~ Chapter 8 ~

Living on Land

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1. Water and air have different **physical** properties.
2. Air is less **viscous** and less dense than water, so streamlining is a minor factor for tetrapods, whereas a skeleton that supports the body against the pull of gravity is essential.
3. Respiration is also different; gills don't work in air. Because air density and viscosity are low, **tetrapods** can use a tidal flow of air in and out of a saclike lung.
4. Terrestrial habitats can have large **temperature differences** over a very short distance, & terrestrial animals can maintain body temperatures that are different from air temperatures.

8.1 Support and Locomotion on Land

1) Gravity has little significance for a fish living in water because vertebrates have approx. the **same density** as water. Hence fish are essentially weightless in water.
2) But gravity causes problems for land vertebrates; the skeleton must support the body.
3) Because water is dense, fish swim by passing a **sine wave** along the body – the sides of the body & the fins push backwards against the water, and the fish moves forward.
4) Most tetrapods use their legs and feet to transmit a **backward force**. Skeleton is composed of bone which supports the body as the animal moves.
5) Bone has a **remodelling capacity**, **e.g.** In humans, intense physical activity increases bone mass, whereas inactivity results in loss of bone mass.

Bone

1) Amniotes have bone that is arranged in concentric layers around blood vessels forming cylindrical units called **Haversian systems** (**Figure 8-1 a**).
2) External layers of a bone are formed of dense, compact bone, but the internal layers are lighter, spongy (**cancellous**) bone (**Figure 8-1 b**).

3) **Joints** at the ends of bones are covered by a smooth layer of **cartilage** that reduces friction. The bone within the joint is composed of cancellous bone, and the entire joint is enclosed in a **joint capsule** containing synovial fluid for lubrication.

The Axial System: Vertebrae and Ribs

1) Vertebrae & ribs of fishes stiffen the body so it will **bend** when muscles contract. In tetrapods, the axial skeleton is modified for support on land.
2) Processes called **zygapophyses** on the vertebrae of tetrapods (**Figure 8-2**) interlock and resist twisting and bending, allowing the spine to act like a suspension bridge to support the weight of the body (**Fig. 8-3**).
3) Tetrapods that have permanently returned to the water have lost the zygapophyses.
4) **Bony fishes** use the opercular bone to protect gills and ventilation.
5) With the loss of the **opercular bones**, which connected the head of bony fishes to the pectoral girdle (so the fish cannot turn its head, but the entire body turns), **tetrapods** now have a distinct neck region.
6) Neck (**cervical**) vertebrae (**Fig. 8-3**) allow the head to move separately from the rest of the body. Head can move side to side & up and down.
7) Two most anterior cervical vertebrae are the **atlas** and **axis**; highly specialized.
8) **Trunk** vertebrae are in the middle region of the body and bear the ribs. In mammals these are differentiated into:
   i. **Thoracic** vertebrae (bear ribs)
   ii. **Lumbar** vertebrae (lost ribs).
9) **Sacral** vertebrae fuse with the pelvic girdle & allow the hind limbs to transfer force to the appendicular skeleton.
10) Early vertebrates have a **single** sacral vertebra, mammals (& amphibians) have **3 – 5**, and some dinosaurs had a **dozen** or more. Modern amphibians have lost their ribs.

Axial Muscles

1) Two **roles** in tetrapods: supporting shape & ventilation of the lungs.

2) More complex functions than side-to-side bending produced by axial muscles of fishes.

3) Axial muscles help in **locomotion** in primitive tetrapods, producing the lateral bending of the backbone seen during movement by many amphibians and reptiles.

4) However in birds and mammals, limb movements have replaced the trunk bending.

5) **Dorsoventral** bending is important component of mammalian locomotion.

The Appendicular Skeleton

1) Appendicular skeleton includes the limbs and limb girdles.

2) In primitive gnathostomes such as sharks, the pectoral girdle (supporting the front fins) is a simple cartilaginous bar called the **coracoid bar** with small scapular process.

