Karbala University-College of veterinary medicine
Medical Physics-Lecture (8)

Electricity within the body

Electricity within the body

We first review the various elements of electrostatics and current flow needed to understand electricity in the body, including the flow of an electrical pulse long an axon:

The electric field at a distance *r caused by a point charge q is given by* Coulomb's Law:

$$E = \frac{kq}{r^2}$$

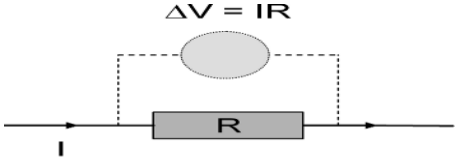
The constant $k = 9 \times 10^9$ *N-m*^{2} */* C^2

The potential of that charge is:

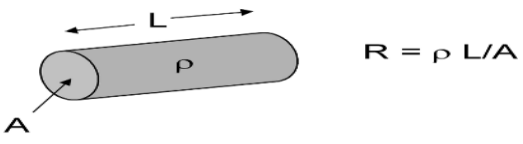
$$V = \frac{kq}{r}$$

In the body, charged ions, such as Na+, K+, Ca2+, Cl−, and negatively-charged proteins, are the important carriers of charge. Electrons are the charge carriers in most man-made electronic circuits.

When a current flows along a material with resistance R (in ohms, Ω), there is a voltage drop V (in volts V) across the material given by Ohm's law: $V = IR$



(a)



(b)

a) Ohm's Law and (b) evaluating resistance *R from resistivity ρ*

The resistance is an extensive property that depends on the intensive property resistivity ρ of the material, and the cross-sectional area A and length L of the structure

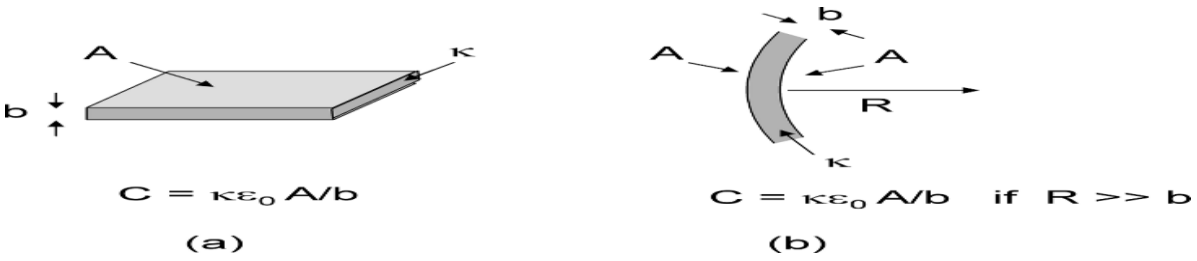
$$R = \frac{\rho L}{A}$$

A voltage or potential difference V can also develop between two structures, one with a charge +q and the other with charge −q, because of the electric fields that run from one to the other. This voltage is:

$$V = \frac{q}{C}$$

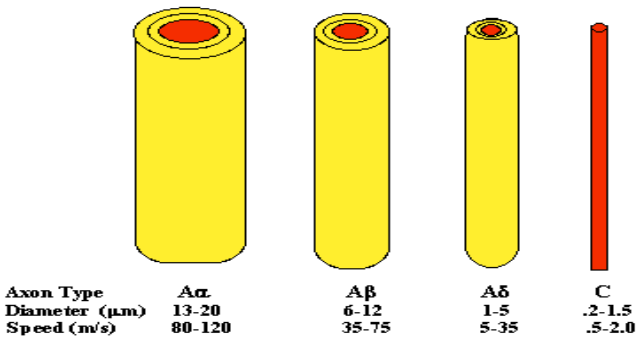
where C is the capacitance (in farads, F) of the system

The capacitance C depends on the geometry of these two structures. For example, they could be two parallel plates or two concentric cylinders, which is similar to the axon of a neuron.



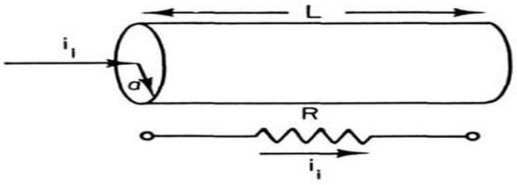
Capacitance for (a) parallel plates and (b) cylindrical shells

Speed of action potential propagation and axon diameter



resistance along the axon

Because the external and internal fluids are conductive, a current can flow inside or outside of the axon.
The interior fluid has a certain resistance, which is determined by the conductivity ρ_i of the fluid and by the axon radius a and length L.



