Electricity within the body

Electrical potentials of nerves

The ability of neurons to receive and transmit electrical signals is fairly well understood.

Across the surface or membrane of every neuron is an electrical potential (voltage) difference due to the presence of more negative ions on the inside of the membrane than on the outside. The neuron is said to be polarized. The inside of the cell is typically 60-90 mV more negative than the outside. This potential difference is called the resting potential of the neuron. Figure 1 shows schematically the typical concentrations of various ions inside and outside the membrane of an axon. When the neuron is stimulated a large momentary change in the resting potential occurs at the point of stimulation. This potential change, called the action potential, propagates along the axon. The action potential is the major method of transmission of signals within the body. The stimulation may be caused by various physical and chemical stimuli such as heat, cold, light, sound, and odors. If the stimulation is electrical, only about 20 mV across the membrane is needed to initiate the action potential.

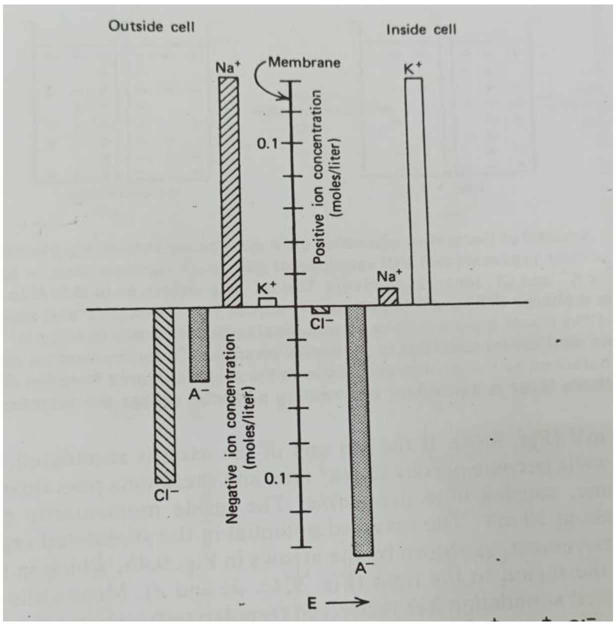

Figure 1

Examination of the axons of various neuron with an electron microscope indicates that there are two different types of nerve fibers. The membranes of some axons are covered with a fatty insulating layer called myelin that has small uninsulated gaps called nodes of Ranvier every few millimeters (Fig. 2); these nerves are referred to as myelinated nerves. The axons of other nerves have no myelin sleeve (sheath), and these nerves are called unmyelinated nerves.

Myelinated nerves, the most common type in humans, conduct action potential much faster than unmyelinated nerves.

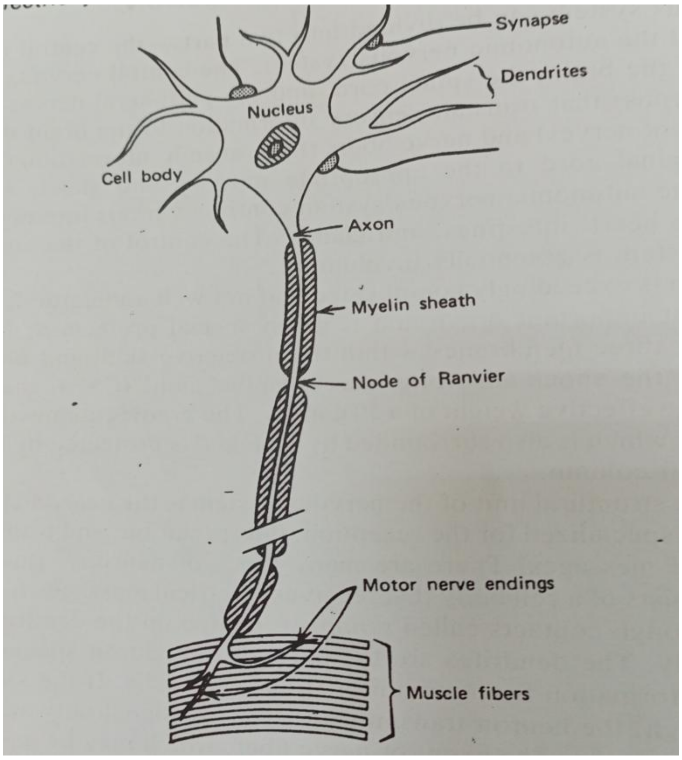

Figure 2

Electromyogram (electrical signals from muscles)

One means of obtaining diagnostic information about muscles is to measure their electrical activity. In this section we briefly trace the transmission of the action potential from the axon into the muscle, where it causes muscle contraction. The record of the potentials from muscles during movement is called the electromyogram, or EMG.

