Lecture Two

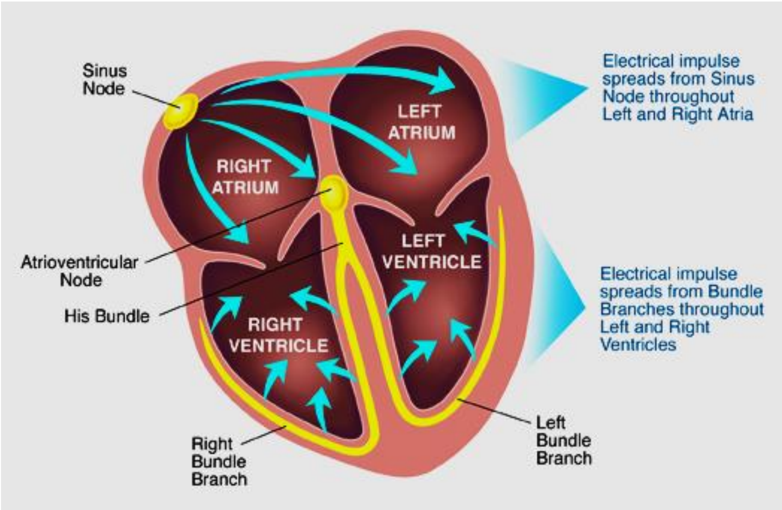
Electrocardiography (ECG)

Origin of the ECG signals

The heart has its own system for generating and conducting action potentials through a complex change of ionic concentration across the cell membrane. Located in the top right atrium, are a group of cells known as the sino-atrial node (SA node) that initiate the heart activity and act as the primary pace maker of the heart. The SA node generates impulses at the normal rate of the heart, about 72 beats per minute at rest.

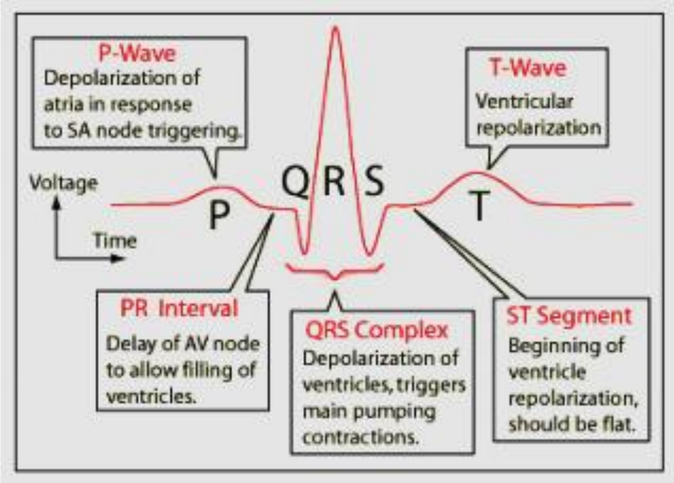
Because the body acts as a purely resistive medium, the potential field generated by the SA node extends to the other parts of the heart. The wave propagates through the right and left atria at a velocity of about 1m/s. About 0.1s are required for the excitation of the atria to be completed. The action potential contracts the atrial muscle and the impulse spreads through the atrial wall about 0.04s to the AV (atrio-ventricular) node.

This node is located in the lower part of the wall between the two atria. The AV node delays the spread of excitation for about 0.12s, then, a special conduction system, known as the bundle of His carries the action potential to the ventricles. The atria and ventricles are thus functionally linked only by the AV node and the conduction system. The AV node delay ensures that the atria complete their contraction before there is any ventricular contraction. The impulse leaves the AV node via the bundle of His. The fibers in this bundle, known as Purkinje fibres after a short distance split



into two branches to initiate action potentials simultaneously in the two ventricles.

The normal wave pattern of the electrocardiogram is shown below, the PR and PQ interval, measured from the beginning of the P wave to the onset of the R or Q wave respectively, marks the time, which an impulse leaving the SA node takes to reach the ventricles.

