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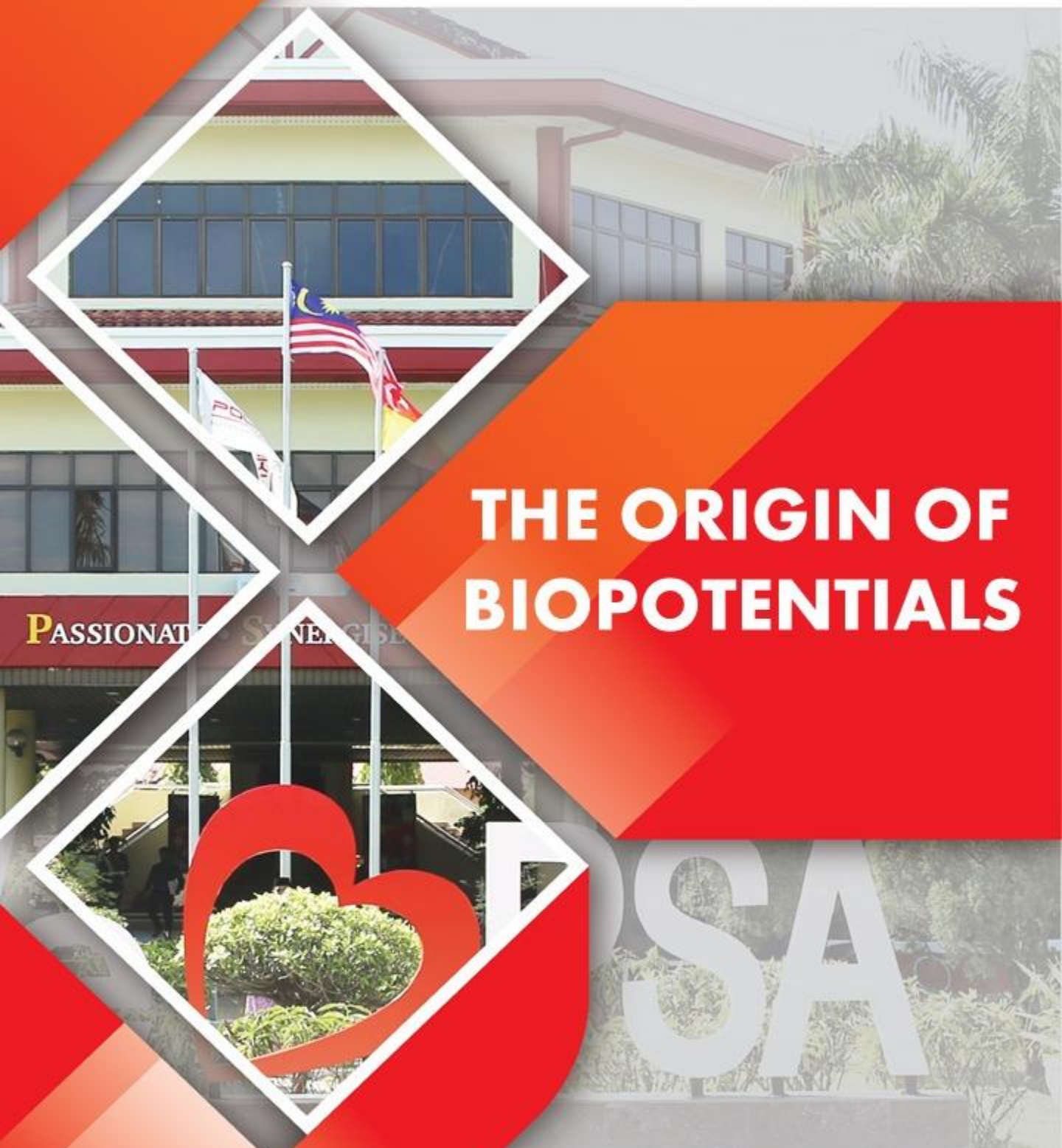
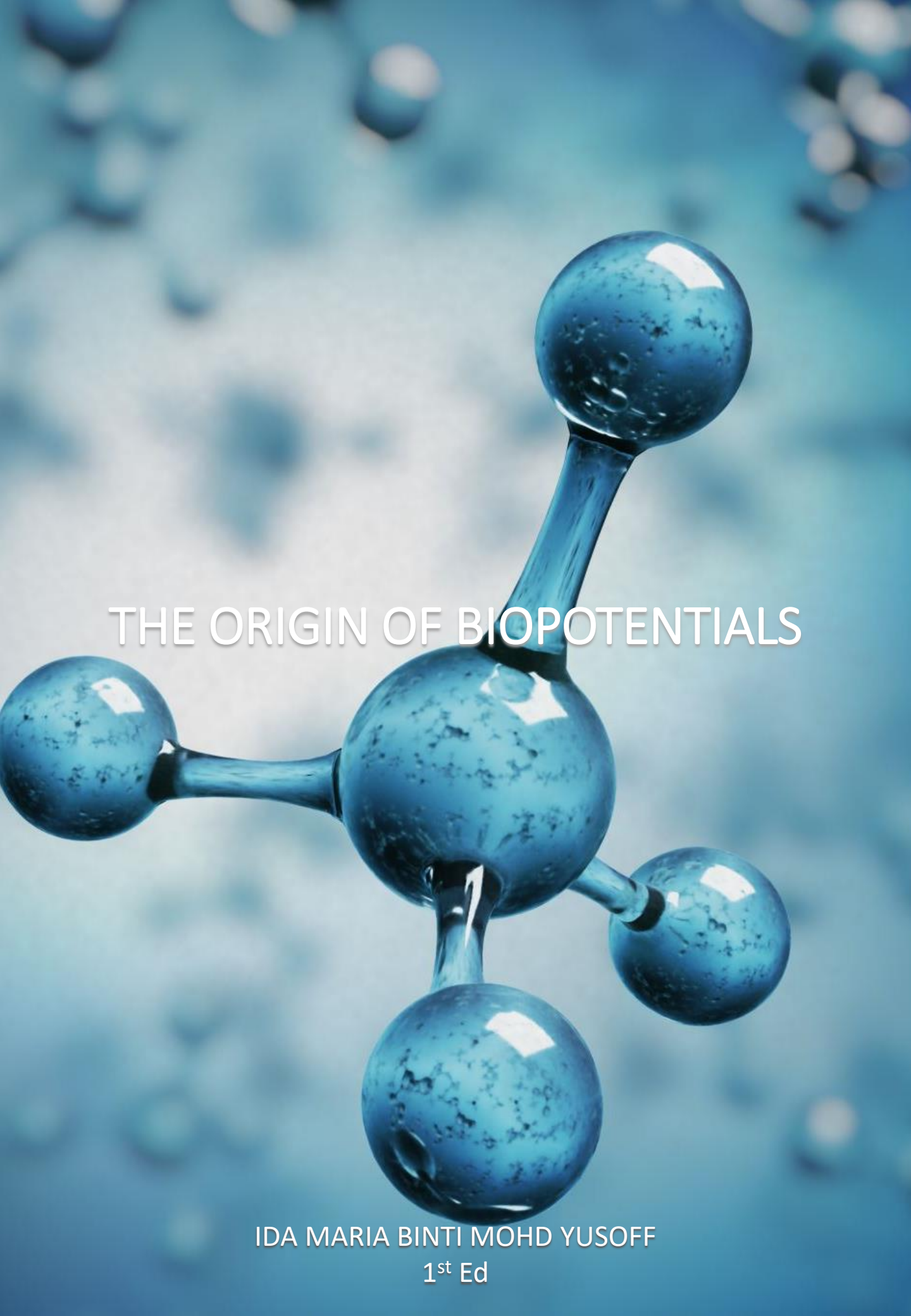


# THE ORIGIN OF BIOPOTENTIALS

IDA MARIA BINTI MOHD YUSOFF

***ELECTRICAL ENGINEERING DEPARTMENT***



# THE ORIGIN OF BIOPOTENTIALS

IDA MARIA BINTI MOHD YUSOFF

1st Ed



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Ida Maria binti Mohd Yusoff

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# PREFACE

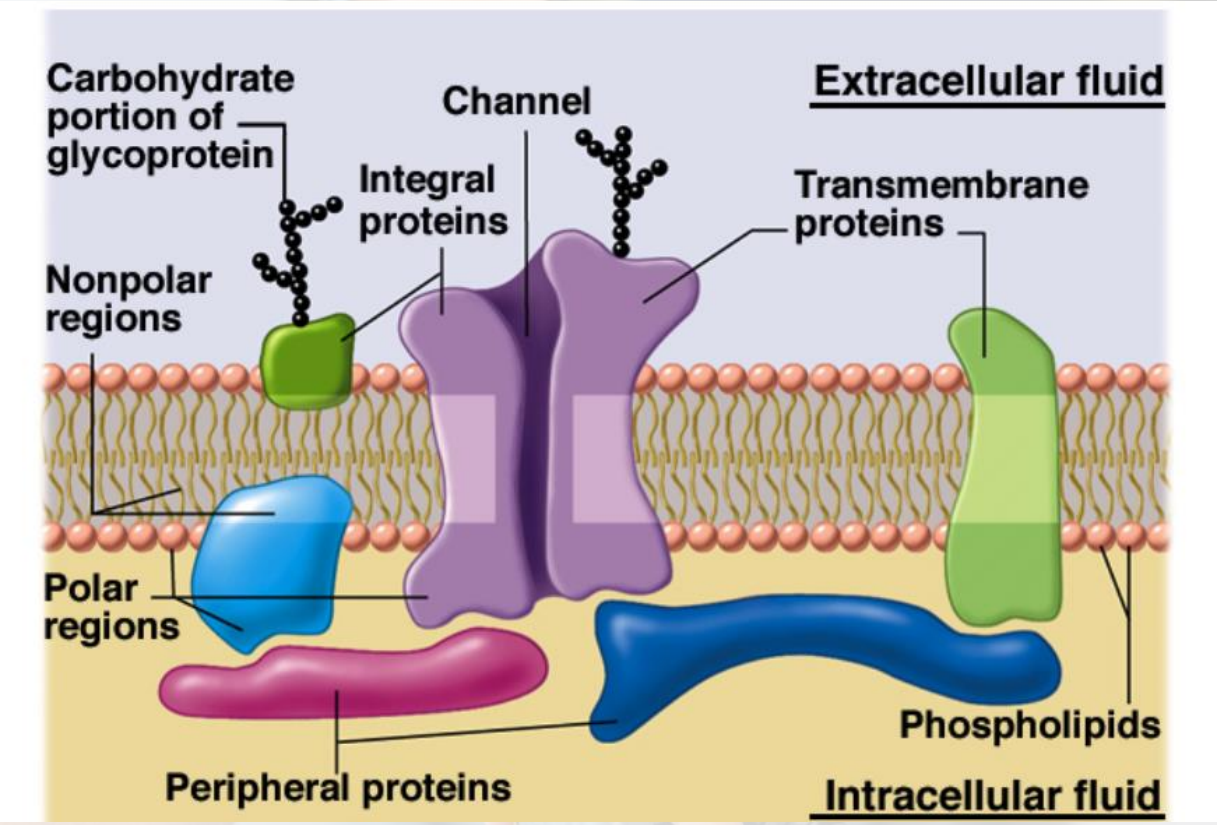
It gives great pleasure to release the first edition of this book as a reference for students who enrol in Diploma of Electronic Engineering (Medical).
It has never been easy to accept this challenge. Many ideas presented in this book originated from classroom experiences.
This book contain selected topic for Chapter 1: The Origin of Biopotentials. One of the features of this book is, that it does not have a textbook structure when the chapters, in order to be understood, need to be read in the sequence given. In fact, you can read based on your interests, tastes, and preferences.
It is hope that this book will help readers understand more about this topic.

“Great things are not done by impulse, but by a series of small things brought together” ~Vincent Van Gogh

IDA MARIA BINTI MOHD YUSOFF
Department of Electrical Engineering
Politeknik Sultan Salahuddin Abdul Aziz Shah

# TABLE OF CONTENT

# Cell Membrane Potential




**Cell Membrane**

- very thin (7-15 nm) lipid-protein complex
- transmembrane ion channels (pores) allow flow of ions across the membra
- like a leaky capacitor: a thin dielectric material acts as a charge separator

- impermeable to intracellular protein and other organic anions
- selectively permeable to sodium (Na+), potassium(K+)and chlorine(Cl-)ions
- ion concentration difference across membrane creates a diffusion gradient
- ions flow, creating an electric field that opposes flow, until an equilibrium is established
- similar to p-n junction, ions flow by diffusion and create a potential difference which inhibits further flow of charged ions

# Action Potential

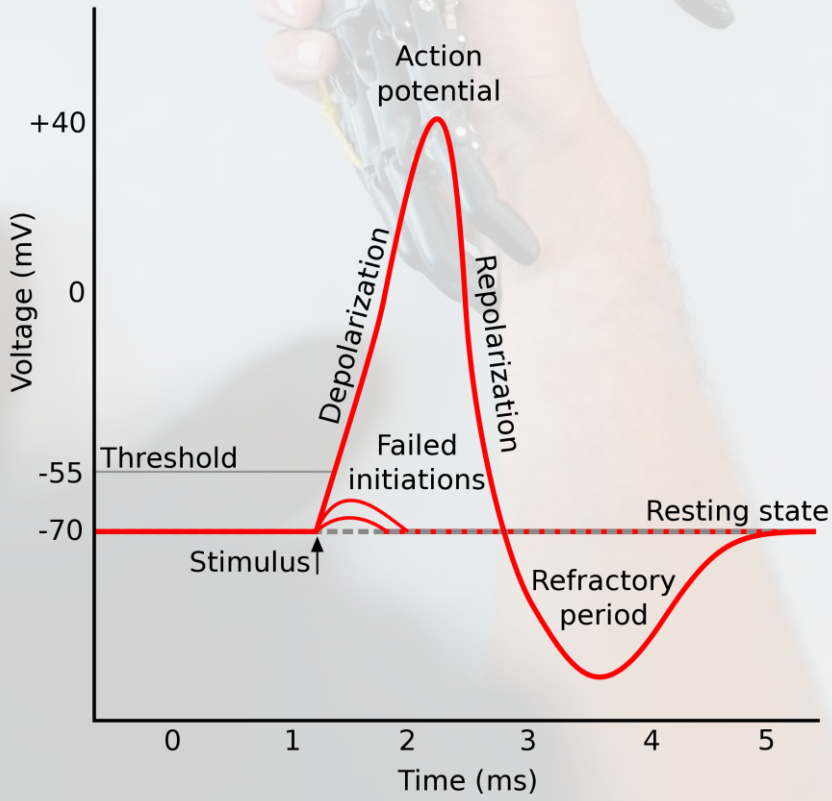
The action potential (AP) is the electrical signal that accompanies the mechanical contraction of a single cell when stimulated by an electrical current (neural or external)

It is caused by the flow of sodium *(Na+), potassium (K+),*chloride (Cl~), and other ions across the cell membrane.

