ICT for HEART MONITORING

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INTRODUCTION

CLASSES OUTLINE

- Lesson 1 (22/05) → Theoretical background
- Lesson 2 (24/05) → Heart Rate Variability
- Lesson 3 (29/05) → ECG reconstruction

ICT FOR HEALTHCARE

Information and Communication Technology (ICT) is expected to play a pivotal role in **healthcare**, improving current health practices toward a more **efficient** and **accessible** system

- **Higher efficiency** → Actual practices can be performed more rapidly, without losing precision

- **Higher accessibility** → New practices are developed, making it possible to provide medical treatment under conditions that today are considered too complex

ICT FOR HEALTHCARE

- **Telemedicine** makes it possible for patients to interact with physicians and caregivers remotely, reducing unnecessary hospitalization

- The **Internet of Things (IoT)** makes it possible to continually record physiological signals, allowing physicians to monitor patient status over long periods

- **Big data analytics**, including Machine Learning (ML), makes it possible to identify new biomarkers that are not perceivable with a traditional analysis

ICT FOR HEALTHCARE

Designing an ICT device for healthcare requires strong **cooperation with physicians** and healthcare professionals

- We must be aware of the **clinical goal** of the device and its **practical limits** in a **real scenario**

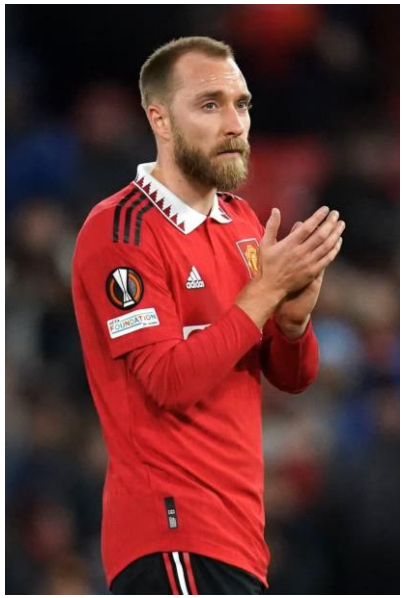
Two major challenges: **privacy** and **usability**

- **Data breaches** lead to the diffusion of sensitive information to end users
- **Little usability** may prevent the implementation of the device despite its performance

PART 1
HEART MONITORING

HEART MONITORING

Christian Eriksen (Danish soccer player) suffered a cardiac infarction during the European Championship at the age of 29



→ He still plays soccer with the support of a cardioverter defibrillator

Davide Astori (Italian soccer player) died because of ventricular fibrillation (a type of arrhythmia) at the age of 31

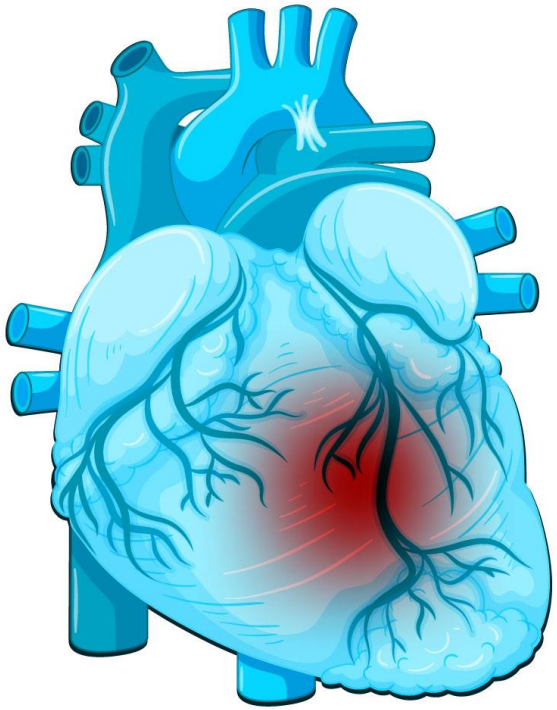
→ The reason was a genetic disorder causing ventricular arrhythmias

