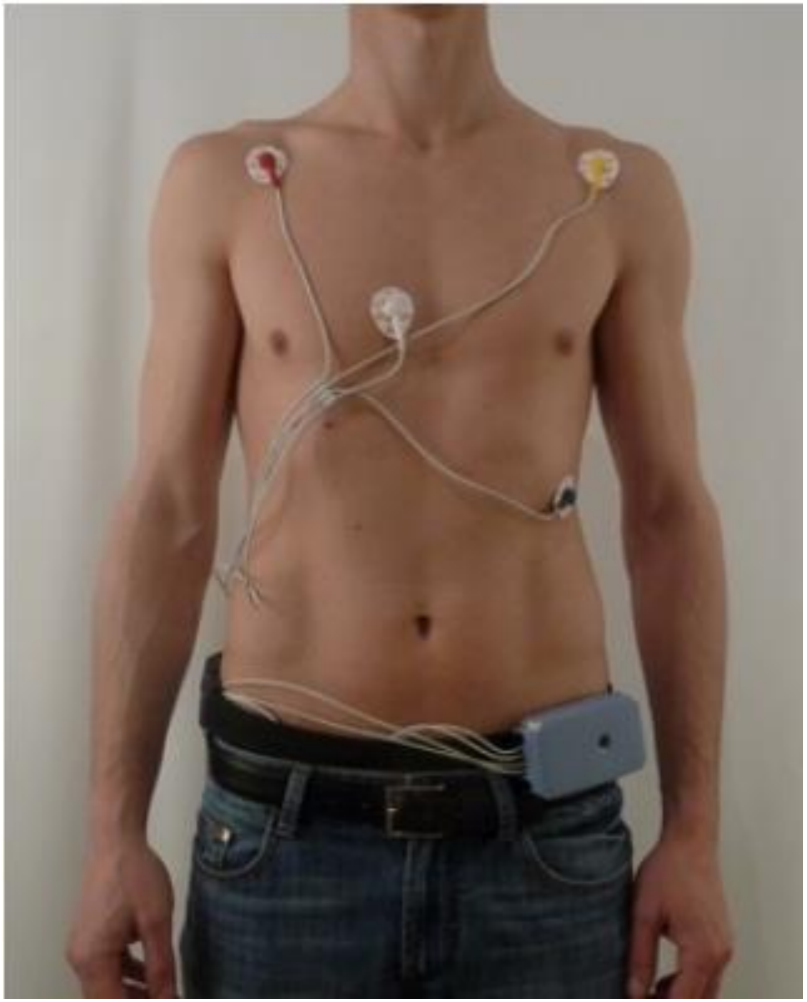
Diagnosis from the ECG

atrial fibrillation

Example given here is of atrial fibrillation (top) and normal sinus rhythm (bottom) on Lead I.

Electrical Activity of the Heart

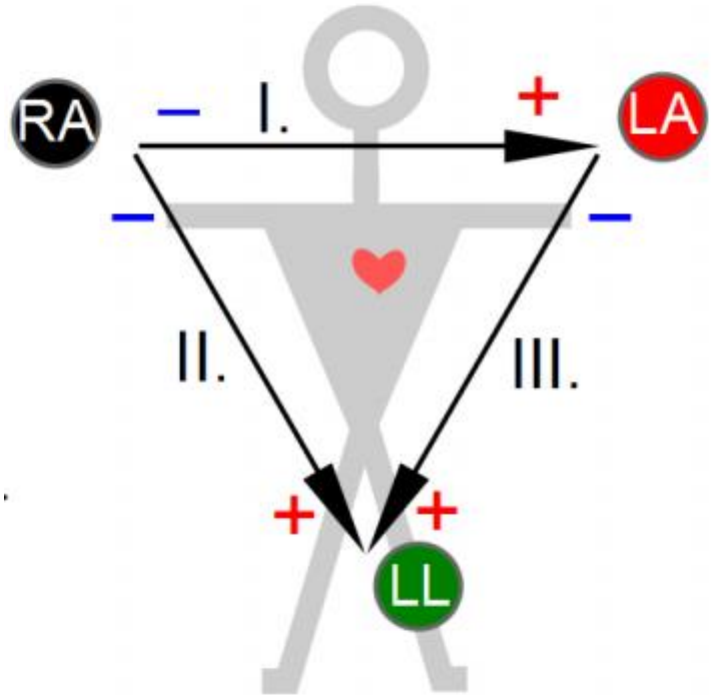
Holter monitor

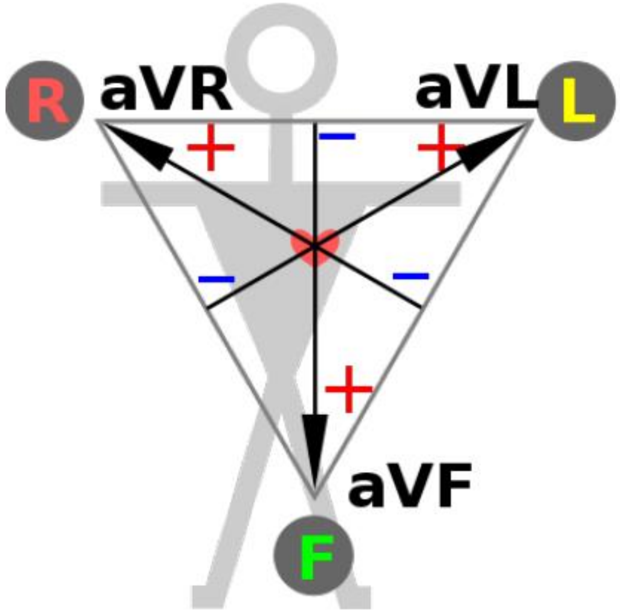


Electrical Activity of the Heart

Worked Problem – solution available online.