3) In bony fishes, the pectoral girdle (**Scapulocoracoid**) is attached to the opercular bones that form the posterior portion of dermal skull roof.

4) Pelvic girdle in both kinds of fishes has no connection with the vertebral column.

5) Tetrapod limb is derived from the fin of fishes. **Basic structure of fin:** fanlike basal elements supporting one or more ranks of cylindrical radials which articulate with raylike structures.

6) Tetrapod limb is composed of limb girdle and five segments that join end-to-end.

7) All tetrapods have **jointed limbs** with forwardly knee and backwardly elbow, wrist/ankle joints, & hands and feet with digits (**Fig. 8-4 a**).

8) Feet of amniotes are used as levers to propel the animal, and the ankle forms a distinct hinge joint (**mesotarsal joint; Fig. 8-4 no. 10**).

9) Basic tetrapod skeleton is shown in **Fig. 8-5**.
   - Pelvic girdle is fused to sacral vertebrae.
   - Hind limbs are the primary propulsive mechanism.
   - Pelvic girdle contains three paired bones on each side (total = 6): **ilium**, **pubis**, and **ischium**. The ilia on each side connect pelvic limbs to vertebral column.

10) In bony fishes, the pectoral girdle and forelimb are attached to the back of the head via the **opercular** and **gular bones** (**Fig. 8-6**).

11) In tetrapods, these bones are lost & the pectoral girdle is freed from the dermal skull roof, **i.e.** tetrapods have a flexible neck whereas in fishes, head is fused to shoulders.

12) Only **endochondral bones** are scapula, coracoids girdle, & some other bones of the girdle.

13) Pectoral girdle does not articulate directly with the vertebral column. The connection consists of muscles & connective tissue that hold the pectoral girdle to the **sternum** and ribs. Sternum is a midventral structure that links right and left thoracic ribs in amniotes.

- Sternum is solid and strong only in **birds** & **mammals**.
- This shows that the pectoral & pelvic fins of the **fishes** led to the development of limbs in tetrapods.

14) Appendicular muscles of **tetrapods** are more complex than those of fishes.

Locomotion on Land

Locomotion on land costs more **energy** than locomotion in water.

Figure 8-7 shows the phylogenetic view of tetrapod locomotion:

A. Primitive tetrapod condition, retained today in salamanders: movement mainly via axial movements of the body, limbs moved in diagonal pairs (basic walk-trot gait).

B. Jumping form of locomotion in the frog, relying on limb muscles.

C. Primitive amniote condition, seen in many extant **lizards**: limbs used more for propulsion, with development of the walk gait (limbs moved one at a time independently).

D. Diapsid amniote condition (**e.g.** lizards) with hind limbs longer than forelimbs.

E. Derived limbless condition with snakelike locomotion (**e.g.** in snakes).

F. Primitive **archosaur** condition, with upright posture and tendency to bipedalism.

G. Secondary return to **quadrupedalism** in crocodilians.

H. **Obligate bipedality** in early dinosaurs and

I. birds.

J. Return to **quadrupedality** within dinosaurs.

K. Primitive mammalian condition: upright posture and the use of the **bound** as a fast gait with dorsoventral flexion of vertebral column.

L. Condition in larger mammals where the bound is turned into the **gallop** (jumping off the hind legs and landing on forelegs).

M. The **true trot** (distinct jump from one pair of legs to other) as seen in larger mammals.

N. The **Ricochet**, a hopping gait of kangaroos and some rodents.

O. The **amble**, a speeded-up walk gait seen as the fast gait of elephants & some horses.

P. Human condition of upright bipedality.

Eating on Land

1) Difference between water & air profoundly affects feeding by tetrapods.

2) In water, food items are nearly weightless and can be sucked into the mouth.

3) This is not possible in terrestrial animals because air is less dense than water. They use their **jaws** and **teeth** to seize food items, & their **tongues** and **cheeks** to manipulate items in the mouth. The head is moved over the prey.

4) Tongue of jawed fishes is small and bony, whereas tongue of tetrapods is large & muscular.