(Internal resistance) $R_i = \frac{\rho_i L}{\pi a^2}$ [Hence, $R_i \alpha 1/a^2$]

If the conductivity of the fluid inside an axon is 1.6 x 10^{7} (Ωm), length of the axon is 90 (cm)
and the axon diameter is 5 x10^{-6} (m). Calculate the value of the internal resistance (R_i)

$R_i = \rho_i L/\pi a^2$

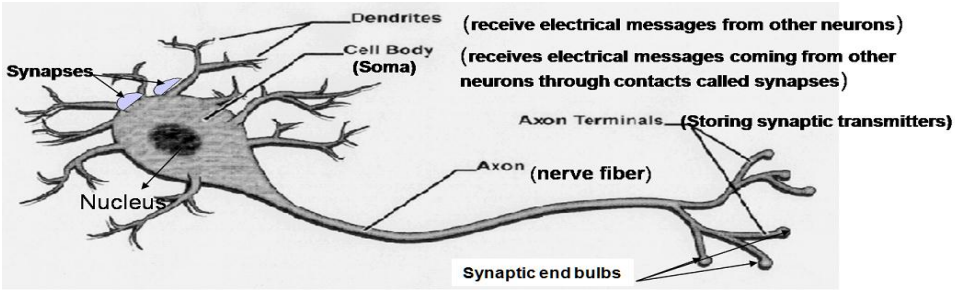
ρ_i = 1.6 x 10^{7} (Ωm)
Length (L) = 90 (cm) = 0.9 (m) ,
Diameter = 5 x10^{-6} (m), radius (a) = 2.5 x 10^{-6} (m)
π = 22/7 = 3.142857

R_i =(1.6 x10^{7} x 0.9)/[3.142857 x (2.5 x 10^{-6})^2]=(1.44 x 10^{7})/[19.642857 x 10^{-12}]

R_i = 0.0733 x 10^{19} (Ω)

Electrical potentials of nerves(الاعصاب)

Neuron consists of the followings:



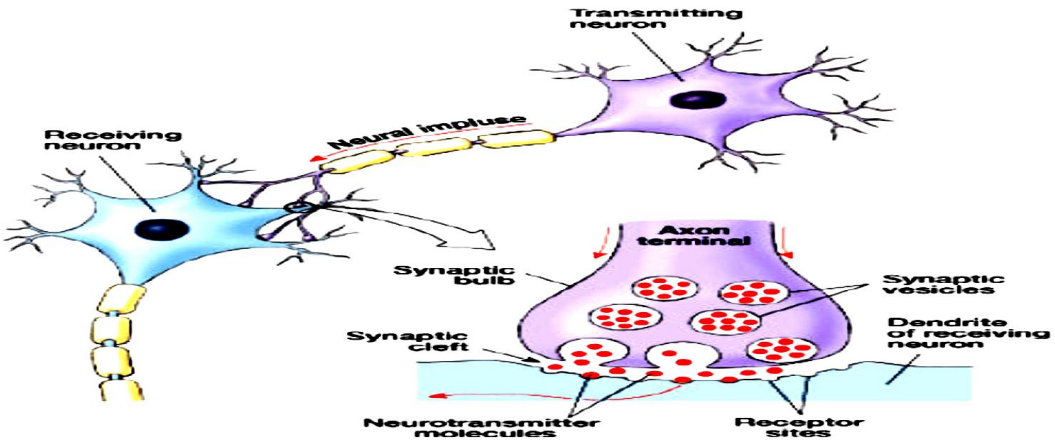
1- Dendrites(التشعبات): Short, branched & unmyelinated part of the neurons specialized for

receiving electrical messages (signals) from stimuli or from other neurons towards the cell body. Its surfaces is specialized for contact with other neurons.

2- Soma (Cell body): Surrounded by cell membrane contains: nucleus & cytoplasmic organelles, it receives electrical messages (signals) from other neurons through body. [If the stimulus (such as touch, sound, light, and so on), is strong enough, the neuron will transmit an electrical signal outwards along a fiber called an *axon*].

