ANIMAL PHYSIOLOGY II

Lecture I

Thermal Relations

Temperature is important for –
- denature enzymes / affect metabolic pathways
- diffusion of molecules
- viscosity of membrane

Ectotherm : body T is close to external temperature low metabolic heat, so thermoregulation by behavioral adaptations.

Endotherm : high metabolic heat to maintain constant body T using autonomic and behavioural mechanisms.
Have greater range but it comes at a cost – large portion of food is used for thermoregulation.

Poikilotherm – body T changes with environmental temperature it refers to variability of body temperatures, while ectothermy emphasizes that outside conditions determine body T.
Poikilothermy is most common type of thermal relation.

Eurythermal
Can function over wide range of body temperatures

Stenothermal
Have comparitively low range If body T changes too much, metabolic rate is influenced.

Acute response : metabolic rate is an approximately exponential function of body T
In Zebrafish, rise in T from 27°C to 31°C increases O_2 consumption by two-fold

Eg: Oxygen consumption in tiger moth doubles with every 10° rise in T.

Q_{10} effect : Metabolic processes are very sensitive
Rates of enzyme-mediated reactions increase 2-3 fold for every 10°C ΔT

Q_{10} is the measure of temperature sensitivity of enzymatic reaction rate due to ΔT 10°C
Most Q_{10} value are around 2.

Behavioural thermoregulation

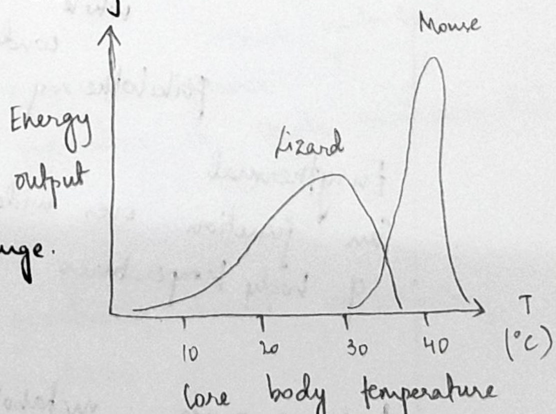
Ectotherms produce low metabolic heat and lose it quickly because they're not well-insulated.
But high thermal conductance allows them to absorb T heat readily from surroundings.
So principal means of thermoregulation is behavioural
Eg. lizard moves around cage, closer to & away from heat source to maintain body T

Behavioural mechanisms -

* burrowing
* seeking shade
* position-orientation
* sun-basking
* climbing vegetation

Heart rate of marine iguana increases during heating and decreases during cooling

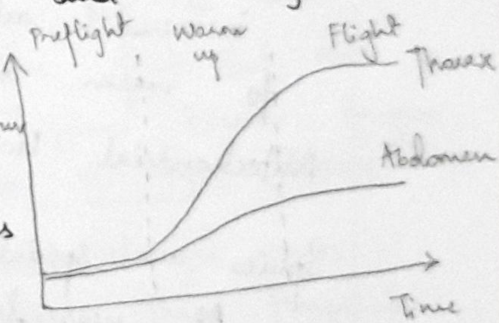
Homeotherms have higher energy output, over a narrow range. But poikilotherms have lower output over a wider range.



Consequences for poikilotherms –

- Poikilotherms may have 4-10 different enzymes that operate at different temperatures, for an important reaction.
  So they have larger, more complex genomes, as compared to homeotherms in same niche.
- Because there metabolism is variable, and generally low, sustained high energy activity, like flying or maintaining a large brain is outside their capacity
- Their metabolism favors sit-and-wait hunting over chasing prey.
- For same body weight, poikilotherms need only 5-10% of energy

Heterothermy
Physiological term for animals that vary between self-regulating their body T and allowing surrounding T to affect it.



Hawk moth body T

→ Acclimatization
Overall change that an animal undergoes in its natural setting
??

→ Acclimation
Specific physiological changes that occurs over time in lab in response to variation in single environmental condition

→ Adaptation
Should be reserved for genetically based evolutionary changes over many generations.

↓ ↑ LDH activity reflects capacity for anaerobic energy

(04)

Chronic response

?? acclimation often blunts metabolic responses to temperature.

Lizards acclimated to cooler ambient temperature have higher average metabolic rate at any given T, as compared to warm-acclimated lizards

Enzymatic changes during acclimation

Most common & crucial response is that cells modify their rate-limiting enzymes, those involved in Krebs cycle and electron transport chain.

During acclimation to cold T, greater amounts of these enzymes are synthesized.

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Lecture 2

In the lower acclimated animals, to increase metabolic efficiency, the amount of respiratory enzymes of the cell increases

Cold acclimated fish have more mitochondria and increased activity of cytochrome oxidase as compared to warm acclimated fish.

Mitochondrial biogenesis paper.

Species are specialised to live at their respective body T - w

At near freezing tissue T, protein synthesis is greater in polar fish/species liver as compared to temperate species. Also, muscles work better at polar T

Eg. Antarctic toothfish (-2°C)
Soldierfish (15°C)
Cow (25°C)
} Comparing crystallin, which is a protein found in lens and cornea

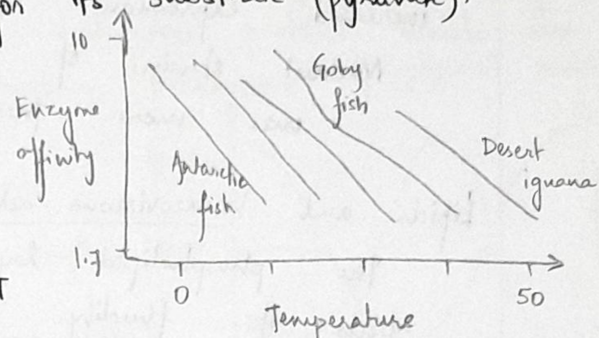
When kept at 0°C for 1.5-2 days, lens of latter two becomes opaque, but not that of the antarctic toothfish.
↓ cold cataract

Level of LDH activity reflects capacity for anaerobic energy production & level of resistance to hypoxia

→ Comparative study of Lactate dehydrogenase (LDH)

Look at affinity of LDH for its substrate (pyruvate).

Pyruvate —LDH, anaerobic→ Lactate.



The optimum temperature for enzyme efficiency increases as the ambient T of adapted species increases.

The enzyme differs only by 4 out of 330 amino acids among species (the substrate binding sequence is conserved)

This is true for a lot of proteins.

→ Protein isoforms change during acclimation and acclimatization

Cyprinus carpio

Common carp (Carassius auratus) → Gold fish has a very wide range.

When fish from warm water are put in cold water, they initially cannot swim fast. But over several weeks, they improve. This happens because ~~they're~~ there's a change in isoform of myosin heavy chain.

They also get cues from photoperiod changes across period — its ~~po~~ more dependable than temperature.

Heat shock proteins

Heat shock response is mediated by heat shock Tx factor HSF1 which is monomeric usually, but trimerizes when the cell is stressed and bind to promoters of heat shock genes.

Its a universal homeostatic autonomous reaction of the cell.

HSPs and chaperonin play an important role in protein folding.

Read about HSPs!

HSPs are important for folding and preservation of proteins.

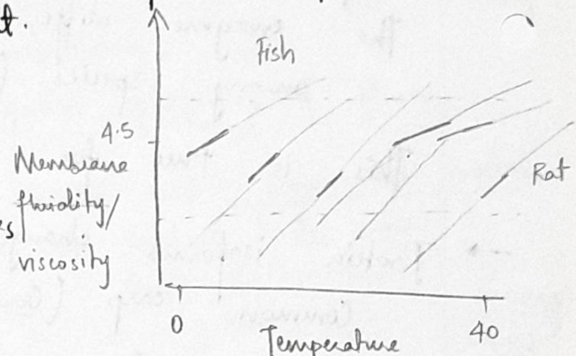
Eg: Comparing Marine (T. funebralis) and intertidal (T. brunnea) snails' HSPs

Intertidal snail faces more heat stress and we see increased expression of HSP70 in them.

Mutant strain of drosophila (with 12 extra copies of HSP) was more thermotolerant than other strains.

Lipids and <u>homeoviscous adaptation</u>

The phospholipid layer is semi-fluid and temperature affects its fluidity. The composition of cell membrane is adjusted so that the fluidity of membrane is more or less constant.



Viscosity is maintained at same level across species living at different temperatures

Acclimated to cold climate

More acclimated to warm climate

Unsaturated ⇒ kinks ⇒ lesser tight packing → decreases melting point → increases fluid

Restructuring cell membrane composition with saturated/ unsaturated phospholipids helps the animal acclimate while keeping the viscosity the same.

Usually this may take weeks, but it happens in a day, everyday, in fish that live in desert pond.

Ectotherms in cold & freezing environments

They need to make sure that they don't freeze when they're living in ~~anti~~ freezing conditions.

