SEB4233
Biomedical Signal Processing

Physiological Origin of Biomedical Signal

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Origin of Biomedical Signals

- Human body is made up of a number of systems
  - e.g- respiratory, cardiovascular, nervous system, etc
- Each of these systems is made up of several subsystems that carry on many physiological processes.
- Each physiological process is associated with certain types of signals that reflect their nature and activities.
- These signals are referred as *biomedical signals*.
- Different types ob biomedical signals:
  - Biochemical - hormones, neurotransmitters
  - Electrical - potentials, currents
  - Mechanical - pressure, temperature

Origin of Biomedical Signals

- *Bioelectric signals* are specific types of biomedical signals which are obtained by electrodes that record the variations in electrical potential generated by physiological processes.
- Examples of bioelectric signals:
  - electrocardiogram (ECG)
  - electroencephalogram (EEG)
  - electromyogram (EMG)
  - electrooculogram (EOG) among others.
- Observing these signals and comparing them to their known norms, we can often detect a disease / disorders.
- When such measurements are observed over a period of time, a one dimensional time-series is obtained - **this is a physiological signal**

Origin of Biomedical Signals

- Example:
  - Heart problem – changes in electrocardiogram (ECG), or changes in blood pressure
  - Neurological disorders (such as epilepsy)-changes in electroencephalogram (EEG)

What is a signal

- A signal is a single-valued representation of information as a function of an independent variable (e.g., time) (Bruce, 2001).
- The specific type of information being represented may have real or complex values.
- A signal may be a function of another variable besides time or even a function of two or more variables.

Commonly used Biomedical Signals

- The action potential: mother of all biological signals
- The electromyogram (EMG): electrical activity of the muscle cells
- The electrocardiogram (ECG): electrical activity of the heart / cardiac cells
- The electroencephalogram (EEG): electrical activity of the brain
- The electrogastogram (EGG): electrical activity of the stomach
- The phonocardiogram (PCG): audio recording of the heart's mechanical activity
- The carotid pulse (CP): pressure of the carotid artery
- The electoretinogram (ERG): electrical activity of the retinal cells
- The electrooculogram (EOG): electrical activity of the eye muscles

Action Potential (AP)

- All biological signals of electrical origin are made up from integration of many action potentials

- The AP is the electrical signal that is generated by a single cell when it is mechanically, electrically or chemically stimulated

  - It is the primary mechanism through which electrical signals propagate between cells, tissues and organs
  - It is due in part, to an electrochemical imbalance across the cell membrane, and in part, due to selective permeability of the membrane to certain ions

Action Potential

- At resting state, the cell membrane is permeable to K+ and Cl-, but not to Na+
- Lots of Na+ trapped outside make the intracellular region electrically more negative, with a resting membrane potential of -60 ~-80 mV
- When the cell is disturbed, ion channels across the membrane open up and allow an influx of Na+ : depolarization - inside of the cell becomes more positive: +20mV
- However, the channels close soon after, forcing the membrane potential back to its resting stage: repolarization
- The change in membrane potential is the AP, which itself then stimulates the neighboring cell, and starts the transmission of the APs

Electromyogram (EMG)

- The EMG is the graphic representation of the electrical activity of the electrical activity of the muscle cells

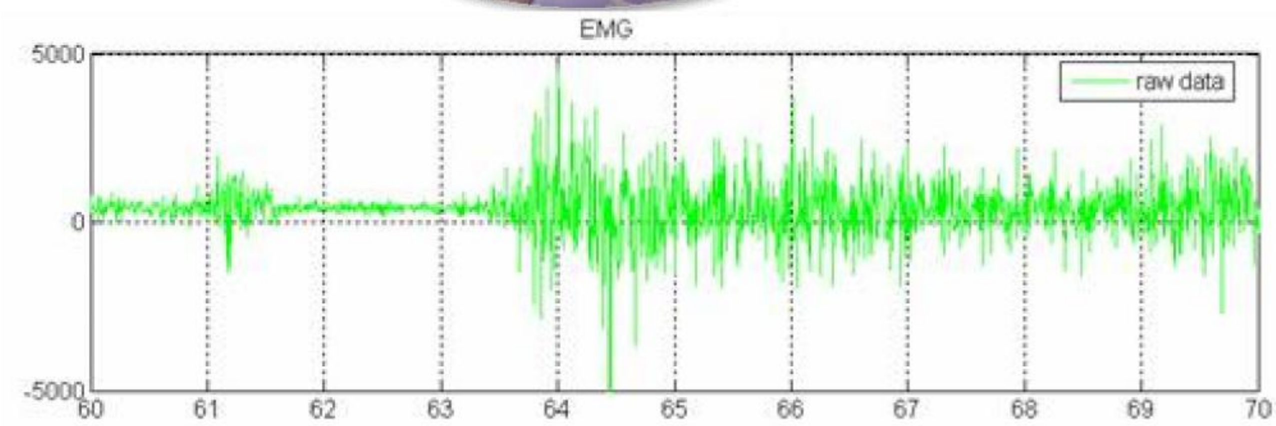
- It is the integration of millions of muscle APs as measured from the skin surface

Recording EMG

- EMG is a surface signal obtained through surface and/or needle electrodes.

- Usually, muscle electrical activity is recorded by placing electrodes near the muscle of interest as shown in following figure.

