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# A HANDBOOK ON ANATOMY OF SKELETAL SYSTEM


JV'n Dr. Neha Saini

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# INDEX

## *Learning Objectives:*

*By the end of this, you will be able to:*

- **Understand the definition and function of skeletal system**
- **To know about the types of bones and bone cells**
- **Understand the bone growth**
- **Identify the types of cartilage**
- **Demonstrate the different types of body movements**
- **Identify the joints that allow for these motions**
- **Biomechanics of synovial joints**
- **Clinical anatomy**

- ❖ ***INTRODUCTION:***

The skeletal system is composed of bones and cartilage connected by ligaments to form a framework for the rest of the body tissues. There are two parts to the skeleton:

- Axial skeleton – bones along the axis of the body, including the skull, vertebral column and ribcage;
- Appendicular skeleton – appendages, such as the upper and lower limbs, pelvic girdle and shoulder girdle.

Bones, cartilage and ligaments are tightly joined to form a strong, flexible framework bone is active tissue. Each individual bone is a separate organ of the skeletal system~270 bones (organs) of the Skeletal System with age the number decreases as bones fuse by adulthood the number is 206 (typical) even this number varies due to varying numbers of minor bones.

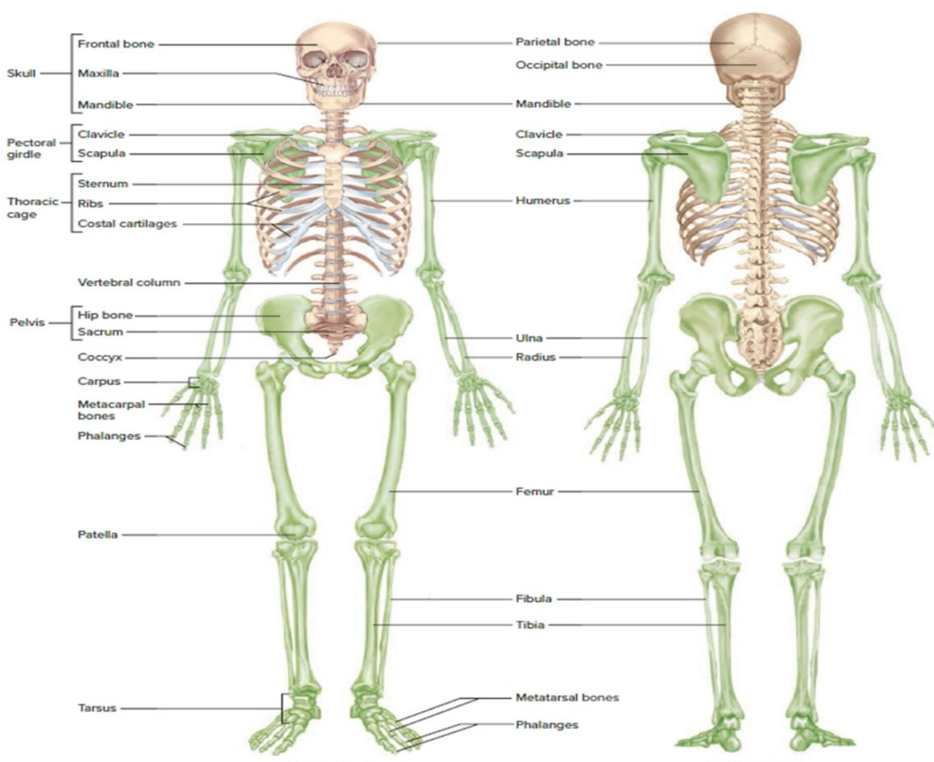



**Fig- 1: The Skeletal System**

## ❖ ***FUNCTION:***

### *Support and movement*

Bones are a site of attachment for ligaments and tendons, providing a skeletal framework that can produce movement through the coordinated use of levers, muscles, tendons and ligaments. The bones act as levers, while the muscles generate the forces responsible for moving the bones.

### *Protection*

Bones provide protective boundaries for soft organs: the cranium around the brain, the vertebral column surrounding the spinal cord, the ribcage containing the heart and lungs, and the pelvis protecting the urogenital organs.

### *Mineral homoeostasis*

As the main reservoirs for minerals in the body, bones contain approximately 99% of the body's calcium, 85% of its phosphate and 50% of its magnesium (Bartl and Bartl, 2017). They are essential in maintaining homoeostasis of minerals in the blood with minerals stored in the bone are released in response to the body's demands, with levels maintained and regulated by hormones, such as parathyroid hormone.

### *Blood-cell formation (haemopoiesis)*

Blood cells are formed from haemopoietic stem cells present in red bone marrow. Babies are born with only red bone marrow; over time this is replaced by yellow marrow due to a decrease in erythropoietin, the hormone responsible for stimulating the production of erythrocytes (red blood cells) in the bone marrow. By adulthood, the amount of red marrow has halved, and this reduces further to around 30% in older age (Robson and Syndercombe Court, 2018).

### *Triglyceride storage*

Yellow bone marrow acts as a potential energy reserve for the body; it consists largely of adipose cells, which store triglycerides (a type of lipid that occurs naturally in the blood).

## ❖ BONE COMPOSITION AND STRUCTURE

Bone is composed of bone matrix and cells. Bone matrix has three main components:

- 25% organic matrix (osteoid);
- 50% inorganic mineral content (mineral salts);
- 25% water (Robson and Syndercombe Court, 2018).

Organic matrix (osteoid) is made up of approximately 90% type-I collagen fibres and 10% other proteins, such as glycoprotein, osteocalcin, and proteoglycans (Bartl and Bartl, 2017). It forms the framework for bones, which are hardened through the deposit of the calcium and other minerals around the fibres (Robson and Syndercombe Court, 2018).

Mineral salts are first deposited between the gaps in the collagen layers with once these spaces are filled, minerals accumulate around the collagen fibers, crystallizing and causing the tissue to harden; this process is called ossification (Tortora and Derrickson, 2009). The hardness of the bone depends on the type and quantity of the minerals available for the body to use; hydroxyapatite is one of the main minerals present in bones.

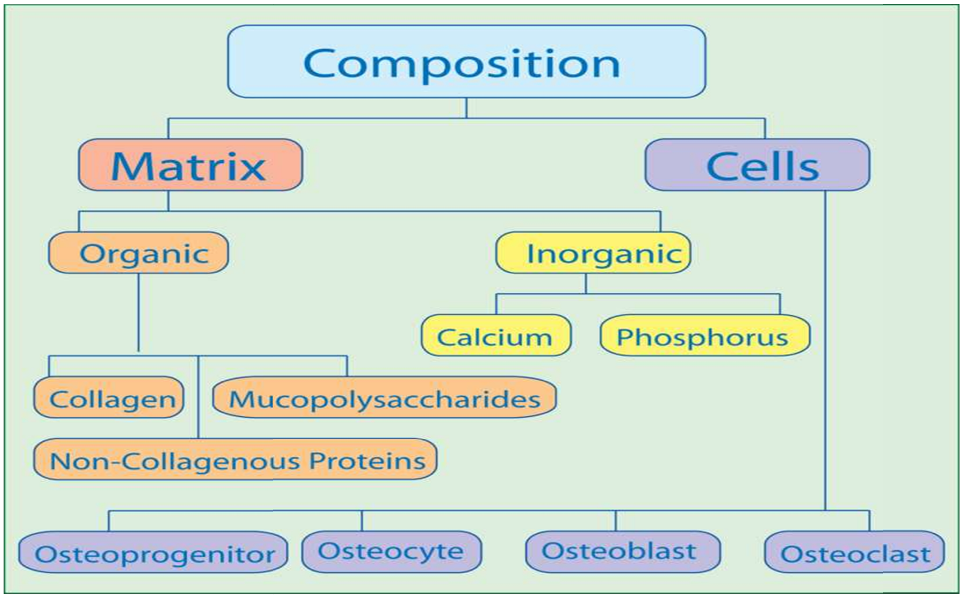



**Fig- 2: Composition of the Skeletal System**

While bones need sufficient minerals to strengthen them, they also need to prevent being broken by maintaining sufficient flexibility to withstand the daily forces exerted on them. This flexibility and tensile strength of bone is derived from the collagen fibers. Over-mineralization of the fibers or impaired collagen production can increase the brittleness of bones – as with the genetic disorder osteogenesis imperfecta – and increase bone fragility (Ralston and McInnes, 2014).

**BONE CELLS-**

**Osteogenic cells-** Origin- pericytes. They are flat cells with pale basophilic cytoplasm and central flat nuclei rich in ribsomes and rER. Found in Bone Marrow cavities, Endosteum & inner layer of Periosteum. Function - Bone Growth and Healing.

**Fig- 3: Osteogenic cells**

**Osteoblast cells- Origin**- osteogenic cells. They are small, oval branched cells with few cytoplasmic processes. They have oval, eccentric, open face nuclei. They have deep basophilic cytoplasm with negative Golgi image close to the nucleus. They show plenty of ribosomes, rER, well developed Golgi apparatus and mitochondria. Site- activated osteogenic layer of Periosteum, Endosteum, and Walls of bone marrow spaces. It is rich in these enzymes- a) Alkaline phosphatase enzyme- Which facilitates deposition of calcium by creation of alkaline medium; b) Pyrophosphatase enzyme- which inhibit the action of pyrophosphate substances "these substances retard the process of calcification" i.e. indirect calcification effect.

**Function-** 1-They are responsible for bone formation by synthesis and secretion of bone matrix (Osteocalcin protein). 2- They are concerned with calcification of bone by secretion of Alkaline Phosphatase and pyrophosphatase enzymes. Matrix vesicles, budding from the cell membrane which store Ca+. They change into osteocytes when they are surrounded by lacunae and calcified matrix.

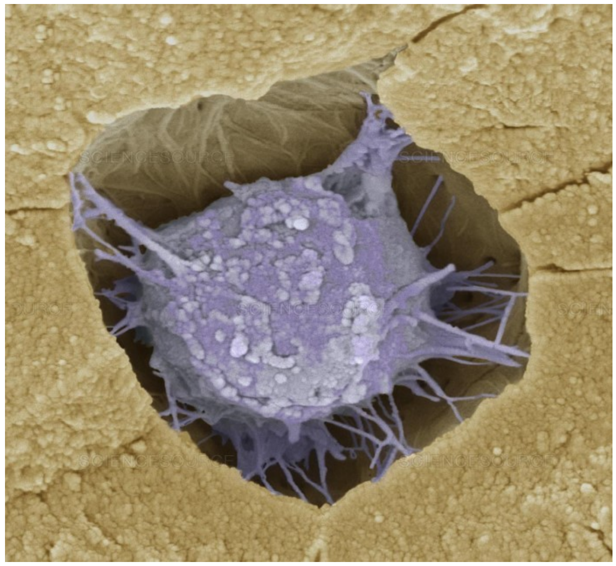


**Fig-4: Osteoblast cell**

**Osteocyte cells**- Origin is from Osteoblast. They are oval, branched cells. They have oval, central nuclei. The cytoplasm is slightly basophilic rich is alkaline phosphatase enzyme. Osteocytes can't divide so present singly in each lacuna. They contain rER, ribosomes, Golgi apparatus, and many cytoplasmic microtubules. The cells are present inside lacunae between bone lamellae. They are connected with one another by processes passing through bone canaliculi which connect adjacent lacunae together. These cell processes intercommunicate with one another by gap junctions. Which allow the electrolytes to pass freely from one cell to the other. Function- They form bone matrix and vesicles rich in enzymes which preserve the integrity of the bone matrix and maintain its inorganic components. They are related to mobilization of Ca+ from the bone to the blood in times of need.

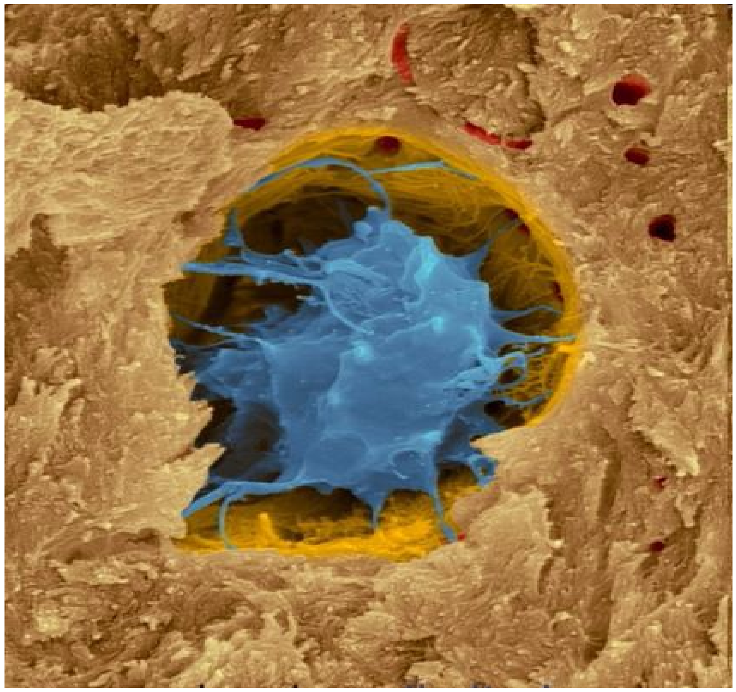


**Fig-5: Osteocyte singly present in lacuna**

**Osteoclast- Origin-** Monocytes. Site: 1- On the inner surface of bone where resorption takes place, Bone marrow spaces, Medullary cavities, Endosteum. Each cell lies in a shallow cavity called “Howships Lacuna”. Size: Oteoclast is large cell “20-30 um”. Nucleus: It is multinucleated cell “4-50” nuclei. Shape: It is irregular in shape. Cytoplasm: is foamy acidophilic. Border: The cells have striated or brush border facing the bone surface. Function: 1) They are concerned with bone resorption during ossification causing remodeling of the bone by the following mechanisms. A- Secretion of acids “lactic and carbonic acids” in the tissue fluids creates an acidic medium causing decalcification of bone matrix. B- Secretion of collagenase enzyme which dissolves bone matrix during ossification.2) They remove bone debris during ossification and after healing of bone fracture.

**Fig-6: Osteoclasts in Howships lacunae**

## Structure

Bone architecture is made up of two types of bone tissue:

- Cortical bone;
- Cancellous bone.

### *Cortical bone*

Also known as compact bone, this dense outer layer provides support and protection for the inner cancellous structure. Cortical bone comprises three elements:

- Periosteum
- Intracortical area;
- Endosteum (Bartl and Bartl, 2017).

The periosteum is a tough, fibrous outer membrane. It is highly vascular and almost completely covers the bone, except for the surfaces that form joints; these are covered by hyaline cartilage.

Tendons and ligaments attach to the outer layer of the periosteum, whereas the inner layer contains osteoblasts (bone-forming cells) and osteoclasts (bone-resorbing cells) responsible for bone remodelling.

The function of the periosteum is to:

- Protect the bone;
- Help with fracture repair;
- Nourish bone tissue (Robson and Syndercombe Court, 2018).

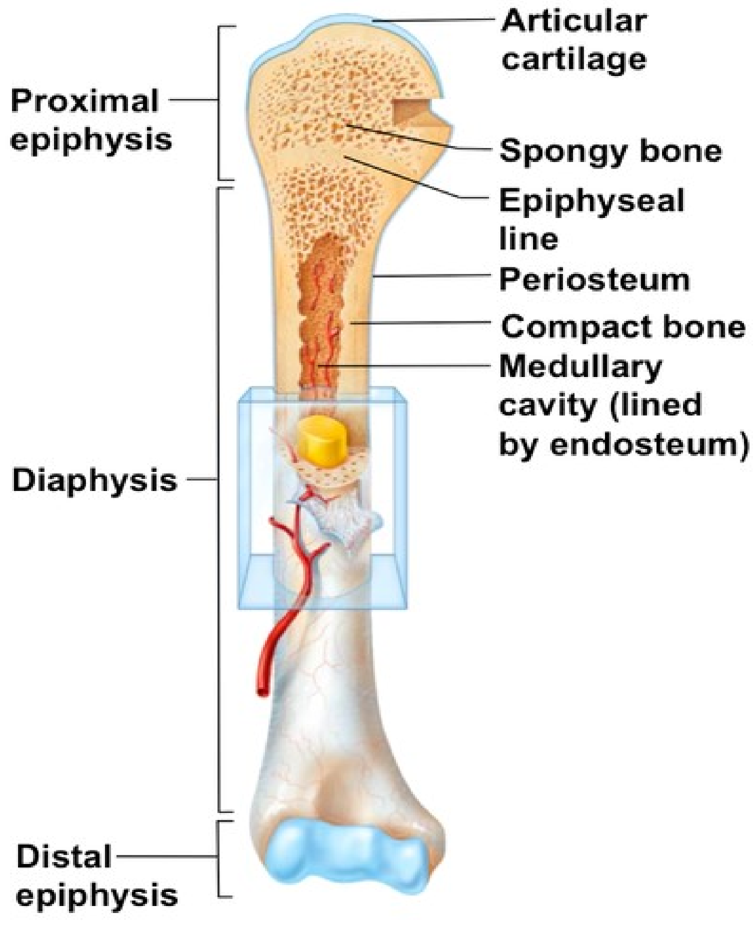
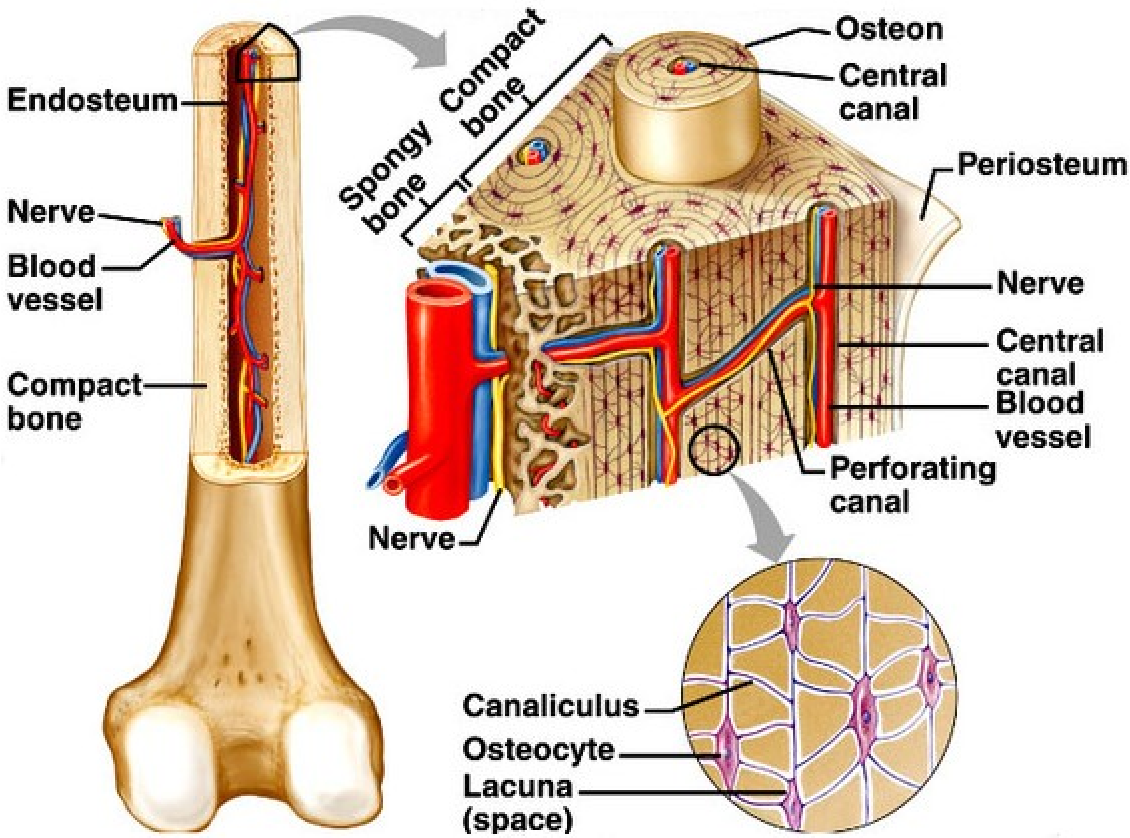



**Fig- 6: Structure of a long bone**

It also contains Volkmann's canals, small channels running perpendicular to the diaphysis of the bone; these convey blood vessels, lymph vessels and nerves from the periosteal surface through to the intracortical layer. The periosteum has numerous sensory fibers, so bone injuries (such as fractures or tumours) can be extremely painful (Drake et al, 2019).

The intracortical bone is organized into structural units, referred to as osteons or Haversian systems. These are cylindrical structures, composed of concentric layers of bone called lamellae, whose structure contributes to the strength of the cortical bone. Osteocytes (mature bone cells) sit in the small spaces between the concentric layers of lamellae, which are known as lacunae. Canaliculi are microscopic canals between the lacunae, in which the osteocytes are networked to each other by filamentous extensions. In the centre of each osteon is a central (Haversian) canal through which the blood vessels, lymph vessels and nerves pass. These central canals tend to run parallel to the axis of the bone; Volkmann's canals connect adjacent osteons and the blood vessels of the central canals with the periosteum. The endosteum consists of a thin layer of connective tissue that lines the inside of the cortical surface (Bartl and Bartl, 2017)



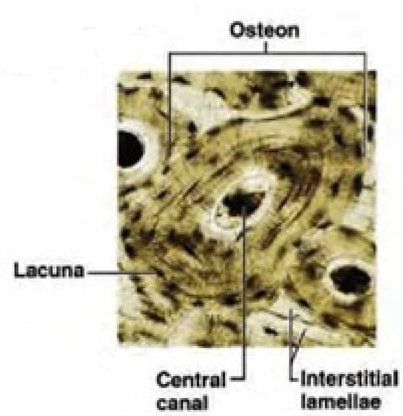




**Fig- 7: The types of bony tissue**

### *Cancellous bone*

Also known as spongy bone, cancellous bone is found in the outer cortical layer. It is formed of lamellae arranged in an irregular lattice structure of trabeculae, which gives a honeycomb appearance. The large gaps between the trabeculae help make the bones lighter, and so easier to mobilize.