A muscle is made up of many motor units. A motor unit consists of a single branching neuron from the brain stem or spinal cord and the 25 to 2000 muscle fibers (cells) it connects to via motor end plates (Fig. 3a). The resting potential across the membrane of a muscle fiber is similar to the resting potential across a nerve fiber. Muscle action is initiated by an action potential that travels along an axon and is transmitted across the motor end plates into the muscle fibers, causing them to contract. The record of the action potential in a single muscle cell is shown schematically in Fig. 3b. Such a measurement is made with a very tiny electrode (microelectrode) thrust through the muscle membrane.

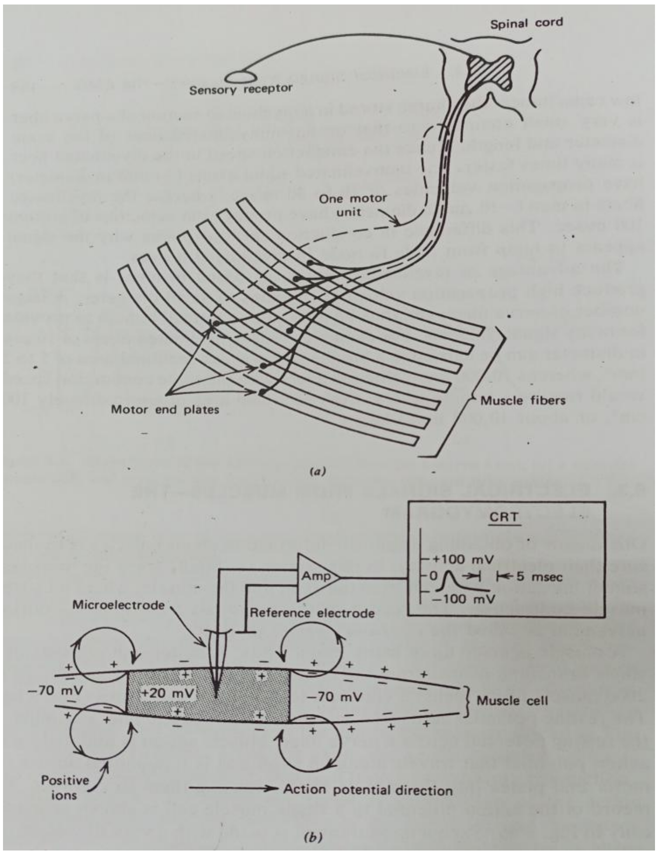

Figure 3

The electrocardiogram (electrical signals from the heart)

The heart has a double pump and four chambers (Fig. 4); the two upper chambers, the left and right atria, are synchronized to contract simultaneously, as are the two lower chambers, the left and right ventricles. The right atrium receives venous blood from the body and pumps it to the right ventricle. This ventricle pumps the blood through the lungs, where it is oxygenated. The blood then flows into the left atrium. The contraction of the left atrium moves the blood to the left ventricle, which contracts and pumps it into the general circulation; the blood passes through the capillaries into the venous system and returns to the right atrium.