The action potential is the basic component of all bioelectrical signals.

the sodium–potassium pump

- actively transports Na+out of cell and K+into cell in the ratio 3Na+: 2K+
- associated pump current iNaK is a net outward current that tends to increase the negativity of the intracellular potential
- energy for the pump is provided by a common source of cellular energy, adenosine triphosphate(ATP) produced by mitochondria in the cell



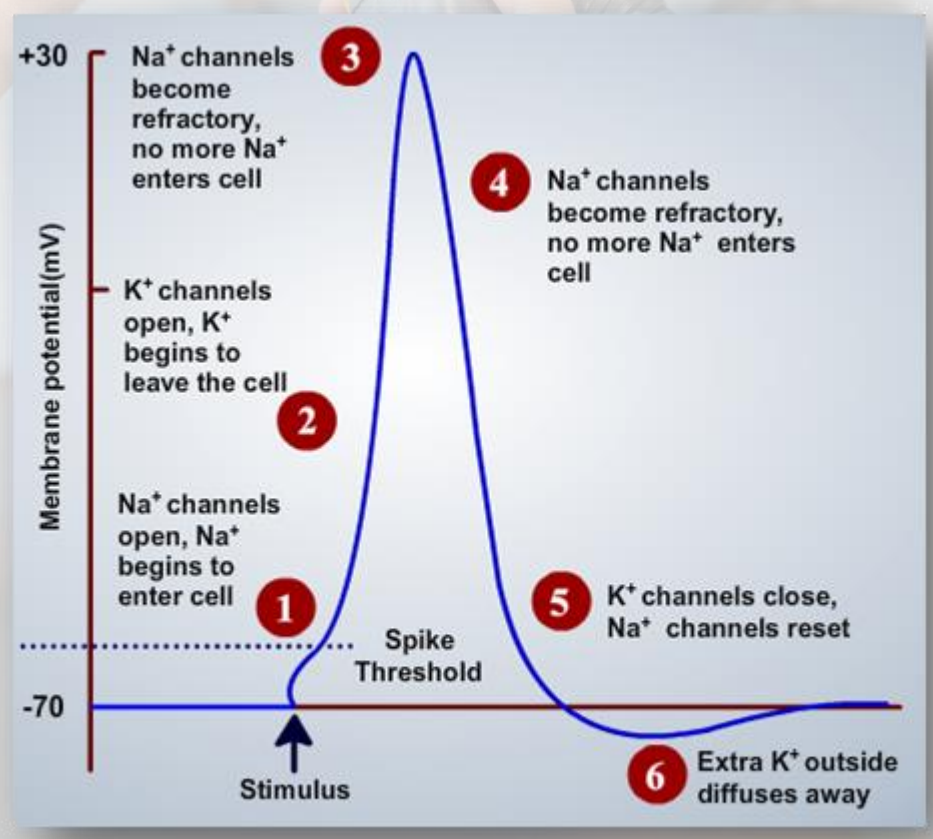
# Resting Potential

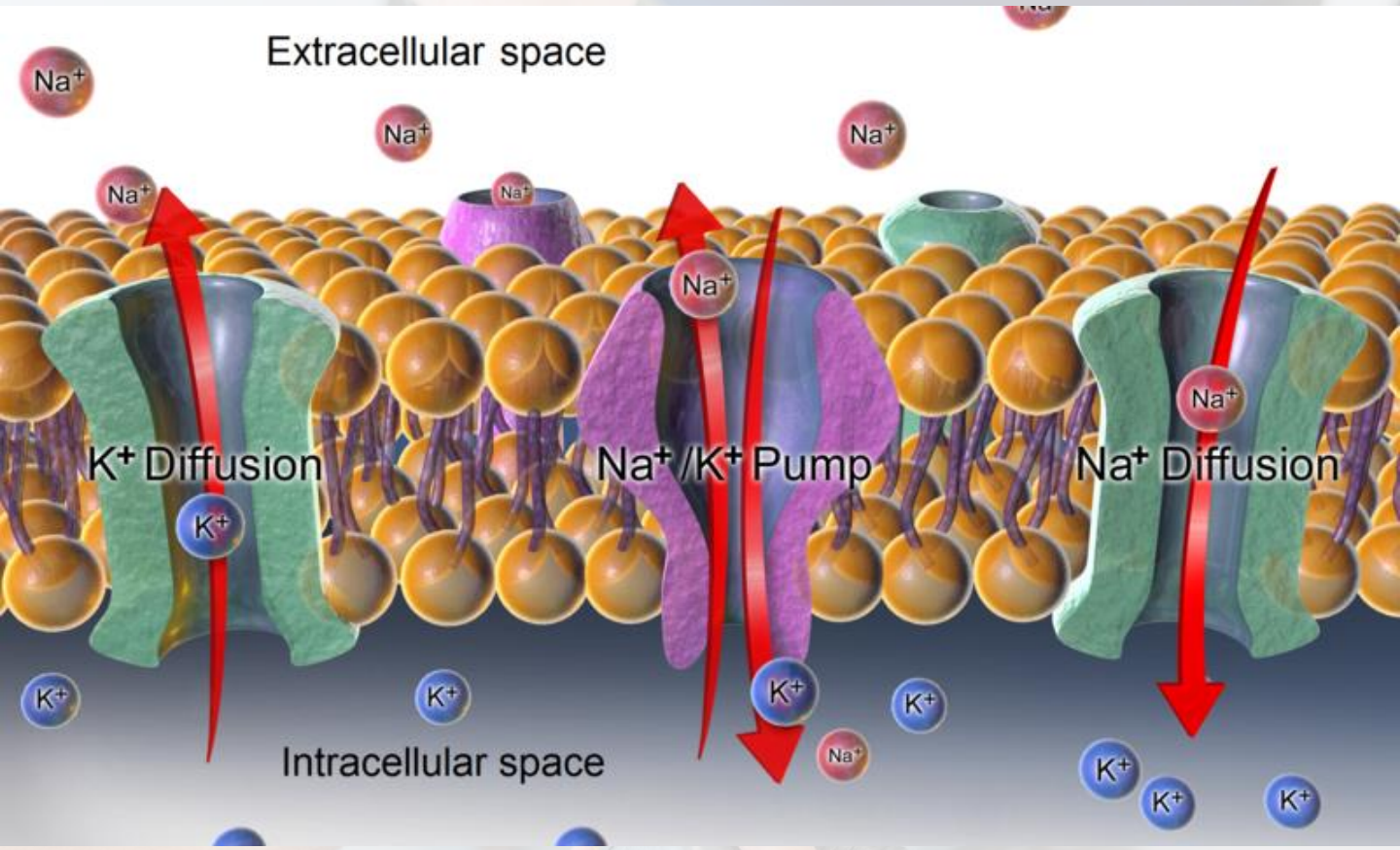
Nerve and muscle cells are encased in a semi-permeable membrane that permits selected substances to pass through while others are kept out.

Body fluids surrounding cells are conductive solutions containing charged atoms known as ions.

In their resting state, membranes of excitable cells readily permit the entry of K+ and Cl~ ions, but effectively block the entry of Na+ ions (the permeability for K+ is 50-100 times that for Na+).

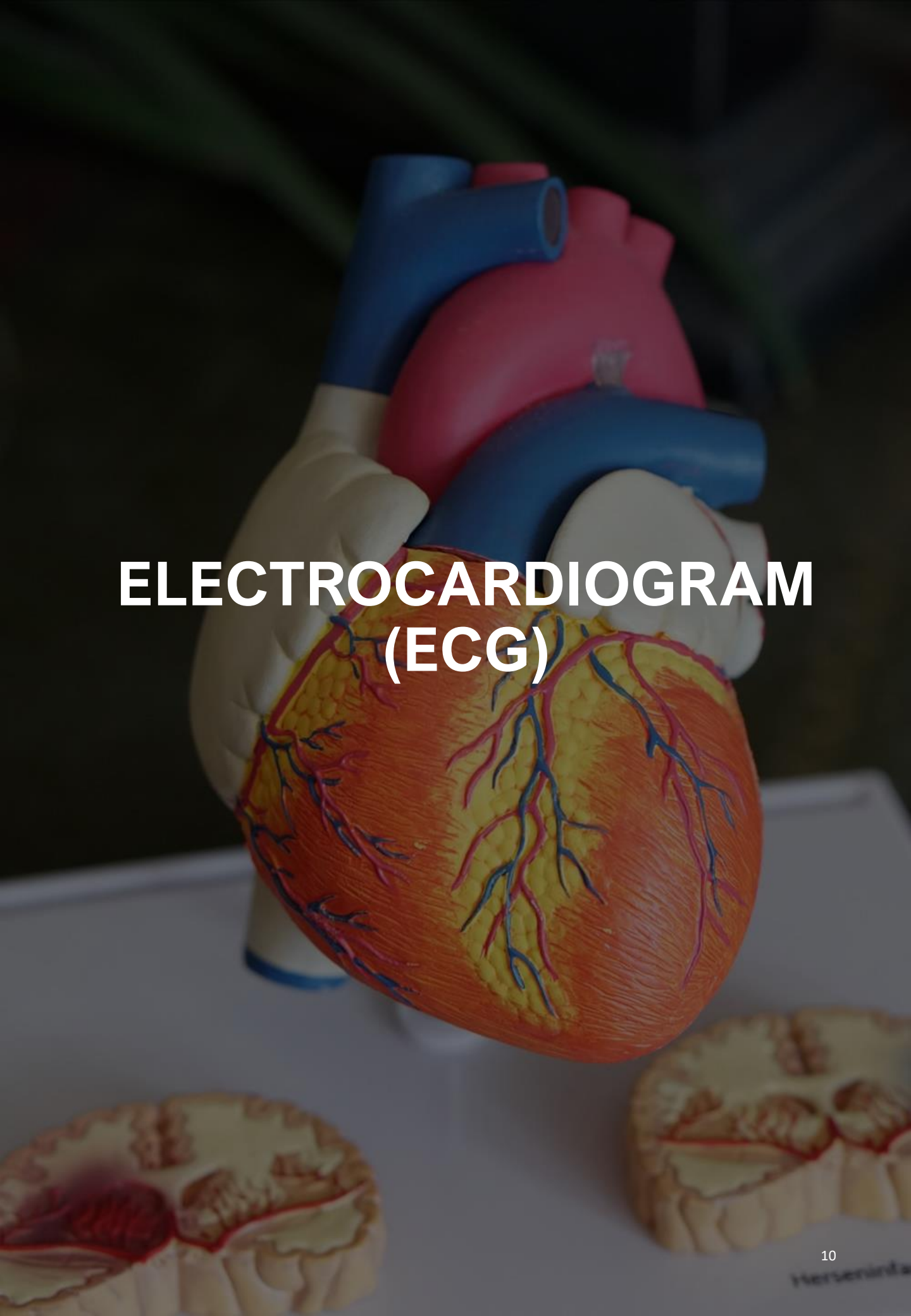
Various ions seek to establish a balance between the inside and the outside of a cell according to charge and concentration






The inability of Na+ to penetrate a cell membrane results in the following:

- Na+ concentration inside the cell is far less than that outside.
- The outside of the cell is more positive than the inside of the cell.
- To balance the charge, additional *K+ ions enter the cell, causing higher K+* concentration inside the cell than outside.
- Charge balance cannot be reached due to differences in membrane permeability for the various ions.
- A state of equilibrium is established with a potential difference, with the inside of the cell being negative with respect to the outside
- A cell in its resting state is said to be polarized. Most cells maintain a resting potential of the order of **- 70** to **-90** mV until some disturbance or stimulus upsets the equilibrium

