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Introduction to Bioelectricity Part III

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Recap

- A biopotentials is an electric **voltage** that is measured between points in a living cell, tissue, or organ, and which is due to biochemical processes

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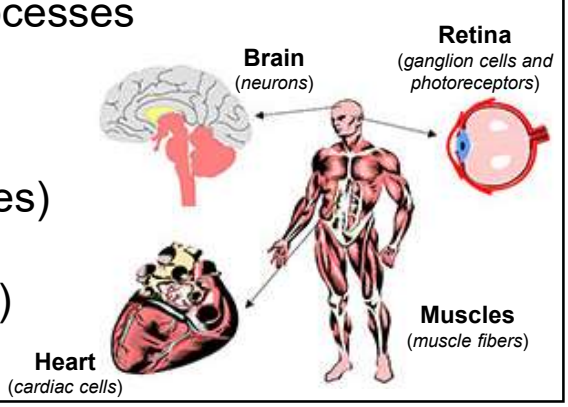
- If measured in a tissue or organism, the biopotentials capture the overlap of action potentials fired by many cells concurrently

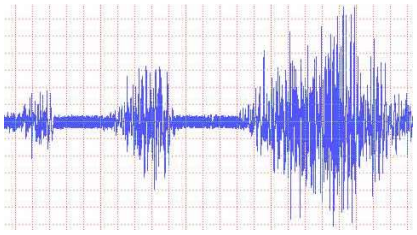
Recap

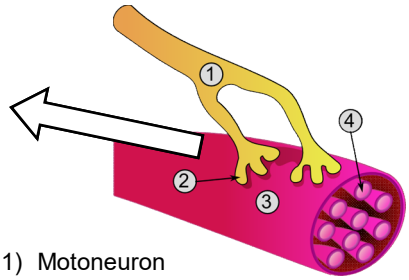
- A biopotentials is an electric **voltage** that is measured between points in a living cell, tissue, or organ, and which is due to biochemical processes
- Examples:
  - EEG (Brain)
  - EMG (Muscles)
  - ECG (Heart)
  - ERG (Retina)



Recap: EMG

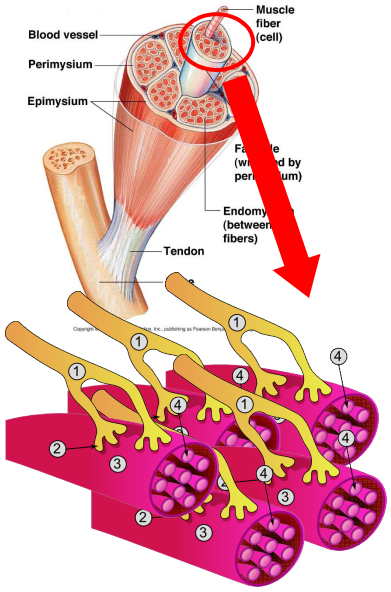
- EMG measures the electric potential outside the muscle fibers innervated by one or more motoneurons
- Motoneurons are nervous cells with the soma in the spinal cord and the axon projecting to the muscle

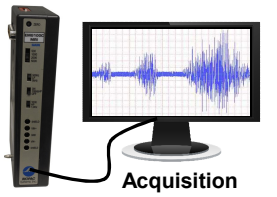




1) Motoneuron
2) Neuro-muscular junction
3) Muscle fiber
4) Tubular filaments that are contracted because of the action potential

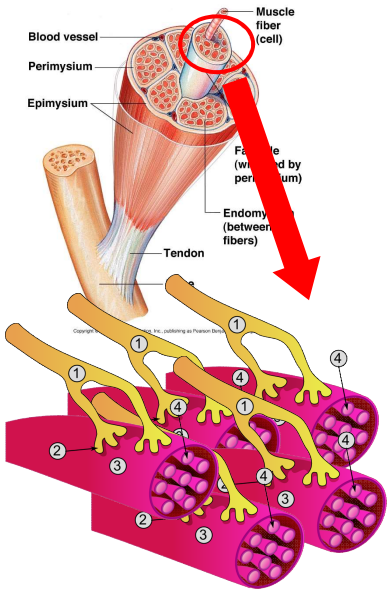
How to measure EMG

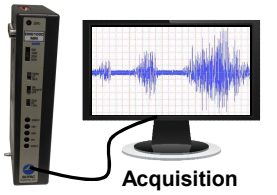




Acquisition system (HW + SW)

How to measure EMG





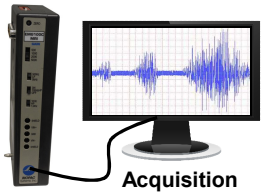
Acquisition system (HW + SW)

Problem #1:
The EMG electrode is on the skin surface while the muscle fibers are deep underneath.