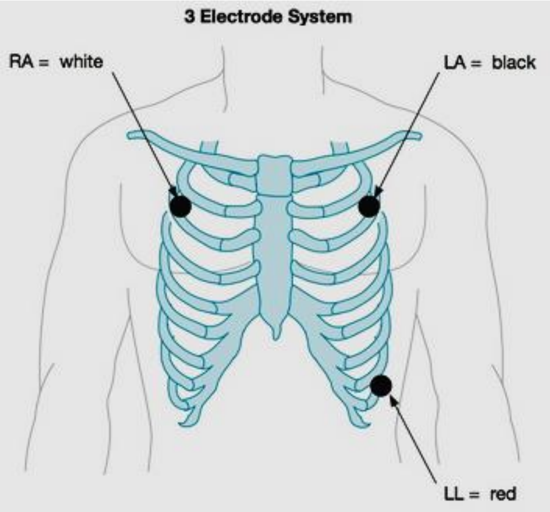


Types of ECG electrodes

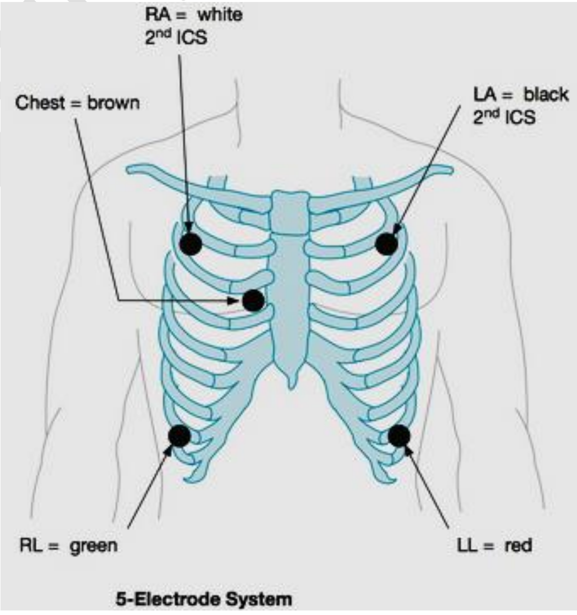
Electrodes come in a few different varieties, but the basis is the same. An ECG electrode is usually composed of a small metal plate surrounded by an adhesive pad, which is coated with conducting gel to help transmit the electrical signal. The wire that connects the ECG electrode to the ECG machine is clipped to the back of the electrode. Electrodes (small, plastic patches) are placed at certain locations on the chest, arms, and legs.

The placement of the ECG electrodes on the patient has been established by medical protocols. The most common protocols require the placement of the electrodes in a 3-lead, a 5-lead or a 12-lead configuration.

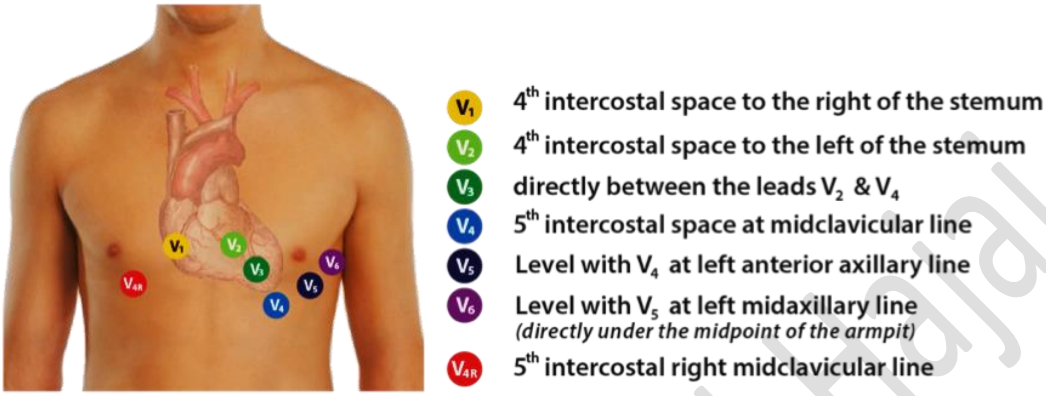
A 3-lead configuration requires the placement of three electrodes; one electrode adjacent each clavicle bone on the upper chest and a third electrode adjacent the patient's lower left abdomen.



A 5-lead configuration requires the placement of the three electrodes in the 3-lead configuration with the addition of a fourth electrode adjacent the sternum and a fifth electrode on the patient's lower right abdomen.