Trabeculae are characteristically oriented along the lines of stress to help resist forces and reduce the risk of fracture (Tortora and Derrickson, 2009). The closer the trabecular structures are spaced, the greater the stability and structure of the bone. Red or yellow bone marrow exists in these spaces. Red bone marrow in adults is found in the ribs, sternum, vertebrae and ends of long bones; it is haemopoietic tissue, which produces erythrocytes, leucocytes (white blood cells) and platelets.

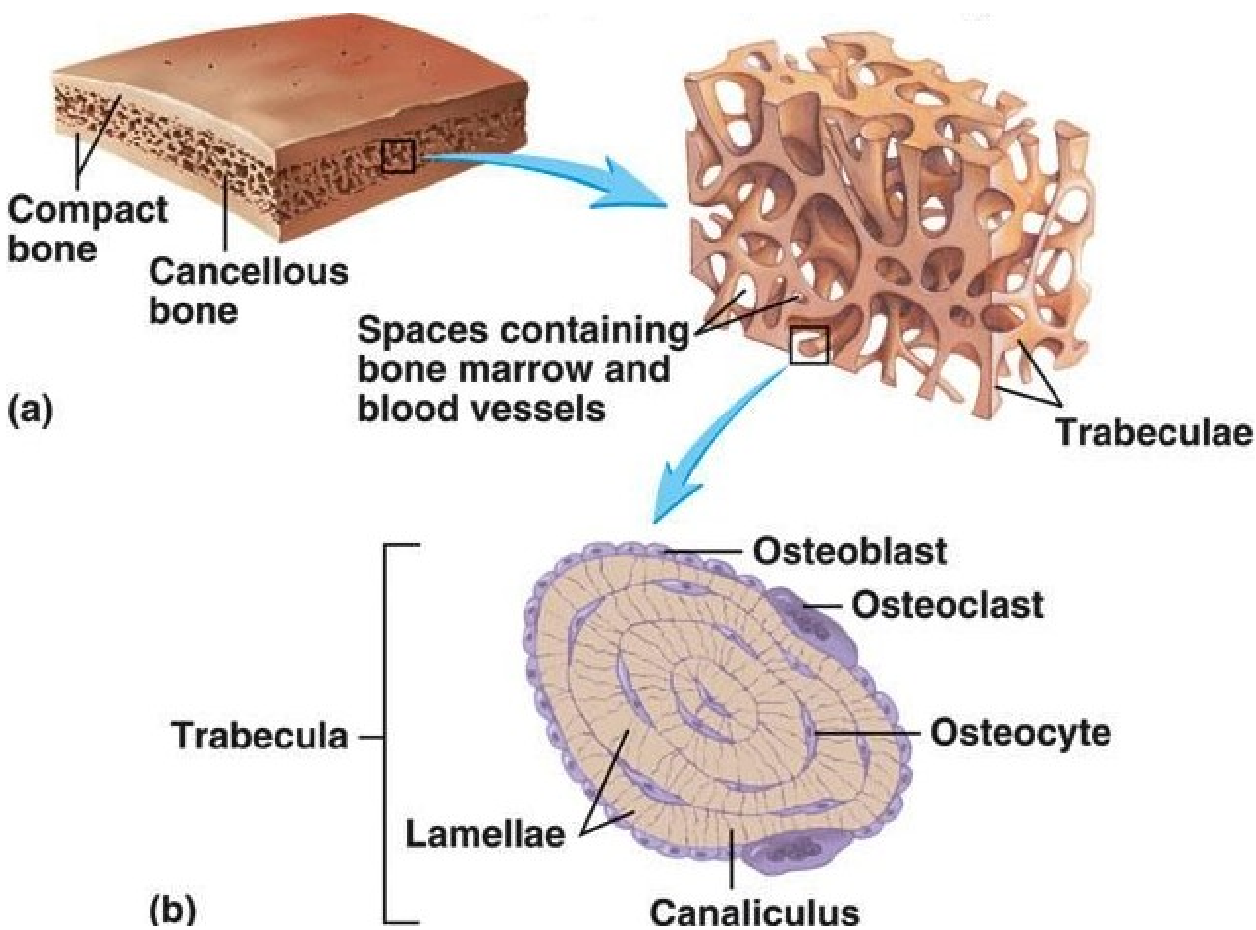



**Fig- 8: The Cancellous bone**

- **TYPES OF BONES:** On the basis of shape they can be categorized as-

- **Long bones** – typically longer than they are wide (such as humerus, radius, tibia, and femur), they comprise a diaphysis (shaft) and epiphyses at the distal and proximal ends, joining at the metaphysis. In growing bone, this is the site where growth occurs and is known as the epiphyseal growth plate. Most long bones are located in the appendicular skeleton and function as levers to produce movement.

- **Short bones** – small and roughly cube-shaped, these contain mainly cancellous bone, with a thin outer layer of cortical bone (such as the bones in the hands and tarsal bones in the feet)

- **Flat bones** – thin and usually slightly curved, typically containing a thin layer of cancellous bone surrounded by cortical bone (examples include the skull, ribs and scapula). Most are located in the axial skeleton and offer protection to underlying structures

- **Irregular bones** – bones that do not fit in other categories because they have a range of different characteristics. They are formed of cancellous bone, with an outer layer of cortical bone (for example, the vertebrae and the pelvis)

- **Sesamoid bones** – round or oval bones (such as the patella), which develop in tendons

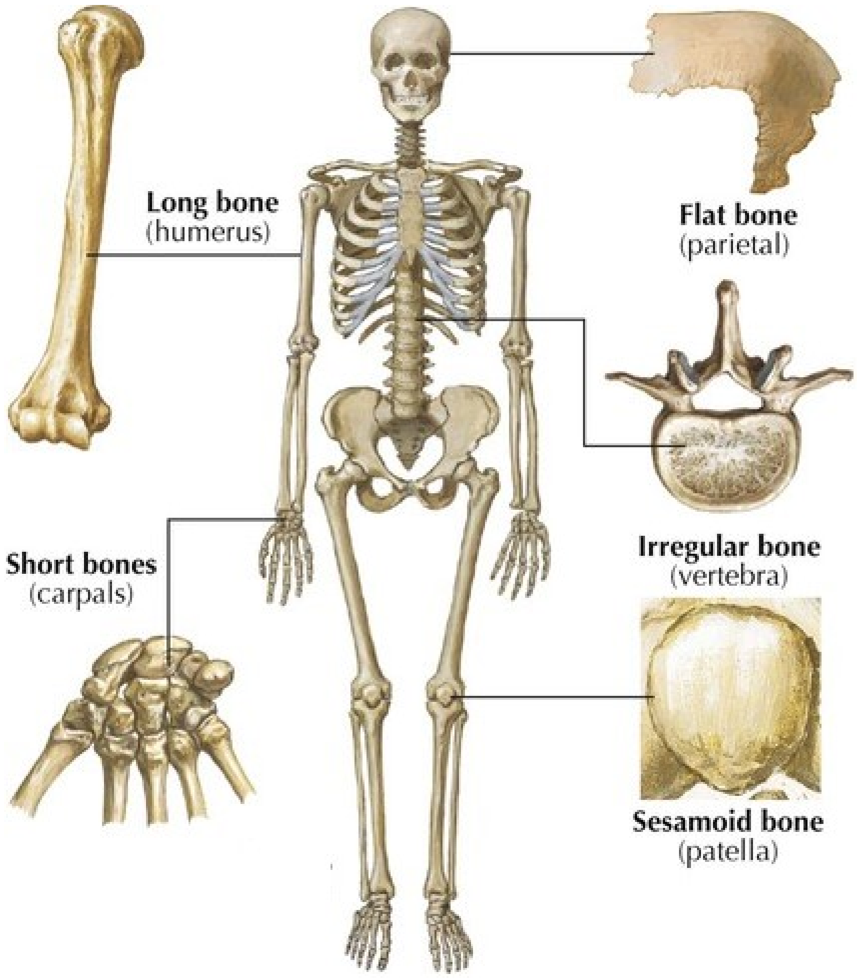



**Fig- 9: Types of bones**

- ***Gross structure of a long young bone-***

  - **Diaphysis**- Shaft portion of a bone. Composed of compact bone
  - **Epiphysis**- Ends of the bone. Composed mostly of spongy bone
  - **Metaphysis**- epiphyseal end of diaphysis. It is highly vascular.
  - **Periosteum-** Outside covering of the diaphysis. Fibrous connective tissue membrane
  - **Sharpey's fibers**- Secure periosteum to underlying bone
  - **Arteries**- Supply bone cells with nutrients
  - **Articular cartilage** - Covers the external surface of the epiphyses. Made of hyaline Cartilage. Decreases friction at joint surfaces

- **Medullary cavity**- Cavity of the shaft. Contains yellow marrow (mostly fat) in adults and red marrow (for blood cell formation) in infants
- **Epiphyseal plate-** made of hyaline cartilage. It is present at the epiphyseal end of metaphysis.

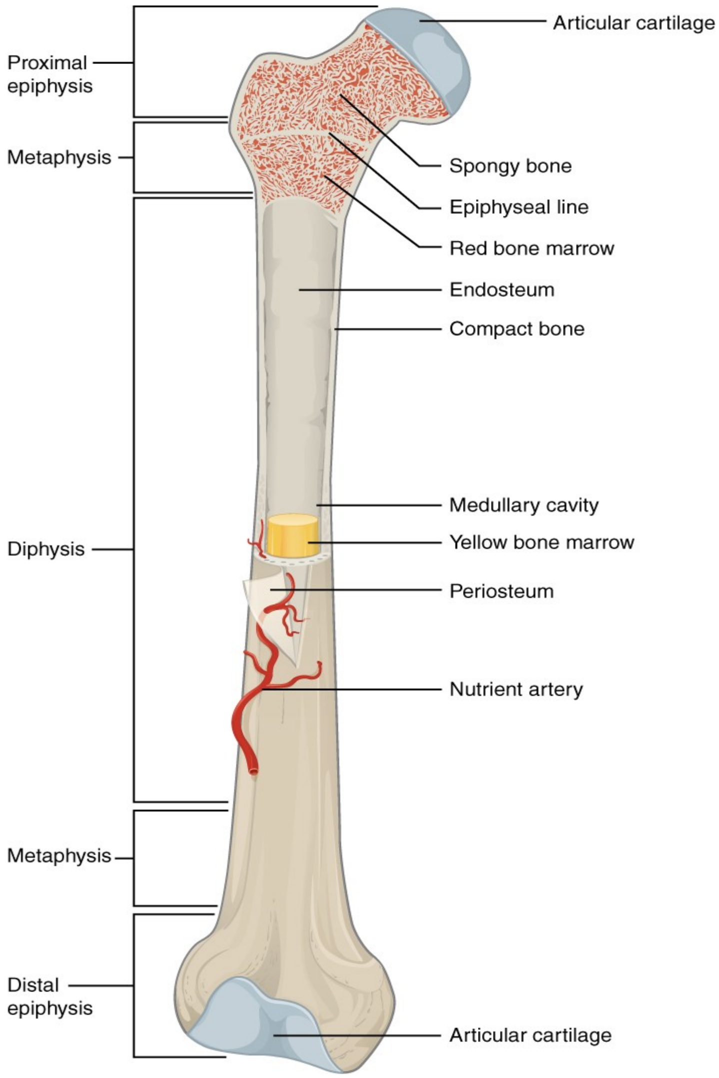



**Fig- 10: Parts of a long young bone**

## ❖ BONE FORMATION AND REMODELLING:

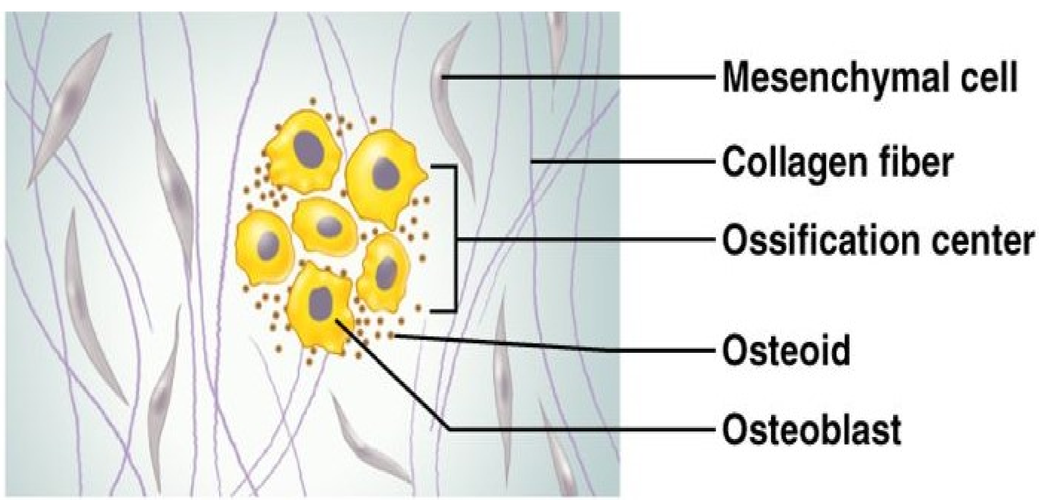
The natural process of bone formation is known as Ossification. It begins through centers of ossification. There are of two types- **Primary ossification center** – appears before birth. **Secondary ossification center**- appears after birth

**LAW OF OSSIFICATION:**

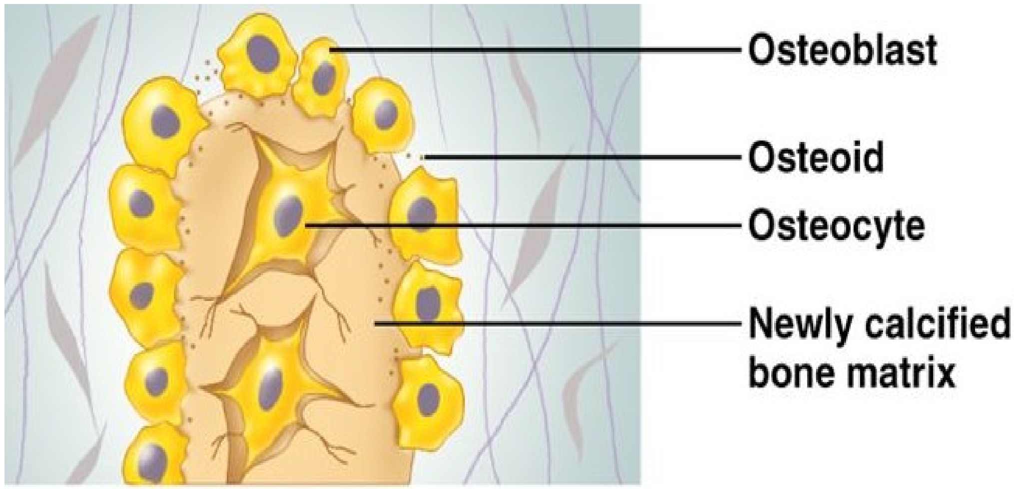
***"Ossification center which appears first is usually last to fuse except for Fibula."***

*There are two types of ossifications-*

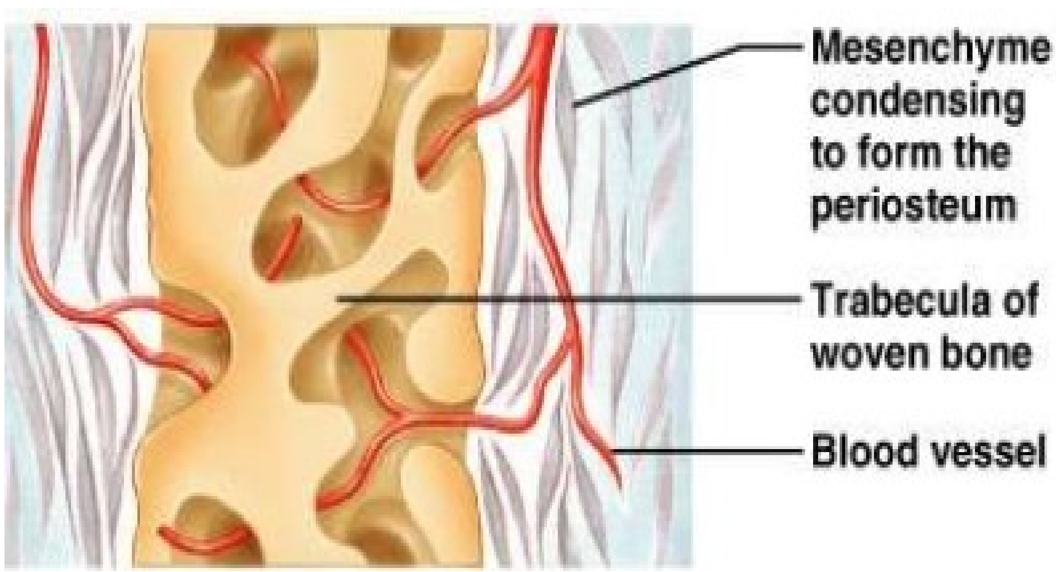
1) **Intramembranous-** replacement of thin connective tissue membrane with bone. It occurs in flat bones. Stages of intramembranous ossification are-
   a) **An ossification centre appears in the fibrous connective tissue membrane.** Selected centrally placed mesenchymal cells collected and differentiate into osteoblasts, forming an ossification centre.



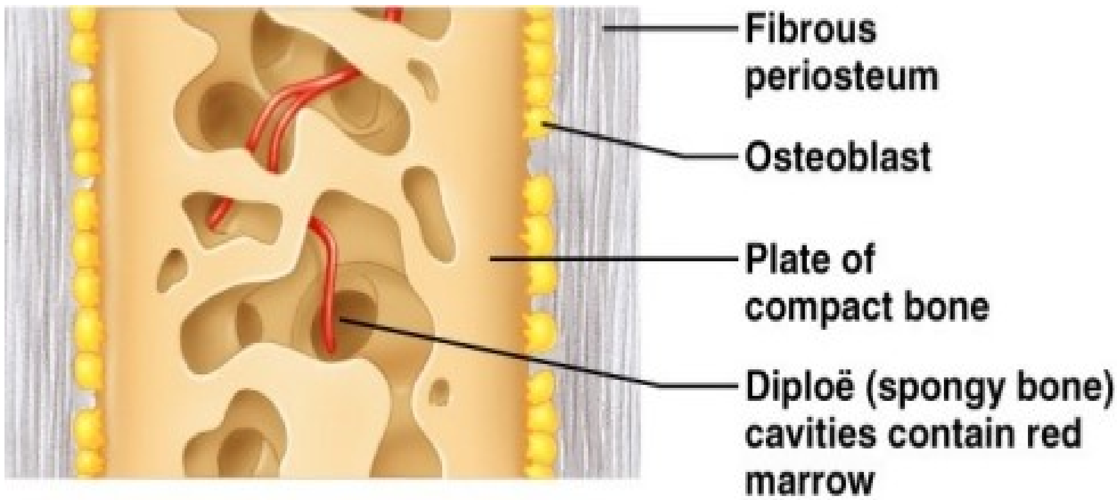

   b) **Bone matrix is secreted within the fibrous membrane.** Osteoblasts begin begin to secrete osteoid, which is mineralised within few weeks. Trapped osteoblasts become osteocytes.




c) **Woven bone and periosteum form-** Accumulating osteoid is laid down between embryonic blood vessels, which form a random network. The result is a network of trabeculae. Vascularised mesenchyme condenses on the external face of the woven bone and becomes the periosteum.




d) **Bone collar of compact bone forms and red marrow appears.** The trabeculae just deep to the periosteum thicken, forming a woven bone collar that is latter replaced with mature lamellar bone. Spongy bone consisting of distinct trabeculae persists internally and its vascular tissue becomes red marrow.




2) **Endochondral ossification**- In **endochondral ossification**, bone develops by *replacing* hyaline cartilage. Cartilage does not become bone. Instead, cartilage serves as a template to be completely replaced by new bone. Endochondral ossification takes much longer than intramembranous ossification. Bones at the base of the skull and long bones form via endochondral ossification.

In a long bone, for example, at about 6 to 8 weeks after conception, some of the mesenchymal cells differentiate into chondrocytes (cartilage cells) that form the cartilaginous skeletal precursor of the bones. Soon after, the **perichondrium**, a membrane that covers the cartilage, appears. As more matrix is produced, the chondrocytes in the center of the cartilaginous model grow in size. As the matrix calcifies, nutrients can no longer reach the chondrocytes. This results in their death and the disintegration of the surrounding cartilage. Blood vessels invade the resulting spaces, not only enlarging the cavities but also carrying osteogenic cells with them, many of which will become osteoblasts. These enlarging spaces eventually combine to become the medullary cavity.