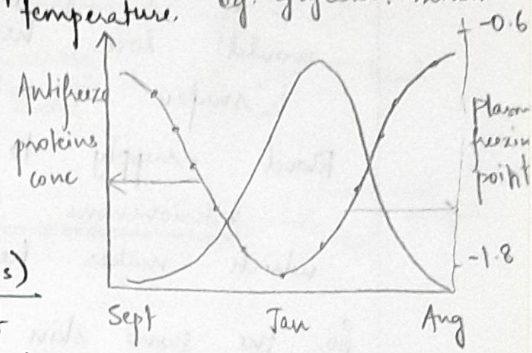
If ice crystals form in cells, the crystals grow and rupture the cell.

Some poikilotherms spend the winter at the bottom of the lake, which doesn't freeze

Thermal hysteresis — freezing point < melting point

Animals have compounds like glycerol which decreases the freezing ~~polo~~ point. → colligative antifreezers

Polar animals also have antifreeze proteins which also lowers the plasma freezing temperature. eg. glycerol, sorbitol



Eg: Winter flounders (fish)

The liver secretes AFPs according to a circannual rhythm

AFPs & ice structuring proteins (ISPs) bind to ice crystals and prevent it from growing or recrystallising, thereby increasing (?) non-colligative properties of plasma.

AFPs are glycoproteins that binds and covers ice crystals so it doesn't come in contact with the rest of the plasma. 1/300th to 1/500th of ISP are enough as compared to colligative AFPs

Lecture 3

Thermoregulation in endotherms

The core T of endotherms is maintained almost at a constant (birds - 39-40°C). Losing control of this can be very bad.

This came with tradeoff — losing thermotolerance (wide range) for better performance at optimal range.

We've the same skin to insulate when cold and radiate when it's too hot.

> 42°C : protein denatured, impaired DNA synthesis
< 27°C : neuromuscular, cardiovascular changes — fatal

Evaporation

Helps the body tolerate high T. We always lose 'some' water — this is called insensible evaporation. ~700ml

Sweating actually helps in cooling body & this is regulated by sympathetic system.

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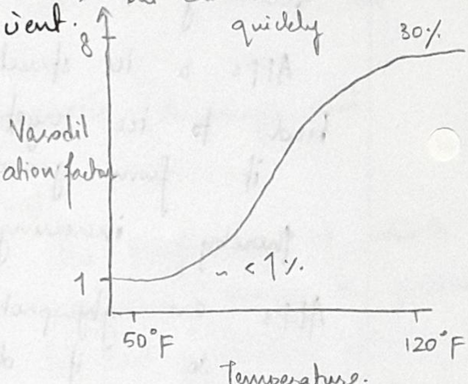
Adipose tissue helps in insulating the body — the conduction of heat through fat is 1/3rd that of dermis. In arctic animals, the fat layer is very thick & it's called blubber.

Blood flows to the skin from the core to transfer heat to the periphery. But if it's too cold, the blood would lose heat completely, so blood flow to the surface is stopped. (skin can survive w/ v. low O_2)

Blood supply to subcutaneous tissue is through arteriovenous anastomosis (direct connection without capillaries) → but can also be reduced quickly
which makes heat transfer efficient.



So, the same skin helps us survive in wide range of temperatures by changing vasodilation of blood vessels

Preganglionic SNS, PNS — ACh

Constriction : NE
Vasodilation : ACh

Postganglionic sympathetic NS releases norepinephrine at the peripheral blood vessels, which triggers adrenergic receptors and makes the vessels constrict.

As ambient T increases, an endotherm should stop producing heat and start sweating through eccrine glands. They're stimulated by postganglionic Sympathetic NS which releases Acetyl choline here [EXCEPTION!]

Sweat glands have muscarinic receptors which when activated stimulate the gland to —

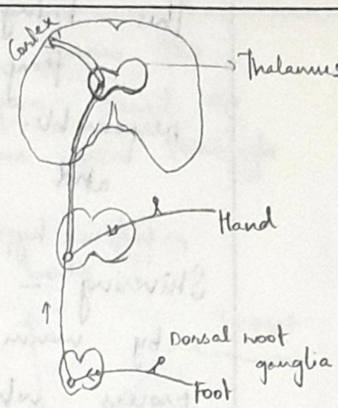
a) secrete sweat
b) secrete bradykinin — which acts on blood vessels and vasodilates.
c) decrease in heat production, sweating, vasodilation

When cold —

1) Vasoconstriction
2) Piloerection — hair standing on its end, this insulates the body in animals with fur
3) Thermogenesis.

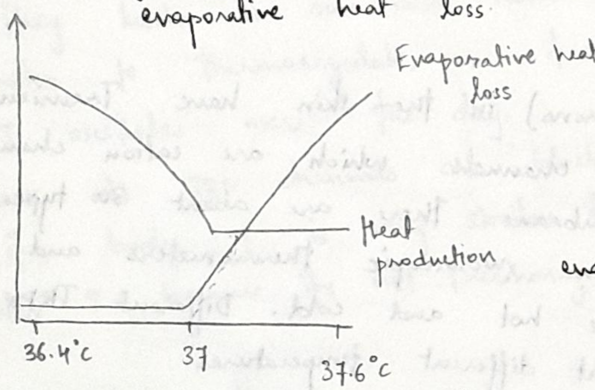
The information about heat goes through sensory nerves along

Dorsal root ganglia, synapses on spinal column, goes to thalamus via medulla oblongata, & 3rd order neurons go to the cortex, which processes the information and instructs body what to do.



The same pathway is followed in pain reception as well

Effect of hypothalamic T on thermogenesis (shivering) and evaporative heat loss.



The temperature at which minimum energy is present (in heat production & evaporation) is called the thermoneutral point.

A nude person can maintain their body T in dry air for ΔT b/w 70° to 150°F.

<u>Anterior hypothalamic</u> (preoptic) area in thermostatic detection

Neurons in this area — some are sensitive to heat and some to cold. These neurons fire 2-10 times faster when temperature increases.

When T of hypothalamus is increased in a rabbit and lower the room T, the rabbit still shows evaporative cooling & so on. Hypothalamus dominates the response because it has more <u>autonomic connections</u>.

Tan et al 2016 — describes warm-sensitive and cold-sensitive neurons in the brain of a rat.

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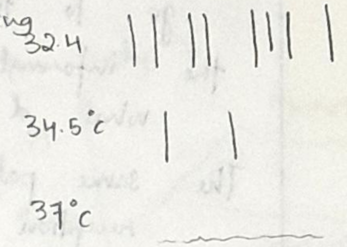
When we cool / heat the hypothalamus, the metabolic rate increases / decreases in response.

This brings us to the concept of set-point for temperature control. But we don't know the circuitry responsible. For instance, what happens when we have fever and it seems that set point is increased to 39°c.

→ posterior hypothalamus; 1° motor center for shivering

Shivering – it's a response to hypothermia by warm blooded animals. It is a process where skeletal muscles around vital organs start contracting irregularly to generate heat to maintain homeostasis.



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Thermoreceptors (neurons) in the skin have Transient Receptor Potential (TRP) channels which are cation channels in plasma membrane. There are about 30 types of TRPs which act as microscopic thermometers and used in animals to sense hot and cold. Different TRPs are activated at different temperatures.

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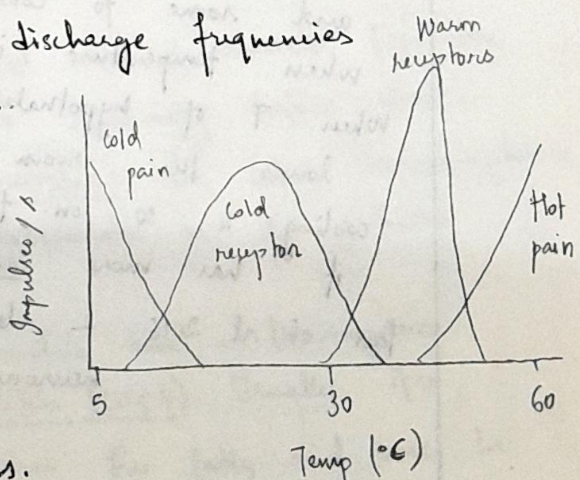
Lecture 4

TRP channels are found in a lot of places and also react to sensation of pain, different tastes, pressures & vision. They're activated by capsiacin, peppers etc.

Different TRP channels have discharge frequencies at different temperatures.



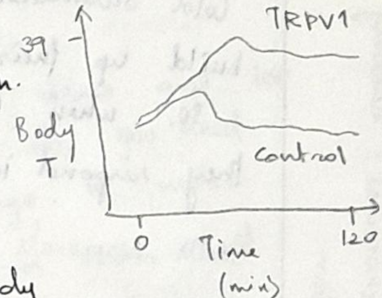
Cold TRP receptors are activated by mint, menthol etc.

TRP channels are made of 4 subunits, each of which have 6 transmembrane domains.

Too cold → NE ⇒ BAT —Lipase→ triglyceride ⟶ glycerol + fatty acid

The loop of transmembrane unit ~~allow~~ forms the hole through which cations can pass. Based on temperature & amino acids, certain cations pass through and activates the channel.

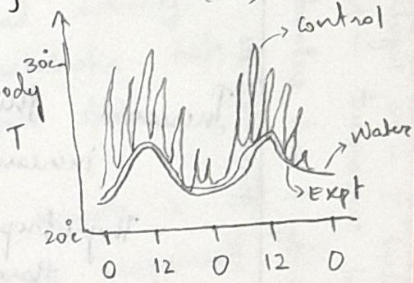
If TRPV1 (warm receptor) is blocked, the body T of the rat increases because it doesn't think there's enough warmth.