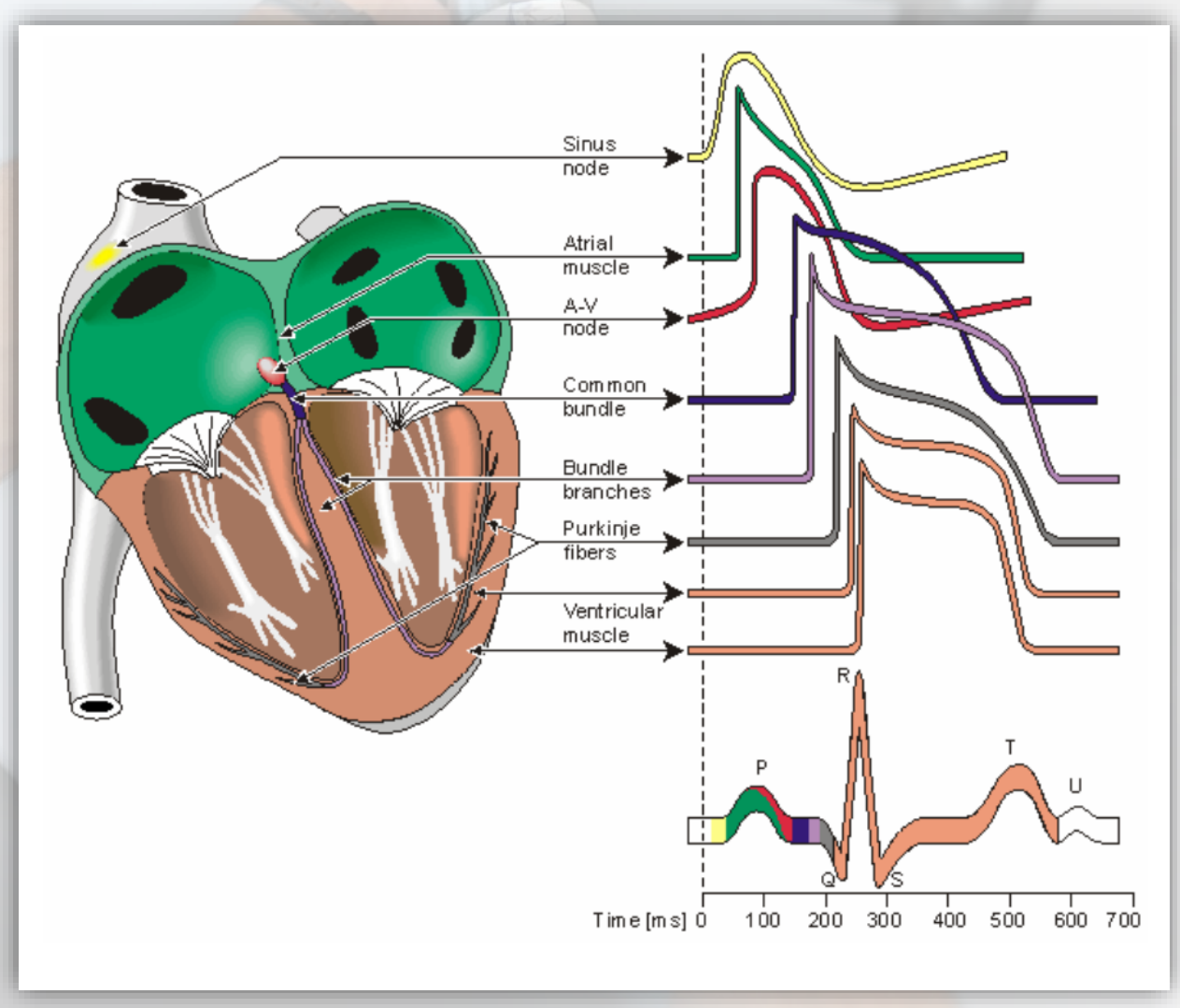


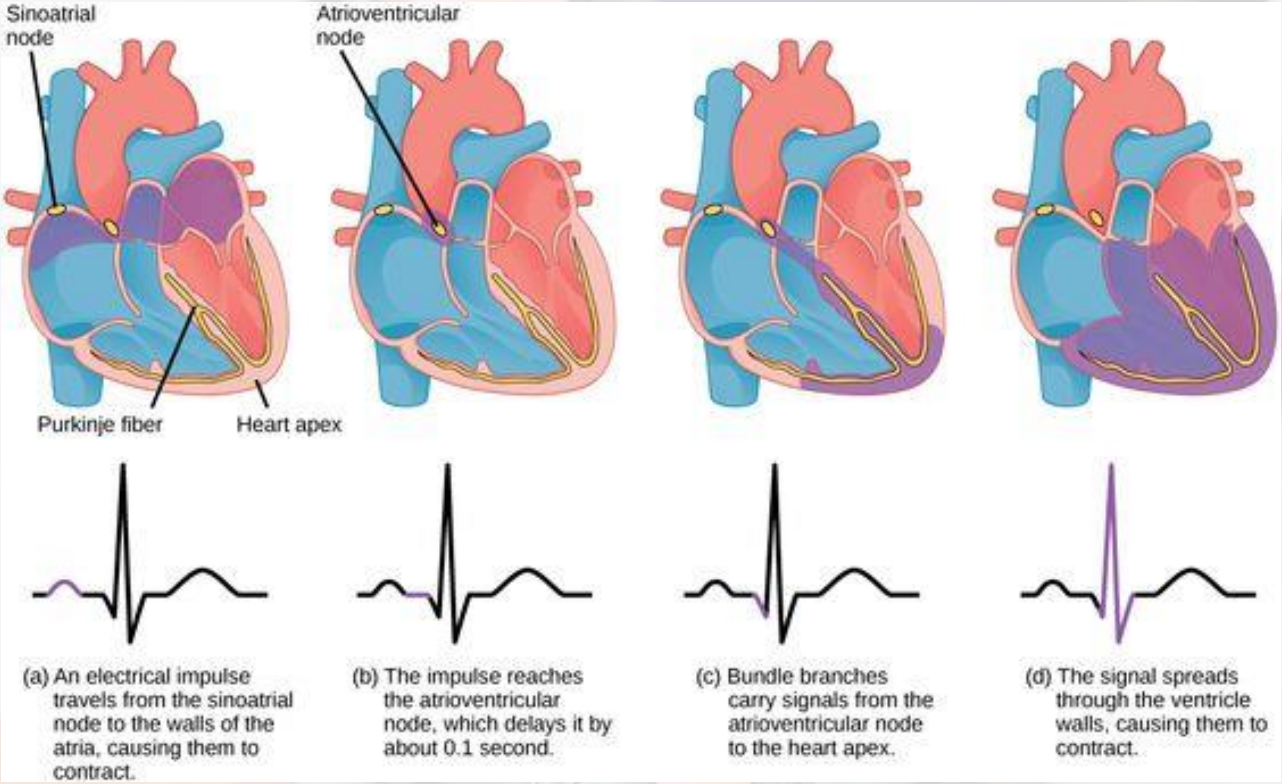
# ELECTROCARDIOGRAM (ECG)

# ELECTROCARDIOGRAM

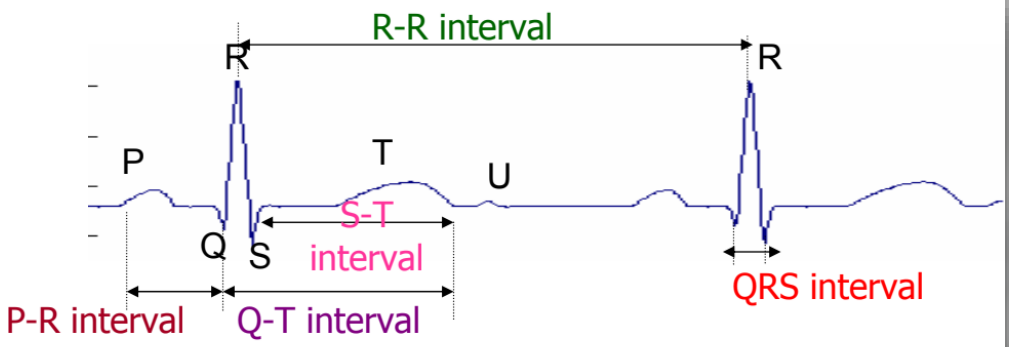
ECG also known EKG. ECG is a biopotential generated by muscles of the heart. It also represent the electrical activity of the heart.

An electrocardiogram (ECG) is one of the simplest and fastest tests used to evaluate the heart. Electrodes (small, plastic patches that stick to the skin) are placed at certain spots on the chest, arms, and legs. The electrodes are connected to an ECG machine by lead wires.

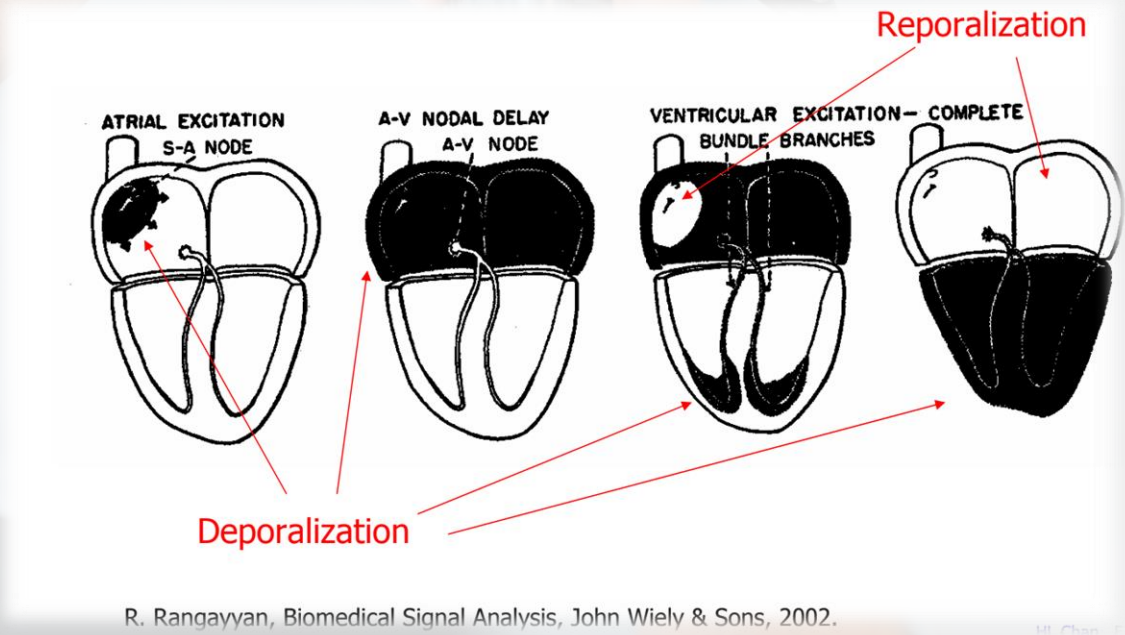





- Cardiac impulse originates in the SA node
- Traverses the atria simultaneously – no special conduction wires in atria – so the delay
- Reaches AV node – the check post – so delay
- Enters bundle of His and branches – through specialized conducting wires called Purkinje fibers - activates both ventricles – quick QRS
- First the septum from L to R, then right ventricle and then the left ventricle and finally the apex
- Then the ventricles recover for next impulse

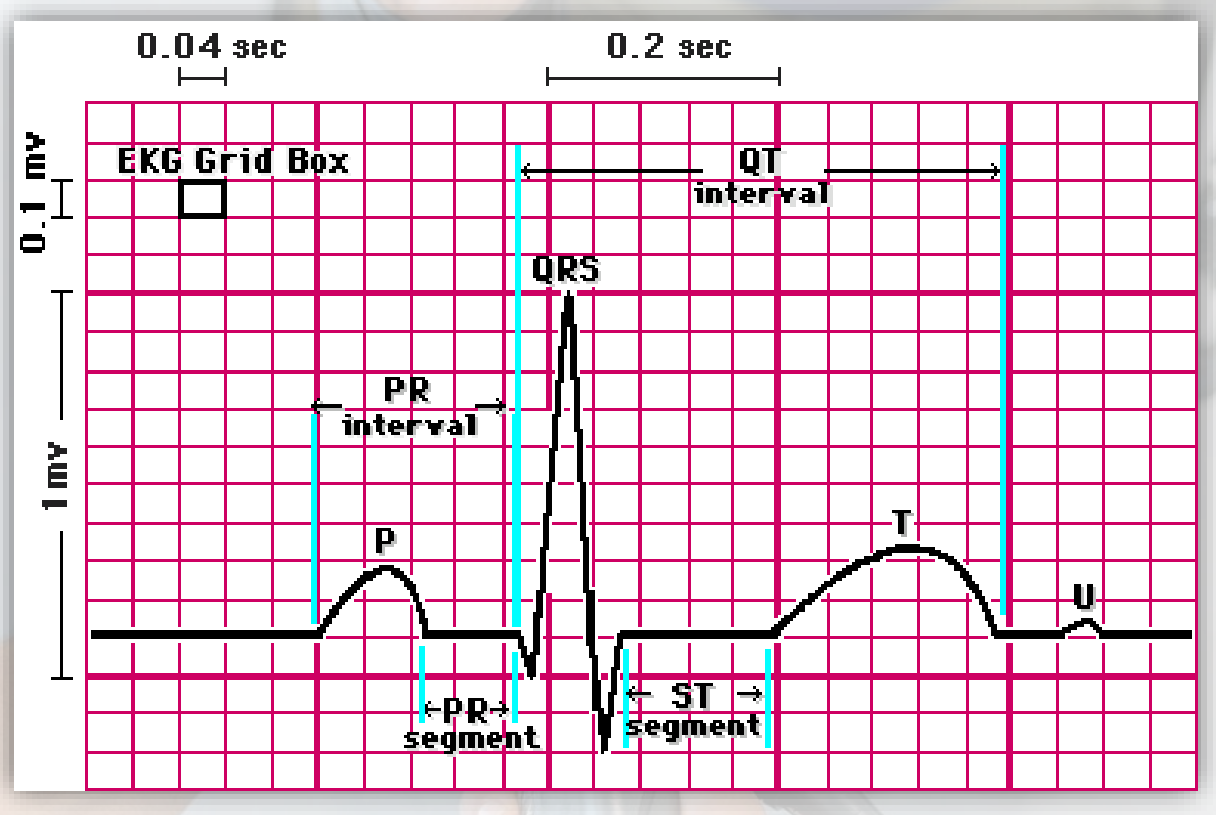



P wave : Atrial depolarization
QRS complex : Ventricular depolarization
T wave : Ventricular repolarization
U wave : Slow repolarization of ventricular muscle
R-R : Heart period
P-R : Conduction delay in the AV-node
Q-T, S-T : Ventricular repolarization time




