LOCOMOTION AND MOVEMENT

- Locomotion is the movement of an animal as a whole from one place to another (L. *locus* = place, *moveo* = to move).
- Locomotion takes several forms such as walking (man), **creeping** (earthworm, lizard), **hopping** (frog, rabbit), **running** (dog, horse), **flying** (insects, birds) and **swimming** (fish, whale).
- Movement is defined as any visible change of position, exhibited either by whole organism or by any part of the body.
- **Study of movement is called kinesiology.**

TYPES OF MOVEMENT

- Cells of the human body exhibit three main types of movements, namely, amoeboid, ciliary and muscular.
  - **Amoeboid movement** is exhibited by specialised cells such as macrophages and leucocytes. This movement is made with the help of **pseudopodia** formed by the streaming of protoplasm. Cytoskeletal elements like microfilaments are also involved in amoeboid movement.
  - **Ciliary movement** occurs in most of our internal tubular organs which are lined by **ciliated epithelium.** Sperms swim in water or in female genital tract by **flagellar movements.**
  - Movement of our limbs, jaws, tongue, etc, requires **muscular movement.** The contractile property of muscles are effectively used for locomotion and other movements by human beings and majority of multicellular organisms.

MUSCLE

- Muscle is a specialised tissue of **mesodermal origin.** About 40-50 per cent of the body weight of a human adult is contributed by muscles. Muscles have special properties like **excitability, contractility, extensibility** and **elasticity.**
- Muscles have been classified using different criteria namely location, appearance and nature of regulation of their activities. Based on their location, three types of muscles are identified: **Skeletal, visceral** and **cardiac.**
  - **Skeletal** muscles are attached to the bones by tendons and help in movement of parts of the skeleton. These muscles are under the control of conscious mind and are called **voluntary muscles.** Under the microscope, these muscles exhibit transverse stripes and hence are designated as **striated muscles.**
  - **Smooth** muscles are **non-striated** and **involuntary muscles.** These are found inside the wall of the hollow visceral organs (*e.g.* alimentary canal, blood vessels, reproductive tract). So, are also called visceral muscles.
  - **Cardiac** muscles are also striated and are not under voluntary control. These occur exclusively in the walls of heart.

SKELETAL MUSCLE

- Each muscle fibre is elongated and syncytial (multinucleate). Its membrane is called **sarcolemma** and its cytoplasm is called **sarcoplasm.** The myofibrils are arranged in a number of sections of functional units of contraction called **sarcomeres.** The endoplasmic reticulum *i.e.*, **sarcoplasmic reticulum** of the muscle fibres is the storehouse of calcium ions. A characteristic feature of the muscle fibre is the presence of large number of parallelly arranged filaments in the sarcoplasm called **myofilaments or myofibrils.**
- The sarcomeres are delineated by a very thin and comparatively dense **Z-line** (Krause's membrane). A dark anisotropic band **(A-band)** is present in the centre of the sarcomere. Adjacent to this lies a light isotropic band **(I-band).** At the centre of the A-band, a comparatively less dark zone called **H-zone** (Hensen zone) is present. In the centre of H-zone, **M-line** is present formed by threads that connects the myofilaments. The Z-line is located at the centre of the I-band.

Structure of contractile proteins

- Each sarcomere is a bundle of fine longitudinal myofilaments of two types :– **Primary myofilaments** and **secondary myofilaments.** Primary myofilaments are formed of the protein called **myosin.** Myosin (thick) filament is a polymerized protein. Many monomeric proteins called **meromyosins** constitute one thick filament. Each meromyosin has two important parts, a globular head with a short arm and a tail, the former being called the **heavy meromyosin (HMM)** and the latter, the **light meromyosin (LMM).** The HMM component, *i.e.*, the head and short arm, projects outwards at regular distance at an angle from each other and from the surface of a polymerised myosin filament. It is known as cross arm. The globular head is an active **ATPase enzyme** and has binding sites for ATP and active sites for actin.

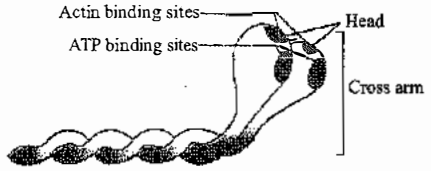

Fig.: Myosin monomer (Meromyosin)

- Secondary myofilaments are composed of **actin** and its regulatory proteins called **tropomyosin** and **troponin.** Actin (thin) filament is made of two 'F' (filamentous) actins helically wound to each other. Two filaments of tropomyosin run close to 'F' actin throughout its length. Troponin is distributed at regular intervals on the tropomyosin. In the resting state, a subunit of troponin masks the active binding sites for myosin on the actin filaments.