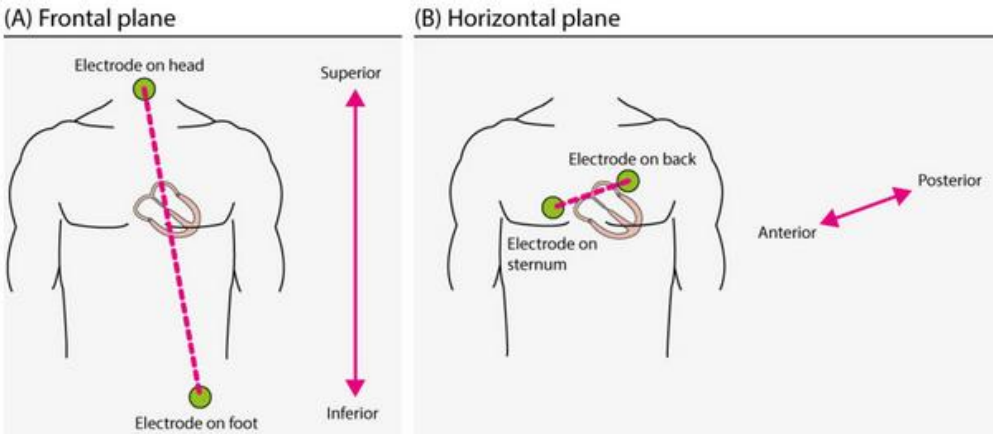
A 12-lead configuration requires the placement of 10 electrodes on the patient's body. Four electrodes, which represent the patient's limbs, include the left arm electrode (LA lead), the right arm electrode (RA lead), the left leg electrode (LL lead), and the right leg electrode (RL lead). Six chest electrodes (V1-V6 leads) are placed on the patient's chest at various locations near the heart. Three standard limb leads are constructed from measurements between the right arm and left arm (Lead I), the right arm and the left leg (Lead II) and the left arm to left leg (Lead III). The ten electrodes provide 12 measurement points consisting of Leads I, II, III, AVL, AVR, AVF, and V1-V6 with the right leg electrode typically used as a ground.