Thermoregulation in crocodile

They bask in sun and return to water to thermoregulate, so it's body T oscillates over the day.

When all TRP channels are blocked, it's body T is very similar to water T, because it's not thermoregulating.



Brown adipose tissue

Newborn babies, infants and children experience greater net heat loss, as compared to adults. But when cold, infants cannot shiver, because it takes a while to develop. So, infants have BAT, which has a lot of mitochondria and vascularisation. And this recedes with age.

This tissue is actually modified skeletal muscle. Especially small animals build BAT seasonally before winter.

These cells have β-adrenegic receptors. So, when norepinephine activates the receptor, triglycerides in fat globules are broken down.

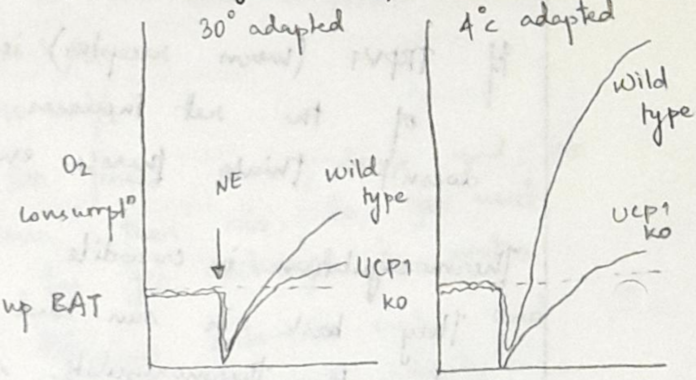
The ~~outer~~ inner membrane of mitochondria has a thermogenic protein called Uncoupling protein (UCP1). Usually, it's blocked by ATP molecules. When free fatty acid conc. in the cell increases, and ATP unbinds from UCP and free fatty acid enters mitochondria. This leads to respiration in mitochondria uncoupled from ATP synthesis, so this just produces heat!

This protein is only found in mitochondria of BAT.

Effect of cold acclimation on thermogenic response to NE

Cold acclimated animals build up their BAT, so, when NE is given, they respond immediately.

Small mammals also build up BAT



Increased thyroxine output as long term cause of increased heat production

Thyrotropin Releasing Hormone (TRH) [Hypothalamus] ⟶ Thyroid stimulating hormone [Anterior pituitary] ⟶ T3 / T4 [Thyroid]

Cold acclimation occurs by increasing TRH secretion, which ultimately increasing thyroxine secretion.

This happens over several weeks.

Thyroid glands increase in size by 20-40%

Behavioural Control of Body Temperature

Fever

It's a body temperature above the normal range and it's caused by toxins or abnormalities.

Causes - bacterial disease, brain tumor, environmental factors

Breakdown product of proteins and some toxins, like lipopolysaccharide toxins can alter the set point of hypothalamus to be higher. Such substances are called pyrogens.

Thermoneutral zone → metabolic rate independent of ambient T – no regulatory changes

Heterothermy in Alaskan mammals. | Mammals in hot environment – behavioural; insulatory defense

Counter current heat exchange | Torpor – reduced body T and metabolism

eg. bats and hummingbirds

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Lecture

Respiration in fishes

Ventilation in water

O_2 content in water is 30x less compared to air

Freshwater : $8 cm^3/L$

Air : $210 cm^3/L$

Water is also ~800 times more dense and 100 times more viscous than air. So, you need high surface area for gas exchange in water.

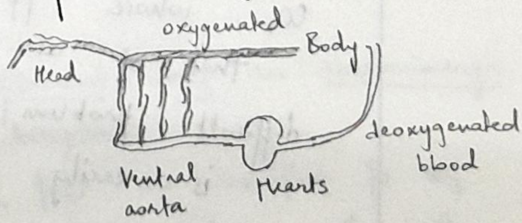
O_2 has 10,000x less diffusion rate in water and solubility changes with T and salinity.

But, fish have much lower metabolic rate, but it's still in O_2 deprived state.

One-way traffic of water - in through mouth & out through gill slits - reduces energy required for respiration.

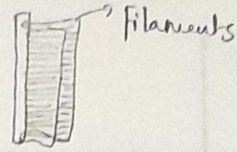
Bony fish - have 4 gill arches gill slits are covered by operculum, which is not true for cartilagenous fish

Buccal-Opercular pump

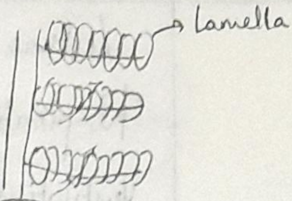


- When mouth is open, operculum is closed
- Operculum is a flap such that water can't come in from the gills.
- This movement is also caused by CPG in the medulla

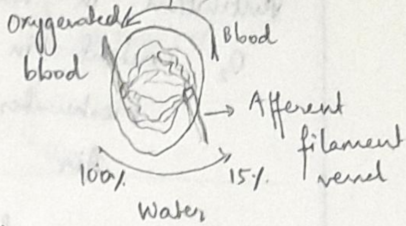
Anatomy of gills

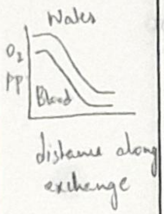


Each gill arch is made of 2 flaps called filaments, and each filament dorsoventrally has upper and lower level of lamellae



Lamellae of successive filaments are juxtaposed so that water goes through a seive-like structure.





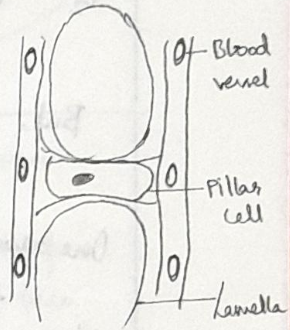
Gas exchange occurs at lamellae and water & blood flow in opposite direction — counter current exchange

Gills are covered by mucus secretion, which creates a boundary layer. This mucus contains large number of antimicrobial peptides

Pillar cells – make up the lamellae

Gills would collapse without the water density

Cross section of gill

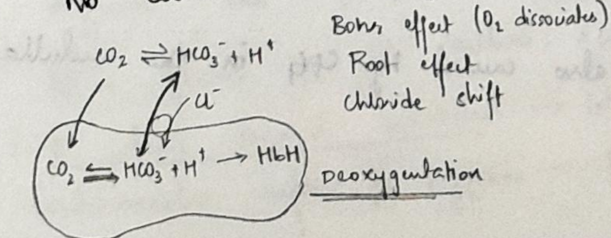


CO_2 partial pressure in water breathers

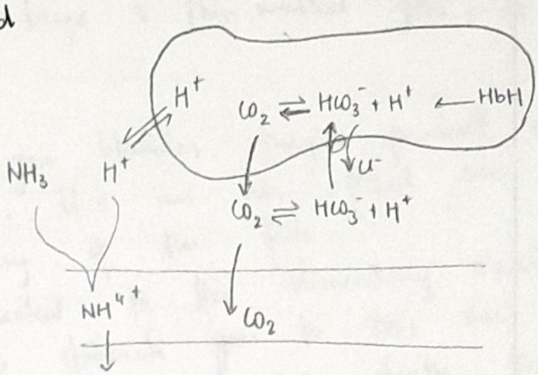
In air breathers, it's important to get rid of CO_2, whose pp. is much greater in blood than that of air. But in fish, getting O_2 is a more difficult problem than getting rid of CO_2 which is easily soluble in water.

CO_2, H^+ and ion movement through RBC in gills

No carbonic ~~ad~~ anhydrase in the blood!

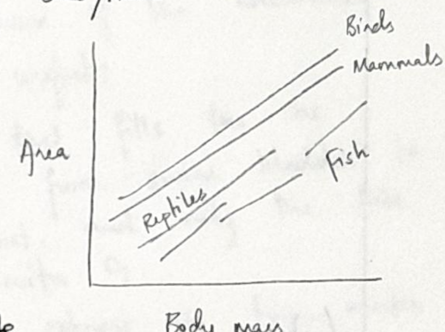


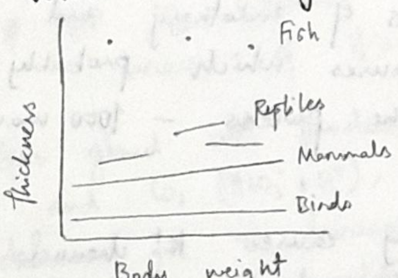
Ammonia is directly excreted into the water as NH_4^+



Allometric relationship between body size/mass and respiratory surface area

There is a positive correlation b/w respiratory SA and body size. The slope is greater for birds and mammals which have greater metabolic rate





Thickness of respiratory surface also varies across taxa
But does it change with body size?
Rainbow trout – increases 7-fold.

Reduced O_2 levels – ↑ gill ventilation

Serotonin: 5-hydroxy tryptamine (5-HT)

Neuroepithelial Cells (NEC)

NECs are present along the filament. They are seratonionergic and serve as oxygen receptors.