Fig.: Actin

MECHANISM OF MUSCLE CONTRACTION

- According to **sliding filament theory** of muscle contraction, the actin and myosin filaments slide past each other with the help of **cross-bridge** to reduce the length of the sarcomeres.
- During muscle contraction, **chemical energy is changed into mechanical energy.** Muscle contraction is initiated by a signal sent by the central nervous system (CNS) *via* a motor neuron. A motor neuron along with the muscle fibres connected to it constitute a motor unit. The junction between a motor neuron and the sarcolemma of muscle fibre is called the **neuromuscular junction** or **motor-end plate.**
- In a resting muscle fibre, the outside of sarcolemma is positively charged with respect to the inside. This potential difference across a membrane is called **resting potential.** Sodium ions predominate on the outside of the sarcolemma and potassium ions predominate on the inside. Sodium ions are pumped out and potassium ions enter inside by **sodium pump.**
- When neural signal reaches motor-end plate, it releases a neurotransmitter, **acetylcholine,** which generates an action potential by depolarizing the sarcolemma. This spreads through the muscle fibre and causes the release of calcium ions into the sarcoplasm. The calcium ions bind to troponin causing a change in its shape and position. This in turn alters shape and the position of tropomyosin, to which troponin binds. This shift exposes the **active sites** on the F - actin molecules. Myosin cross - bridges are then able to bind to these active sites.
- In the presence of **myosin ATPase,** Ca^{++} and Mg^{++} ions, ATP breaks down into ADP and inorganic phosphate, releasing energy in the head. Energy from ATP causes energized myosin cross bridges to bind to actin and move, causing thin myofilaments to slide along the thick myofilaments. Thus, the energy for contraction of muscle is obtained from **ATP.** In a resting muscle, ATP combines anaerobically with **creatine** to form **creatine phosphate.**

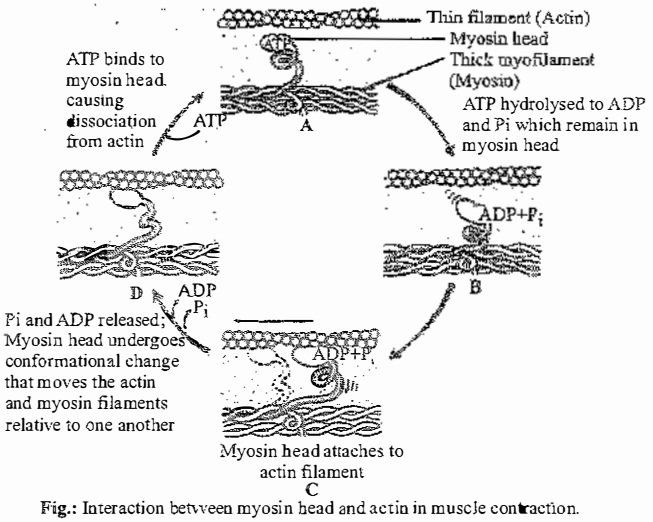

Fig.: Interaction between myosin head and actin in muscle contraction.

Table: Sequence of events between a motor neuron action potential and skeletal muscle fibre contraction