R. Rangayyan, Biomedical Signal Analysis, John Wiely & Sons, 2002.

# ECG GRAPH PAPER

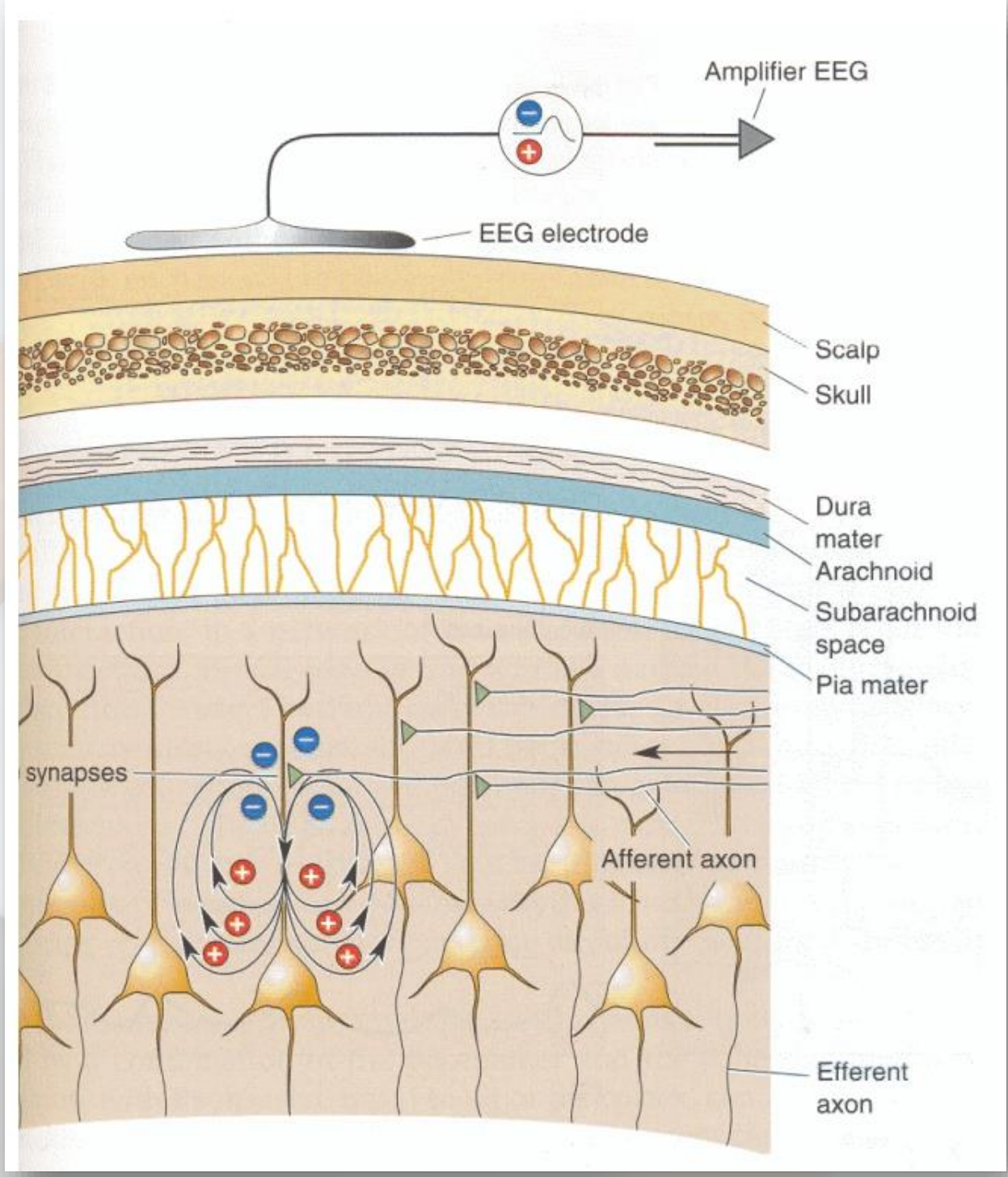



- X-Axis represents time - Scale X-Axis – 1 mm = 0.04 sec
- Y-Axis represents voltage - Scale Y-Axis – 1 mm = 0.1 mV
- One big square on X-Axis = 0.2 sec (big box)
- Two big squares on Y-Axis = 1 milli volt (mV)
- Each small square is 0.04 sec (1 mm in size)
- Each big square on the ECG represents 5 small squares
  = 0.04 x 5 = 0.2 seconds
- 5 such big squares = 0.2 x 5 = 1sec = 25 mm
- One second is 25 mm or 5 big squares
- One minute is 5 x 60 = 300 big squares

# ELECTROENCHEPALOGRAM (EEG)

# ELECTROENCHEPHALOGRAM

EEG is the biopotential generated by the neuronal activity of the brain. The EEG (popularly known as brain waves) represents the electrical activity of the brain



An EEG can determine changes in brain activity that may be useful in diagnosing brain disorders, especially epilepsy. An EEG can't measure intelligence or detect mental illness. An EEG may be helpful for diagnosing or treating the following disorders:

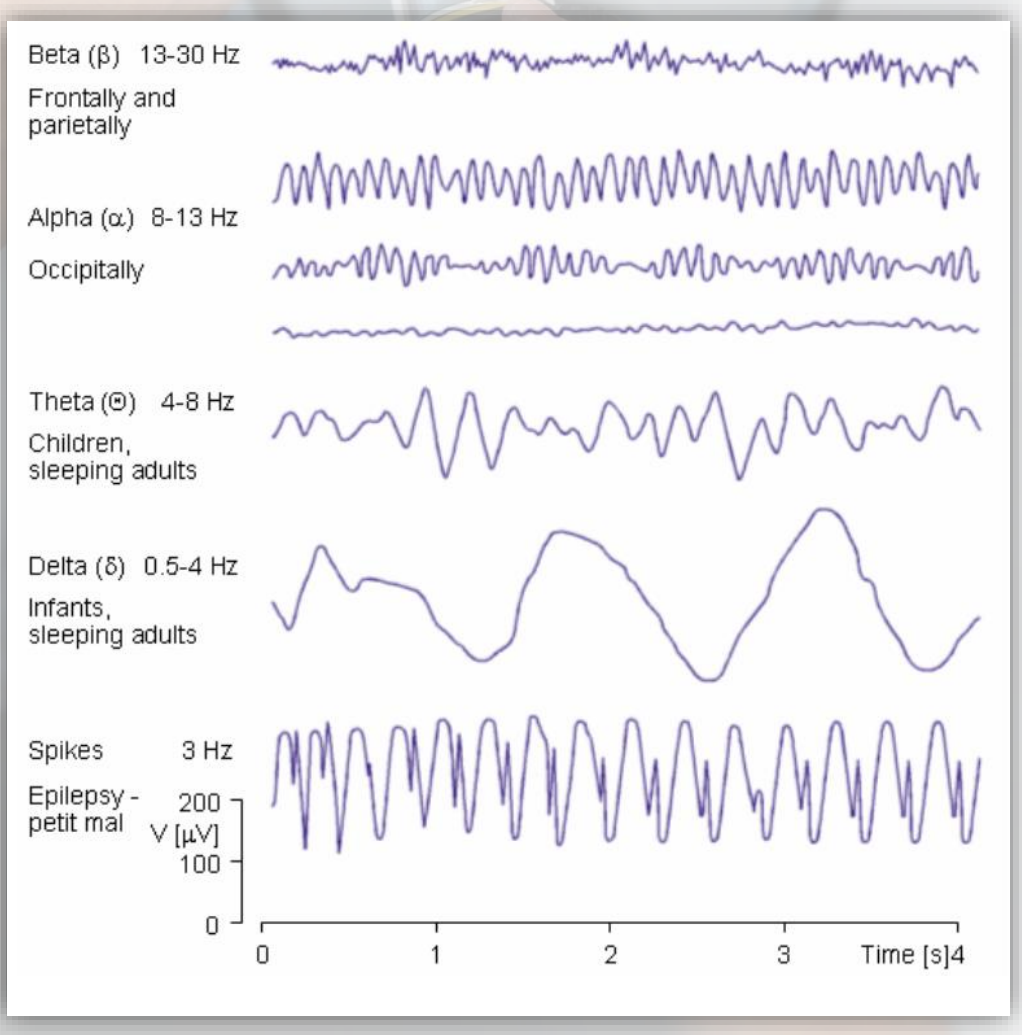
- Epilepsy or other seizure disorder
- Brain tumor
- Head injury
- Brain dysfunction that may have a variety of causes (encephalopathy)
- Inflammation of the brain (encephalitis)
- Stroke
- Sleep disorders
- Dementia

An EEG may also be used to confirm brain death in someone in a persistent coma. A continuous EEG is used to help find the right level of anesthesia for someone in a medically induced coma

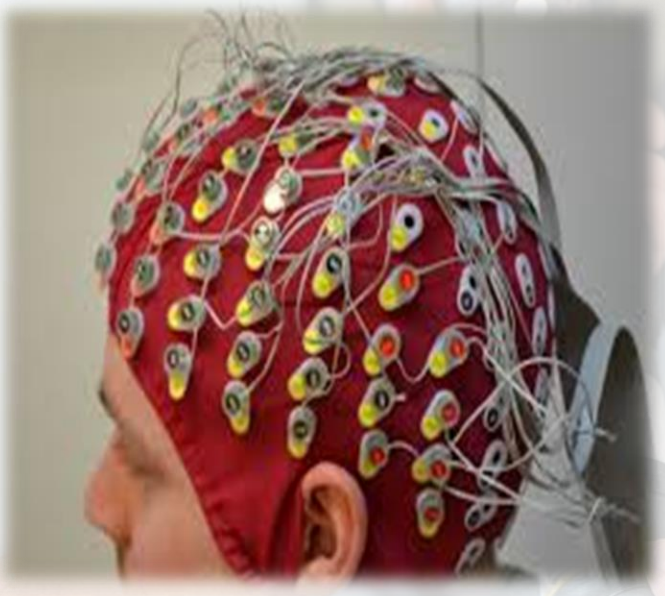
There are at least four areas of applications for brainwave detection devices:

- Medical/clinical applications
- Assistive technology for people with disability i.e. to control, for example, a wheelchair or a mouse
- Hands-free gaming
- Market research - evaluating new ads or packaging by reading consumer brainwaves

| | | |
|---|---|---|
| Delta | < 4 Hz | sleeping, in awakeness pathological |
| Theta | 4 -8 Hz | drowsiness in children, pathological in aduls (hyperventilation, hypnosis, |
| Alpha | 8 -13 Hz | relaxation physical / mental |
| Beta | 13 - 30 Hz | wakefulness, active concentration |
| Gamma | 30–80 Hz | higher mental activity including perception and consciousness |



# Type of EEG Electrodes



Brain cap for adult and children

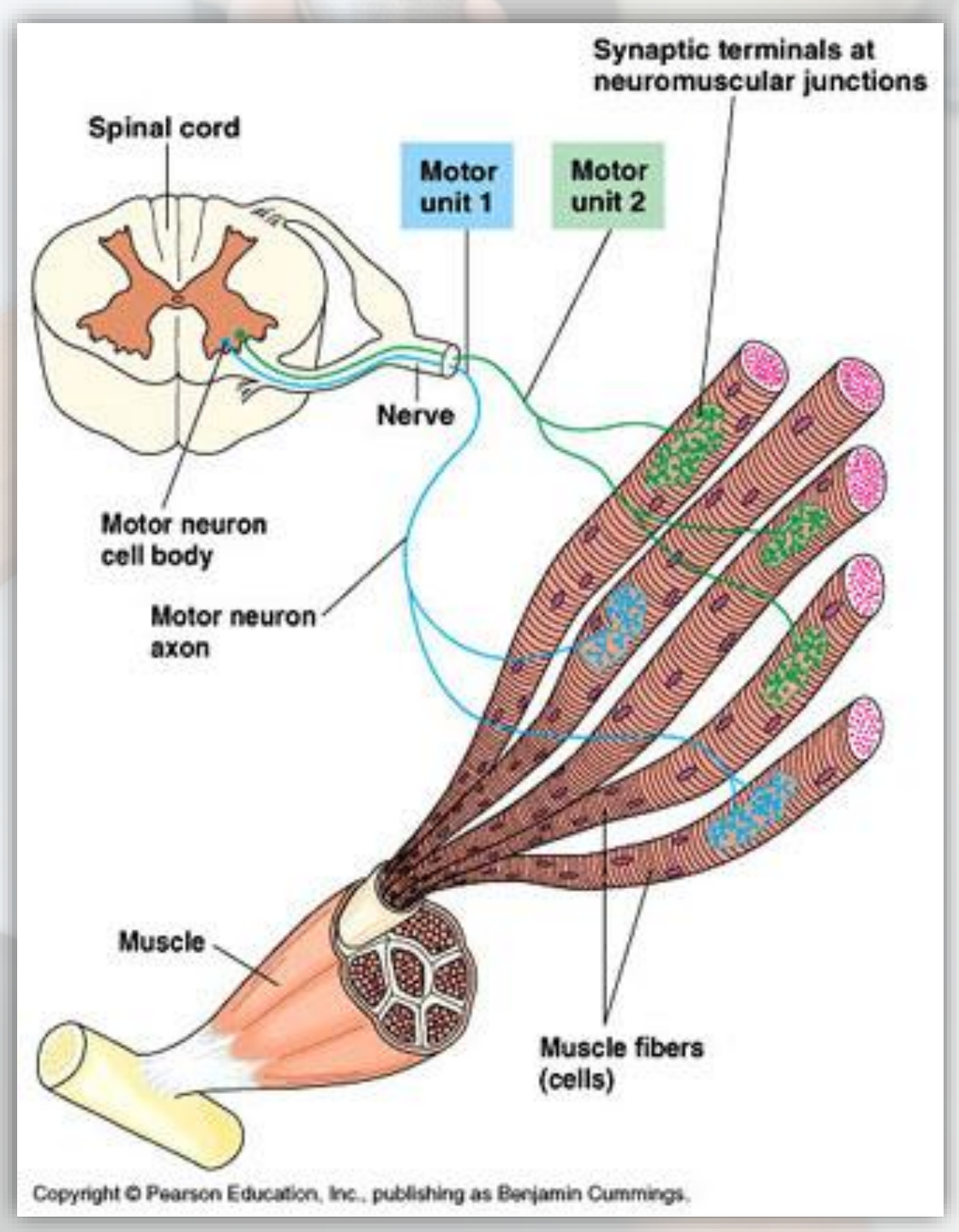
The Mynd is wireless, uses dry, "smart" electrodes (thus eliminating the use of gels) and is claimed to provide full-brain coverage using "a dense-array" of EEG sensors, each one capturing brainwave activity at 2,000 times a second.

# ELECTROMYOGRAM (EMG)

# ELECTROMYOGRAM

EMG is the bioelectric potentials associated with muscle activity.