3- Axon (nerve fiber): Carries (propagates) and conveys electrical messages (signals) away from the cell body into the nerve terminals. Axons are ≈ 1 (m) long. There are two types of nerve fibers (myelinated and unmyelinated nerve fibers).

4- Axon terminals: Transmit electrical messages (information) from the neuron to muscles, glands or other neurons. Synaptic end bulbs: contain vesicles filled with *neurotransmitters*.



The human brain is composed of billions of nerve cells which communicate through specialized connections called synapses (located on the dendrites or on the cell body). At each synapse, a chemical neurotransmitter is released from one cell and binds to receptors on the second cell. This chemical transmission generates electrical and biochemical signals in the second cell that are then passed along to a network of nerve cells. Thus, *a synapse* is the basic unit of communication in the brain. Building the correct network of synapses is essential for brain development and understanding how those synapses go is key to many neurological disorders.

Neurotransmitters molecules are the red round dots which are released from the

synaptic vesicles in the above cell to bind with the receptors sites in the cell bellow in order to generate electrical and biochemical signals in the second cell that are then passed along to a network of nerve cell.

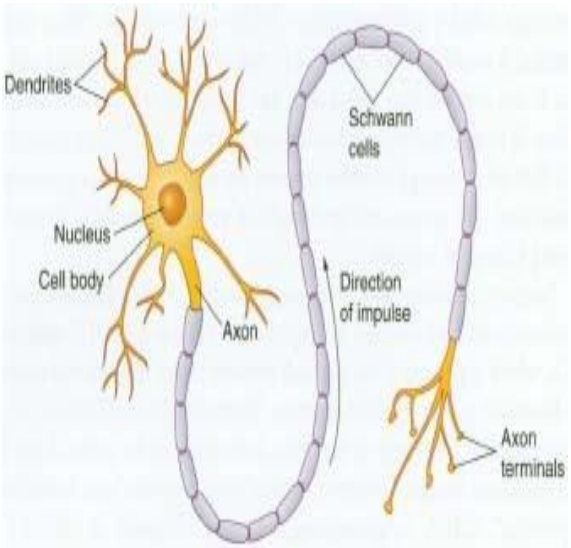
Electrical and Chemical Beings

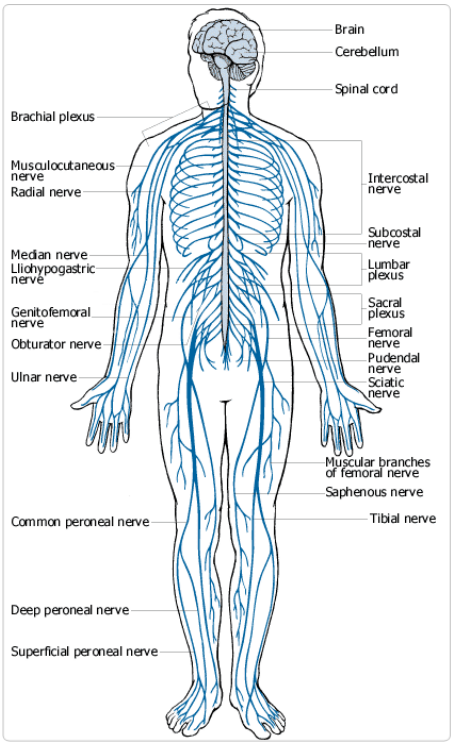
Our nervous systems use messenger cells called neurons to convey electrical signals called nerve impulses.

Electrical and Chemical Signalling To create a nerve impulse, our neurons have to be excited. Stimuli such as light, sound and pressure can all excite neurons, but in most cases, chemicals released by other neurons will trigger a nerve impulse.

(تفرز الخلايا العصبية مواد كيميائية يؤدي الى النبضة العصبية).

The brain and spinal cord comprise our central nervous system. The network of nerves that connect to the spinal cord control both conscious and unconscious activities. Information flows through the spinal cord to and from these nerves.