As the cartilage grows, capillaries penetrate it. This penetration initiates the transformation of the perichondrium into the bone-producing periosteum. Here, the osteoblasts form a periosteal collar of compact bone around the cartilage of the diaphysis. By the second or third month of fetal life, a bone cell development and ossification ramp up and creates the **primary ossification center, a region deep in the periosteal collar where ossification begins.**

While these deep changes are occurring, chondrocytes and cartilage continue to grow at the ends of the bone (the future epiphyses), which increases the bone's length at the same time bone is replacing cartilage in the diaphyses. By the time the fetal skeleton is fully formed, cartilage only remains at the joint surface as articular cartilage and between the diaphysis and epiphysis as the epiphyseal plate, the latter of which is responsible for the longitudinal growth of bones. After birth, this same sequence of events (matrix mineralization, death of chondrocytes, invasion of blood vessels from the periosteum, and seeding with osteogenic cells that become osteoblasts) occurs in the epiphyseal regions, and each of these centers of activity is referred to as a **secondary ossification center.**

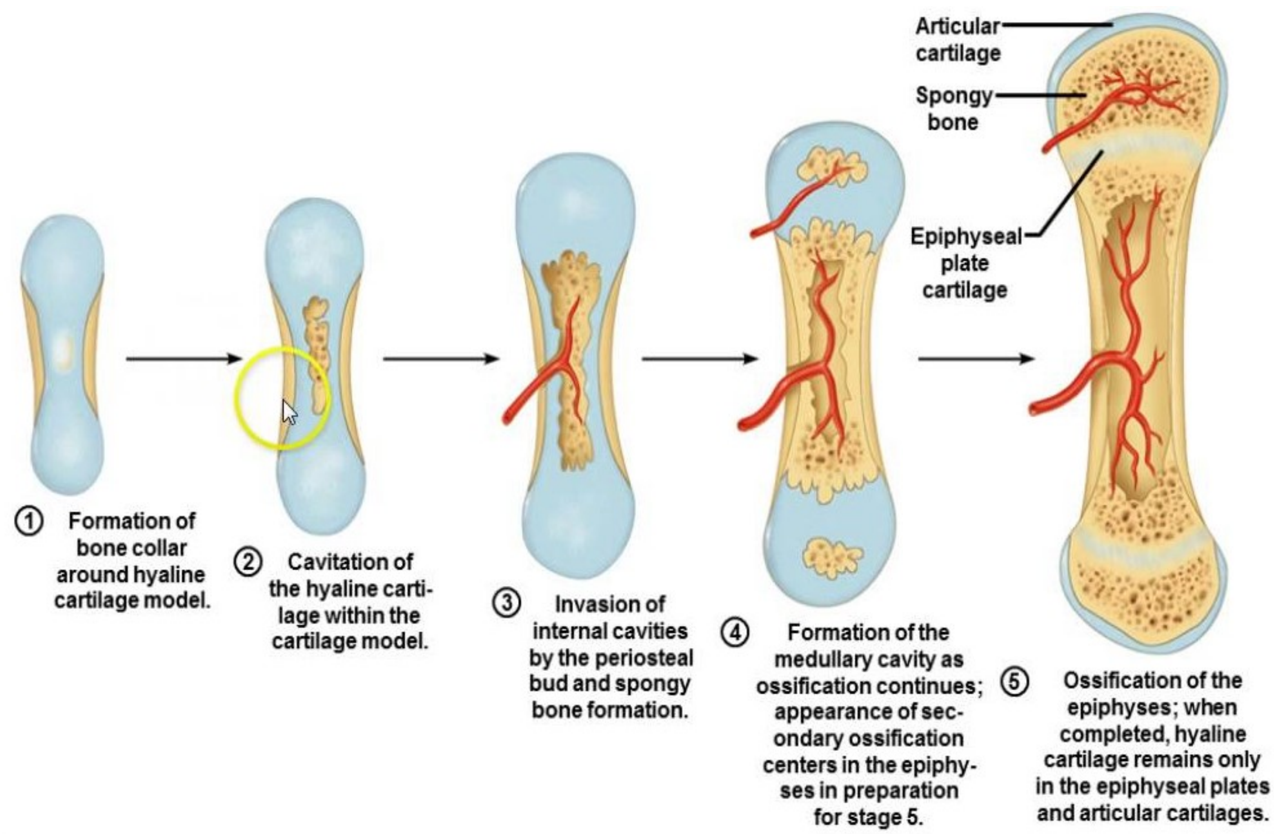



**Fig- 11: Endochondral ossification**

❖ **BONE GROWTH**- Bone grows in length as well as in width. When it grows in length, it is known as interstitial growth and when its width enlarges it is known as appositional growth.

**A) Interstitial growth-** The epiphyseal plate is the area of growth in a long bone. It is a layer of hyaline cartilage where ossification occurs in immature bones. On the epiphyseal side of the epiphyseal plate, cartilage is formed. On the diaphyseal side, cartilage is ossified, and the diaphysis grows in length. The epiphyseal plate is composed of four zones of cells and activity. The **reserve zone** is the region closest to the epiphyseal end of the plate and contains small chondrocytes within the matrix. These chondrocytes do not participate in bone growth but secure the epiphyseal plate to the osseous tissue of the epiphysis. Zones of bone growth-

- **Proliferative zone** is the next layer toward the diaphysis and contains stacks of slightly larger chondrocytes. It makes new chondrocytes (via mitosis) to replace those that die at the diaphyseal end of the plate.
- **Zone of maturation and hypertrophy**, are older and larger than those in the proliferative zone. The more mature cells are situated closer to the diaphyseal end of the plate. The longitudinal growth of bone is a result of cellular division in the proliferative zone and the maturation of cells in the zone of maturation and hypertrophy.
- **Zone of calcification-** Most of the chondrocytes in the **zone of calcified matrix**, the zone closest to the diaphysis, are dead because the matrix around them has calcified. Capillaries and osteoblasts from the diaphysis penetrate this zone, and the osteoblasts secrete bone tissue on the remaining calcified cartilage. Thus, the zone of calcified matrix connects the epiphyseal plate to the diaphysis. A bone grows in length when osseous tissue is added to the diaphysis.

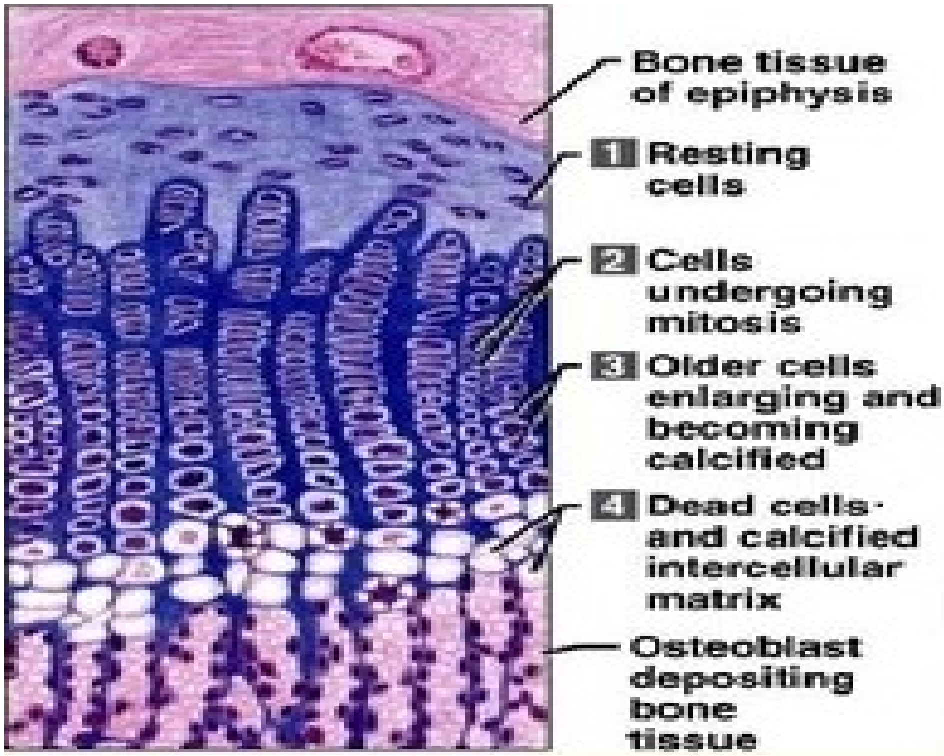



**Fig- 12: Zones of bone growth**

Bones continue to grow in length until early adulthood. The rate of growth is controlled by hormones, which will be discussed later. When the chondrocytes in the epiphyseal plate cease their proliferation and bone replaces the cartilage, longitudinal growth stops. All that remains of the epiphyseal plate is the **epiphyseal line**

**B) Appositional growth**- While bones are increasing in length, they are also increasing in diameter; growth in diameter can continue even after longitudinal growth ceases. This is called appositional growth. Osteoclasts resorb old bone that lines the medullary cavity, while osteoblasts, via intramembranous ossification, produce new bone tissue beneath the periosteum. The erosion of old bone along the medullary cavity and the deposition of new bone beneath the periosteum not only increase the diameter of the diaphysis but also increase the diameter of the medullary cavity. This process is called **modeling**.

## ❖ BONE REMODELLING-

The process in which matrix is resorbed on one surface of a bone and deposited on another is known as bone modeling. Modeling primarily takes place during a bone's growth. However, in adult life, bone undergoes **remodeling**, in which resorption of old or damaged bone takes place on the same surface where osteoblasts lay new bone to replace that which is resorbed. Injury, exercise, and other activities lead to remodeling. Those influences are discussed later in the chapter, but even without injury or exercise, about 5 to 10 percent of the skeleton is remodeled annually just by destroying old bone and renewing it with fresh bone.

## ❖ BONE MARKINGS-

External surfaces of bones have:- bumps, grooves, and holes. They serve as sites of muscle, ligament, tendon attachment, joint surfaces, or conduits for nerve fibers and blood vessels. Two types of bone markings:

- Projections (aka processes) that grow out from the bone
- Depressions (cavities) that indent the bone

- **Joint Projections-** 1) Condyle: Rounded articular projection

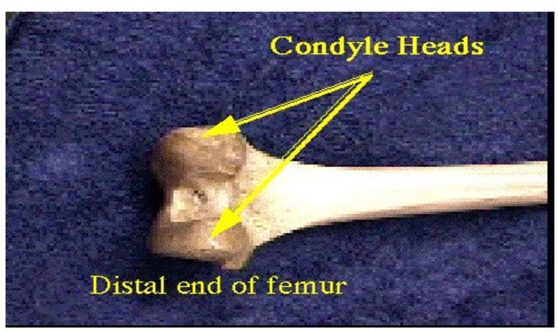



**Fig- 13: The Condyle**

2) Head: bony expansion on a narrow neck

**Fig- 14: The head**

3) Facet: smooth, nearly flat articular surface

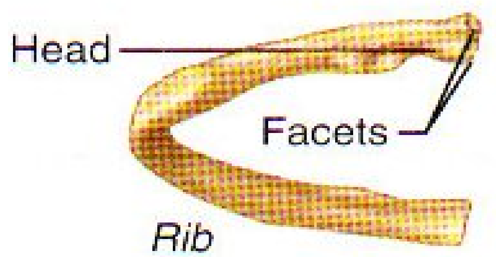



**Fig- 15: The facet**

4) Ramus**:** Arm like bar of bone

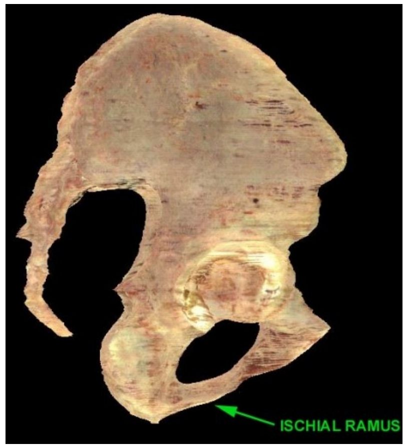



**Fig- 16: The ramus**

5) Crest: Narrow ridge of bone (Line: smaller than a crest)

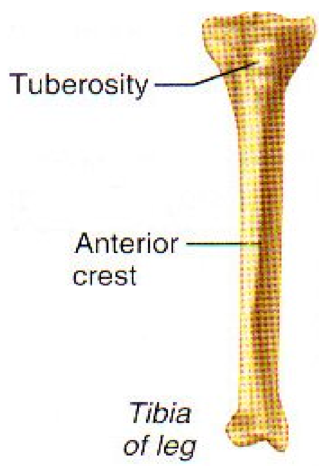



**Fig- 17: The crest**

6) Epicondyle: Raised area on or above a condyle.

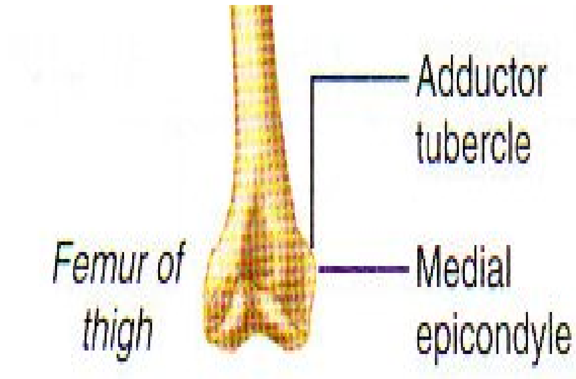



**Fig- 18: The Epicondyle**

7) Tubercle: Small rounded projection

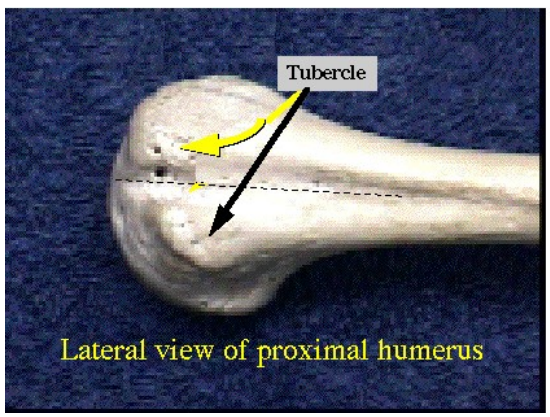



**Fig- 19: The Tubercle**

8) Tuberosity: large rounded or roughened projection

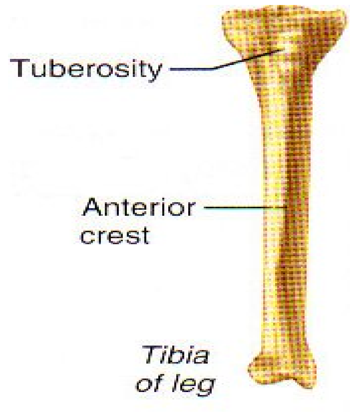



**Fig- 20: The tuberosity**

9) Trochanter: very large, blunt projection (only on femur)

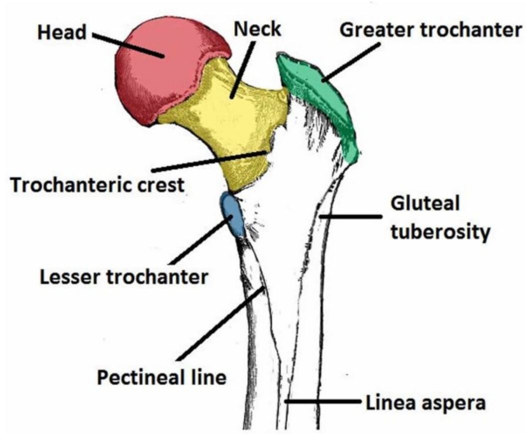



**Fig- 21: The trochanter**

10) Spine: Sharp, pointed projection

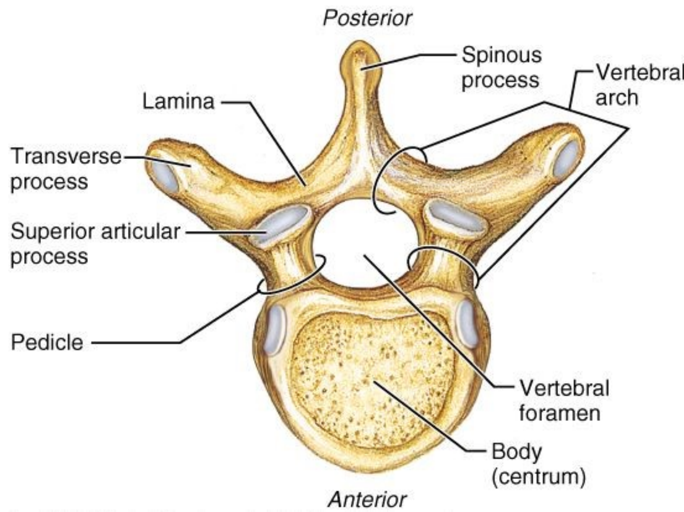



**Fig- 22: The spine**

11) Process: ANY bony prominence

- **Depressions-** Allow blood vessels or nerves to pass through.

   1) Meatus: Canal or tube

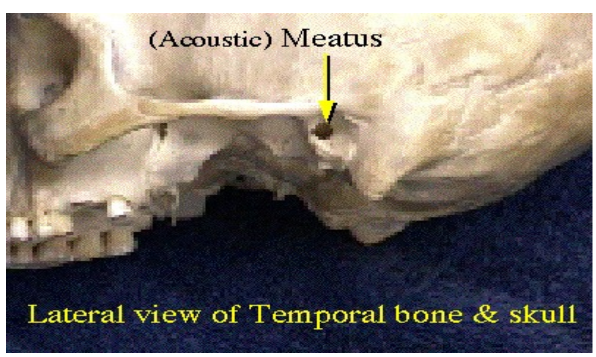



**Fig- 23: The Process**

   2) Fossa: shallow basin, often serving as an articular surface

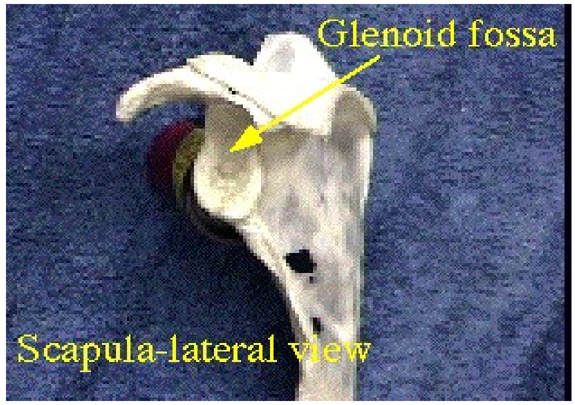



**Fig- 24: The fossa**

3) Fissure: narrow, slit-like opening

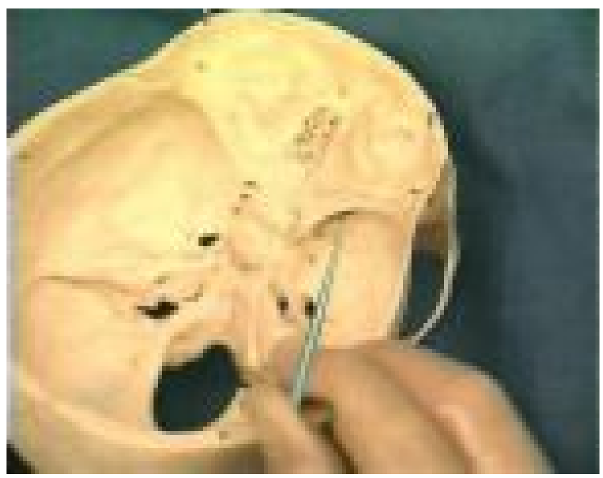


**Fig- 25: The fissure**

4) Sinus: Cavity within a bone; filled with air and lined with mucous membranes

**Fig- 26: The Sinus**

5)  Foramen:  Round or oval opening

**Fig- 27: The foramen**

6) Sulcus, Groove or Furrow:  a shallow depression

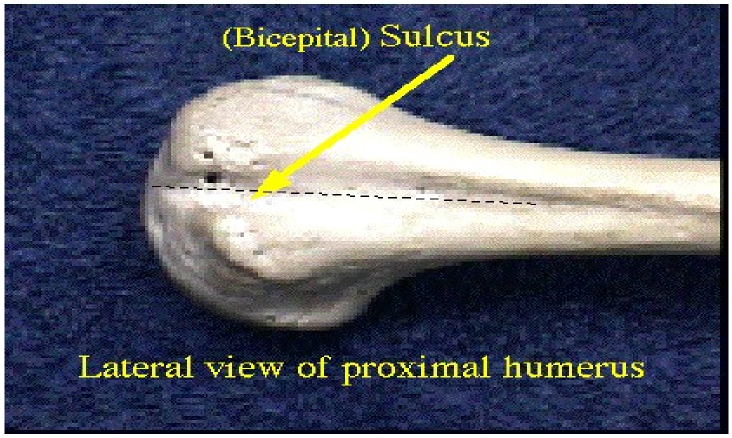



**Fig- 28: The Sulcus**

- **CARTILAGE:** It is a connective tissue composed of cells (chondrocytes) and fibres (collagen) in matrix, rich in mucopolysaccarides. Derived from latin word cartilago – gristle= tendinous,or fibrous matter)

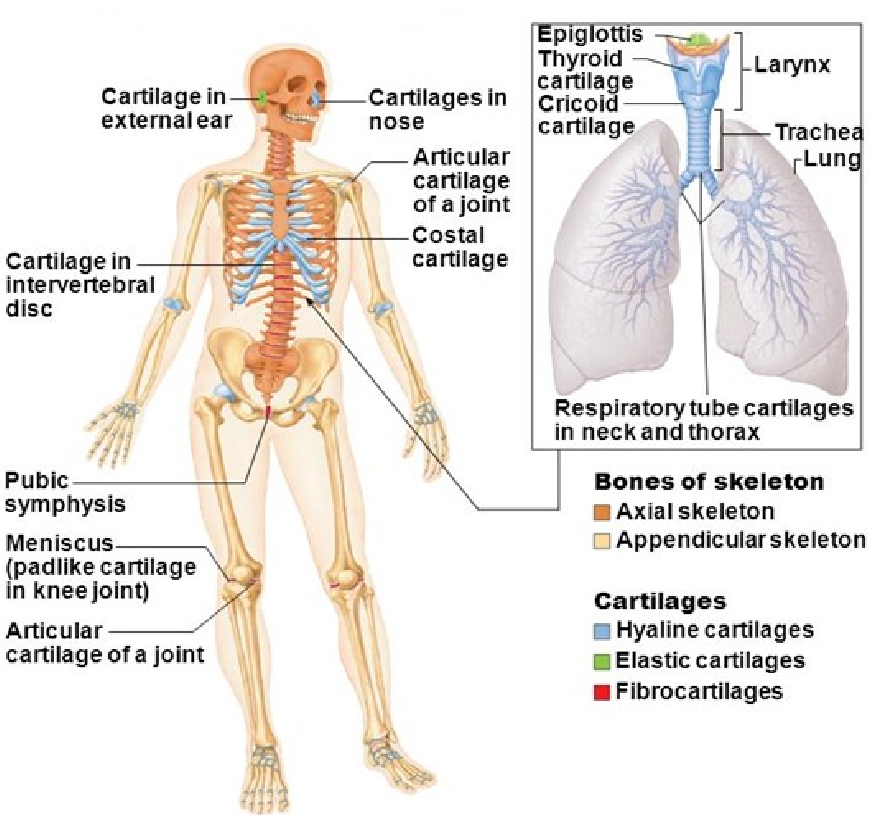



**Fig- 29: Locations of Cartilage in human body**

**General features-**

- Has no blood vessels or lymphatics
- Nutrition is by diffusion through matrix
- No nerves – insensitive
- Surrounded by a fibrous membrane – perichondrium
- Articular cartilage has no perichondrium – regeneration after injury inadequate
- When calcifies – chondrocytes die – replaced by bone

