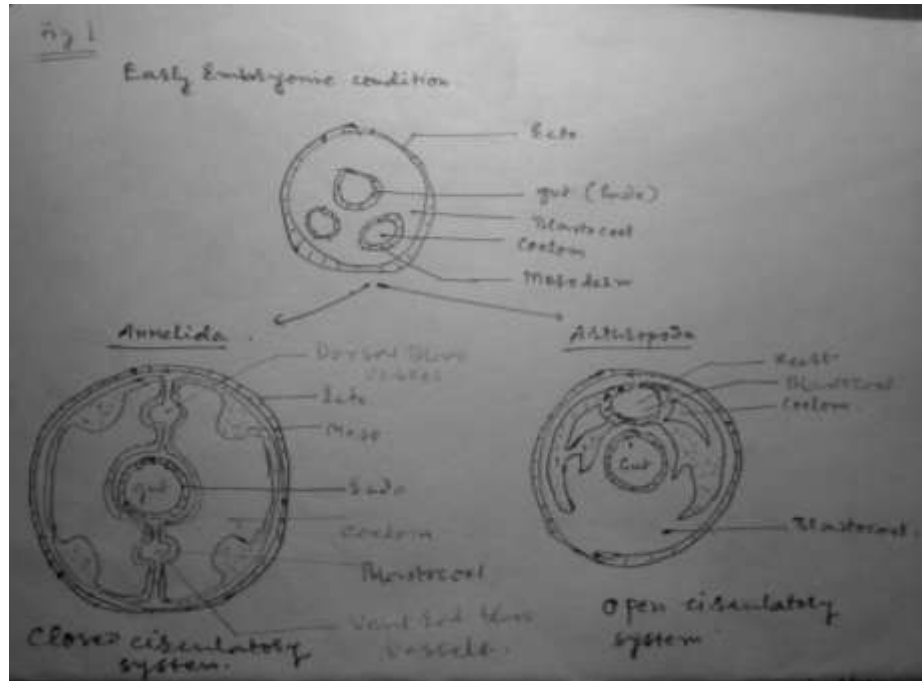


REGULATION OF BLOOD CIRCULATION

Embryologically the circulatory system develops from mesoderm or mesenchyme. Mesoderm cells when spread in the blastocoel, enclose the blastocoel in them thus forming blood vessels.



As shown in the figure--

In lower animals the blastocoel remains dominant. It is filled with body fluid. Vessels formed by mesoderm are few (usually the heart). Hence the circulatory system in these animals is of open type.

In higher animals the coelom grows more and become dominant as compared to blastocoel. Due to this growth of mesoderm and coelom the blastocoel gets trapped in many places in the mesoderm thus forming many blood vessels and a network of blood vessels. These blood vessels are filled with body fluid i.e. blood and thus a closed type of circulatory system is formed.

In open type of circulatory system the body fluid freely flows in the cavity however to facilitate proper circulation some pumping device is necessary which is either in form of tubular heart (Cockroach) or sac like heart (Crustaceans and daphnia). Tubular Heart act like suction pump. It sucks blood when it expands and then it pumps.

In closed type of circulatory system the blood vessels spread to distant tissues hence pumping of blood becomes essential and hence the heart has to be muscular but if the heart is muscular and thick walled it cannot accommodate more blood. To overcome this difficulty the heart initially evolved to become 2-chambered heart. The atrium being thin walled can accommodate more blood and ventricle being thick walled can pump the blood efficiently. The heart of closed circulatory system is pressure pump which pumps by force. This 2 chambered heart (sharks) later on in evolution became 3-chambered (amphibian) and then 4-chambered (Reptiles, birds, mammals).

Heart size – it varies from animal to animal and has correlation with the animal activity. For better comparison the heart size is given as percentage of body weight. In man heart is 0.43% of body weight in male is and 0.4% of body weight in females.

It is approx. 300 gms in male and is size of clinched first. The size depends on activity. An active animal like deer has heart 1% of body weight. In fishes the heart is smaller 0.2% of body weight. In amphibian is 0.46% of body weight. Reptiles 0.51% body weight and birds have the largest heart among vertebrates which 0.8% of body weight.