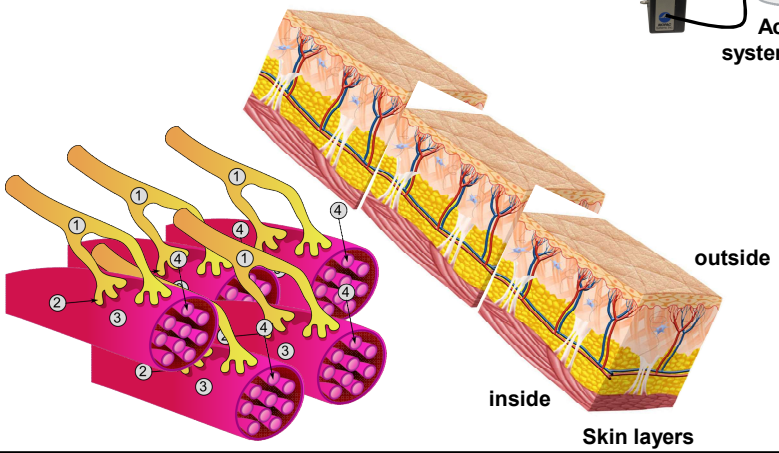
<u>How do we measure the potential?</u>

How to measure EMG

It turns out that the skin lets the ion currents flow toward the surface

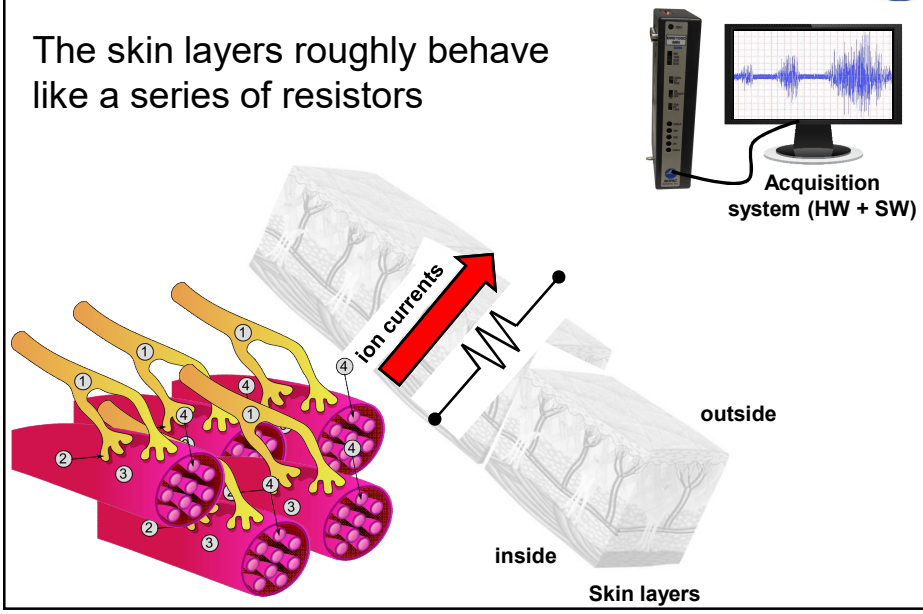


Acquisition system (HW + SW)

