SUPPORT AND MOVEMENT

Locomotion: The act of changing position of the **entire** body.
Movement: The act of displacing body parts while maintaining the whole body in one position.
The study of movements is called **kinesiology.**
Movement involves these basic mechanisms.

1. **Amoeboid movement**
   Importance of the mechanism to the organisms that exhibit it;
   a. Enables amoeba to move about to;
      i. obtain food
      ii. avoid dangers
   b. Enables white blood cells (leucocytes) like phagocytes, macrophages of the lymph and Kupffer cells of liver to;
      i. engulf antigen or microbes
      ii. immigrate in the circulatory fluid
2. **Ciliary and flagella movement**
   Importance of the mechanism to the organisms that exhibit it:
   a. Ciliary movement enables paramecium to;
      i. avoid danger
      ii. drive water and food into its gullet.
   b. In certain molluscs, ciliary movement facilitates gaseous exchange by passing water currents over the gills
   c. In echinoderms, ciliary movement enables locomotion by driving water through the water vascular system.
   d. Ciliary movement of the cells lining the respiratory tract of humans drives away the microbes and dust particles towards the nose or mouth.
   e. Ciliary movement in the oviduct or fallopian tubes of human female moves ova towards the uterus.
   f. Ciliary movement in nephridia of annelids e.g. earthworms moves metabolic wastes
   g. Flagellum of sperms enables their swimming movement.
   h. Flagellum enables the movement in certain protozoans like *Euglena Spp*
3. **Muscular movement**
   Muscular movements enable:
   a. animals to find food, mates, avoid predators and unsuitable environmental conditions
   b. the flow of contents in the gut and arteries
   c. the positioning of eyes and external ears for effective functioning in some animals

AMOEBOID MOVEMENT

Definition: this is a crawling-like type of movement characterised by protoplasmic protrusion to form temporary feet-like structures called pseudopodia.
Several theories have been advanced about the formation of pseudopodia, but the most accepted now-a-days is the **sol-gel-sol** transformation of the cytoplasm.
Description of amoeboid movement according to the sol-gel-sol theory
The plasmalemma attaches to the substratum.

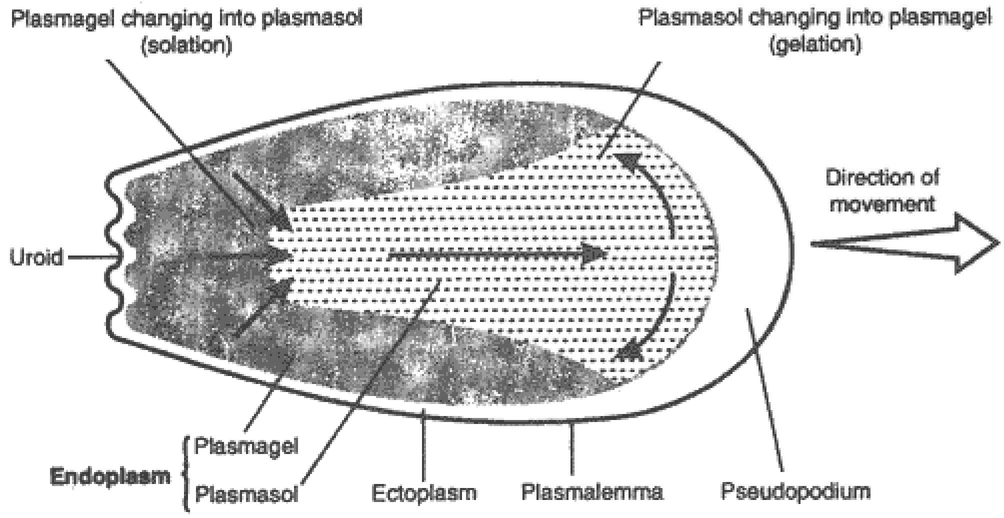
Stimulation of the ectoplasm (plasma gel) at a certain point causes its conversion to plasma sol, and flowing of the pressured plasma sol (endoplasm) into the weakened area, forming first a bulge and then a tube.

The movement is sustained by contraction of the outer gel layer which squeezes inwards, causing cytoplasmic streaming towards the tip of the pseudopodium.

Within the advancing tip at the **fountain zone**, plasmasol is converted to plasmagel which is then deposited on the sides of the pseudopodium. At the temporary posterior (hind) end of the cell the plasma gel is converted to plasmasol, which then flows forwards into the newly formed pseudopodium so much so that the whole of body cytoplasm comes into it.

Now the plasmagel tube contracts and the body moves forwards. Soon after this a new pseudopodium is again formed in this direction.

Draw from biological science, Roberts or Clegg



Sol-gel theory of amoeboid movement 2classnotes

CILIARY MOVEMENT

Definition: this is the rhythmic beating of fine hair-like processes projecting from the cell membrane of certain cells (cilia).

A ciliary beat cycle consists of an **effective (power) stroke phase** and a **passive recovery stroke phase.**

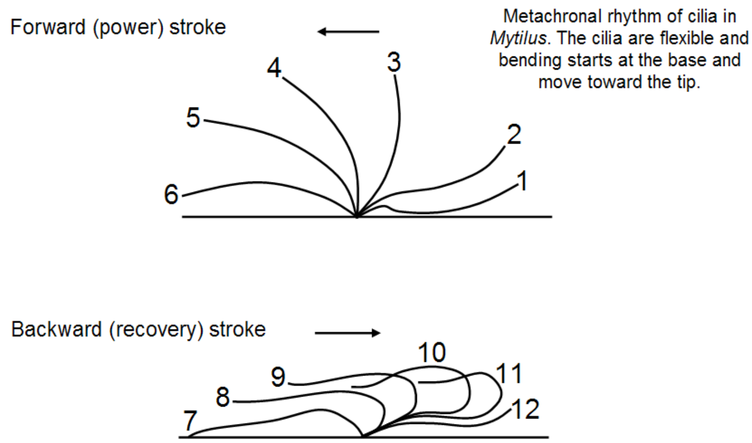
During the effective stroke phase the fully extended cilium makes an oar-like movement towards one side exerting maximum force on the surrounding fluid. The cilia beat in reverse when the power stroke is directed toward the anterior end of the organism so as to propel it backwards while beating towards the posterior end causes the cell or organism to swim forward.

In the passive recovery stroke phase which follows the effective stroke, the cilium moves back by propagating a bend from base to tip in an unrolling motion to reduce drag.

The cycles of adjacent cilia are slightly out of phase so that they do not bend at exactly the same moment, resulting in metachronal rhythm in which waves of ciliary activity pass along the organism from front to rear.

Metachronal rhythm*:* these are movements produced by the sequential action of structures such as cilia, segments of worms or many legs, producing the appearance of a travelling wave.

Description by diagrammatic illustration **either:** *N.P.O. Green; et.al. Biological science* ***Or:*** *M.B.V Roberts, functional approach* ***Or:*** *Philips and Chilton*



FLAGELLAR MOVEMENT

The anteriorly positioned euglena flagellum exhibits wave-like motion along its length in a spiral manner from base to tip with increase in amplitude and velocity. This causes the body to rotate (spin) about its longitudinal axis as well as propelling it forwards along a helical (corkscrew) pathway through the water.
Change of direction and body shape occurs by contraction of contractile myonemes.
Draw euglena's path of movement from: **N.P.O. Green; et.al. Biological science**

MUSCULAR MOVEMENT

In this compilation, muscular movement has been limited to a few vertebrates, insects and earthworms.
The unique properties of muscles which enable their functionality include:

a. Excitability
b. Contractibility
c. Extensibility
d. Elasticity

Muscular movement is dependent on skeletal systems.

TYPES OF SKELETONS

HYDROSKELETON OR HYDROSTATIC SKELETON

This is a high-pressured fluid in a cavity (coelom), surrounded by muscle layers at different orientations.
It's the most widespread type of skeleton found in:

a) **Organisms** like annelids (e.g. earthworms), cnidarians (e.g. jellyfish, sea anemones), and nematodes (e.g. round worms)
b) **Structures** like mammalian eyes (the aqueous and vitreous humour), spinal cord (cerebrospinal fluid), extra embryonic membranes (amniotic fluid), hearts (move blood), and intestines (move food).

The **main principle** on which the hydroskeleton operates is the low compressibility of liquid water (often assumed incompressible). Muscle contractions exert pressure on the coelomic fluid causing stiffening of the outer structures to form a strong rigid skeletal unit that provides a base against which movement can occur.
The optimal volume of fluid for a particular system must remain constant for effective contraction and expansion of the antagonistic muscles. Too much loss of fluid causes limpness of tissues and pressure loss, and too much gain causes over swelling, both of which fail muscle stretching and hence movement fails. This explains why snails and earthworms are restricted in their activity to moist conditions.

Advantage / Function

Hydro skeleton is elastic and can bend accordingly when a muscle contracts enabling fitting in narrow burrows.

Limitations / Disadvantages

i. Coelenterates that use a hydroskeleton regularly face a problem of loss of pressure because their skeleton is also their gut
ii. Due to lack of a strong supportive system, majority of the invertebrates are small
iii. The slow motion, due to lack of effective ways to support a large body, compromises the animals' escape response from predators.
iv. The organisms are limited to moist habitats because of the need to minimise water loss by evaporation

DESCRIPTION OF HYDROSKELETON OF THE EARTHWORM

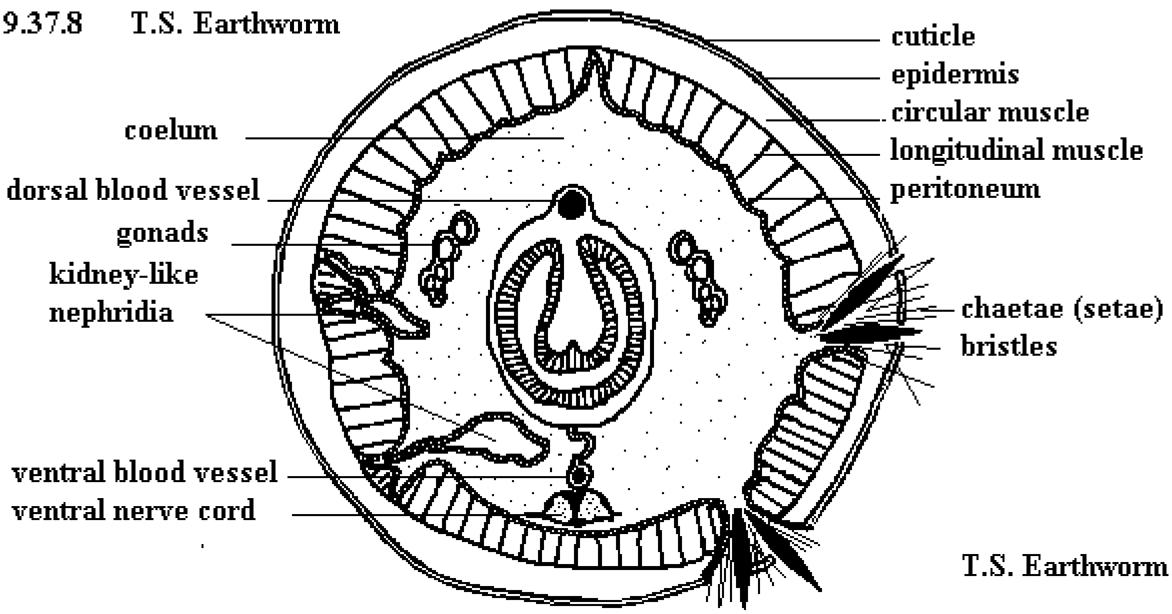
The body is cylindrical (tubular), the digestive system is within a tube, partitioned transversely into many small separate, but coordinated segments. Each segment is enclosed by a thick wall made of two layers of muscles i.e. circular muscles surrounding the cavity and longitudinal muscles running from the anterior end to the posterior end. The inside contains a highly pressured incompressible fluid-filled cavity (coelom). Everybody segment bears four pairs of chaetae (setae), except the first and last segments.

NB: segmental partitioning prevents backflow of the coelomic fluid which would provide little elongation

Philips and Chilton, A-level Biology pg 426

(Draw and label the main features in transverse section)

9.37.8 T.S. Earthworm



T.S. Earthworm

DESCRIPTION OF THE EARTHWORM'S LOCOMOTION

Draw and label from: **Philips and Chilton, A-level Biol. pg 427** *or* **N.P.O. Green; etal, Biol. science**

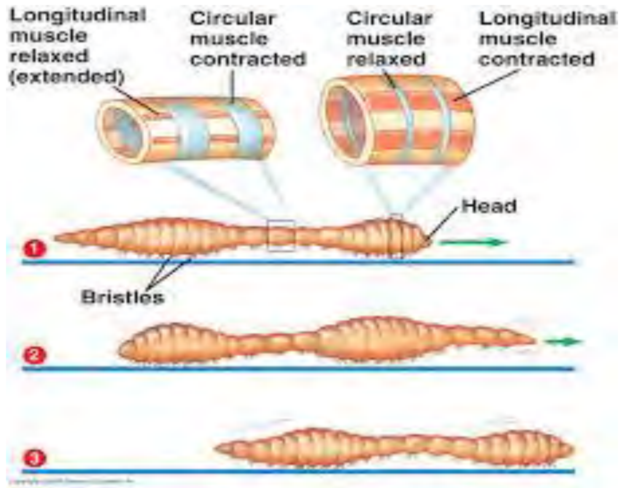
Crawling is initiated when circular muscles at the anterior end contract while longitudinal muscles relax, segment by segment backwards as a wave along the body, there by exerting pressure on the coelomic fluid, which is forced to move at right angles to the squeezing circular muscles, while at the same time the chaetae retract inwards in this region of contracted circular muscles. The net result is forward extension of the anterior end.

The movement of the fluid stretches the set of longitudinal muscles, which then contract to stretch the circular muscles back to the relaxed position, causing segments to elongate and become thin.

Forward extension of the anterior end is coupled with contraction of longitudinal muscles and relaxation of circular muscles in the more posterior segments causing body swelling and protrusion of chaetae in this region.

As the successive peristaltic waves approach towards the posterior end of the body, longitudinal muscles in the anterior region contract, circular muscles relax, the chaetae protrude to anchor at the ground and pull the posterior end forward.

Control of muscle contraction is brought about by a complex network of ***inter and intra segmental neurones***



EXOSKELETON

This is a **non living** external body structure that supports and protects an organism.

Exoskeletons are secreted by the ectoderm. Exoskeletons do not grow with the body so in arthropods they must be periodically shed to allow growth, mollusks e.g. snails continually enlarge their shells as they grow. In insects and spiders the epicuticle is waterproof.