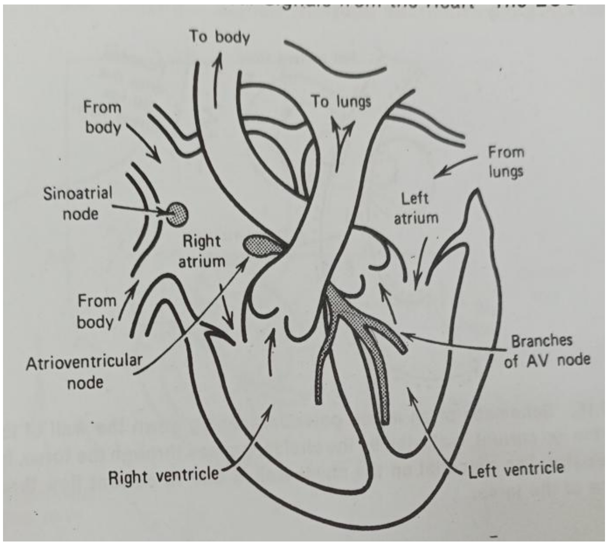

Figure 4

The rhythmical action of the heart is controlled by an electrical signal initiated by spontaneous stimulation of special muscle cells located in the right atrium. These cells make up the sinoatrial (SA) node, or the pacemaker (Fig. 4). The SA node fires at intervals about 72 times per minute; however, the rate of firing can be increased or decreased by nerves external to the heart that respond to the blood demands of the body as well as to other stimuli. The electrical signal from the SA node initiates the depolarization of the nerves and muscles of both atria, causing the atria to contract and pump blood into ventricles. Repolarization of the atria follows. The electrical signal then passes into the atrioventricular (AV) node, which initiates the depolarization of the right and left ventricles, causing them to contract and force blood into the pulmonary and general circulations. The ventricle nerves and muscles then repolarization and the sequence begins again.

The nerves and muscles of the heart can be regarded as sources of electricity enclosed in an electrical conductor, the torso. Obviously it is not practical to make direct electrical measurements on the heart; diagnostic information is obtained by measuring at various places on the surface of the body the electrical potentials generated by the heart. The record of the heart's potentials on the skin is called the electrocardiogram (ECG).

The relationship between the pumping action of the heart and the electrical potentials on the skin can be understood by considering the propagation of an action potential in the wall of the heart as shown in Fig. 5. The resulting current flow in the torso leads to a potential drops as shown schematically on the resistor. The potential distribution for the entire heart when the ventricles are one-half depolarized is shown by the equipotential lines in Fig. 6. Not that the potential measured on the surface of the body depend upon the location if the electrodes.

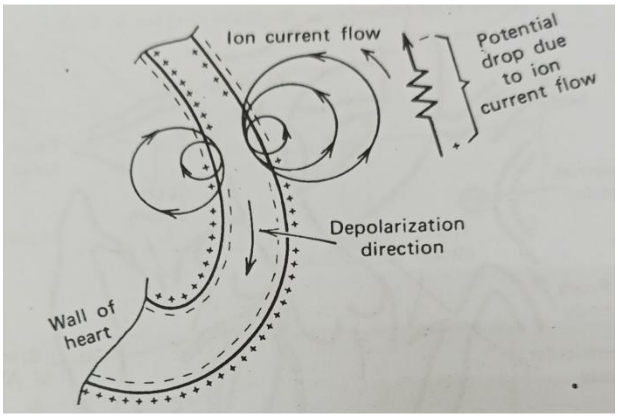

Figure 5

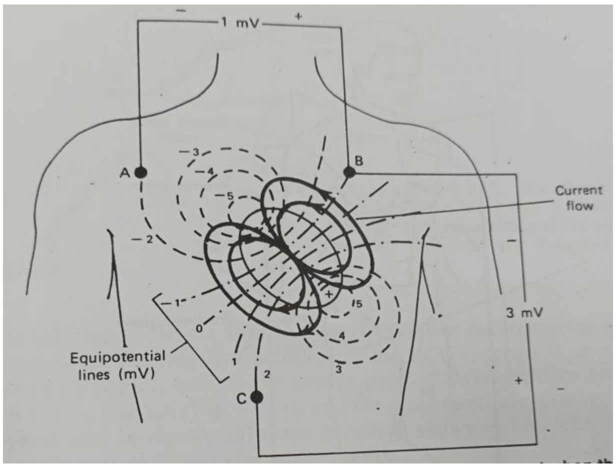

Figure 6

The electrical (cardiac) potential that we measure on the body's surface is merely the instantaneous projection of the electric dipole vector in a particular direction. As the vector changes with time, so does the projected potential. Figure 7 shows an electric dipole vector along with the three electrocardiographic body planes.