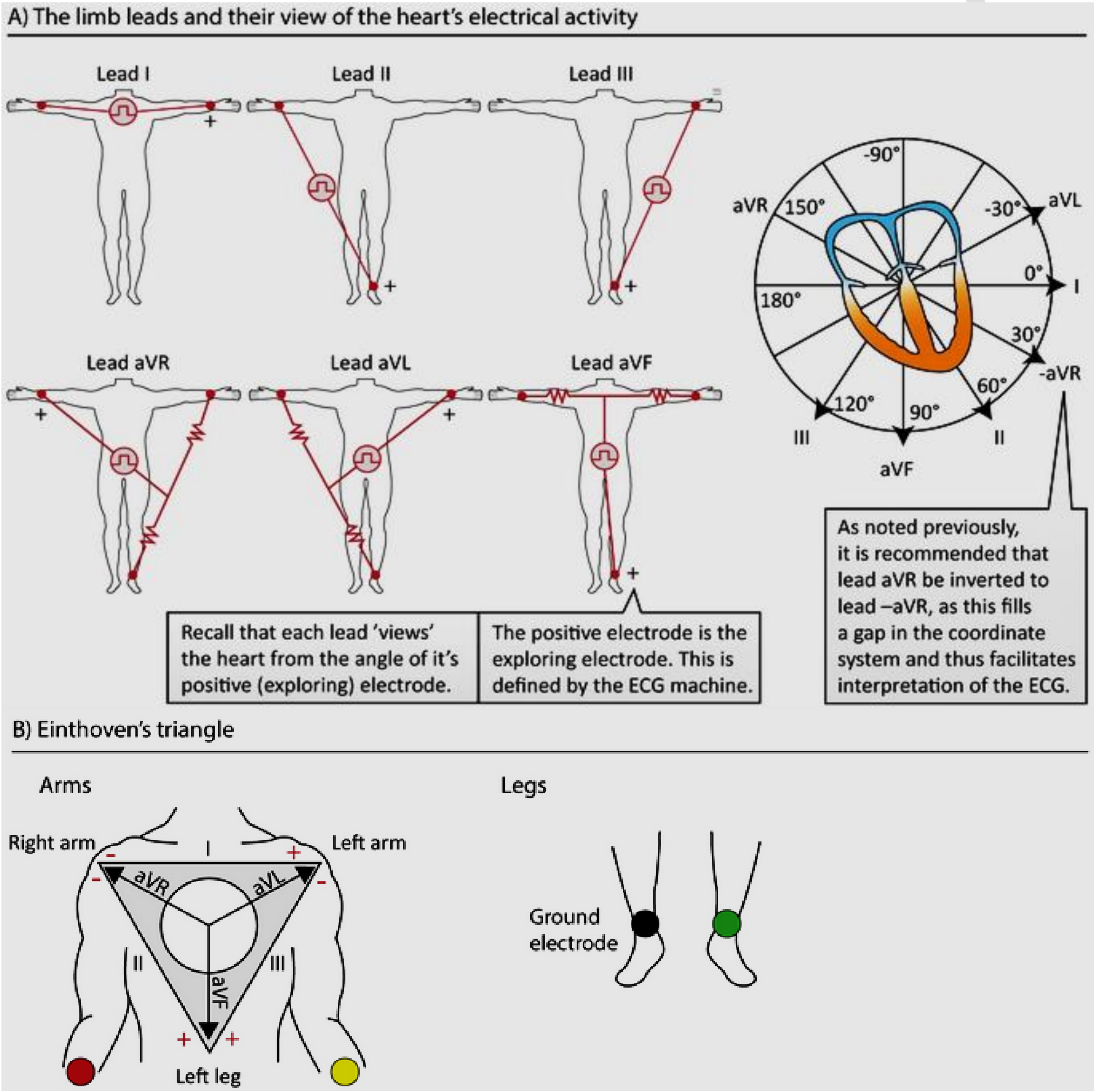
Anatomical planes and ECG leads

The electrical activity of the heart can be observed from the horizontal plane and the frontal plane. The ability of a lead to detect vectors in a certain plane depend on how the lead is angled in relation to the plane, which in turn depend on the placement of the exploring lead and the reference point.

Consider a lead with one electrode placed on the head and the other electrode placed on the left foot. The angle of this lead would be vertical, from the head to the foot. This lead is angled in the frontal plane and it will primarily detect vectors traveling in that plane. Now consider a lead with an electrode placed on the sternum and the other electrode placed on the back (on the same level). This lead will be angled from the back to the anterior chest wall, which is the horizontal plane. This lead will primarily record vectors traveling in that plane.



The limb leads, of which there are six (I, II, III, aVF, aVR and aVL), have the exploring electrode and the reference point placed in the frontal plane. These leads are therefore excellent for detecting vectors traveling in the frontal plane. The chest (precordial) leads (VI, V2, V3, V4, V5 and V6) have the exploring electrodes located anteriorly on the chest wall and the reference point located



inside the chest. Hence, the chest leads are excellent for detecting vectors traveling in the horizontal plane. Only three leads, namely leads I, II and III (which are actually Willem Einthoven's original leads) are derived by using only two electrodes. The remaining nine leads use a reference which is composed of the average of either two or three electrodes. See Figure 6.

Figure 6 The organization of the limb leads. Note that the electrode on the right leg is not included in any lead, but serves as a ground wire. Leads I, II and Ill are Einthoven's original leads, and they can be presented with Einthoven's triangle (lower panel). Leads aVR, aVL and aVF were constructed by Goldberger; their reference point is the average of two electrodes. Lead aVR can be inverted into lead —aVR which is recommended as it may facilitate interpretation. All modern ECG machines are capable of presenting both aVR and -aVR.

Principle of limb electrodes

ECG Leads I, II and Ill (Willem Einthoven's original leads)

Leads I, II and III compare electrical potential differences between two electrodes. Lead I compares the electrode on the left arm with the electrode on the right arm, of which the former is the exploring electrode. It is said that lead I observes the heart "from the left" because its exploring electrode is placed on the left (at an angle of 0°, see Figure 18). Lead II compares the left leg with the right arm, with the leg electrode being the exploring electrode. Therefore, lead II observes the heart from an angle of 60°. Lead III compares the left leg with the left arm, with the leg electrode being the exploring one. Lead III observes the heart from an angle of 120° (Figure 6).