- **Hagfishes** and **lampreys** also have muscular tongues but these are not homologous with the tongues of tetrapods because the innervations are different.
- Most salamanders and lizards have sticky tongues used to transport prey into the mouth. This phenomenon is called **prehension**.

5) Salivary glands are known only in terrestrial vertebrates, for lubrication to aid in swallowing of food. Saliva also contains enzymes & some species have venoms that kill prey.

6) **Figure 8-10:** Head and neck musculature

a) The **adductor mandibulae** closes the jaws.

b) The **depressor mandibulae** muscle (hyoid) opens the mouth.

c) The **sphincter colli** muscle (hyoid) aids in swallowing food.

Reproduction on Land *(new edition)*

1. Amniotic egg has special advantage for land animals.

2. More than one mechanism and the presence of egg shell support the egg & restricts water movement in and out of the egg.

3. Presence of shell allows amniotes to deposit their eggs in places that are not suitable for the non-amniotes.

8.2 Breathing Air

1) Air is an easier medium for respiration than is water.
2) Low density and viscosity of air make breathing (**tidal ventilation**) possible, & the high oxygen content of air reduces the volume of fluid that must be pumped.
3) It was assumed lungs evolved in fishes living in oxygen-depleted water, and were not evolved for breathing on land.
4) In contrast to the **positive**-pressure **buccal** pump that nonamniotic tetrapods used to inflate the lungs, amniotes use a **negative**-pressure **aspiration** pump.
   - Expansion of rib cage by **intercostal hypaxial** muscles creates a negative pressure (i.e. below atmospheric pressure) in the abdominal cavity & sucks air into the lungs.
   - Air is expelled by compressing the abdominal cavity, through elastic return of the rib cage & the contraction of the lungs.
5) Amphibians have simple lungs. In contrast, **amniotes** have lungs that are subdivided, sometimes in very complex ways, to increase surface area for gas exchange.
6) Amniotes have a long **trachea** (windpipe) and bronchi (**Fig. 8-4 no. 11**). *#5 in new ed.?*
7) Amniotes possess a **larynx** at the junction of pharynx & trachea, which is used for sound production.

8.3 Pumping Blood Uphill

1) Blood is weightless in water, and the heart needs to overcome only **fluid resistance** to move blood around the body.
2) Circulation is more difficult for a terrestrial animal because blood must be forced from the lower limbs back up to the heart by pumping more blood into the arteries.
3) Thus, tetrapods require blood pressures high enough to push blood upwards against the pull of gravity. **Valves** in the limb veins resist backflow.
4) High blood pressure in blood vessels forces some blood plasma out of the vessels & into the intercellular spaces of body tissues.
   - This fluid is recovered & returned to circulatory system by **lymphatic system**.

5) Lymphatic system is a one-way system of blind-ended, veinlike vessels that parallel the veins & allow fluid in the tissues to drain into the **venous system** at the base of the neck.

  1. Lymphatic system is also well developed in teleost fishes, but it is of critical importance on land because cardiovascular system is affected by gravity.
  2. **Lymph nodes** (concentrations of lymphatic tissues) are found in mammals & some birds at intervals along the lymph channels.
  3. Lymphatic tissue is also involved in the **immune system**; white blood cells (macrophages) travel through lymph vessels, & lymph nodes trap foreign material.

6) In fishes, the heart lies in gill region in front of shoulder (pectoral) girdle, whereas in tetrapods it lies behind the shoulder girdle in the thorax.

7) The **sinus venosus** & **conus arteriosus** are reduced or absent in the hearts of tetrapods.

8) Blood circulatory system is referred to as a double circulation: **pulmonary** circuit supplies lungs with deoxygenated blood & **systemic** circuit supplies oxygenated blood to the body.

Figure 8-11 is important

9) Right side of heart receives **deoxygenated** blood returning from the body via systemic veins. Left side receives **oxygenated** blood returning from the lungs via pulmonary veins.