Examples of exoskeletons;

i. ***Chitinous exoskeleton*** as in arthropods like insects, arachnids (e.g. spiders) crustaceans (e.g. crabs, lobsters), some fungi and bacteria. A Chitinous exoskeleton has complex muscular system which enables insects to lift or pull an object 20 or more times heavier than their body weights! Grasshoppers have about 900 muscles, caterpillars up to 4,000 yet human beings have fewer than 700 muscles.
ii. ***Calcified exoskeleton*** is in shelled mollusks (e.g. snails, clams), some polychaetes like lugworms.
iii. ***Silicated exoskeleton*** is in diatoms.
iv. ***Bone, cartilage, or dentine*** make up the exoskeletons of turtles and primitive fish

Advantages / Functions

i. Exoskeletons contain rigid and resistant components that offer protection against predators, bacterial attack and desiccation while on land.
ii. Exoskeletons contain rigid components that offer support enabling the maintenance of body shape.
iii. Exoskeletons of arthropods contain rigid framework of ingrowths known as apodemes which serve as attachment sites for muscles.
iv. In arthropods the exoskeleton is modified into appendages which offer more rapid locomotion than the hydroskeleton
v. The arthropod exoskeleton contains various folds, flaps and parts modified for feeding and structures for respiration.
vi. Exoskeletons are often highly coloured for camouflage from predators, recognition by mates, and warning to scare off predators
vii. The arthropod exoskeleton is jointed enabling flexibility in locomotion.

Limitations / Disadvantages

i. An exoskeleton cannot support large sized animals because of their large volume and body mass in proportion to the cube of their linear dimensions, necessitating an impossibly heavy and thick exoskeleton

ii. It requires modifications in movement. Many individual muscles are attached to the outer shell in order to create movement. In the appendages, these muscles are set up within multiple hinge joints, as these allow a wide range of motions.

iii. Since exoskeletons are rigid and do not grow with the body, in arthropods they disrupt smooth and steady growth and so must be periodically shed to allow growth, which makes the animal temporarily vulnerable for predation and water loss by evaporation until hardening.

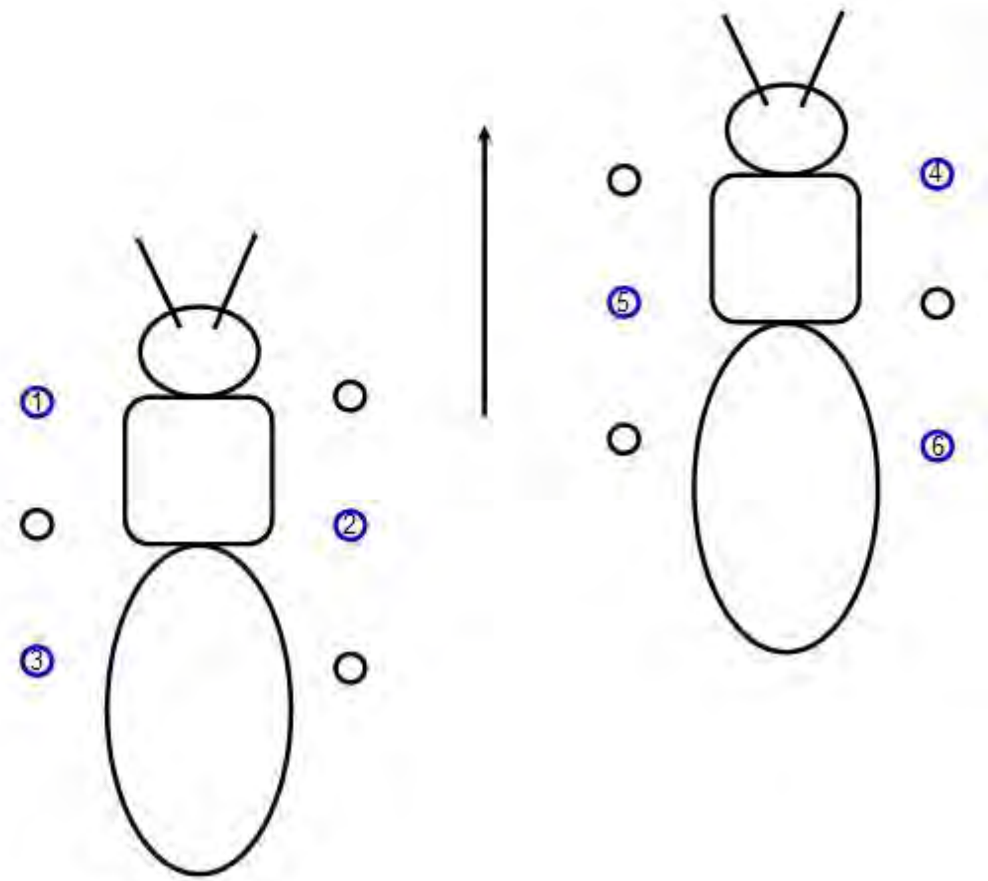
NB: Snails and many other mollusks solve that problem by continually enlarging their shells as they grow.

DESCRIPTION OF A TYPICAL ARTHROPOD EXOSKELETON

It is a multi-layered structure with 4 main regions; from out - inwards: epicuticle, procuticle, epidermis and basement membrane.
Epicuticle: a multi-layered external barrier made of lipoproteins, fatty acids, wax and sometimes cement. It prevents water loss (desiccation) and bacterial invasion.
Procuticle: lies immediately below the epicuticle, is secreted by the epidermis, and contains chitin surrounded by a matrix of protein. At times procuticle stratifies into a sclerotised exocuticle and a soft, inner endocuticle. (Sclerotisation involves linking protein molecules together by quinone compounds into a solidified protein matrix, creating rigid "plates" of exoskeleton known as sclerites)
Epidermis: made up of a single layer of epithelial cells, secretes the basement membrane and all of the overlying layers of cuticle.
Basement membrane: a supportive bilayer of mucopolysaccharides and collagen fibers, it is where epidermal cells rest.

DESCRIPTION OF WALKING IN INSECTS

Walking is achieved by the coordinated activity of 6 legs all attached on the thorax.
Bending and straightening of limbs is brought about by the **reciprocal innervation** of flexor and extensor muscles attached to the inner surface of the exoskeleton on either side of a joint.
Reciprocal innervation refers to the simultaneous excitation of one muscle with the inhibition of its antagonist.
A limb bends (folds) by contraction of flexor muscle and relaxation of extensor muscle simultaneously (at the same time).
A limb straightens (extends) by contraction of extensor muscle and relaxation of flexor muscle simultaneously.
When the insect starts to walk, the 2nd leg on one side and the 1st and 3rd legs on the other side support the body off the ground while the other 3 move forward.
The 1st leg on the side where the 2nd leg is stationary pulls the insect, while the 3rd leg of the same side and the 2nd leg on the other side push.
The process is then repeated but with the role of each trio of limbs reversed.
Draw from **Clegg and Mackean, Adv. Biol Princ & Applic.Pg482 fig. 22.7 –** (Steps in walking)



DESCRIPTION OF FLIGHT IN INSECTS

Flight is brought about by muscular attachment in 2 forms, direct flight muscles and indirect flight muscles.

1. **Direct flight muscles**

These are in insects with large wings, in which flight muscles insert **directly at the wing bases.**

During the ***upstroke***, the **elevator muscles** contract, the **depressor muscles** relax at the same time, the wings are elevated.

During the ***down stroke***, the depressor muscles contract, the elevator muscles relax at the same time, the wings are depressed down.

Draw from: **N.P.O. Green; et.al, Biol. Science** *or* **Clegg and Mackean, Adv. Biol Princ. & Applic. Pg 483 fig. 22.8-** (upper one only)

Insects which have direct flight muscles include dragonflies, butterflies and grasshoppers.

2. **Indirect flight muscles**

These are in insects with smaller wings in which flight muscles, the **dorso-ventrals** are attached to the **tergum** (roof) and **sternum** (floor) of the thorax, and the **longitudinals** are attached at the anterior and posterior of the thorax, but the wing bases are attached at the sternum and side of the thorax.

During the ***down stroke***, the **longitudinal muscles** (depressor muscles) contract, the **tergo-sternal muscles** (dorso-ventral muscles) relax at the same time, the thorax is compressed, its dorsal surface notum arches (bulges / bows upward), the wings flip downward (depress).

During the ***upstroke***, the **tergo-sternal muscles** (elevator muscles) contract, the **longitudinal muscles** (depressor muscles) relax at the same time, the notum is pulled downward (flattens), causing the wings to flip upward (elevate).

Draw from: **Philips & Chilton, A-level Biol. pg 442, fig. 49.9 A& B-**(upper ones only) *or* **Michael Roberts, etal Adv. Biol. Pg. 432** *or* **Clegg and Mackean, Adv. Biol Princ & Applic.Pg483 fig. 22.8**

Examples of insects that exhibit indirect flight muscles include bees, wasps, house flies, e.t.c.

NOTE
Insects with large wings like dragonflies, butterflies and grasshoppers have **synchronous flight muscles** i.e. a single nerve impulse causes a muscle fiber to contract once resulting in a slow rate of wing beat (about 5-50 times/second) while smaller insects like bees, wasps, house flies, etc have **asynchronous flight muscles** i.e. a single nerve impulse causes a muscle fiber to contract multiple times. This allows the frequency of wing beats to exceed the rate at which the nervous system can send impulses (about 120-200 beats in house flies to 1,000 beats/second in midges). The latter muscles exhibit **stretch reflex** i.e. automatic contraction in response to being stretched.

ENDOSKELETON

The vertebrate skeletal tissue is composed either of **cartilage only** like in elasmobranch fishes e.g. dogfish and sharks or **both cartilage and bone** covered by a muscular system.

Advantages / Functions

i. Vertebrates have a versatile support system and as a result, they develop faster and bigger bodies than invertebrates.
ii. It's jointed for flexibility to allow diverse range of locomotory patterns; swimming, running, climbing, and flying.
iii. An endoskeleton does not limit space available for internal organs and can support greater weight.
iv. Bones are hard for protecting delicate parts like the brain, lungs, heart, spinal cord, e.t.c.
v. Bone tissue is mineralised and hence acts as mineral reserve for the body's' physiological processes.
vi. Mammalian bones manufacture the defensive leucocytes

Limitations / Disadvantages

i. Endoskeletons are enclosed in other tissues hence do not offer much protection from predators in some animals.
ii. Endoskeletons do not contribute to minimizing water loss from the body by evaporation

FEATURES OF CARTILAGE

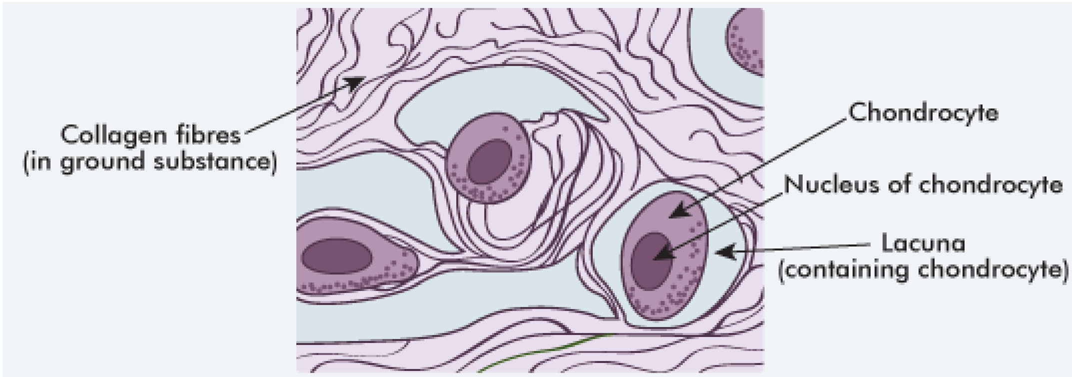
Has cells called **chondroblasts** and matrix called **chondrin.** And it is of three types; **Hyaline, Yellow/ elastic** and **White/ fibro-cartilage.**

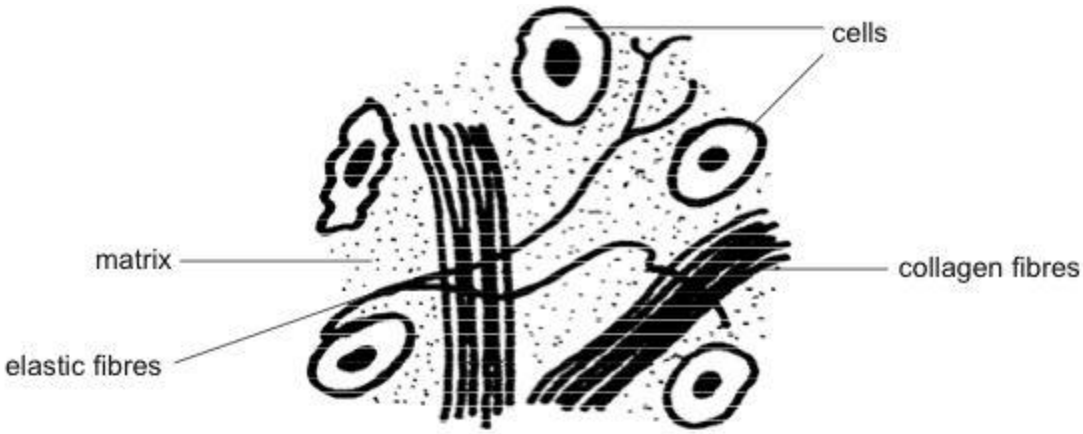
a. Hyaline cartilage

It's the most common type of cartilage. Its matrix is translucent and contains very fine collagenous fibres.
Location: nose, ends of long bones, ribs, trachea rings, foetal skeleton.

Description

It's a solid flexible connective tissue composed of a translucent mucopolysaccharide matrix **(chondrin)** in which are distributed cartilage cells (**chondroblasts)** and many intercellular substances like fibres.
Each **chondroblast** lies in a small chamber called **lacuna** surrounded by a capsule.
Chondrin lacks direct blood supply except in the **Perichondrium;** a tough fibrous membrane surrounding cartilage.
In some cases **chondroblasts** occur in cell nests i.e. a pair or 2 pairs of cells encased by one capsule.
NB: Chondroblasts that become embedded in the matrix are called **chondrocytes.**
draw from **Philips & Chilton, A-level Biol. pg 216, fig. 27.2** ***or*** **Michael Roberts, et.al Adv. Biol. Pg. 67 fig. 4.9**

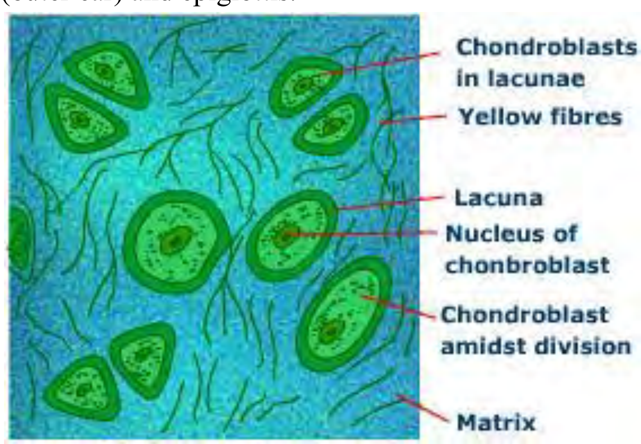




b. Yellow / elastic cartilage

It's more flexible than hyaline cartilage because the matrix contains many elastic fibres in addition to collagen fibres.

