Electrocardiogram
Outline

• definition
• basic electrophysiological principles
• lead systems
• normal ECG
Definition

- the electrocardiogram (ECG or EKG) is a record of potential differences arising within the heart that are measured by electrodes placed on the body surface
- ECG records only electrical activity and is not a measure of the mechanical behavior of the heart
- three of five major properties of the cardiac muscle can be evaluated by the ECG:
  - chronotropy (automaticity, pacemaker activity, the ability to initiate an electrical impulse)
  - dromotropy (conductivity, the ability to conduct an electrical impulse)
  - bathmotropy (irritability, modification of the degree of excitability: i.e. threshold of excitation, the ability to respond to direct stimulation)
Resting membrane potential

- cardiac myocytes are excitable cells with polarized membranes (there is an electrical potential difference between the interior and exterior of a cell)
- the membrane potential arises from the interaction of ion channels and ion pumps embedded in the membrane that maintain different ion concentrations on the intracellular and extracellular sides of the membrane
Definitions

• depolarization is a change in a cell's membrane potential, making it more positive, or less negative
  – a large enough depolarization may result in an action potential
  – usually caused by influx of cations
• repolarization: restoring the resting membrane potential
  – usually caused by efflux of cations
• hyperpolarization: a change in a cell's membrane potential that makes it more negative
  – often caused by efflux of cations
Activation of myocardial cells

• cardiac myocytes are activated by an electrical signal
  – in experiments: external stimulus
  – in the working heart: an action potential
Action potential
Activation of myocardial cells

- cardiac myocytes are activated by an electrical signal
  - in experiments: external stimulus
  - in the working heart: an action potential
- once initiated the depolarization will propagate in every direction and from cell to cell
Electric dipole

- the electric dipole, consists of two equal and opposite charges, separated by some (usually small) distance

- the potential differences arising in the heart (cardiac dipoles) can be represented by electrical vectors
Dipoles/vectors

- vectors by convention point to the positive pole (orientation) while the length of the vector indicates the magnitude of the potential difference

- all basic vector operations can be applied to the cardiac vectors

- thus cardiac vectors as well can be added, moved, measured and projected on conventional axes corresponding to leads
Dipoles/vectors

- each depolarizing myocardial cell is in fact a dipole and thus can be represented by a vector = elementary vector
- the sum of all elementary vectors will create an instantaneous vector
Dipoles/vectors (continued)

- the potential differences generated by the heart change from moment to moment during the cardiac cycle
- once a single cell is stimulated the depolarization will propagate in every direction: a propagating wave of depolarization will be created
- each of these moments can be described by an instantaneous vector (with a different size and orientation)
- all these vectors can be brought to a single common point: electrical center of the heart
Dipoles/vectors (continued)

• by recording the magnitude and direction of the electrical forces that are generated by the heart by means of a continuous series of vectors that form curving lines around a central point one can record the vectorcardiography

• the projection of this curve as function of time on an axis corresponding to a lead is actually the ECG in that particular lead
Download animation separately!
Impulse propagation through the heart

- **S-A node (sinoatrial node, SAN):** the heart's normal pacemaker (initiates each heartbeat); located in the right atrium of the heart
- **A-V node (atrioventricular node, AVN):** the electrical bridge between the atria and ventricles; located in the septum close to the tricuspid valve
- **His-Purkinje system:** conducts the electrical signals to and throughout the ventricles. It consists of the following parts:
  - His Bundle
  - Right bundle branch (Tawara)
  - Left bundle branch (Tawara)
  - Purkinje fibers
- Microscopically, the wave of de/repolarization propagates to adjacent cells via gap junctions located between the cells. The heart is a functional syncytium: electrical impulses propagate freely between cells in every direction.
Impulse propagation through the heart

Cardiac Conduction System

- Interatrial septum
- S-A node
- A-V node
- Left bundle branch
- Interventricular septum
- A-V bundle
- Purkinje fibers
Depolarizing wave

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Depolarizing wave - ventricle
ECG leads

- electrodes for recording the potential changes of the heart are placed on the body surface in a standard way
- potential changes recorded by specifically connected electrodes is called a lead
- each lead will be assigned with an axis and each of the axes will have an orientation: by convention the sense of the axis is toward the positive electrode
- the projection of the cardiac vectors as function of time on the axis corresponding to a lead is actually the ECG trace in that particular lead
Limb leads – placement of electrodes

- electrode placement is standard (developed by Einthoven)
- bipolar: records the potential difference between two electrodes influenced by the dipole
Limb leads – Lead I

- bipolar lead
- uses electrodes: R and L
- $D_1 = V_L - V_R$
- axis orientation toward the positive electrode (L)
Limb leads – Lead II

- bipolar lead
- uses electrodes: R and F
- D2 = VF - VR
- axis orientation toward the positive electrode (F)
Limb leads – Lead III

- bipolar lead
- uses electrodes: L and F
- D3 = VF - VL
- axis orientation toward the positive electrode (F)
Limb leads – Einthoven’s triangle

- the limb leads form the points of what is known as Einthoven's triangle
  - equilateral
  - heart is in the orthocenter of the triangle
  - $D_2 = D_1 + D_3$

- the projection of the cardiac vectors as function of time on the axis corresponding to a lead is actually the ECG trace in that particular lead
• when a depolarization wave front (or mean electrical vector) moves toward a positive electrode, it creates a positive deflection on the ECG in the corresponding lead.

• when a depolarization wave front (or mean electrical vector) moves away from a positive electrode, it creates a negative deflection on the ECG in the corresponding lead.