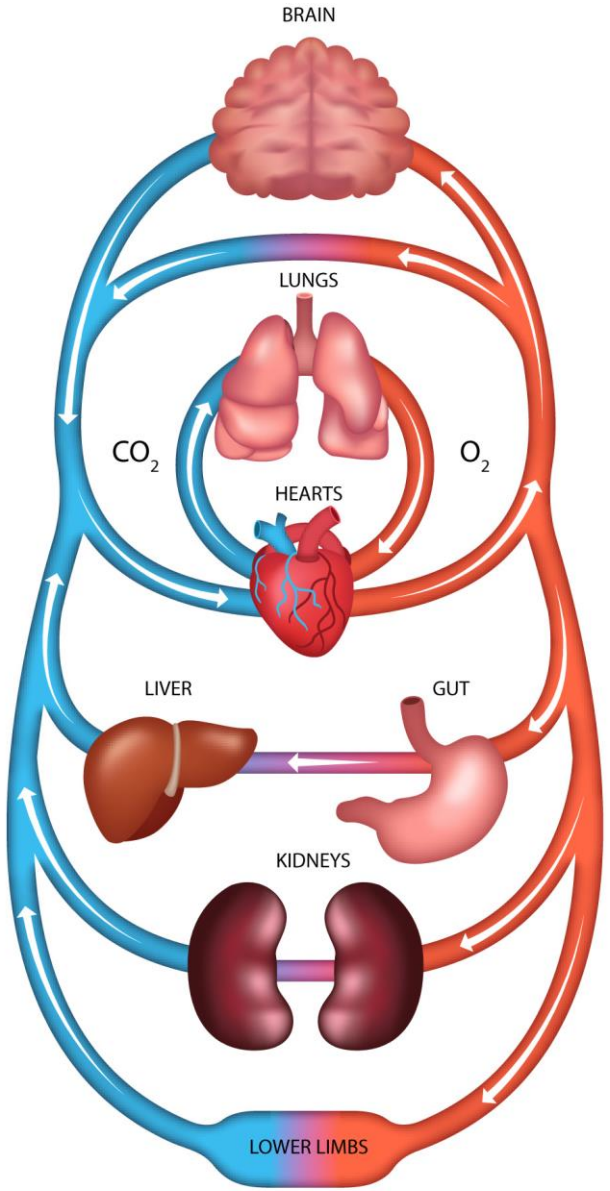
HEART MONITORING

Monitoring heart activity is fundamental for ensuring that a person does not present cardiac abnormalities

- **Coronary Artery Diseases (CADs)**, including ischemia and infarction, involve a limitation of the blood flow toward the heart

- **Heart arrhythmias**, including tachycardias and bradycardias, involve irregularities in the heartbeat cycle





CARDIOVASCULAR SYSTEM

The cardiovascular system includes the heart and two groups of vessels

- The **arteries** carry blood away from the heart
- The **veins** carry blood back to the heart

It is organized into two sub-systems

- The **systemic circulation** provides blood with oxygen to the cells
- The **pulmonary circulation** makes fresh oxygen enters the blood

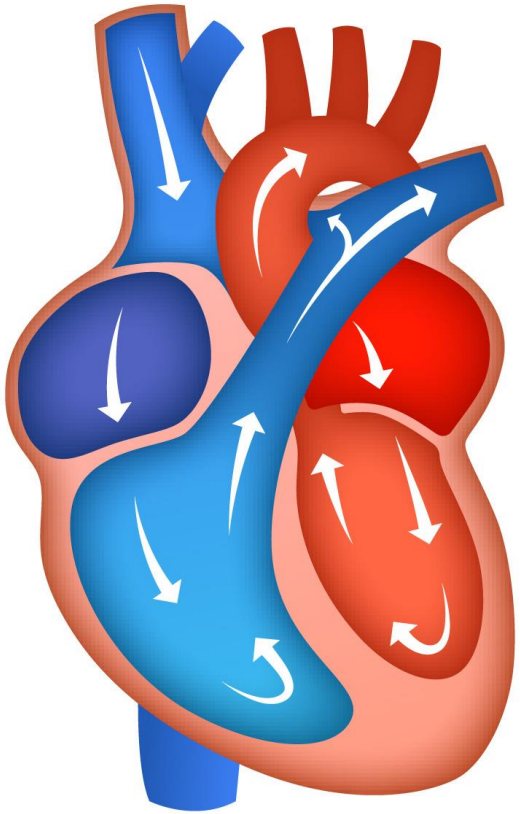
CARDIOVASCULAR SYSTEM

The heart includes four chambers:

- two **atria** (right and left)
- two **ventricles** (right and left)

The four chambers alternately **contract (systole)** and **relax (diastole)** to pump blood throughout the human body

The **cardiac cycle** is allowed by the polarization and depolarization of **cardiomyocytes**, i.e., the cardiac muscle cells

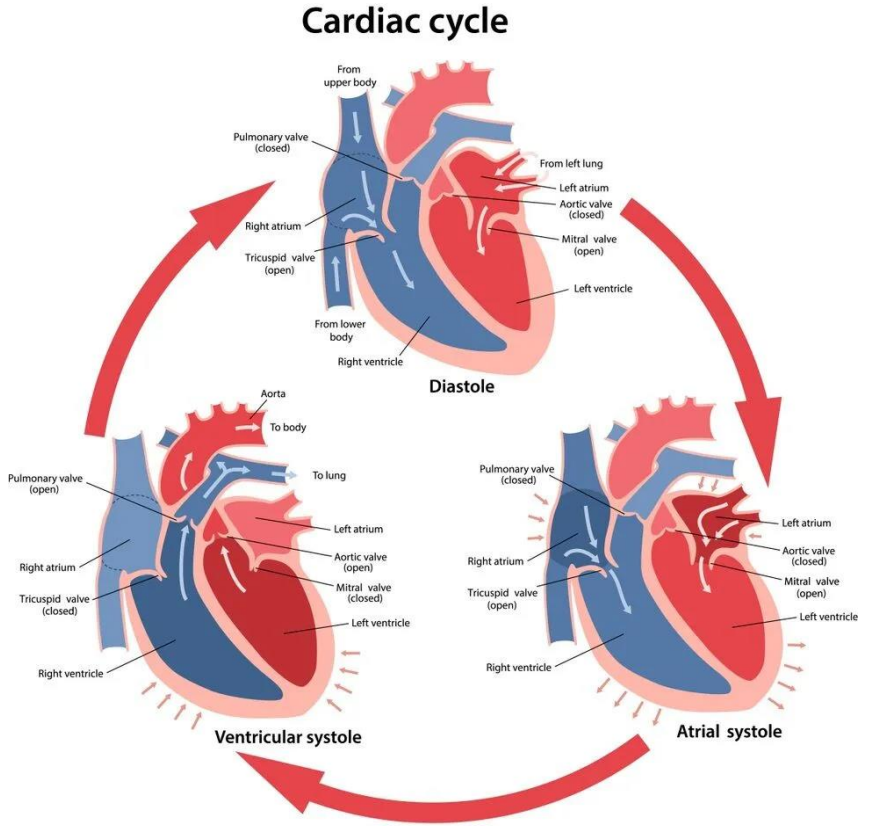


CARDIAC CYCLE

1. **Atrial** and **ventricular diastole**
   - the atria and the ventricles expand
   - atrial filling