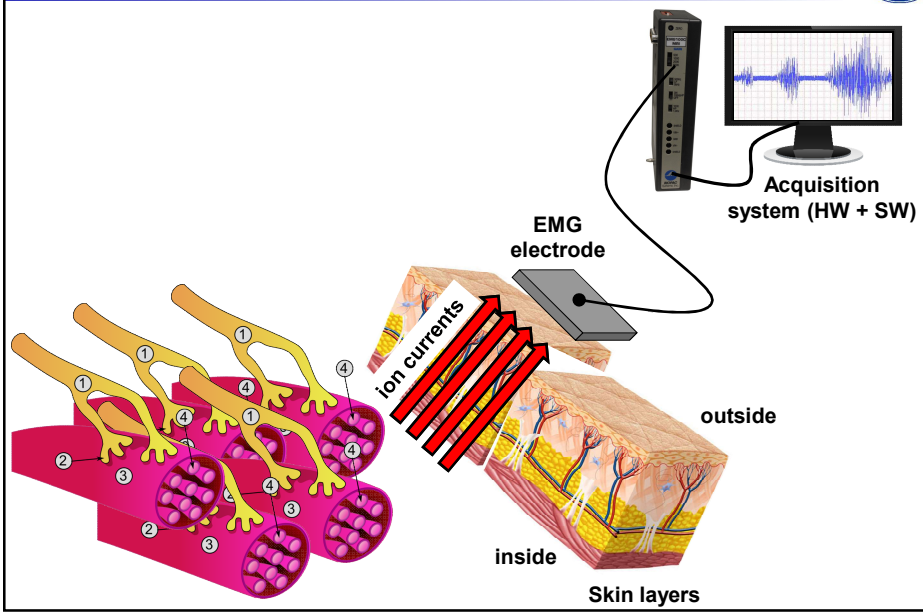


How to measure EMG

The skin layers roughly behave like a series of resistors



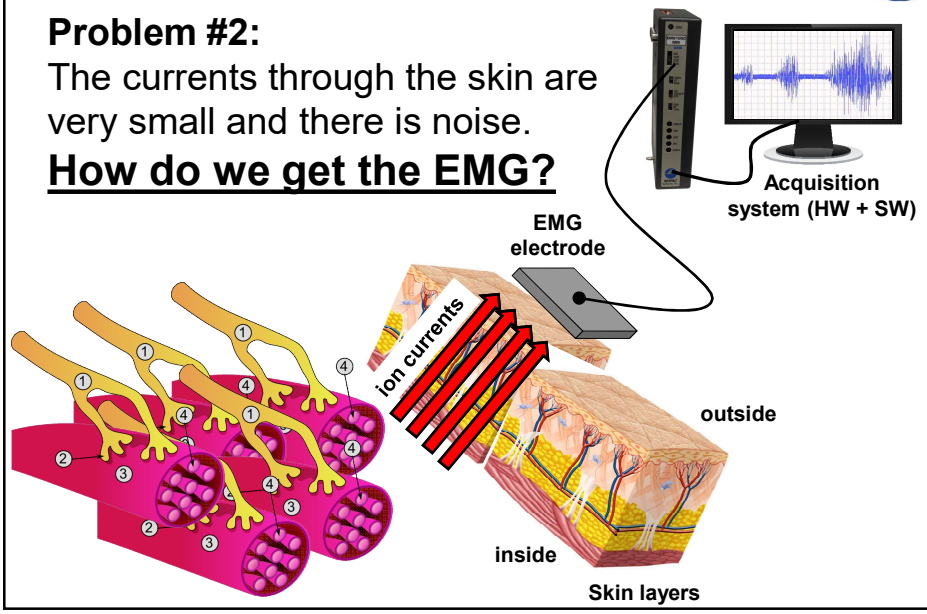
How to measure EMG



How to measure EMG

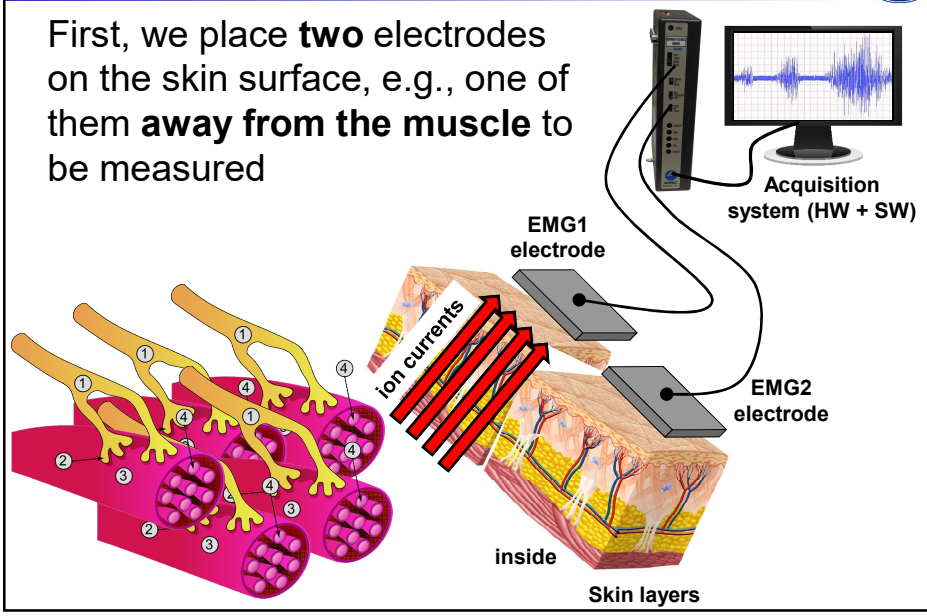
Problem #2:
The currents through the skin are very small and there is noise.

How do we get the EMG?



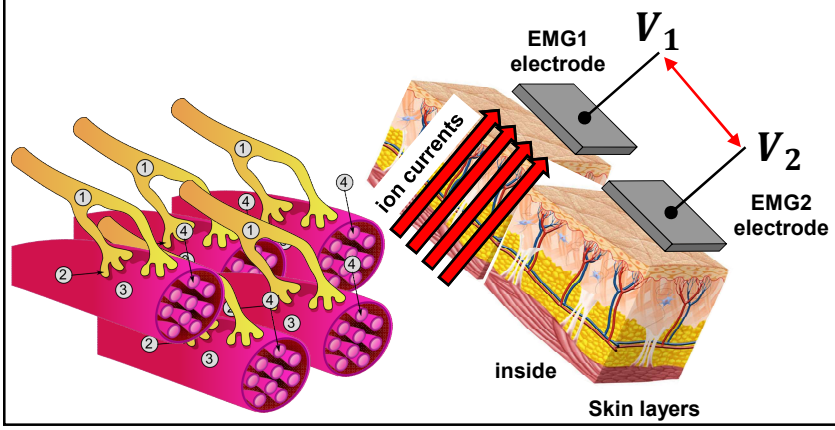
How to measure EMG

First, we place **two** electrodes on the skin surface, e.g., one of them **away from the muscle** to be measured



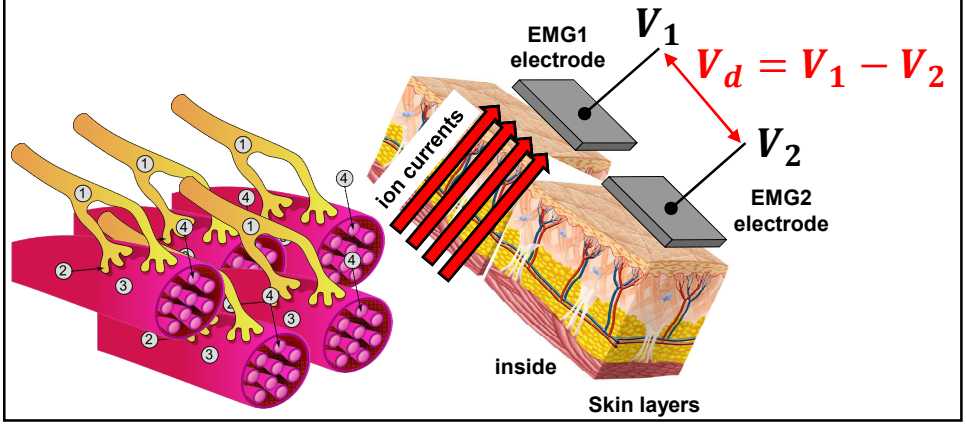
How to measure EMG

Second, we measure the **difference** between the potentials at the electrodes



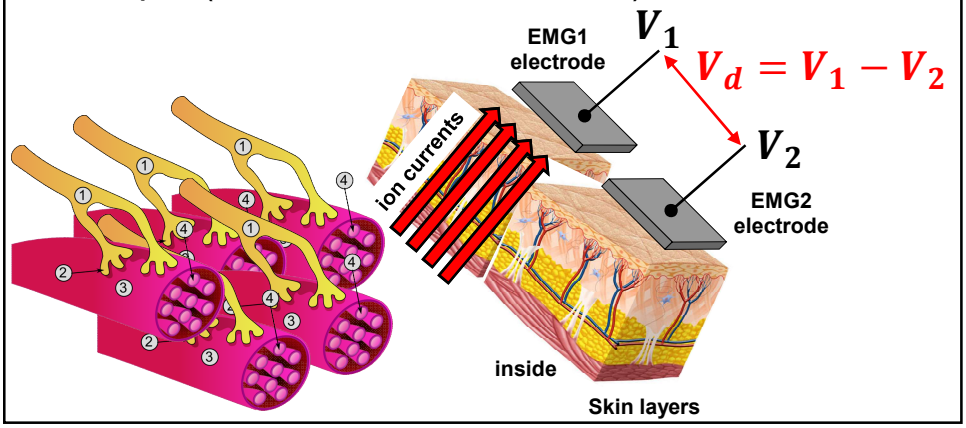
How to measure EMG

In this way, we attenuate the noise that is commonly present to both electrodes



How to measure EMG

Third, we have an electronic circuit (**amplifier**) inside the acquisition system that amplifies $\boldsymbol{V_d}$, i.e., it receives $\boldsymbol{V_d}$ in input and gives $\boldsymbol{V_A = G \times V_d}$ in output ($\boldsymbol{G}$ =20, 100, or 1000, etc.)