Heart rate --

In every animal heart rate is variable. It is faster in smaller animals than the larger.

Ex.

Mammals

Elephants and horses – 25 – 40 / min.

Dog – 80 / min.

Cat – 125 / min.

Rabbit – 200 / min.

Mouse – 300 – 500 / min.

Man – 72 / min.

Birds

Domest fowl – 150 – 300 / min.

Sparrow – 400-500 / min.

Humming bird – 500-600 / min.

Crustacea

Cray fish – 30-60 / min.

Ascellus – 180-200 / min.

Daphnia – 250-450 / min.

Heart rate depends on various factors

- i) Rest and exercise – At rest heart beat slowly, during exercise it is faster.
- ii) Locomotor activity increases heart rate
- iii) At low temperature heart rate is low and warm temperature heart rate is high.
- iv) Nervous excitement leads to adrenal secretion and raises the heart rate
- v) Sluggish animals have slow heart rate whereas active animals have faster heart rate.

Clam or bivalve is sluggish – the heart rate - 0.2 to 22 / min.

Octopus or Squid are active – 40-80 / min.

Tuna fishes have faster heart rate

Like wise during activity heart rate is faster.

Sphinx moth – At rest – 40-45 / min.

When Active – 110-140 / min.

In Bat, Normal rate is 250-440 / min.

Excite rate is 880 / min.

Diurnal Lethargy rate is 120-180 / min.

In some animals heart rate depends on pressure. At low pressure the heart rate is low and high blood pressure causes high heart rate.

e.g. In clam → Heart rate rises when foot contracts.

→ Heart rate decreases when foot extends.

In Poikilotherm, rise in temperature by 10⁰C rises heart rate 2-3 times.

Homeotherms have more heart rate than poikilotherm.

Oxygen level in blood affects the heart rate. Low oxygen level normally slows down heart rate.

Slower heart rate is known as Bradycardia

Faster heart rate – Tachycardia

Cardiac output

Cardiac output is the amount of blood pumped by heart / min.

C.O. = Blood pumped at each contraction X No. of Beats/min.

= Stroke volume X heart rate

Normally in man C.O. is 5.6 l/min. or 80 ml/kg/min.

For this oxygen estimations are made.

i) O₂ absorbed by lungs in ml/min.

ii) Arterial O₂ in ml/l.

iii) Venous O₂ in ml/l.

$$\text{C.O. (litres/min.)} = \frac{\text{O}_2 \text{ absorbed in lungs ml/min.}}{\text{Difference between Arterial and Venous O}_2 \text{ ml/l.}}$$

Ex. If arterial blood has O₂ 200 ml/l

venous blood has O₂ 160 ml/l

lungs have absorbed 200 ml/min. O₂

$$\begin{aligned} \text{C.O.} &= \frac{200}{200 - 160} \\ &= \frac{200}{40} \\ &= 5 \text{ litres/min.} \end{aligned}$$

In lower animals stroke volume is amount of blood pumped by single ventricle. In higher animals when two ventricles are there the stroke volume is amount of blood pumped by anyone ventricle.

Normally poikilotherms have relatively low C.O. Birds have relatively high C.O. In domestic birds it is 200-400 ml/kg/min. In the invertebrate the C.O. is very low. It is 1 ml/kg/min. in lobster. In some animals it is 17 ml/kg/min. whereas in fishes it is 5-100 ml/kg/min. During exercise C.O. rises due to a) rise in stroke volume b) rise in rate of heart beat.

In Octopus and lower invertebrates stroke volume rises and heart rate remains unchanged.

In mammals heart rate rises and stroke volume remain same.

Neurogenic and Myogenic hearts

In animals with open circulatory system the heart is usually sac-like or tubular. It has ostia or lateral openings which get closed when heart contracts and opens when heart relaxes. When heart relaxes vacuum is created to suck blood in the heart. Hence these hearts are known as suction pumps. In higher animals with closed circulatory system 2, 3 or 4 chambered hearts are seen with muscular ventricles which pumps the blood in the body with pressure and hence heart are known as pressure pumps. In most of the suction pump hearts the beating rhythm is set through nerve impulses. Such hearts are known as Neurogenic hearts.