Location: frame work of Pinna (outer ear) and epiglottis.



c. White / fibro-cartilage

Contains dense collagenous fibres embedded in matrix, it absorbs shock and reduces friction between joints and can withstand tension and pressure.

Location: intervertebral discs, wedges in the knee joint, insertion of tendon on patella.

FUNCTIONS OF CARTILAGE TISSUE

i. Reducing friction at the joints
ii. Supporting tracheal and bronchial tube
iii. Acting as shock absorbers between vertebrae
iv. Maintaining the shape and flexibility of ear and nose.

FEATURES OF BONE TISSUE

It's a rigid, tough, connective tissue composed mainly of calcified substance. Bones occur in a variety of shapes, have complex internal and external structures and are lightweight yet strong.
Several tissue types make up bone; including the mineralized bone tissue that gives it rigidity and brittleness, collagen fibres that provide slight elasticity, marrow, endosteum, periosteum, nerves, blood vessels and cartilage.
All bones consist of living and dead cells embedded in the mineralized organic matrix called **osteon** that makes up the bone tissue.

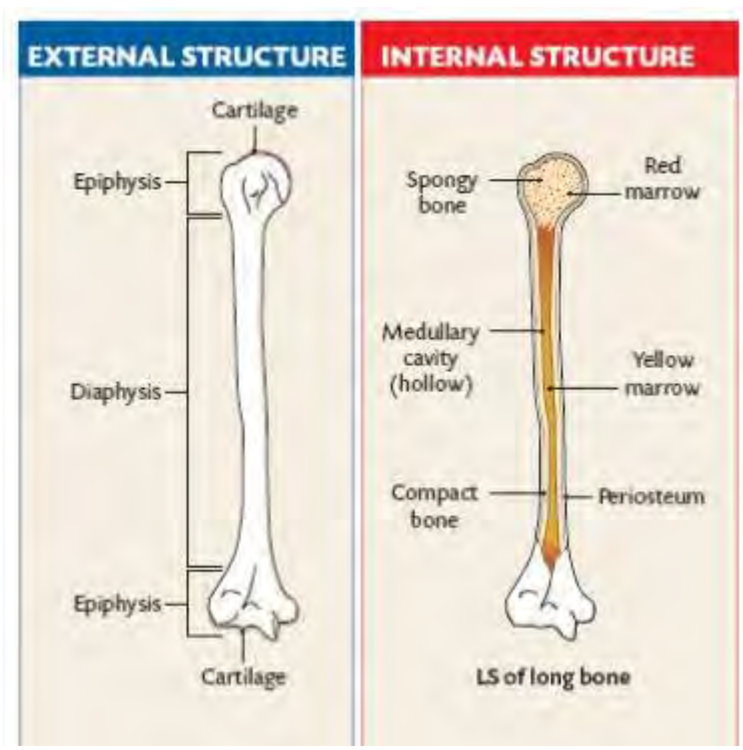
DESCRIPTION OF BONE STRUCTURE

a. **External structure**

A tough, fibrous, vascularised connective tissue called **periosteum** encloses a **compact** inner layer.
The **epiphyses** (ends of bone) are usually expanded while the **diaphysis / shaft** (portion between two epiphyses) is slightly narrow.
Each epiphysis is covered by articular cartilage.

b. **Internal structure**

Filling the interior of the bone is the **cancellous** or **spongy bone or trabecular bone** tissue (an open cell porous network), which is composed of a network of rod- and plate-like elements that make room for blood vessels and marrow.
Fatty yellow marrow fills the medullary cavity in the diaphysis while red marrow occurs in the **spongy bone** at the epiphyses.



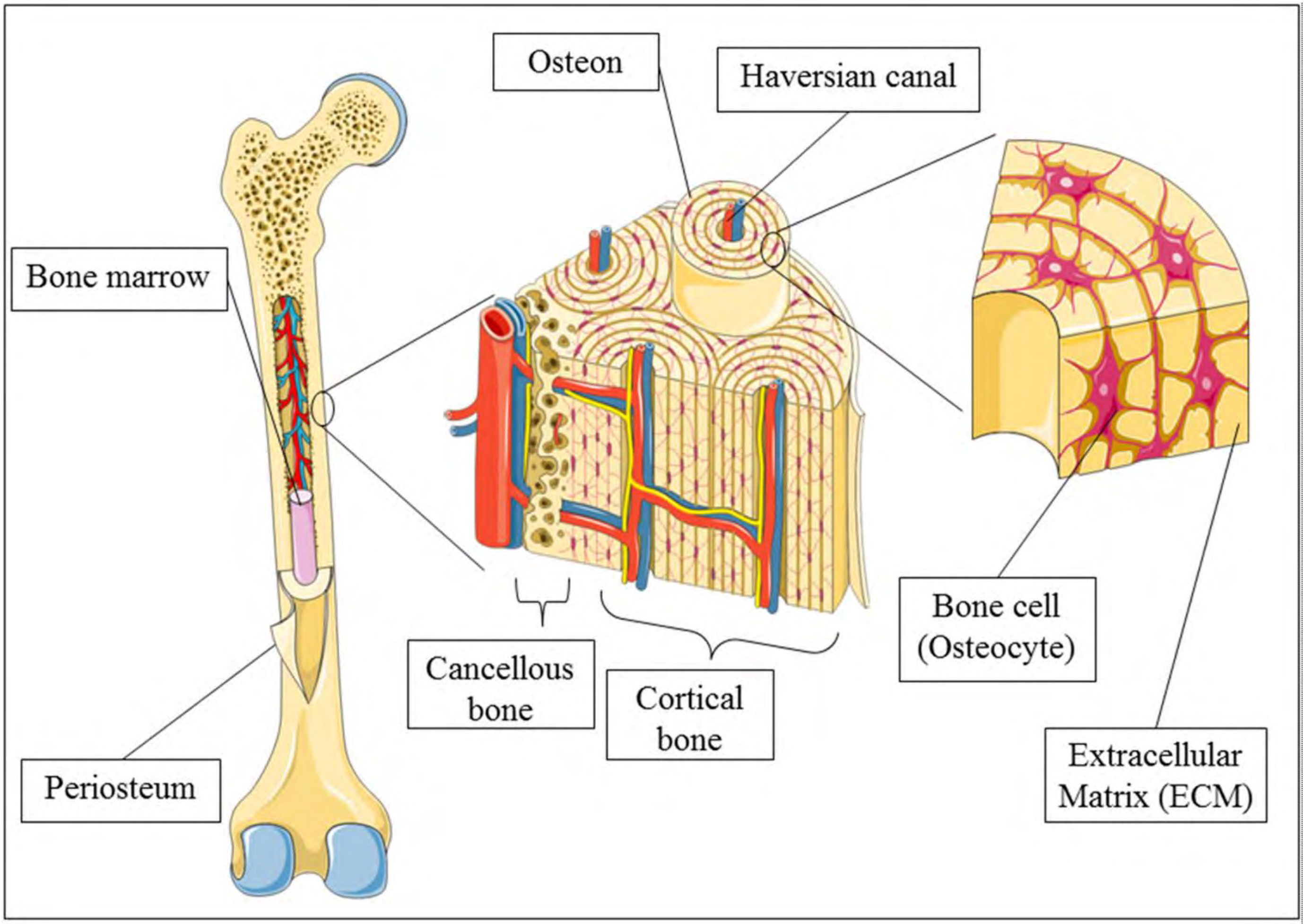
c. **Molecular and Cellular structure**

Bone matrix (**osteon**) of compact bone is made up of organic substances mainly collagen fibres, and inorganic materials like calcium, phosphorus and magnesium salts arranged in concentric layers called **lamellae** around **Haversian canals** that contain blood vessels and nerves.
Osteoblasts (immature bone forming cells) and **Osteoclasts** (bone breakdown cells) are located at the bone surface.
Osteocytes (mature bone forming cells) occupy **lacunae** (spaces in the lamellae) and bear many **canaliculi** (fine protoplasmic extensions) that span across lacunae.

Osteocyte functions include, to varying degrees;

i. formation of bone
ii. matrix maintenance
iii. calcium homeostasis
iv. act as mechano-sensory receptors (regulating the bone's response to stress and mechanical load)

NB: Osteoclasts are closely related to macrophages



BONE GROWTH AND DEVELOPMENT

Bones of the human skeleton form by a process called **Ossification**, which occurs in 3 ways:

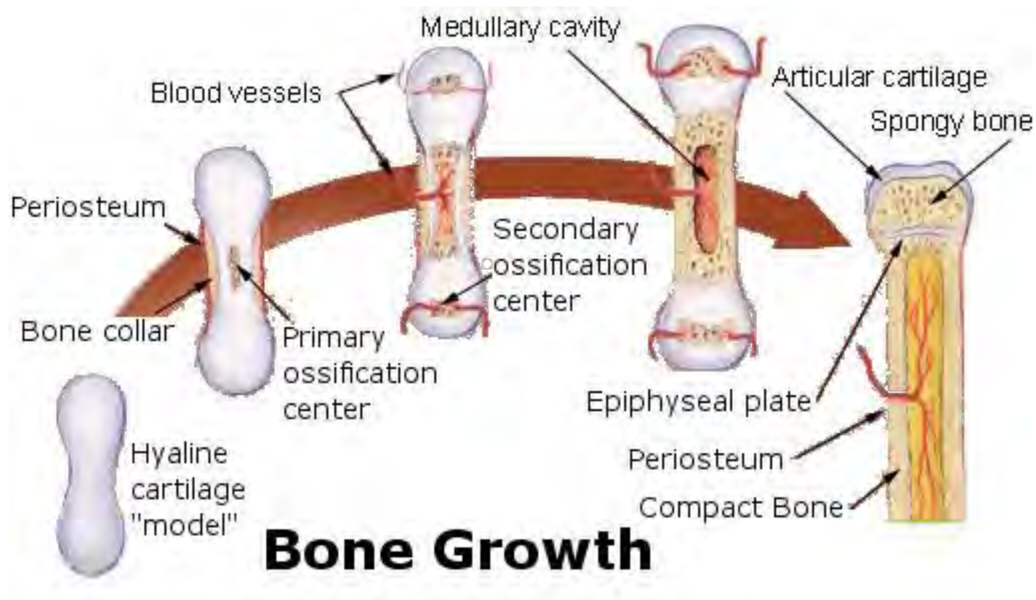
1. Intramembranous ossification; the process by which connective tissue other than cartilage is converted to bone e.g. in the skull, mandible, maxilla, and clavicles

2. Heteroplastic ossification; bone formation in tissues other than the skeleton e.g. Os penis, Os cordis of bovine heart.

3. Endochondral ossification (Intracartilaginous ossification); bone formation from cartilage e.g. the formation of long bones and most other bones in the body

DESCRIPTION OF ENDOCHONDRAL OSSIFICATION

See: **Philips & Chilton, A-level Biol. Revised ed. Pg 218, fig. 27.6**



Endochondral ossification involves the following stages:
Development and growth of the cartilage model i.e. cartilage templates (structures shaped like future bones) form.
Primary ossification centre develops at the diaphysis i.e. the cartilage cells, at the point where ossification is starting, enlarge and arrange themselves in rows. Chondroblasts secrete more matrix in which they get imbedded, so that they become further separated from each other. Calcification of the matrix separates the cells from each other completely by calcified substance which encloses the chondroblasts in cavities thus limiting their nutrition and causing death. The spaces left by dead cells are invaded by blood vessels and osteoclasts which erode the matrix leaving spaces which eventually fuse to form the medullary (marrow) cavity. Blood vessels penetrate the perichondrium to stimulate some of its cells to become osteoblasts which produce a collar of compact bone in the shaft region.
Development of the *secondary ossification centres* in the epiphyses in a manner similar to the development of primary ossification centre.
Articular cartilage forms and **epiphyseal discs** with actively dividing cells remain in the epiphyses, until the bone attains the desired length and then the discs disappear.

NB: In long bones the epiphyseal plate / discs (a plate of cartilage) remains through adolescence at the junction between epiphysis and diaphysis), which is a site of bone elongation.

BONE REMODELING

Adult human bones experience continual remodeling i.e. there is reabsorption followed by replacement of bone with little change in shape. **Osteoclasts** (mature bone breakdown cells) degrade worn-out cells and deposit calcium in the blood, followed by the disappearance of osteoclasts and the destruction they would have caused is repaired by osteoblasts (immature bone forming cells). As the osteoblasts absorb calcium from blood to form a new bone, some of them get caught in the matrix they secrete and are converted to osteocytes (mature bone cells)
The purpose of bone remodeling is to regulate calcium ion levels in blood, repair micro-damaged bones (from everyday stress) but also to shape and sculpture the skeleton during growth.

OSTEOPOROSIS

This is a bone disorder during which bone mineral density is reduced, bone micro architecture is disrupted, and the amount and variety of non-collagenous proteins in bone is altered due to bone synthesis exceeded by bone absorption.
Osteoporosis is increased by:

- advancing age
- high alcohol consumption
- decreased oestrogen levels in women
- smoking
- low calcium, protein and fluoride intake
- reduced physical exercise.

HOW STRUTURE IS RELATED TO FUNCTION IN COMPACT BONE

1. Bone matrix (**osteon**) is made up of organic substances mainly collagen fibres, and inorganic materials which provide great tensile strength.
2. There is continual remodelling which enables compact bone to respond to mechanical stress of varying loads placed on it.
3. **Haversian canals** contain blood vessels for efficient supply of nutrients to and draining of wastes from bone cells.
4. Osteocytes (mature bone forming cells) bear many **canaliculi** (fine protoplasmic extensions) that span across lacunae to improve on material exchange between the bone cells.
5. Bundles of collagen fibres originate from the bone surface and act as a firm base for tendon insertions.

MAIN FUNCTIONS OF BONES

A. Mechanical

i. They protect internal organs, e.g. the **skull** protects the brain, the **rib cage** protects the heart and lungs.
ii. They provide a frame work to keep the body supported.
iii. Bones, skeletal muscles, tendons, ligaments and joints function together to generate and transfer forces to cause movement.
iv. Bones in the ear (ossicles) transmit vibrations that result in hearing.