1.	Action potential is initiated and propagates to motor neuron axon terminals.
2.	Ca^{2+} enters axon terminals through voltage-gated Ca^{2+} channels.
3.	Ca^{2+} entry triggers release of ACh from axon terminals.
4.	ACh diffuses from axon terminals to motor end plate in muscle fibre.
5.	ACh binds to nicotinic receptors on motor end plate, increasing their permeability to Na^+ and K^+.
6.	More Na^+ moves into the fibre at the motor end plate than K^+ moves out, depolarising the membrane and producing the end-plate potential (EPP).
7.	Local currents depolarise the adjacent muscle cell plasma membrane to its threshold potential, generating an action potential that propagates over the muscle fibre surface and into the fibre along the T-tubules.
8.	Action potential in T-tubules induces DHP (dihydropyridine) receptors to pull open ryanodine receptor channels, allowing release of Ca^{2+} from lateral sacs of sarcoplasmic reticulum.
9.	Ca^{2+} binds to troponin on the thin filaments, causing tropomyosin to move away from its blocking position, thereby uncovering cross-bridge binding sites on actin.
10.	Energized myosin cross-bridges on the thick filaments bind to actin: $A + M \,.\, ADP.\ P_i \rightarrow A \,.\, M.\, ADP \,.\, P_i$
11.	Cross-bridge binding triggers release of ATP hydrolysis products from myosin, producing an angular movement of each cross-bridge: $A \,.\, M \,.\, ADP.\ P_i \rightarrow A \,.\, M. + ADP + P_i$
12.	ATP binds to myosin, breaking linkage between actin and myosin and thereby allowing cross-bridges to dissociate from actin: $A \,.\, M + ATP \rightarrow A + M.\, ATP$
13.	ATP bound to myosin splits, energizing the myosin cross-bridge: $M \,.\, ATP \rightarrow M.\, ADP \,.\, P_i$
14.	Cross-bridges repeat steps 10 to 13, producing movement (sliding) of thin filaments past thick filaments. Cycles of cross-bridge movement continue as long as Ca^{2+} remains bound to troponin.
15.	Cytosolic Ca^{2+} concentration decreases as Ca^{2+} - ATPase actively transports Ca^{2+} into sarcoplasmic reticulum.
16.	Removal of Ca^{2+} from troponin restores blocking action of tropomyosin, the cross-bridge cycle ceases, and the muscle fibre relaxes.

RED AND WHITE MUSCLES

- The skeletal muscles are of two types – **red** and **white muscles.** The **red muscles** contain very high amount of red pigment, **myoglobin,** while the **white muscles** have very low amount of myoglobin. Myoglobin can store O_2 in the form of **oxymyoglobin** which provides energy for muscle contraction by **aerobic oxidation.** Little **lactic acid** accumulates in this respiration, thus, enabling the red muscle fibres to carry on slow and sustained contractions for long periods without fatigue *e.g.*, extensor muscles of back. White muscles derive energy for their fast contractions by anaerobic oxidation, accumulate lactic acid during strenuous work and soon get fatigued.

PROPERTIES OF SKELETAL MUSCLES

- **Excitability:** Muscles respond to stimuli which can be nervous, chemical, electrical, thermal or mechanical.
- **Conductibility and contractibility :** Stimulus acting in one region of a muscle fibre spreads to all parts within no time. On being stimulated, the muscles fibres contract and shorten. Shortening is followed by relaxation. Muscles can pull a structure and not push it.
- **Threshold or liminal stimulus :** A muscle fibre would contract only when it receives stimulation of certain intensity called threshold stimulus/liminal stimulus.
- **All or none law (Bowditch's Law) :** Response of a muscle fibre to a stimulus is not proportionate to its intensity. It is absent when the intensity is subliminal.
- **Summation of stimuli :** Two or more subliminal stimuli applied simultaneously or successively get added up and evoke a response if the added up value becomes equal to or exceeds threshold one.
- **Elasticity :** All the muscles can be stretched to a small degree. The ability to get stretched is called tensility.
- **Muscle fatigue :** Failure of a muscle to respond to a fresh stimulus after a prolonged previous activity is called muscle fatigue. It is due to accumulation of lactic acid, consumption of stored glycogen, ATP and creatine phosphate (CP).
- **Rigor mortis :** It is the state of body stiffening after death due to non-separation of actin and myosin filaments caused by non-availability of ATP/CP. Rigor mortis persists till decomposition starts.
- **Muscle twitch :** It is defined as the response of a muscle fibre to a single brief stimulus. The twitch consists of 3 phases— latent, contraction and relaxation.
  - **Latent period :** It is the time period immediately after the stimulus is applied. A certain time gap (about 0.5 sec) elapses before the contraction begins.
  - **Contraction phase :** It lasts approximately for 0.04 of a second during which the action potential sweeps the muscle.
  - **Relaxation phase :** It occupies about 0.05 of a second during which the muscle gradually resumes its former length (condition).
- **Refractory period :** After stimulation the muscle fibres pass through a period of time during which, they cannot be excited again.
- **Tetanus :** A skeletal muscle fibre can maintain continuous tension if it is stimulated frequently enough within a given period of time. Due to such rapid excitations, there is no time gap between the stimuli for the fibres to relax (*i.e.*, the contraction and relaxation phases are much longer than the refractory period). Hence the fibres are in a state of sustained contraction.
- **Tetany:** Muscular spasm that occurs due to deficiency of parathyroid hormone.
- **Hypertrophy :** When muscles are repeatedly and forcefully contracted over several weeks, either isotonically or isometrically, the muscle mass increases. The increase in mass is due to increase in the number of filaments in the sarcomeres, in the number of mitochondria, and in the amount of sarcoplasm but it does not involve the division of muscle cells to increase the number of cells.
- **Atrophy :** It is reduction in the size of individual muscle cells. In atrophy the number of filaments and mitochondria and the amount of sarcoplasmic reticulum are reduced.