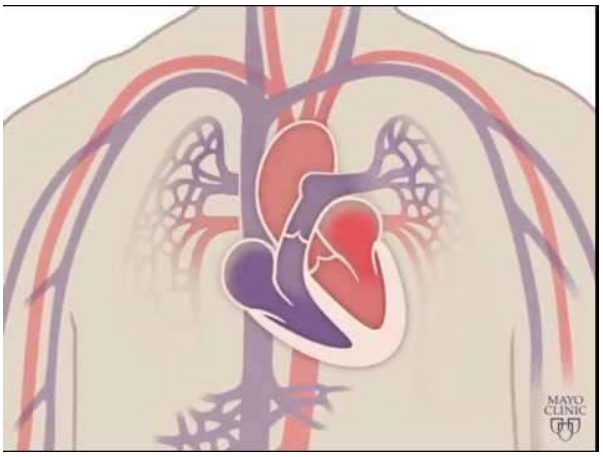


Electrocardiogram (ECG)

Let us move on now and focus on the **electrocardiogram**…

The mechanics of heart

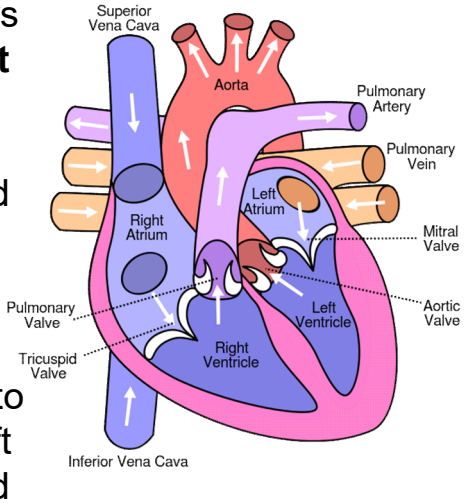
To understand the origins of the ECG, let us first review how the heart works



Source: *https://youtu.be/CWFyxn0qDEU* © Mayo Clinic

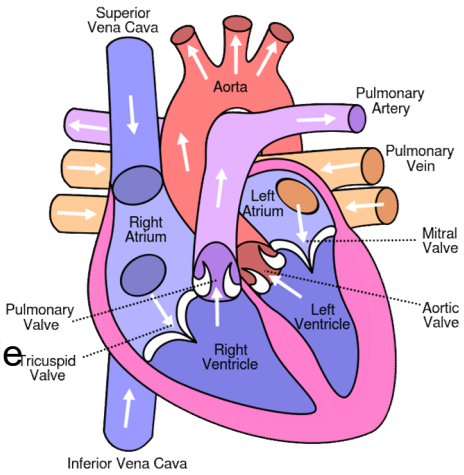
The mechanics of heart: key points

- Blood **rich with CO_2** flows from the body to the **right atrium** and then to the **right ventricle**. The right ventricle pumps the blood to the lung
- Blood **rich with oxygen** flows from the lung into the **left atrium** and then to the **left ventricle**. The left ventricle pumps the blood to the rest of the body



The mechanics of heart: key points

- **Diastole** is the resting or **filling phase** (i.e., ventricle chambers are filled) of the heart cycle
- **Systole** is the contractile or **pumping phase** (i.e., ventricle chambers are emptied) of the heart cycle
- The heart valves ensure unidirectional blood flow through the heart thus preventing backflow



Cardiac muscle tissue

The sequence of diastole and systole is achieved by timely contracting **muscle tissue** that is placed within the walls of the heart

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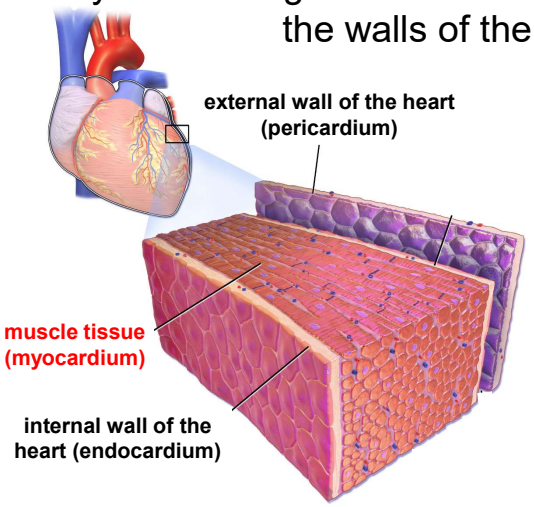

Cardiac muscle tissue

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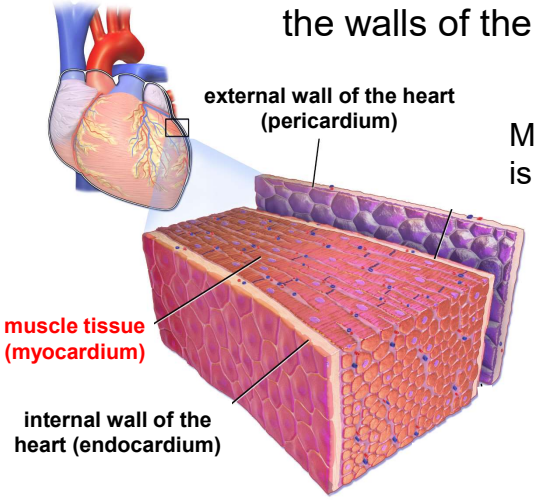
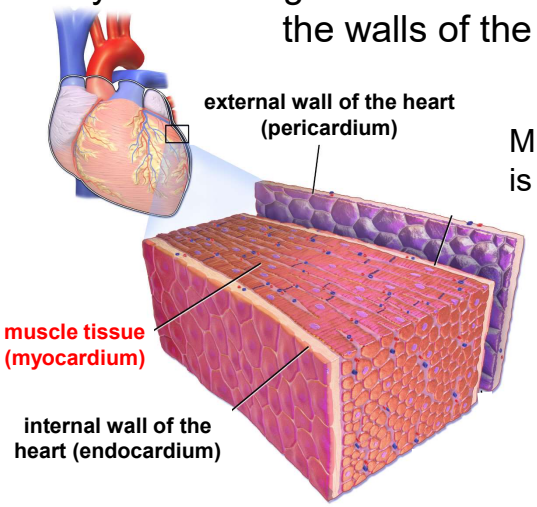