2. **Atrial systole** (and ventricular diastole)
   - the atria contract
   - ventricular filling

3. **Ventricular systole** (and atrial diastole)
   - the ventricles contract
   - ventricular ejection



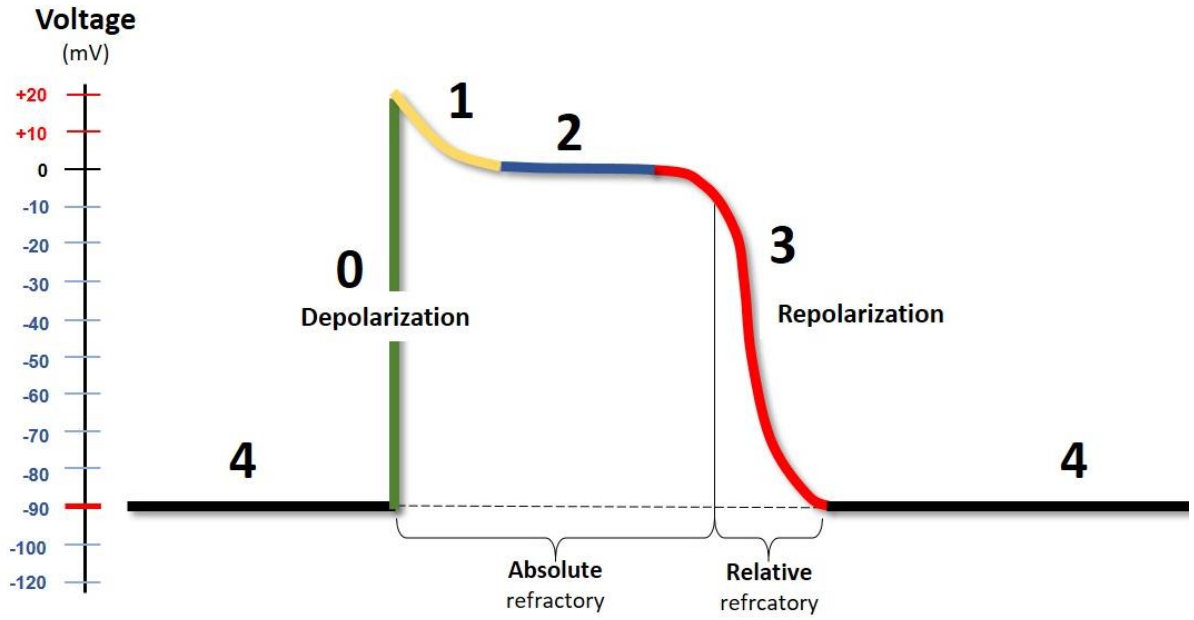
https://biologydictionary.net/cardiac-cycle/

POLARIZATION AND DEPOLARIZATION

- When the heart is at rest, the potential inside of cardiomyocytes **is approximately $-90\ mV$** with respect to the potential outside

- During the action potential, the potential inside of cardiomyocytes **becomes positive** with respect to the potential outside

- After the action potential, the potential inside of cardiomyocytes returns to the resting conditions