Electromyogram (EMG)



Electrocardiogram (ECG)

- ECG is the graphical recording of the electrical activity of the heart.

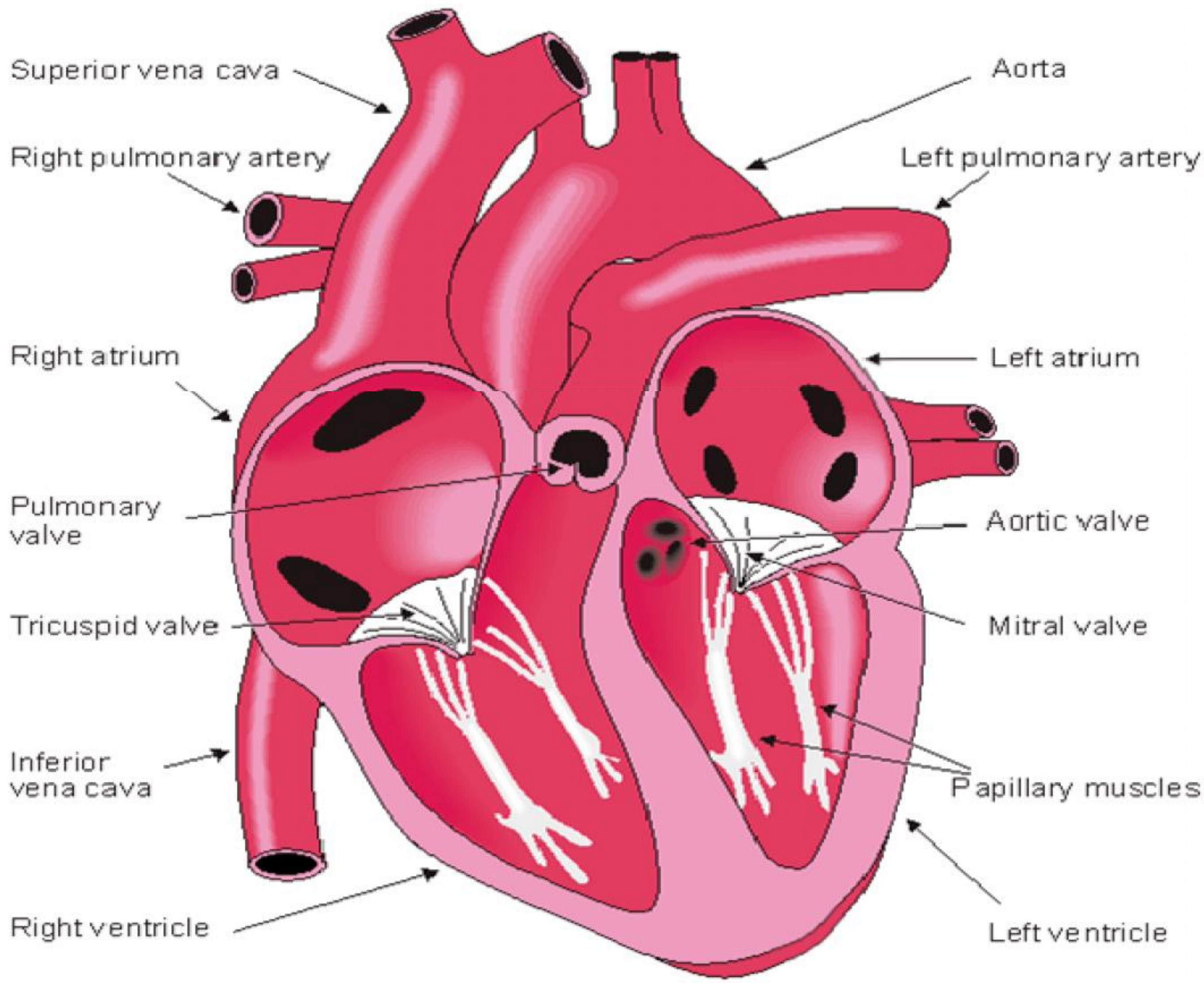
- It is the combination of many APs from different regions of the heart that makes up the ECG

- Very commonly used signal in medical; thus reviewed intensively

Anatomy of Heart

- Human's heart is made of powerful muscle called as Myocardium which composed of cardiac muscle fibers.
- Heart anatomy is divided into four chambers which are: left atrium, right atrium, left ventricle and right ventricle.
- Two atria are thin-wall chambers used to receive blood from veins while two ventricles are thick-wall chambers which pump blood out of the heart.

Anatomy of Heart



Anatomy of Heart

- The heart has four valves consist of:
  - Mitral valve: lies between left atrium and ventricle.
  - Tricuspid valve: lies between right atrium and ventricle.
  - Pulmonary valve: lies between right ventricle and pulmonary artery.
  - Aortic valve: lies in the outflow tract of the left ventricle.