Muscle tissue (**myocardium**) is 99% of the heart

Cardiac muscle tissue

The sequence of diastole and systole is achieved by timely contracting **muscle tissue** that is placed within the walls of the heart

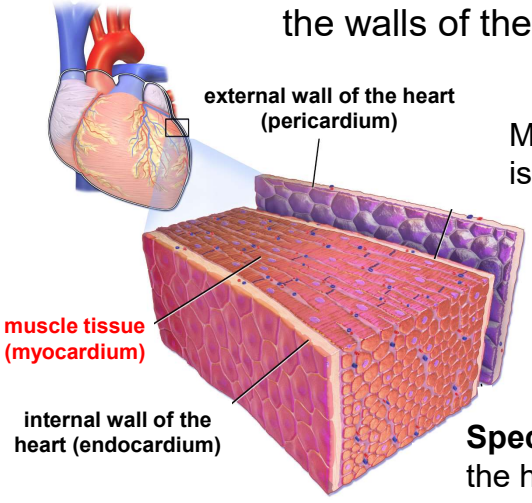


Muscle tissue (**myocardium**) is 99% of the heart

Like any other muscle tissue, it needs cells that activate contraction via action potentials

Cardiac muscle tissue

The sequence of diastole and systole is achieved by timely contracting **muscle tissue** that is placed within the walls of the heart



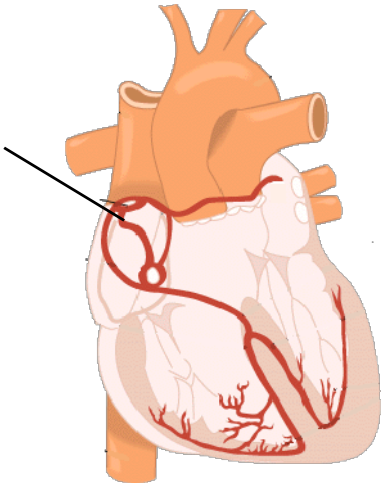
Muscle tissue (**myocardium**) is 99% of the heart

Like any other muscle tissue, it needs cells that activate contraction via action potentials

Special cardiac cells (1% of the heart) give such activation

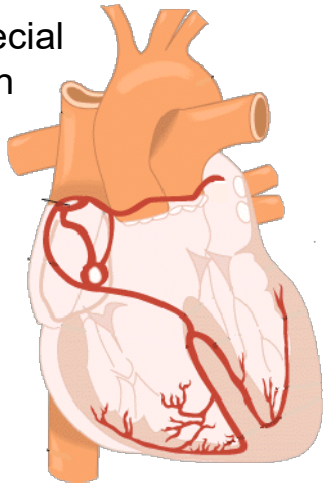
Electrical activity in the heart

These special cardiac cells are strategically placed along the red pathway



Electrical activity in the heart

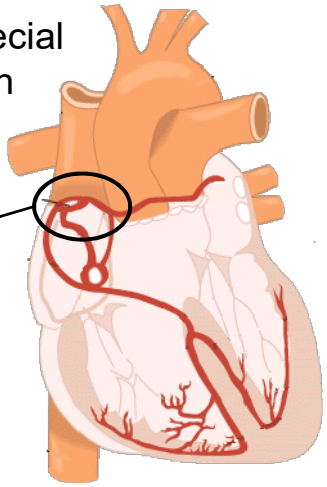
During an heart beat, these special cells always generate the action potentials in a fixed order



Electrical activity in the heart

During an heart beat, these special cells always generate the action potentials in a fixed order

First, the cells in the top right atrium (**SA node**)



SA $\stackrel{\text{def}}{=}$ Sino-Atrial

Electrical activity in the heart

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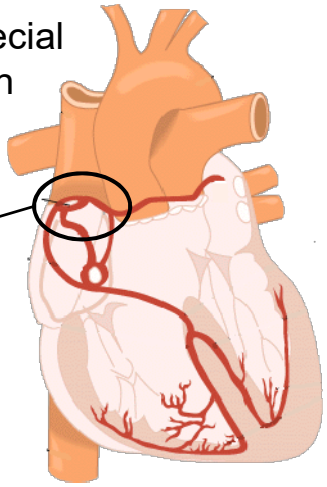
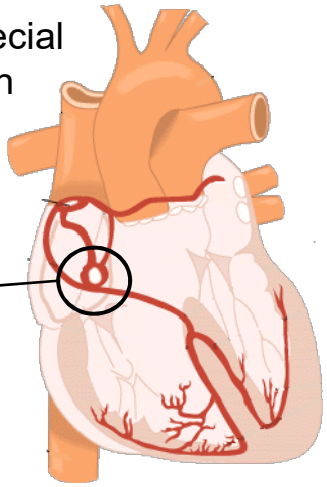


These cells are called ***pacemaker cells*** *and, during an heart beat, generate the action potentials* ***periodically***

Electrical activity in the heart

During an heart beat, these special cells always generate the action potentials in a fixed order

Second, the cells in the area between the two atria (**AV node**)

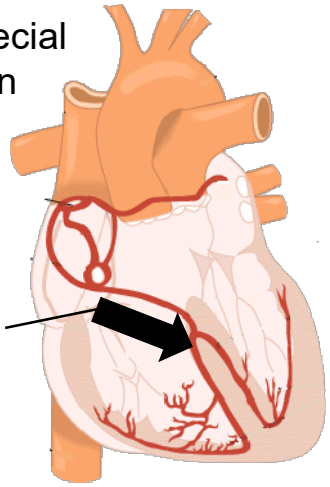


AV $\stackrel{\text{def}}{=}$ Atrio-Ventricular

Electrical activity in the heart

During an heart beat, these special cells always generate the action potentials in a fixed order

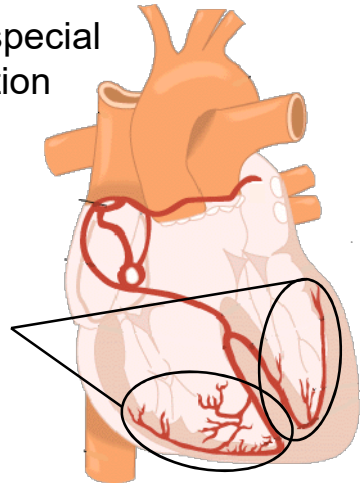
Third, the cells along the bundle that goes from the AV node to the two ventricles