SKELETAL SYSTEM

- The prime importance of skeletal system is to give physical support for maintaining body shape, protection of internal organs from external hazards and it has a significant role in movement of the body. **Bone and cartilage are specialised connective tissues.** Bone has a very hard matrix due to **calcium salts** in it and cartilage has slightly pliable matrix due to **chondroitin salts.**
- It is grouped into two divisions - the axial and the appendicular skeleton.
- Skeletal system is divided into **exoskeleton** and **endoskeleton.**

Exoskeleton

- **The exoskeleton consists of hard parts present on the surface of the body.** It is found in invertebrates as well as the vertebrates. Examples are shells of molluscs and the bony plates of tortoises and armadillos.
- **Scales, feathers, hair, claws, nails, hoofs** and **horns** are examples of **exoskeletal elements** in the vertebrates.
- These structures develop from the **epidermis** of the skin. They are composed of a nonliving, protein material called keratin or horn. Of these, only hair and nails occur in man.

Endoskeleton

- Endoskeleton of mammals is made chiefly of bone and very little of cartilage.
- New born baby has 300 bones which fuses to give 206 bones in adult.
- Human skeleton is made up of **270 bones which get fused to become 206.** Out of these 6 occur as ear ossicles and the remaining 200 bones are distributed into **axial** and **appendicular skeleton.**
  - **Axial skeleton,** that lies along the longitudinal axis of the body. It supports and protects organs of the head, neck and trunk. It includes **skull, ribs, sternum** and **vertebral column.**

- **Appendicular skeleton,** which is associated with the appendages. It consists of **two girdles,** the **pectoral** and **pelvic girdles** and the **limb bones.**

Axial skeleton

Skull

- **Skull** is the bony framework of head. The **skull** is composed of two sets of bones- **cranial** and **facial,** that totals to **22 bones.** Cranial bones are **8** in number. They form the hard protective outer covering, **cranium,** for the brain. The facial region is made up of **14** skeletal elements which form the front part of the skull.
- A single U-shaped bone called **hyoid** is present at the base of the buccal cavity and it is also included in the skull.
- Bones of cranium include 1 **frontal,** 2 **parietal,** 1 **occipital,** 2 **temporal,** 1 **sphenoid** and 1 **ethmoid.**
- The cranial bones fit together by wavy, immovable boundries called **sutures. The sutures help dissipate the shock of a blow to the head.**
- Each middle ear contains three tiny bones - **malleus, incus** and **stapes,** collectively called **ear ossicles.**
- A large hole, called **foramen magnum,** at the base of the skull allows the brain to continue into the spinal cord which is located in the backbone.
- The facial bones are :
  - The **mandible** is the lower jawbone. It articulates with the temporal bones which forms the only freely movable joint in the head. It provides the **chewing motion. It is the longest bone of the face and the strongest of all the bones of body.**
  - The left and right **maxilla** are the upper jaw bones. They form part of the nose, orbits, and roof of the mouth.
  - The left and right **zygomatic** are the cheek bones. They form portions of the orbits as well.
  - The left and right **nasals** form the superior portion of the bridge of the nose.
  - The left and right **lacrimal** help to form the orbits.
  - The **vomer** forms part of the nasal septum (the divider between the nostrils).
  - The left and right inferior **turbinate** forms the lateral walls of the nose and increase the surface of the nasal cavity.