**Function:-**

- Supports soft tissues
- shock absorbing and sliding area for joints (smooth surface),
- essential for the development and growth of long bones

**Composition:**

**A: CELLS:** 1. Chondrocytes - synthesize and secrete extracellular matrix

- located in matrix cavities – **lacunae**

**EM:** organelles typical of protein secretory cells (rER, GA)

2. Chondroblasts – synthesize and secrete extracellular matrix

3. Chondroclasts – belong to mononuclear phagocyte system involved in destruction of the cartilage

**B: EXTRACELLULAR MATRIX:**

**a) Amorphous ground substance**

1. Glycosaminoglycans – hyaluronic acid, chondroitinsulfate, keratansulfate
2. Proteoglycans – form proteoglycan aggregates that interact with collagen and bind the water
3. Structural glycoproteins - chondronectin

**b) Fibrils** – 1. Collagen II – fibers are not formed, fibrils with diameter 20nm

2. Collagen I – form fibers, in fibrocartilage
3. Elastic fibers – in elastic cartilage

- The cartilage matrix immediately surrounding each chondrocyte is rich in glycosaminoglycans and poor in collagen – **territorial** or **capsular matrix** (intense basophilia, metachromasia). Matrix located between the capsules – **interrteritorial matrix**

**PERICHONDRIUM**

- Capsule like sheath of dense connective tissue that surrounds cartilage
- Harbors the vascular supply for avascular cartilage
- Connects cartilage with the surrounding tissues
- Articular cartilage – covers the surfaces of the bones of movable joints- is devoid of perichondrium and the nutrition is assigned by the diffusion of oxygen and nutrients from the synovial fluid

**Composed of two layers:**

**1. Fibrous** – **stratum fibrosum** - external part, contains fibres collagen I, small amount of cells - fibroblasts

**2. Cellular** – **stratum chondrogenicum** abundant cells – fibroblasts and chondroblats

## Growth

- Newly formed chondrocytes synthesize collagen fibrils and ground substance

**1. Appositional growth** – resulting from the differentiation of perichondrial cells chondroblats of the perichondrium proliferate and become chondrocytes; once they have surrounded themselves with extracellular matrix, they are incorporated into the existing cartilage

**2. Interstitial growth** – mitotic division of preexisting chondrocytes

1. During early phases of cartilage formation
2. Within the epiphyseal plates in long bones (increasing the length)
3. Within articular cartilage

**Regeneration**

- By appositional growth from perichondrium;
- The chondroblasts from perichondrium invade the damaged area and generate new cartilage
- In extensively damaged areas the cartilage is replaced by dense connective tissue

**Types of cartilage-**

a) Hyaline cartilage
b) Fibrocartilage
c) Elastic cartilage

a) **Hyaline cartilage**- G. hyalos - transparent stone)

**Occurrence:** articular surfaces, wall of large respiratory passages – larynx, trachea, bronchi, epiphyseal plate, ventral ends of ribs, embryonic temporary skeleton

**Appearance:** bluish-white, translucent

**Composition:**

**1. Chondrocytes**

-Spherical in shape, at the periphery elliptic

- Appear in groups - up to 8 cells originating by mitotic division of a single chondrocyte – **isogenous group**

- Housed in matrix cavities- **lacunae** (in living tissue fill the lacunae, shrinking during preparation)

**2. Extracellular matrix - (glassy) -** cells are surrounded by basophilic matrix **– territorial (capsular)** matrix (rich in acidic glycosaminoglycans) and **interterritorial matrix** – smooth, paler, less basophilic (**collagen II** - does not form fibres, fibrilles interact with proteoglycan aggregates, are not visible by LM because their refractive index is similar to that of ground substance and are masked by the glycosaminoglycans; hence the matrix appears homogeneus and smooth)

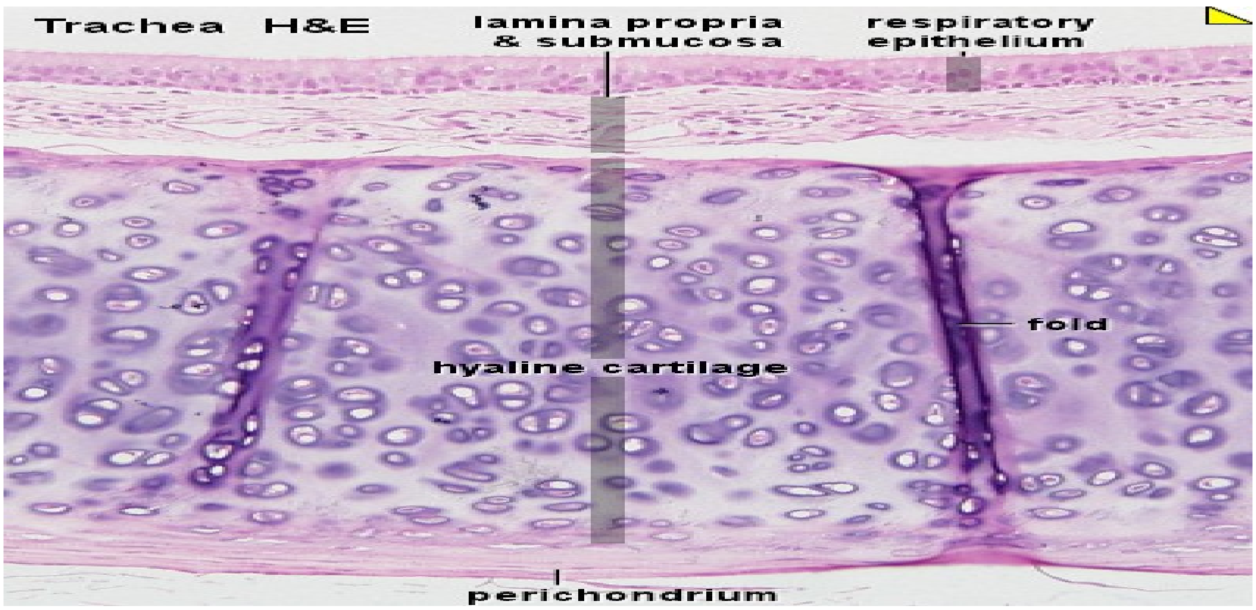



**Fig-30: Microanatomy of hyaline cartilage**

**2. ELASTIC CARTILAGE**

**Occurrence:** epiglottis, auricle of the ear, Eustachian tube, cuneiform and corniculate cartilages in larynx

**Appearance:** yellowish color

**Composition:**

**1. Chondrocytes –** similar to hyaline cartilage, housed in lacuna singly or in pairs (coffee bean)

**2. Extracellular matrix –** fibrils of collagen II and network of fine elastic fibers (are arranged in more or less regular fashion between the cells), less amount of ground amorphous substance. On the surface - perichondrium is identifiable

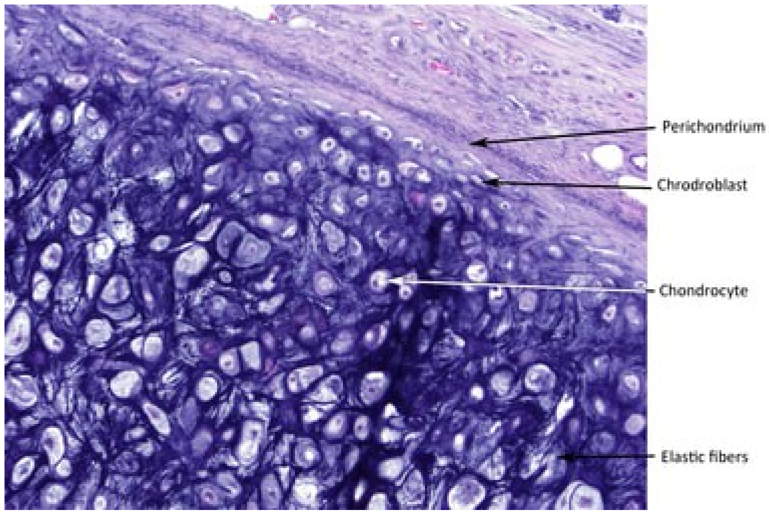



**Fig-31: Microanatomy of Elastic cartilage**

**3. FIBROCARTILAGE**

**Occurrence:** intervertebral discs, symphysis pubis

INTERVERTEBRAL DISC

• Shock absorber

• Situated between articular surfaces of neighboring vertebrae

• Have 2 components:

1. Annulus fibrosus – fibrocartilage, concentric layers

2. Nucleus pulposus – in the centre; ground substance + few cells, col. II.

**Appearance:** characteristics between dense connective tissue and cartilage

**Composition:**

**1. Chondrocytes –** small, spindle-shaped, similar to fibroblasts arranged singly or in long rows

**2. Extracellular matrix** – great number of collagen I fibers – acidophilic, amorphous matrix less abundant. Perichondrium is not identifiable.

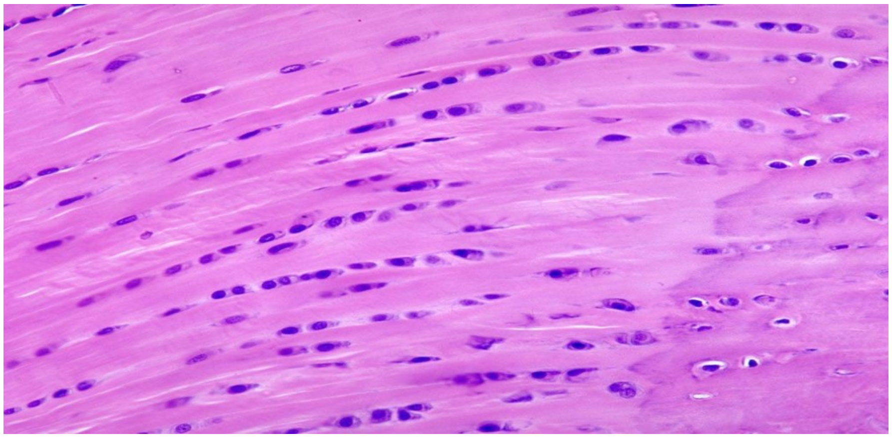


**Fig-32: Microanatomy of Fibrocartilage**

## ❖ JOINTS:

***Definition-***

Any point where two bones meet, whether or not the bones are movable at that interface. Joints link the bones of the skeletal system, permit effective movement, and protect the softer organs. Joint anatomy and movements will provide a foundation for the study of muscle actions

***Types-***

1. Fibrous joints
2. Cartilaginous joints
3. Synovial joints

1) **Fibrous joints** - synarthrosis, or synarthrodial joint—adjacent bones are bound by collagen fibers that emerge from one bone and penetrate into the other.

Three kinds of fibrous joints:

–Sutures

–Gomphoses

–Syndesmoses

– **Sutures**—immobile or slightly mobile fibrous joints in which short collagen fibers bind the bones of the skull to each other

•Sutures can be classified as:

- **Serrate:** interlocking wavy lines. Eg. Coronal, sagittal, and lambdoid sutures
- **Lap (squamous):** overlapping beveled edges. Eg. Temporal and parietal bones
- **Plane (butt):** straight, non-overlapping edges. Eg. Palatine processes of the maxillae
- **Denticulate**- shape of suture is tooth like- Eg.- Lambdoid suture
- **Schindylesis-** in this, two bones are joined by fitting the ridge of one bone into the groove of another. Eg. Between rostrum of sphenoid and upper border of vomer.

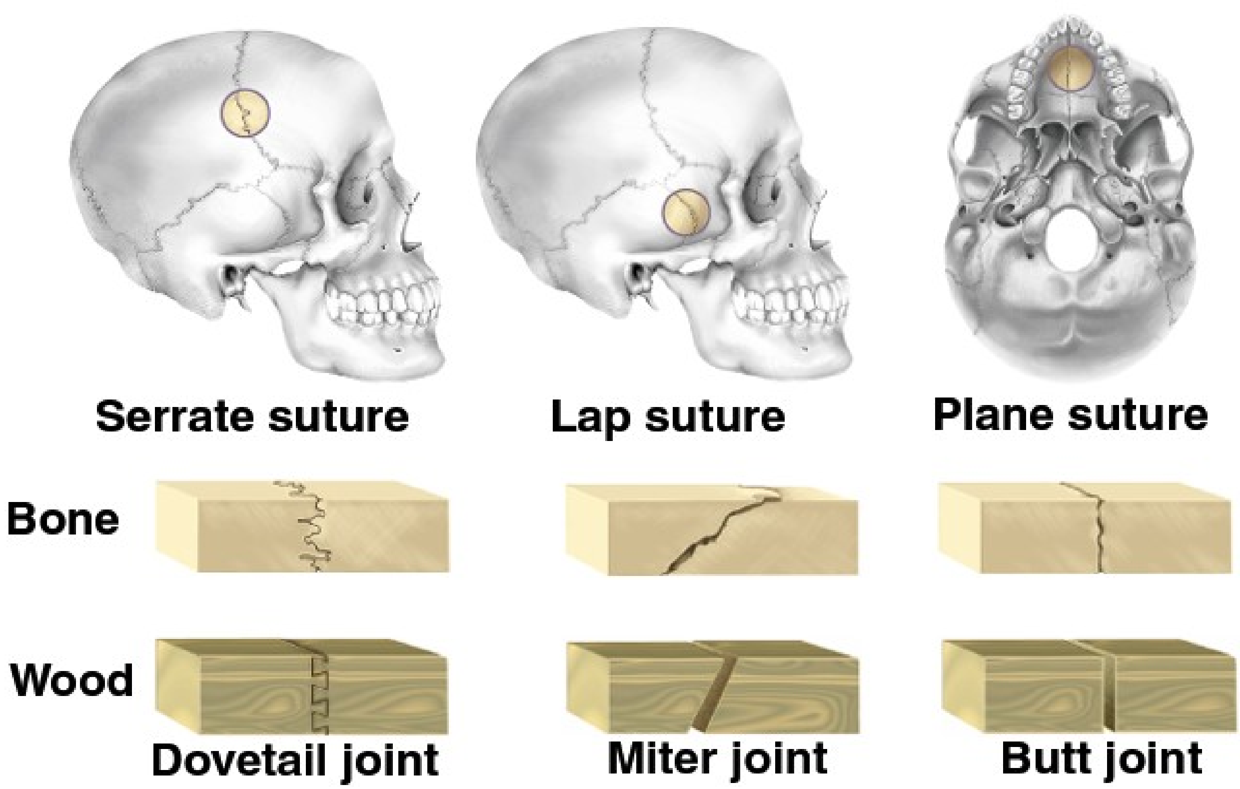



**Fig-33: Types of Sutures**

– **Gomphosis (fibrous joint)**—attachment of a tooth to its socket. Held in place by fibrous **periodontal ligament.** Collagen fibers attach tooth to jawbone. Allows the tooth to move a little under the stress of chewing.

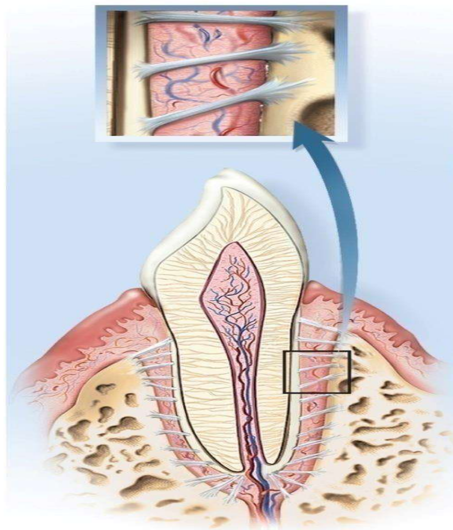


**Fig-34: Gomphosis**

– **Syndesmosis**—a fibrous joint at which two bones are bound by long collagen fibers
Eg: **interosseus membrane** joining radius to ulna allowing supination and pronation and **joint between tibia to fibula**

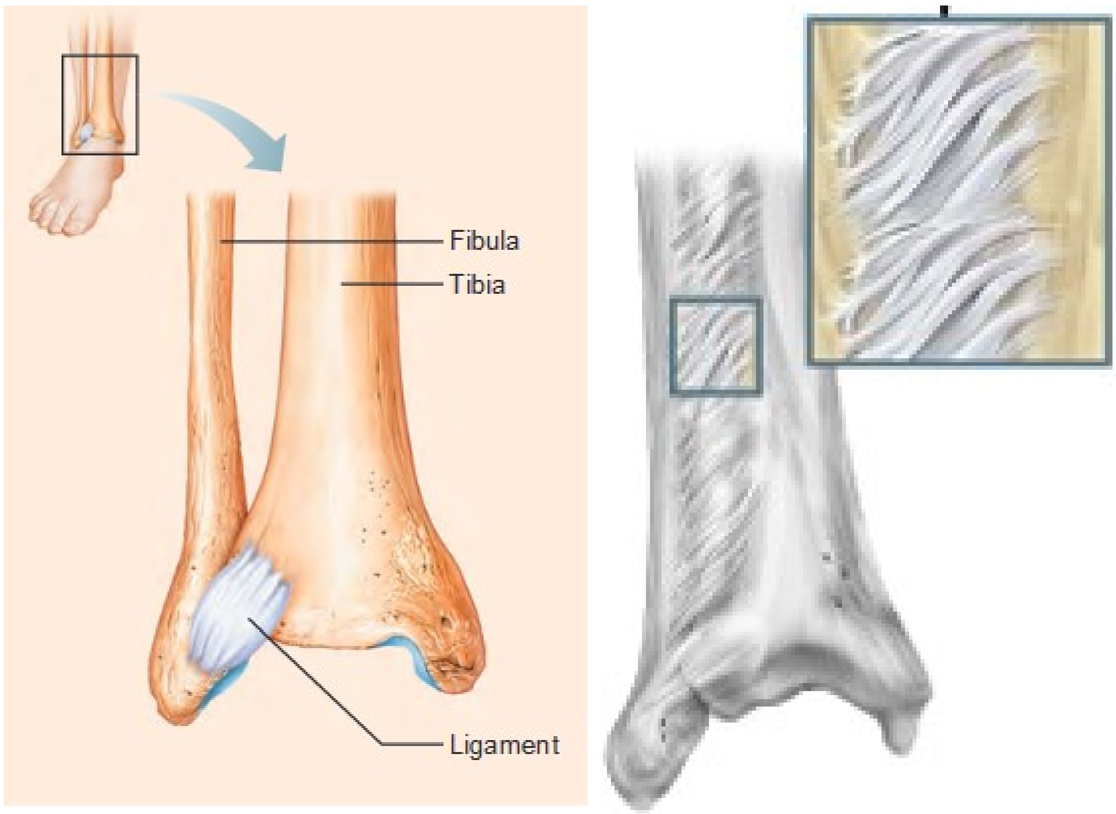



**Fig-35: Syndesmosis**

## 2) Cartilaginous joints-

**Cartilaginous joint, amphiarthrosis,** or **amphiarthrodial joint**—two bones are linked by cartilage. **Two types** of cartilaginous joints:

a) Synchondroses
b) Symphyses

**a) Synchrondrosis**—bones joined by **hyaline cartilage.** Temporary joints in the epiphyseal plates in children.

Eg.- joint between epiphysis and diaphysis. First rib attachment to sternum. Other costal cartilages joined to sternum by synovial joints.

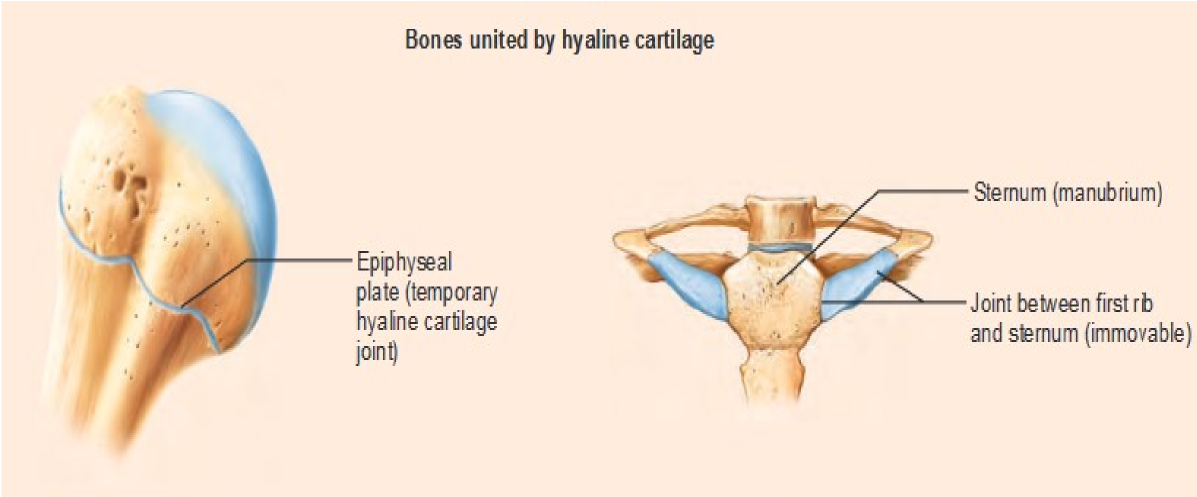



**Fig-36: Primary cartilaginous joint**

b) **Symphysis**—two bones joined by **fibrocartilage.** Only slight movements between adjacent vertebrae. Collective effect of all 23 discs gives spine considerable flexibility.