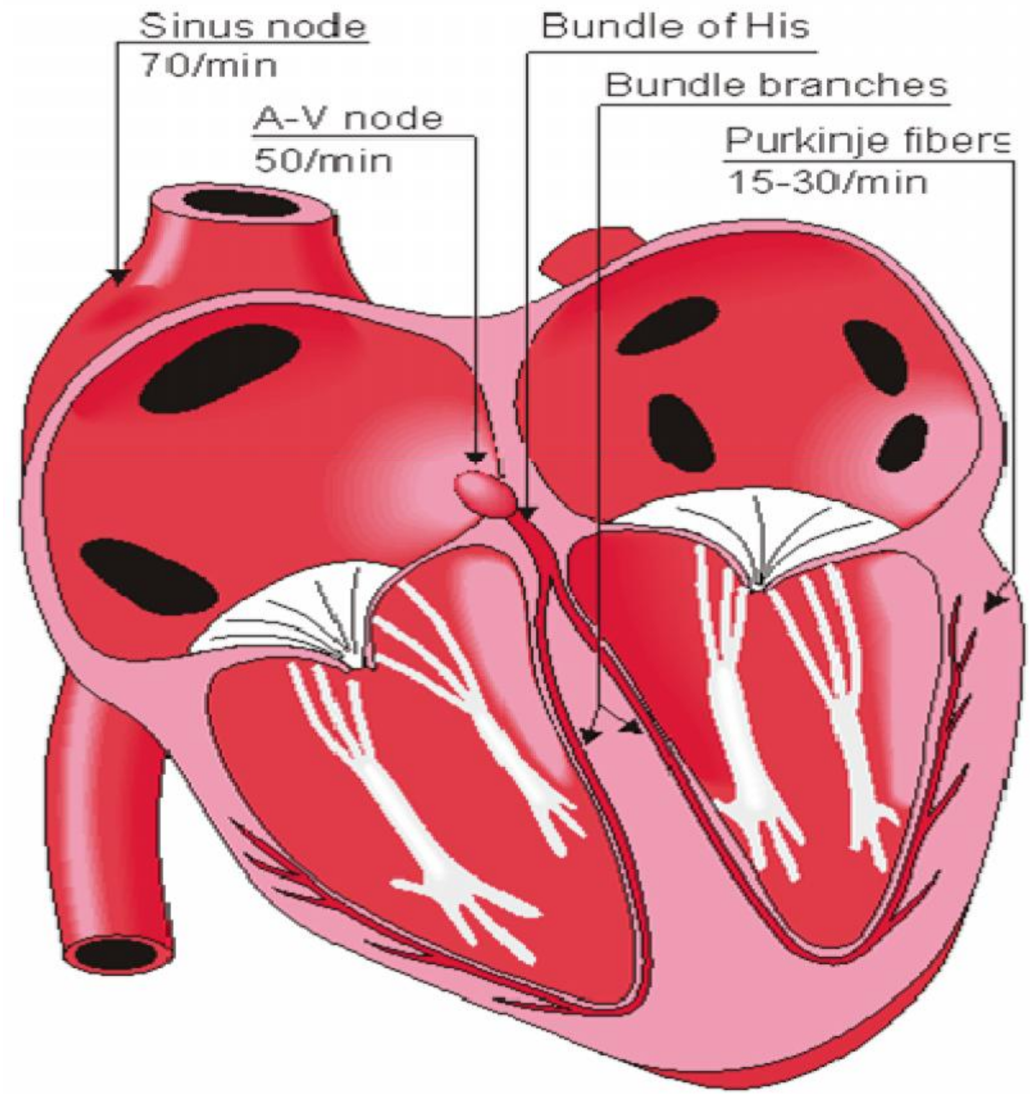
The Conduction System of the Heart

- The conduction system of the heart is controlled by two nodes known as sinus node (sinusatrial or SA node) and atrioventricular node (AV node).
- The SA node is located in the right atrium at the superior vena cava.
- The SA nodal cells are self-excitatory known as pacemaker cells.
- Pacemaker cells generate an action potential at the rate about 70 per minute. The action potential is then propagates from SA node throughout the atria but cannot propagate directly across the boundary between atria and ventricles.
- The AV node is located at the boundary of atria and ventricles.