Whereas mostly in pressure pump heart the rhythm is set in specialised muscle cells within the heart. They are known as Myogenic hearts.

Most of the embryonic hearts are myogenic which later on may become myogenic or neurogenic.

Myogenic heart and their pacemakers –

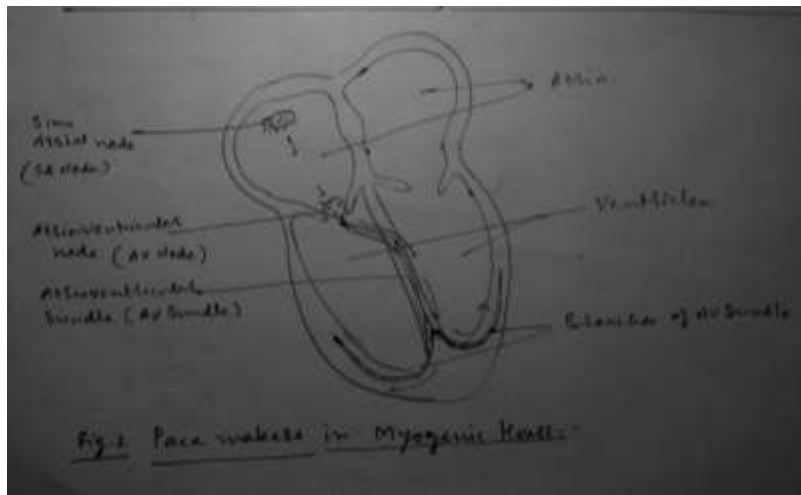
In some invertebrates and all vertebrates the heart is myogenic. In them the setting of the rhythm (pacemaking) is by specialized cells (pacemakers). These cells are highly specialized for generating and conducting the impulse. In some animals they can be distinguished histologically from the other heart muscles whereas in some others the distinction is not clear.

| | | |
|----------------|---|---|
| e.g. In Snakes | } | |
| Turtles | } | |
| Bat | } | Pace maker cells cannot be distinguished i.e. the distinction |
| Rat | } | |
| Guinea pig | } | between pacemakers and other cells is not clear. |
| Rabbit | } | |
| Humming bird | } | |
| Chick | } | |
| Platypus | } | |
| Anteater | } | Specialized cells can be distinguished or differentiated. |
| Sheep | } | |
| Cow | } | |
| Pig etc. | } | |

The pacemaking regions are different from animal to animal.

- 1) In Teleost cells of floor of atrium and auriculo-ventricular junction act as pacemaker.
- 2) In elasmobranch fishes sinus venosus, auriculoventricular junction and truncus arteriosus act as pacemaker.
- 3) In amphibians and reptiles sinus venosus act as pacemakers
- 4) In mammals and birds sinoatrial and auriculoventricular nodes act as pacemakers.
- 5) In invertebrates the pace making area is wandering i.e. changing place.

In birds and mammals as mentioned above pacemaking impulse arises in sino-atrial node (S.A. node). It is a small mass in right atrium. (In man 2 cm x 2cm) It is situated near entrance of vein. Atrio-ventricular node (A.V. node) is situated near auriculoventricular junction from which the impulse is carried to ventricle by specialised conducting muscles forming auriculoventricular bundle (AV bundle) or Bundle of 'His' i.e. bundle of God.

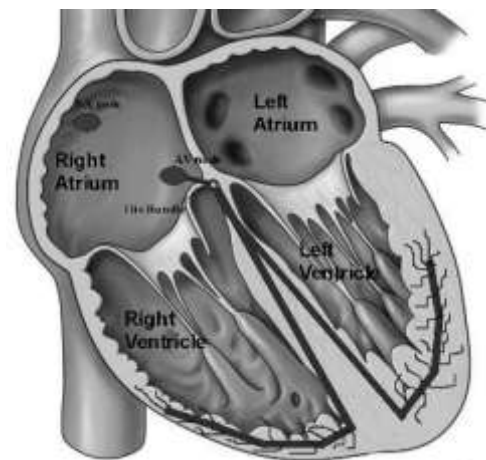


In birds bundle of His forms a network in atria.