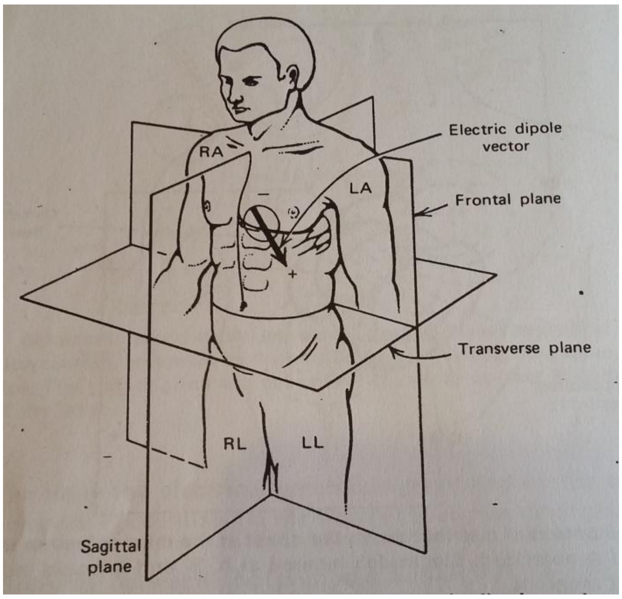

Figure 7

The surface electrodes for obtaining the ECG are most commonly located on the left arm (LA), right arm (RA), and left leg (LL), although the location of the electrodes can vary in different clinical situations; sometimes the hands or positions closer to the heart are used. The measurement of the potential between RA and LA is called Lead I, that between RA and LL is called Lead II, and that between LA and LL is called Lead III (Fig.8).

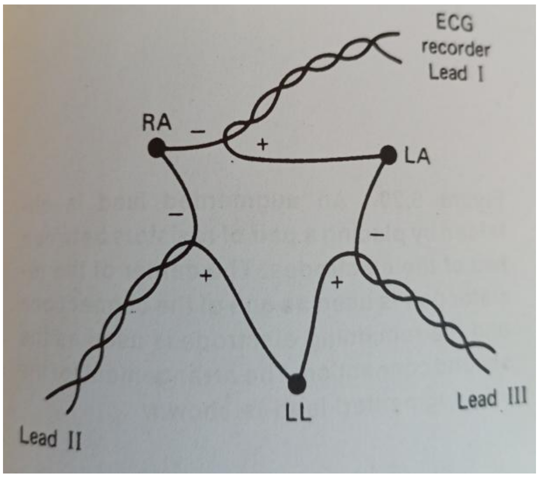

Figure 8

Three augmented lead configurations, aV_R , aV_L , and aV_F , are also obtained in the frontal plane. For the aV_R lead, one side of the recorder is connected to RA and the other side is connected to the center of two resistors connected to LL and LA (Fig. 9). The other two augmented leads are obtained in a similar manner; for the aV_L lead, the recorder is attached to the LA electrode and resistors are connected to RA and LL; for the aV_F lead, the recorder is attached to the LL electrode and the resistors are connected to RA and LA.

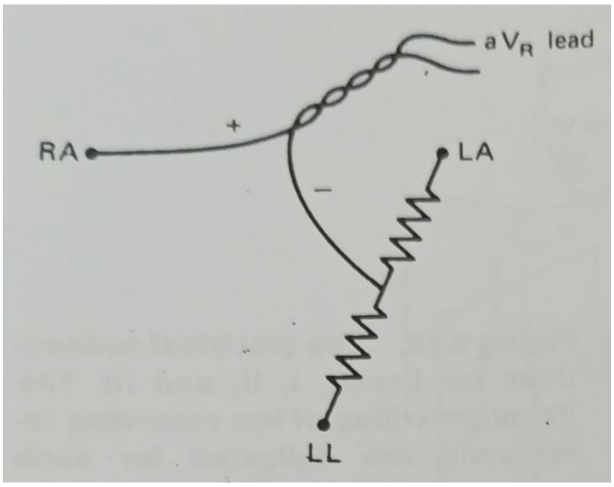

Figure 9

Each ECG tracing maps out a projection of the electric dipole vector, or the electrical activity of the heart, through each part of its cycle. Figure 10 shows schematically the Lead II output with the standard symbols for the parts of the pattern. The major electrical events of the normal heart cycle are:

1. The atrial depolarization, which produce the P wave**.**
2. The atrial repolarization, which is rarely seen and is unlabeled**.**
3. The ventricular depolarization which produces the QRS complex.
4. The ventricular repolarization, which produces the T wave (Fig. 10).