Electrical activity in the heart

During an heart beat, these special cells always generate the action potentials in a fixed order

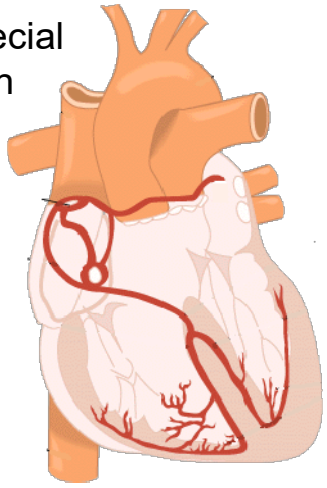
Forth, the cells placed at the bottom of left and right ventricle (**Purkinje fibers**)



Electrical activity in the heart

During an heart beat, these special cells always generate the action potentials in a fixed order

The order is meant to contract different parts of the muscle tissue at different times



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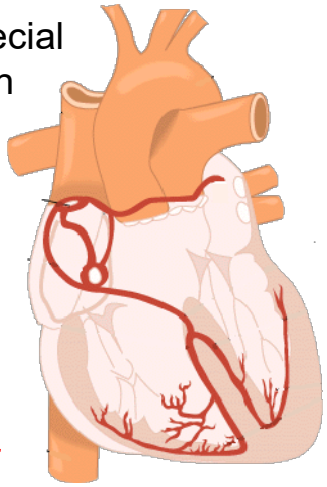

The order is meant to contract different parts of the muscle tissue at different times

This causes the sequence of diastole and systole during each heart beat

Electrical conduction and ECG

The electrocardiogram (ECG) reflects the change in potential occurring throughout the myocardium due to the electrical conduction

Electrical conduction and ECG

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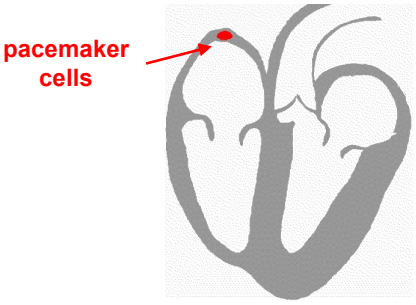
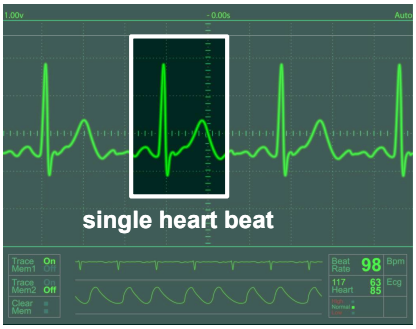


ECG

Electrocardiogram (ECG)

Typical shape of the ECG

Electrocardiogram (ECG)



Typical shape of the ECG

Electrocardiogram (ECG)

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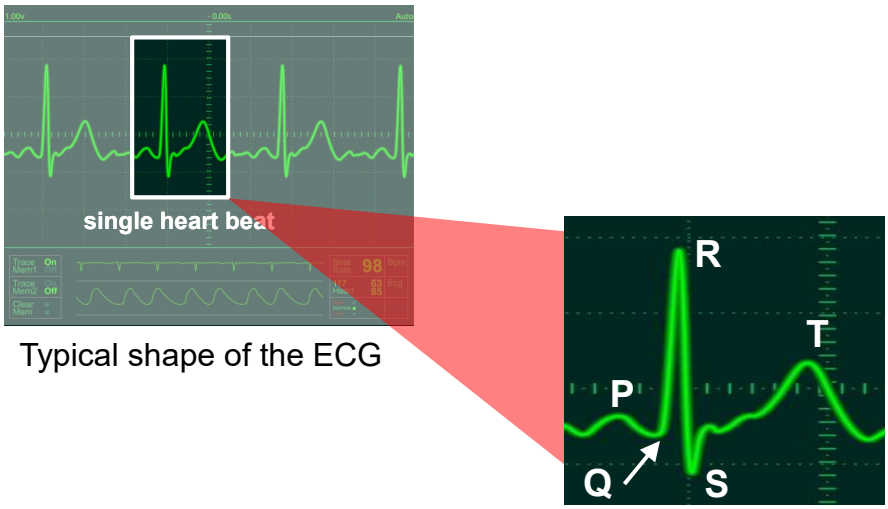
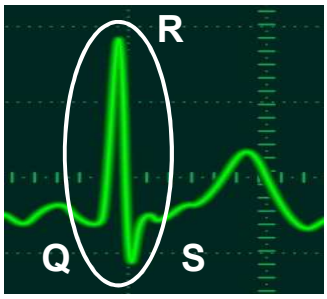


Typical shape of the ECG

Understanding the ECG waveform

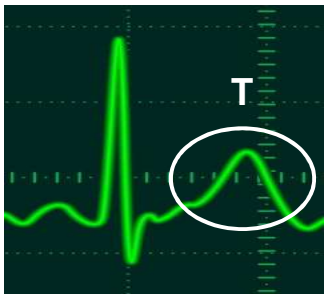
The **P-wave** is the small wave centered on the local maximum **P**. It captures the **depolarization** of the atrial chambers (i.e., roughly from the SA node to the AV node)

Understanding the ECG waveform



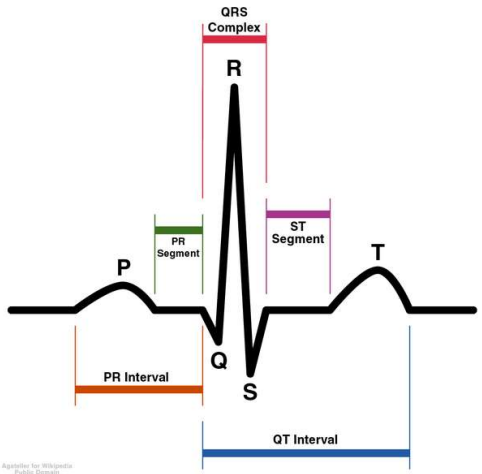
The **QRS-complex** is the wave from minimum **Q** to minimum **S** passing through maximum **R**. It captures the rapid **depolarization** of the large muscle mass in the ventricles