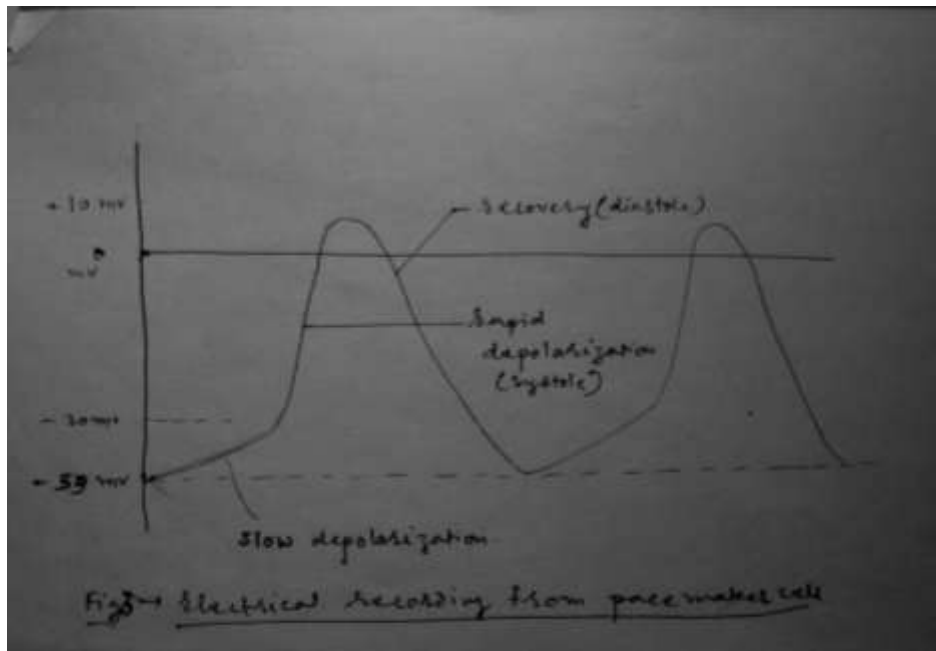
The diagram below shows pacemakers in myogenic heart.

S.A. node is known to be true pacemaker. If it is surgically manipulated or given temperature, chemical or electrical stimuli, it affects cardiac activity, thus the wave of heart action starts from this point. The wave is picked up by A.V. node situated in right atrium near AV septum and then spreads into ventricle through the branches of auricular-ventricular bundles which forms a network in ventricle.

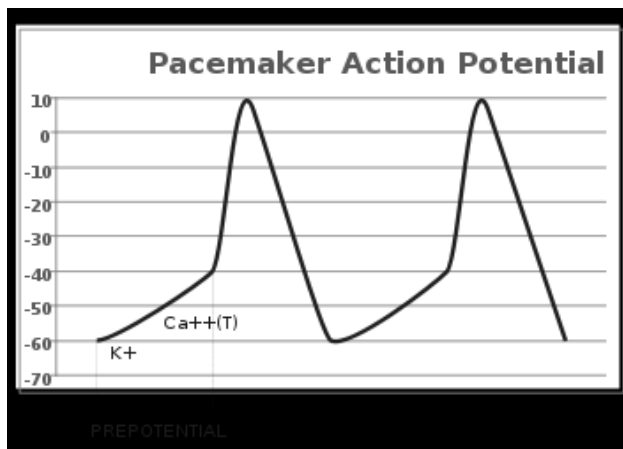
(Purkinje fibres) In birds network is present in right and left atria as well. AV bundle tissue is highly specialized in conductance and hence spreads the impulse very fast.