These cells are like neurons that are sensitive to ~~CO_2~~ O_2. Fish don't need CO_2 sensors because it easily diffuses out to water.

NECs found in gill arches, sensitive to low O_2

K^+ leak channel inhibited → cell depolarised → Ca^{2+} channels open

Cardiovascular reflex to hypoxia – bradychardia

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Lecture

Assignment: focus on the merits of endothermy and discuss the evolutionary pressures which probably contribute' to the process - 1000 words

→ NEC sensory mechanism

When PO_2 is low, something causes K^+ channels close, so K^+ ions can't leak out. This depolarises the membrane, which opens Ca^{2+} channels. There's an influx of Ca^{2+} ions from the outside and the ER. This triggers release of seratonin which is sent to the medulla & CPG, which increases respiration rate

→ Ram ventilation, (Eg. Tuna)

Some fish donot have strong enough ocular pumping power to run water over their gills. So they keep their mouth open and swim very fast (50-80 cm/s) so that water runs over their gills

Water runs over their large & thin-walled gills, so respiration increases.

Swim bladder

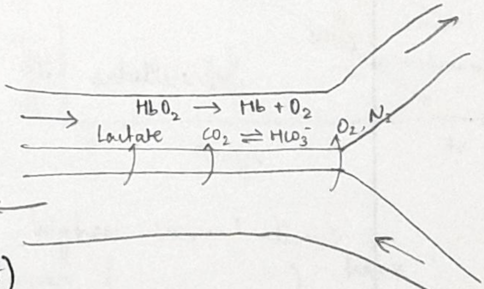
Also called swim / air / gas bladder, they're present in most telost fish. It's an air filled sac that increases buoyancy of the fish.

They are a sac connected to the alimentary canal. So gas from the stomach goes to this sac.

But when the fish is at a certain depth, the sac is going deflate because of the enormous pressure. So how to keep it useful?

Rete mirabile is a gas gland that fills the sac with oxygen. The connection from swim bladder to the alimentary cannal is lost, and only the Rete mirabile pumps the bladder with O_2.

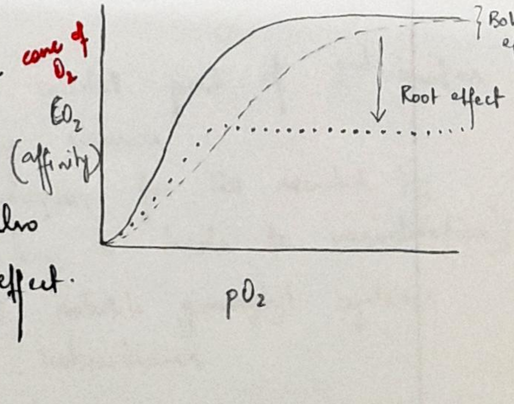
Not CO_2, because it's hard to extract CO_2 from water because of it's solubility.



Gas gland cells produce lactate and CO_2 ($HCO_3^- + H^+$), which decreases pH ⇒ decreases affinity of O_2 to haemoglobin (Bohr effect)

Because of countercurrent set up, even O_2 from the venous blood goes to arterial blood.

Bohrs effect : O_2 saturation



Root effect

In fish, & some other animals, an increase in H^+ decreases the amount of O_2 that can bind to respiratory pigment also decreases. This is called Root effect.

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Swim bladder is evolutionary homologous to lungs, but they are not supplied with vascularised blood vessels. So, it can't be used for respiration.

Respiration in Amphibians

All amphibians are found near fresh water. They have bucco-pharyngeal and cutaneous respiration. The tadpoles have gills.

Buccal pressure-pump mechanism of respiration.

Insects

Tracheal system – tubes, spiracles → muscles

Flight – ↑ O_2 (10–100x)

Lined by a cuticular intima

Open > Closed > Flutter – CO_2 excretion ? water loss
↓
mins

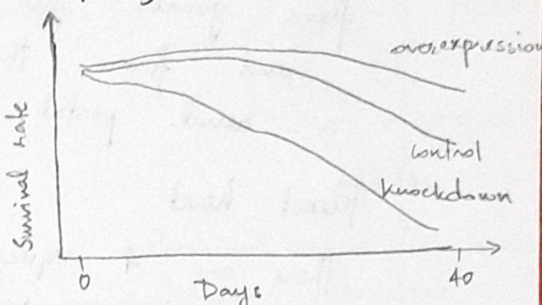
Intracellular Hb – fat bodies + trachea

Lecture 6/9

Fat bodies in insects

- They act like the liver and metabolise proteins. They're also an important endocrine and immune organ in insects.
- Fat bodies also have haemoglobin, which serves as a reserve of O_2 when partial pressure is low.
- Fat bodies surround the the alimentary canal of the insects and process metabolites.

Globin genes in Drosophila
Glob-1 is highly expressed in fat bodies and trachea.
Glob-1 knock-out and transgenic overexpression lines were generated. At 5% O_2 (hypoxic conditions), the knock out had much lesser survival rate & overexpression line had slightly higher survival rate as compared to wild type.

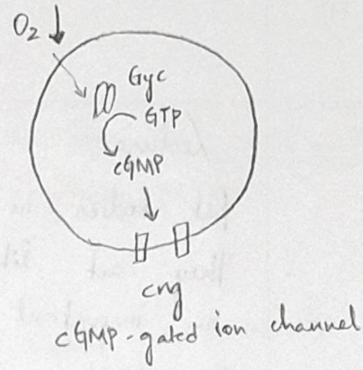


Similar hemoglobins are present in higher concentrations in trachea of some flies. Larvae ( ) have it in their hemolymph and so red in color.

Haemocyanin : copper based respiratory pigment.

Oxygen sensing in drosophila
Terminal sensory cone in the caudal part of 3rd instar larva has a bipolar sensory neuron.
Gcy : Guanylyl cyclase (they're a receptor for NO secreted by endothelial cells when O_2 is low, & leads to vasodilation)
This sensory neuron has atypical soluble guanylyl cyclases (Gyc-88E / Gyc-89Da) which is a heterodimer.

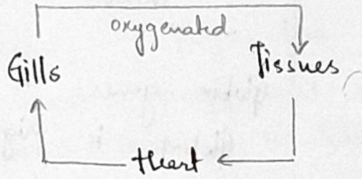
Decrease in O_2 activates Gyc, which converts GTP to cGMP, which in turn triggers the opening of cng, which stimulates the neuron.



Cardiovascular system in Fish

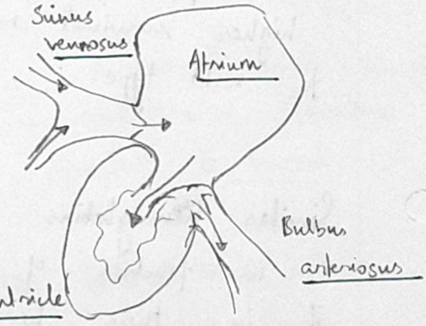
Mammals have double circulation, and the blood moves in series through pulmonary and systemic circulation.

Circulatory plan in fish:



Oxygenated blood goes to all the important organs and venous blood from gonads, gut and spleen goes to the liver and forms the hepatic portal system. Fish also have a renal portal system.

Teleost heart



There are 4 sequential chambers.

Myocardium in the ventricle is spongy and oxygenated by blood from ventricular lumen.

Pacemaker is in the sinus venosus.

Myocardial walls is in sheets of muscle called trabuculae, so blood flows along the muscle and acts as source of oxygen for the muscle.

There's no coronary circulation in most fish!

Shark have conus arteriosus which is made of cardiac muscle and has several valves, as compared to bulbus arteriosus, which is made of smooth muscle, like a blood vessel

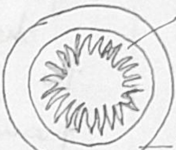
Blood pressure in the ~~aorta~~ bulbus arteriosus is 30-40 mmHg, but by the ~~ty~~ time it exits the gills, pressure is 20 mmHg.

Elasmobranch heart (shark)

Their pericardium is a hard shell, unlike in mammals. The pericardial fluid moves ~~in~~ such that when atrium expands, the ventricle is contracted and fluid moves down, and when ventricle expands, it moves up.

Relatively inactive fish have spongy heart eg. Puffer fish.

Active fish like tuna fish have inner spongy and outer compact heart, which requires coronary circulation to transport O_2 to the muscles.



Lecture

7/7/22

Air breathing fish

arboresent-organ / air sac

Eg: Magur / Cat fishes

Accessory respiratory organ - like a cauliflower-structure related to gill arches; another structure is buccal mucosal breathing.

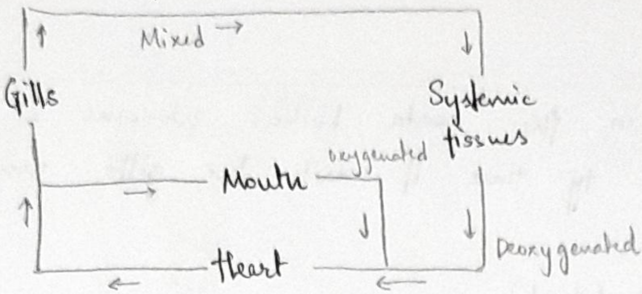
Such structures are found in 450 (out of 22k) species and they have evolved parallely several times.