Leads I, II and III are the original leads constructed by Wilhelm Einthoven. The spatial organization of these leads forms a triangle in the chest (Einthoven's triangle). According to Kirchhoff's law, the sum of all currents in a closed circuit must be zero, thus emerges Einthoven's law:

$$\textbf{Lead I + Lead III = Lead II}$$

This law implies that the sum of the potentials in lead I and lead III equals the potentials in lead II. In clinical electrocardiography this means that the amplitude of, for example, the R-wave in lead II is equal to the sum of the R-wave amplitudes in lead I and III.

ECG lead aVR, aVF and aVL (Goldberger's leads)

These leads were originally constructed by Goldberger. In these leads the exploring electrode is compared with a reference which is based on an average of the other two limb electrodes. The letter a stands for augmented, V for voltage and R is right arm, L is left arm and F is foot.

In aVR the right arm is the exploring electrode and the reference is composed by averaging the left arm and left leg. Lead aVR can be inverted into lead -aVR (which means that the exploring and reference point has switched positions), which is identical to aVR but upside-down. There are three advantages of inverting aVR into -aVR:

1. -aVR fills the gap between lead I and lead II in the coordinate system.
2. -aVR facilitates calculation of the hearts electrical axis.
3. -aVR improves diagnosis of acute ischemia/infarction (inferior and lateral ischemia/infarction).

In lead aVL the left arm electrode is exploring and the lead views the heart from -30°. In lead aVF the exploring electrode is placed on the left leg, so this lead observes the heart directly from south. Since Godlberger's leads are composed of the same electrodes as Einthoven's leads, it is not surprising that all these leads display a mathematical relation. The equations follow:

$$aVL: \frac{Lead\ I - Lead\ III}{2}$$

$$-aVR: \frac{Lead\ I + Lead\ II}{2}$$

$$aVF: \frac{Lead\ II + Lead\ III}{2}$$

Chest leads (Precordial leads)

Frank Wilson and colleagues constructed the central terminal, later termed Wilson's central terminal (WCT). This terminal is a theoretical reference point located approximately in the center of thorax, or more precisely in the centre or Einthoven's triangle.

WCT is computed by connecting all three limb electrodes (via electrical resistance) to one terminal. This terminal will represent the average of the electrical potentials recorded in the limb electrodes.

Under ideal circumstances, the sum of these potentials is zero (Kirchoff's law). WCT serves as the reference point for each of the six electrodes which are placed anteriorly on the chest wall. The chest leads are derived by comparing the electrical potentials in WCT to the potentials recorded by each of the electrodes placed on the chest wall. There are six electrodes on the chest wall and thus six chest leads (Figure 7). Each chest lead offers unique information that cannot be derived mathematically from other leads. Since the exploring electrode and the reference is placed in the horizontal plane these leads primarily observe vectors moving in that plane.

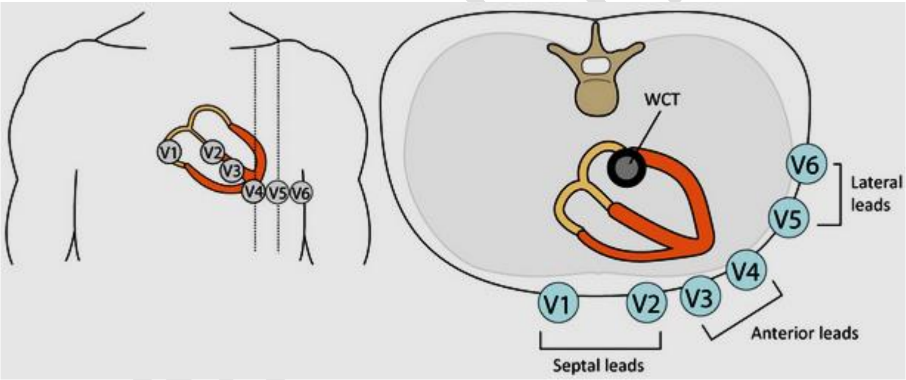


Figure 7 Precordial leads, WCT= Wilson's Central Terminal.