In myogenic heart in fact all cells have ability to set the rhythm. But certain cells are more specialized. The difference in them and other cells is they are highly unstable and have changing electrical potential. These cells are known as pacemaker cells. According to Kollikar and Miller heart have 3 type of cells 1) Pacemaker muscle cell 2) Conductive muscle cell 3) Contracting muscle cells



Pacemaker cells initially have inside negative as compared to outside and have a charge or potential of about -55 mV. This charge is unstable there is a slow leakage up to -30 mV which is known as slow depolarization. This is followed by rapid depolarization up to $+10$ mV. This depolarization causes contraction of muscles. The depolarization is followed by repolarisation which causes relaxation or diastole.



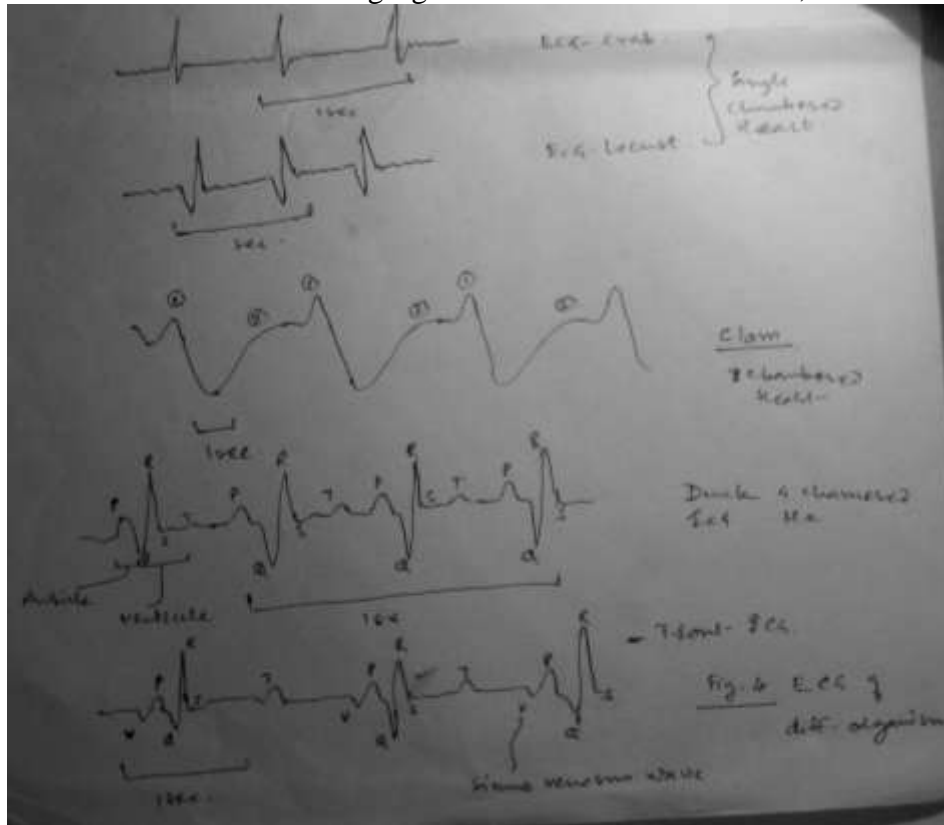
This way the charges on pacemaker cells keep on changing constantly. These changes in the form of depolarisation and repolarisation spread in the heart muscle through conducting cells causing rhythmic contraction and relaxation of heart.

ECG (Electro Cardio Gram)

When heart muscles together contract or relax it leads to change in electrical potential on the body surface near the heart and also gets carried all over the body. By some sensitive equipment the electrical potential can be recorded graphically which is known as electro cardiogram. In an ECG normally upward movement of line represents depolarisation and downward movement represents repolarisation.

However in different animals different types of heart are there such as two-chambered, 3- chambered and 4-chambered and in the heart auricles are thin walled and less muscular whereas ventricles are thick walled and more muscular.