The Conduction System of the Heart

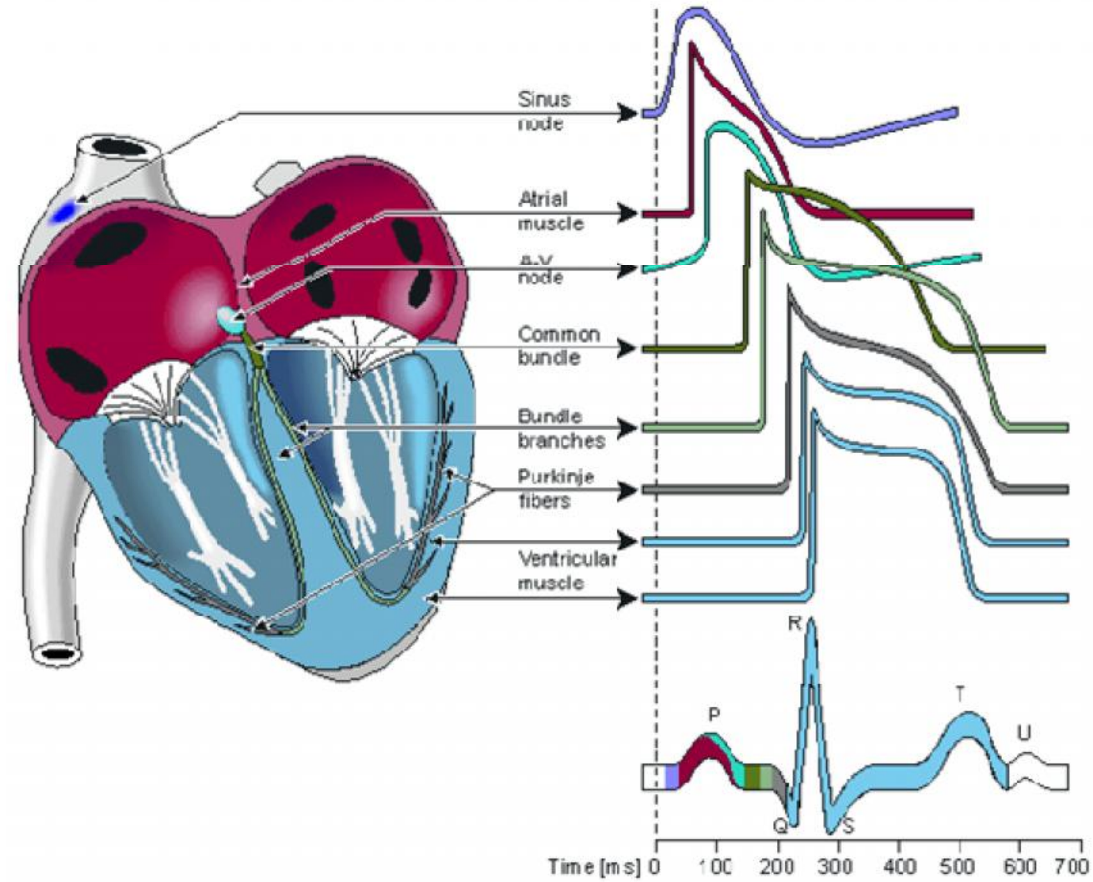
- In the normal heart, the AV node provides the propagating path of action potential from atria to ventricles.
- From AV node, the action potential propagate to the ventricles through a specialized conduction system known as 'Bundle of His' which named after German physician, Wilhelm His, Jr. 1893-1934.
- This bundle separate into two: left and right bundle branches. These two branches are then ramify into purkinje fibers of ventricles. Following figure illustrate conduction system of the heart.

The Conduction System of the Heart



The Conduction System of the Heart

- The waveform of action potentials at different location of the heart is shown.



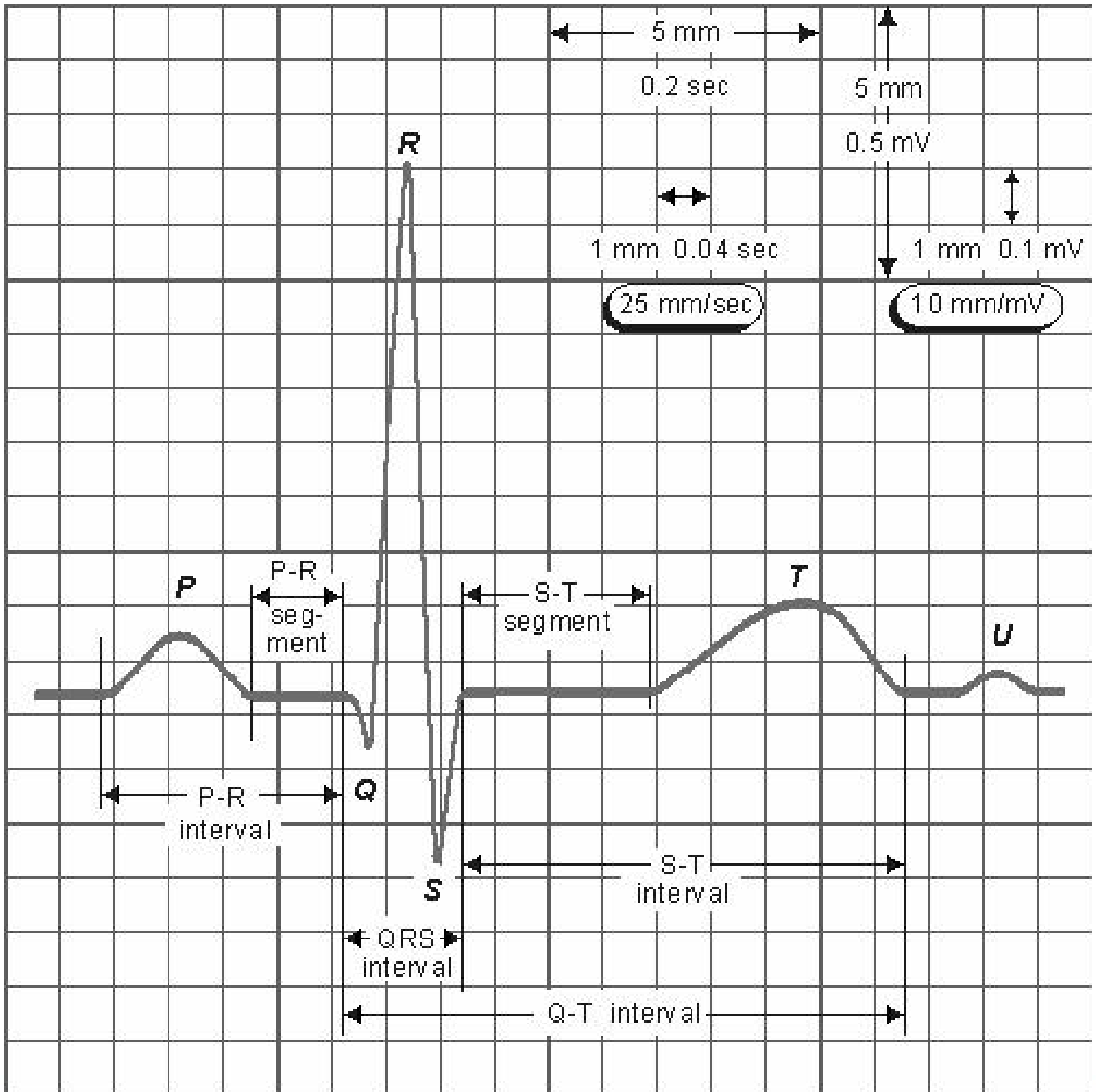
The waveform of action potential at different location of the heart

Insight of ECG

- ECG consists of waveforms that represent the polarization, depolarization, and repolarization of the atria and ventricles of the heart.