Anatomical aspects of the chest (precordial) leads

• V1-V2 ("septa) leads"): primarily observes the ventricular septum, but may occasionally display ECG changes originating from the right ventricle. Note that none of the leads in the 12-lead ECG are adequate to detect vectors of the right ventricle.

• V3-V4 ("anterior leads"): observes the anterior wall of the left ventricle.

• V5-V6 ("anterolateral leads"): observes the lateral wall of the left ventricle.

Figure 8 shows the combined views of all leads in the 12-lead ECG.

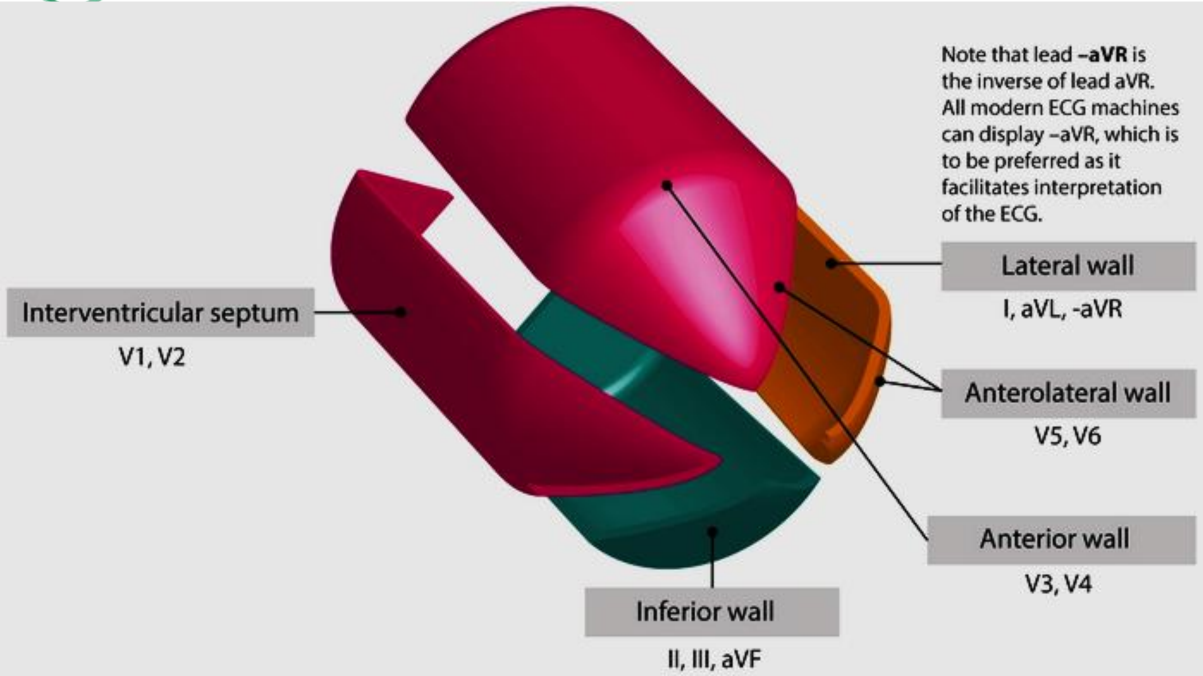


Figure 8 The 12-lead ECG records information on electrical activity of the left ventricle (and not so much of the right ventricle). As seen in the figure above the left ventricle has the shape of a bullet. The left ventricle is traditionally divided into four walls, and the figure above shows which leads that best observe electrical activity of each wall.

Presentation of ECG leads

The ECG leads may be presented chronologically (i.e I, II, III, aVL, aVR, aVL, V1 to V6) or according to their anatomical angles. Chronological order does not respect that leads aVL, I and -aVR all view the heart from a similar angle and placing them next to each other can improve diagnostics.

In the Cabrera system, the leads are placed in their anatomical order. The inferior limb leads (II, aVF and III) are place in proximity, and the same goes for the lateral limb leads and the chest leads. All modern ECG machines can display the leads according to the Cabrera system, which should always be preferred.

The ECG below shows an example of the Cabrera layout with aVR inverted into —aVR. Note the clear transition between the waveforms in neighboring leads.