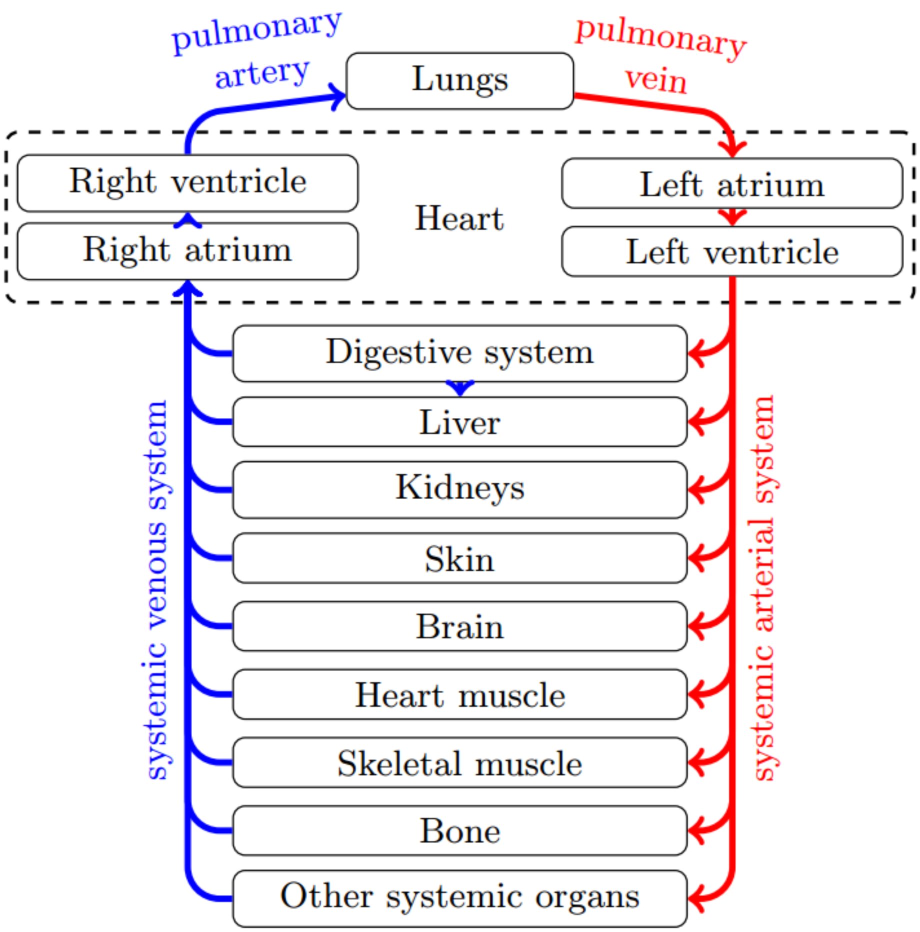
A three lead ECG is used and at a certain point in time: the right arm is at +0.2 mV; the left arm is at -0.1 mV; and lead II is reading -0.1 mV. Calculate the LL voltage, and the aVF voltage.



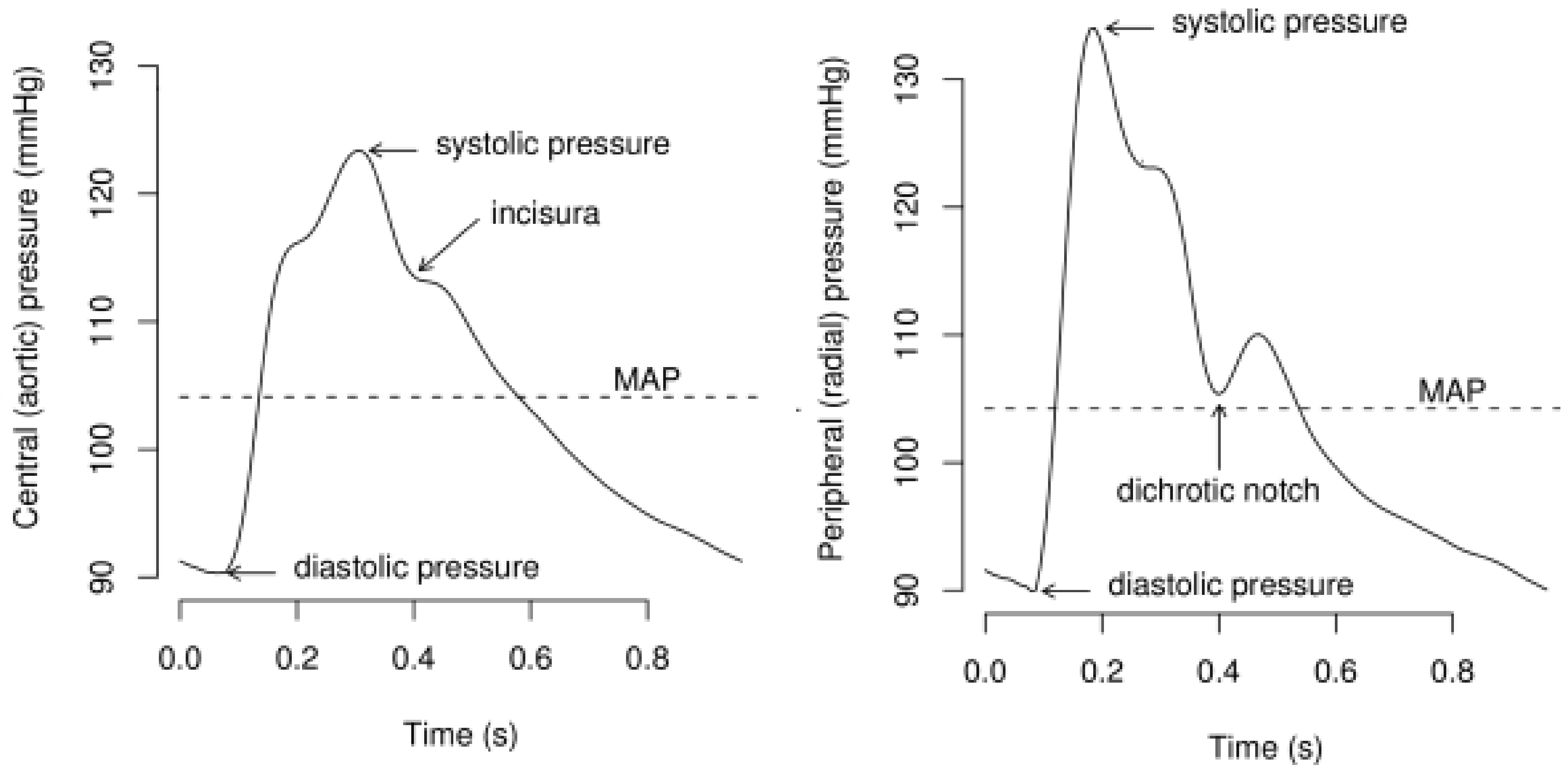


Blood Pressure Measurement

Where do we measure blood pressure?