https://studmed.uio.no/elaring/fag/hjertesykdommer/en/ecg/basal_elfys.html

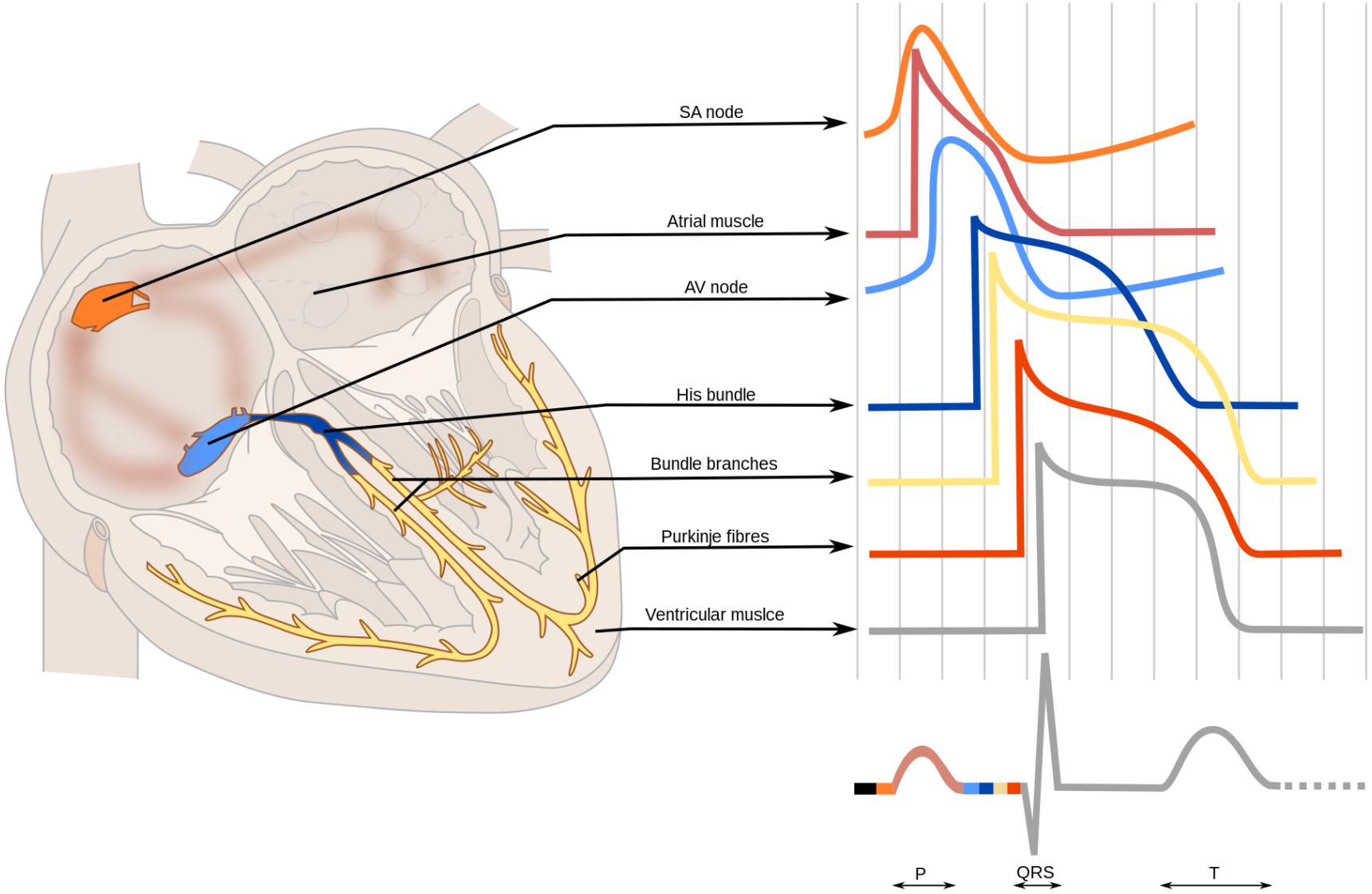
POLARIZATION AND DEPOLARIZATION

- The cells of the **sinoatrial (SA) node** depolarize first, causing the contraction of the atria

- The cells of the **atrioventricular (AV) node** conduct the depolarization down a bundle of fibers, causing the contraction of the ventricles

- There is an **inherent delay** in this conduction process, making the atria contract before the ventricles and ensuring the correct heart operation

POLARIZATION AND DEPOLARIZATION



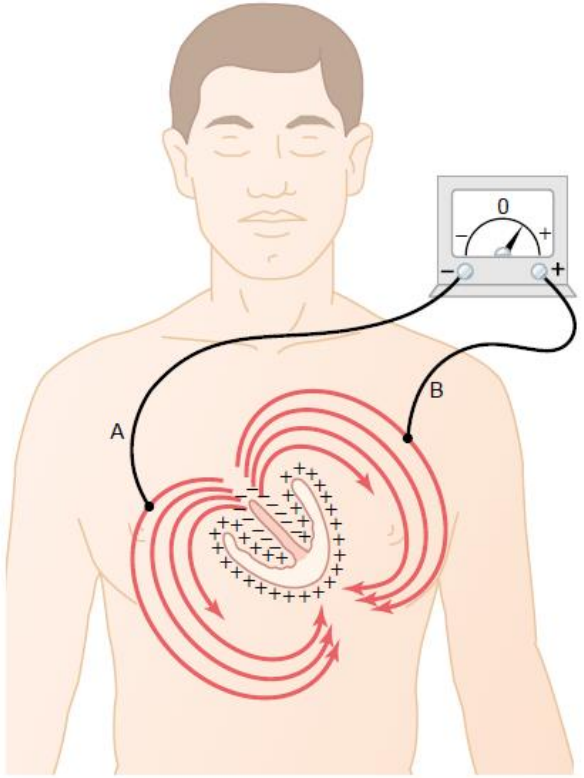
ELECTROCARDIOGRAM

We can measure the effect of the heart polarization and depolarization directly over the skin surface by an **electrocardiogram (ECG)**