Figure 8-12 is important; shows the development associated with aortic arches in tetrapods.

10) Arches 2 and 5 are lost in most adult tetrapods. Three major arches are retained:

  1. the 3^{rd} (**carotid** arch) going to the head
  2. the 4^{th} (**systemic** arch) going to the body
  3. the 6^{th} (**pulmonary** arch) going to the lungs

11) In amniotes, the **pulmonary artery** receives blood from right ventricle & the right systemic and carotid arches receive blood from the left ventricle.

12) In modern amphibians (**e.g.** frogs), the skin helps in exchange of oxygen & CO_2. The pulmonary arch is actually a **pulmocutaneous arch** to supply the skin.

  1. The **cutaneous vein** carries oxygenated blood back to the systemic system via the **subclavian** vein and into the right atrium.
  2. Thus oxygenated blood enters the amphibian **ventricle** from both the left atrium (supplied by the pulmonary vein) & the right atrium (supplied by the skin).

13) Ventricular septum is present in all amniotes, but the form is different in the various lineages.

How is oxygen supplied to the heart muscles?

1) Modern amphibians & non-avian reptiles:

- **a)** Have **lower** blood pressures than mammals and birds.
- **b)** Their hearts don't work as hard.
- **c)** Ventricles allow some mixing of blood.
- **d)** Hearts lack the coronary arteries.

2) Ventricular muscles of mammals and birds are thicker and must work harder.

3) These animals have a permanent **ventricular septum**, so the right ventricle contains only deoxygenated blood.

4) Both birds & mammals have **coronary arteries** that supply oxygenated blood to the muscles of both ventricles.

Figure 8-12 a–e

8.4 Sensory Systems in Air

- Air is not dense enough to help the lateral line system to work, and does not conduct electricity well enough to support **electrosensation**.
- However, chemical systems work well on land for smaller molecules, & air offers advantages for both vision and hearing.

Vision

1) Sense of vision is easier to use on land than in water because light is transferred through air with less disturbance than through water.

2) Air is rarely murky in the way that water can be, so vision is more useful as a **distance sense** in air than in water.

3) In air, the cornea (**define cornea** = the transparent covering of the front of the eye) participates in focusing an image on the retina.

4) **Define retina** = Innermost layer of the vertebrate eyeball containing the photoreceptors.

5) Fishes focus light by moving the position of the **lens** within the eye, while tetrapods focus by changing the shape of the lens.

6) In air, the eye's surface must be clean. New features in tetrapods include eyelids, glands (**e.g.** tear-producing glands), & a **nasolacrimal duct** to drain tears from eyes into nose.

Hearing

1) Sound perception is very different in air than in water.

2) Density of animal tissue is nearly the same as density of water, & sound waves pass freely from water into animal tissue.

3) Because water is dense, movement of water molecules directly stimulates the hair cells of the **lateral line system**.

4) Air is not dense enough to move hair cells, & the lateral line system is lost in all tetrapods except for larval or permanently aquatic amphibians.

5) Function of inner ear is hearing **airborne sounds**, with the transmission of sound waves through bones in a middle ear.

6) In water, sound waves must travel through other routes.

Box 8-2, Figures 8–14 and 8–15

7) Considerably more energy is needed to set the fluids of the inner ear in motion than most airborne sounds impart, & the middle ear is a **sound amplifier**.

8) It receives the relatively low energy of sound waves on its outer membrane, the **tympanum** (eardrum), and these vibrations are transmitted by the middle ear bones to the **oval window** of the **otic capsule** in the skull.

9) Area of tympanum is much larger than that of oval window, and the difference in area amplifies sound waves.

10) In and out movement of oval window produces waves of compression in the inner ear fluids, and these waves stimulate the hair cells in the **organ of Corti**.

    a) This organ discriminates the frequency and intensity of vibrations it receives & transmits this information to the CNS.

    b) Organ of Corti lies within a flask-shaped structure, the **lagena**, (**Figure 8–15**). The lagena is larger in derived tetrapods, and is called **cochlea** in mammals.