Eg.- **Pubic symphysis** joins right and left pubic bones with **interpubicdisc**. **Bodies of vertebrae** joined by **intervertebral discs.**

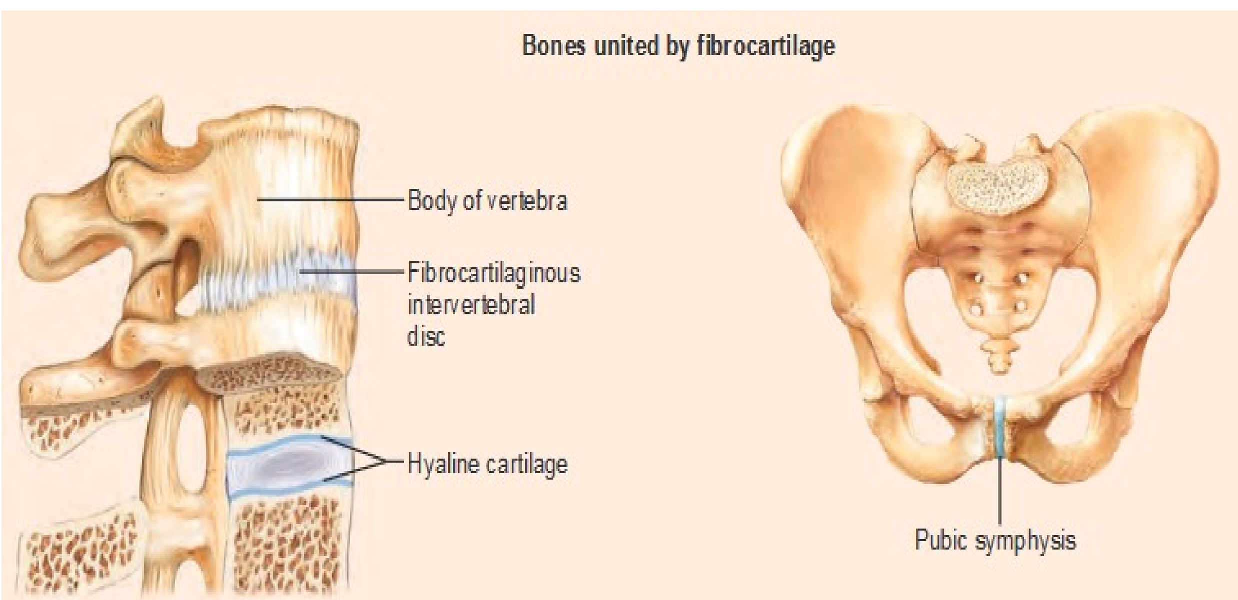



**Fig-37: Secondary cartilaginous joint**

## 3) Synovial joints

(si-nove-al; “joint eggs”) are those in which the articulating bones are separated by a fluid-containing joint cavity. This arrangement permits substantial freedom of movement, and all synovial joints are freely movable diarthroses. Nearly all joints of the limbs—indeed, most joints of the body—fall into this class.

### General Structure

Synovial joints have six distinguishing features:

1. **Articular cartilage**- Glassy-smooth hyaline cartilage covers the opposing bone surfaces as articular cartilage. These thin (1 mm or less) but spongy cushions absorb compression placed on the joint and thereby keep the bone ends from being crushed.

2. **Joint (synovial) cavity**- A feature unique to synovial joints, the joint cavity is really just a potential space that contains a small amount of synovial fluid.

3. **Articular capsule**- The joint cavity is enclosed by a two-layered articular capsule, or joint capsule. The external layer is a tough fibrous capsule, composed of dense irregular connective tissue that is continuous with the periostea of the articulating bones. It strengthens the joint so that the bones are not pulled apart. The inner layer of the joint capsule is a synovial membrane composed of loose connective tissue. Besides lining the fibrous capsule internally, it covers all internal joint surfaces that are not hyaline cartilage.

4. **Synovial fluid-** A small amount of slippery synovial fluid occupies all free spaces within the joint capsule. This fluid is derived largely by filtration from blood flowing through the capillaries in the synovial membrane. Synovial fluid has a viscous, egg-white consistency (ovum= egg) due to hyaluronic acid secreted by cells in the synovial membrane, but it thins and becomes less viscous, as it warms during joint activity.

Synovial fluid, which is also found within the articular cartilages, provides a slippery weight-bearing film that reduces friction between the cartilages. Without this lubricant, rubbing would wear away joint surfaces and excessive friction could overheat and destroy the joint tissues, essentially “cooking” them. The synovial fluid is forced from the cartilages when a joint is compressed; then as pressure on the joint are relieved, synovial fluid seeps back into the articular cartilages like water into a sponge, ready to be squeezed out again the next time the joint is loaded (put under pressure).

This process, called weeping lubrication, lubricates the free surfaces of the cartilages and nourishes their cells. (Remember, cartilage is avascular.) Synovial fluid also contains phagocytic cells that rid the joint cavity of microbes and cellular debris.

5. **Reinforcing ligaments**- Synovial joints are reinforced and strengthened by a number of bands like ligaments. Most often, these are capsular, or intrinsic, ligaments, which are thickened parts of the fibrous capsule. In other cases, they remain distinct and are found outside the capsule (as extra capsular ligaments) or deep to it (as intracapsular ligaments).

Since intracapsular ligaments are covered with synovial membrane, they do not actually lie within the joint cavity. People said to be double-jointed amaze the rest of us by placing both heels behind their neck. However, they have the normal number of joints. It's just that their joint capsules and ligaments are stretchier and loose than average.

6. **Nerves and blood vessels**- Synovial joints are richly supplied with sensory nerve fibers that innervate the capsule. Some of these fibers detect pain, as anyone who has suffered joint injury is aware, but most monitor joint position and stretch, thus helping to maintain muscle tone. Stretching these structures sends nerve impulses to the central nervous system, resulting in reflexive contraction of muscles surrounding the joint.

Synovial joints are also richly supplied with blood vessels, most of which supply the synovial membrane. There, extensive capillary beds produce the blood filtrate that is the basis of synovial fluid. Besides the basic components described above, certain synovial joints have other structural features. Some, such as the hip and knee joints, have cushioning fatty pads between the fibrous capsule and the synovial membrane or bone. Others have discs or wedges of fibrocartilage separating the articular surfaces. Where present, these so-called articular discs, or menisci (me˘-niski; "crescents"), extend inward from the articular capsule and partially or completely divide the synovial cavity in two (see the menisci of the knee. Articular discs improve the fit between articulating bone ends, making the joint more stable and minimizing wear and tear on the joint surfaces. Besides the knees, articular discs occur in the jaw, and a few other joints.

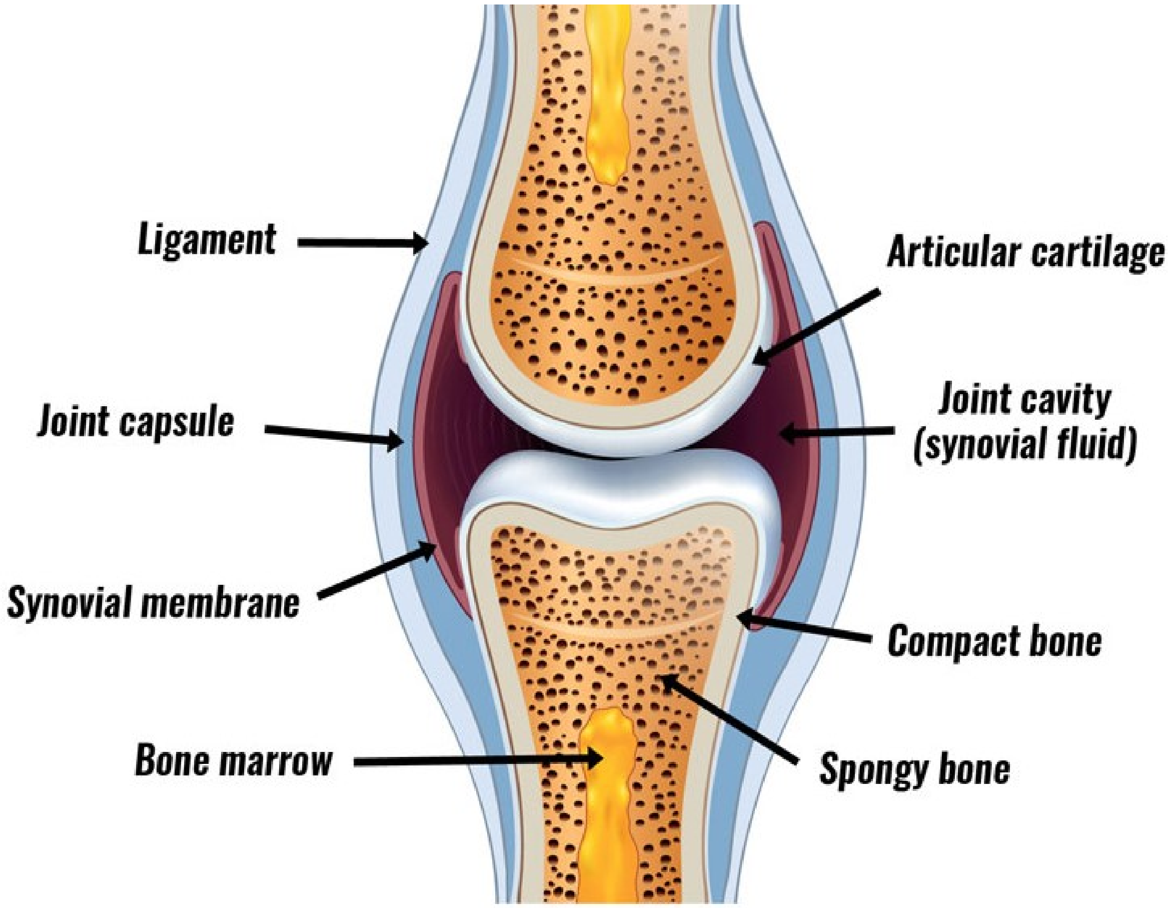



**Fig-38: General structure of Synovial joint**

- **Bursae and Tendon Sheaths**

Bursae and tendon sheaths are not strictly part of synovial joints, but they are often found closely associated with them. Essentially bags of lubricant, they act as “ball bearings” to reduce friction between adjacent structures during joint activity. Bursae (berse; “purse”) are flattened fibrous sacs lined with synovial membrane and containing a thin film of synovial fluid. They occur where ligaments, muscles, skin, tendons, or bones rub together. A tendon sheath is essentially an elongated bursa that wraps completely around a tendon subjected to friction, like a bun around a hot dog. They are common where several tendons are crowded together within narrow canals (in the wrist region, for example).

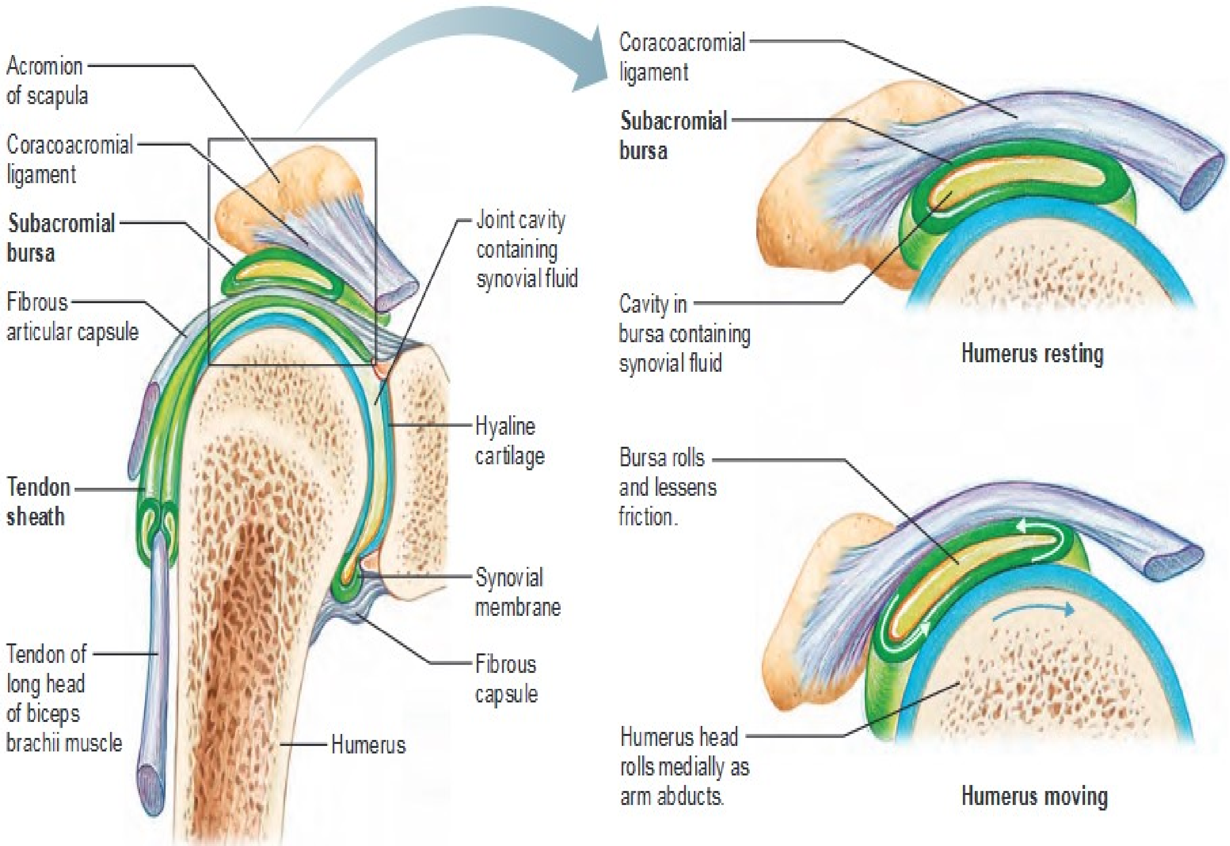



**Fig-39: Primary cartilaginous joint**

**Factors Influencing the Stability of Synovial Joints:**

Because joints are constantly stretched and compressed, they must be stabilized so that they do not dislocate (come out of alignment). The stability of a synovial joint depends chiefly on three factors: the shapes of the articular surfaces; the number and positioning of ligaments; and muscle tone.

- **Articular Surfaces**

The shapes of articular surfaces determine what movements are possible at a joint, but surprisingly, articular surfaces play only a minor role in joint stability. Many joints have shallow sockets or non-complementary articulating surfaces ("misfits") that actually hinder joint stability. But when articular surfaces are large and fit snugly together, or when the socket is deep, stability is vastly improved. The ball and deep socket of the hip joint provide the best example of a joint made extremely stable by the shape of its articular surfaces.

- **Ligaments**

The capsules and ligaments of synovial joints unite the bones and prevent excessive or undesirable motion. As a rule, the more ligaments a joint has, the stronger it is. However, when other stabilizing factors are inadequate, undue tension is placed on the ligaments and they stretch. Stretched ligaments stay stretched, like taffy, and a ligament can stretch only about 6% of its length before it snaps. Thus, when ligaments are the major means of bracing a joint, the joint is not very stable.

- **Muscle Tone**

For most joints, the muscle tendons that cross the joint are the most important stabilizing factor. These tendons are kept taut at all times by the tone of their muscles. (Muscle tone is defined as low levels of contractile activity in relaxed muscles that keep the muscles healthy and ready to react to stimulation.) Muscle tone is extremely important in reinforcing the shoulder and knee joints and the arches of the foot.

**Types of Synovial joints:**

## Planar Joints

Planar joints have bones with articulating surfaces that are flat or slightly curved. These joints allow for gliding movements; therefore, the joints are sometimes referred to as gliding joints. The range of motion is limited and does not involve rotation. Planar joints are found in the carpal bones in the hand and the tarsal bones of the foot, as well as between vertebrae.

## Hinge Joints

In hinge joints, the slightly-rounded end of one bone fits into the slightly-hollow end of the other bone. In this way, one bone moves while the other remains stationary, similar to the hinge of a door. The elbow is an example of a hinge joint. The knee is sometimes classified as a modified hinge joint.

## Pivot Joints

Pivot joints consist of the rounded end of one bone fitting into a ring formed by the other bone. This structure allows rotational movement, as the rounded bone moves around its own axis. An example of a pivot joint is the joint of the first and second vertebrae of the neck that allows the head to move back and forth. The joint of the wrist that allows the palm of the hand to be turned up and down is also a pivot joint.

## Condyloid Joints

Condyloid joints consist of an oval-shaped end of one bone fitting into a similarly oval-shaped hollow of another bone. This is also sometimes called an ellipsoidal joint. This type of joint allows angular movement along two axes, as seen in the joints of the wrist and fingers, which can move both side to side and up and down.

## Saddle Joints

Each bone in a saddle joint resembles a saddle, with concave and convex portions that fit together. Saddle joints allow angular movements similar to condyloid joints, but with a greater range of motion. An example of a saddle joint is the thumb joint, which can move back and forth and up and down; it can move more freely than the wrist or fingers.

## Ball-and-Socket Joints

Ball-and-socket joints possess a rounded, ball-like end of one bone fitting into a cup-like socket of another bone. This organization allows the greatest range of motion, as all movement types are possible in all directions. Examples of ball-and-socket joints are the shoulder and hip joints.

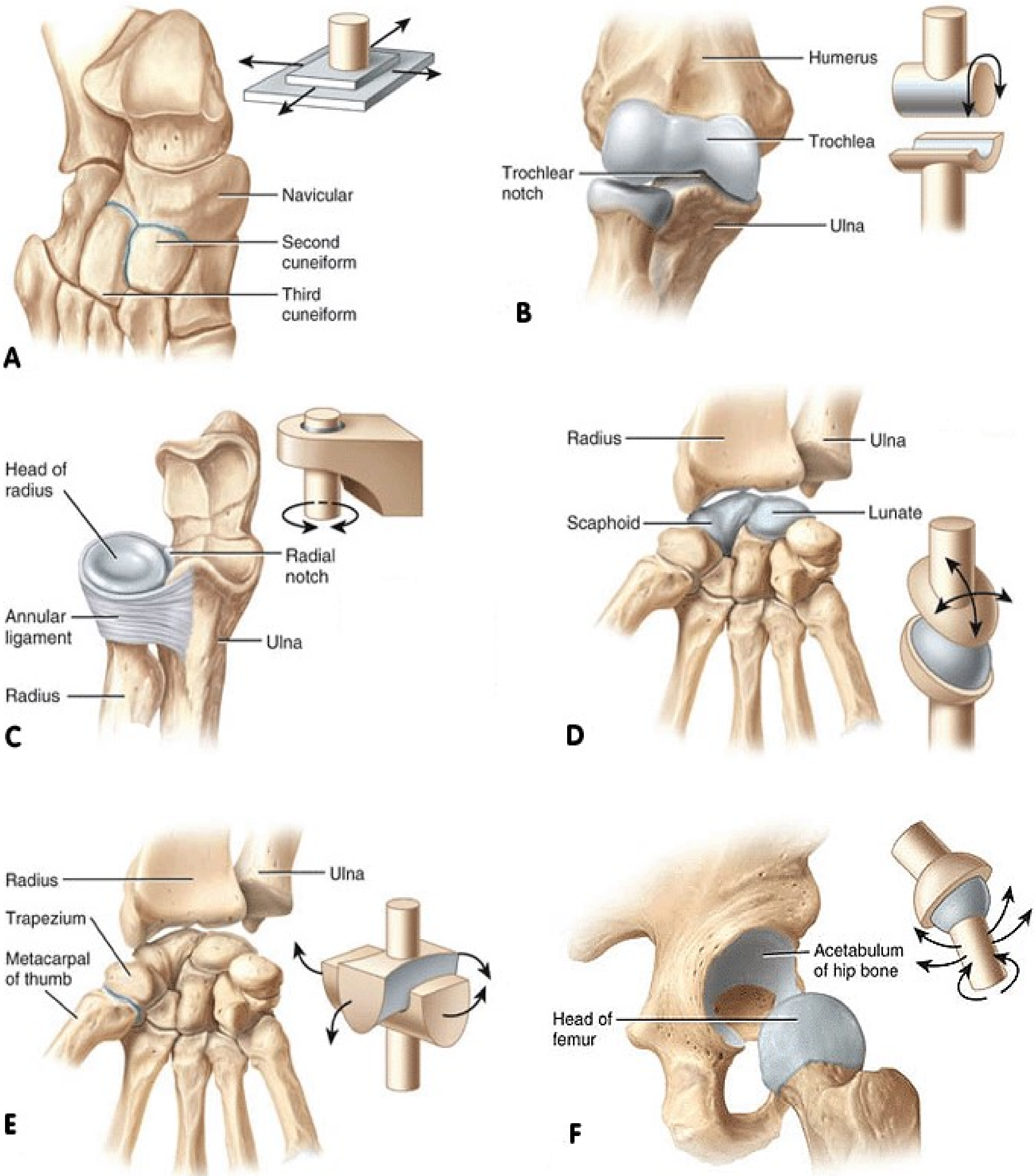



**Fig-40: Synovial joints**

## Movements Allowed by Synovial Joints:

Every skeletal muscle of the body is attached to bone or other connective tissue structures at no fewer than two points. The muscle's origin is attached to the immovable (or less movable) bone. Its other end, the insertion, is attached to the movable bone. Body movement occurs when muscles contract across joints and their insertion moves toward their origin. The movements can be described in directional terms relative to the lines, or axes, around which the body part moves and the planes of space along which the movement occurs, that is, along the transverse, frontal, or sagittal plane. Range of motion allowed by synovial joints varies from non axial movement (slipping movements only, since there is no axis around which movement can occur) to uniaxial movement (movement in one plane) to biaxial movement (movement in two planes) to multiaxial movement (movement in or around all three planes of space and axes). Range of motion varies greatly in different people. In some, such as trained gymnasts or acrobats, range of joint movement may be extra-ordinary.

There are three general types of movements: Gliding, Angular movements, and Rotation.

**Gliding Movements**

Gliding movements are the simplest joint movements. Gliding occurs when one flat, or nearly flat, bone surface glides or slips over another (back-and-forth and side-to-side) without appreciable angulation or rotation. Gliding movements occur at the intercarpal and intertarsal joints, and between the flat articular processes of the vertebrae.