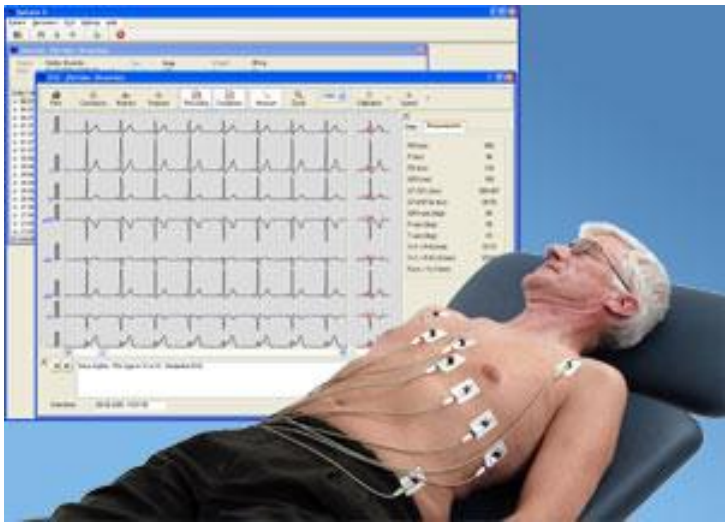


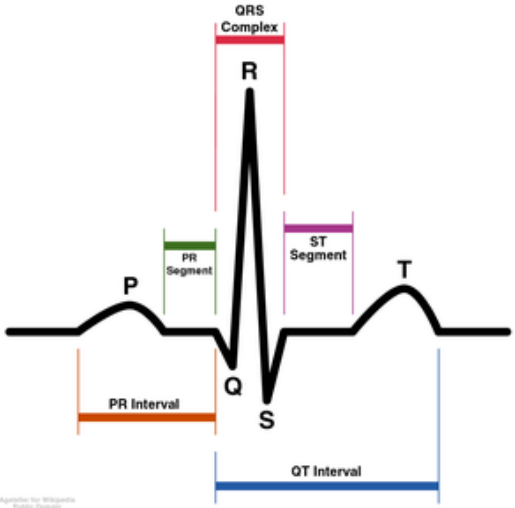
Electrical Activity

ECG and EEG

1-ECG

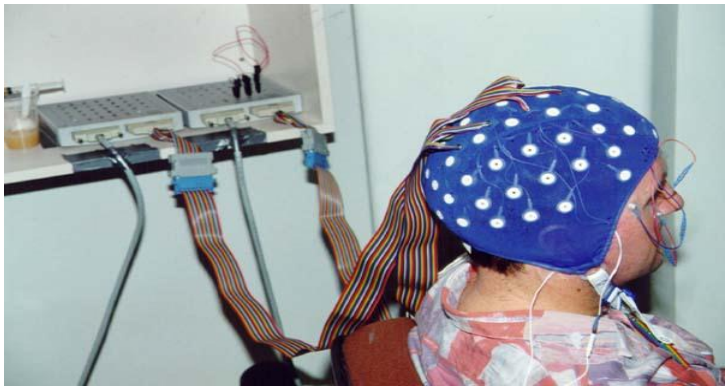
- An electrocardiogram (**ECG**) is a test that records the electrical activity of the heart(اختبار النشاط الكربلائي للقلب).
- It is used for monitoring and diagnosing a variety of heart conditions(رصد وتشخيص امراض القلب).
- The normal heart beat has phases P, QRS and T as shown below.

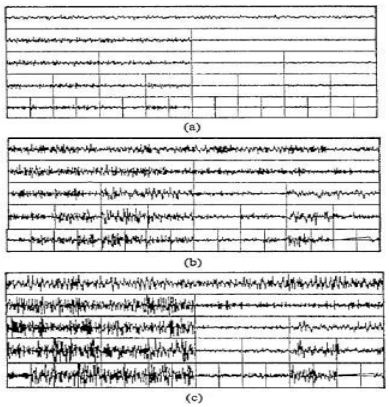




2- EEG

- The EEG (Electroencephalography)(التخطيط الدماغي) is a test that records the electrical activity of the brain.
- It is used for monitoring(الصرع) and diagnosing epilepsy(اضطراب النوم), sleep disordersالغيبوبة, coma and brain-deathالموت الدماغي.
- *Alpha*, *beta*, *delta* and *theta* are 4 of the traditionally recognised EEG signal frequency types.