- The waveforms are labelled as (Cheryl Passanisi, et al., 2001):
  - **P wave**: atrial depolarization
  - **QRS complex**: ventricular depolarization
  - **T wave**: ventricular repolarization
  - **U wave**: repolarization of the Purkinje fibers
  - **Baseline**: the polarized state

Insight of ECG



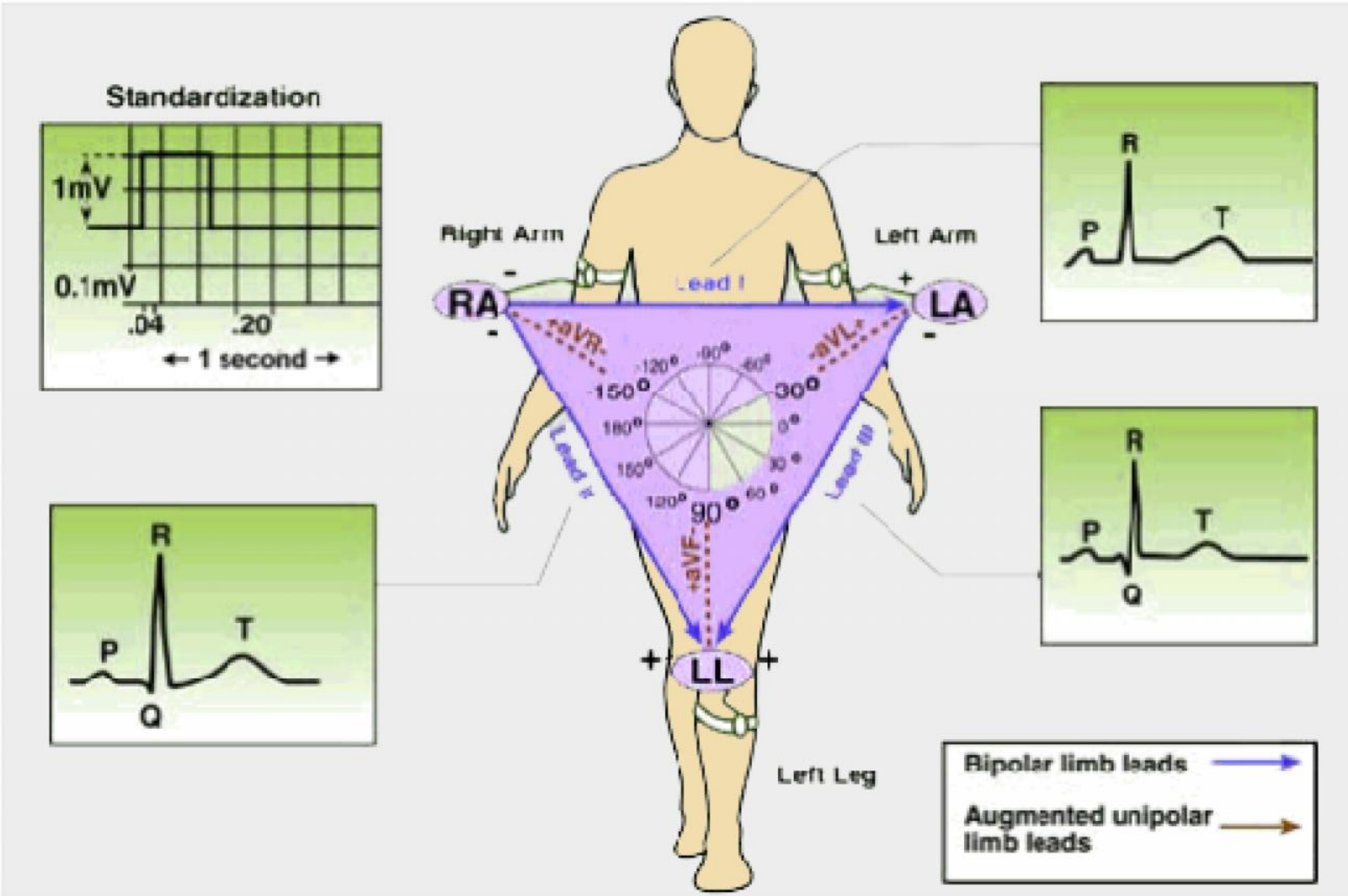
The Standard 12-Lead ECG

- The ECG signal is recorded in three different electrode positions.
  - Standard Limb Leads I, II, III (Bipolar Limb Leads)
  - Unipolar limb leads (Augmented Limb Leads)
  - Unipolar chest leads. a. Standard Limb Leads – I, II, III