More in tropics as compared to temperate - warmer temperature means lesser dissolved O_2 in water and fish have higher basal metabolic rate, so they also need more oxygen.

Some are facultative, while other fish are obligate air breathers.

(18)

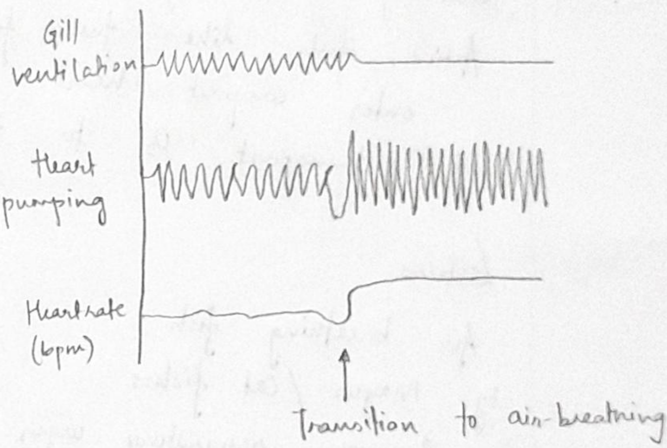
Circulatory plan



Autonomic nervous system plays an important role in sending certain amount of blood to gills/ Accessory breathing organ based on the respiratory source.

Oxygenated blood from ABO goes to heart via venous connection, so heart pumps mixed blood

Physiological processes change when the eel/ fish transitions to air breathing

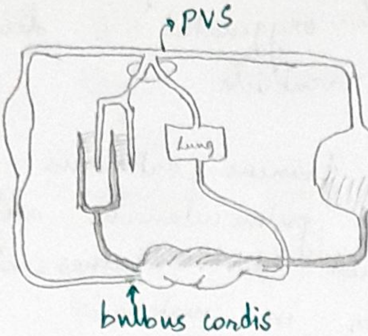


Lungfish

They are thought to be the precursors of terrestrial animals. In their circulatory plan, They have near full separation of oxygenated and deoxygenated blood - there's a septum partially separating atrial and ventricular chambers.

(PVS) Pulmonary vasomotor segment - it regulates the amount of blood that goes to the lungs - i.e. constricts the pulmonary artery when the fish is underwater.

Absence of lamellae in anterior gill arches permits blood flow directly to systemic circulation via dorsal aorta.



Circulatory plan of Lung fish

Regulation of Cardiovascular system → chromaffin tissue

Kidney of the fish extends to the head and there is diffused tissue where smaller cells secrete steroids and neuronal derived cells secrete epinephrine & norepinephrine — sort of like adrenal gland, but it's not called that

ANS regulation
para cholinergic - inhibitory
symp adrenergic - excitatory

Baroreceptors in fish

13/7/22

Lecture

Circulatory system of Frog

The oxygenated blood from ventricle goes to the right and left aortic arches, which then come together to form the dorsal aorta.

This is a remnant of sending blood to right & left gill slits, even though adult frog doesn't have gills.

Mammals have lost right arch, whereas birds have lost the left.

Other features:
- 2 atria & 1 ventricle
- Only SV node
- Spongy heart (trabeculae)
- ~~Sinus venosus~~ Truncus arteriosus (: aorta)

Sinus venosus is where deoxygenated blood gets ~~constracted~~ collected and flows into right auricle.

Blood from lungs goes into left auricle & when the atria contract, oxygenated & deoxygenated blood mixes in the ventricle

Ventricle is connected to truncus arteriosus and then to aortic arches : pulmocutaneous arch - blood flow is regulated based on whether the animal is on land or in water.

The blood from ventricles that goes to the body tissues & the lungs is sufficiently separated.

In bullfrog, 91% of oxygenated blood is channeled into systemic arteries and 84% of deoxygenated blood is directed into pulmonary arteries.

This is possible because of spiral valves in truncus arteriosus, where the walls curve such that blood from one side (left auricle - oxygenated) flows along the dorsal side to go to carotid and systemic artery. Deoxygenated blood goes to pulmocutaneous artery.

Based on the needs, the frog can send blood to where it's needed based on where it's needed.

Skin is respiratory - it has to be thin, moist and vasularized. So, more than a 1000 anti-microbial peptides have been isolated from the skin of frog.

Pseudis paradoxa

Paradoxical or shrinking frog in South America is very big as a larvae (27 cm), but it shrinks as it metamorphoses, and the adult is smaller that the tadpole

Reminder : Muscarinic ACh [para] - opens K^+ channels ⇒ hyperpolarise
β1 adrenergic receptor - influx of Ca^{2+}

Effect of ACh and adrenaline on isolated frog heart.
Vagal stimulation (parasympathetic)

Frog has myogenic heart - the pacemaker is in the sinus venosus and conduction of impulse starts from there

Incompletely divided central circulation can be an advantage for intermittent breathers — when they're not using the lungs, they can shunt blood away from lungs — whereas mammals cannot do that because volume of blood in the two loops has to be kept constant.

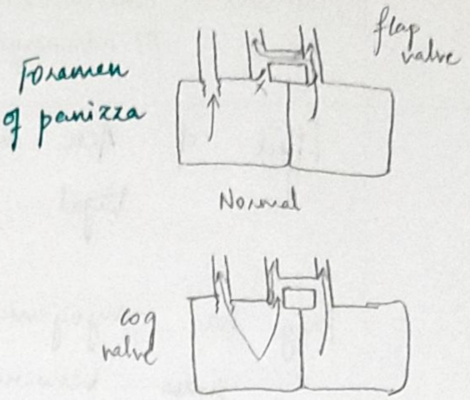
When frogs dive in water, their heart rate falls because O_2 availability is low and metabolism is also low (because of Temp.) [Bradychardia] + vasoconstriction of pulmocutaneous artery through vagal stim.

Baroreceptors in frog.
Chemoreceptors - present in carotid, systemic and pulmonary
Recorded from multi-unit chemoreceptor discharge frequency (MCDF), which started firing more when PO_2 fell to 40-60 mmHg

Reptiles
In ~~ventar~~ reptiles, the ventricles are partly divided, but crocodiles have fully divided ventricles.
In crocodiles, normal rate : 10 bpm, but when it dives, it lowers to 1-2 bpm, because it's an intermittent breather
To be able to regulate blood to the lungs, it has a special anatomy

(22)

Myoglobin to store O_2 in muscles

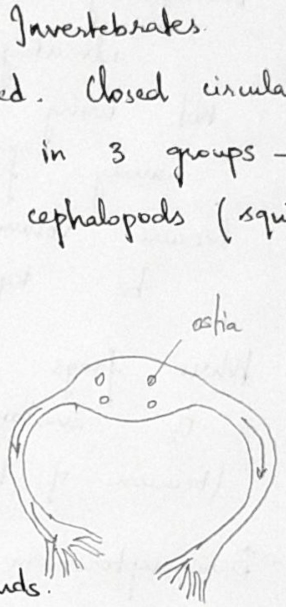


14/9

Lecture ~~14~~

Open and closed circulatory system in Invertebrates.

In vertebrates, circulatory system is closed. Closed circulatory system has evolved independently in 3 groups — vertebrates, annelids (earthworm-like) and cephalopods (squids and octopus)



Blood flows through vessels ~~on~~ which just open to the tissues. Blood drains into the heart through ostia.

Main disadvantage: low pressure, so the animal can't have high O_2 demands.

Earthworm closed circulatory system

It has 5 striated-muscled, pulsatile hearts which pump blood. They don't have endothelium cells.

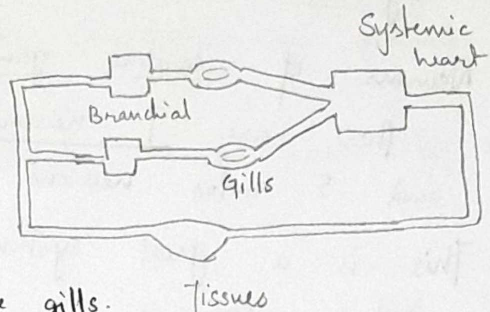
Squid

Viscera in cephalopods is covered by a sheet of muscle called <u>mantle</u>. Collar is a part between head and mantle. Collar opens and water is taken in, and gills are present in the cavity. Then, collar closes and water is extruded through a the opening funnel, which allows the animal to move via jet propulsion.

In cold conditions with low O_2, haemocyanin > Hb

Octopus circulatory plan

The blood looses pressure when it goes through tissues, so there are branchial hearts which pump the blood to the gills.



Avg pressure: 30-37 mmHg   7 mm Hg in systemic vein

Respiratory pigment: haemocyanin. (solvated in blood, not contained in cells) → parallely evolved from arthropods i.e. independently

Haemocyanin has 2 Cu atoms held by 6 histidine molecules. Single protein doesn't show cooperativity, but 6 ~~m~~ sets of 6 molecules come together to form a 36-mer, which has a Hill's coefficient of ~6.

But increasing haemocyanin, increases the viscosity of blood, which is not true for vertebrates.