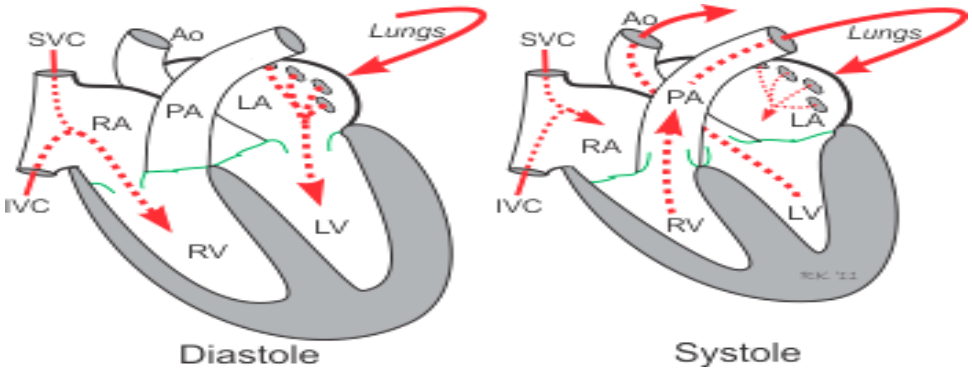


Electrical signals from the heart (Electrocardiogram) ECG or EKG

The electrocardiograph (ECG) is an instrument that records surface potentials associated with the electrical activity of the heart. The surface potentials are conducted

to the instrument by metal contacts called *electrodes which are* fixed to various parts of the body. Usually the electrodes are attached to the four limbs and over the heart. Voltages

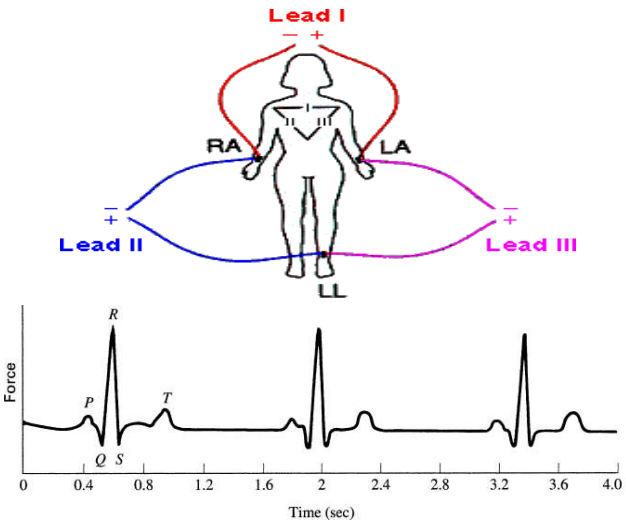
are measured between two electrodes at a time. Rhythmical action of the heart is defined as" The ability of the heart to beat regularly and initiate its own regular repetitive beats independent on nerve supply". This rhythmical action is controlled by an electrical signal initiated by spontaneous stimulation of special muscle cells located in the right atrium. These muscle cells make up the sinoatrial (SA) nodes or Heart Pacemaker (Initiate cardiac impulses). Electrical signals from SA node initiates the depolarization of the nerves and muscles of both left and right atrium, causing the atria to contract and pump blood into the ventricles. Repolarization of the atria then follows.

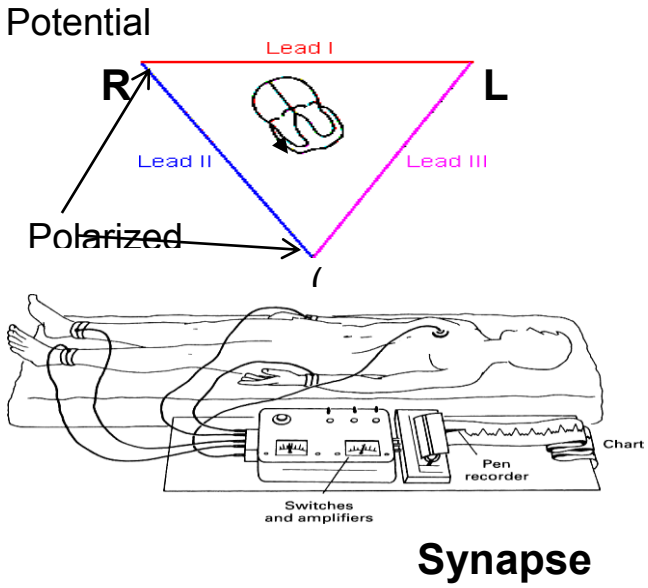


Electrical signal then passes into the atrioventricular (AV) node via *His bundle* and the *Purkinje fibers* to the ventricles which, initiates the depolarization of the right and left ventricles causing them to contract and force blood into the pulmonary and general circulation. The ventricle nerves and muscles then repolarize and the sequence begin again. ECG is defined as " The recording of cardiac action potentials during the cardiac cycle" Nerves and muscles of the heart can be regarded as source of electricity enclosed in an electrical conductor (torso).