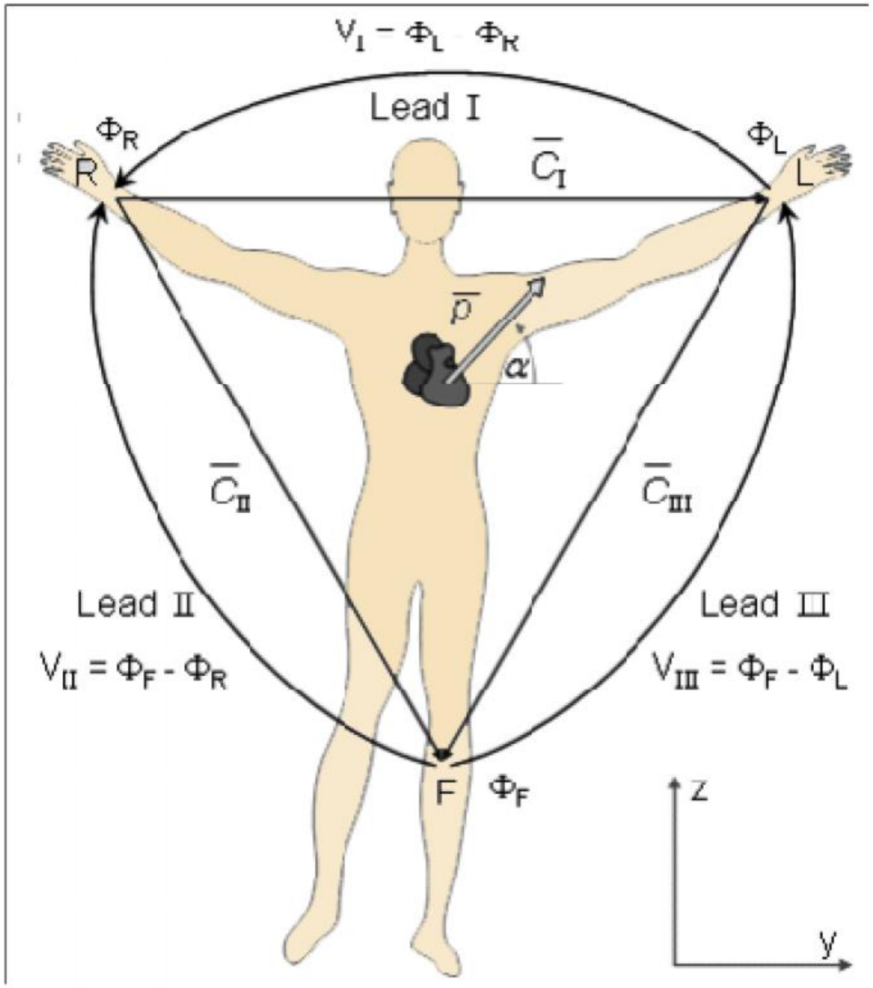
- Each lead gives different reading.

- Twelve reading is obtained where 3 from the standard leads, 3 from the unipolar leads and 6 from the chest lead. (Jari Viik, et al., 2004)

The Standard 12-Lead ECG



Bipolar Limb Leads: Standard Limb Leads I, II, III



Einthoven Limb Leads and Einthoven's Triangle, Malmivuo and Plonsey (1995)

Bipolar Limb Leads: Standard Limb Leads I, II, III

- The electrode I, II and III is attached to the left arm, right arm and the leg. Each of these leads measures voltage between two points on the body.
- **Lead I**: Measure the voltage between the left arm and right arm in which the left arm is the positive pole. Most useful for seeing electrical activity moving in a horizontal direction.
- **Lead II**: connects the right arm to the leg, and therefore electricity moving down and leftward.
- **Lead III**: Measure the voltage potential between the left arm and the leg, thus monitor electricity moving down and rightward with the ECG regarded as the positive pole (Jari Viik, et al., 2004).
- The connection of these standard leads is known as the 'Eithoven Triangle".