As the electrical wave begins in auricle, the auricle contracts first followed by contraction of ventricle. The auricular contraction usually produces a weak electrical wave on the body surface and ventricular contraction produces a strong electrical wave on the body surface. Hence in ECG the auricular wave is smaller and the ventricular wave is bigger. However many times due to the difference in recording method different types of ECG are obtained. Following figures shows some of the ECG,



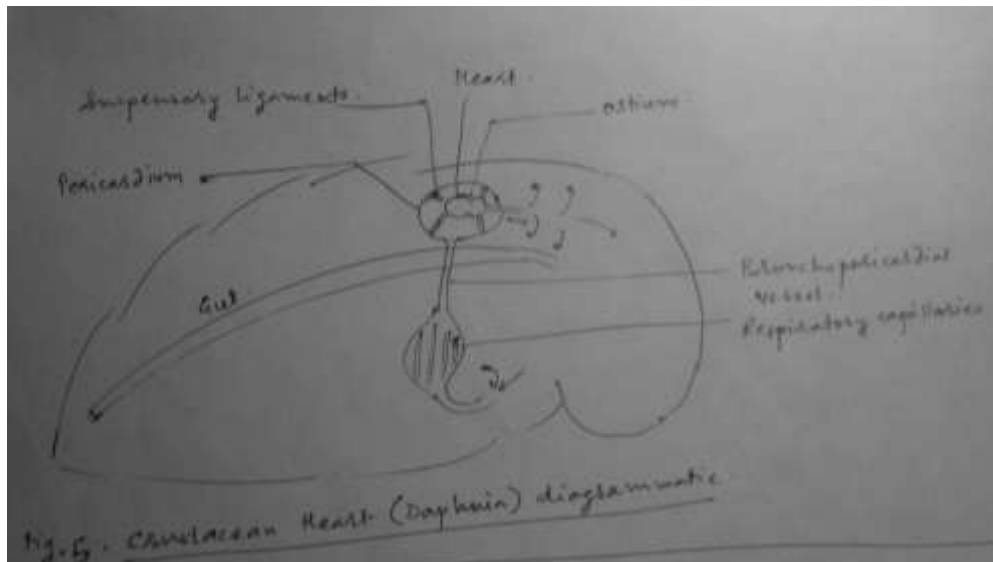
Auricular (Artial) wave is small denoted by P. Ventricular wave is bigger in magnitude denoted by QRS. Repolarisation wave is small denoted by T. Some examples shown below :-

In animals where sinus venoses is present its additional wave is some seen as v-wave.

Neurogenic heart

As mentioned earlier the neurogenic heart are normally present in invertebrates with open circulatory system. The hearts are either sac like or tubular with lateral ostia. This heart when relaxed produce vaccum due to which the haemolymph is sucked in and then pumped. Hence these hearts are known as suction pump.

Ex. Daphnia heart.

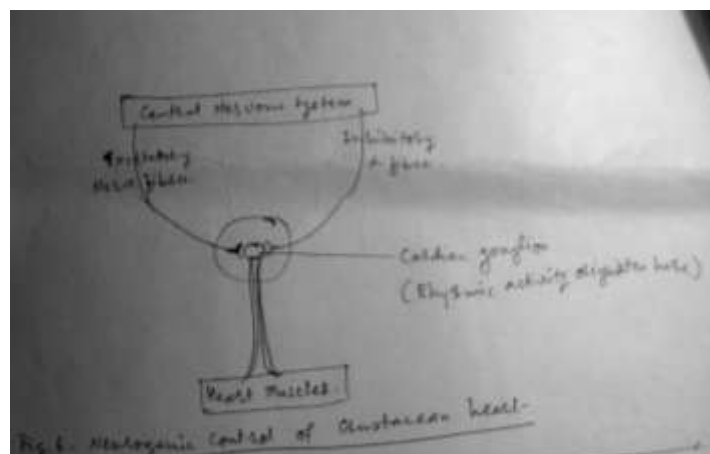


In neurogenic heart there are nerve fibres innervating in heart. They fire electrical impulses causing rhythmic beating of heart. The nerve cells innervating the heart come together to form a ganglion near the heart known as cardiac or heart ganglion.