1. the **P-wave** represents the atrial systole, i.e., the atrial depolarization

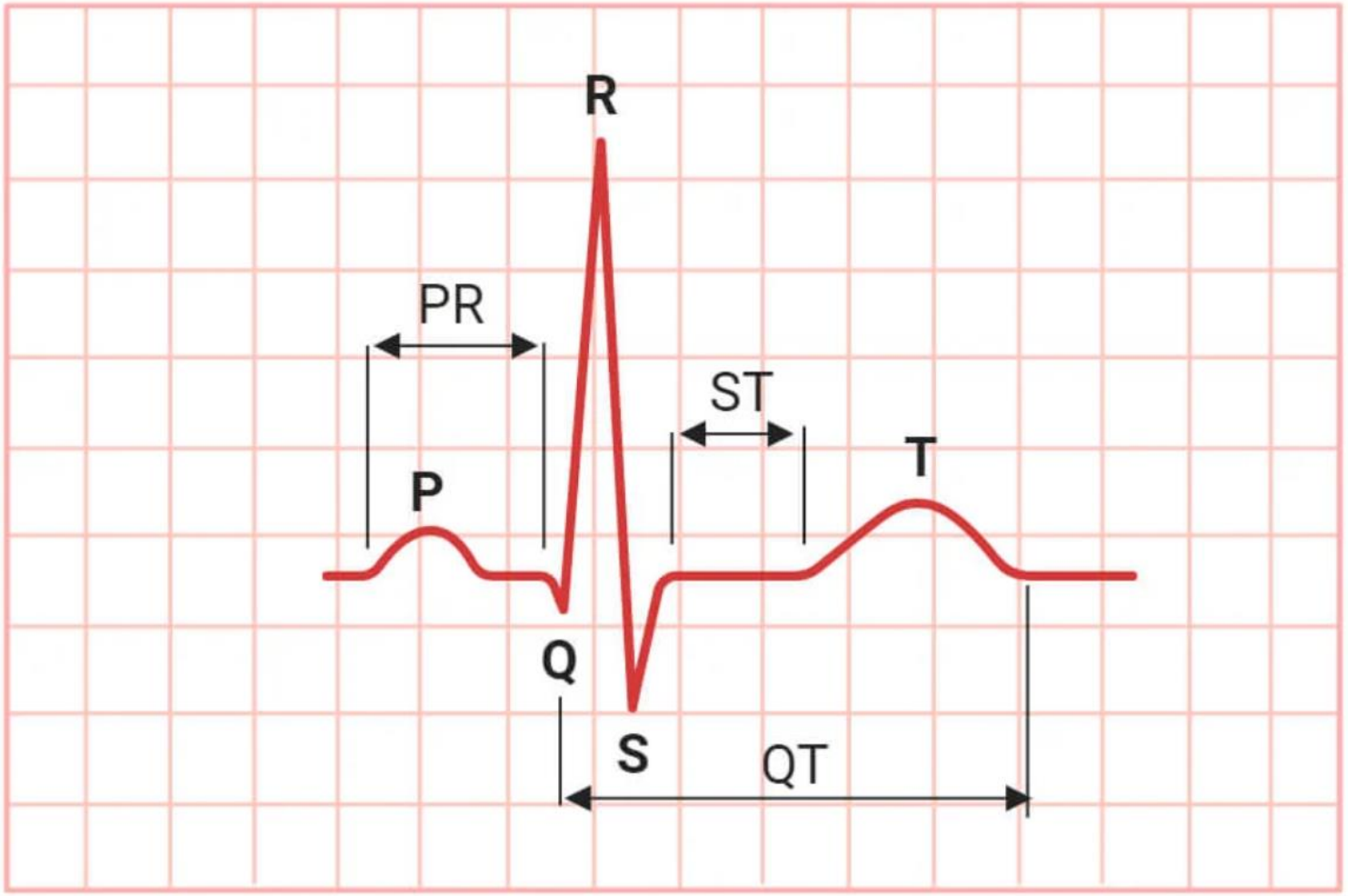
2. the **QRS complex** represents the ventricular systole, i.e., the ventricular depolarization

3. the **T-wave** represents the ventricular diastole, i.e., the ventricular repolarization



https://www.brainkart.com/article/Flow-of-Current-Around-the-Heart-During-the-Cardiac-Cycle_19239/

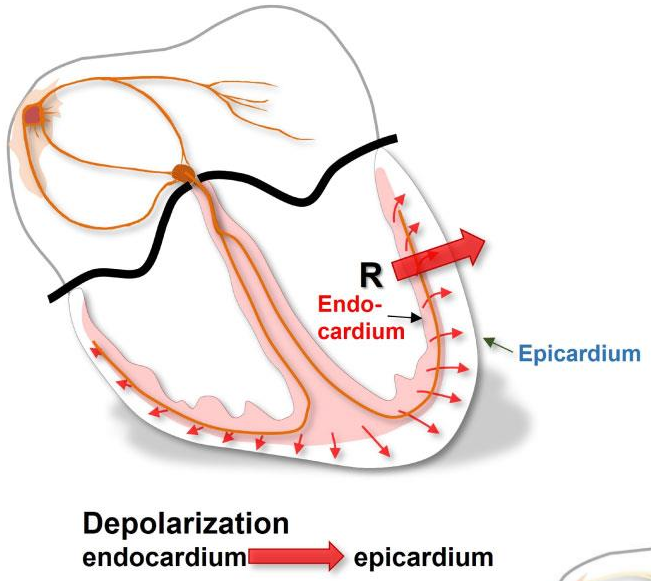
ELECTROCARDIOGRAM

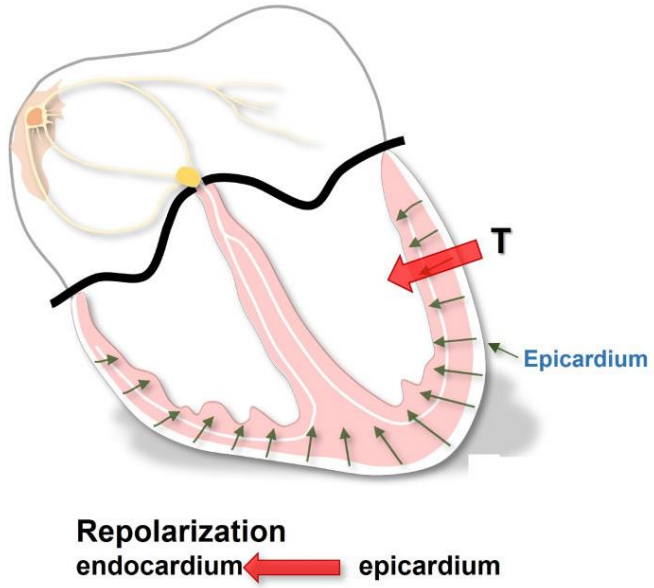


T WAVE SHAPE

Despite representing a repolarization phenomenon, the **T-wave is upright**!