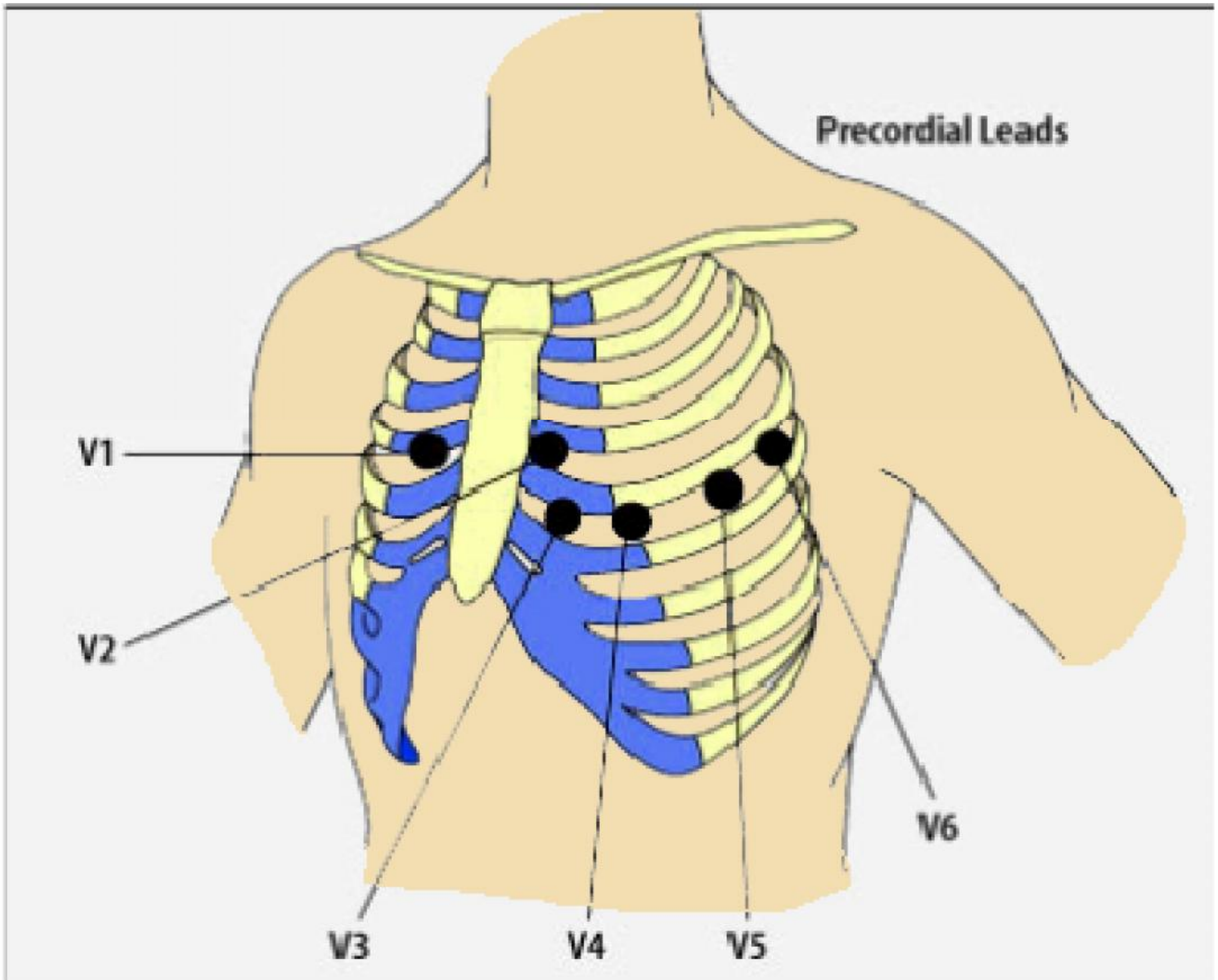
Unipolar Limb Leads

- The same three leads that form the standard leads also form the three unipolar leads known as the augmented leads.

- These three leads are referred to as aVR (right arm), aVL (left arm) and aVF (left leg) and also record a change in electrical potential in the frontal plane.

- These leads are unipolar in that they measure the electric potential at one point with respect to a null point. This null point is obtained for each lead by adding the potential from the other two leads (Jari Viik, et al. 2004).

Unipolar Chest Leads (Precordial Leads)



Unipolar Chest Leads (Precordial Leads)

- For measuring the potentials close to the heart, Wilson introduced the precordial leads (chest leads) in 1944 (Jaakko Malmivvo and Robert Plonsey. 1995).

- These leads, V1-V6 are located over the left chest.
  - The points V1 and V2 are located at the fourth intercostal space on the right and left side of the sternum
  - V4 is located in the fifth intercostals space at the midclavicular line
  - V3 is located between the points V2 and V4
  - V5 is at the same horizontal level as V4 but on the anterior auxiliary line
  - V6 is at the same horizontal level as V4 but at the midline.

Characteristics of ECG

- **P Wave** (with normal physiology and with the SA node acting as the pacemaker of the heart):
  - The amplitude should not more than 3 mm tall.
  - The peak of the P wave should be smooth and rounded.
  - The P wave deflects in positive direction in 1, 11 and aVF leads (Welch Allyn Protocol Inc., 2003).
- **PR Interval** (Welch Allyn Protocol Inc. 2003)
  - Measure from the beginning of the P wave to the beginning of the QRS complex.
  - The normal PR interval duration is 0.12 to 0.20 seconds or 120–200 ms.

Characteristics of ECG

- **QRS Complex:**
  - The wave of ventricular depolarization - QRS complex, even if not all of the components (the Q, the R, and the S) are present.
  - Q wave: the first downward stroke.
  - R wave: the first positive stroke
  - S wave: a negative stroke that follows a positive upstroke.
  - The QRS should be at least 5 mm and not more than 20 mm tall.
  - The width of the QRS is measured from the beginning of the Q wave to the end of the S.
  - Normal QRS duration is 0.06 to 0.10 seconds, and does not exceed 0.12 seconds

Characteristics of ECG

- **ST Segment** (Welch Allyn Protocol Inc., 2003)
  - Begins at the J point (the point at which the QRS complex ends and the ST segment begins).
  - The ST segment duration starts from the J point up to the beginning of the T wave.
  - Indicate the period of time between the end of ventricular depolarization and the beginning of ventricular repolarization.
  - Generally the ST segment is isoelectric, or on the baseline.
  - A deviation of the ST segment from the baseline (either a depression or elevation) may be indicative of myocardial ischemia.