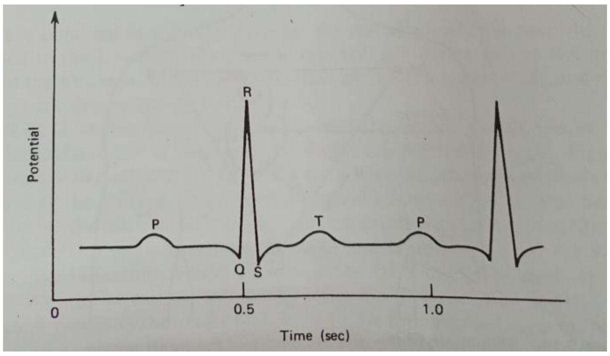

Figure 10

Figure 11 shows the six frontal plane ECGs for a normal subject. Note that in some cases the waveform is positive and in other cases it is negative; the sign of the waveform depends upon the direction of the electric dipole vector and the polarity and position of the electrodes of the measuring instrument.

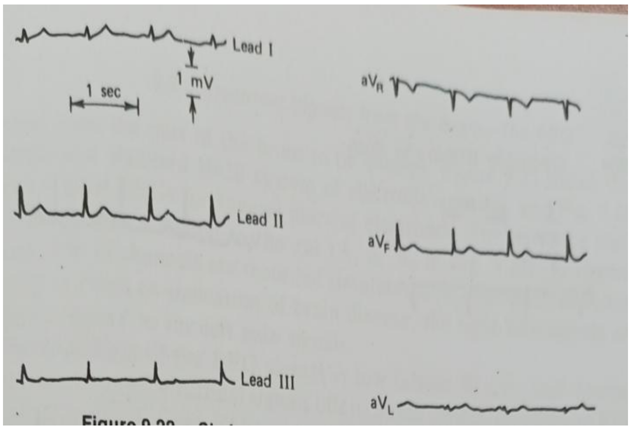

Figure 11

In a clinical examination, six transverse plane ECGs are usually made in addition to six frontal plane ECGs. For the transverse plane measurement the negative terminal of the ECG recorder is attached to an indifferent electrode at the center point of the three resistors connected to RA, LL, and LA (Fig. 12 a), and the other electrode is moved across the chest wall to the six different position shown in Fig. 12. Figure 13 shows typical transverse plane ECGs.