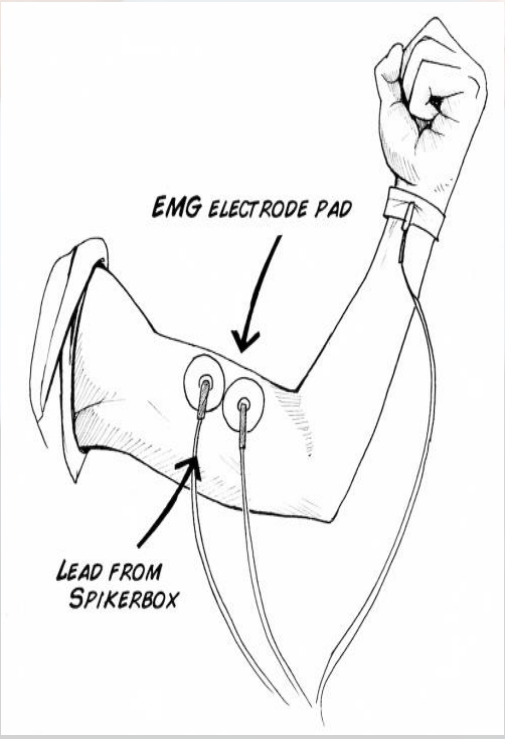
These potentials may be measured at the surface or directly from the muscle by penetrating the skin



- Skeletal muscle is organized functionally on the basis of the single motor unit (SMU).
- SMU is the smallest unit that can be activated by a volitional effort where all muscle fibers are activated synchronously.
- SMU may contain 10 to 2000 muscle fibers, depending on the location of the muscle.

**Factors for muscle varying strength**

1. Number of muscle fibers contracting within a muscle
2. Tension developed by each contracting fiber




**Field potential of the active fibers of an SMU**

- 1- triphasic form
- 2- duration 3-15 msec
- 3- discharge rate varies from 6 to 30 per second
- 4- Amplitude range from 20 to 2000 μV

- Surface electrode record field potential of surface muscles and over a wide area.
- Monopolar and bipolar insertion-type needle electrode can be used to record SMU field potentials at different locations.

- The shape of SMU potential is considerably modified by disease such as partial denervation.

Doctors may order an EMG if there are signs or symptoms that may indicate a nerve or muscle disorder. Such symptoms may include:

- Tingling
- Numbness
- Muscle weakness
- Muscle pain or cramping
- Certain types of limb pain

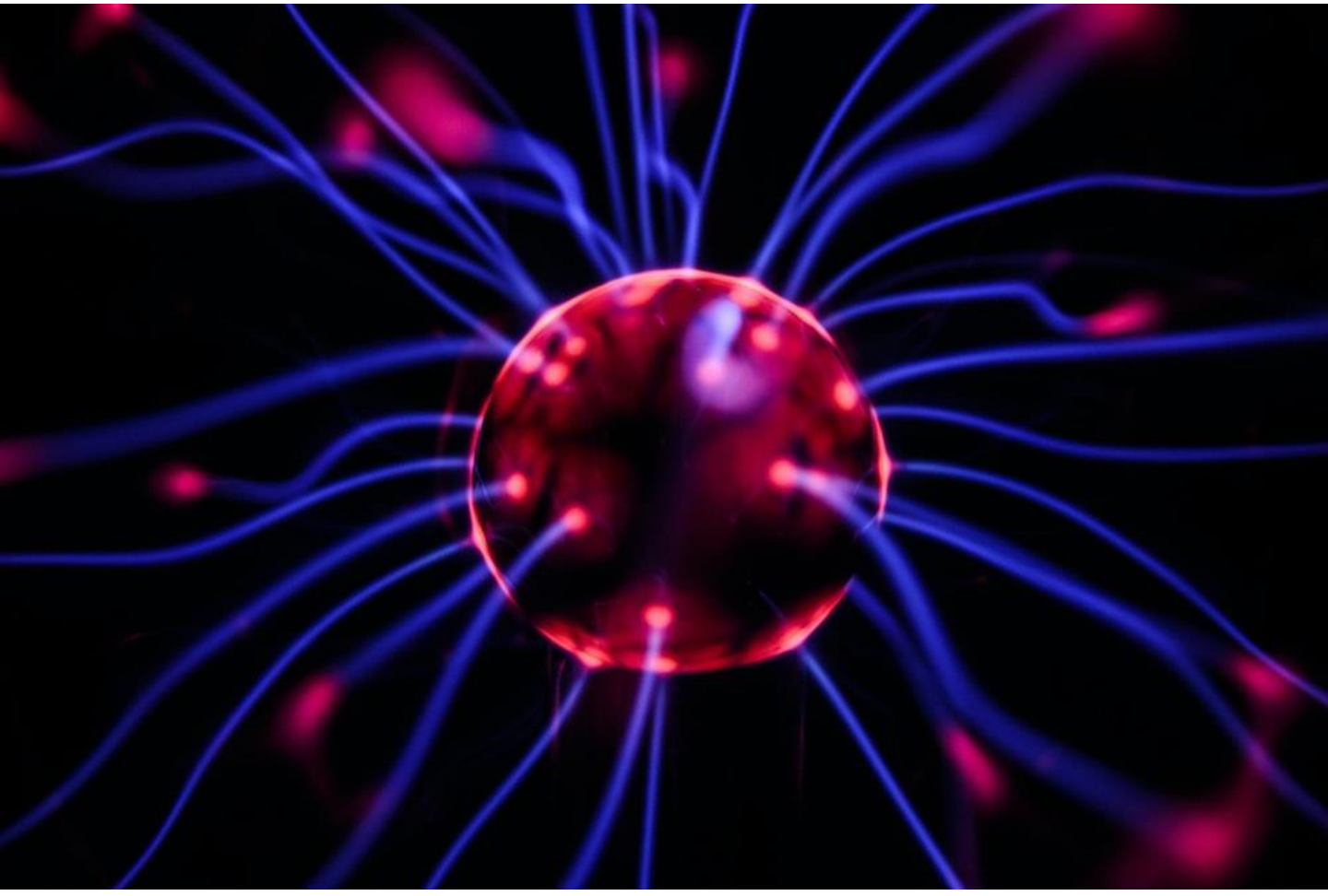
EMG results are often necessary to help diagnose or rule out a number of conditions such as:

- Muscle disorders, such as muscular dystrophy or polymyositis
- Diseases affecting the connection between the nerve and the muscle, such as myasthenia gravis
- Disorders of nerves outside the spinal cord (peripheral nerves), such as carpal tunnel syndrome or peripheral neuropathies
- Disorders that affect the motor neurons in the brain or spinal cord, such as amyotrophic lateral sclerosis or polio
- Disorders that affect the nerve root, such as a herniated disk in the spine

**Risk**

- EMG is a low-risk procedure, and complications are rare. There's a small risk of bleeding, infection and nerve injury where a needle electrode is inserted.
- When muscles along the chest wall are examined with a needle electrode, there's a very small risk that it could cause air to leak into the area between the lungs and chest wall, causing a lung to collapse (pneumothorax)

# ELECTRONEUROGRAM (ENG)



# ELECTRONEUROGRAM

- The ENG is an electrical signal observed as a stimulus and the associated nerve action potential propagate over the length of a nerve.
- It may be used to measure the velocity of propagation (or conduction velocity) of a stimulus or action potential in a nerve
- ENGs may be recorded using concentric needle electrodes or silver -silver-chloride electrodes *(Ag - AgCl)* at the surface of the body.
- Recording the field potential of an excited nerve.

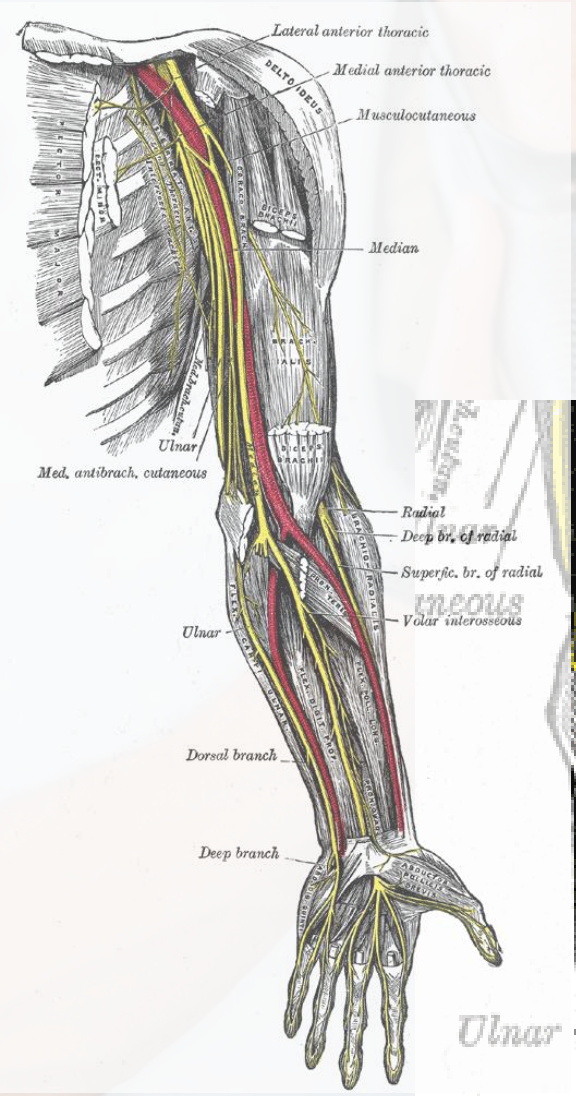
**Neural field potential is generated by**

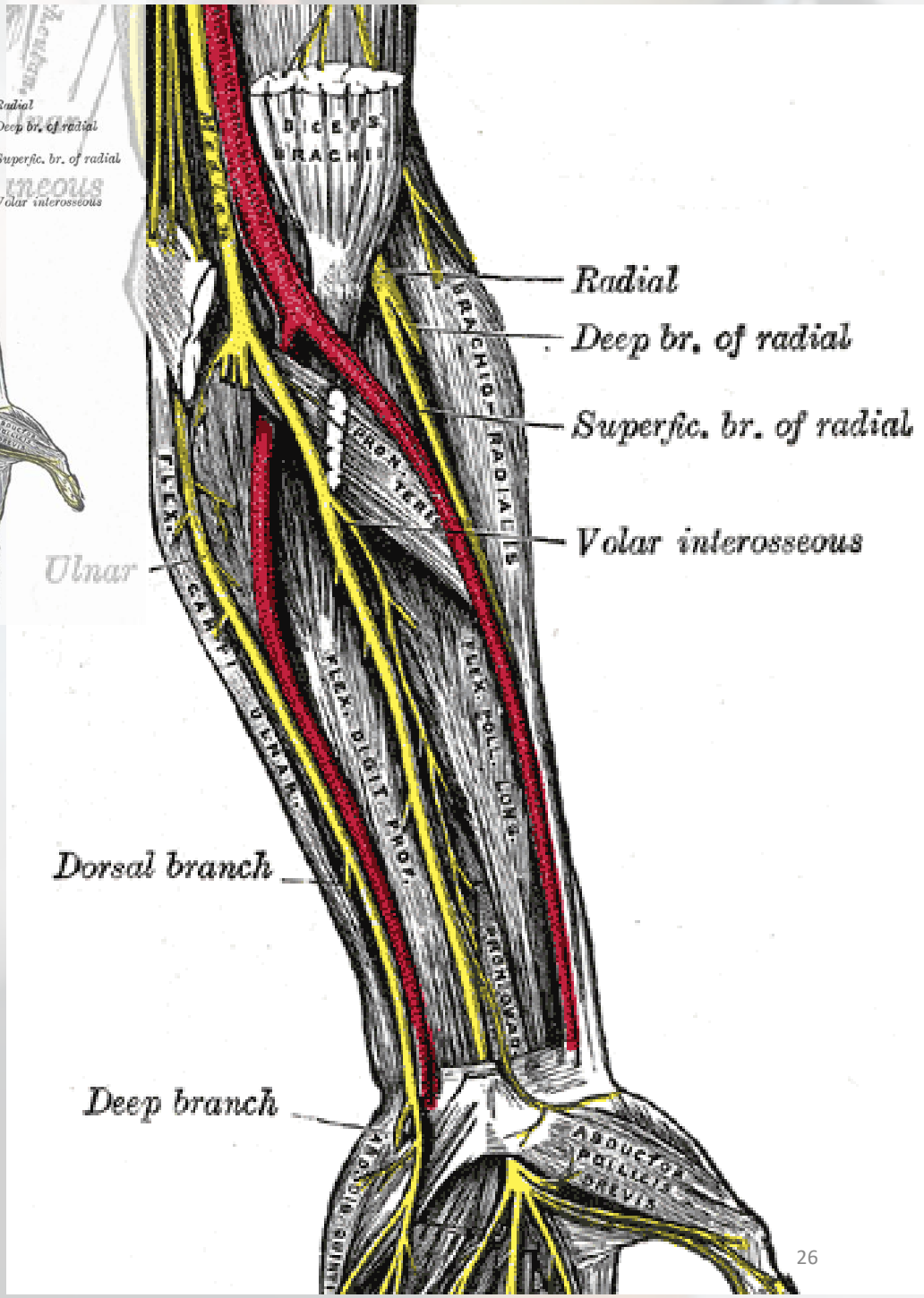
- Sensory component
- Motor component

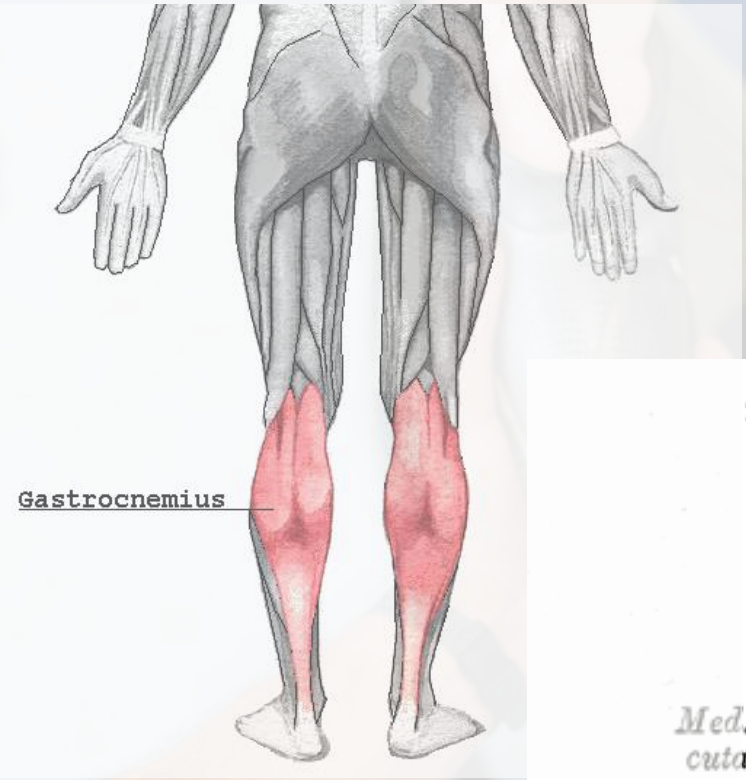
**Parameters for diagnosing peripheral nerve disorder**