Characteristics of ECG

- **T Wave** (Welch Allyn Protocol Inc. 2003)
  - The wave of ventricular repolarization.
  - Usually deflects in the same direction as the QRS complex, and should be smooth and rounded.
  - The period from the beginning of the T wave to nearly the end is called the "relative refractory period". At this time, the ventricles are vulnerable. A stronger than normal stimulus could trigger depolarization.
  - If an R wave (ventricular depolarization) should occur during this time, a potentially fatal arrhythmia could result.

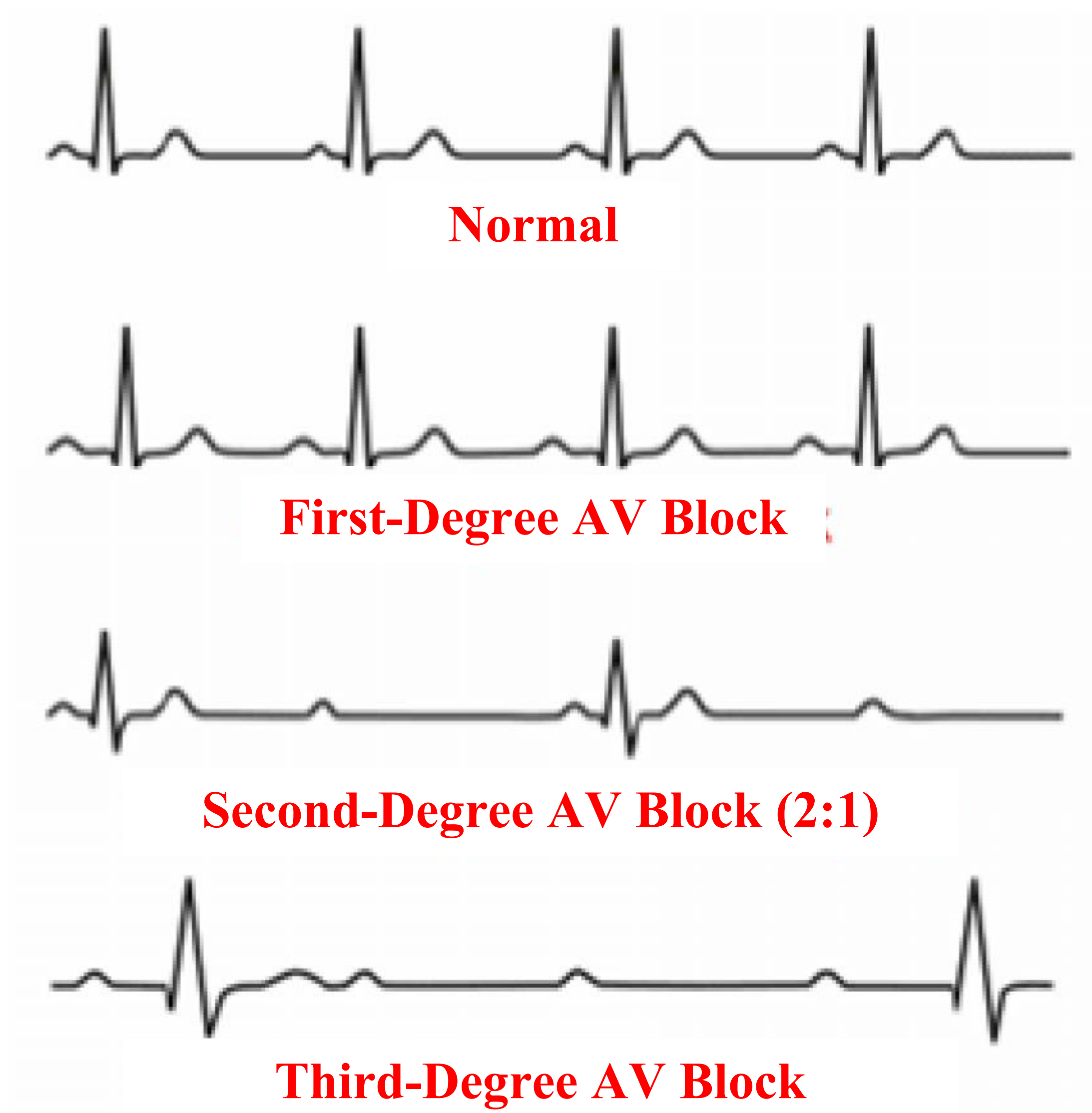
Characteristics of ECG

- **The baseline (isoelectric line)** (Cheryl Passanisi, et al. 2001)
  - The resting phase of the conduction cycle, or the polarized state
  - The straight line on the ECG tracing, represent an absence of electrical activity.
  - Important because the beginning of a waveform is marked by a departure (or movement away) from the baseline.
  - The ending of a waveform is marked in terms of a return to the baseline. This is critical to understand because in order to be able to examine and measure a waveform, a clear understanding of where the waveform begins and ends is necessary.
  - The baseline is the reference point for determining the beginning and end of a waveform.

Arrhythmia

- **Arrhythmia**: any change from the normal sequence of electrical impulses, causing abnormal ECG (Jaakko Malmivvo and Robert Plonsey. 1995).
- **Tachycardia**: a heart rate of more than 100 beats per minute.
- **Bradycardia**: a heart rate of less than 60 beats per minute.
- Arrhythmias can take place in a healthy heart and be of minimal consequence, but they may also indicate a serious problem and lead to heart disease, stroke or sudden cardiac death.

Arrhythmia


Normal
First-Degree AV Block
Second-Degree AV Block (2:1)
Third-Degree AV Block