B. Synthetic

Bone marrow, located within the medullary cavity of long bones and interstices of cancellous bone, produces blood cells in a process called **haematopoiesis.**

C. Metabolic

i. Bones act as reserves of minerals important for the body, most notably calcium and phosphorus.
ii. Mineralized bone matrix stores important growth factors such as insulin-like growth factors, transforming growth factor, e.t.c.
iii. The yellow bone marrow acts as a storage reserve of fatty acids.
iv. Bone buffers the blood against excessive pH changes by absorbing or releasing alkaline salts.
v. Bone tissues can also store heavy metals and other foreign elements, removing them from the blood and reducing their effects on other tissues. These can later be gradually released for excretion
vi. Bone controls phosphate metabolism by releasing fibroblast growth factor – 23, which acts on kidneys to reduce phosphate reabsorption.
vii. Bone cells also release a hormone called osteocalcin, which contributes to the regulation of blood glucose and fat deposition. **Osteocalcin** increases both the insulin secretion and sensitivity, in addition to boosting the number of insulin-producing cells and reducing stores of fat

COMPARISON OF BONE AND CARTILAGE

Similarities

– Both bone and cartilage consist of living cells and extracellular matrix

- Cells reside in lacunae in both.
- Both are capable of growth.
- Both have collagen fibres

Differences

CHARACTERISTIC	CARTILAGE	BONE
Mechanical properties	Stiff but flexible and incompressible	Rigid and brittle.
Innervation	Lacks nerve stimulation	Has nerve fibers
External covering	Covered by perichondrium	Covered by periosteum
Nature of growth	There is both **appositional growth** (addition of new cells and matrix onto the outside of the growing structure) and **interstitial growth** (cell division and secretion of new matrix within an established structure). ●Mature cartilage is relatively permanent.	There is only **appositional growth** (addition of new cells and matrix onto the outside of the growing structure) ● Internal remodelling (continual destruction and renewal) occurs throughout life.
Internal anatomy	Cartilage is compact, no marrow ● Occurs in 3 forms; hyaline, fibro-cartilage and elastic cartilage. ●No lamellae, no Haversian canals. ●No Haversian systems. ●Matrix is gel-like and non calcified ● Chondrocytes are spherically-shaped. ● Avascular (no blood vessels). ● Matrix allows tissue fluid diffusion.	Most mature bones have a marrow-filled cavity. ●Occurs in 2 forms; compact and spongy bone. ●Organic and inorganic substances are arranged in concentric layers called lamellae around Haversian canals ●Compact bone has lamellae organized into sets of Haversian systems. ● Matrix is highly calcified. ●Osteocytes bear canaliculi (fine protoplasmic extensions). ● Vascular (has blood vessels). ● Matrix impermeable to tissue fluid diffusion.

MUSCULAR TISSUE

Muscular tissue is derived from the mesoderm and is specialised for contraction. It is made up of contractile units called muscle fibres bound in a framework f vascular connective tissue which also provides an anchorage to the skeleton or skin.

TYPES OF MUSCLE

a. Smooth (Involuntary / visceral) muscle

Location: walls of blood vessels; ciliary muscle; erector (arrector) pilli muscle; gastrointestinal, urinogenital and respiratory tracts

Invertebrates with smooth muscle include platyhelminthes e.g. liver fluke, free living flatworms such as planaria, nematodes e.g. round worms, annelids like earthworm.

b. Skeletal (voluntary) muscle

Location: attached to bones, abdominal wall, diaphragm, rectus muscle, under skin and middle ear.

c. Cardiac (heart) muscle

Location: found in the heart only.

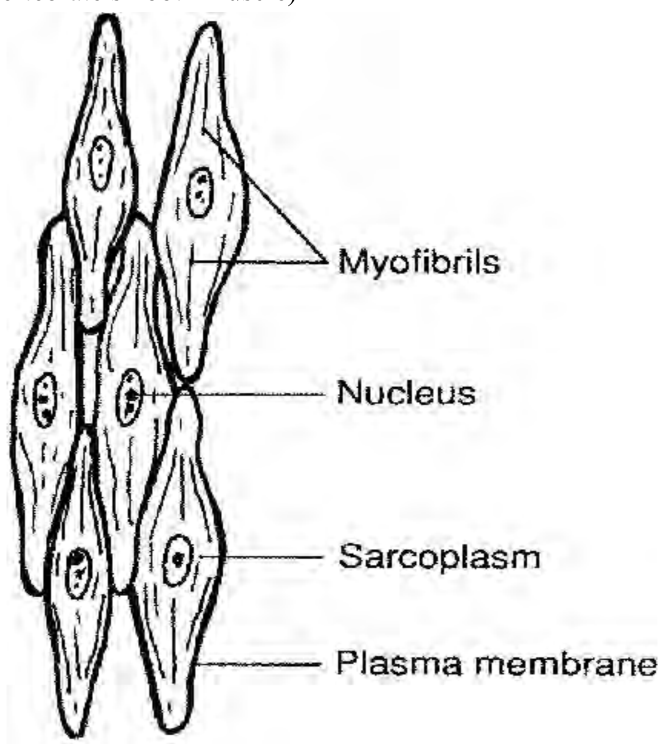
DESCRIPTION OF SMOOTH MUSCLE STRUCTURE

Smooth muscle may be single-unit or multi-unit, in which the fibers are assembled in different ways.
The muscle fibers of the single-unit muscle are densely and irregularly packed together into sheets or bands.
The fibers / cells are long, fusiform shaped (spindle shaped) i.e. broad in the middle and tapering at both ends, mono-nucleate at the broadest central part, are small in diameter, lack visible cross striations, overlapping - run roughly parallel so that the narrower portion of one fiber lies against the wider portion of its neighbour.
The fibers have connections, the plasma membranes of two neighbouring fibers form gap junctions that act as low resistance pathway for the rapid spread of electrical signals throughout the tissue.
The multi-unit smooth muscle fibers have no interconnecting bridges. They are mingled with connective tissue fibers.

NB: Smooth muscle cells are

1. *Similar to fibroblasts in the ability to synthesize collagen, elastin, and proteoglycans (like fibroblasts).*
2. *Responsible for involuntary movements e.g. peristalsis*

N.P.O. Green; etal, Biol. Sci. (vertebrate smooth muscle)



NOTE

i. Although involuntary, smooth muscles do respond to psychological states such as stress and excitement.
ii. While slow to contract, they have the ability to remain contracted for long periods of time.
iii. Smooth muscles exhibit spontaneous contractile activity (doesn't require nervous stimulation). Thus, the innervation that is present acts to modify the contractile activity rather than initiate it

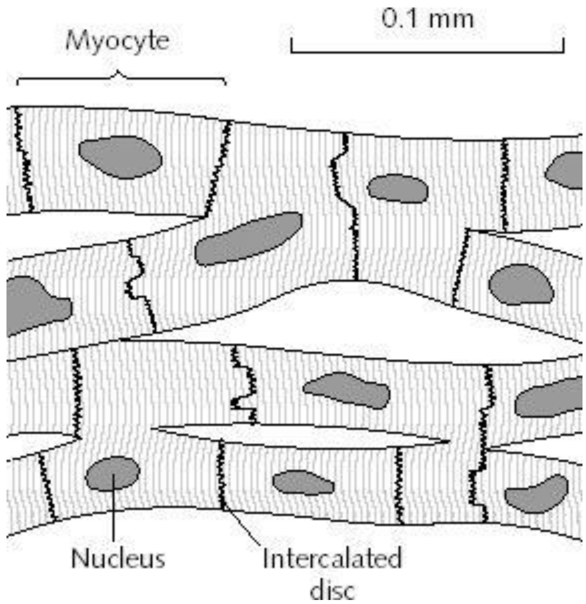
DESCRIPTION OF CARDIAC MUSCLE STRUCTURE

- Each fibre consists of cells which are arranged in columns, cylindrical, small, short, may be mono- or bi-nucleate (**syncytium**), striated, branched (Y-shaped).
  ***Syncytium**: A multinucleated mass of cytoplasm that is not separated into individual cells.*

- Adjacent columns interlock by oblique connections called **intercalated disks.**
- The ultra structure shows that myofibrils and mitochondria occupy about 85% of the heart cell volume; the rest contains the sarcolemma (cytoplasm of muscle cells excluding the myofibrils), transverse tubules, sarcoplasmic reticulum (smooth endoplasmic reticulum of muscle cells).

NB: Intercalated disks are a unique and prominent feature of cardiac muscle. Their two main functions are to act as a glue to hold muscle cells to avoid separation when the heart contracts; and to allow an electrical connection between the cells, enabling synchronized contraction of cardiac tissue.

Draw from: **Michael Roberts, et.al. Adv. Biol. Pg. 233 fig. 14.10 *or* N.P.O. Green; et.al, Biol. Sci.** (structure of cardiac muscle)



DESCRIPTION OF SKELETAL MUSCLE STRUCTURE

A. *As seen under the light microscope*

●Skeletal muscle is highly compartmentalized, and each compartment is treated as a separate entity.

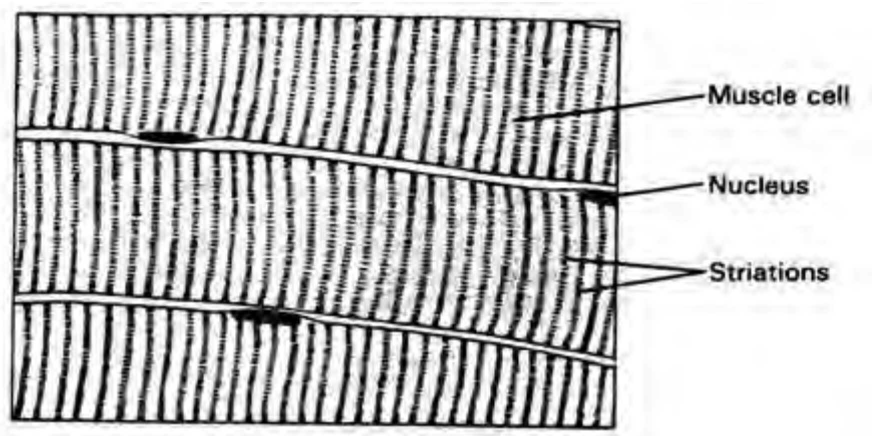
●The entire muscle is a collection of several muscle fibre bundles enclosed by connective tissue called **epimysium**.

●One entire muscle contains many muscle fibres surrounded by connective tissue called **perimysium**. Within each perimysium, each muscle fibre is enclosed by **endomysium,** a meshwork of collagen fibres and fibroblasts**.**

●Each striated muscle cell (**muscle fiber**) has a fluidy **sarcoplasm** (cytoplasm), bound by the sarcolemma (plasma membrane), is multinucleate (is a **syncytium)**, the nuclei are at the periphery of the cell, it is long, cylindrical, with longitudinally oriented threadlike structures-**myofibrils** exhibiting periodic cross striations repeatedly.

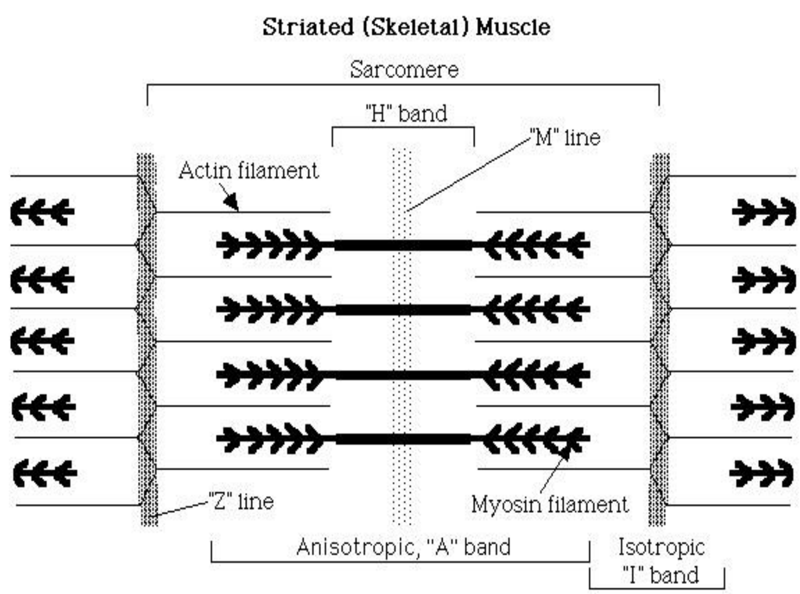
●**The sarcoplasm** contains Golgi apparatus, many mitochondria, ribosomes, sarcoplasmic reticulum (endoplasmic reticulum), glycogen, lipid droplets, and myoglobin.

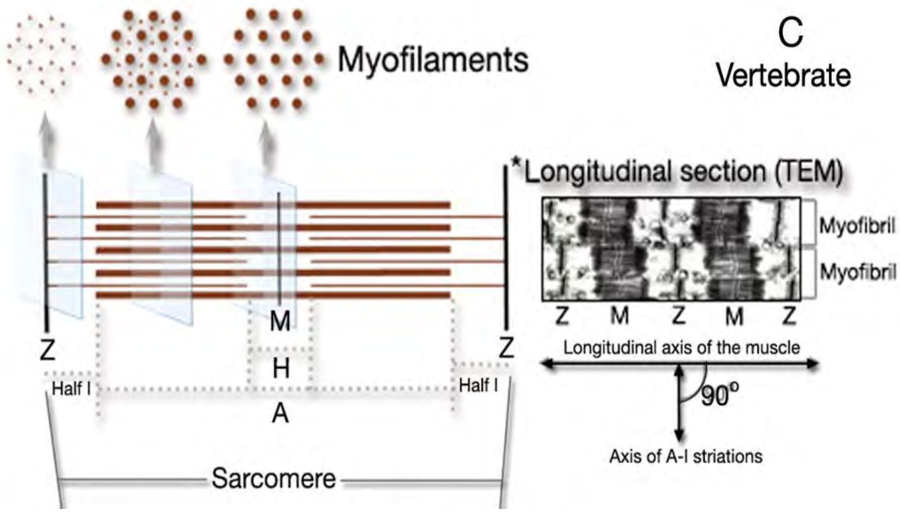
Draw from: **Michael Roberts, et.al Adv. Biol. Pg. 405 fig. 23.3 A &B *or* Vines & Rees, Plant & Anim. Biol. Vol. 1. Pg 586 fig. 20.29 (a), (b), (c) *or* N.P.O. Green; etal, Biol. Sci.** [fine structure of skeletal muscle - **(a) &(b)]*or* M.B.V. Roberts; stud. Manual, 2nd ed. Pg. 196 fig. 20.3 A & C**



B. ***As seen under the electron microscope***

1. One myofibril shows alternating cross striations, which are light (isotropic) and dark (anisotropic) bands.
2. One myofibril is made of filamentous proteins, myosin (thick) and actin (thin) overlapping to give the striated appearance.
3. Actin filaments are anchored at their midpoints to a structure called the **Z-line.**
4. The region from one z-line to the next is called a **sarcomere,** which is the functional unit of muscle contractions.
5. Sarcomeres are sections of myofibrils that are separated from each other by areas of dense material called **"Z discs".**
6. **"A band"** is the relatively darker area within the sarcomere that extends along the total length of the thick filaments.
7. **"H zone"** is the region in which there are only thick filaments, and no thin filaments at the centre of the A band of each sarcomere.
8. The **"I band"** is the region between adjacent A bands, in which there are only thin filaments, and no thick filaments.
   (Each I band extends across two adjacent sarcomeres)





HOW SKELETAL MUSCLE STRUCTURE RELATES TO FUNCTIONING

1. Each muscle cell is long to allow considerable contractile effect.
2. The fibres are parallel to each other so that contractile effect is transmitted along same axis.
3. Muscle fibres taper at both ends for interweaving to improve muscle strength.
4. Muscle fibres have very many mitochondria to provide much ATP needed in muscle contraction.
5. Cross bridges enable actin and myosin to fit into each other to allow sliding during muscle contraction.
6. There is a rich supply of blood vessels to supply nutrients to and drain wastes away from the cells.
7. There is much myoglobin for storage of oxygen needed very much in aerobic respiration during exercising.
8. There are motor end plates to allow innervation that result in contraction.
9. There is a dense network of internal membrane system (including transverse tubules) for calcium ion storage which is very much needed in muscle contraction.
10. Reciprocal innervation ensures antagonistic muscular contraction to bring about realistic movement

MECHANISM OF MUSCLE CONTRACTION AND RELAXATION

The sliding filament theory / Ratchet mechanism

Arrival of an action potential at the synaptic terminal of motor neuron causes the influx of Ca^{2+} ions from the extracellular fluid into the presynaptic neuron's cytosol followed by exocytosis of synaptic vesicles containing acetylcholine.