Squid blood can maximally carry 5ml of O_2 per 100 ml of blood. Also, venous blood is completely deoxygenated, at rest! whereas in vertebrates, venous blood still has extra 75% of O_2. When they increase activity, they have to increase heart rate!

Invertebrates with Open circulatory system

Haemolymph flows through lacunae and sinuses & small/sessile crustaceans don't have a heart. Blood circulates because of body movements.

Some larger crustaceans have a heart with some arteries which go to some limbs / kidney / liver.

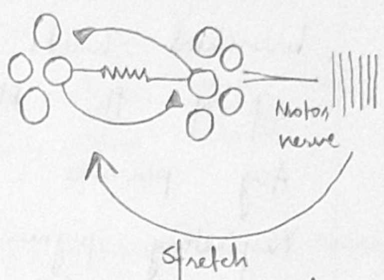
The heart is neurogenic.

Ostia are covered by flaps
Arteries are under local, muscular control

Heart contracts and sends haemolymph through the vessels, and it goes into diastole because of suspensory ligaments. When it relaxes, blood enters the heart.

Neurons of cardiac ganglion control the heart contraction. There are 9 neurons in this CPG — 4 pre-motor and 5 motor neurons.

This is a great system to study CPG.



Crustacean cardioactive peptide (CCAP)
— cardioacceleratory

Lecture 21/9

Circulation in insects

There's a tube along the medial dorsal line, transporting haemolymph from rostral to caudal end.

The heart is pulsatile and peristaltic, & moves blood one way and then the other.

The blood mainly flows through lacunae & sinuses. Drains into the heart through ostia.

Insect heart is myogenic & regulated by sympathetic/parasympathetic & hormones in the adult.

Fluorosence image visualised using phalloidin which binds to actin. The heart consists of a series of valves within the tube & helical coils of muscle that surround the tube.

Alary muscles: triangular bundles that anchor the heart to the back wall. They assist in increasing the peristaltic movement of the heart.

Heart has ostia and valves, which close the opening when heart contracts. No hematocytes are present inside the heart.

6 pairs of ostia in abdomen, 1 in thorax for mosquito

Drosophila heart

Primary pacemaker is situated at the posterior end, & a secondary one at the anterior end which reverses the flow.

At larval stage, there's no neural innervation ⇒ myogenic.

Heart is modulated by neuropeptides and neurotransmitters.

List of them.

Glutamate : Insects :: Acetylcholine : Insects

Veins in wings of insects are pathways for haemolymph, passage of trachea and routing of nerves.

Drosophila – 2 wings on 2nd thoracic segment

Halties : reduced wings on the 3rd thoracic segments.

Accessory pulsatile organs are present at the base of antennae, wings and legs to move haemolymph to the ends of appendages.

Dilator muscle contracts → valves on ampulla open, haemolymph will flow in → dilator muscle relaxes → ampulla is pushed, valve closes & volume reduces → haemolymph is pushed into antennal tube

Haemolymph

Body composition : larvae – 20-40%

adult – < 20%

(26)

Constituents –

90% H_2O

Plasma – amino acids, phosphates, organic acid

trehalose (energy rich disaccharide characteristic of insect blood)

Cl^-, Na^+, K^+, Ca^{2+}

Haemocytes – with diverse function.

Chironomus larvae – haemoglobin found diffused in the haemolymph.

Functions of haemolymph –

- transport
- Osmoregulation
- Temperature control
- Skeletal function
- Moulting process – to increase volume of body & shed away the old exoskeleton
- predatory defence.

Hexamerins

They are haemocyanin-related 6-mer polymeric protein found in insects & accumulate to high conc in larvae. They can't bind to O_2 (lose of function).

They were originally described as storage proteins that provide amino acids when starving. They're also involved in transport of hormones, cuticle formation, humoral immune defense.

Holometabolous – fat bodies } AMP production
Hemimetabolous – hemocytes

Fat body – adipose tissue + liver

endocrine regulation, systemic immunity, vitellogenesis & housing microbial symbionts.

Plasmocytes – 95% of hemocytes, show phagocytic activity

Cecropins – AMPs – Attacins, lysozymes, defensins, diptericins

↳ act by attacking different parts of bacterial envelope

Anti fungal also

Amphipathicity allows them to partition the lipid bilayer

Lecture

Voltage-gated ion channels are a prerequisite for excitable cells.
Chemosensory cells - first sensory channels to evolve
Nervous system first evolved in animals like hydra, which has a rudimentary nervous system.

Paramecium - single celled eukaryote, belongs to Ciliata taxa
It has mechanically stimulated Ca^{2+} ion channels, so when it bumps into something, channels open and Ca^{2+} rushes in
Once the membrane is depolarised, the cilia start beating in the opposite direction. So, even before NS evolved, ~~we~~ Pm had ion channels & voltage gated channels.

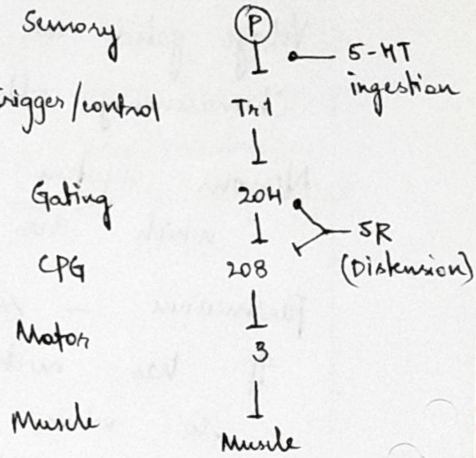
Hydra has a few hundred to few thousand neurons (either sensory or ganglionic neurons) which form a 2D lattice called nerve net. They have neurotransmitters to transfer action potential - ACh, GABA, serotonin etc. Hydra is diploblastic.

C. elegans
In hermaphrodite C. elegans, 302 out of 959 cells are neurons in this 1 mm animal. 20 neurons in pharynx and 282 in various ganglia. 68 neurons are sensory neurons detecting various soluble & volatile chemicals, tactile stimuli and temperature.
We know the connectome of the animal but can't predict its behaviour.
Uses a whole host of neurotransmitters.

Leech

It's a segmented animal with 32 ganglia. In some ganglia, certain neurons have been identified — they can be recognised & behaviours reproduced in all leeches.

Neural circuit governing swimming behaviour



Hirudin - anticoagulant

Crayfish (Arthropoda)

It has a cerebral ganglia, ventral nerve cord & body ganglia

Squid (mollusca)

It has nerves ~~from~~ with giant axons

Evolution of Nervous System - general principles

- NS of all animals is based on neurons
- Organization of NS evolved through elaboration of one fundamental pattern : reflex arc.
- There has been a trend in evolution towards gathering neurons into a CNS ~~(cephalization)~~
- Neurons are concentrated in the head (cephalization) in complex organisms.
- New structures are added to older structures, rather than replacing them.

As animals became larger & behaviours more complex, the coordination between parts requires speed.

To solve this, invertebrates increased the diameter of nerves to reduce resistance (Vertebrate myelinated the nerves).

Hodgkin & Huxley worked on the squid giant axon by recording membrane potential to develop a model of action potential.

In addition to spiking neurons, insects have several non-spiking graded interneurons, which don't produce action potential — instead they release neurotransmitter in a graded manner. They maybe v. important in initiating rhythmic behaviours.

Lect 11

Insect Nervous System

Brain of locust

They have oesophagal ganglia, thoracic & abdominal ganglia in the CNS.

Brain — supraoesophageal & suboesophageal ganglia connected by circumoesophageal connective.

Supraoesophageal ganglion is divided into —

Protocerebrum (ocellar & ocular (?) nerves)

Duetrocerebrum (input from antenna)

Tritocerebrum (input from mouth parts)

The brain is connected to important endocrine glands — corpus cardiacum, corpus allatum and prothoracic/molt gland.

→ Cross-section of brain

In the medial part, there are structures called mushroom bodies. This is important for processing information & learning and memory in insects.

The deutocerebrum has antennal lobes — receives olfactory input from antenna.

There are huge optic lobes in the side, right next to compound eyes.

Mushroom bodies (corpora pedunculata) have two cups or calyces and one stalk or peduncle. Within the cups lie kenyon cells.

Olfactory Receptor Neurons (ORNs) project to glomeruli in the antennal lobe. Each glomerulus gets projections from neurons triggered by a specific odarant.

Projection neurons (pseudounipolar) from antennal lobe send axons to kenyon cells and then to the lateral horn.

Kenyon cells form thousands of parallel fibers and helps in coincidence detection.

Projections to KC change in response to experience & learning

Learning and memory is decentralised — a headless cockroach can still learn.

→ Thoracic ganglia

The cell bodies of neurons are in the periphery of the cross-section of the ganglion. The core has tract, commissure and neuropil.

Trichoid sensillum — tiny spines on the cuticle of insects that are important for mechanosensation.

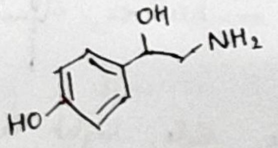
Acetylcholine is released at excitatory synapse.

→ Neural circuit mediating cockroach startle response.

Neurotransmitter released at the neuromuscular junction — glutamate.