Blood Pressure Measurement



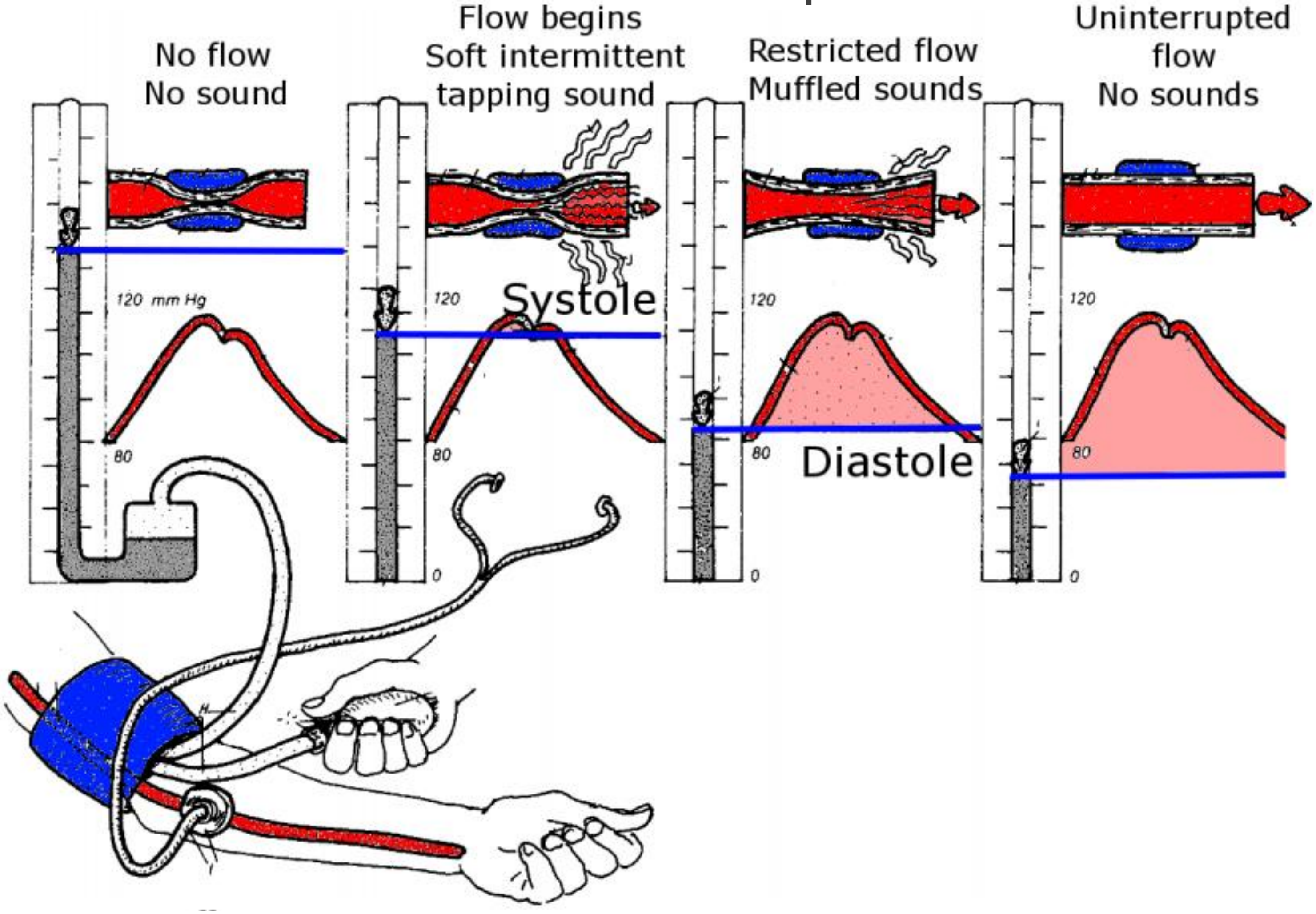
Pulsepressure = *systolic − diastolic*

Mean pressure = *area under the curve*

≈ *diastolic pressure* + 1/3 *pulse pressure*

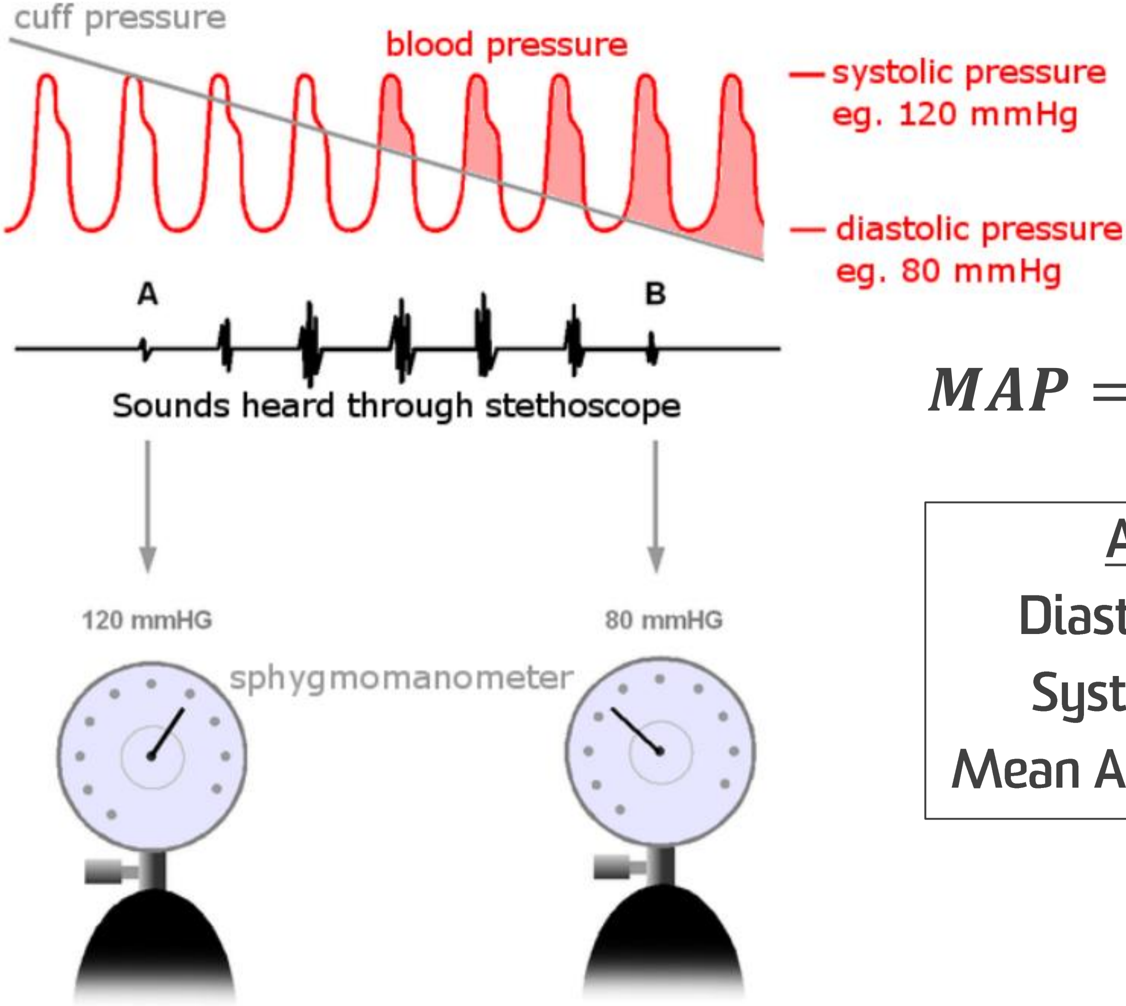
Blood pressure measurement

Non-invasive measurement of arterial blood pressure – Korotkoff technique



Blood pressure measurement

Non-invasive measurement of arterial blood pressure – Korotkoff technique



$$MAP = DP + \frac{SP - DP}{3}$$