Acetylcholine diffuses across the synaptic cleft of neuromuscular junction to depolarize the sarcolemma and trigger an action potential that spreads through the transverse tubules, causing the sarcoplasmic reticulum to release Ca^{2+} into the sarcoplasm.

(i.e. Na^+ / K^+ channels open, permeating more rushing in of Na^+ but less trickling out of K^+ and so the sarcolemma becomes more positively charged)

Ca^{2+} binds to troponin of actin to cause cooperative conformational changes in troponin-tropomyosin system, releasing the inhibition of actin and myosin interaction.

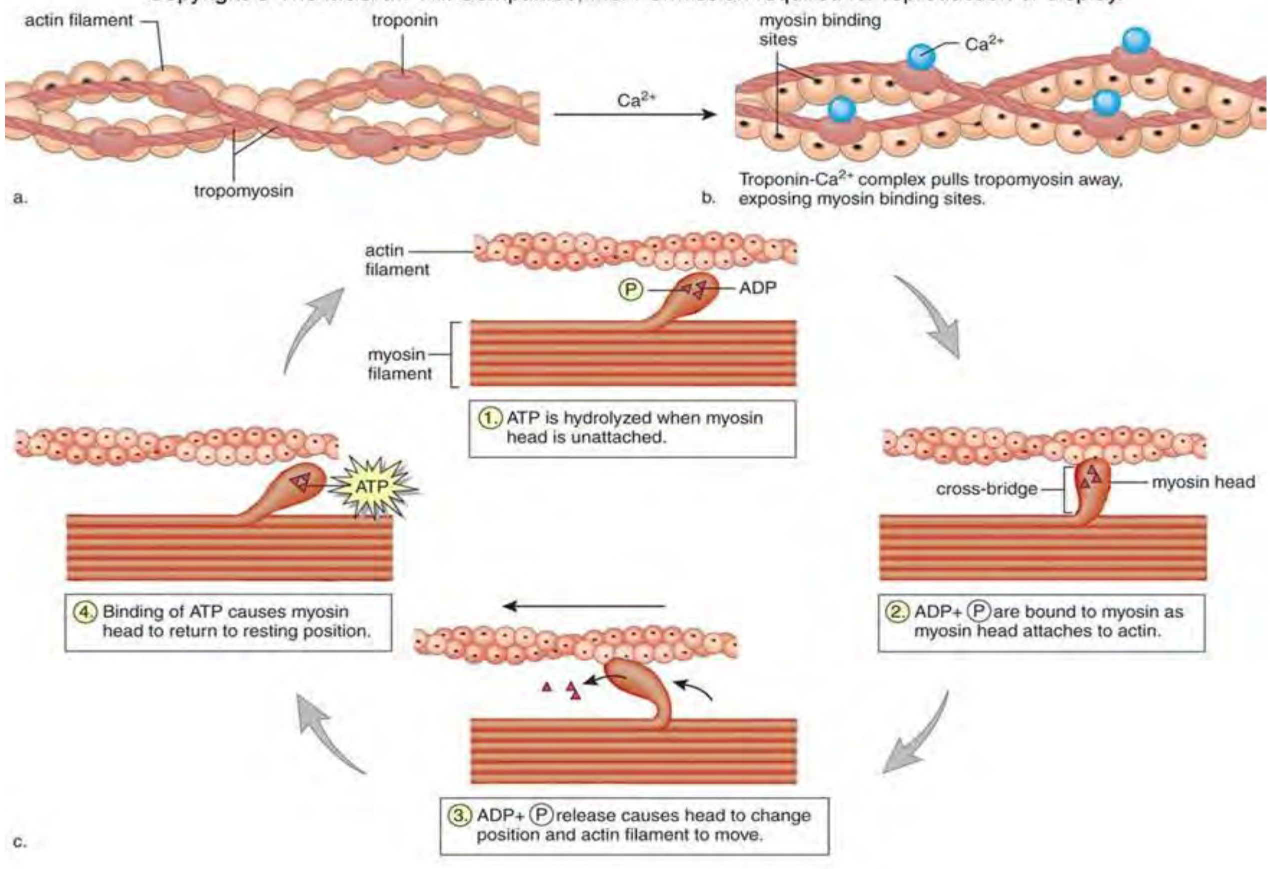
Myosin hydrolyses ATP and undergoes a conformational change into a high-energy state. The myosin head binds to actin forming a cross-bridge between the thick and thin filaments. This is accompanied by energy release, ADP and inorganic phosphate dissociation from myosin. The resulting relaxation entails rotation of myosin head, which flexes the cross bridge to move actin a small distance pulling the Z-bands towards each other, thus shortening the sarcomere and the I-band. The collective flexing of many cross bridges by myosin to move actin in the same direction results in muscle contraction.

Relaxation

Ca^{2+} are pumped back into sarcoplasmic reticulum.

Again ATP binds to myosin head, detaching it from actin as the myosin head "recharges" or "cocks".

Troponin-tropomyosin regulated inhibition of actin and myosin interaction is restored
Finally, active tension disappears and the rest length is restored. This completes the contraction-relaxation cycle.
NB: high concentration of Ca^{2+} in the sarcoplasm coupled with lack of ATP results in Rigor mortis (see below for details on this phenomenon)
Draw from: Michael Roberts, Pg. 409 fig. 23.8 & pg. 410 A & B *or* N.P.O. Green; etal [excitation-contraction coupling] *or* Clegg and Mackean, Adv. Biol Princ & Applic.Pg491 fig. 22.20 (down-right hand)



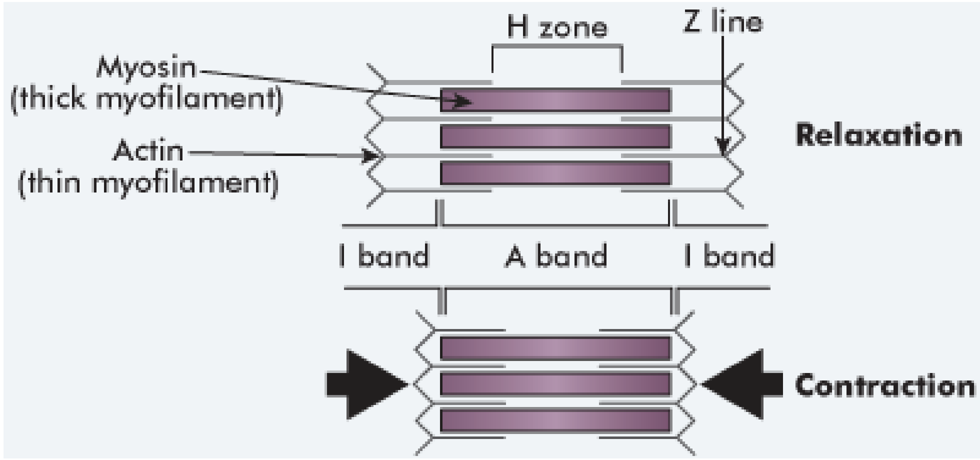
EVIDENCE OF SLIDING FILAMENT THEORY (OBSERVATIONS) IN A CONTRACTING MUSCLE FIBRE

i. Each sarcomere shortens / Z lines come closer
ii. I Band shortens
iii. H zone shortens greatly (usually disappears).
iv. A Band remains unchanged in length during contraction or relaxation
v. Cross bridges are visible between actin and myosin in photomicrographs.

CHANGES DURING MUSCLE PASSIVE STRETCHING

i. Sarcomere lengthens
ii. I Band elongates.

Draw from: Michael Roberts, Pg. 408 fig. 23.6 A & B (lower-lower) *or* M.B.V. Roberts, functional approach



WHAT IS EXCITATION-CONTRACTION COUPLING?

The sequence of events by which an action potential in the plasma membrane of the muscle fibre leads to force production via an increase in intracellular calcium and cross bridge formation and turn-over

RIGOR MORTIS

The progressive stiffening of the body that occurs several hours after death as a result of failure of contracted muscles to relax.

CAUSES RIGOR MORTIS

Upon death, there's increased permeability of sarcoplasmic membrane to Ca^{2+}, allowing Ca^{2+} influx into the sarcoplasm hence promoting the cross-bridge formation between actin and myosin (muscle contraction).
However efflux of Ca^{2+} from the sarcoplasm into the sarcoplasmic reticulum fails because of lack of ATP since respiration would have ceased. This causes the muscle to remain contracted, relaxing only when decomposition starts.
NB: Interestingly, meat is generally considered to be tenderer if it is consumed after expiry of rigor mortis.

WHAT IS A NEUROMUSCULAR JUNCTION (NMJ) / MOTOR END PLATE?

A single synapse or junction made between one motor neuron and one muscle fiber.
Draw and label from: N.P.O. Green; etal, Biological Science [motor end-plate at a neuromuscular junction] *or* Clegg and Mackean, Adv. Biol Princ & Applic.Pg489 fig. 22.16 (extreme bottom – right hand corner)

COMPARISON OF SMOOTH, SKELETAL AND CARDIAC MUSCLES

Characteristic	Smooth	Skeletal	Cardiac
Sarcolemma	Absent	Present	Present
Myofibrils	Not visible	Visible	Fairly visible
Fibre length	Fairly long	Very long	Very short
Diameter of fibre	Very narrow	Wide	Fairly wide

Branching of fibre	None	None	Branched
Composition of fibre	Mononucleate	Multinucleate syncytium	Mono- or binucleate
Position of nucleus	Central	Peripheral	Central
Cross striations	Absent	Present	Present
Intercalated discs	Absent	Absent	Present
Contraction	Slow, rhythmic, sustained	Rapid, powerful, not sustained	Moderately rapid, with rests between contractions. Not sustained
Control of contraction	Impulses from CNS not essential for contraction	Neurogenic; contracts only in response to motor impulses from CNS	Myogenic; but rate controlled by autonomic nervous system

ATP PRODUCTION DURING MUSCLE CONTRACTION

1. **Phosphorylation of ADP by creatine phosphate** provides a very rapid means of forming ATP at the onset of contractile activity.

Phosphocreatine + ADP $\longrightarrow$ ATP + creatine

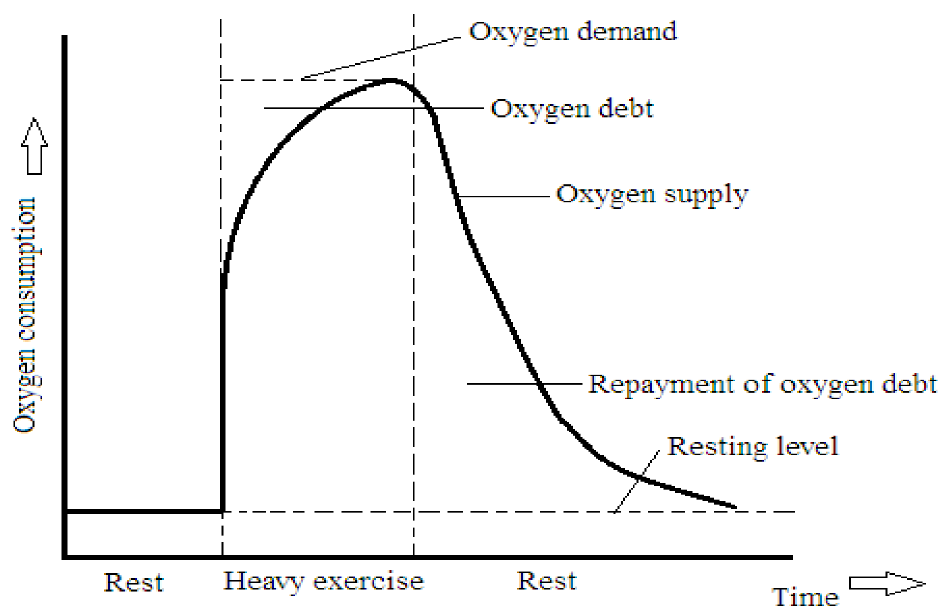
In a resting muscle fiber, the concentration of ATP is always greater than ADP leading to the reformation of creatine phosphate.

2. **Oxidative phosphorylation of ADP in mitochondria** during aerobic respiration (need myoglobin for oxygen transfer)
3. **Substrate phosphorylation of ADP in glycolysis during anaerobic respiration** to form lactic acid in the process. The accumulation of lactic acid is associated with muscle fatigue, which is broken down later in the liver using oxygen to constitute what is called **oxygen debt.**

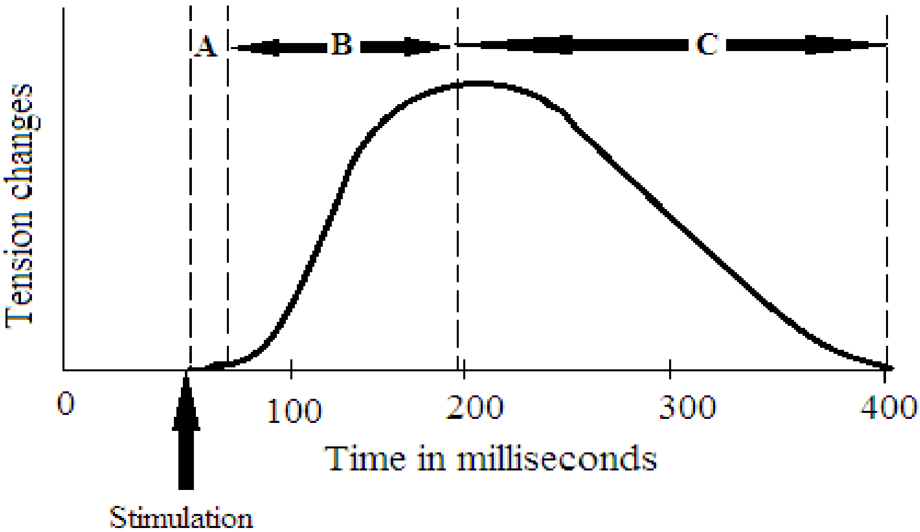
WHAT IS THE OXYGEN DEBT?