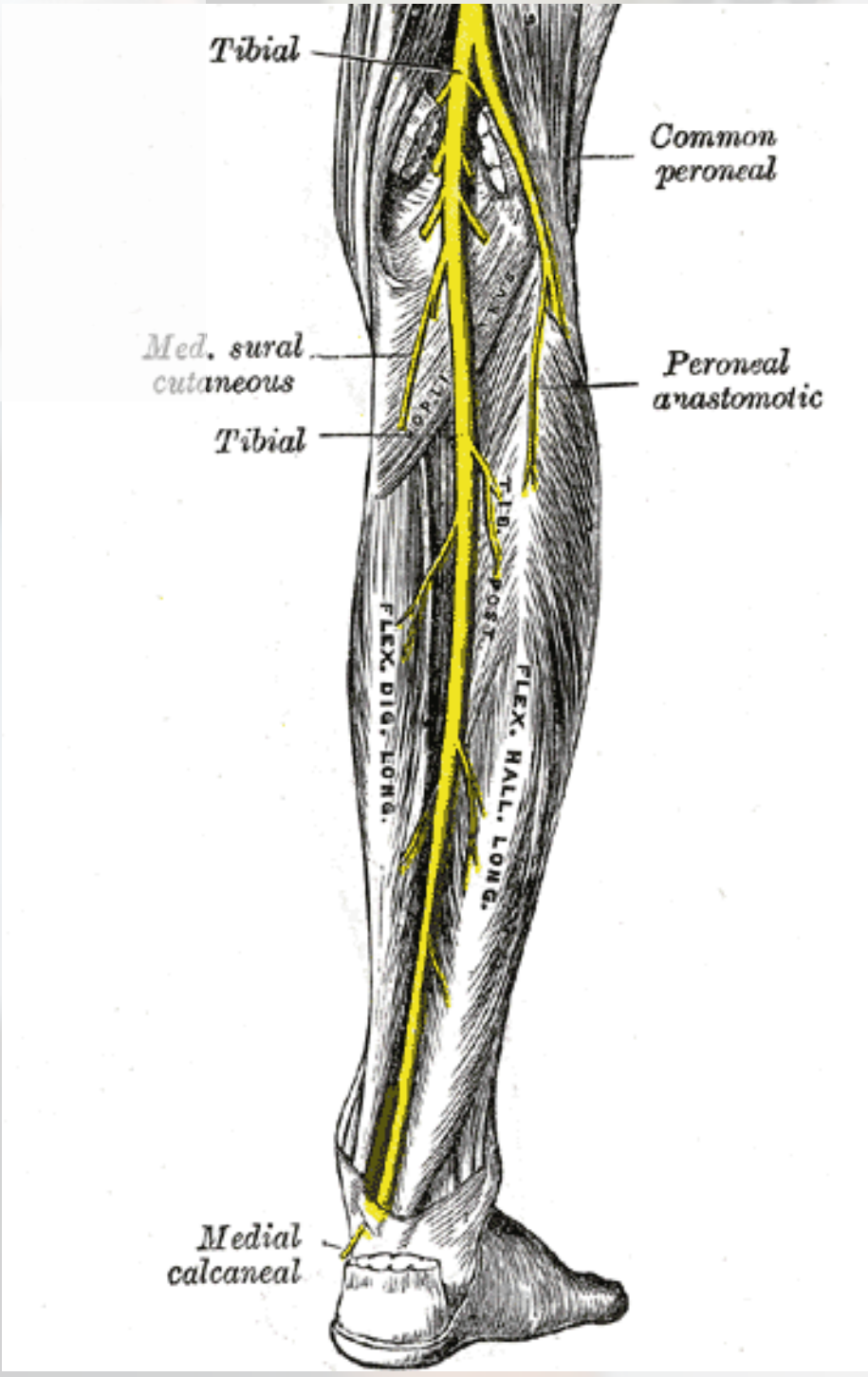
- Conduction velocity
- Latency
- Characteristic of field potentials evoked in muscle supplied by the stimulated nerve (temporal dispersion)

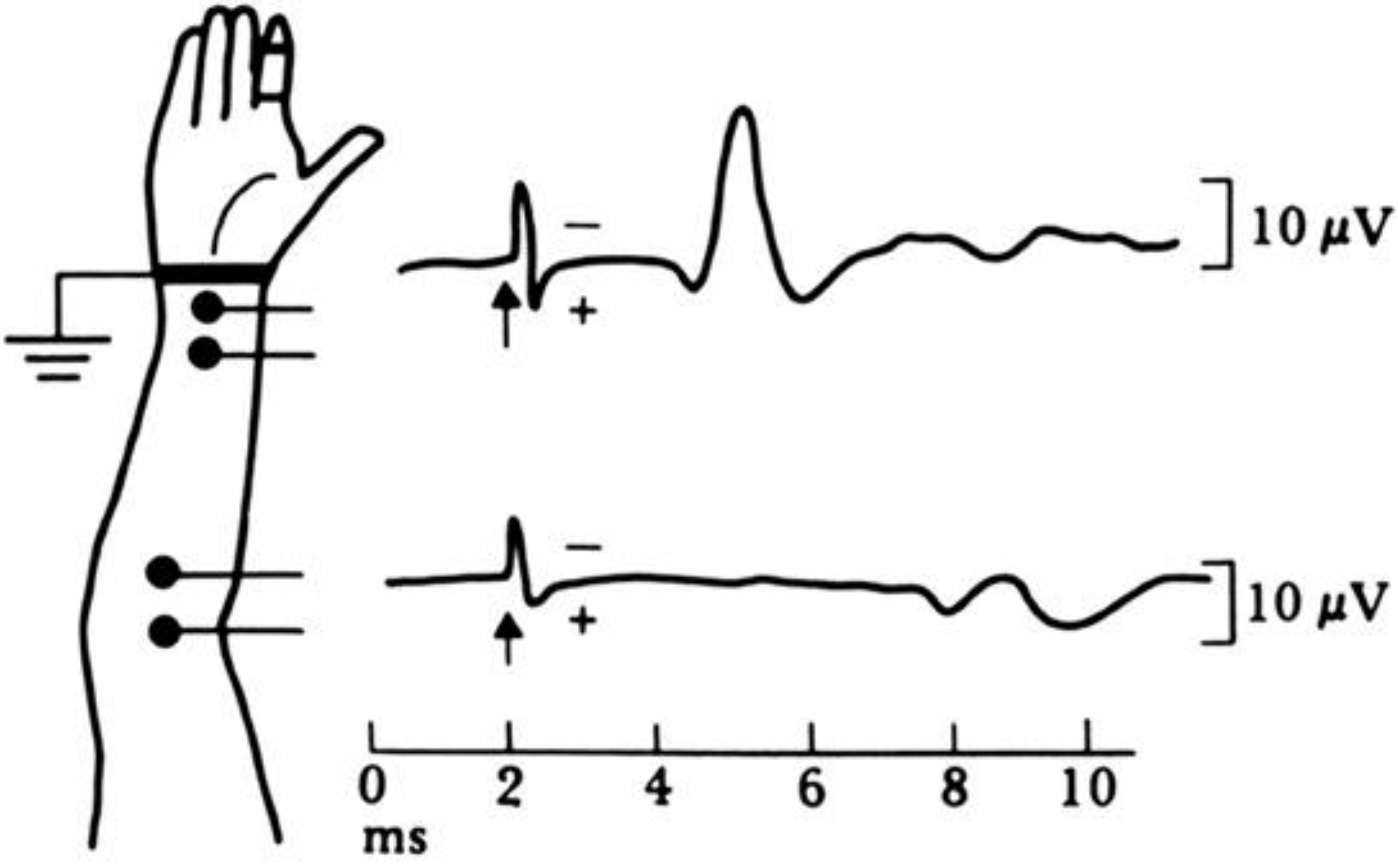
# The Nerve


Lateral anterior thoracic
Medial anterior thoracic
Musculocutaneous
Median
Ulnar
Med. antibrach. cutaneous
Radial
Deep br. of radial
Superfic. br. of radial
Volar interosseous
Ulnar
Dorsal branch
Deep branch


Radial
Deep br. of radial
Superfic. br. of radial
Volar interosseous
Ulnar
Dorsal branch
Deep branch

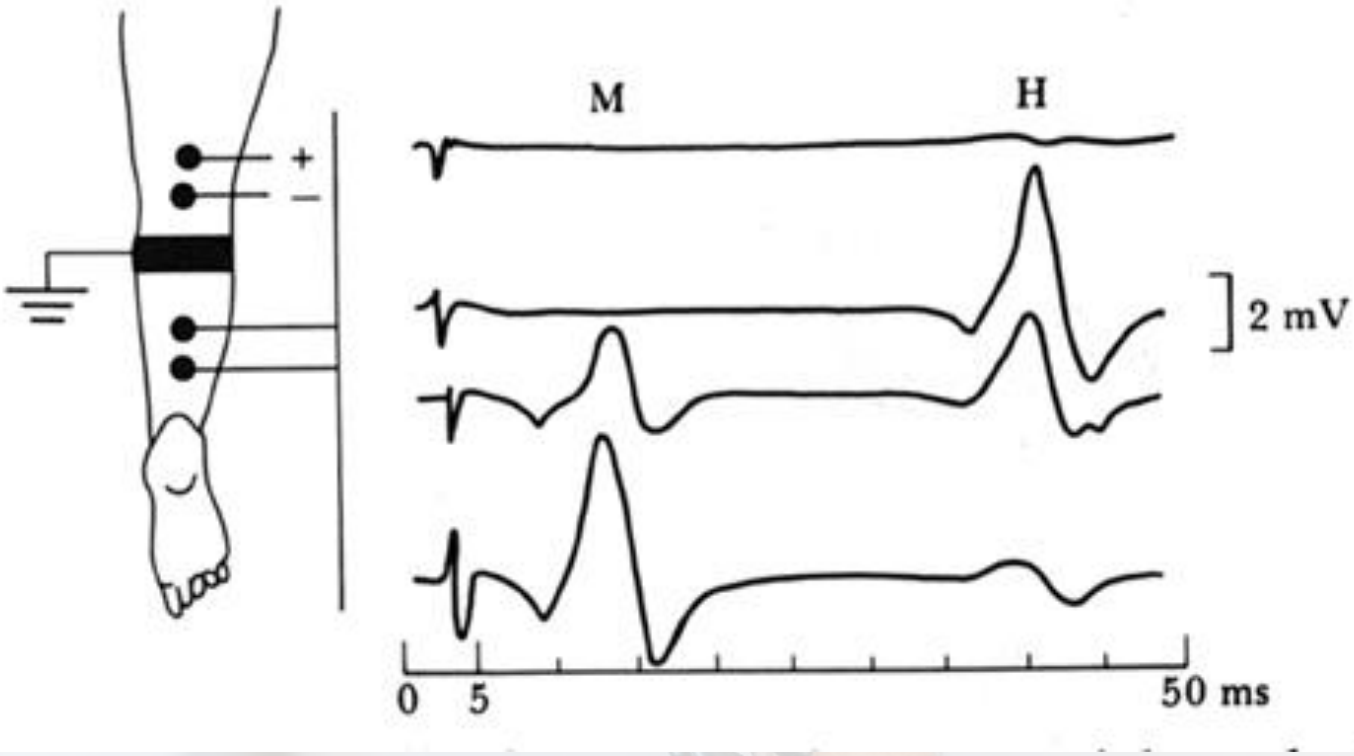

Gastrocnemius


Tibial
Common peroneal
Med. sural cutaneous
Peroneal anastomotic
Tibial
FLEX. DIG. LONG.
FLEX. HALL. LONG.
Medial calcaneal




Sensory nerve action potentials evoked from median nerve of a healthy subject at elbow and wrist after stimulation of index finger with ring electrodes. The potential at the wrist is triphasic and of much larger magnitude than the delayed potential recorded at the elbow. Considering the median nerve to be of the same size and shape at the elbow as at the wrist, we find that the difference in magnitude and waveshape of the potentials is due to the size of the volume conductor at each location and the radial distance of the measurement point from the neural source.