<u>Abbreviations</u>

Diastolic Pressure: DP

Systolic Pressure: SP

Mean Aortic Pressure: MAP

Blood pressure measurement

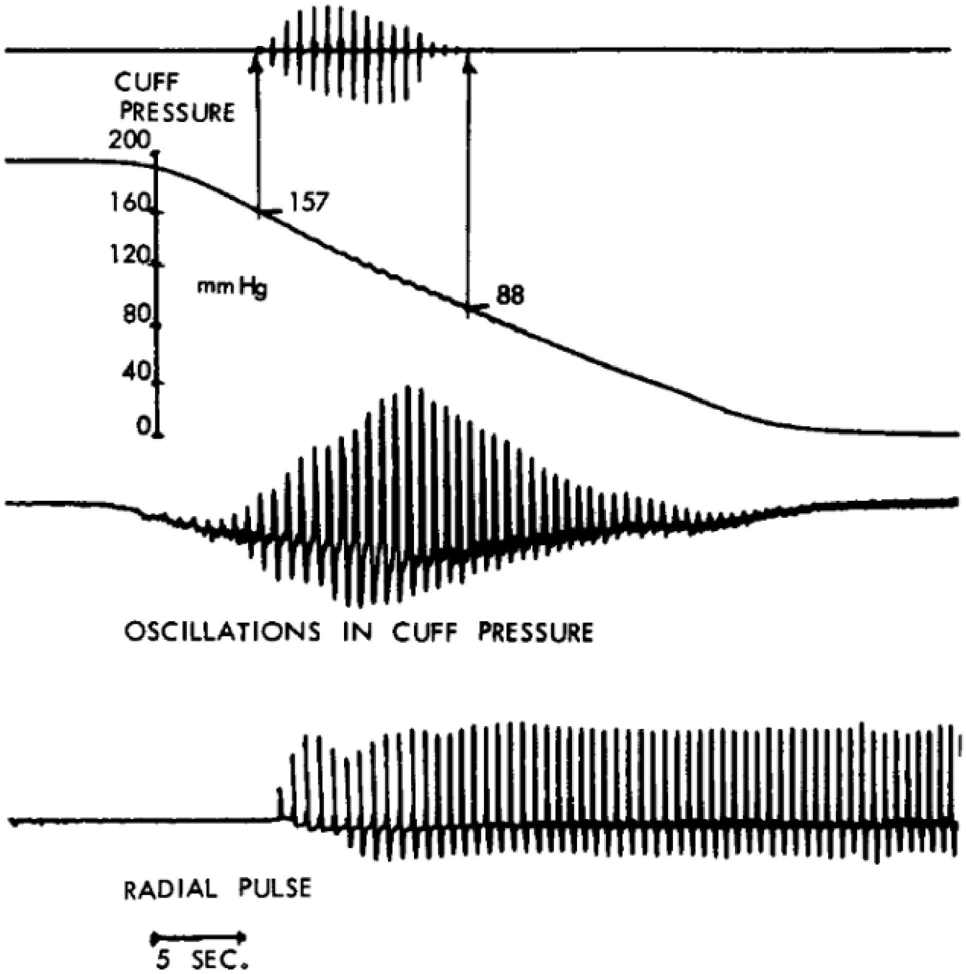
Non-invasive measurement of arterial blood pressure – Korotkoff technique

Problems with the Korotkoff technique

1. Diastolic is a bit subjective
2. Operator dependent – skilled operator required
3. Requires good hearing
4. User errors
    1. cuff pressure falls too quick
    2. rounding errors