The amount of extra oxygen required by muscle tissue to oxidise lactic acid and replenish depleted ATP and phosphocreatine following vigorous exercise.

Oxygen uptake at rest, in heavy exercise and in recovery

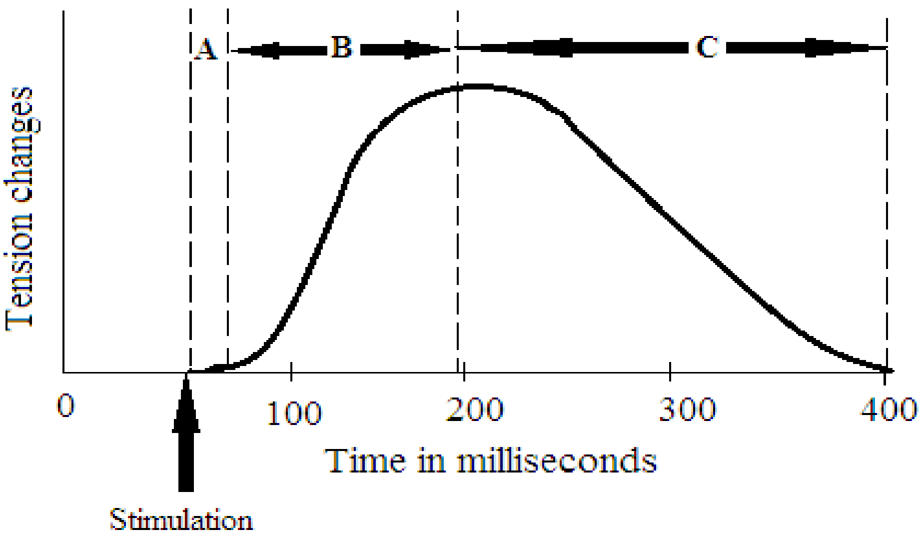


MUSCLE STIMULATION FREQUENCY AND THE LENGTH-TENSION RELATIONSHIP



Phases **A, B, C** together represent one muscle twitch

What each phase represents
A: Latent period
B: contraction phase
C: relaxation phase



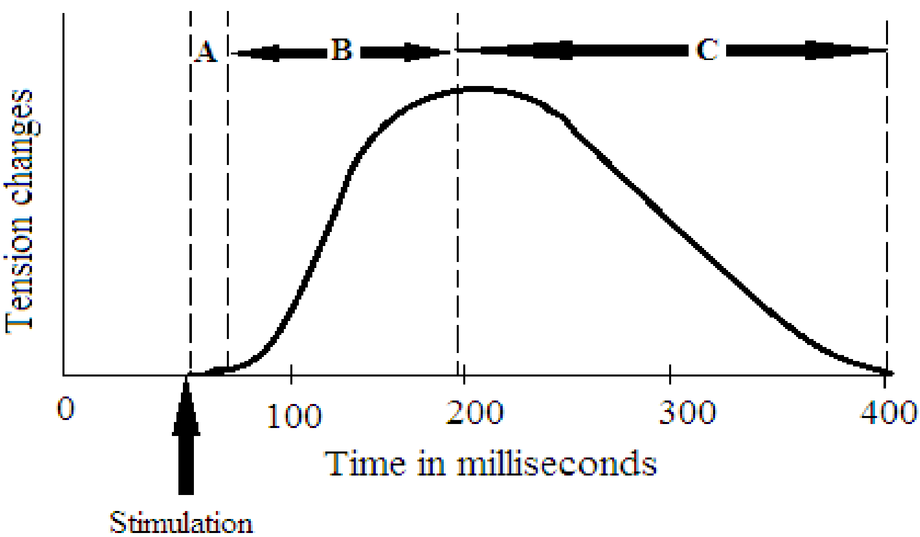
fibre contraction. During latent period,

MUSCLE

ıs, provided the stimulus is of threshold

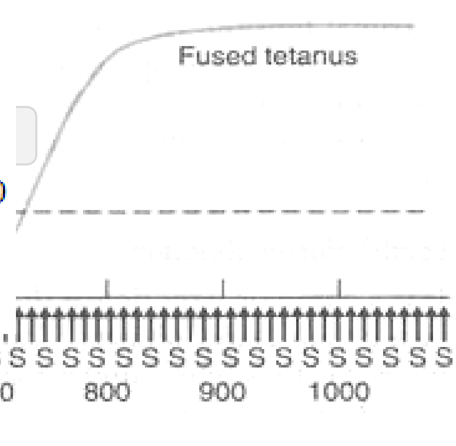
al amount of contraction depends on the

(for nervous tissue), one muscle fiber (for



ction potential is triggered.

little time and **later no time** for complete



MECHANICHAL SUMMATION / UNFUSED TETANY

This is the condition whereby multiple stimulation of a muscle or nerve before full relaxation results in a series of twitches added together to produce a more sustained contraction.

TETANY

This is the smooth, sustained maximal contraction of a muscle in response to rapid firing by its motor neuron.

NB: the ability of a muscle to undergo tetany depends upon its refractory period.

REFRACTORY PERIOD

This is a short period of in-excitability in a nerve or muscle cell following stimulation.

OR The amount of time it takes for an excitable membrane to be ready for a second stimulus once it returns to its resting state following excitation.

MUSCLE FATIGUE

This is a condition of the muscle in which its capacity to produce maximum voluntary action, or to perform a series of repetitive actions, is reduced.

Muscle fatigue results when there is tissue oxygen deprivation, glycogen or Phosphocreatine depletion, and increased level of blood and muscle lactic acid in an exercised muscle.

LOCOMOTION IN FISH

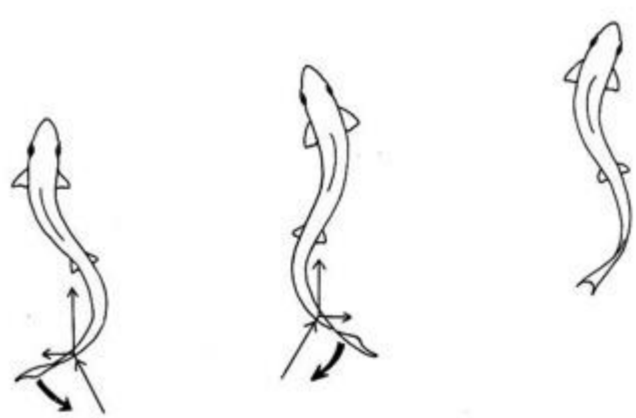
Most fish have a line of muscle blocks, called myomeres (myotomes**),** along each side of the vertebral column. To swim, they alternately contract one side and relax the other side in a progression which goes from the head to the tail. In this way, an undulatory locomotion results, first bending the body one way in a wave which travels down the body, and then back the other way, with the contracting and relaxing muscles switching roles. They use their fins to propel themselves through the water in this swimming motion.

DIAGRAMS SHOWING THE EFFECTS OF MUSCLE CONTRACTION IN FISH

Michael Roberts, Pg. 427 fig. 24.13B *or* M.B.V. Roberts, functional approach

DIAGRAM SHOWING THE FORCES GENERATED BY THE LASHING ACTION OF THE TAIL

Michael Roberts, Pg. 427 fig. 24.13 C *or* M.B.V. Roberts, functional approach *or* N.P.O. Green; etal, Biological Science [forces exerted by the caudal fin of a dog fish as it lashes from side to side**]**



When myotomes on one side of body contract, those of the opposite side relax at the same time, the tail pushes against the water towards the contracted side, generating a thrust that can be resolved into 3 forces:

a. The **reaction force** which is the reaction of the water against the pushing action of the water and is equal and opposite to the thrust.
b. The **forward (propulsive) force** that pushes the fish forward.
c. **Lateral drag (sideways) force** that swings the tail towards the left and the head towards the right and thus slows (drags) the fish. Lateral drag is countered by:
   i. Pressure of the water against the head
   ii. Pressure of the water against the dorsal fin,

   both pressure enable the fish to move forward without swinging from side to side very much i.e. the lateral forces essentially cancel out.

TYPES OF LOCOMOTION IN FISH

Anguilliform locomotion

Occurs in eels and other fish with elongated bodies

Draw from: **M.B.V. Roberts, functional approach**

The myotomes of entire body undergo alternate contractions on one side and relaxation on the other side in a progression which goes from the head to the tail causing anterior to posterior lateral undulations resulting in thrust forces that cause forward propulsion.

Carangiform locomotion

Occurs in elasmobranchs like dog fish and teleosts like perch

Draw from: **M.B.V. Roberts, functional approach**

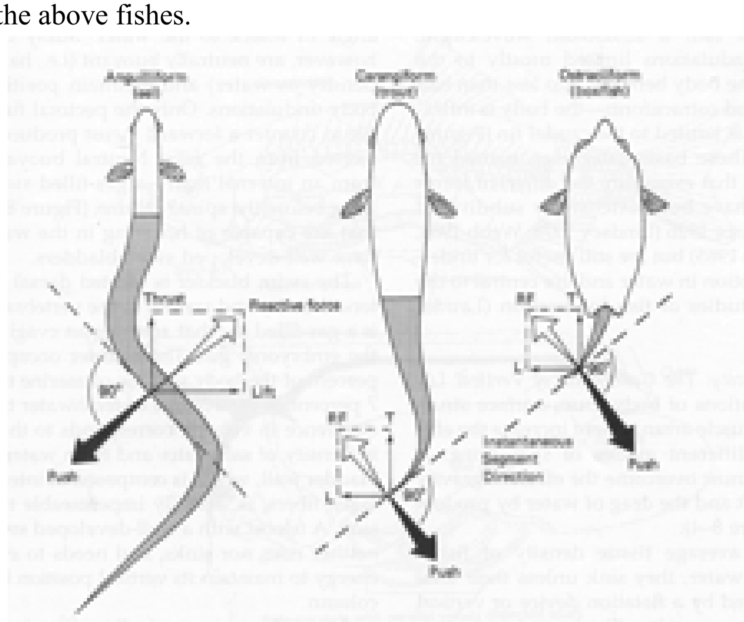
The myotomes on one body side contract while those of the opposite side relax at the same time, resulting in side to side lashing of the posterior half of body to generate the thrust forces that cause forward propulsion.

Ostraciform locomotion

Occurs in Ostracium (trunk fish)

Forward propulsion results from thrust forces that are generated by the vigorous side to side flapping of a very short tail against the water.

NOTE: Many invertebrates like round worms and some flagellated cells including spermatozoa exhibit the principles involved in propulsion as in the above fishes.



SUPPORT (BUOYANCY) IN FISH

In **Elasmobranchs** like dog fish, sharks, skates and rays, support is provided by **constant swimming** using **fins.**

These fish's density is slightly greater than that of water and must swim continuously to avoid sinking.

How they are adapted to this:

i. possession of large pectoral and pelvic fins which direct swimming upwards
ii. possession of **heterocercal** tail i.e. a tail with smaller upper and larger lower lobes for generating much lift and forward motion

During forward motion the pectoral and pelvic fins are all held at a slight angle to the body, generating a force which can be resolved into upward and backward components.

The upward component force lifts the anterior end up in the water while the backward component force called **backward drag** being small only slightly impedes motion and is easily suppressed.

In **Teleosts like perch** support is provided by adjusting air in the **swim bladder** which may be **;**

i. a closed swim bladder filled with gaseous mixture of oxygen, nitrogen and carbondioxide – all secreted from blood vessels in its wall. ***The closed type is the most common in bony fish.***
ii. an open swim bladder having a duct connection to the pharynx and operates as follows:

Expulsion of air from the swim bladder increases the fish's relative density and it sinks. If it's to stay afloat, the fish first swims to the water surface then gulps air into the swim bladder to decrease the specific gravity so that the body weight equals the weight of water displaced.

NB: Unlike in elasmobranchs, the teleost's pectoral fins are only moved at will e.g. during braking and steering but do not act as main support structures.

Draw from: **M.B.V. Roberts, functional approach** (forces acting at the anterior end of fish during active swimming)

INSTABILITY IN FISH

Rolling, this is the rotation of the body about its longitudinal axis. It's **counteracted** by dorsal, ventral (vertical) and pectoral (horizontal) fins acting like stabilizers on a ship.

Pitching is tendency of the fish's anterior end to plunge vertically downwards (transverse axis rotation). It's **counteracted** by;

i. pectoral fins and to a lesser extent pelvic fins
ii. dorsal-ventral flattening of the body in the dogfish.

Yawing is the lateral side to side deflection of the anterior part of the body resulting from the propulsive action of the tail (vertical axis rotation). It's **counteracted** by;

i. general massiveness of anterior part of body
ii. water's pressure against the body side
iii. water's pressure against the vertical fins (dorsal, anal, ventral fins)
iv. lateral flattening (compression) of the body

ADAPTATIONS FOR LOCOMOTION IN FISH:

i. Fish's body is fusiform-shaped (spindle shaped) and laterally compressed to reduce water resistance during swimming
ii. The slippery layer of mucus on the skin reduces water resistance during swimming
iii. The presence of many rayed-fins enables the fish to swim and also maintain its balance / stability in water
iv. The lateral line enables sensitivity of fish and also functions as an echo location process for the fish to identify its surroundings while in water
v. Scales are arranged in a head-to-tail direction to reduce water resistance during swimming
vi. The swim bladder in bony fish maintains buoyancy
vii. Extensive blood vascular system supplies oxygen and nutrients to the muscle tissues for contraction and drain away wastes
viii. Body is highly muscular to generate great propulsive force against water resistance
ix. The neuromuscular activity is highly coordinated resulting in **reciprocal innervation.**

LOCOMOTION IN BIRDS

EXTERNAL AND INTERNAL FEATURES THAT ADAPT BIRDS TO LOCOMOTION

i. Birds' bodies are streamlined (spindle shaped) during flight for overcoming air-resistance
ii. The endoskeleton is hollow **(pneumatized)** to reduce weight, and many unnecessary bones are fused into a single structure e.g. some vertebrae, pelvic girdle, finger and leg bones.
iii. Many unnecessary parts like urinary bladder and pinna are totally eliminated while reproductive organs (testes, ovaries and oviducts) are kept tiny during non-breeding seasons to reduce weight.
iv. The sternum bone is extended into a large keel, for the attachment of large powerful flight muscles.
v. The forelimbs have become modified into wings which act as aerofoil, generating lift when passed into air.
vi. The vanes of the feathers have hooklets called **barbules** that zip them together, giving the feathers the strength needed to hold the airfoil.
vii. The major wing bones have internal **strut-like reinforcements** to prevent buckling during stress.
viii. The respiratory system is extensive and very efficient in supplying muscles with oxygen to facilitate much energy release needed in muscle contraction during respiration
ix. Their efficient circulatory system powered by a four-chambered heart enables fast supply of oxygen and food to the body tissues and carries away wastes.
x. The large brains that are connected to eyes coupled with high-speed nerve transmission enable quick decision making especially when landing.
xi. The large size of eyes in relation to their body size, coupled with eye keenness enable high visual acuity without crashing into objects.
xii. The flight muscles of most birds contain oxygen-carrying compounds, (myoglobin and cytochrome) for storing much oxygen which facilitates the release of much energy needed in muscle contraction.
xiii. They have high body temperature which maintains the high metabolic rate for generating much energy.