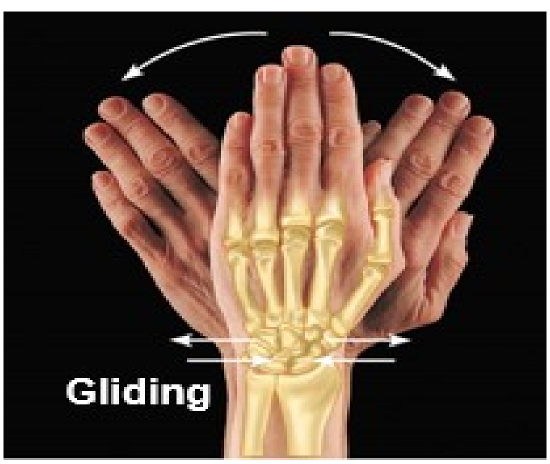



**Fig-41: Gliding joints**

**Angular Movements**

Angular movements increase or decrease the angle between two bones. These movements may occur in any plane of the body and include flexion, extension, hyperextension, abduction, adduction, and circumduction.

**Flexion**

Flexion is a bending movement, usually along the sagittal plane, that decreases the angle of the joint and brings the articulating bones closer together. Examples include bending the head forward on the chest and bending the body trunk or the knee from a straight to an angled position. As a less obvious example, the arm is flexed at the shoulder when the arm is lifted in an anterior direction.

**Extension**

Extension is the reverse of flexion and occurs at the same joints. It involves movement along the sagittal plane that increases the angle between the articulating bones and typically straightens a flexed limb or body part. Examples include straightening a flexed neck, body trunk, elbow, or knee.

In the limbs, flexion decreases the angle between the bones (bending of the joint), while extension increases the angle and straightens the joint. For the upper limb, all anterior motions are flexion and all posterior motions are extension. These include anterior-posterior movements of the arm at the shoulder, the forearm at the elbow, the hand at the wrist, and the fingers at the metacarpophalangeal and interphalangeal joints. For the thumb, extension moves the thumb away from the palm of the hand, within the same plane as the palm, while flexion brings the thumb back against the index finger or into the palm. These motions take place at the first carpometacarpal joint. In the lower limb, bringing the thigh forward and upward is flexion at the hip joint, while any posterior-going motion of the thigh is extension. Note that extension of the thigh beyond the anatomical (standing) position is greatly limited by the ligaments that support the hip joint. Knee flexion is the bending of the knee to bring the foot toward the posterior thigh, and extension is the straightening of the knee. Flexion and extension movements are seen at the hinge, condyloid, saddle, and ball-and-socket joints of the limbs.

**Hyperextension** is the abnormal or excessive extension of a joint beyond its normal range of motion, thus resulting in injury. Similarly, **hyperflexion** is excessive flexion at a joint. Hyperextension injuries are common at hinge joints such as the knee or elbow. In cases of "whiplash" in which the head is suddenly moved backward and then forward, a patient may experience both hyperextension and hyperflexion of the cervical region.

**Abduction**

Abduction ("moving away") is movement of a limb away from the midline or median plane of the body, along the frontal plane. Raising the arm or thigh laterally is an example of abduction. For the fingers or toes, abduction means spreading them apart. In this case "midline" is the longest digit: the third finger or second toe. However, lateral bending of the trunk away from the body midline in the frontal plane is called lateral flexion, not abduction.

**Adduction**

Adduction ("moving toward") is the opposite of abduction, so it is the movement of a limb toward the body midline or, in the case of the digits, toward the midline of the hand or foot.

**Circumduction**

Circumduction is moving a limb so that it describes a cone in space (circum= around; duco= to draw). The distal end of the limb moves in a circle, while the point of the cone (the shoulder or hip joint) is more or less stationary. A pitcher winding up throwing a ball is actually circumducting his or her pitching arm. Because circumduction consists of flexion, abduction, extension, and adduction performed in succession, it is the quickest way to exercise the many muscles that move the hip and shoulder ball-and-socket.

## Rotation

**Rotation** can occur within the vertebral column, at a pivot joint, or at a ball-and-socket joint. Rotation of the neck or body is the twisting movement produced by the summation of the small rotational movements available between adjacent vertebrae. At a pivot joint, one bone rotates in relation to another bone. This is a uniaxial joint, and thus rotation is the only motion allowed at a pivot joint. For example, at the atlantoaxial joint, the first cervical (C1) vertebra (atlas) rotates around the dens, the upward projection from the second cervical (C2) vertebra (axis). This allows the head to rotate from side to side as when shaking the head "no." The proximal radioulnar joint is a pivot joint formed by the head of the radius and its articulation with the ulna. This joint allows for the radius to rotate along its length during pronation and supination movements of the forearm.

Rotation can also occur at the ball-and-socket joints of the shoulder and hip. Here, the humerus and femur rotate around their long axis, which moves the anterior surface of the arm or thigh either toward or away from the midline of the body. Movement that brings the anterior surface of the limb toward the midline of the body is called **medial (internal) rotation**. Conversely, rotation of the limb so that the anterior surface moves away from the midline is **lateral (external) rotation**. Be sure to distinguish medial and lateral rotation, which can only occur at the multiaxial shoulder and hip joints, from circumduction, which can occur at either biaxial or multiaxial joints.

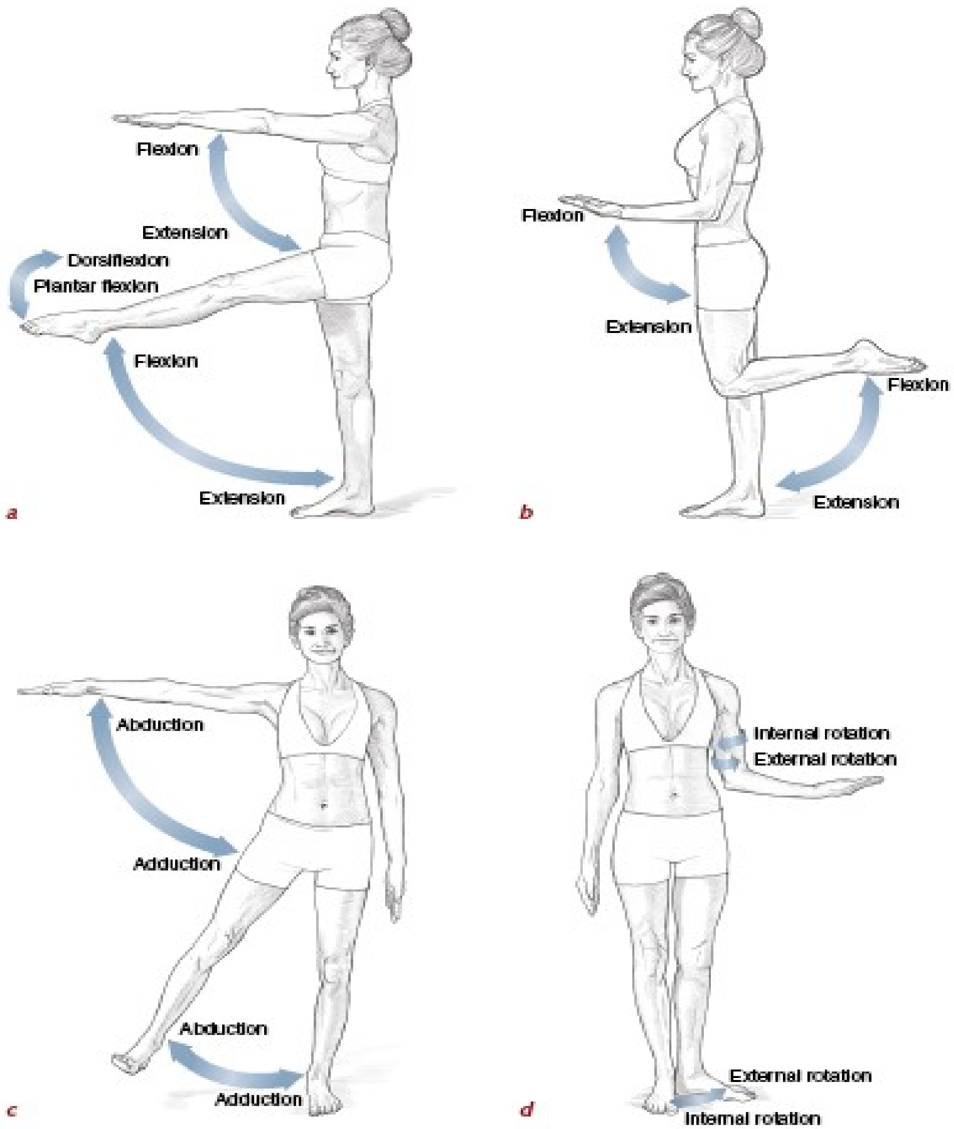



**Fig-42: Angular movements**

## Special Movements

Certain movements do not fit into any of the above categories and occur at only a few joints. Some of these special movements are illustrated in:

**Supination and Pronation**

The terms supination ("turning backward") and pronation ("turning forward") refer to the movements of the radius around the ulna. Supination and pronation are movements of the forearm. In the anatomical position, the upper limb is held next to the body with the palm facing forward. This is the **supinated position** of the forearm. In this position, the radius and ulna are parallel to each other. When the palm of the hand faces backward, the forearm is in the **pronated position**, and the radius and ulna form an X-shape.

Supination and pronation are the movements of the forearm that go between these two positions. **Pronation** is the motion that moves the forearm from the supinated (anatomical) position to the pronated (palm backward) position. This motion is produced by rotation of the radius at the proximal radioulnar joint, accompanied by movement of the radius at the distal radioulnar joint. The proximal radioulnar joint is a pivot joint that allows for rotation of the head of the radius. Because of the slight curvature of the shaft of the radius, this rotation causes the distal end of the radius to cross over the distal ulna at the distal radioulnar joint. This crossing over brings the radius and ulna into an X-shape position. **Supination** is the opposite motion, in which rotation of the radius returns the bones to their parallel positions and moves the palm to the anterior facing (supinated) position. It helps to remember that supination is the motion you use when scooping up soup with a spoon. A trick to help you keep these terms straight: "beggars are supinators and donors are pronators".

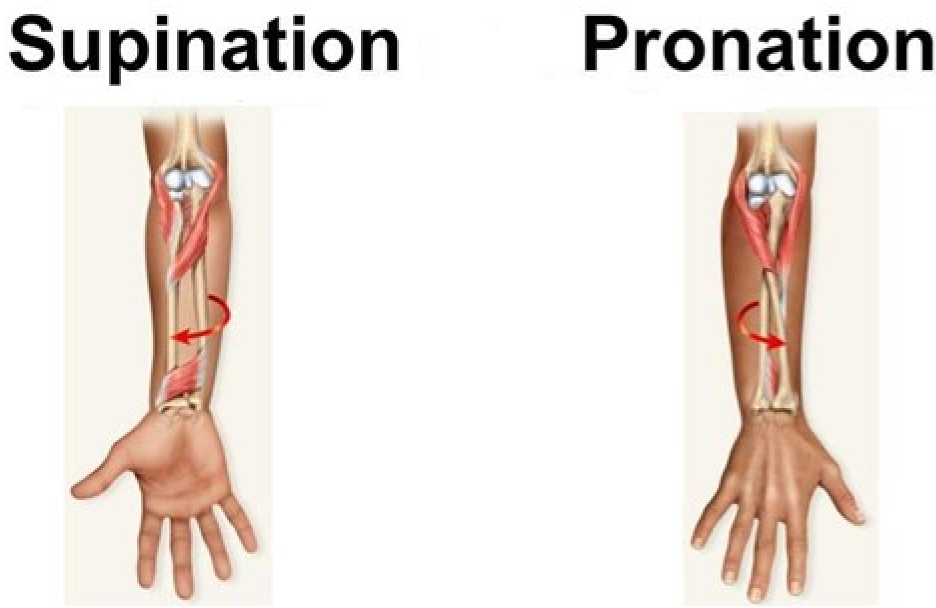



**Fig-43: Supination and Pronation**

**Dorsiflexion and Plantar Flexion of the Foot**

The up-and-down movements of the foot at the ankle are given more specific names. Lifting the foot so that it's superior surface approaches the shin is dorsiflexion (corresponds to wrist extension), whereas depressing the foot (pointing the toes) is plantar flexion (corresponds to wrist flexion).

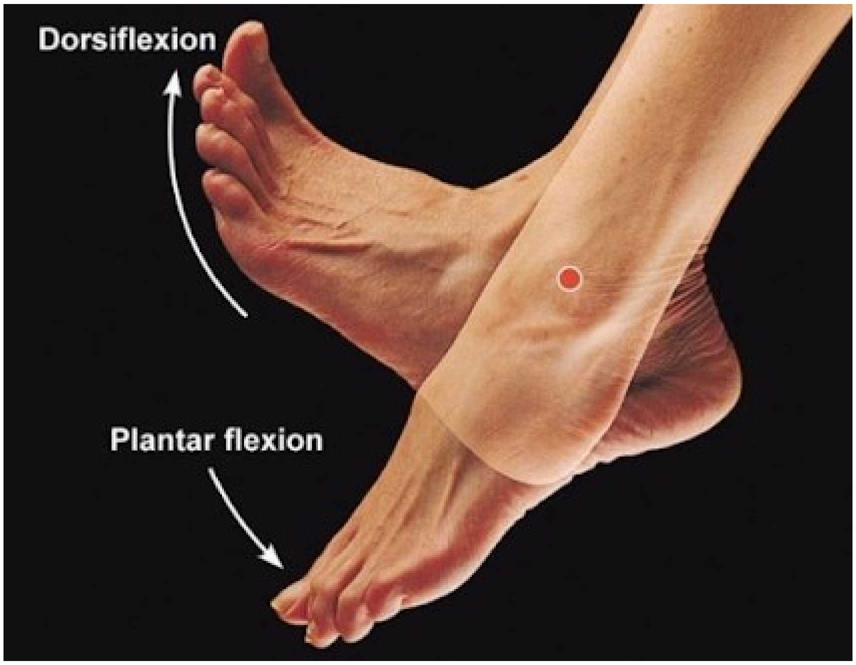



**Fig-44: Dorsiflexion and Planterflexion**

**Inversion and Eversion**

Inversion and eversion are complex movements that involve the multiple plane joints among the tarsal bones of the posterior foot (intertarsal joints) and thus are not motions that take place at the ankle joint. **Inversion** is the turning of the foot to angle the bottom of the foot toward the midline, while **eversion** turns the bottom of the foot away from the midline. The foot has a greater range of inversion than eversion motion. These are important motions that help to stabilize the foot when walking or running on an uneven surface and aid in the quick side-to-side changes in direction used during active sports such as basketball, racquetball, or soccer.

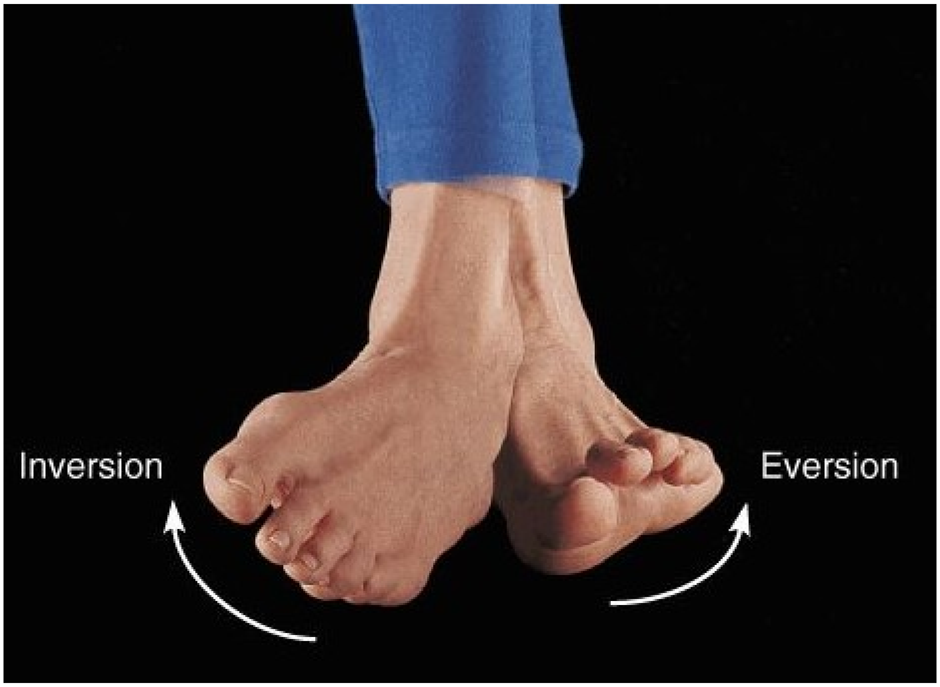



**Fig-45: Inversion and Eversion**

**Protraction and Retraction**

**Protraction** and **retraction** are anterior-posterior movements of the scapula or mandible. Protraction of the scapula occurs when the shoulder is moved forward, as when pushing against something or throwing a ball. Retraction is the opposite motion, with the scapula being pulled posteriorly and medially, toward the vertebral column. For the mandible, protraction occurs when the lower jaw is pushed forward, to stick out the chin, while retraction pulls the lower jaw backward.


**Fig-46: Protraction and Retraction**

**Elevation and Depression**

Elevation means lifting a body part superiorly. For example, the scapulae are elevated when you shrug your shoulders. Moving the elevated part inferiorly is depression. During chewing, the mandible is alternately elevated and depressed.

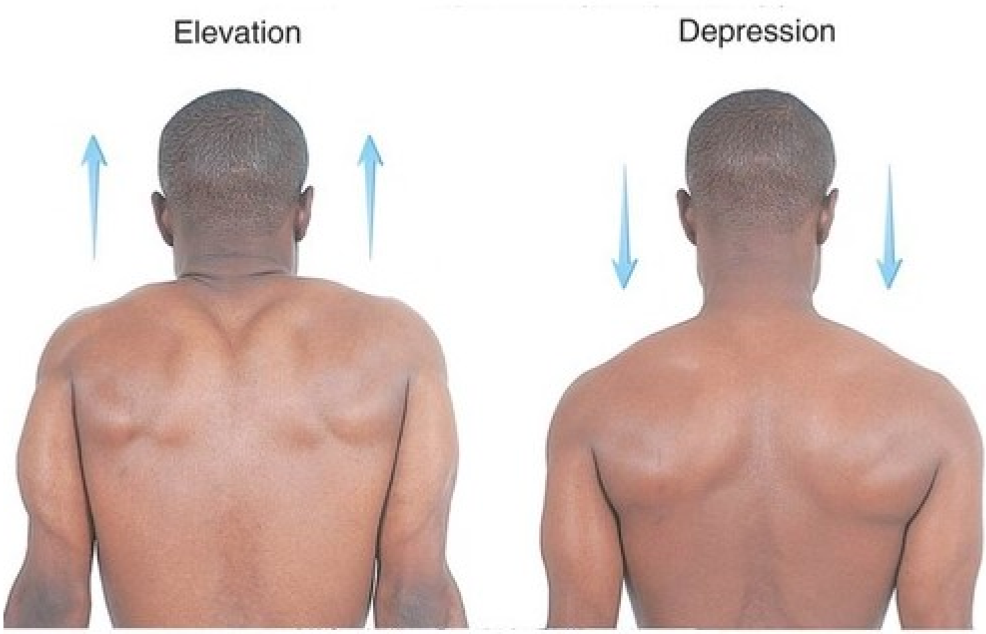


**Fig-47: Elevation and Depression**

### Excursion

Excursion is the side to side movement of the mandible. **Lateral excursion** moves the mandible away from the midline, toward either the right or left side. **Medial excursion** returns the mandible to its resting position at the midline.

### Opposition

The saddle joint between metacarpal 1 and the trapezium allows a movement called opposition of the thumb. This movement is the action taken when you touch your thumb to the tips of the other fingers on the same hand. It is opposition that makes the human hand such a fine tool for grasping and manipulating objects.

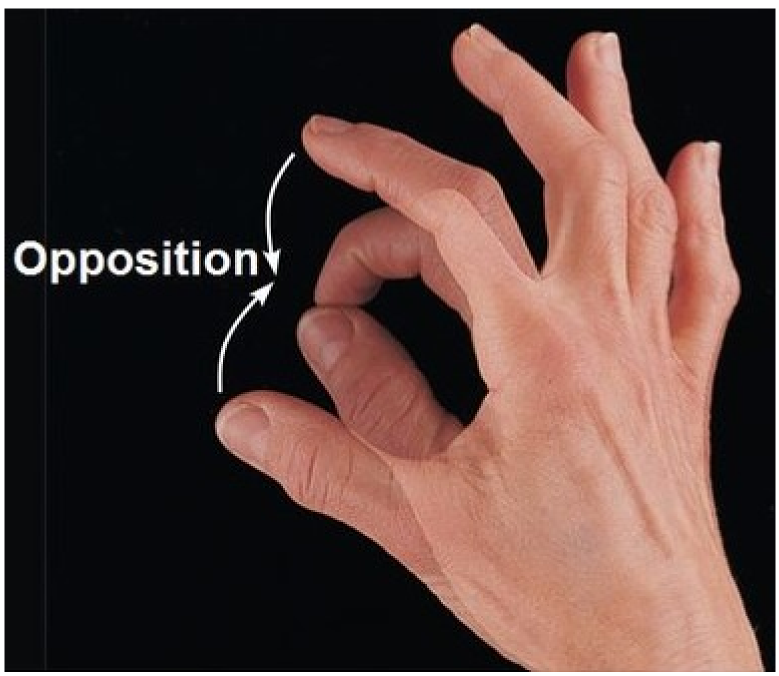



**Fig-48: Opposition**

## Developmental Aspects of Joints:

As bones form from mesenchyme in the embryo, the joints develop in parallel. By week 8, the synovial joints resemble adult joints in form and arrangement, and synovial fluid is being secreted. During childhood, a joint's size, shape, and flexibility are modified by use. Active joints have thicker capsules and ligaments, and larger bony supports. Injuries aside, relatively few interferences with joint function occur until late middle age. Eventually advancing years take their toll and ligaments and tendons shorten and weaken. The intervertebral discs become more likely to herniate, and osteoarthritis rears its ugly head. Virtually everyone has osteoarthritis to some degree by the time they are in their 70s. The middle years also see an increased incidence of rheumatoid arthritis. Exercise that coaxes joints through their full range of motion, such as regular stretching and aerobics, is the key to postponing the immobilizing effects of aging on ligaments and tendons, to keeping cartilages well nourished, and to strengthening the muscles that stabilize the joints. The key word for exercising is "prudently," because excessive or abusive use of the joints guarantees early onset of osteoarthritis. The buoyancy of water relieves much of the stress on weight-bearing joints, and people who swim or exercise in a pool often retain good joint function as long as they live. As with so many medical problems, it is easier to prevent joint problems than to cure or correct them. The importance of joints is obvious: The skeleton's ability to protect other organs and to move smoothly reflects their presence. Now that we are familiar with joint structure and with the movements that joints allow, we are ready to consider how the muscles attached to the skeleton cause body movements by acting across its joints.