Octapamine — biogenic amine closely related to noradrenaline

best understood role: locust jump



it modulates muscle activity, making leg contract more effectively

Octapamine makes the insects alert – inspires them to move and allows them to perform physically demanding (31)

Jewel wasp – first stings the thoracic segment & releases a paralysing agent. Then it stings the head and damages the octapamine secreting neurons. Then it leads the live cockroach to its nest to lay an egg on it and the cockroach doesn't resist.

19/10

Lecture

Behavior and eclosion rhythm in 3 'per' mutants

Monitor activity of drosophila over several days of different mutant strains: short-day, long day and arrhythmic.

These experiments are done in total darkness to see if they have an endogenous rhythm

Benzer also studied the eclosion of these mutant strains

The gene is only related to rhythmicity & nothing else

Entrainment – the fine-tuning of rhythmicity to keep the rhythm coincided with day-night cycle.

150 neurons identified related to circadian rhythm that express genes such as period, timeless (tim), cryptochrome (cry) etc.

Molecular interactions of clock genes

cyc – cycle
clk – clock
dbt – double-time

PER : period
PDF : pigment dispersing factor

When sunlight is present, DBT is produced, which continuously breaks down PER. When PER & TIM are not destroyed, they dimerize & enter the nucleus and binds to clr 3 ...

Neurogenic heart of lobster
Stomatogastric nervous system — controls the rhythm of the stomach to mechanically breakdown food.

Aplysia californica (Sea hare)
Physical basis of learning and memory: gill withdrawal reflex
The animal has several pairs of ganglia.

Siphon — sensory neuron — motor neuron — Gill
\ interneuron / (L7)

Molecular basis of habituation — it leads to decreased neurotransmitter release and hence reduced withdrawal
We can study how neurons encode behaviours

Hormones in insects
Metamorphosis
Two types — hemimetabolous : gradual (cockroach, grasshopper)
holometabolous : dramatic (butterflies, moths)

26/10

Vision
Animal vision evolved ~700 million years ago
They sense light through Opsins — a GPCR that has 7-transmembrane proteins.
Opsins are coupled to photopigment molecule such as retinal
Retinal has 2 forms — all-trans and 11-cis.
The aldehyde group of retinal is covalently bound to a lysine molecule in the opsin protein.
When light hits retinal, it's structurally ~~active~~ modified —
11 cis → all-trans
This mechanism is conserved in all of animal kingdom.

Presence / Absence of light is the first step. The animal would also need to know the direction of light and eventually form an image, for which you need a lens to refract light.

Rods (which detect light) are about a 1000 x more sensitive than cones (which sense colour).

6 of 33 phyla have evolved eyes, but these animals make up 96% of all species.

Eyespot in Euglena (flagellate protozoan)

They have a light sensitive organnelle at the base of the flagella. This eyespot is sheilded by pigment molecule so that when the animal rotates, it gets a sense of directionality of light.

Complexity of eye across phyla.

Functional convergence of eyes of fish and squid, even though they're not homologous, because they live in the same environment.

Pax-6 [Paired box protein]

This gene initiates eye development in in diverse animals. It interacts with other regulatory genes in other animals.

The assembly to light-sensitive rhodopsin molecules is regulated by this gene.

(34) Lecture

1/11/22

Water - Refractive Index

A crustacean has multiple lenses to focus the image on retina

Human Eye

Complex structure - pit where image is focused - fovea

If we look closely at the structure of Retina, the rodes and cones are inverted along the axis of incoming light because they need to be embedded in the pigment layer.

The membrane of rod and cone cells are embedded with rhodopsin

When focusing on an object, the sharp image is formed on the most sensitive spot of retina called fovea. there, the ganglion cell and inner ~~non~~ nuclear layer are pushed away and light directly falls on the cones.

Nocturnal animals: more rods Birds: more cones.

The photons that don't activate rods and cones are absorbed by the pigment layer. In albino people, the photons reflect and fall on rods and cones again - this messes with the sharpness of image.

Light → Rhodopsin → Transducin (G protein) → cGMP phosphodiesterase
↓
↓ cGMP → 5'-GMP
Na+ channel
closed ↔ Open

Light causes the closure of Na^+ channels in the membrane - so it inhibits rods and cone cells!

In the dark, rod cell is continuously releasing glutamate NT to bipolar cells. When there's light, bipolar cells are <u>not</u> excited.

This mechanism is very energy expensive, but allows vertebrates to detect various shades and intensities of light.

Pigment cell layer is a reservoir of vitamin A, so that rods have a continuous supply.

Eye of octopus

Also has spherical lens, ciliary muscles and retina. But, in octopus, the rods ~~and cones~~ layer is in front of the layer of nerve fibers, so there's no blind spot

No cones in octopus, only rods.

Vision in insects

Ocelli - simple eyes : presence /absence of light

Ommatidia - compound eyes : forms a mosaic image

These two pathways are visually and functionally different pathways. Compound eyes covers a 360° visual feild but their visual acuity is lesser.

Ommatidia of Limulus (Horseshoe crab) - model organism to study compound eyes.

Cornea → Pseudocone → Supporting cell → Retinular cells

On the medial side of Retinular cells, they have several microvilli with rhodopsin molecules. This microvilli structure is also called Rhabdomere.

The retinular cells are talking to the dendrite of eccentric cells via gap junctions. When enough Retinular cells ~~do~~ are activated, the eccentric cell gets depolarised

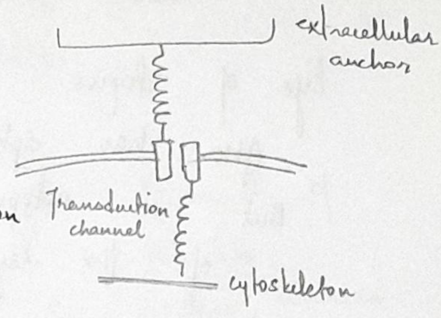
Each ommatidia is separated by a pigment layer cell

 Lecture

Mechanosensation

Insect mechanosensory bristle

Mechanoreceptor neuron – current varies with amplitude of deflection of the bristle.



Neuron is covered by sheath cell and supporting / socket cells.

Basic structure of mechanoreceptor – transduction channel is anchored by extracellular anchor / bristle and intracellular cytoskeleton.

This set up is universal.

Proprioceptors – hair plate at the joints tell the insect about the position and movement of its limbs.

Johnston's organ

The pedicel at the base of the antenna senses the movement of hairs on the antenna.

Male *Aedes aegyptii* are attracted to sound of freq range 449 - 600 Hz. which falls in range of 500 - 550 Hz.

So the female flight resonates with the bushy antennae of males. The organ is super-specialised in mosquitoes.

Crustaceans

Stretch receptors in the tail of crayfish

As the muscle contracts, the stretching activates the opening of transduction channel and the cell body depolarises and above a certain threshold, the axon hillock also gets activated and action potentials are generated.

Lobster – organ of equilibrium : statocysts

It consists of hollow fluid-filled cavity lined with mechanoreceptor cells that make contact with statolith – an object made of sand grain or calcareous material

In many other animals (aquatic invertebrates), it's a sac-like organ with a mineralised mass at the end

When molting, it needs a new statolith.

Lateral line

It's the mechanosensory organ in fish. A bunch of neurons come together and form a pole-like structure. Some neuromasts lie on the surface whereas others lie in a canal. The animal can sense currents, waves and pressure of the water – forms a hydrodynamic 'image' of the water.

Neuromast consists of a ~~bub~~ bundle of hair cells covered by a cupula. Based on movement of ~~hair cells~~, neuromast, the hair cell body depolarise & communicate with afferent neurons.

There is a pattern of arrangement – kinocilium & many stereocilia – and they are connected differently to alternate hair cells.

Neuromasts in sharks are in a canal, just below surface and the water's properties are reliably sensed.

Shoaling – swimming somewhat independently, in a social group

Schooling – swimming in the same direction in a coordinated way.

If lateral line is blocked, the fish can't integrate.

Such system is also present in tadpole & frog

Independently evolved in molluscs.

(38) Inner ear in fish - Otolith organ

Hearing system first arose in fish - hair cells connected to otolith organ

Semicircular canals in vestibular organ of humans and cochlea also have hair cells that are suspended in extracellular fluid that is very rich in K^+ ions

So when ~~ion~~ channels open, K^+ ions go in.

The gas gland has different sensitivity (to sound waves), and it's put closer to the inner ear, so the fish can detect a wide range of frequencies

Receptors in humans

→ Several receptors under the skin - Merkel, Meissner, Pacinian

→ Golgi Tendon Organ

→ Intrafusal muscle fiber

Human ear

Ear drum → Ear ossicles → Cochlea (Organ of Corti) → Semicircular canals

9/11

Lecture

In vertebrates, the common mechanosensory unit is the hair cell - kinocilium and several stereocilia connected with tip links. It's found in the lateral line, auditory sensation and the vestibular system.

There are 3 semicircular canals filled with endolymph, rich in K^+. At the base of each canal is a swelling called ampulla.

Each hair cell is penetrates into a gelatinous cupula. When head moves, the endolymph moves more slowly because of inertia and this allows it to sense the acceleration of movement.