- Ventricular depolarization begins in the endocardium and spreads toward the epicardium, while ventricular repolarization follows the opposite pattern





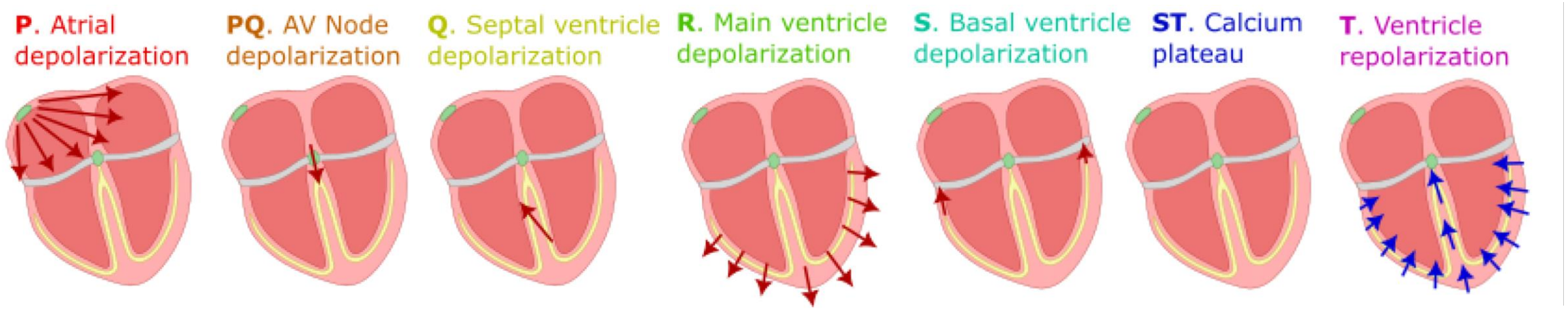
- Hence the distribution of **positive and negative charges is similar** during ventricular depolarization and repolarization

https://studmed.uio.no/elaring/fag/hjertesykdommer/celle_papir_en/del2/komponenter.html

CARDIAC DIPOLE

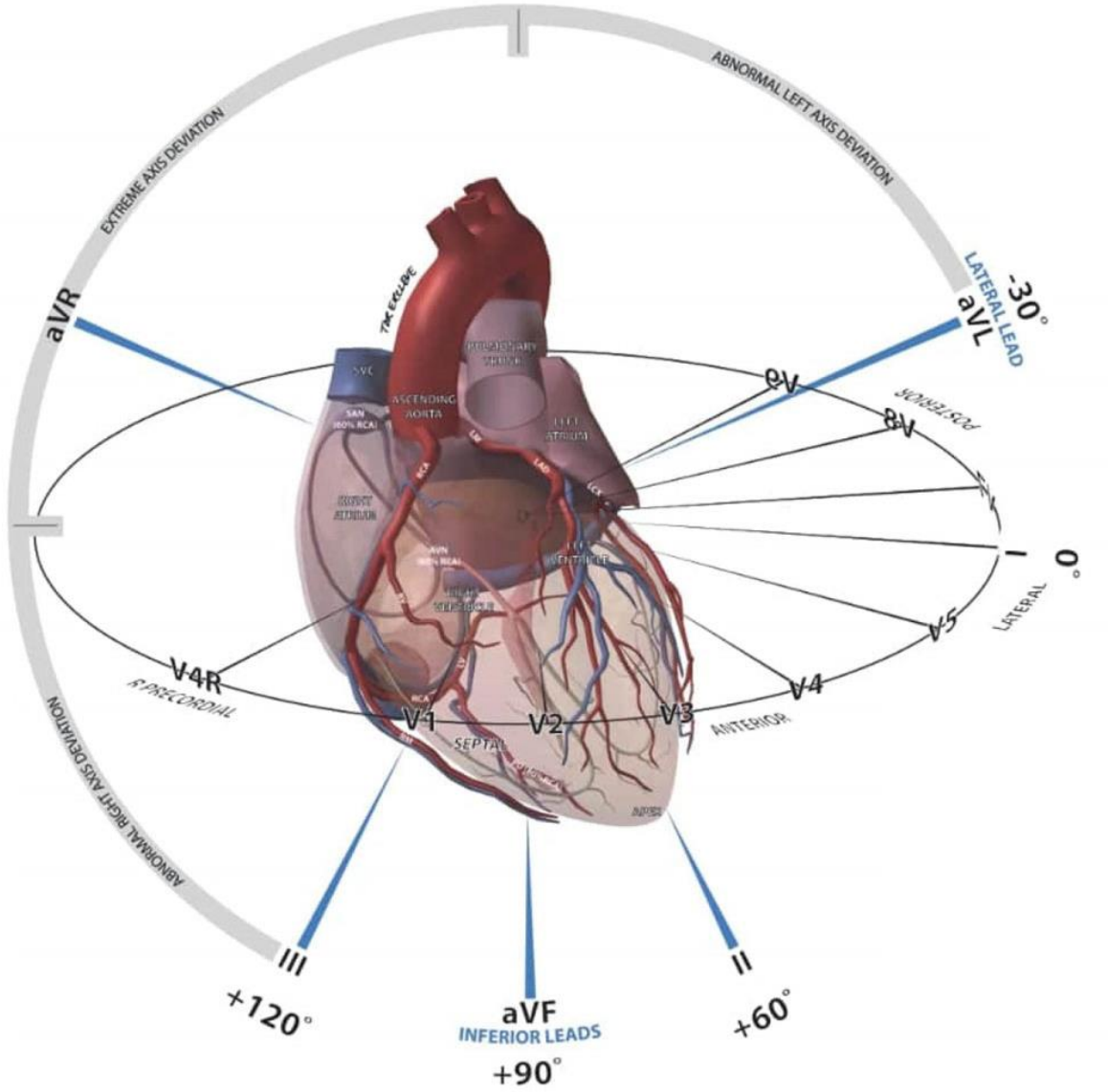
- When one portion of the heart is polarized and an adjacent portion is depolarized, an **electrical current** moves through the muscle