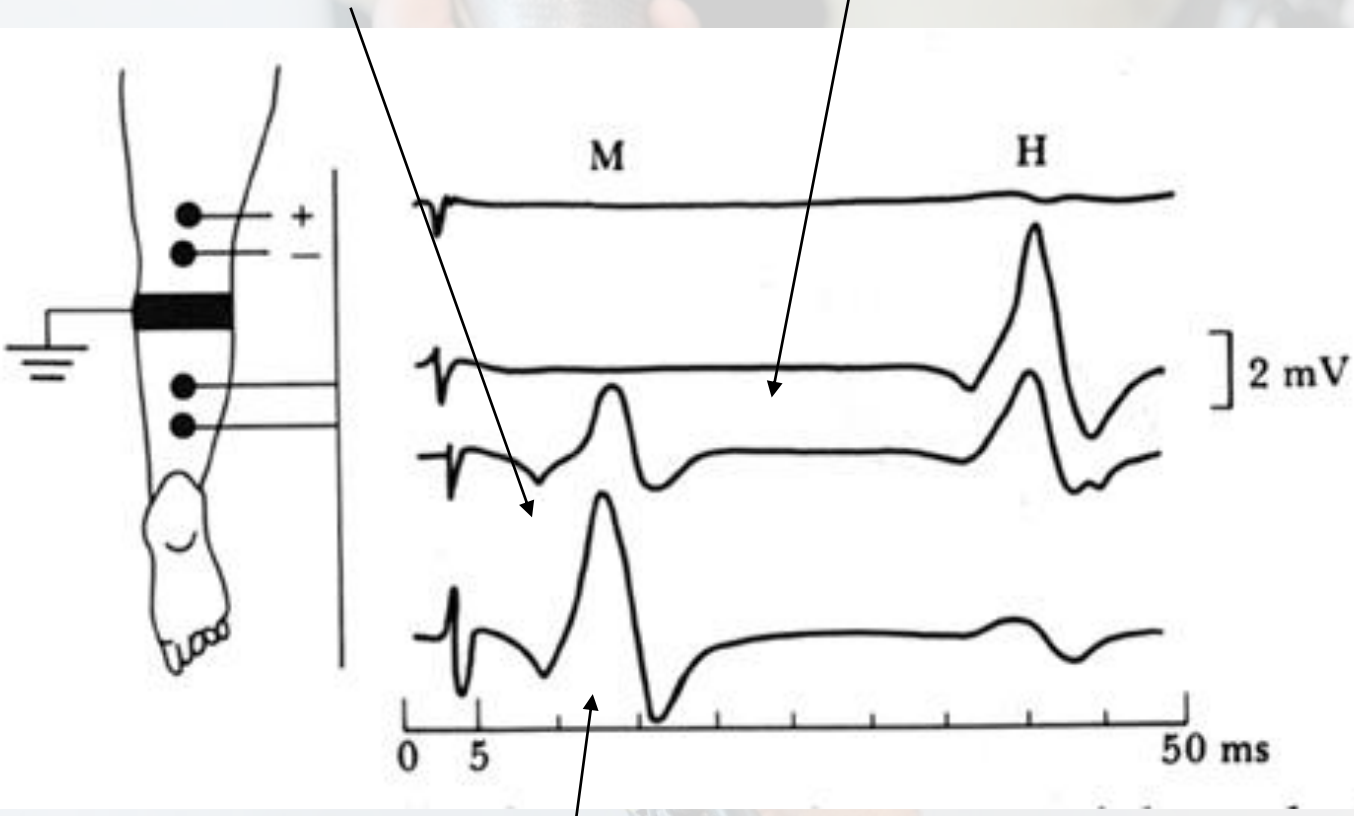
Some times when a peripheral nerve is stimulated, a two evoked potentials are recorded in the muscle the nerve supplies. The time difference between the two potentials determined by the distance between the stimulus and the muscle.




- Stimulated nerve: posterior tibial nerve
- Muscle: gastrocnemius

Medium intensity stimulus stimulate smaller motor fibers in addition to the large sensory fibers. Motor fibers produce a direct muscle response the M wave.

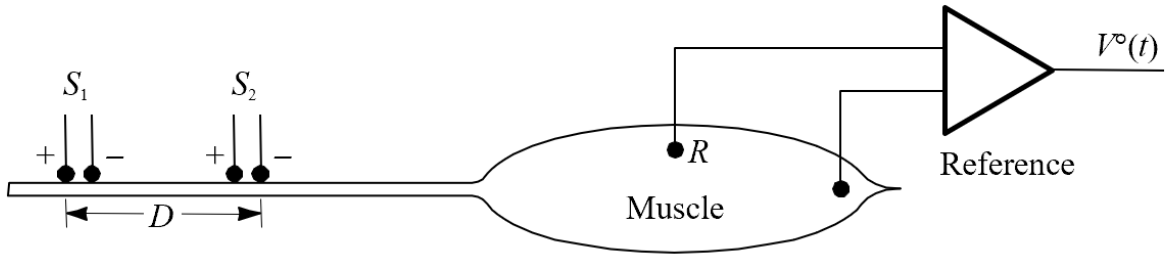
Low intensity stimulus stimulate only the large sensory fibers that conduct toward the CNS. No M wave

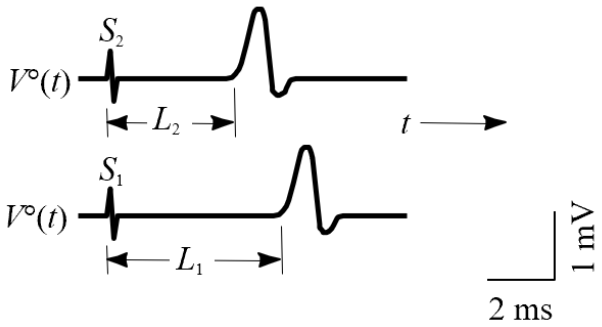



With strong stimuli, the excited motor fibers are in their refractory period so only the M wave is produced.

**The H reflex** The four traces show potentials evoked by stimulation of the medial popliteal nerve with pulses of increasing magnitude (the stimulus artifact increases with stimulus magnitude). The later potential or H wave is a low-threshold response, maximally evoked by a stimulus too weak to evoke the muscular response (M wave). As the M wave increases in magnitude, the H wave diminishes.

# Conduction velocity of a Nerve




$$\text{Velocity} = u = \frac{D}{L_1 - L_2}$$

Measurement of neural conduction velocity via measurement of latency of evoked electrical response in muscle. The nerve was stimulated at two different sites a known distance *D* apart.

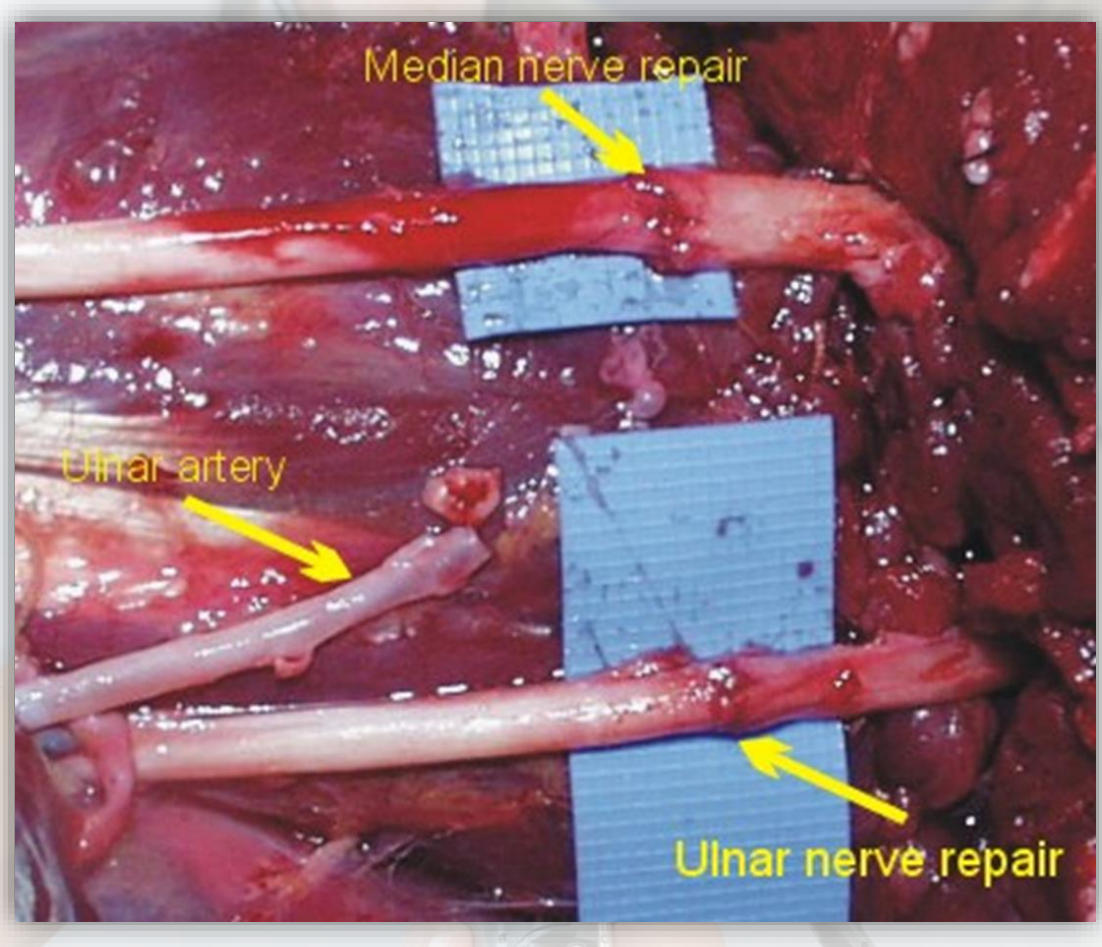
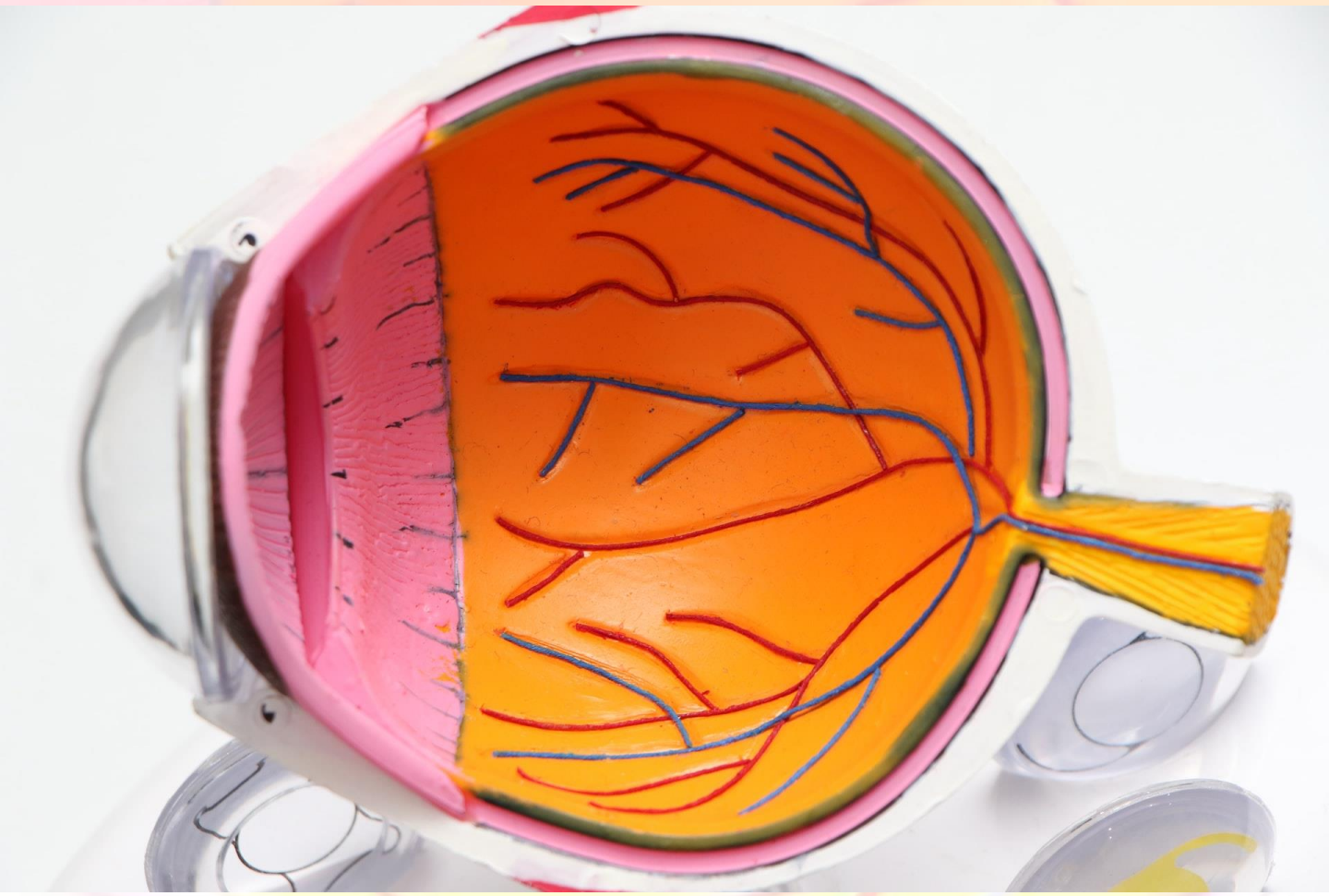
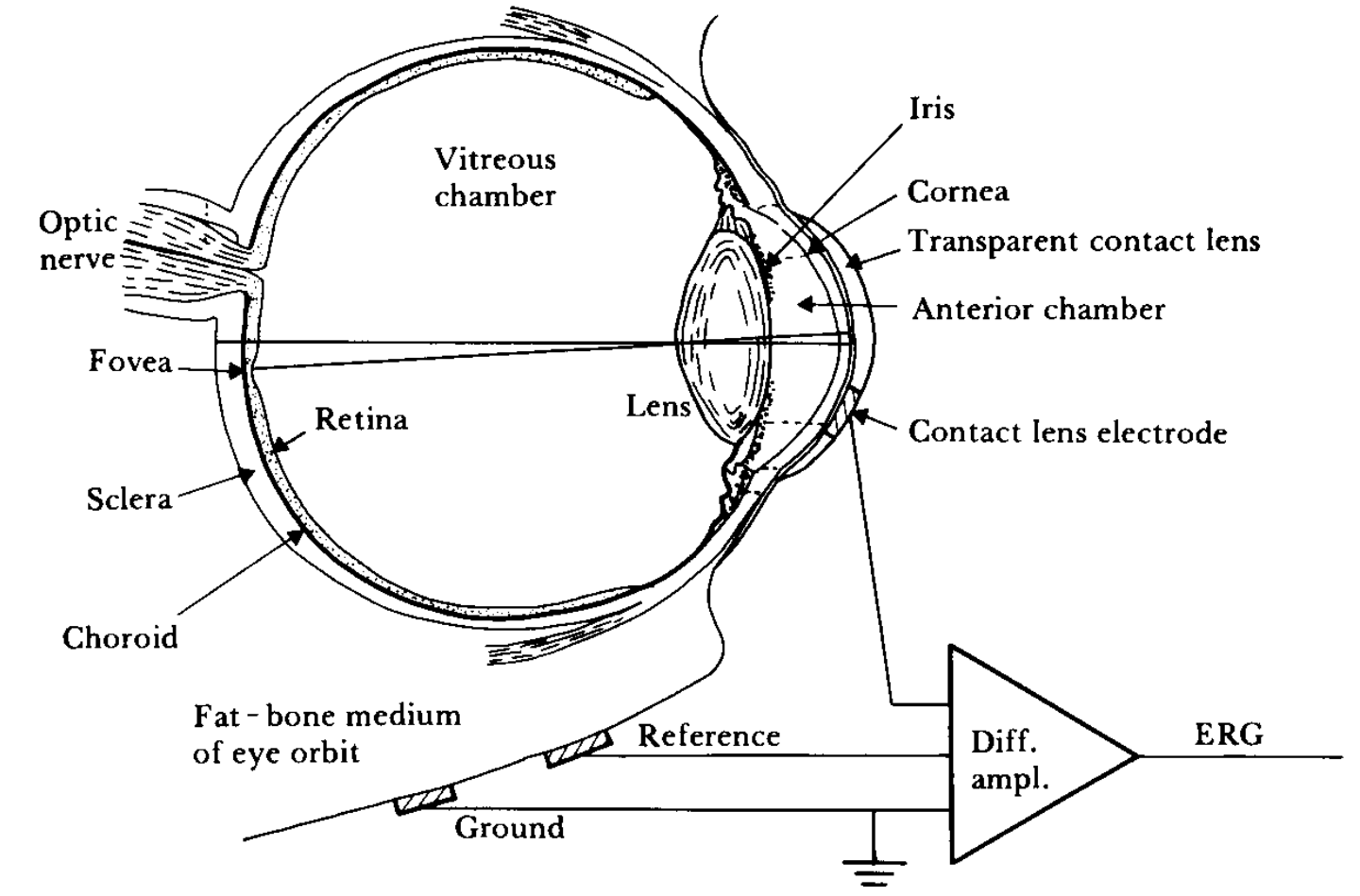