• when a depolarization wave front (or mean electrical vector) moves perpendicular to a positive electrode, it creates an equibiphasic complex on the ECG. It will be positive as the depolarization wavefront (or mean electrical vector) approaches, and then become negative as it passes by.
Augmented limb leads

- the same electrodes in the same position as with the limb leads

- unipolar:
  - one of the electrodes (exploring electrode, always positive) measures the potential generated by the dipole
  - one electrode (indifferent) is not influenced by the dipole

- $VR + VL + VF = 0$

- name always starts with “a” to show that these smaller potentials are augmented
Augmented limb leads – aVL

- unipolar lead
- axis orientation toward the positive electrode (L)
- perpendicular on the RF axis
Augmented limb leads – aVF

- unipolar lead
- axis orientation toward the positive electrode (F)
- perpendicular on the RL axis
Augmented limb leads – aVR

- unipolar lead
- axis orientation toward the positive electrode (R)
- perpendicular on the LF axis
Hexaaxial system

• all limb leads explore the heart in frontal plane
Hexaaxial system
Precordial leads - electrode placement

- electrodes used for limb leads – connected to a central terminal (Wilson) - indifferent
- six electrodes on the chest (each of them separately exploring electrodes):
  - **V1** - fourth intercostal space, just to the **right** of the sternum
  - **V2** - fourth intercostal space, just to the **left** of the sternum
  - **V3** - between leads V2 and V4
  - **V4** - fifth intercostal space in the mid-clavicular line
  - **V5** - horizontally even with V4, but in the anterior axillary line
  - **V6** - horizontally even with V4 and V5 in the midaxillary line
12-lead ECG

- different leads "view" the heart from different angles
12-lead ECG

- different leads "view" the heart from different angles
  - anterior: V1-V4
  - lateral: D1, aVL, V5-V6
  - inferior: D2, D3, aVF

- unfortunately none of the leads views the posterior wall of the left ventricle
  - mirror image: V1-V2
  - other leads (beside the 12-lead ECG):
    - V7-V8-V9
    - esophageal, intracardiac, etc.
Morphological analysis of ECG

- describes the elements of the ECG trace recorded during one heart cycle
- the ECG can be recorded on ECG paper
- standard output:
  - on the y axis:
    1 mm represents 0.1 mV
    1 mV is represented as 10 mm
  - on the x axis (paper speed of 25mm/s):
    1 mm represents 0.04 seconds
    1 sec is represented as 25 mm
Morphological analysis – normal ECG

• normal ECG trace:

- waves
- segments
- intervals
Morphological analysis - WAVES

- waves are deflections of the ECG trace from the isoelectric line
- described by their:
  - duration (mm or msec/sec)
  - amplitude (mm or mV)
  - axial orientation (degrees)
  - shape

The baseline voltage of the electrocardiogram is known as the isoelectric line. Typically the isoelectric line is measured as the portion of the tracing following the T wave and preceding the next P wave.
Morphological analysis - SEGMENTS

- segments are parts of the ECG trace situated between two adjacent waves
- described by their:
  - duration (mm or msec/sec)
  - position to the isoelectric line
  - if deviated from the baseline:
    - direction
    - amplitude
    - shape
Morphological analysis - INTERVALS

• intervals are parts of the ECG trace situated between two markers
• described by their:
  – duration (mm or msec/sec)
Normal ECG

- **P wave:**
  - represents the atrial depolarization
  - duration: 0.08-0.1 sec (2-2.5 mm)
  - amplitude: max. 0.25-0.3 mV (2-2.5 mm)
  - axial orientation: 30-60°
  - shape: round, in V1 can be biphasic (max. amplitude 1.5 mm)
Normal ECG

• PQ (PR) segment:
  – represents the delay of conduction at the AV junction
    • duration: 0.02-0.12 sec
    • position: isoelectric

• PQ (PR) interval:
  – represents the electrical conduction from the SAN to the ventricles
    • duration: 0.12-0.21 sec
Normal ECG

- QRS complex:
  - represents the ventricular depolarization
  - duration: below 0.12 sec / 3 mm (measured at the isoelectric line)
  - amplitude: 0.5-1.6 mV (5-16 mm) in limb leads and augmented limb leads, in precordial leads:
    - axial orientation: 30-60°
    - shape: sharp waves
Normal ECG

- QRS complex:
  - shape: sharp waves
  - nomenclature: lowercase if < 3 mm, uppercase if > 3 mm
Normal ECG

• ST segment:
  – represents the early phase of ventricular repolarization
    • duration: no practical importance
    • position: isoelectric
      – small ST segment elevations or depressions are not considered pathological

at most 1mm in V1 and V2
and/or at most 2mm in all other leads
Normal ECG

• T wave:
  – represents the final ventricular repolarization
  • duration: 0.12-0.3 sec (no practical importance)
  • amplitude: approximately 1/3 of the largest R wave
  • axial orientation: 30-60°
  • shape: round and asymmetrical
  • normally T wave is positive in every lead except aVR
Normal ECG

• QT interval:
  – represents ventricular electrical systole
  • duration: frequency dependent, usually considered normal if it’s under 50% of I_{RR} (very important for pathology)

-use charts or formulas

[Graph showing QT interval corrected for heart rate]
Normal ECG

• **U wave:**
  – not always present
  – created by ventricular afterdepolarizations
    • duration: 0.15-0.25 sec
    • amplitude: less than 2 mm
    • shape: round
ECG genesis

Download animation separately!
Next week...

- interpretation of ECG