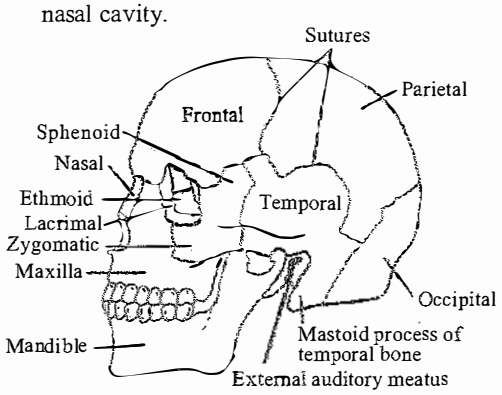

Fig.: Human skull in lateral view

Ribs

- The **ribs** are thin, flat, curved bones that form a protective cage around the organs in the upper body.
- Ribs are comprised of **24 bones arranged in 12 pairs.** Each rib remains attached to the respective thoracic vertebra.
- The **first seven ribs** are attached directly with the sternum and are called **true ribs.** The **8th, 9th and 10th** are attached to the rib above each. These are called **vertebrochondral ribs** or **false ribs.** The last two **(11th and 12th)** ribs remain free anteriorly and are called **floating ribs.**
- The ribs serve three important **functions :**
  - They protect the heart, large blood vessels and lungs.
  - They bear respiratory muscles (external and internal intercostal muscles).
  - Lower two pairs of ribs protect the kidneys.

Sternum

- The sternum is a flat, dagger shaped bone located in the middle of the chest. **It is longer in males than females.**
- The sternum is composed of three processes : manubrium, mesosternum and xiphoid; that are connected to the ribs.
- **Vertebral column** is also called **backbone** or **spine.** It is curved, vertical rod, about **70 cm. long,** in the mid-dorsal line of the neck and trunk. It consists of a row of 33 movably articulated, ring - like bones, the **vertebrae.** The vertebral column is the main axis of the body which articulates with skull, pectoral girdle, pelvic girdle and the ribs. The vertebral column is differentiated into **cervical (7), thoracic (12), lumbar (5), sacral (1-fused)** and **coccygeal (1-fused)** regions starting from the skull. The number of cervical vertebrae are seven in almost all mammals including human beings.
- The various functions of vertebral column are : it forms a strong beam with which the viscera is suspended by means of mesenteries; it carries the weight of the body in motion and when the animal is standing; it allows flexion and bending of the back and the body without injuring internal organs; it protects the nerve cord.

Appendicular skeleton

- Each limb is made of 30 bones. **Forelimb** constitutes **1 humerus** (upper arm), **1 ulna** and **1 radius** (lower arm), **8 carpals** (wrist), **5 metacarpals** (palm) and **14 phalanges** (digits). Humerus bone is smooth, large and rounded at the top where it fits into the **scapula** of shoulder bone (pectoral bone). On the bottom of the humerus, are two depressions, where the humerus connects to the ulna and radius of the forearm. The ulna is longer than the radius and connected more firmly to the humerus. Each wrist is composed of eight carpals which are arranged in proximal and distal rows.

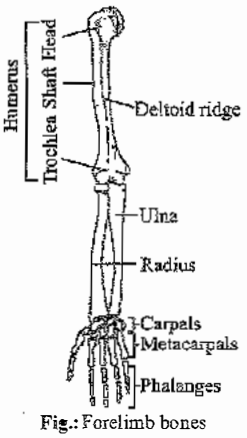

Fig.: Forelimb bones

- **Hindlimb** constitutes **1 femur, 1 patella, 1 tibia, 1 fibula, 7 tarsals, 5 metatarsals** and **14 phalanges. Femur, tibia** and **fibula** bones together support the shank of the leg. The **tarsals** form the ankle, **metatarsals** form the sole and **phalanges** form the digits of the foot. The **femur** is the **longest, largest,** and **strongest bone** in the body whose head fits into the acetabulum of hip girdle. The **tibia** connects to the femur to form the knee joint. The **tibia is larger than the fibula** because it bears most of the weight, while the fibula serves as an area for muscle attachment.
- **Pectoral** and **pelvic girdle** bones help in the articulation of the upper and the lower limbs respectively with the axial skeleton. Each girdle is formed of two halves.

Table : Total number of bones in human body

AXIAL SKELETON			APPENDICULAR SKELETON		
Skull — Cranium		8	**Pectoral Girdle**		
Skull — Face		14	Clavicle		2
Skull — Hyoid		1	Scapula		2
Skull — Ear ossicles	3 × 2	6	**Forelimbs**		
Vertebral column		26	Humerus		2
Sternum		1	Ulna		2
Ribs	12 × 2	24	Radius		2
		80	Carpals	8 × 2	16
Cranial Bones			Metacarpals	5 × 2	10
Frontal		1	Phalanges	14 × 2	28
Parietals		2			60
Temporals		2			
Occipital		1			
Sphenoid		1			
Ethmoid		1			
		8	**Pelvic Girdle**		
Facial Bones			Coxal, hip or pelvic		2
Nasals		2			
Maxillae		2			
Zygomatic bones		2	**Hindlimbs**		
Mandible		1	Femur		2
Lacrimal bones		2	Tibia		2
Palatines		2	Fibula		2
Inferior nasals		2	Patella		2
Vomer		1	Tarsals	7 × 2	14
		14	Metatarsals	5 × 2	10
Vertebral Column			Phalanges	14 × 2	28
Cervical	7				60
Thoracic	12				
Lumbar	5				
Sacrum	1	(5)			
Coccyx	1	(4)			
	26	33			