The ganglion may be one or more. 1st ganglion studied was by Thomson 1904 in Limulus which has series of ganglia on dorsal side of heart. Carlson proved that

- i) If heart ganglia are damaged heart beat stop
- ii) If temperature of ganglia is changed it alters the rate of heart beat
- iii) If the nerves from CNS to ganglia are stimulated by chemical, electrical or temperature impulses.
- iv) Thus it proves that the cardiac ganglia is under control of CNS

The CNS sends excitatory and inhibitory neurons to cardiac ganglion. The system is represented below diagrammatically.

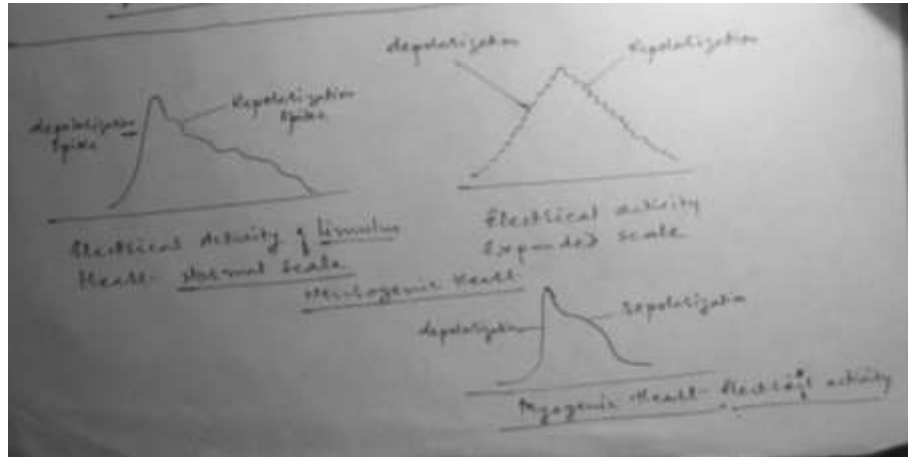


Lobster cardiac ganglion has 9 cells. Squilla cardiac ganglion has 16 cells.

In some organisms heart muscles are innervated by neurons from own segment ganglion and in some there is additional innervation from the distant segment ganglion. Such organisms have more than one cardiac ganglion.

The transmitter substances in neuron vary greatly. It has been found that glutamate stimulates GABA inhibits. Acetylcholine excites crustacean heart but very high concentration is required.

In neurogenic heart also the contraction and relaxation is by change in electrical potential. Depolarisation causes contraction and repolarisation causes relaxation. The ECG recording shows the graph as below



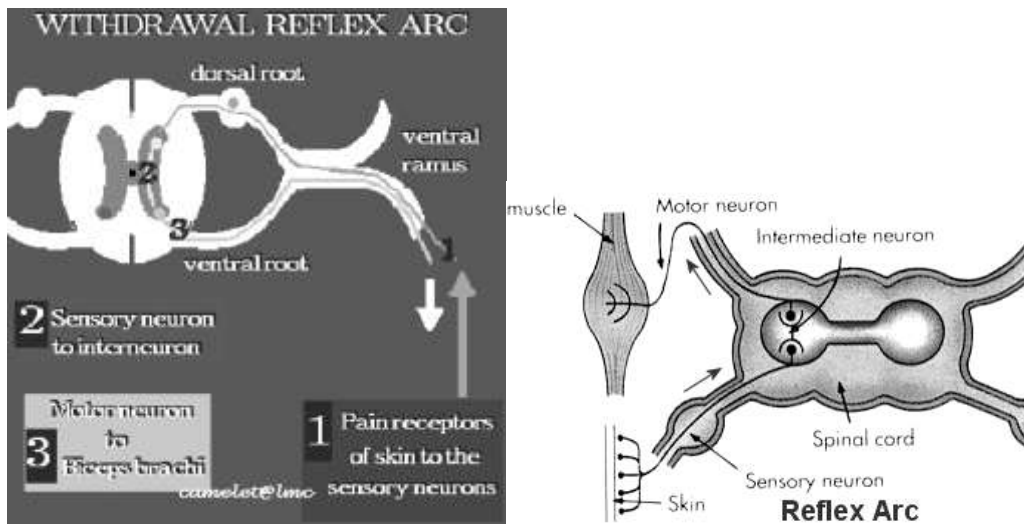
As shown the depolarisation spike looks smooth in short time scale. Whereas when it is observed in expanded time scale it looks as if made up of many small depolarisation spikes.