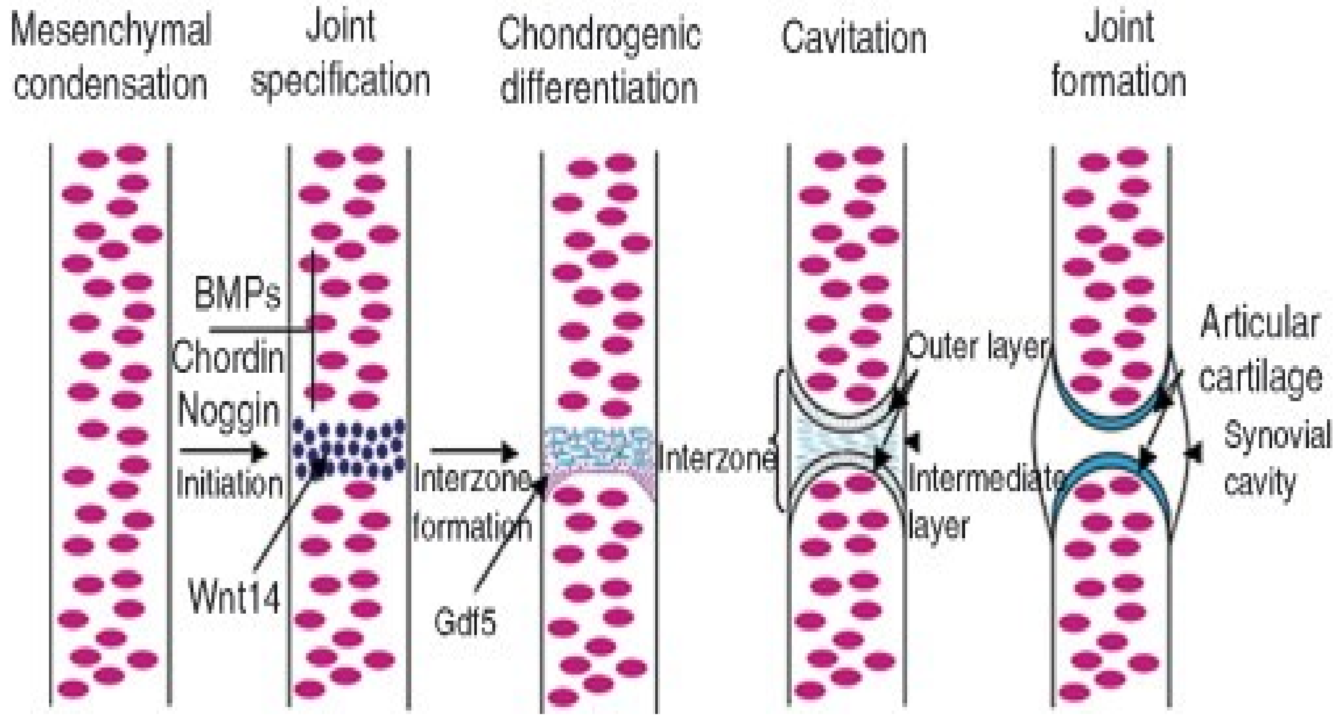



**Fig-49: Development of joints**

## Biomechanics of Synovial joints

**FUNDAMENTAL CONCEPTS, PRINCIPLES, AND TERMS**

Mechanics is the study of forces and their effects. Biomechanics is the application of mechanical laws to living structures, specifically to the locomotor system of the human body. Therefore biomechanics concerns the interrelations of the skeleton, muscles, and joints. The bones form the levers, the ligaments surrounding the joints form hinges, and the muscles provide the forces for moving the levers about the joints.

Kinematics is a branch of mechanics that deals with the geometry of the motion of objects, including displacement, velocity, and acceleration, without taking into account the forces that produce the motion. Kinetics, however, is the study of the relationships between the force system acting on a body and the changes it produces in body motion. Knowledge of joint mechanics and structure, as well as the effects that forces produce on the body, has important implications for the use of manipulative procedures and, specifically, chiropractic adjustments. Forces have vector characteristics whereby specific directions are de-lineated at the points of application. Moreover, forces can vary in magnitude, which will affect the acceleration of the object to which the force is applied.

**Levers**

A lever is a rigid bar that pivots about a fixed point, called the *axis* or *fulcrum,* when a force is applied to it. Force is applied by muscles at some point along the lever to move the body part (resistance). The lever is one of the simplest of all mechanical devices that can be called a *machine.* The relationship of fulcrum to force to resistance distinguishes the different classes of levers. In a first-class lever, the axis (fulcrum) is located between the force and the resistance; in a second-class lever, the resistance is between the axis and the force; and in a third-class lever, the force is between the axis and the resistance (Figure 50).

Every movable bone in the body acts alone or in combination, forcing a network of lever systems characteristic of the first- and third-class levers. There are virtually no second-class levers in the body, although opening the mouth against resistance is an example.

With a first-class lever, the longer the lever arm is, the less force is required to overcome the resistance. The force arm may be longer, shorter, or equal to the resistance arm, but the axis will always be between these two points. An example of a first-class lever in the human body is the forearm moving from a position of flexion into extension at the elbow through contraction of the triceps muscle.

Third-class levers are the most common types in the body because they allow the muscle to be inserted near the joint and can thereby produce increased speed of movement, although at a sacrifice of force. The force arm must be smaller than the resistance arm, and the applied force lies closer to the axis than the resistance force. A example of a third-class lever is flexion of the elbow joint through contraction of the biceps muscle.

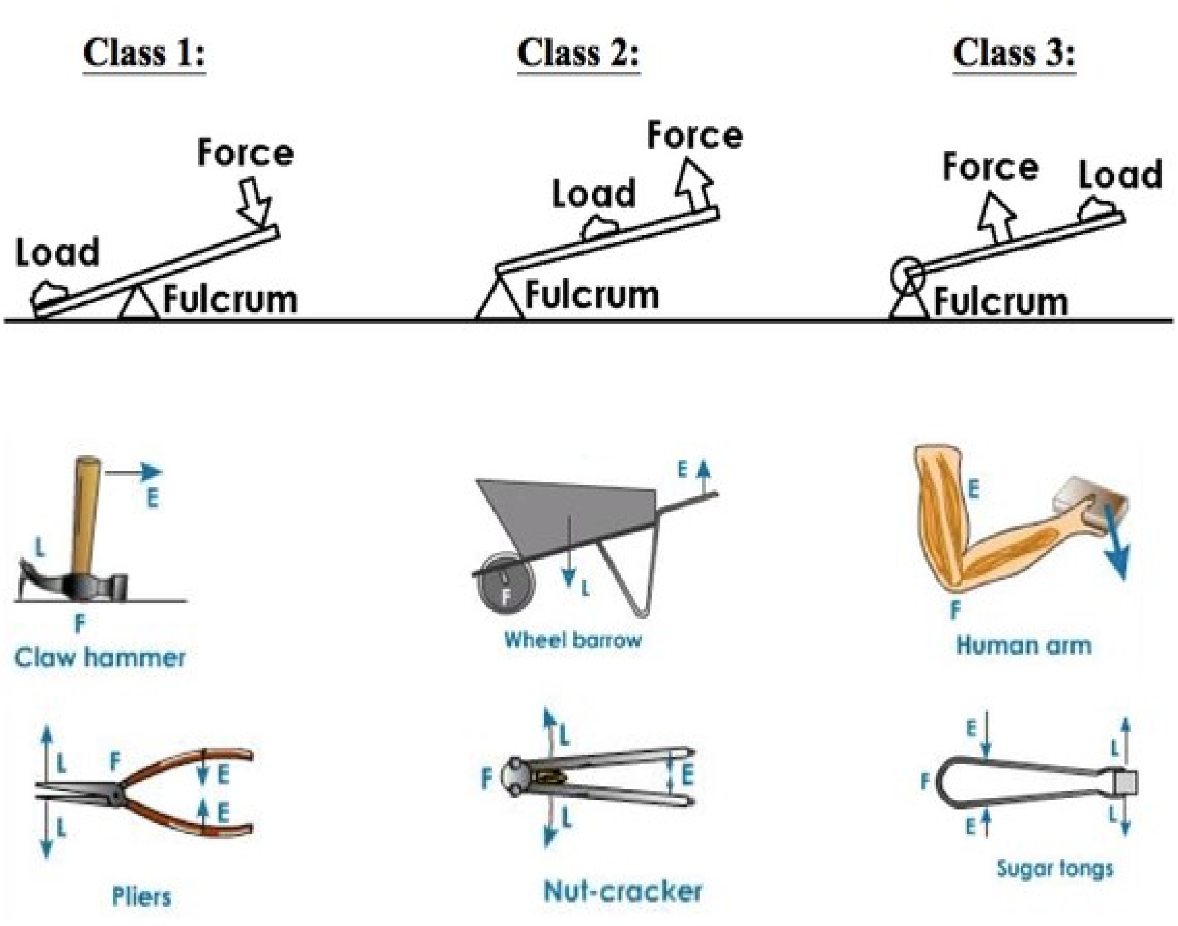
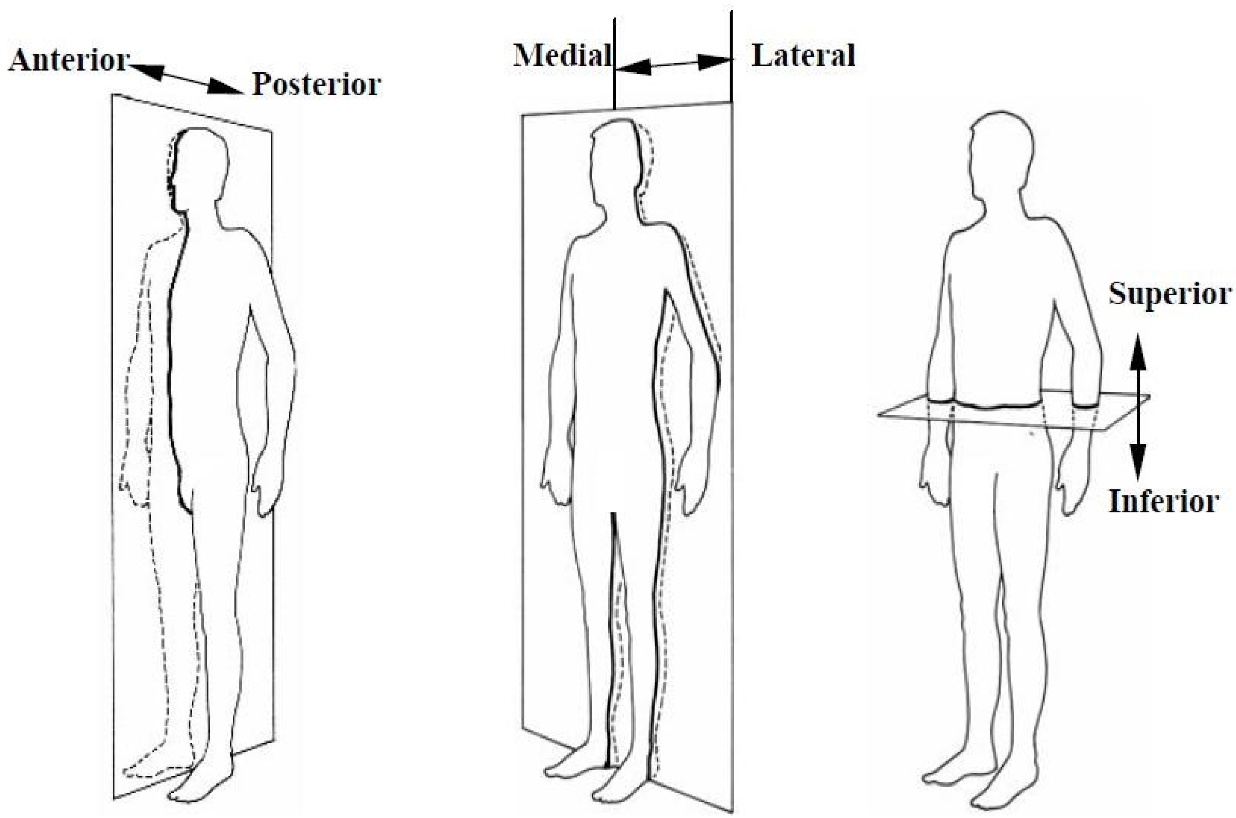



**Fig-50: Classes of lever**

**Body Planes**

It is also necessary to delineate the specific body planes of reference, since they will be used to describe structural position and directions of functional movement. The standard position of reference, or anatomic position, has the body facing forward, the hands at the sides of the body, with the palms facing forward, and the feet pointing straight ahead. The body planes are derived from dimensions in space and are oriented at right angles to one another.

The *sagittal plane* is vertical and extends from front to back, or from anterior to posterior. Its name is derived from the direction of the human sagittal suture in the cranium. The *median sagittal plane,* also called the *midsagittal plane,* divides the body into right and left halves (Figure 51). The *coronal plane* is vertical and extends from side to side. Its name is derived from the orientation of the human coronal suture of the cranium. It may also be referred to as the *frontal plane,* and it divides the body into anterior and posterior components. The transverse plane is a horizontal plane and divides a structure into upper and lower components.




Sagittal plane Coronal plane Transverse plane

**Fig-51: Body planes**

### Axes of Movement

An axis is a line around which motion occurs. Axes are related to planes of reference, and the cardinal axes are oriented at right angles to one another. This is expressed as a three-dimensional coordinate system with x, y, and z used to mark the axes (Figure 52). The significance of this coordinate system is in defining or locating the extent of the types of movement possible at each joint— rotation, translation, and curvilinear motion. All movements that occur about an axis are considered *rotational,* whereas linear movements along an axis and through a plane are called *translational. Curvilinear* motion occurs when a translational movement accompanies rotational movements. The load that produces a rotational movement is called *torsion;* a force that produces a translational movement is called an *axial* or *shear force.*

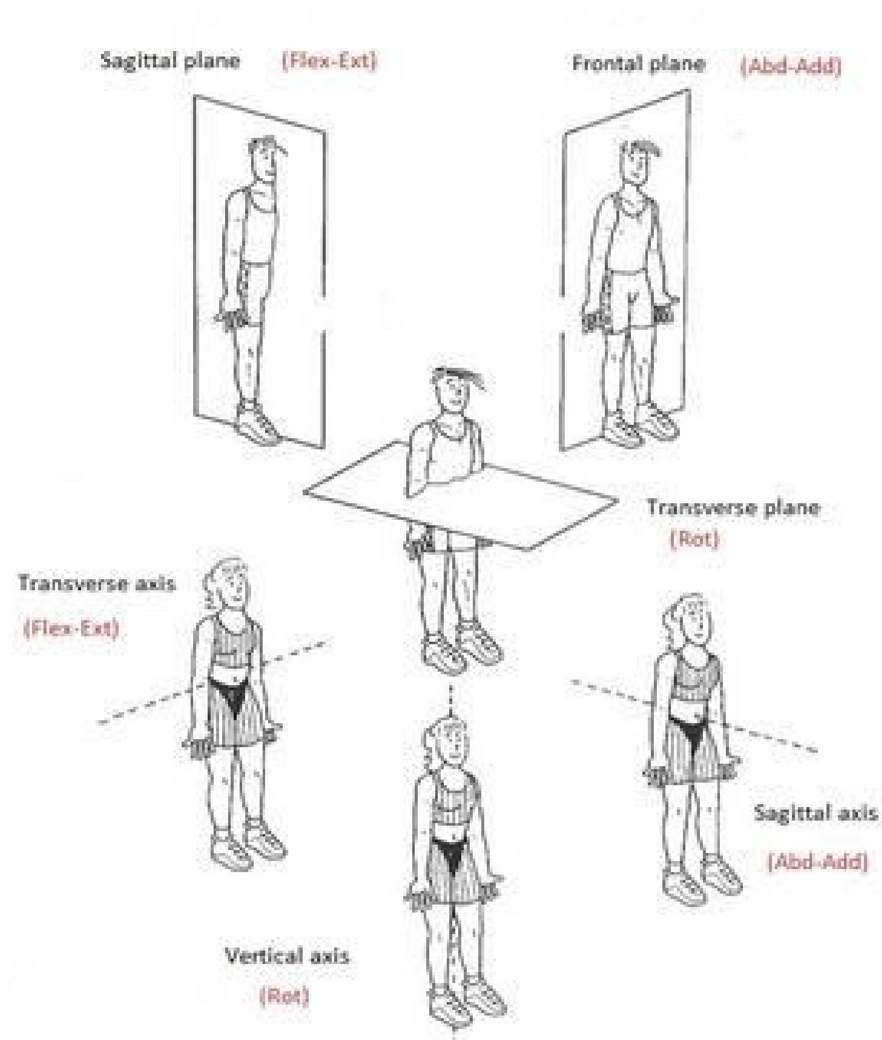



**Fig-52: Axes of Movement**

## Joint Motion

*Motion* can be defined as a continuous change in position of an object. The axis around which movement takes place and the plane through which movement occurs define specific motions or resultant positions. The coronal axis (x-axis) lies in the coronal plane and extends from one side of the body to the other. The motions of flexion and extension occur about this axis and through the sagittal plane. Flexion is motion in the anterior direction for joints of the head, neck, trunk, upper extremity, and hips **(Figure 53, *A*)**. Flexion of the knee, ankle, foot, and toes is movement in the posterior direction. Extension is the motion opposite of flexion. The sagittal axis (z-axis) lies in the sagittal plane and extends horizontally from anterior to posterior.

Movements of abduction and adduction of the extremities, as well as lateral flexion of the spine, occur around this axis and through the coronal plane. Lateral flexion is a rotational movement and is used to denote lateral movements of the head, neck, and trunk in the coronal plane (Figure 53, *B*). In the human, lateral flexion is usually combined with some element of rotation. Abduction and adduction are also motions in a coronal plane. Abduction is movement away from the body, and adduction is movement toward the body; the reference here is to the midsagittal plane of the body. This would be true for all parts of the extremities, excluding the thumb, fingers, and toes. For these structures, reference points are to be found within that particular extremity.

The longitudinal axis (y-axis) is vertical, extending in a head-to-toe direction. Movements of medial (internal) and lateral (external) rotation in the extremities, as well as axial rotation in the spine, occur around it and through the transverse plane (Figure 53, *C*). Axial rotation is used to describe this type of movement for all areas of the body except the scapula and clavicle. Rotation occurs about an anatomic axis, except in the case of the femur, which rotates around a mechanical axis. In the human extremity, the anterior surface of the extremity is used as a reference area. Rotation of the anterior surface toward the midsagittal plane of the body is medial (internal) rotation, and rotation away from the midsagittal plane is lateral (external) rotation. Supination and pronation are rotation movements of the forearm. Because the head, neck, thorax, and pelvis rotate about longitudinal axes in the midsagittal area, rotation cannot be named in reference to the midsagittal plane. Rotation of the head, spine, and pelvis is described as rotation of the anterior surface posteriorly toward the right or left. Rotation of the scapula is movement about a sagittal axis, rather than about a longitudinal axis. The terms *clockwise* or *counterclockwise* are used.

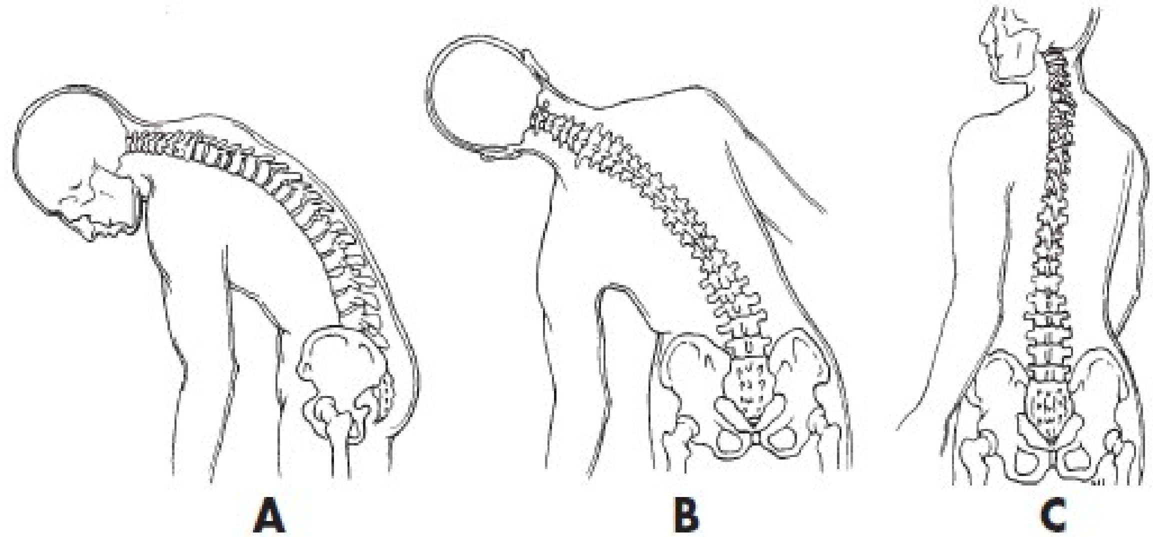



**Fig-53: Movements of trunk**

Translational movements are linear movements or, simply, movements in a straight line. Gliding movements of the joint are translational in character. The term *slide* has also been used in referring to translational movements between joint surfaces. Posterior-to-anterior (P-A) glide (anterolisthesis) and anterior-to-posterior (A-P) glide (retrolisthesis) are translational movements along the z axis. Lateral-to-medial (L-M) glide and medial to lateral (M-L) glide (laterolisthesis) translate along the x axis. Distraction and compression (altered interosseous spacing) translate along the y axis. Curvilinear motion combines both rotational and translational movements and is the most common motion produced by the joints of the body (Figure 54). Moreover, the potential exists for each joint to exhibit three translational movements and three rotational movements, constituting 6 degrees of freedom. The extent of each movement is based more or less on the joint anatomy and, specifically, the plane of the joint surface. Each articulation in the body has the potential to exhibit, to some degree, flexion, extension, right and left lateral flexion, right and left axial rotation, A-P glide, P-A glide, L-M glide, M-L glide, compression, and distraction.