Understanding the ECG waveform



The **T-wave** is the small wave centered on the local maximum **T**. It capture the **repolarization** of the large muscle mass in the ventricles

ECG waveform in summary



P-wave ~ 80ms
PR interval ~ 120-200ms

QRS complex ~ 80-100ms
T-wave ~160ms

ECG waveform and heart diseases

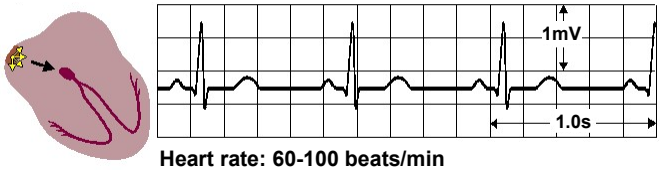
Normal conditions

Heart rate: 60-100 beats/min

- Voltage amplitude:
  1 – 5 mV
- Frequency bandwidth:
  0.05 – 100 Hz

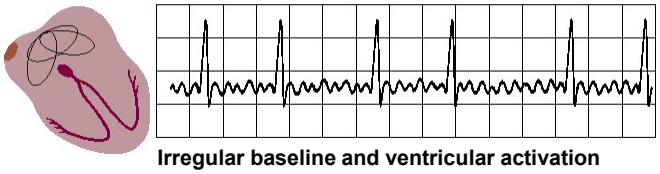
ECG waveform and heart diseases

Normal conditions



Heart rate: 60-100 beats/min

Atrial fibrillation (AF)



Irregular baseline and ventricular activation

ECG waveform and heart diseases

Normal conditions

Heart rate: 60-100 beats/min

Atrial fibrillation (AF)

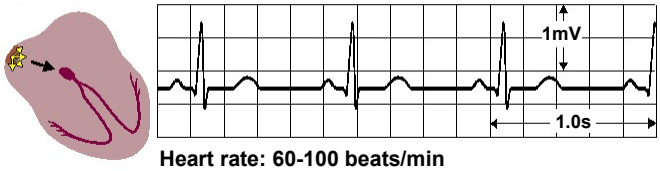
Irregular baseline and ventricular activation

AF causes that the atria beat chaotically and irregularly, with no coordination with the ventricles

- ❑ Palpitation
- ❑ Shortness of breath
- ❑ Weakness

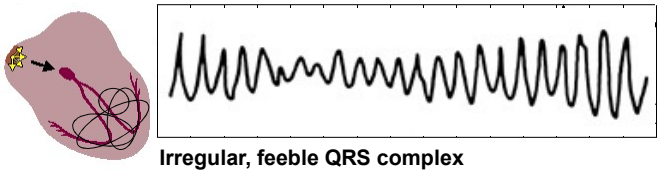
ECG waveform and heart diseases

Normal conditions



Heart rate: 60-100 beats/min

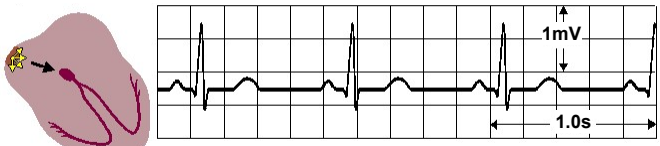
Ventricular fibrillation (VF)



Irregular, feeble QRS complex

ECG waveform and heart diseases

Normal conditions



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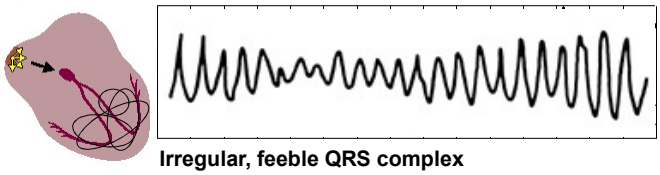


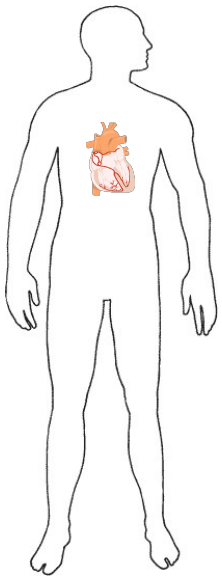
Irregular, feeble QRS complex

VF causes that the ventricles beat chaotically and with irregular amplitude (quivering)

- ❑ Shock (no blood flow)
- ❑ Collapse
- ❑ Brain damage

How to measure ECG

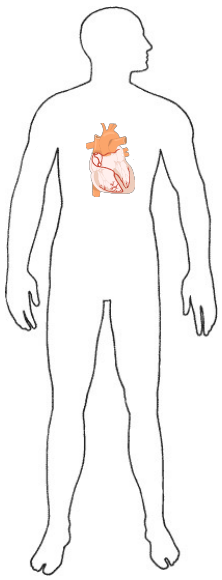
- ECG captures the potential of the muscle tissue during contraction
- ECG must be measured by using skin electrodes like the EMG
- Differently from an EMG, the ECG reflects the sequential contraction of different parts of the heart in 3D



How to measure ECG

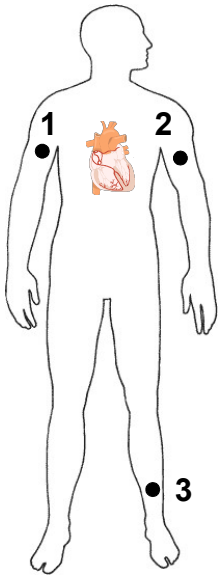
- ECG captures the potential of the muscle tissue during contraction
- ECG must be measured by using skin electrodes like the EMG
- Differently from an EMG, the ECG reflects the sequential contraction of different parts of the heart in 3D

We may need more than two electrodes to clearly reconstruct the contraction pattern of the heart