- The heart constitutes an **electric dipole** in a 3-dimensional space, pointing from the biggest mass of depolarized myocardium to the biggest mass of polarized myocardium



O'Reilly C, Oruganti SDR, Tilwani D, Bradshaw J. Model-Driven Analysis of ECG Using Reinforcement Learning. *Bioengineering*. 2023; 10(6):696.

CARDIAC DIPOLE



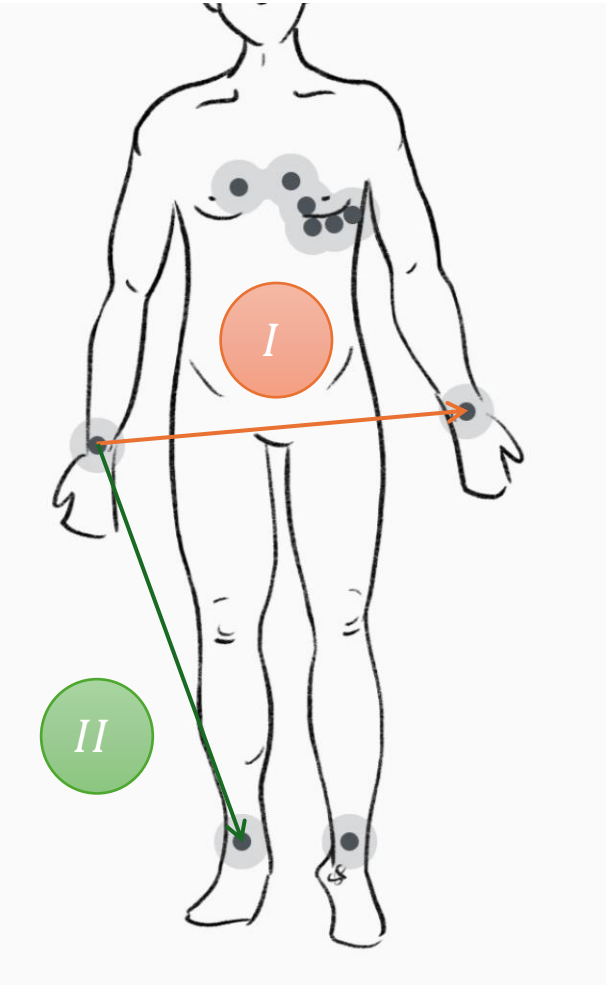
- A single electrode is not sufficient to assess the **direction** and **magnitude** of an electric dipole
- To obtain an accurate representation of the cardiac dipole, we need to combine the measures derived from **multiple electrodes**

ECG RECORDING

A full **12-lead ECG** (the standard ECG format used in medical facilities), requires the placement of **9 surface-skin electrodes**

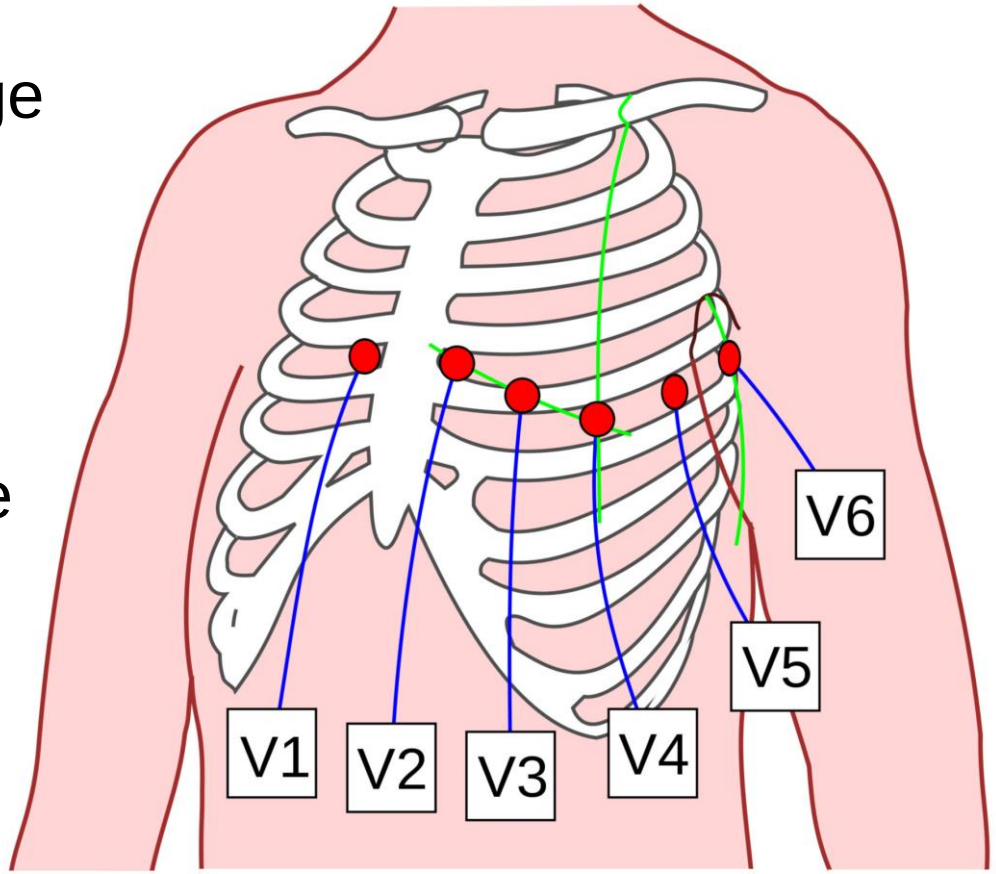
- 3 electrodes on the **patient limbs** enable the recording of the limb leads (I, II, III, aVR, aVF, aVL)