This is because depolarisation is caused by many small depolarisation impulses sent by pacemaker neurons.

Nervous and chemical regulation heart –

Myogenic heart when separated out from the body keep on beating on their own but when in the body the rate of heart beat is modified through various stimuli such as nervous and chemical stimuli. The main structure that regulates the heart beat is medulla oblongata. It has 3 types of reflexes cardiac reflex centre, Respiratory reflex centres, vasoconstrictor reflex centres.

In cardiac reflex centres there are 2 types of area in medulla oblongata which are diagrammatically represented below I) Activator area causing action ii) Inhibition area causing inhibition.



As shown in figure: in the activator and inhibitor area there are interneurons. The excitatory or inhibitory stimuli go to the corresponding areas from where motor stimuli causing excitation or inhibition are sent to the heart, through motor neurons or effector neurons. The motor neurons either bring about the change directly or through pacemakers. The cardiac reflex centres respond to various signals from cerebral hemispheres. In medulla oblongata there are also chemo receptors sensitive to blood O_2 , blood CO_2 and pH which directly affect the cardiac reflex centre.

In the invertebrates with open circulatory system the heart is under control of cardiac ganglion which is governed by excitatory and inhibitory neurons from CNS.

Chemical control

There are various chemical substances affecting heart rate. As mentioned earlier dissolved O_2 in blood, CO_2 in blood and pH of blood affect the chemo receptors in medulla oblongata affect heart beat. They also have direct effect on heart beat.

Low O_2 stimulates Heart beat

Very low O_2 inhibits Heart beat

And prolonged low O_2 causes heart failure.

High CO_2 causes inhibition of heart beat.

Low blood CO_2 causes excitation.

Optimum pH should be 7.4 and acidic pH causes relaxation of heart and reduces strength of contraction.

Transmitter substances and hormones

Mainly Acetylcholine is secreted by parasympathetic pathway and causes inhibition heart. NE/E - Noradrenaline/Adrenaline are secreted by sympathetic pathways and cause excitation of heart rate. Adrenaline secreted by Adrenal makes the heart beat stronger and faster.

Thyroxine secreted by thyroid increases the rate of heart beat.

→ Inorganic ions -- in which K, Na and Ca are very important. If K is in excess it causes relaxation of heart and very high 'K' stops the heart in relaxed condition or flaccid condition.

Effect is called as K-inhibition.

When vagus nerve is stimulated it secretes high 'K' on heart muscles, causing inhibition. If Vagus nerve is stimulated for long time then the heart, which is inhibited, again starts functioning. This phenomenon is known as vagus escape.

→ Excess 'Na' causes relaxation of heart muscles but this is due to antagonistic effect or action with calcium. When 'Na' excess it competes with 'Ca' so 'Ca' availability reduces and 'Ca' essential for contraction.

→ 'Ca' is important mainly for contraction of heart but its excess causes sudden contraction of heart but it stops in contracted state known as 'Ca' rigour. As scientist mae Ringer's solution which balance of Na, K, Ca.

Drugs

- i) Digitalis – increases strength of heart muscles and accelerates heart rate. Used as drug for low B.P. and very high concentration can stop heart.
- ii) Atropin – is a stimulatory drug which accelerates the heart rate by suppressing Acetylcholine and binding with 'K' ions, hence used as antidote against toxic effect many poisonous substances.
- iii) Muscarin, Eserine, Pilocarpine cause inhibition of heart rate by mimicking Acetylcholine. Most of these were used as arrow poison to kill the animals and now –a-days also used as drug.
- iv) Nicotine initially inhibits the heart rate and later on excites the heart rate.

THE BARORECEPTOR REFLEX

The Reflex Control of Blood Pressure