FLIGHT BIOMECHANICS (FLIGHT BIOPHYSICS)

THE BIRD'S WING AS AN AEROFOIL / AIRFOIL

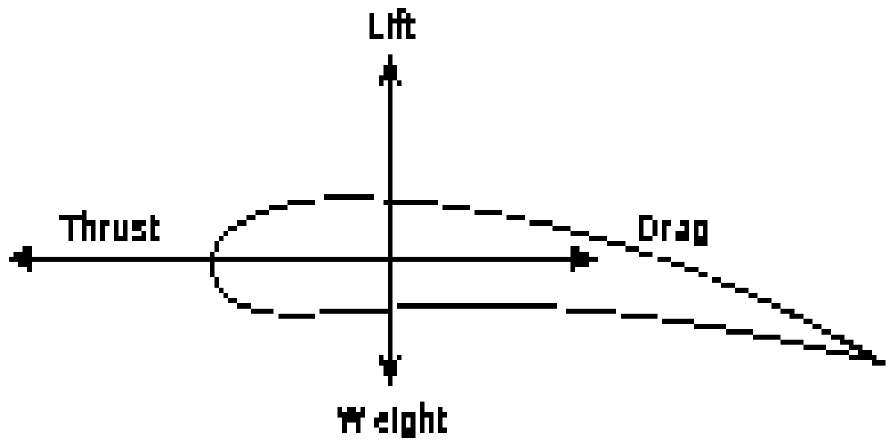
Aerofoil / Airfoil: A structure whose shape and orientation provides lift, propulsion, stability, or directional control in a flying object.

An airfoil-shaped body moved through a fluid (air or liquid) produces an **aerodynamic force,** which is the resultant force exerted on a body by the air in which the body is immersed, and is due to the relative motion between the body and the fluid.

PRINCIPLES OF THE AEROFOIL

The **four** basic forces at work when a bird is in flight are: **Lift, Thrust, Gravity (weight)** and **Drag** of which only **gravity** is **constant** (unchanging), the remaining three forces can be altered.

NB: Weight is a body force, not an aerodynamic force.



If a bird is t

a. **Weight:** a continuous downward force (force of gravity) that flying objects must constantly overcome to stay in the air (aloft). The opposing force of gravity is lift.
b. **Thrust:** the force generated by flapping the wings which moves the bird forward and opposes drag. To move forward the flying bird must overcome drag. Drag can be reduced by streamlined shapes.
c. **Drag (air resistance):** is the friction between the moving object and the air, opposing thrust. The more streamlined or aerodynamic an object is, the less air resistance the object generates.

Drag is higher when;

i. The surface area of the object exposed to the fluid flow is big (the reason why birds spread out their wings to slow down or land)
ii. The object is moving faster (or the relative fluid flow is faster)
iii. The fluid has more momentum, or inertia (high fluid viscosity and density e.g. at low altitudes)

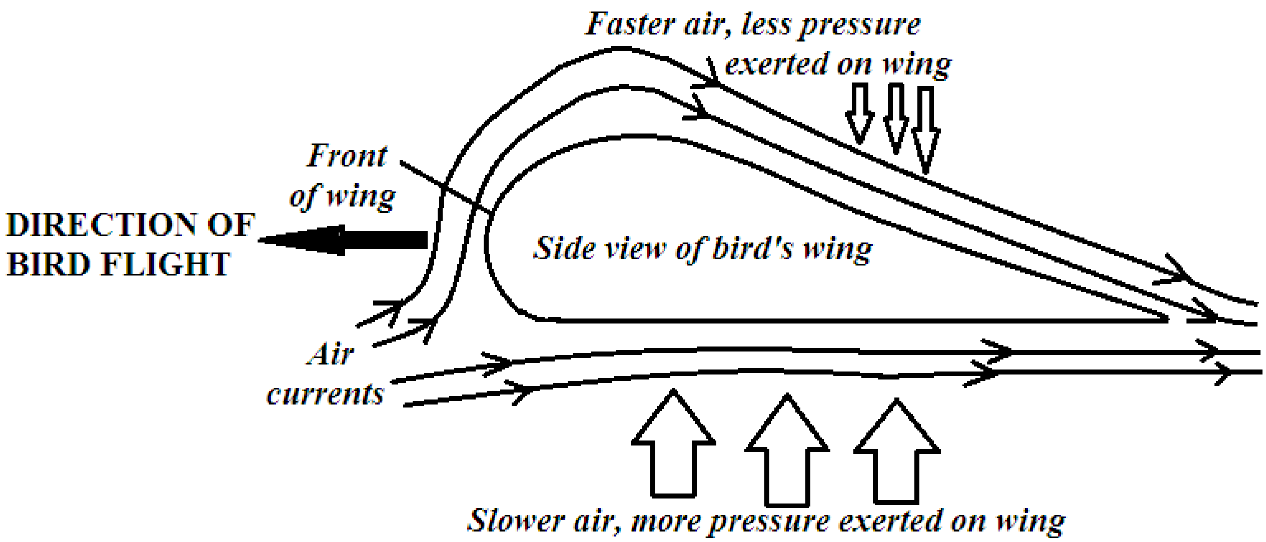
Note that air at lower altitudes has more oxygen to facilitate muscle contraction of wings, but is thicker and therefore increases drag.

d. **Lift:** the mechanical aerodynamic force generated by the wings which directly opposes the (gravity) weight of a bird. Lift is higher when
    i. The area of the bottom of the wing is larger
    ii. The animal is moving faster
    iii. Fluid viscosity and density are higher

NOTE: Thicker air increases thrust by supplying the wings with more mass to move.

BERNOULLI'S PRINCIPLE AND AEROFOIL OPERATION

Daniel Bernoulli's theorem: an increase in the speed of a fluid produces a decrease in pressure and a decrease in the speed produces an increase in pressure.



As the bird flies, the air splitting at the front of the wing must rejoin at the back of the wing so as not to create a vacuum. The curved top surface being longer forces the air to move faster across the top than the bottom. Faster moving fluids create less pressure, so the bottom of the wing creates greater pressure than the pressure exerted downward above the wing, resulting in a net **upward force,** or **lift.**

The faster air moves across the wing the more lift the wing will produce, so moving it through the air by flapping increases this airflow and thus increases lift. The bird doesn't propel air underneath its wing; instead it cuts into the air with the leading edge to obtain the flow over the surface that it requires.

Why does the slower moving air generate more pressure on the wing than the faster moving air?

In calm air, the molecules are moving randomly in all directions. However, when air begins to move, most (but not all) molecules are moving in the same direction. The faster the air moves, the greater the number of air molecules moving in the same direction. So, air moving a bit slower will have more molecules moving in other directions. In the case of a wing, because air under the wing is moving a bit slower than air over the wing, more air molecules will be striking the bottom of the wing than will be striking the top of the wing.

EFFECT OF ANGLE OF ATTACK ON LIFT

The angle of attack: the angle at which the leading edge of wing cuts into the forward airflow.

NB: It is erroneously thought that the angle of attack is the angle of the aerofoil relative to the ground, yet it's the angle of the **wing** relative to **airflow**

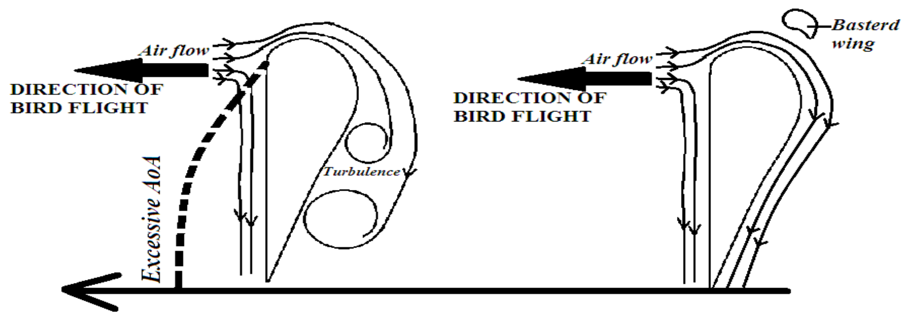
Increasing the angle of attack increases the volume of air diverted over the wing and leads to an increase in lift, but this is at the expense of drag which quickly increases.

In a bird excessive angle of attack results in air turbulence / interruption of airflow **(eddy)** above the wing which causes a flight stall e.g., when taking off or landing.

Air turbulence above the wing in birds is prevented by **(1)** the **alula** (bastard wings) and **(2)** end-feathers, both of which serve as sloths to smoothen the airflow above the wings. The alula is formed by 3 or 4 feathers attached to the first digit.

NB

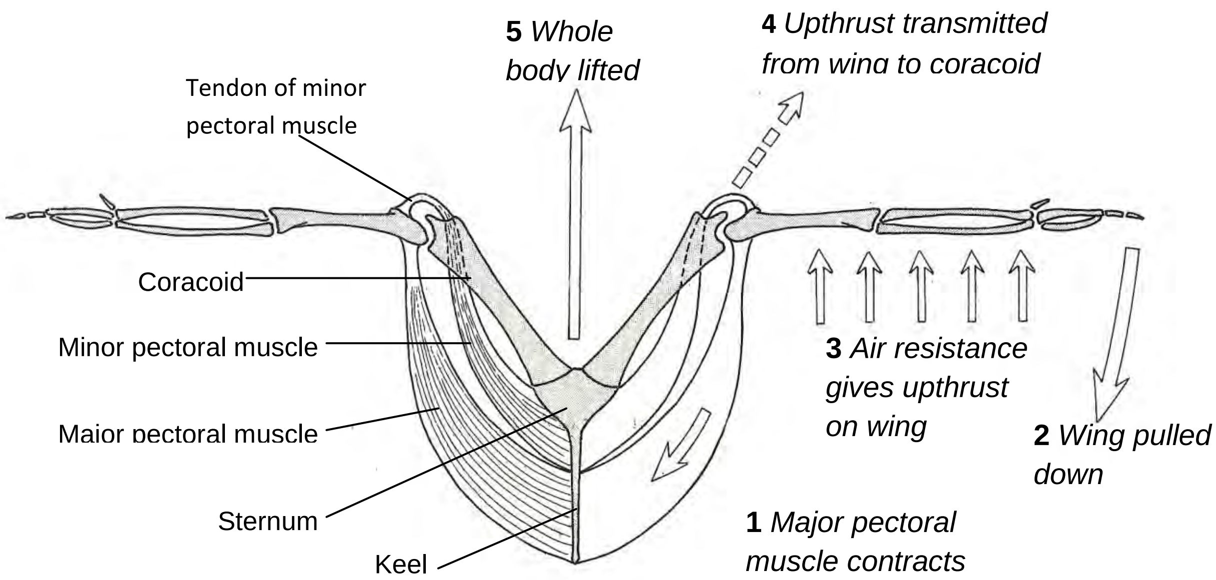
Angle of attack decreases with increasing speed



Forward airflow

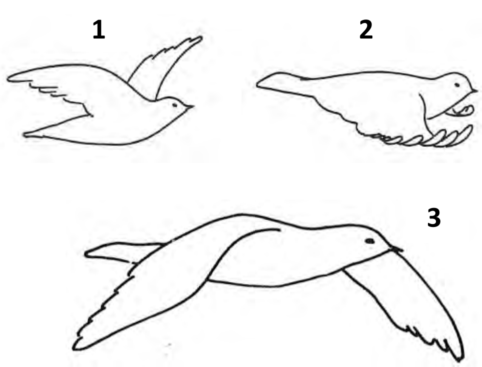
MECHANISM OF FLAPPING FLIGHT

Attachment of flight muscles in a bird's thoracic region



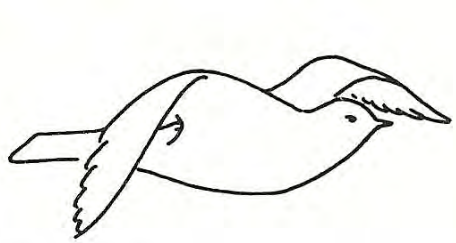
Explanation based on studies of domestic pigeons *(Columba livia)*

Down stroke

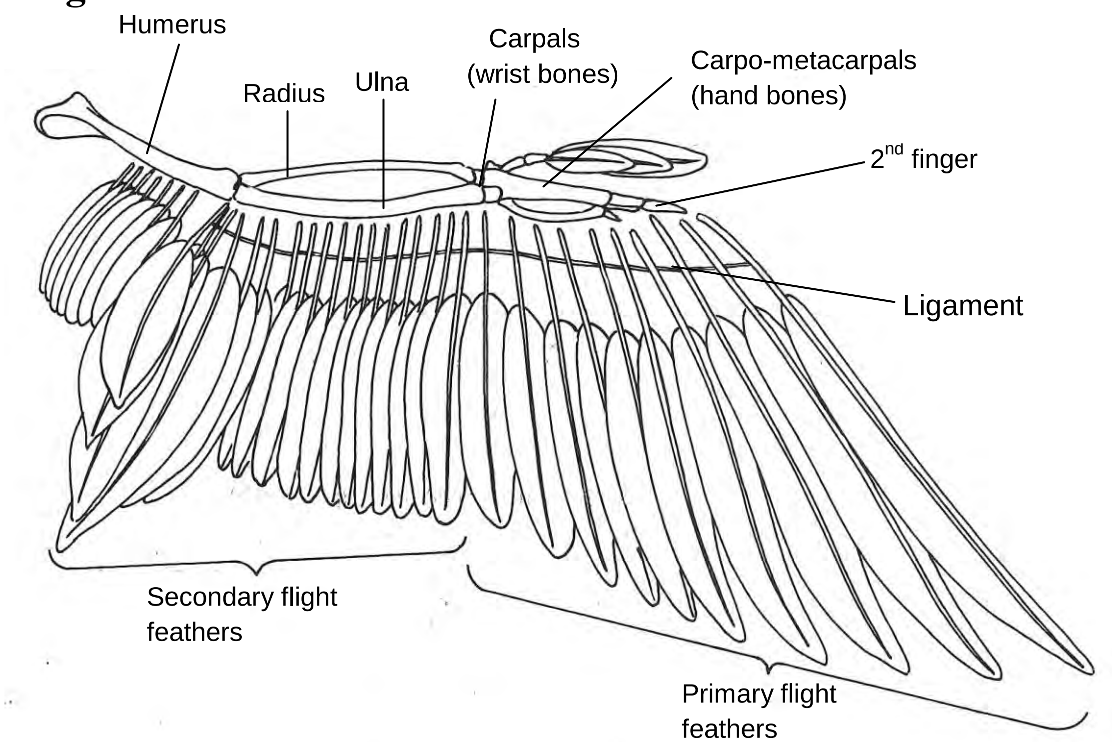


1, **2** and **3** are successive stages of down stroke.