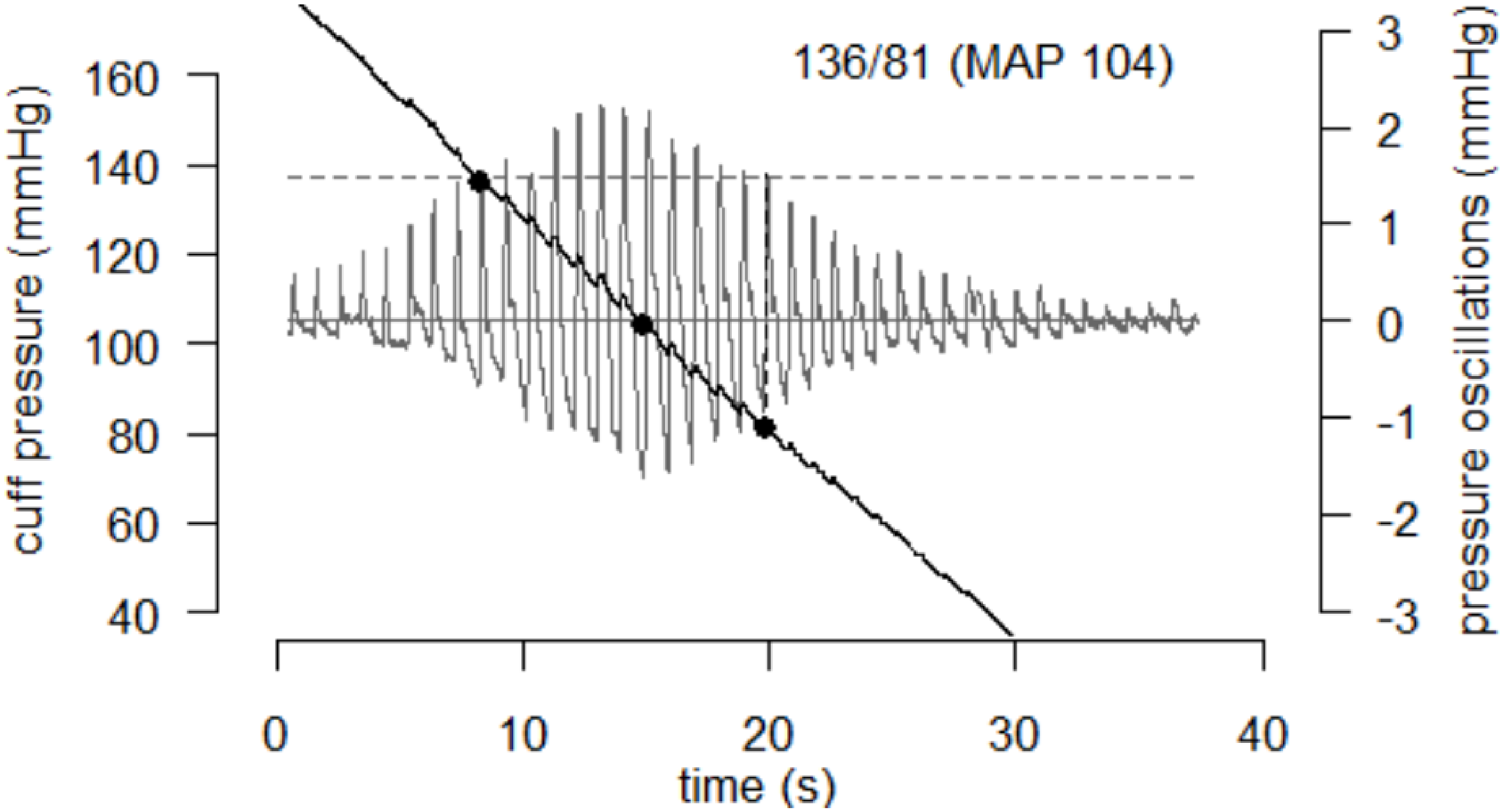
Blood pressure measurement

Non-invasive measurement of arterial blood pressure – Oscillometric technique



Blood pressure measurement

Non-invasive measurement of arterial blood pressure – Oscillometric technique



Blood pressure measurement

White coat hypertension

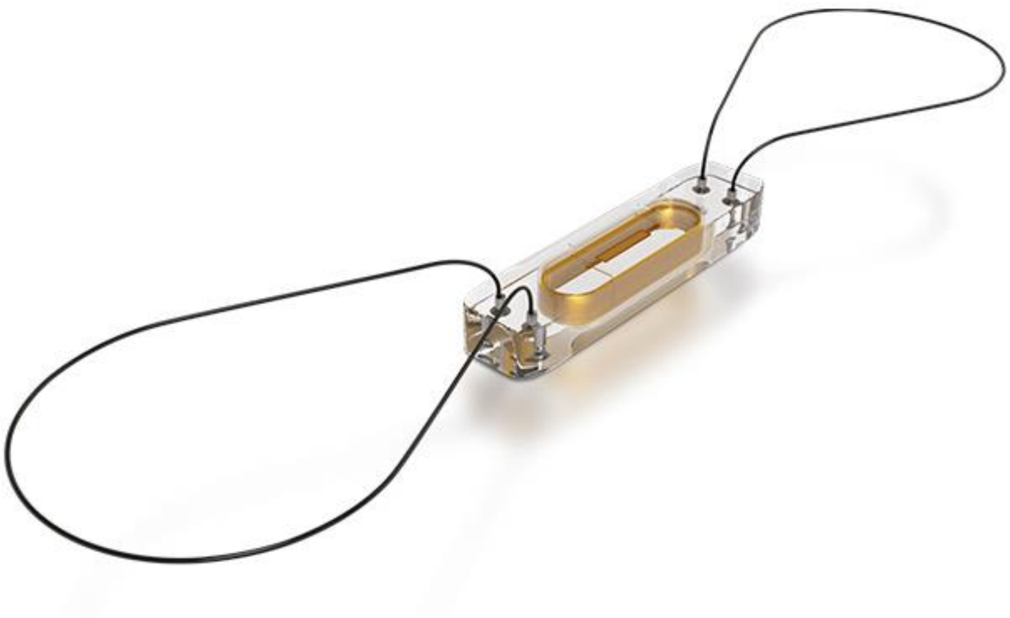
Blood pressure measurement

Ambulatory blood pressure measurement (ABPM)

What about implantable blood pressure sensors?