When the hair cell. (cilia) moves, K^+ channels open and cell is depolarised — this opens Ca^{2+} channels and triggers the hair cells to release glutamate and excite the postsynaptic neuron.

Maculae and statoconia — balancing sensors present in the saccule
Macula contains an otolithic membrane and otoconia ($CaCO_3$ particles) that bend the hair cells in the direction of gravity
It helps maintain a sense of balance

Electroreception
Hair cells in some fish species have lost cilia and can detect electric currents in water produced by active tissues of other fish in the vicinity. Weakly electric fish have specialised organ that generates electric feild to navigate and communicate in turbid waters.
Eg: Electric organs in elephant fish.

Ampullae of Lorenzini — shark's electric sense

Hearing in Insects
Tympanic organ in female cricket is at the base of tibia of the forelegs. There's a cavity inside the leg and there are tympanic membranes with tracheal tubes.
It allows sound to move through the body of animal.
The tympanum also vibrates because of sound from trachea, this allows the animal to detect the direction of sound source.

(40) Olfaction in insects

Male *Antherea polyphemus* moth has pinnate antennae which can detect female pheremones from 0.5 km away.

Chemosensory receptor is present inside sensillum (bristle).

Odorants can enter through pores in the wall and bind to odorant binding protein (OBP) in the hemolymph. This complex binds to membrane receptor and excites the sensory neuron.

Bombykol – pheromone released by female silkworm moth

Electroantennogram – measure electric activity of antenna in vitro.

Insects (drosophila) also has gustatory receptors ~~of~~ on proboscis, legs & wing margins. These receptors are also fine dendrites inside sensillum with pores.

Insects can also detect CO_2

DEET – anti-mosquito compound – binds to odorant binding protein and confuses the insect

Olfaction in humans

~~of~~ Olfactory receptor neurons are bipolar. Cilia of olfactory neurons are suspended in mucus layer. The neurons pass through the cribriform plate of skull and project to the olfactory bulb.

Cells sensitive to a particular odorant all collate at a particular glomerulus.

The cilia have 7 TM GPCR sensitive to specific odorant molecules

There are ~350 types of receptors in humans, and about ~1000 in rats.

Olfactory transduction

Vomeronasal organ / Jacobson's organ – auxiliary olfactory sense organ in several mammals, especially rats, mice, etc.

It detects pheremones from female.

Lecture 15/11 (41)

Water & Salt physiology of animals

Challenges of living on land & in water (fresh / sea) is very different.

Osmolality of human blood - 280 mOsm

fresh water - 5-10 mOsm

sea water - ~~280~~ 1000 mOsm

Lower limit : snails — ~50-60 mOsm

Higher limit : Ancestrally marine animals — can be ~1000 mOsm

Marine animals need not osmoregulate, but they need to ionoregulate

All vertebrates have lower osmolality — ~300-400 mOsm

Hagfish are the only vertebrates with fluid osmolality of ~1000. But lampreys onwards, osmolality decreased

Mechanism of active Na^+ uptake across cells of ~~few~~ freshwater fish gills & frog skin.

Actively pump out H^+, allow Na^+ to come in.

Cl^- uptake — by exchanging it ~~out~~ with HCO_3^- ions

Mitochondria Rich cell (MRCs - 10% of gillcells) — very active in taking up ions.

16/11

Lecture

MRCs pump ions against the gradient — they take in ions from water to make up for the ions lost through urine. When ions in water is less, the no. of MRCs increase.

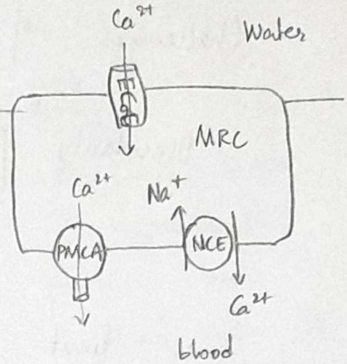
The level of ions is detected by osmoreceptors in hypothalamus. Prolactin (secreted by pituitary gland) in fish help osmoregulate — prolactin secreting cell get swollen and get activated by stretch receptors.

(42) MRCs (in gills) have receptors for prolactin and when activated, the activity of cells increases, and more MRCs are added. Prolactin acts on TRPV4 channel

Calcium uptake model

ECaC : Epithelial Ca^{2+} channel protein on apical side pumps Ca^{2+} into the cell, and from cell it goes to the blood through Ca channel and sodium-calcium exchanger

No Ca^{2+} in fish food



Animals in the ocean

They live in hyperosmotic conditions, the constantly deal with dehydration. Especially teleost fish which have hypo-osmotic blood. Some adaptations are –

- thick skin
- some marine fish have osmolality in higher range (400-500)

Marine fish lose water through gills

Excretion of ions through kidney

- kidneys of marine teleost produce urine that's isoosmotic to plasma – they want to conserve water & lose ions
- kidneys mainly excrete divalent ions (sulfate, calcium etc.)

Replacement of lost water

Marine fish can only get water by drinking seawater. When it drinks seawater, this draws water from the body and osmolality of water in alimentary canal decreases. Then water is extracted by actually drawing in ions, which in turn draws water via aquaporins.

The ions absorbed are excreted through MRCs, which in marine fish (unlike freshwater). These MRCs (→ chloride cells) have crypts or pits.

Cost of osmoregulation by gills is 3% in freshwater & 8% in marine water.

Sea turtles, sea snakes and gulls/other coastal birds have salt glands which help in excreting salts concentrating it 4-5 times the conc. of plasma via a counter current set up.

Sharks are hyperosmotic but also <u>hypoionic</u> to seawater. They have high conc of urea and trimethylamine oxide (TMAO) in the blood, which makes it hyperosmotic.

High conc. of urea usually denatures proteins but sharks have developed mechanisms to deal with it. Urea and TMAO denature the proteins in opposite ways and so proteins stay the same

Sharks have a rectal gland which excretes salts.

Eg. changes in salmon.

Growth hormone & cortisol – promote chloride cells (seawater)

Prolactin – promotes freshwater MRCs

Lecture – 22/11/22

Excretion in animals

Amphibian – adults have nephrons and kidneys – first structure in vertebrates

Malphigian capsule, uriniferous tubule

Bowman's capsule, PCT, intermediate segment, DCT, collecting tubule

Permeable urinary bladder

Na^+, Cl^-, glucose reabsorbed in PCT, & water follows

Urine ~ same as plasma, but more conc when animal is dehydrated

ADH controls permeability of tubule wall ie. high ADH ⇒ ↑ water absorption

Arginine vasotocin (ortholog of vasopressin) – antidiuresis by constricting renal arteries.

(44) Bladder permeability to water varies with ADH levels —
↑ permeability when ADH is high

Water absorption through skin → stored in bladder → reabsorbed

Hormone-challenged individuals increase in weight

Ammonia — easy to synthesize, but toxic — disrupts neuron function, blood-brain barrier & gill permeability

Urea — 10x less water, less toxic, but 5 ATP to synthesize 1 molecule of urea

Hepatic encephalopathy

Lecture

Excretory molecules – ammonia, urea, uric acid, allantoin
1 2 4

Urea is synthesized in the liver through ornithine-urea cycle in vertebrates except teleosts.

When frog metamorphoses from tadpole to adult, it goes from being ammonotellic to uricotellic.

Uric acid – product of metabolizing purines, mammals don't have enzyme to break this down.
It removes N from the solution; and it's less reactive and toxic.

Purine → Hypoxanthine → (Xanthine oxidase) Xanthine → (Xanthine oxidase) Uric acid

Uric acid scavenges potentially harmful radicals (anti-oxidants)
Maintains BP in low salt conditions.

In mammals (other than great apes), uricase converts uric acid → allantoin. Great apes have lost uricase.

Gout – accumulation / precipitation of uric acid in joints causes acute inflammatory arthritis

Arid-land toads also excretes N as uric acid.

Cleidoic egg (closed egg) – internal fertilisation product
Growing embryo excretes uric acid in the allantois (extra-embryonic membrane), and it's rendered harmless.

Antennal gland and urine formation in freshwater of crayfish
Also called as green glands or 2 nephrons.

(46) Excretory system of insects

Groups / Taxa that can concentrate their urine more than the body fluid — mammals, reptiles, insects

Only midgut is not covered in lumen of alimentary canal

At junction of midgut and hindgut, there are fine, blunt tubules tubules called Malphigian tubules — numbers can vary

This system works only through secretion (no ultrafilteration)

Tubules have strips of muscles to contract and move the tubule. Inner side and outer side is thrown into a large no. of folds.

Image — movement of ions.

H^+, K^+ are actively pumped into the lumen

H_2O and Cl^- follow these ions and others ions also move based on their conc in haemolymph

The secretion moves into the rectum, where Na^+, K^+, Cl^-, water, amino acids and phosphates are reabsorbed.

Rectum also lowers pH ⇒ uric acid precipitates & is excreted with v. little loss of water.

Limitation of a secretory system: if some new compounds enter the hemolymph, malphigian tubules maynot be able to secrete it because it doesn't have the machinery. This constrains what insects can eat.

But this doesn't apply to mammals, which have ultrafilteration to get rid of small molecules.