pectoralis major muscle and relaxation of **pectoralis minor** muscle at the same time. Abduction (elevation / rising) of humerus to a nearly vertical position and also retraction (pulling back) of wings to a horizontal position backwards. Full extension of the elbow and wrist joints, **pronation** (dropping of leading edge relative to the trailing edge) and slight protraction (stretching out) slightly of humerus. This is followed by the downward and forward movements of wings until they lie parallel to and infront of the body. This is accomplished in part by

	protraction (stretching out) of the humerus.
Upstroke Flexed wrist reduces air resistance. 	The up-stroke of the wing is much more rapid than the down-stroke. ●During upstroke the pectoralis minor muscles contract, the **pectoralis major** muscles relax at same time, the wings are first adducted (elevated/raised), bent at the wrist, the arm is rotated slightly so that the leading edge is higher than the trailing edge, thus reducing the air resistance and the rush of air lifts the wing. **NB: The secondary feathers provide much of the lifting force and the primaries most of the forward thrust.**

Bird wing structure



QUESTIONS TO EXPLORE

a. Compare gliding and flapping flights

b. Compare the flight mechanism of insects and birds

Please read and summarise notes about joints of the mammalian skeleton

THE HUMAN SKELETON

HIGHLIGHTS OF THE HUMAN SKELETON
●Consists of **206 bones** at adulthood, about **300** at childhood. ●The **longest bone** in the human body is the **femur**; the **smallest** is **stirrup** in the ear. ● Males have slightly thicker and longer legs and arms; females have a wider pelvis and a larger space within the pelvis. ●It is divided into **axial** and **appendicular skeletons** **Axial skeleton** is composed of 80 bones divided into five parts; the human skull, the ossicles of the middle ear, the hyoid bone of the throat, the rib cage, and the vertebral column. The word Axial, taken from the word axis refers to the fact that the bones are located close to or along the central axis of the body. **Appendicular skeleton** is composed of 126 bones divided into six major regions: ●Pectoral Girdles (4 bones) - Left and right Clavicle (2) and Scapula (2). ●Arm and Forearm (6 bones) - Left and right Humerus (2) (Arm), Ulna (2) and Radius (2) (Fore Arm). ●Hands (58 bones) - Left and right Carpal (16) (wrist), Metacarpal (10), Proximal phalanges (10), Middle phalanges (8), distal phalanges (10), and sesamoid (4). ●Pelvis (2 bones) - Left and right os coxae (2) (ilium). ●Thigh and leg (8 bones) - Femur (2) (thigh), Tibia (2), Patella (2) (knee), and Fibula (2) (leg). ●Feet (56 bones) - Tarsals (14) (ankle), Metatarsals (10), Proximal phalanges (10), middle phalanges (8), distal phalanges (10), and sesamoid (4). The word appendicular is the adjective of the noun appendage, which itself means a part that is joined to something large.

FEATURES OF THE MAIN FORE AND HIND LIMB BONES

Main fore limb bones

1. Humerus

Its upper end bears a head which articulates with the **glenoid cavity** of the scapula to form **a ball and socket joint** at the shoulder.

At its lower end is the **trochlea** which articulates with the fore arm to form **a hinge joint** at the elbow.

2. Ulna

Its upper end bears the **olecranon process** just after the elbow joint which when the arm is straightened prevents any further backward movement of the fore arm hence dislocation doesn't occur.

Therefore the olecranon process is considered to be the most important structure on the ulna bone.

It also bears a notch, the **sigmoid notch** close to the upper end which articulates with the **trochlea** of the humerus.

HIND LIMB OF A TYPICAL MAMMAL

Draw from: **Michael Roberts, Pg. 423 fig. 24.8** ***left or*** **M.B.V. Roberts, functional approach**

Hind limb bone

FEMUR

●At its upper end is a round head which articulates with the **acetabulum** of pelvic girdle to form a ball and socket joint at the hip.

●Three (3) **trochanter processes** protrude below the head and provide points of attachment for the thigh muscles.

●The lower end bears two (2) processes called **condyles** which articulate with tibia to form a **hinge joint** at the knee.

A **patella groove** (where the **knee cap** is located) separates the femur's 2 condyles.

ILLUSTRATION OF THE HIND LIMB ACTION IN PROPULSION *Draw from:* **Michael Roberts, Pg. 424 fig. 24.9A** ***left or*** **M.B.V. Roberts, functional approach**

BIPEDALISM

Bipedal locomotion is walking, running, and standing on two rear limbs.

During walking, the calf muscle of the right limb contracts to raise the right heel, causing the ball of foot to exert a contact force on the ground, generating the **ground reaction force** (GRF) which thrusts the body forward and slightly upwards.

The weight of the body shifts to the left foot which is still in contact with the ground to provide support.

Extension of the right limb results in its heel touching the ground first to bear the body weight transferred to it from the left side.

Further forward movement of the body exerts backward pressure against the ground through the right big toe.

As the right leg bears the body weight, the left heel is raised and the whole sequence repeats.

This sequence in which the right leg alternates with the left, heel-and-toe action continues until walking ceases.

The GRF is composed of the lift force which thrusts the body off the ground and the forward force that propels the body forward - the magnitude of which depends on the angle between the ground and the main axis of the limb.

A large angle between the ground and the main axis of the limb (e.g. 90^0) results in large lift force which thrusts the body vertically upwards with no forward force, a small angle causes a relatively bigger forward force and small upward lift.

NB: The ball of the foot is where the toes join with the rest of the foot.

WHY MAN STANDS ON SOLES BUT GENERALLY SPRINTS ON TOES

Standing on soles increases the surface area for supporting the body weight in a balanced posture.

Sprinting on toes increases the effective length of limbs, enabling taking longer strides that propel the body forward over a greater distance and at a faster pace even if the speed of limb movement remains the same.

WHY SPRINTERS CROUCH (BEND DOWN) BEFORE TAKEOFF

Crouching creates a small angle between the ground and the main axis of the limb, resulting in maximum forward thrust rather than upward lift, hence propelling the body a greater distance forward.

QUADRUPEDALISM

Quadruped: an animal especially a mammal, having four limbs all specialized for walking, except humans and the birds.

Tetrapod: a vertebrate animal having four limbs e.g. amphibians, reptiles, birds and mammals.

NB: A Tetrapod may use only two limbs for walking

Contraction of extensor muscle causes each limb to act as a lever by extending and exerting a backward force that presses the foot against the ground thus thrusting the animal forward and slightly upwards, because an equal and opposite force called **reaction force** is transmitted along the length of the limb against the body while **contraction of flexor muscle** pulls the limb forward and lifts it off the ground.

During **walking**, only one limb is raised at a time, the other three remain anchored to the ground to provide tripod support / stability in a sequence of leg movement as follows**: left forelimb, right hind limb, right forelimb, left hind limb** *[N.P.O. Green; etal, Biol Sc]* **or LH; LF; RH; RF [***Michael Roberts Pg 426& FA]*

During **slow running**, tripod support is lost because the two forelimbs are moved together followed by the two hind limbs in the sequence of; **left forelimb, right forelimb, right hind limb, left hind limb.**
During **maximum speed running,** a dog uses its back to attain speed. All the four legs may be lifted off the ground at the same time, with alternate upward arching of the back coupled with rear feet extension in front of the front feet and the front feet extension behind the rear feet, and full extension of the vertebral column coupled with full extension of front legs forward and rear legs rearward to increase stride length.

SUCCESSIVE STAGES IN THE DIAGONAL LOCOMOTORY PATTERN OF A WALKING TETRAPOD
Draw from: **Michael Roberts, et.al. Page 426 fig. 24.11B (walking)** or **M.B.V. Roberts, functional approach**
ASSIGMENT
Summarize the importance of centre of gravity Check: **Michael Roberts,** etal Page 426

PLANTIGRADE, DIGITIGRADE AND UNGULIGRADE LOCOMOTION

●Plantigrade locomotion: walking with the podials and metatarsals flat on the ground e.g. humans, raccoons, opossums, bears, rabbits, kangaroo, mice, pandas, rats and hedgehogs.
●Digitigrade locomotion: walking on the toes with the heel and wrist permanently raised e.g. birds, wolf, dog, coyote, cat, lion, elephant (semi-digitigrade)
●Unguligrade locomotion: walking on the nail or nails of the toes (the hoof) with the heel/wrist and the digits permanently raised. Ungulates include horse, zebra, donkey, cattle, bison, rhinoceros, camel, hippopotamus, goat, pig, sheep, giraffe, okapi, moose, deer, antelope, and gazelle.

Advantage of a plantigrade foot: because of a large surface area, it offers stability and able to bear much weight.
Disadvantage of a plantigrade foot: locomotion is of slow speed because of many bones and joints in the foot making the leg heavier at the far end.
Advantage of digitigrades: They are generally faster and quieter than other types of animals

QUESTION

Explain why in terrestrial tetrapods it is advantageous to have limbs below and parallel to the sides of the body e.g. in mammals rather than lateral to the body e.g. in amphibians

Consult with: Clegg and Mackean, Adv. Biol Princ. & Applic. Page 495

SUPPORT IN TERRESTRIAL PLANTS

Importance of support in terrestrial plants

1. Enables holding leaves to receive maximum sunlight for photosynthesis
2. Enables exposing flowers in the most suitable position for pollination
3. Allows holding fruits and seeds in the possible favourable position for dispersal
4. Maintains plant shape.

SUPPORT MECHANISMS IN DICOTYLEDONOUS PLANTS

1. Turgidity of cells

Turgor pressure: outward pressure from the inside of a fully turgid cell.

When fully turgid, the close packing of parenchyma cells in cortex and pith of the stem causes them to press against one another to keep herbaceous plants and young woody plants erect. Absence / insufficient water reduces turgor pressure causing loss of support due to wilts.

2. Mechanical tissues

(a) Collenchyma cells have uneven thickened cellulose cell walls, and are alive.

(i) Collenchyma tissue provide flexible support (a mechanical function) to stems and leaves, enabling withstanding the lateral force of the wind.

(ii) The walls of collenchyma cells can be deformed by pressure or tension and retain the new shape even if the pressure or tension ceases.

Location: in young plants, herbaceous plants and some organs such as leaves

(b) Sclerenchyma fibres and sclereids have lignified cell walls and are dead when mature.

(i) The tough and elastic cell wall of elongated fibres allow the cell to be deformed but can snap back to their original size and shape when the pressure or tension is released.

(ii) Provides great tensile or compressional strength in plants parts, such as in the vascular tissues of stems and roots and the bundle sheath of leaves

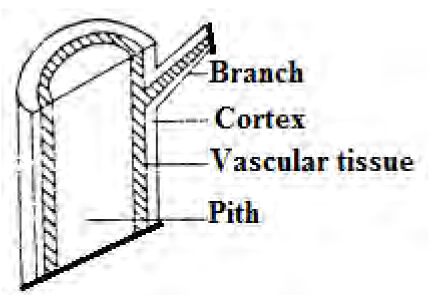
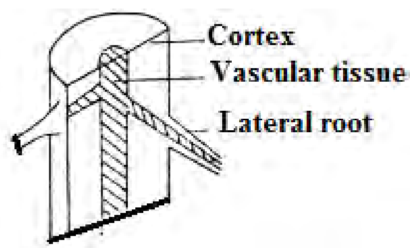
(iii) Support the tree while the elasticity allows the trunk and the branches to sway in the wind without breaking.

Location: found in small groups in cortex, pith, phloem and shells of coconuts.

3. Vascular tissues (xylem vessels and tracheids)

These are dead, the cell walls are lignified and thickened

(i) They provide the greatest mechanical strength to resist bending in the stem, reinforce against pulling in the root and are the most important supporting cells in the veins of leaves.

(ii) Vascular tissue in young dicot stems	(iii) Vascular tissue in dicot roots
Location: at the root periphery (near edge) This increases the resistance to the bending stresses produced by wind or the passing animals.  	***Location:*** at the root centre The solid cylinder increases the tensile strength to resist the uprooting force produced by the pulling effect of wind. The solid cylinder also provides sufficient incompressibility against the longitudinal compression by the load from overhead and against the lateral pressure exerted by the surrounding soil 

(iv) In leaves, vascular tissue is located at the upper side of midrib and lateral veins, and it extends throughout the leaf surface. This enables resisting tearing forces acting on the leaves blade by the wind.
(v) In woody stems, the lignified secondary xylem tissues (known as wood) occupy most part of the woody stem, which makes the stem very hard and rigid to avoid depending on cell turgidity for support

SUPPORT IN AQUATIC PLANTS (HYDROPHYTES)

Support from buoyancy is provided by:
1. Surrounding water, whose density is much higher than that of air, hence providing a larger upthrust force.
2. Presence of numerous large air spaces (intercellular spaces) in stems and leaves, which form air-filled cavities extending through the tissues, inside to give buoyancy.

Note: When removed from water, most hydrophytes collapse quickly because of having poorly developed (some lack) mechanical tissues (i.e. collenchyma and sclerenchyma) and xylem tissue is reduced, since it is unnecessary (no need to transport water within the body and buoyancy is provided by water for support).

COMPARISON OF SUPPORT IN TERRESTRIAL PLANTS AND HYDROPHYTES

Terrestrial Plants	Aquatic Plants
Require mechanical support because air will not hold up plant structures in the same way that water does.	Density of water is much higher than air, hence providing a larger upthrust force
The presence of collenchyma cells, sclerenchyma cells and the abundant highly lignified thick-walled xylem vessels in terrestrial plants implies that support depends on these specialized thick-walled cells.	No collenchyma and sclerenchyma cells are found in aquatic plants, and the poorly developed xylem vessels indicate that aquatic plants do not depend on these cells for mechanical support.
Small air spaces in stem since air with low density only provides limited support to plants.	There are numerous large air spaces in the stem and the leaf of aquatic plants suggest that aquatic plants depend on the buoyancy **T.S of stem**