11) Middle ear is not an airtight cavity. The **Eustachian tube** (auditory tube), derived from the spiracle of fishes, helps release the pressure & connects the mouth with the middle ear. Air flows in or out of the middle ear as air pressure changes.

12) **What happens when the Eustachian tube is blocked?**

When that happens, changes in external air pressure can produce a painful sensation in addition to reduced auditory sensitivity.

13) Middle ear of tetrapods has evolved several times, although in each case the **stapes** (the old fish hyomandibula, called the **columella** in nonmammalian tetrapods) transmits vibrations between the tympanum & oval window.

14) Modern amphibians have an inner ear organisation that is different from that of amniotes (*mammals in new ed.*), indicating an independent evolution of hearing. There are also differences in the anatomy of the inner ear in the nonmammalian tetrapods.

Olfaction

1) Olfactory receptors responsible for sense of smell are located in the **olfactory epithelium** in nasal passages of tetrapods.

- Receptors can be very sensitive, and some chemicals can be detected at concentrations below 1 part in 1 million trillion (10^{15}) parts of air.

2) Among tetrapods, mammals have the greatest olfactory sensitivity, and the area of the olfactory epithelium in mammals is increased by presence of thin bone (**turbinates**).

3) Primates, including humans, have a poor sense of smell because our snouts are too short to accommodate large turbinates.

4) Tetrapods have an additional chemosensory system located in a unique organ of olfaction in anterior roof of mouth – the **vomeronasal organ** or **Jacobson's organ**.

5) **What is so special about this organ in snakes and some mammals?**

When snakes flick their tongues in and out of their mouth, they are capturing molecules in the air & transferring them to this organ.

6) Many hoofed mammals sniff or taste the urine of a female, a behaviour that permits them to determine the stage of her reproductive cycle (*if the female is reproductively mature*).

- This sniffing is followed by **flehmen**, a behaviour in which the male curls the upper lip & hold his head high, probably inhaling molecules of pheromones into the vomeronasal organs.

7) Primates (*including humans*) have flat faces, and the vomeronasal organ is present by may be reduced.

Proprioception – Where Are Your Parts?

1) Aquatic vertebrates don't have long **appendages**, and their appendages have relatively little range of movement in relation to the body.

2) Their heads are attached to their pectoral girdles, and their fins move either from side to side or forward and back (limited range of movement).

3) That is not true of terrestrial animals, which have necks & limbs that can move in **three dimensions** with respect to the body. It's important for a terrestrial vertebrate to know where all the body parts are, & proprioception provides that information.

4) It's the ***proprioceptors*** in your arm that enable you to touch your finger to your nose when your eyes are closed (*what is this receptor?*).

5) Proprioceptors include **muscle spindles**, which detect the amount of stretch in muscle, & **tendon organs**, which convey information about position of joints.

6) Muscle spindles are found only in the limbs of tetrapods, and they are important for determining posture and balance on land.

8.5 Conserving Water in a Dry Environment

1) Bony fishes are covered with **scales**. The immediate fishy ancestors of tetrapods were covered in heavy dermal scales containing layers of enamel, dentine, and bone.

- These scales were lost in the earliest tetrapods: Only scales on the belly (*ventral side of body*) remained for protection.

2) On land, water is evaporated from the body surface and respiratory system as **vapour** & lost through the kidneys as **liquid**.

3) Skin **permeability** of terrestrial vertebrates varies from very high in most amphibians to very low in most amniotes.

4) Outer layer of skin of vertebrates is composed of keratinised epidermal cells, forming the **stratum corneum**.

5) Stratum corneum is only a **few** cell layers deep in fishes & amphibians, but **many** layers deep in the skins of amniotes.

6) Keratinized layers protect the skin, & the presence of an insoluble protein has some waterproofing effect, but **lipids** in the skin are the main agents that limit evaporative water loss.

7) **Sauropsid** and **synapsid lineages** developed different solutions to the problem of minimising water loss through the kidney.