Figure shows an operation on median nerve repair and ulnar nerve repair

# ELECTRORETINOGRAM (ERG)

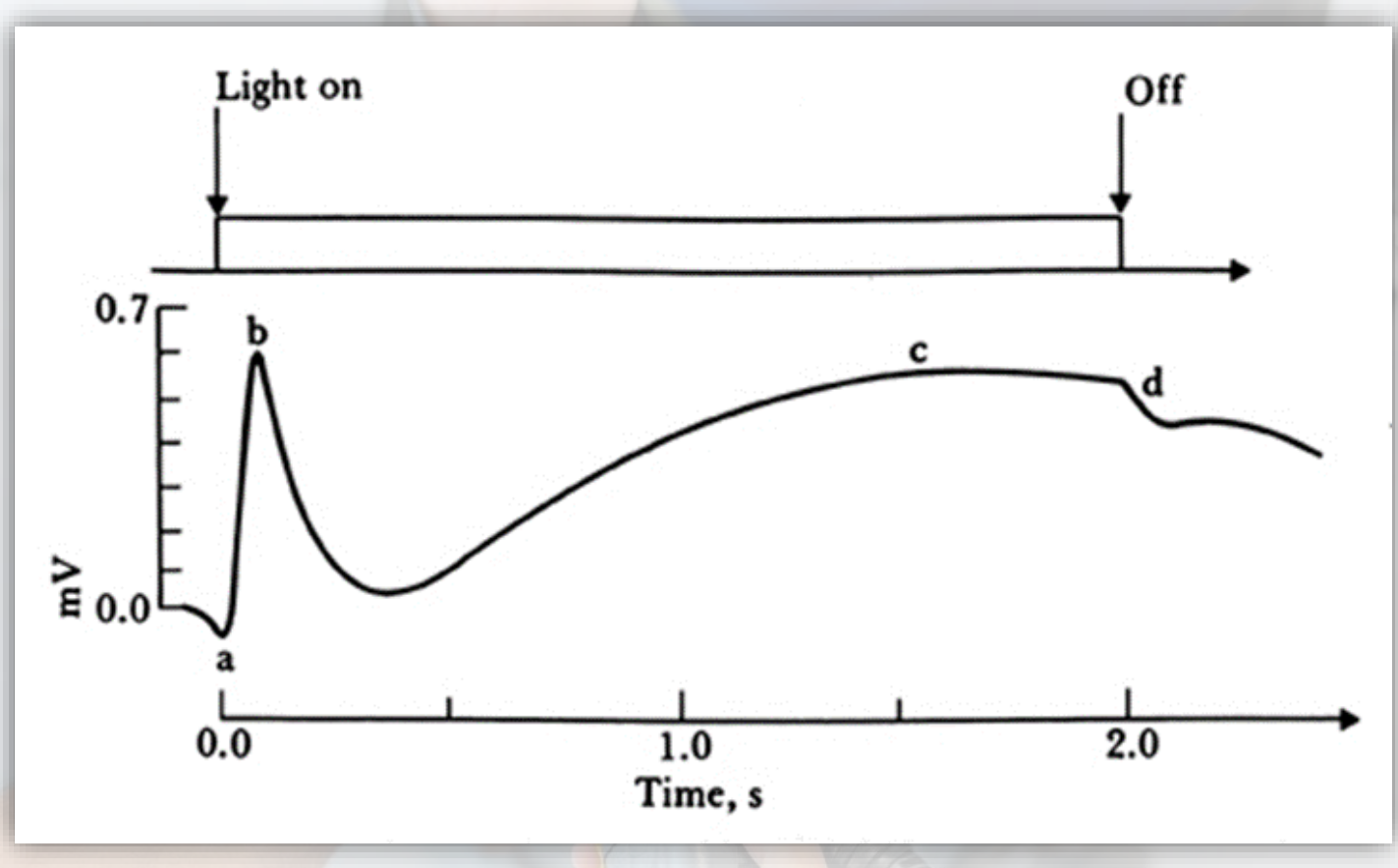


# ELECTRORETINOGRAM




ERG is a recording of the temporal sequence of changes in potential in the retina when stimulated with a brief flash of light.

A transparent contact lens contains one electrode and the reference electrode can be placed on the right temple

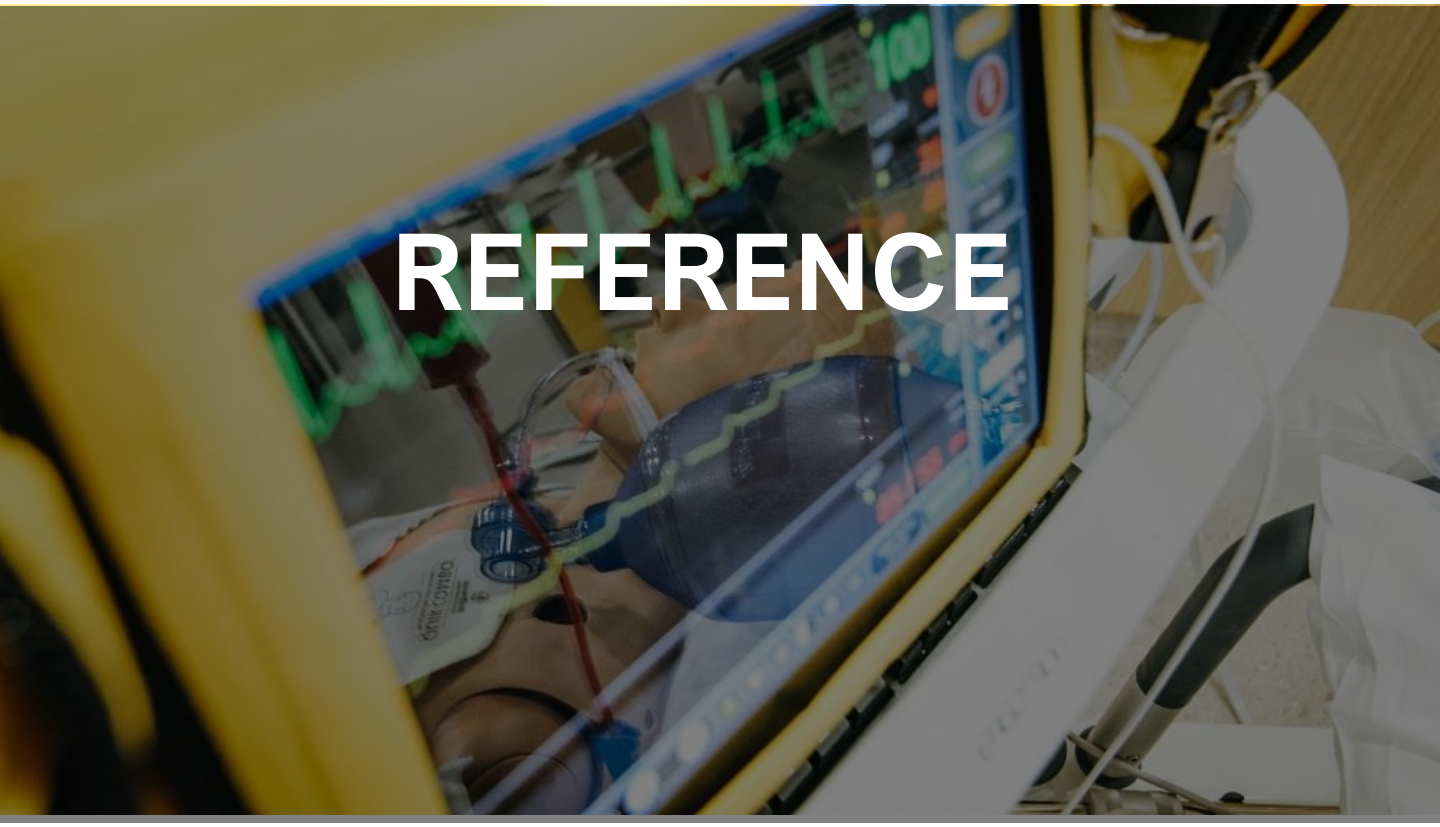



The **a-wave**, sometimes called the "late receptor potential," reflects the general physiological health of the photoreceptors in the outer retina. In contrast, the b-wave reflects the health of the inner layers of the retina, including the ON bipolar cells and the Muller cells (Miller and Dowling, 1970). Two other waveforms that are sometimes recorded in the clinic are the c-wave originating in the pigment epithelium (Marmor and Hock, 1982) and the d-wave indicating activity of the OFF bipolar cells

Some corneal ERG electrode

Burian speculum type electrodes

Cotton wick electrode



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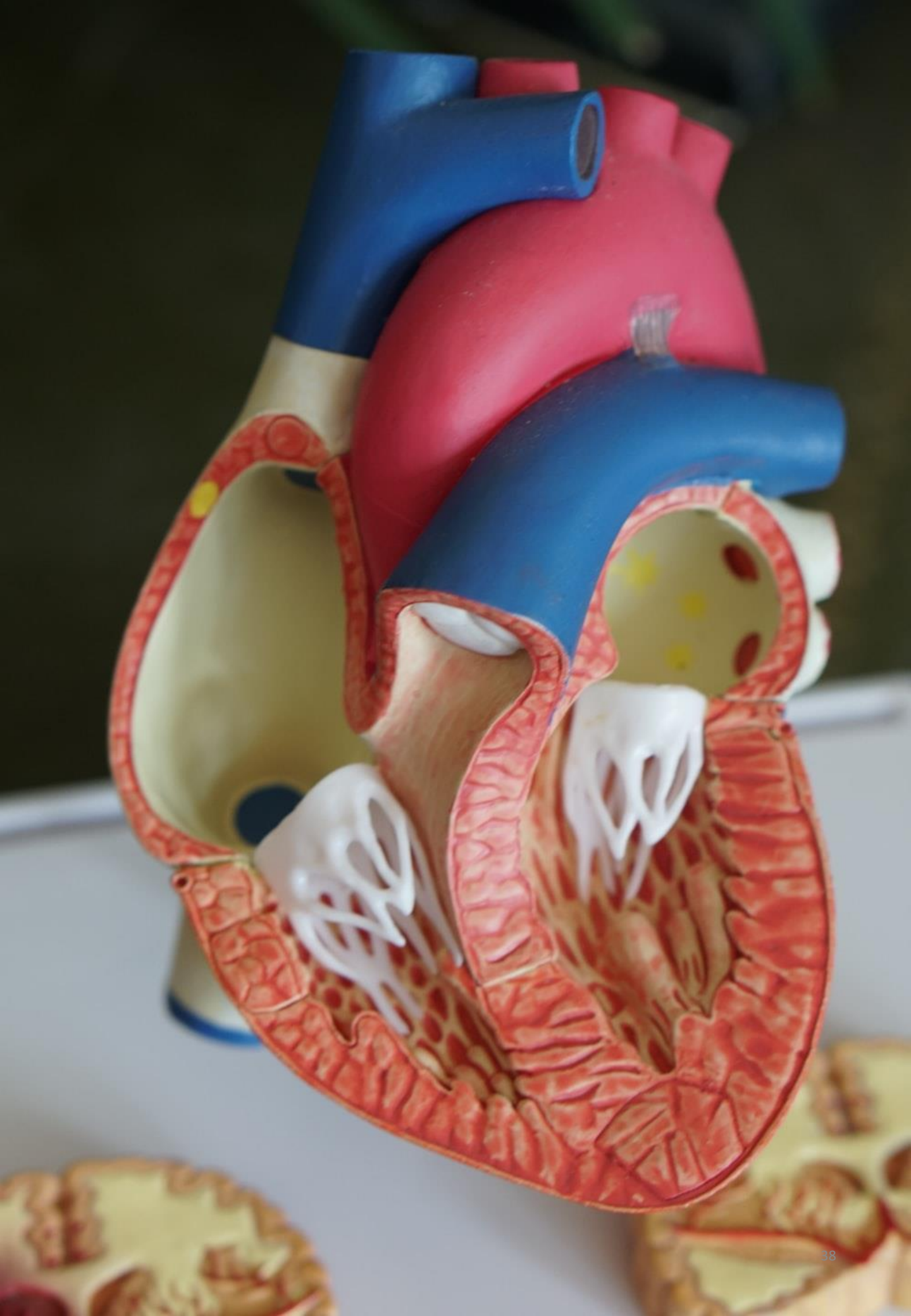

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