CardioMems – Abbott

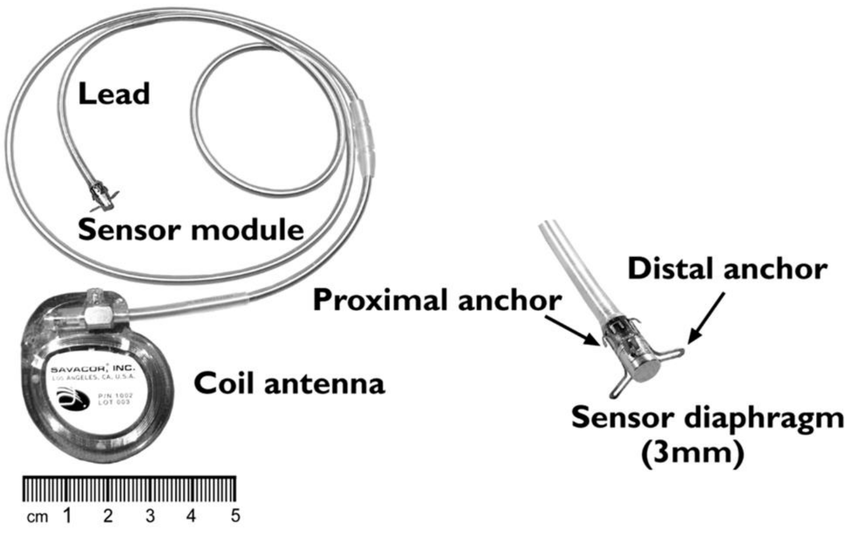
Implantable permanent PA Pressure Sensor



What about implantable blood pressure sensors?

HeartPOD

Left Atrial Pressure Sensor



Cardiac output measurement and estimation

Cardiac Output (CO)
the rate of blood being ejected by the left ventricle into the aorta.

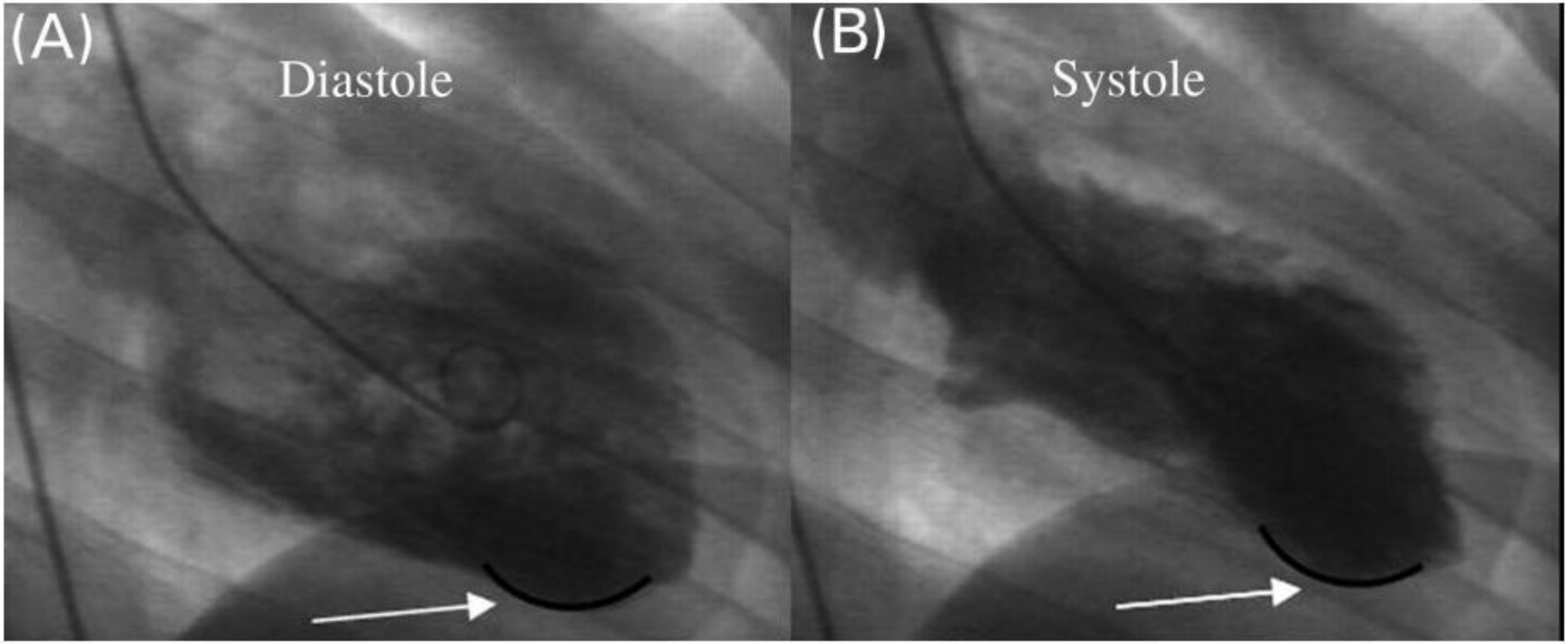
Stroke Volume (SV)
the volume of blood ejected by the left ventricle into the aorta in a single stroke (beat) of the heart.