Total number of bones in adult human 80 + 2 + 2 + 60 + 2 + 60 = 206

Digital formula of both limbs 2, 3, 3, 3, 3

- Each pectoral girdle consists of a **clavicle** and a **scapula.** The scapula (shoulder blade) consists of a sharp ridge, the **spine** and a triangular **body.** The end of the spine projects as a flattened and expanded process called **acromion.** This process articulates with the clavicle. At the point where the superior and lateral borders of the scapula meet, there is a lateral angle which presents a shallow articular surface termed as **glenoid cavity** into which the head of the humerus is articulated. The **primary function of the pectoral girdle** is to provide an attachment point for the numerous muscles that allow the shoulder and elbow joints to move.
- The **pelvic girdle,** also called the **hip girdle,** is composed of two coxal (hip) bones. Each coxal bone consists of three separate parts : **ilium** (short and straight bone), **ischium** (lower elongated bone, run parallel to vertebral column) and **pubis** (inner, smaller bone). On its outer surface it has a deep depression called the **acetabulum,** which with spherical head of the femur, forms the hip joint. The pelvic girdle serves several important functions in the body. It supports the weight of the body from the vertebral column. It also protects and supports the lower organs, including the urinary bladder, the reproductive organs, and the developing foetus in a pregnant woman.

JOINTS

- The place of articulation between two or more bones, or between a bone and a cartilage is called a **joint.** Joints are of three types – **fibrous, cartilaginous** and **synovial.**
- In **fixed or immovable or fibrous joints,** the bones are very tightly held with the help of white fibrous connective tissue. *e.g.,* sutures between the skull bones, articulation of the roots of teeth with sockets of maxillae and mandible.
- In **slightly movable** or **cartilaginous joints,** the opposing surfaces are connected by white fibrocartilage, which allows very little movement, *e.g.,* joints between adjacent vertebrae.
- In **movable** or **synovial joints,** the articulating bones can move extensively upon each other. At movable joint, there is a space between the bones called **synovial cavity** which is filled with a viscous and slippery fluid called **synovial fluid. Ball and socket joint** (between humerus and pectoral girdle), **Hinge joint** (knee joint), **Pivot joint** (between atlas and axis), **Gliding joint** (between the carpals) and **Saddle joint** (between carpal and metacarpal of thumb) are some examples.

DISORDERS OF MUSCULAR AND SKELETAL SYSTEM

- **Arthritis :** It is caused by inflammation of the joints. Arthritis is of several types.
  - **Rheumatoid arthritis** is the most common arthritis. Rheumatoid arthritis is an **inflammation of the synovial membrane** in synovial joints. When this membrane, which is source of synovial fluid, becomes inflamed, it produces too much fluid. The joints swell and become **extremely painful.**
  - **Osteoarthritis** affects the **articular cartilage** at the synovial joints. It is a degenerative joint disease. Usually, affected joints are of **spine, knees and hands.**
  - **Gouty arthritis** is caused either due to excessive formation of **uric acid** or inability to excrete it. It gets deposited in synovial joints as monosodium salt.
- **Osteoporosis :** It is a disease in which bone loses **minerals** and **fibres** from its matrix. Major causative factors are imbalances of hormones like calcitonin, parathormone, sex hormones and deficiencies of calcium and vitamin D.

- **Sprain and strain :** A sprain is a twisting of a joint without dislocating it. Such an injury causes damage to ligaments and also often damages tendons, muscles, blood vessels, and nerves. A strain is less severe stretching or twisting of a joint. Muscles and tendons may be stretched and become somewhat painful, but only minor damage is done to the tissues of the joint.
- **Muscular dystrophy :** It is inborn abnormality of muscles associated with dysfunction and ultimately with deterioration. Lack of dystrophin (protein) causes muscular dystrophy.
- **Myasthenia gravis :** It is an autoimmune disorder affecting neuromuscular junction leading to fatigue, weakening and paralysis of skeletal muscle.

CONCEPT MAP