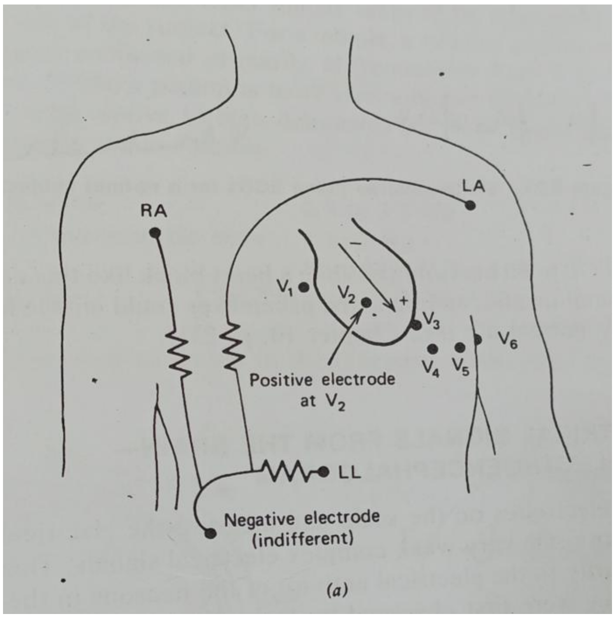

Figure 12 a

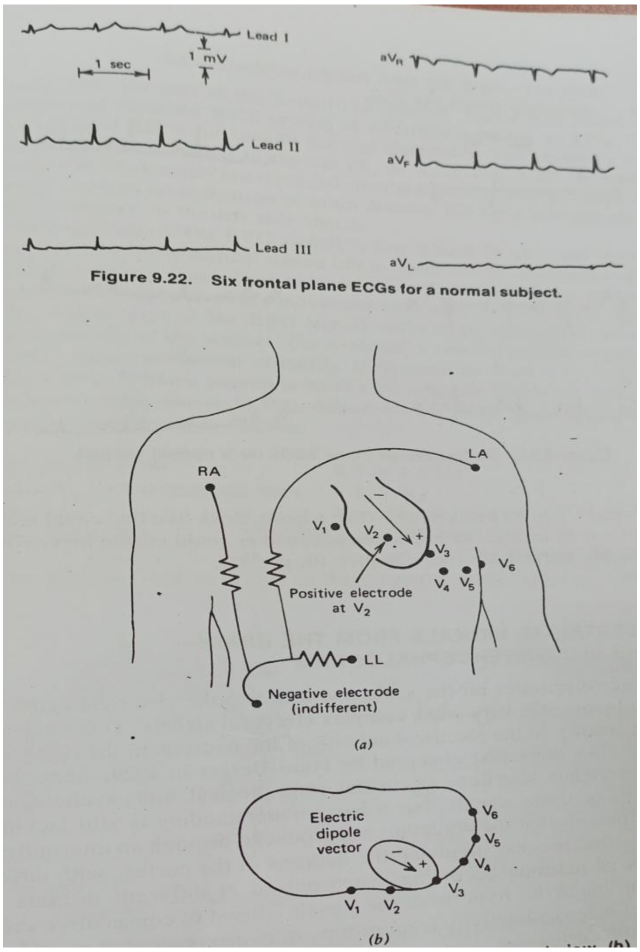

Figure 12

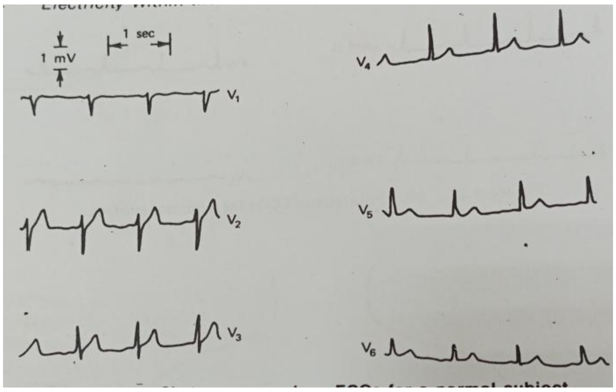

Figure 13

As ECG shows disturbances in the normal electrical activity of the heart. For example, an ECG may signal the presence of an abnormal condition known as heart block. If the normal SA node signal is not conducted into the ventricle, then a pulse from the AV node will control the heartbeat at a frequency of 30 to 50 beats/min, which is much lower than normal (70 to 80 beats/min). While a heart block like this could make a patient a semi-invalid, an implanted pacemaker could enable him to live a reasonably normal life.

The electroencephalogram (electrical signals from the brain)

If you place electrodes on the scalp and measure the electrical activity, you will obtain some very weak complex electrical signals. These signals are due primarily to the electrical of the neurons in the cortex of the brain. One hypothesis is that the potentials are produced through an intermittent synchronization process involving the neurons in the cortex, with different groups of neurons becoming synchronized at different instants of time. According to this hypothesis the signals consist of consecutive short segments of electrical activity from groups of neurons located at various places on the cortex.

The recording of the signals from the brain is called the electroencephalogram (EEG). Electrodes for recording the signals are often small discs of chloride silver. They are attached to the head at locations that depend upon the part of the brain to be studied. Figure 14 shows the international standard 10-20 system of electrode location, and Fig. 15 shows typical EEGs for several pairs of electrodes. The reference electrode is usually attached to the ear (A_1 or A_2 in Fig 14). In routine exams, 8 to 16 channels are recorded simultaneously. Since asymmetrical activity is often an indication of brain disease, the right side signals are often compared to the left side signals.