Electrical conductor (torso). The record of the heart's potentials on the skin is called (ECG). Electrodes for obtaining ECG are located on the left arm (LA), right arm (RA) and left leg (LL).

Measurement of potential between RA and LA is called Lead 1, that between RA and LL is called Lead 2 and that between LA and LL is called Lead 3. The 3 leads are called standard limb leads .





Synapse

Electrical signals from muscles electromyogram *(EMG)*

The record of the potentials from muscles during movement is called EMG. Resting potential across the membrane of a muscle fiber is similar to resting potential across a nerve fiber. Muscle action is initiated by an action potential that travels along an axon and is transmitted across motor end plates (carry nerve impulses from the CNS) into the muscle fibers, causing them to contract. EMG electrodes usually record the electrical activity from several fibers.

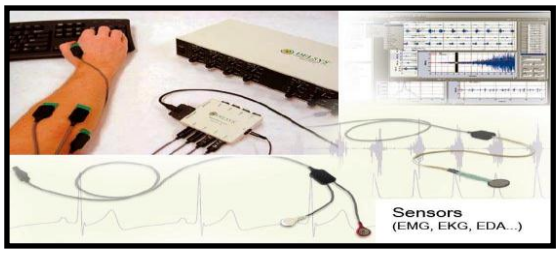
(EMG) measures the electrical activity of muscles at rest and during contraction. Nerve conduction studies measure how well and how fast the nerves can send electrical signals. Nerves control the muscles in the body by electrical signals (impulses), and these impulses make the muscles react in specific ways.

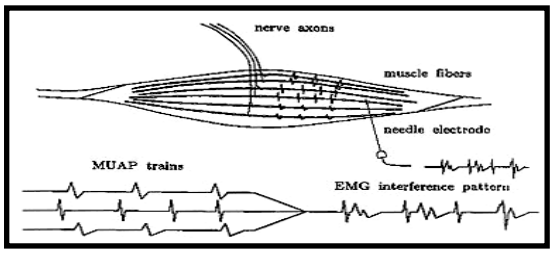
Nerve and muscle disorders cause the muscles to react in abnormal ways. Measuring the electrical activity in muscles and nerves can help find diseases that damage muscle tissue or nerves.

EMG and nerve conduction studies are often done together to give more complete information. Conduction velocity for sensory nerves which carry sensation from outside & inside the body to the CNS can be measured by stimulating at one site and recording at several locations that are known distances from the point of stimulation.

Conduction velocity = Distance of response traveled from one location to another

Time interval between two locations





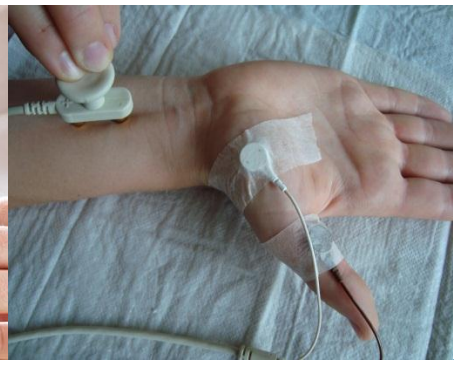
Na^+

The Electromyogram (EMG):

EMG electrodes الاقطاب:

Surface electrodeاقطاب سطحية: Attached to the skin, measures the electrical signals from many motor units.

Needle electrodeاقطاب ابرية: This is inserted under the skin, measure single motor unit activity.



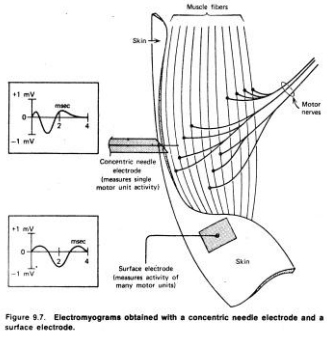


Figure 9.7. Electromyograms obtained with a concentric needle electrode and a surface electrode.

Latency

Latency or latent period is defined as follows: The period (interval, delay) elapsed between the presentation of a stimulus and the obvious response such as the contraction of a muscle.

And it is also, the apparent inactivity between the time the stimulus is applied and the

moment a response occurs. *For example*, the latent period between stimulation and the onset of muscle contraction is about 0.01 s.