- 6 electrodes on the **patient chest** enable the recording of the precordial leads ($V1$, $V2$, $V3$, $V4$, $V5$, $V6$)

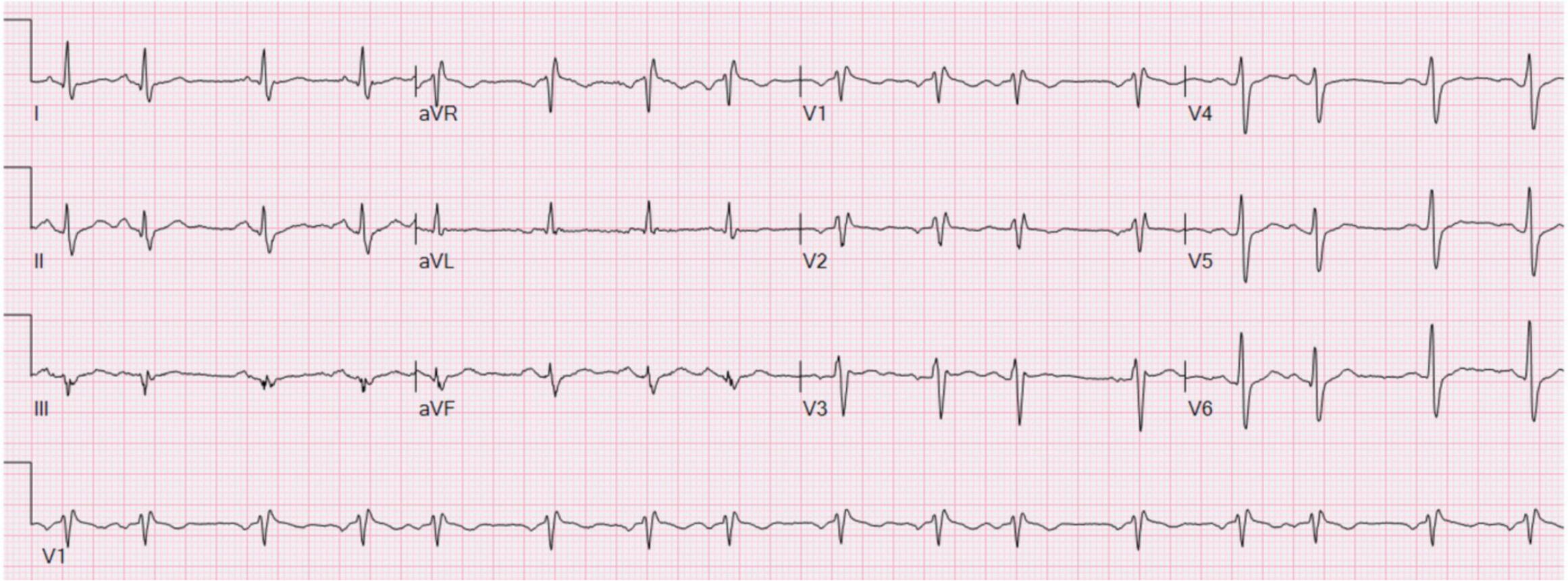


PRECORDIAL LEADS

- $V1$ is placed to the right of the sternal border
- $V2$ is situated to the left of the sternal edge
- $V3$ is placed between $V2$ and $V4$
- $V4$ is placed at the level of the fifth intercostal space in the mid-clavicular line
- $V5$ is placed between V4 and V6
- $V6$ is placed at the level of the fifth intercostal space in the mid-axillary line



12-LEAD ECG



ECG FOR HEART MONITORING

A 12-lead ECG gives full information about the heart's electrical activities, allowing to correlate the **signal morphology** with the different heart functions

- An increase in the **ST segment** is a marker of a reduction of blood flow toward the heart muscles

From a single lead electrocardiogram, it is possible to derive the RR interval and the **heart rhythm**

- Changes in the **heart rate variability** are markers of abnormalities in the autonomic system

HEART MONITORING CHALLENGES

To **diagnose CADs,** it is necessary to examine a full 12-lead ECG, whose recording is possible only by using specific medical equipment

→ How can we provide remote 12-lead ECG monitoring?

To **detect arrhythmias,** it is necessary to monitor the heart rhythm over a long period, which is not feasible during a standard medical exam

→ How can we provide continuous heartbeat monitoring?

Thank you!

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