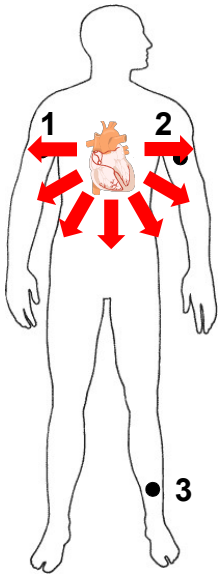
How to measure ECG

- Hence, electrodes are placed on three limbs



How to measure ECG

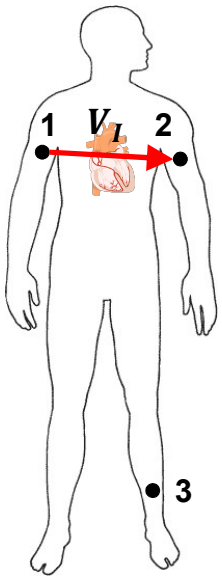
- Hence, electrodes are placed on three limbs
- The ion currents propagate in every direction from the heart tissue toward the skin



How to measure ECG

- Hence, electrodes are placed on three limbs
- The ion currents propagate in every direction from the heart tissue toward the skin
- Three measures of the ECG are generally taken:

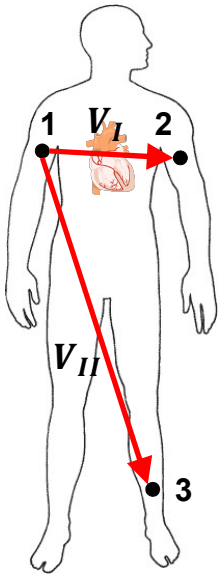
$$V_I = V_2 - V_1 \text{ (lead I)}$$



How to measure ECG

- Hence, electrodes are placed on three limbs
- The ion currents propagate in every direction from the heart tissue toward the skin
- Three measures of the ECG are generally taken:

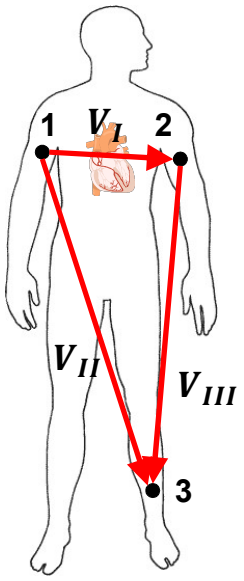
$$V_I = V_2 - V_1 \text{ (lead I)}$$
$$V_{II} = V_3 - V_1 \text{ (lead II)}$$



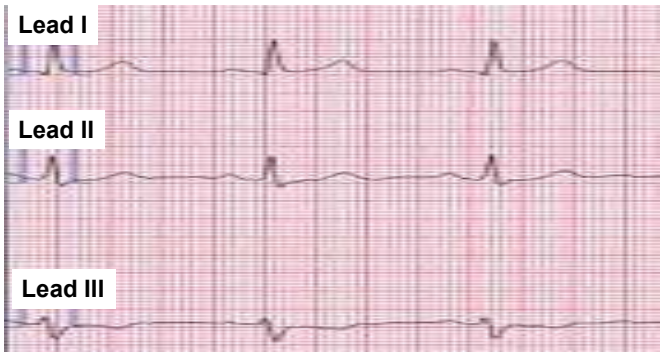
How to measure ECG

- Hence, electrodes are placed on three limbs
- The ion currents propagate in every direction from the heart tissue toward the skin
- Three measures of the ECG are generally taken:

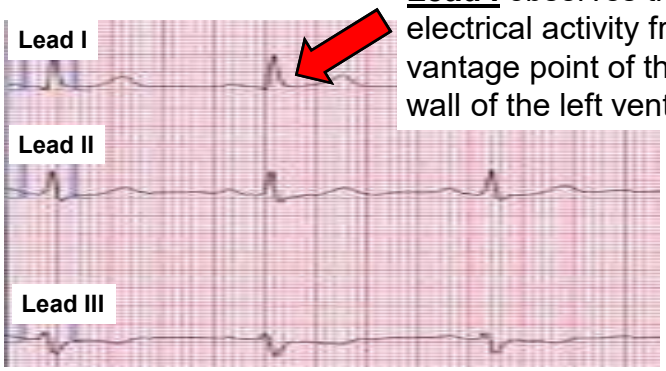
$$V_I = V_2 - V_1 \text{ (lead I)}$$
$$V_{II} = V_3 - V_1 \text{ (lead II)}$$
$$V_{III} = V_3 - V_2 \text{ (lead III)}$$



How to measure ECG

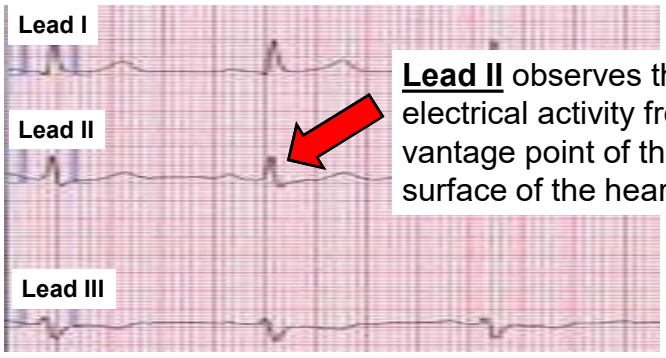


How to measure ECG



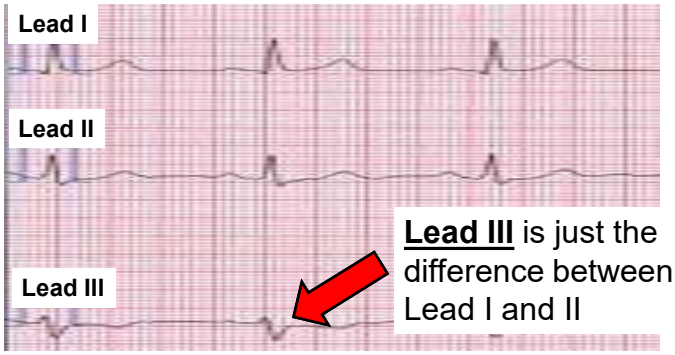
Lead I observes the electrical activity from the vantage point of the lateral wall of the left ventricle

How to measure ECG



Lead II observes the electrical activity from the vantage point of the inferior surface of the heart

How to measure ECG



Lead III is just the difference between Lead I and II