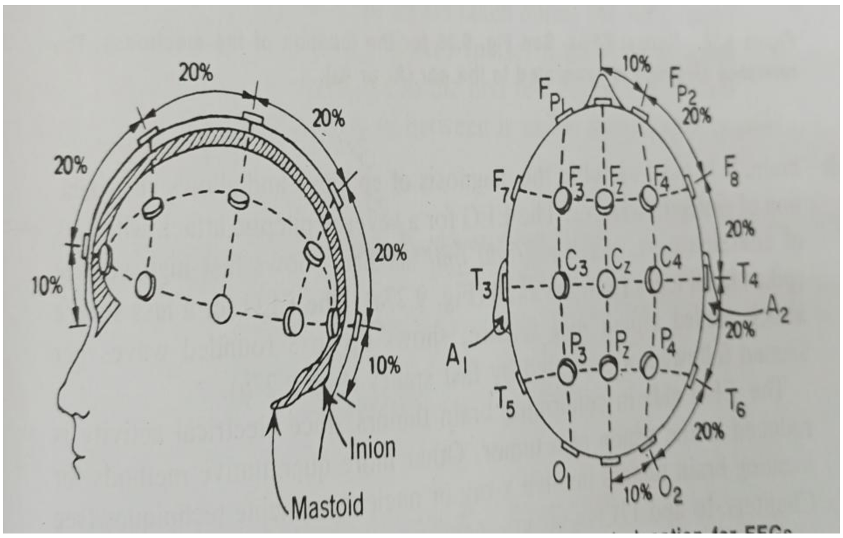

Figure 14

The amplitude of the EEG signals is low (about 50 **μ**V), and interference from external electrical signals often causes serious problems in EEG signals processing. Even if the external noise is controlled, the potentials of muscle activity such as eye movement can cause artifacts in the record.

The frequencies of the EEG signals seem to be dependent upon the mental activity of the subject. For example, a relaxed person usually has an EEG signal composed primarily of frequencies from 8 to 13 Hz, or alpha waves. When a person is more alert a higher frequency range, the beta wave range (above 13 Hz), dominates the EEG signal. The various frequency bands are as follows:

Delta (**δ**), or slow	0.5 to 3.5 Hz
Theta (**θ**), or intermediate slow	4 to 7 Hz
Alpha (**α**)	8 to 13 Hz
Beta (**β**), or fast	greater than 13 Hz

The EEG is used as an aid in the diagnosis of diseases involving the brain. It is most useful in the diagnosis of epilepsy and allows classification of epileptic seizures. The EEG for a severe epileptic attack with loss of consciousness, called a grand mal seizure, shows fast high voltage spikes in all leads from the skull (Fig. 15a). The EEG for a less severe attack, called a petit mal seizure, shows up to 3 rounded waves per second followed or preceded by fast spikes (Fig.15b).

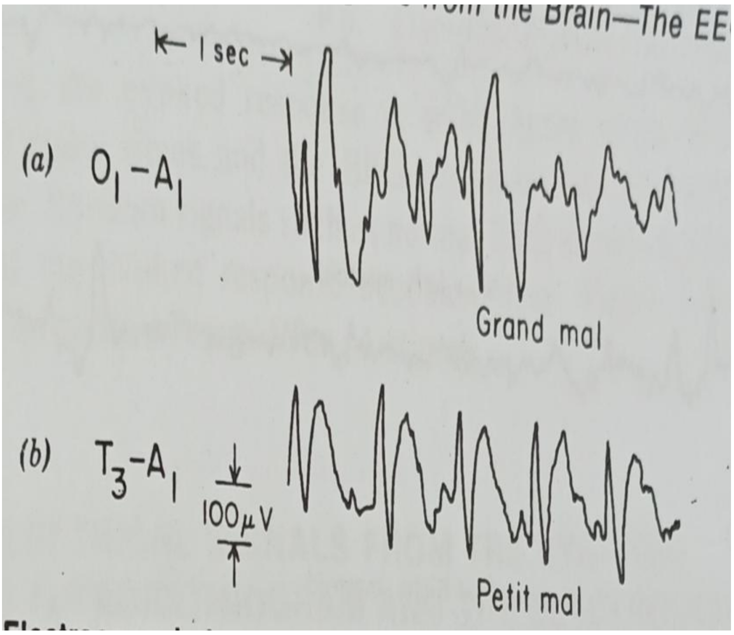

Figure 15

The EEG aids in confirming brain tumors since electrical activity is reduced in the region of a tumor. Other more quantitative methods for locating brain tumors involve x-ray or nuclear medicine techniques.

The EEG is used as a monitor in surgery when the ECG cannot be used. It is also useful in surgery for indicating the anesthesia level of the patient. During surgery a signal channel is usually monitored.