Heart Rate (HR)
number of beats of the heart per unit time (eg. per minute).

$$CO = SV \times HR$$

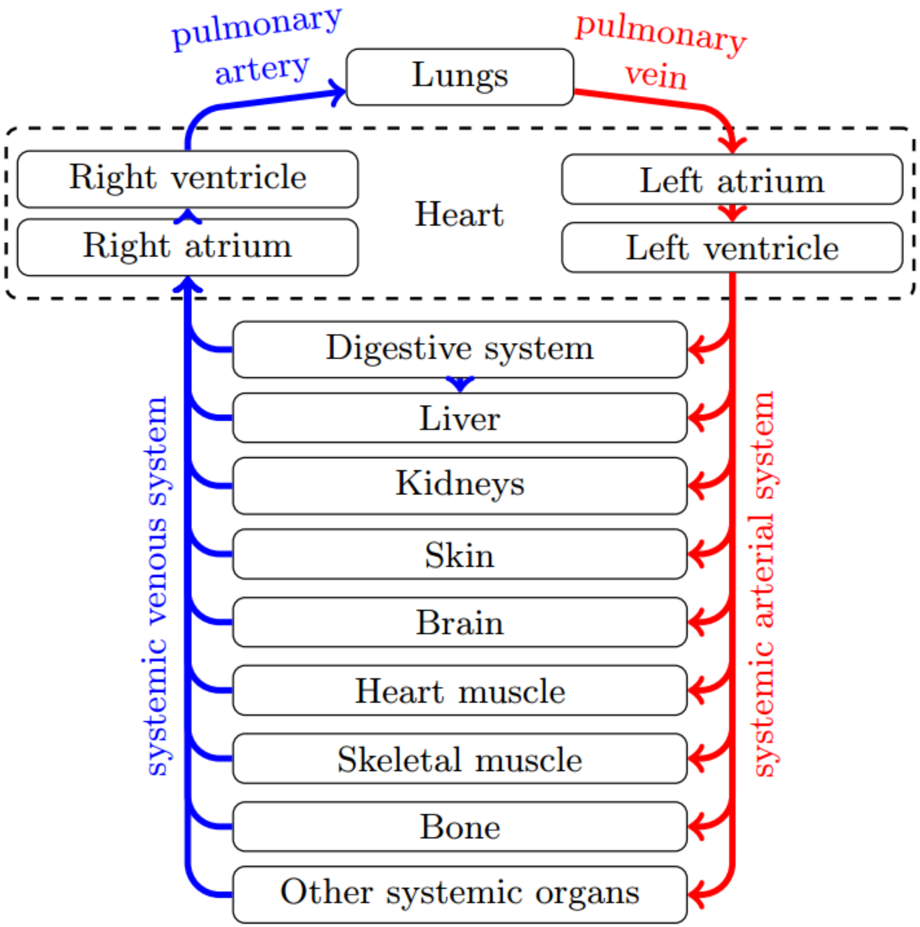
Cardiac output measurement and estimation

Cardiac output from cardiac imaging



Cardiac output measurement and estimation

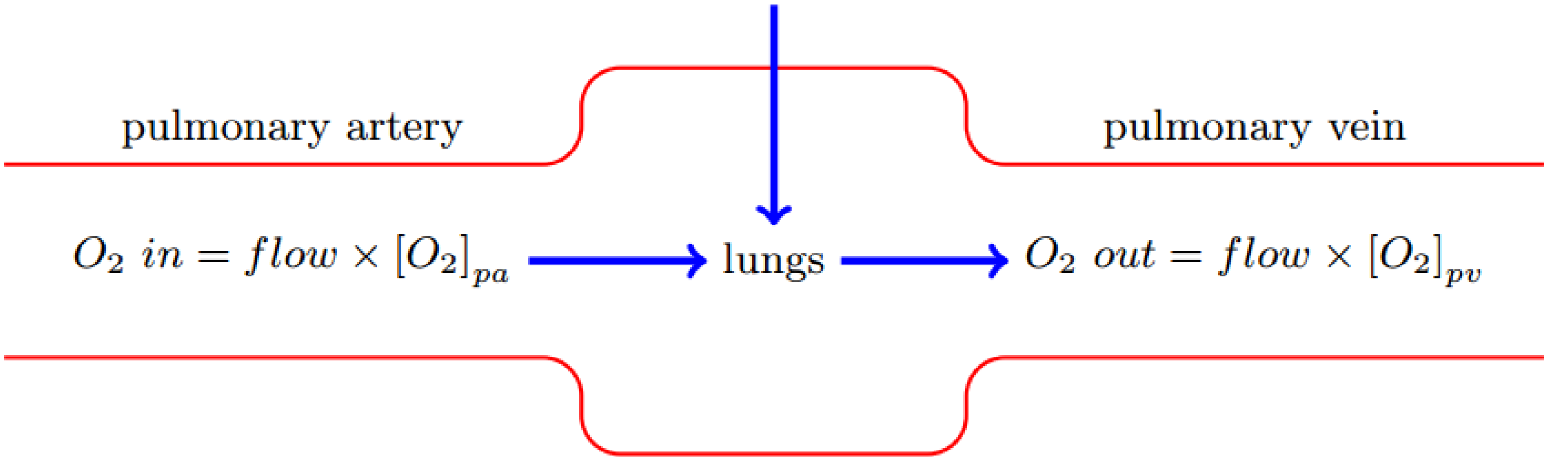
Oxygen intake in the blood: The Fick Principle



Cardiac output measurement and estimation

Oxygen intake in the blood: The Fick Principle

$$VO_2 = O_2 \ breathed \ in - O_2 \ breathed \ out$$



$$\begin{aligned} VO_2 &= O_2 \ out - O_2 \ in \\ &= flow \times [O_2]_{pv} - flow \times [O_2]_{pa} \end{aligned}$$

$$CO = flow = \frac{VO_2}{[O_2]_{pv} - [O_2]_{pa}} = \frac{ml/min}{ml/L} = L/min$$

Cardiac output measurement and estimation

Worked Problem – Cardiac output, Fick principle – worked problem:

If a person breathes in 1000 ml/min O_2 and breaths out 800 ml/min, and we assume that O_2 in the venous system is 160 ml/L and in the arterial system 200 ml/L, calculate the cardiac output.