- However, what they have in common is a urinary bladder (a saclike structure that receives urine from the kidney & voids it to the outside).

  Figure 8–4 (#12 in old, #13 in new)

8) Bladder is a new feature of tetrapods, although some bony fishes have a **bladderlike** extension of the kidney duct.

9) Amniotes have a new duct (the **ureter**) draining the kidney.

10) In most vertebrates the urinary, reproductive, and digestive systems reach the outside through a single common opening, the **cloaca** (**Figure 8–17**).

- ➢ Only in **therian** mammals (marsupials & placentals) is the cloaca replaced by separate openings for urogenital and digestive systems.

11) Penis is a **conduit** (definition: waterway) for urine only in therian mammals.

- ➢ In all other amniotes it is purely an **intromittent organ** (*reproductive organ*) used to introduce sperm into female reproductive tract so the egg can be fertilised before it is encased in a shell.

8.6 Life in a Changing Environment: Controlling Body Temperature on Land

1) An animal on land is in a **physical** environment that varies over small distances and can change rapidly.

2) Temperature varies dramatically in **terrestrial** environments, & this has a direct impact on terrestrial animals – especially small ones – because they gain and lose **heat** rapidly.

3) This difference in aquatic & terrestrial environments results from differences in the **physical** properties of water and air.

4) *Difference in aquatic & land animals results from difference in physical environment.*

5) **Box 4–1:** Water temperature is stable because water heat capacity is high & water conducts heat.

6) **Aquatic** animal has little capacity to change its body temperature by moving.

7) **Terrestrial** animals can *adjust their body temperatures by selecting the appropriate location*. Low heat conductivity of air means that they can maintain body temperatures that are different from air temperature.

8) **Thermoregulation** (regulating body temperature) is essential for most tetrapods because they encounter a wide range of temperatures, from too hot or too cold.

9) In general, **tetrapods** maintain body temperatures that are higher than air temperature (with some exceptions), & to do this they need a source of heat.

   - This heat can come from the chemical reactions of metabolism (**endothermy**) or from being exposed to a heat source (**ectothermy** –ancestral character).

10) Ectothermy is used by almost all **nonamniotes** and by turtles, lepidosaurs & crocodilians.

11) Ectothermal thermoregulation is based on balancing the heat movement between the body and the environment.

Energy Exchange between an Organism & Its Environment (*new ed.*)

Ectothermal thermoregulation

What are the pathways by which thermal energy is exchanged between a living organism and its environment?

1) Sources of heat include: the sun, **infrared radiation**, **convection** (transfer of heat between an animal and a fluid), **conduction** (body and solid object are in direct contact), **evaporation** (from the body and the lungs transferring heat from body to environment), and **metabolic heat production** (animal gains heat but very small amount).
2) Flow of heat can be adjusted. **Fig. 8–18** illustrates pathways of thermal energy exchange. Heat comes from both external & internal sources, & heat can flow in or out of the body.
3) **See textbook for details**

Endothermal thermoregulation

- Animals such as birds and mammals exchange **energy** with the environment same as the ectotherms in terms of behavioural thermoregulation.
- Difference between endotherms and ectotherms is the **amount of heat** produced by their metabolic pathways.
    1) Higher **metabolic** rate in endotherms means that more heat produced.
    2) During this mechanism, chemical bonds are broken & a portion of the energy in those bonds is captured in the bonds of other molecules such as ATP.
    3) The main heat produced is wasted (used to keep **body temperature** stable).

Compare ectothermy and endothermy:

Advantages and disadvantages of both:

1) **Endotherms** produce heat internally independent of the environment so they can live in cold climates, but they require high energy source such as food.
2) Ectotherms save energy by relying on **solar** heating so ectotherms of the same body size eat less. This is why ectotherms can live in places that are not suitable for an endotherm.
3) Intermediate between ectotherms & endotherms = some **fishes** (ectotherms) can maintain body temperature higher than that of the seawater. Some **birds** can allow their body temperatures to drop down at night & then warm up in the sun during the day.