Much research on sleep involves observing the EEG patterns for various stages of sleep (Fig. 16). As a person becomes drowsy, particularly with his eyes closed, the frequencies from 8 to 13 Hz (alpha waves) dominate the EEG. The amplitude increases and the frequency decreases as a person moves from light sleep to deeper sleep. Occasionally an EEG taken during sleep shows a high frequency pattern called paradoxical sleep or rapid eye movement (REM) sleep because the eyes move during this period. Paradoxical sleep appears to be associated with dreaming.

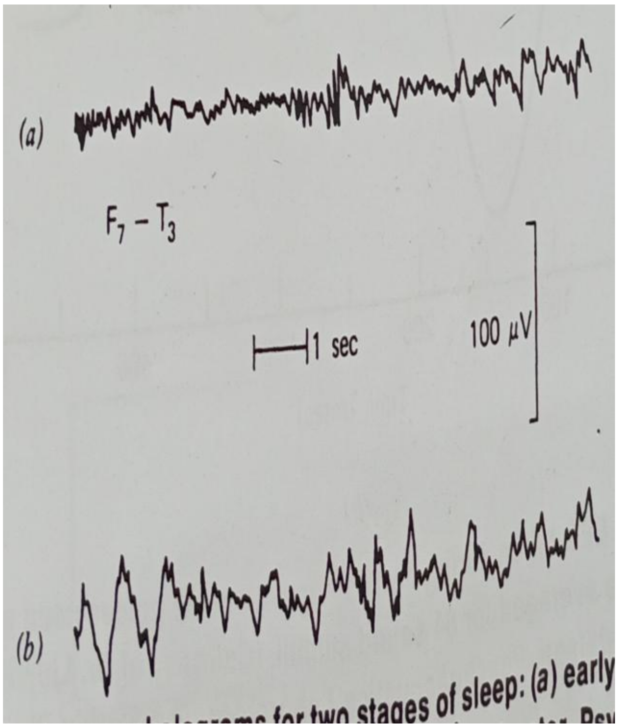

Figure 16

Besides recording the spontaneous activity of the brain, we can measure the signals that result when the brain receives external stimuli such as flashing lights or pulses of sound. Signals of this type are called evoked responses. Figure 17a shows three EEGs taken during the early stages of sleep with a series of 10 sound pulses (noise) used as an external stimulus. The EEGs show responses to the first few pulses and the last two pulses. The lack of responses in between is called habituation.

Because the evoked response is small, quite often the stimulus is repeated many times and the EEG responses are averaged in a small computer. Random signals such as normal EEG signals tend to average to zero and the evoked response becomes clear. Figure 17b shows an evoked response averaged for 64 stimuli.

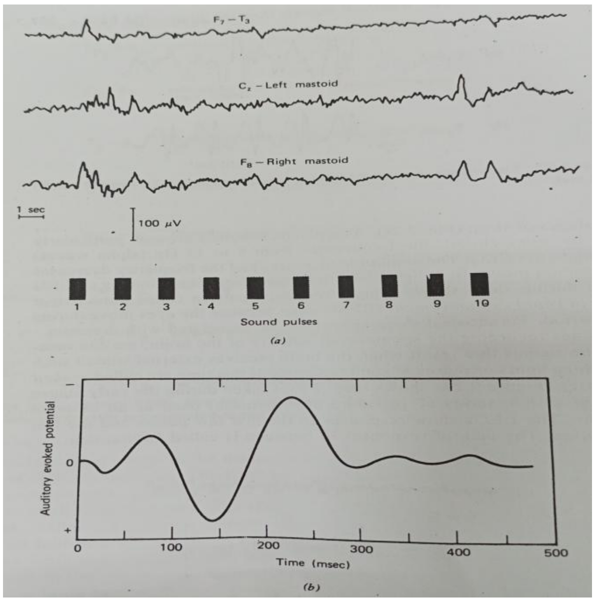
$F_7 - T_3$
C_z – Left mastoid
F_8 – Right mastoid
1 sec
100 μV
1
2
3
4
5
6
7
8
9
10
Sound pulses
(a)
Auditory evoked potential
–
0
+
0
100
200
300
400
500
Time (msec)
(b)

Figure 17