Cardiac output measurement and estimation

Worked Problem – Cardiac output, Fick principle – worked problem:

If a person breathes in 1000 ml/min O_2 and breaths out 800 ml/min, and we assume that O_2 in the venous system is 160 ml/L and in the arterial system 200 ml/L, calculate the cardiac output.

$$VO_2 = O_2 \; breathed \; in \; - O_2 \; breathed \; out$$
$$VO_2 = 1000 - 800$$
$$VO_2 = 200 ml/min$$

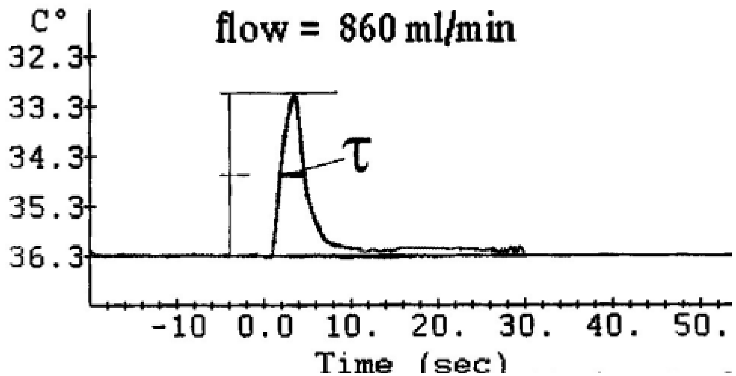
$$\begin{aligned} arteriovenous \; O_2 \; difference &= [O_2]_{pa} - [O_2]_{pv} \\ &= 200 - 160 \\ &= 40 \; ml/L \end{aligned}$$

$$\begin{aligned} CO &= \frac{VO_2}{arteriovenous \; O_2 \; difference} \\ &= \frac{200}{40} \\ &= 5000 \; ml/min \end{aligned}$$

Cardiac output measurement and estimation

Dye or thermodilution technique

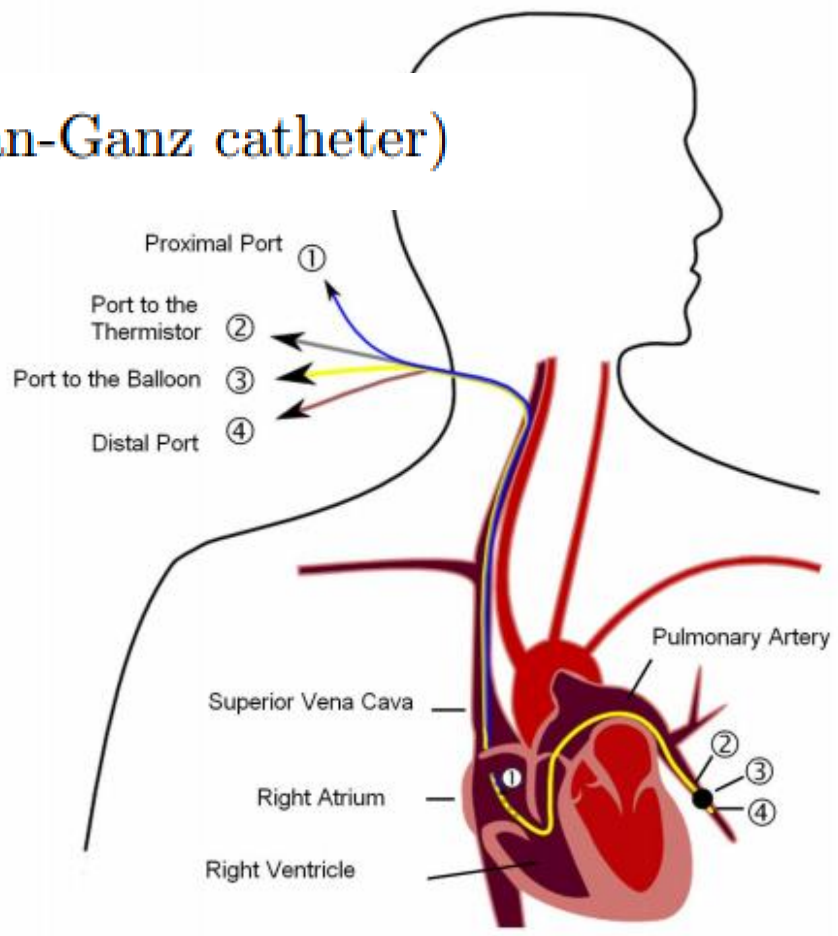
$$
\begin{aligned}
CO &= \frac{amount\ of\ dye\ injected}{\int concentration\ curve \cdot dt} \\
&= \frac{amount\ of\ dye\ injected(mg)}{area\ under\ the\ curve\ (mg/ml \times seconds)} \\
&= ml/sec
\end{aligned}
$$



Cardiac output measurement and estimation

Dye or thermodilution technique

Pulmonary artery catheter (Swan-Ganz catheter)



Cardiac output measurement and estimation

Cardiac output, dilution technique – worked problem

20 mg of dye injected in the inferior vena cava. In the radial artery, an average concentration of 0.025 mg/ml is measured over 12 seconds. What is the cardiac output?

Cardiac output measurement and estimation

Cardiac output, dilution technique – worked problem

20 mg of dye injected in the inferior vena cava. In the radial artery, an average concentration of 0.025 mg/ml is measured over 12 seconds. What is the cardiac output?

$$
\begin{aligned}
CO &= \frac{amount\ of\ dye\ injected}{\int concentration\ curve \cdot dt} \\
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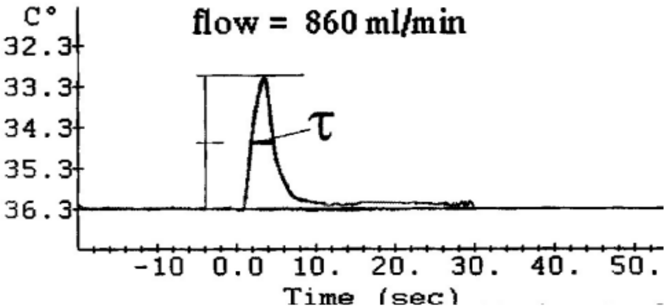
&= ml/sec
\end{aligned}
$$



$$
\begin{aligned}
CO &= \frac{amount\ of\ dye\ injected}{\int concentration\ curve \cdot dt} \\
&= \frac{20}{0.025 * 12} \\
&= 67ml/sec \\
&= 4L/min
\end{aligned}
$$