Joints are classified first by their functional capabilities and then are subdivided by their structural characteristics. Synarthroses allow very little, if any, movement; diarthroses, or true synovial joints, allow significant movement.

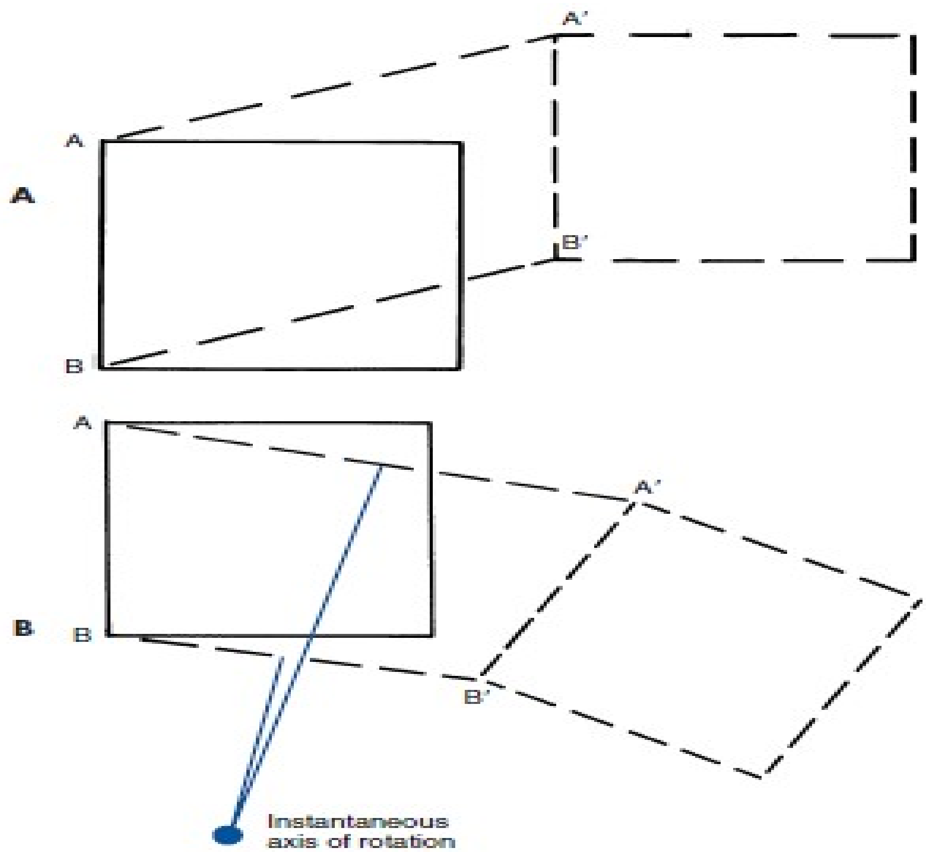



**Fig-54: Translational movement (A) ; Curvilinear movement (B)**

## JOINT FUNCTION

The physiologic movement possible at each joint occurs when muscles contract or when gravity acts on bone to move it. This motion is termed *osteokinematic movement.* Osteokinematic movement describes how each bony joint partner moves relative to the other. The specific movements that occur at the articulating joint surfaces are referred to as *arthrokinematic movement.* Consideration of the motion between bones alone or osteokinematic movement is insufficient, because no concern is given to what occurs at the joint and because movement commonly involves coupling of motion around different axes. Furthermore, arthrokinematic movements consider the forces applied to the joint and include the accessory motion present in a particular articulation. It is therefore important to relate osteokinematic movement to arthrokinematic movement when evaluating joint motion. Figure 55).

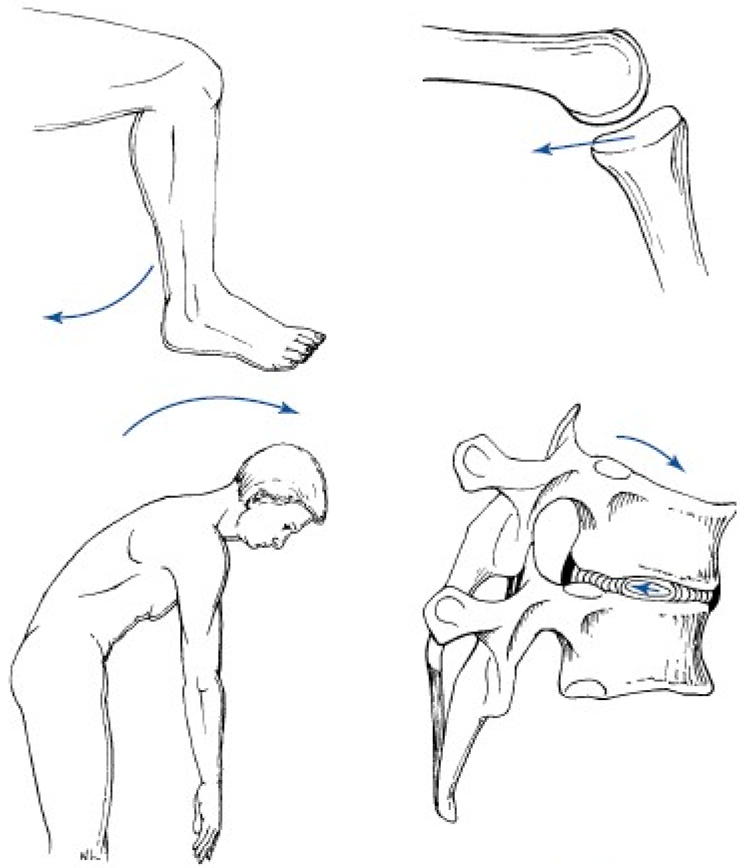



**Fig-55: (A) Osteokinematic movement of knee and trunk flexion.**
**(B) Arthrokinematic movements of tibiofemoral and T6-T7 joint flexion.**

This involves determining the movement of the mechanical axis of the moving bone relative to the stationary joint surface. The *mechanical axis of a joint* is defined as a line passing through the moving bone, oriented perpendicular to the center of the stationary joint surface (Figure 56).

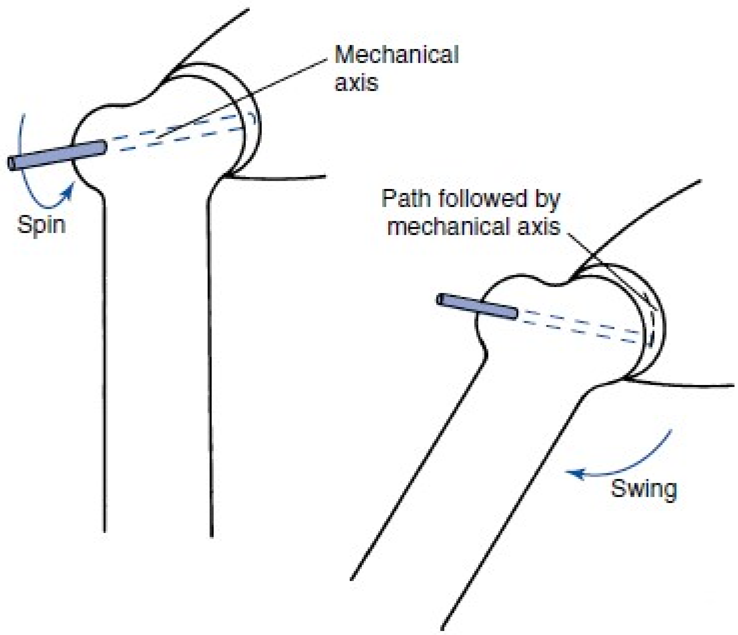



**Fig-56: Mechanical axis of a joint and MacConnail and Basmajian's concept of spin and swing.**

When one joint surface moves relative to the other, spin, roll, slide, or combinations occur. MacConnail and Basmajian28 use the term *spin* to describe rotational movement around the mechanical axis, which is possible as a pure movement only in the hip, shoulder, and proximal radius. *Roll* occurs when points on the surface of one bone contact points at the same interval of the other bone. *Slide* occurs when only one point on the moving joint surface contacts various points on the opposing joint surface (Figure 57).

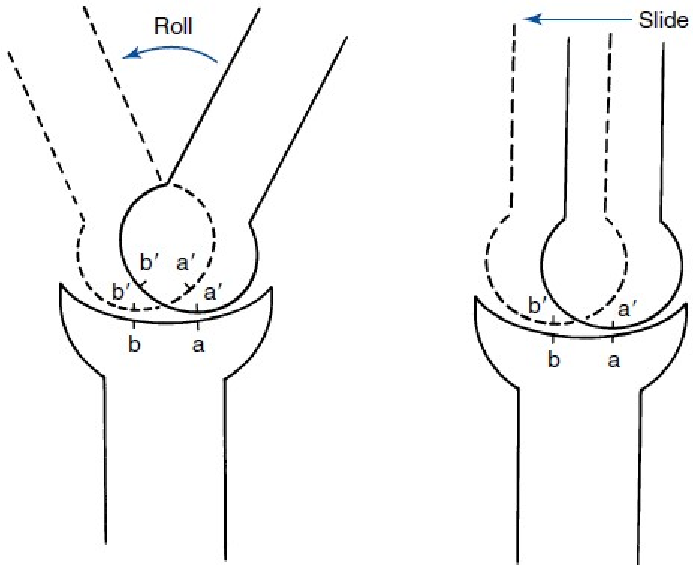



**Fig-57: Arthrokinematic movements of roll and slide.**

In most joints of the human body, these motions occur simultaneously. The concave-convex rule relates to this expected coupling of rotational (roll) and translational (slide) movements. When a concave surface moves on a convex surface, roll and slide movements should occur in the same direction. When a convex surface moves on a concave surface, however, roll and slide should occur in opposite directions (Figure 58).

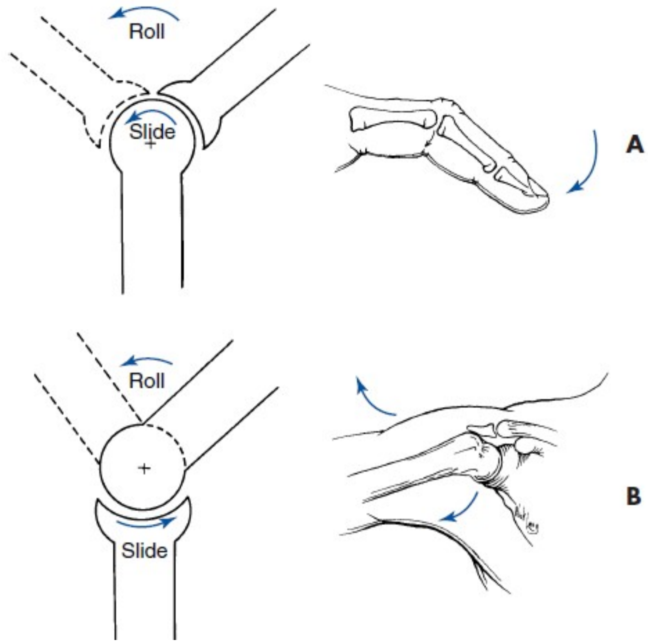



**Fig-58: Concave-convex rule. A, Movement of concave surface on a convex surface. B, Movement of a convex surface on a concave surface.**

Pure roll movement tends to result in joint dislocation, whereas pure slide movement causes joint surface impingement (Figure 59).

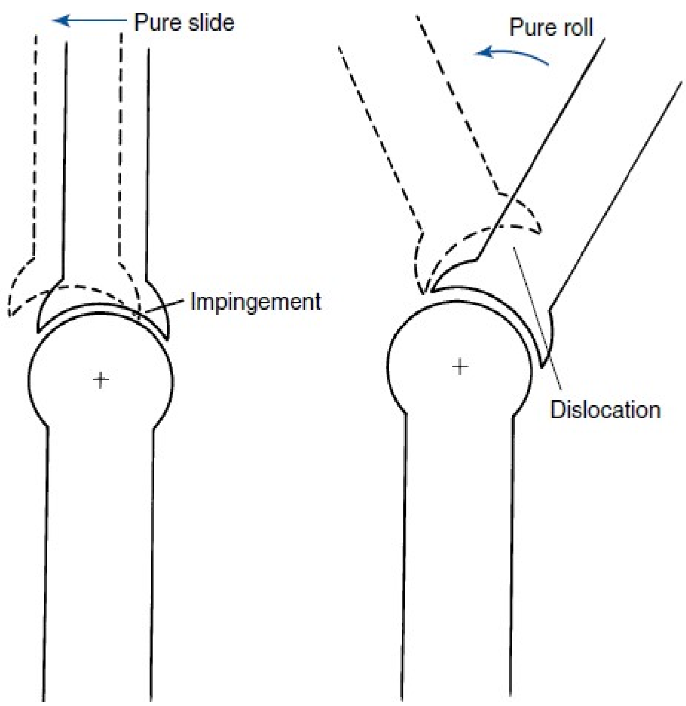


**Fig-59: Consequences of pure roll or pure slide movements**.

Moreover, coupling of roll and slide is important anatomically because less articular cartilage is necessary in a joint to allow for movement and may decrease wear on the joint. These concepts are instrumental in clinical decision making regarding the restoration of restricted joint motion. Roll and spin can be restored with passive range- of-motion procedures that induce the arthrokinematic movements of the dysfunctional joint. Manipulative (thrust) techniques are needed to restore slide movements and can also be used for roll and spin problems. In addition, when an object moves, the axis around which the movement occurs can vary in placement from one instant to another. The term *instantaneous axis of rotation (IAR)* is used to denote this location point. Asymmetric forces applied to the joint can cause a shift in the normal IAR. Furthermore, vertebral movement may be more easily analyzed as the IAR becomes more completely understood (Figure 60).

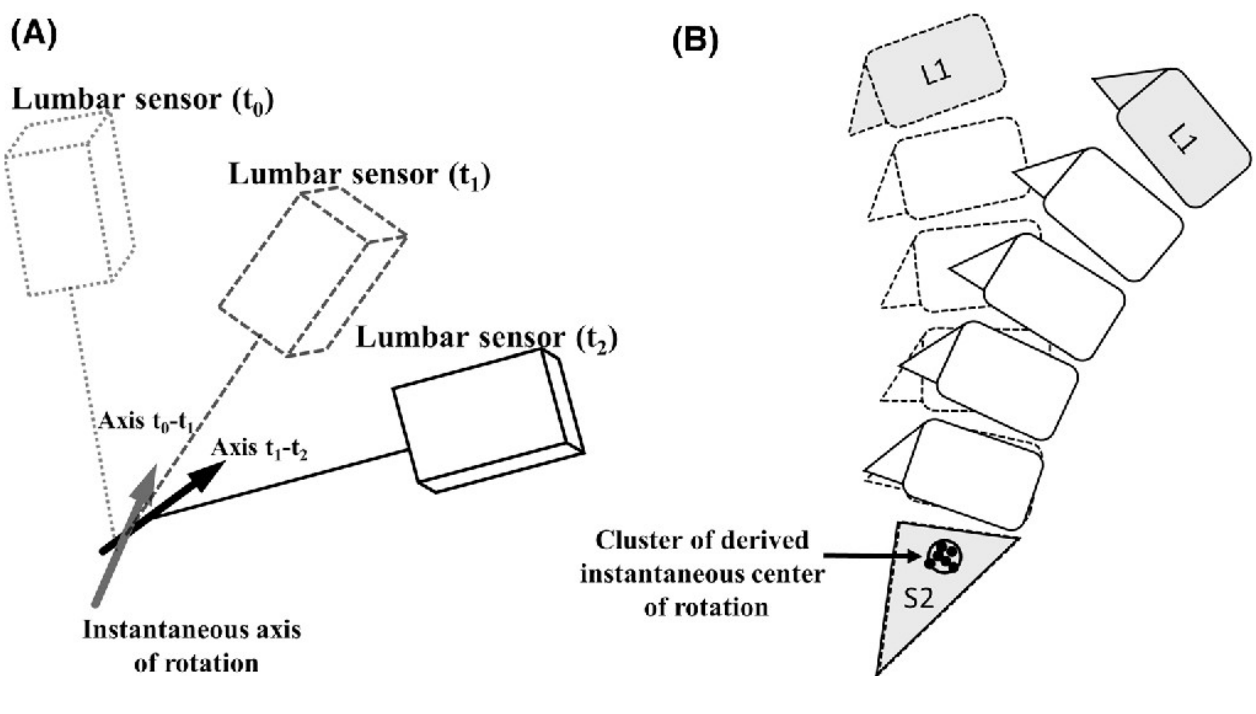



**Fig-60: Instantaneous axis of rotation.**

Researchers point out that the value of this concept is that any kind of plane motion can be described relative to the IAR. Complex motions are simply regarded as many very small movements with many changing IARs.1 This concept is designed to describe plane movement, or movement in two dimensions. When three-dimensional motion occurs between objects, a unique axis in space is defined called the *helical axis of motion (HAM),* or screw axis of motion (Figure 61).

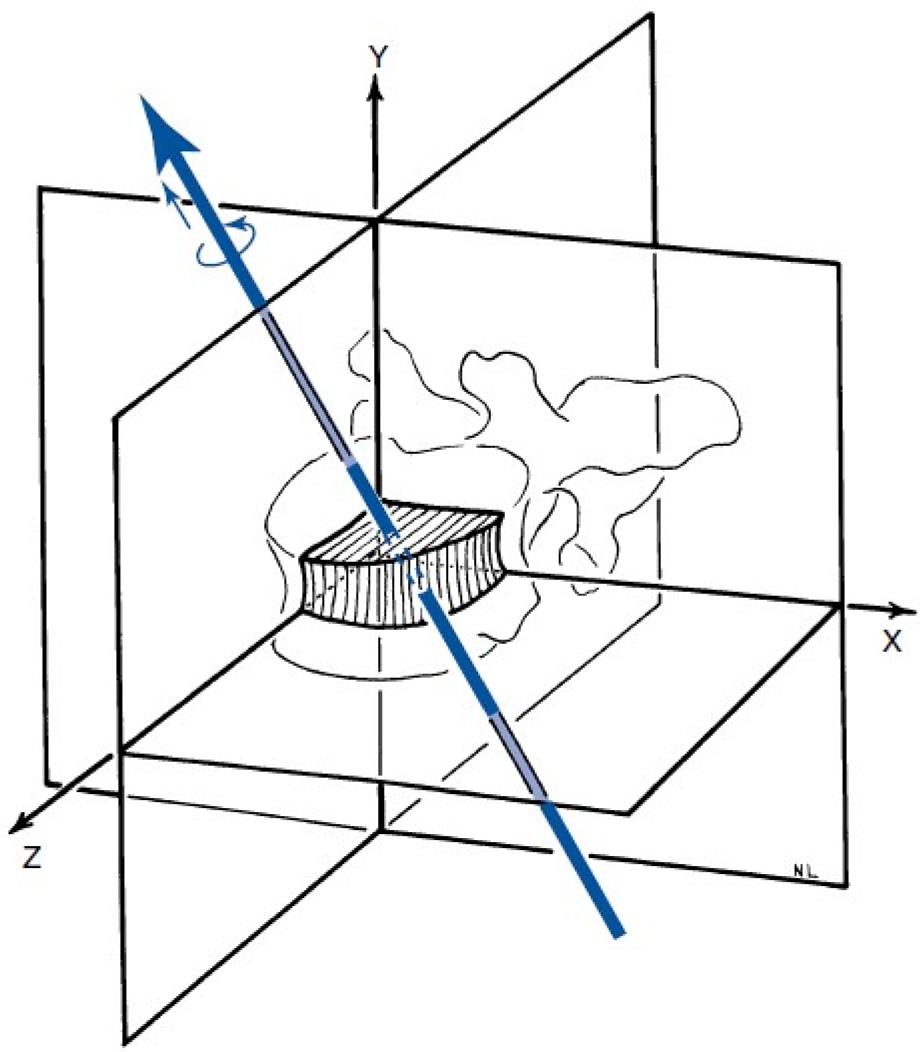



**Fig-61: Helical axis of motion**

HAM is the most precise way to describe motion occurring between irregularly shaped objects, such as anatomic structures, because it is difficult to consistently and accurately identify reference points for such objects. Clearly, most movements occur around and through several axes simultaneously, so pure movements in the human frame rarely occur. The nature and extent of individual joint motion are determined by the joint structure and, specifically, by the shape and direction of the joint surfaces. No two opposing joint surfaces are perfectly matched, nor are they perfectly geometric. All joint surfaces have some degree of curvature that is not constant but changing from point to point. Because of the incongruence between joint surfaces, some joint space and "play" must be present to allow free movement. This joint play is an accessory movement of the joint that is essential for normal functioning of the joint. The resting position of a joint, or its neutral position, occurs when the joint capsule is most relaxed and the greatest amount of play is possible. When injured, a joint often seeks this maximum loose-packed position to allow for swelling.

The close-packed position occurs when the joint capsule and ligaments are maximally tightened. Moreover, there is maximal contact between the articular surfaces, making the joint very stable and difficult to move or separate. Joint surfaces will approximate or separate as the joint goes through a range of motion. This is the motion of compression and distraction. A joint moving toward its close-packed position is undergoing *compression,* and a joint moving toward its open-packed position is undergoing *distraction.* Joint motion consists of five qualities of movement that must be present for normal joint function. These five qualities are joint play, active range of motion, passive range of motion, end feel or play, and paraphysiologic movement. From the neutral close-packed position, joint play should be present. This is followed by a range of active movement under the control of the musculature. The passive range of motion is produced by the examiner and includes the active range, plus a small degree of movement into the elastic range. The elastic barrier of resistance is then encountered, which exhibits the characteristic movement of end feel. The small amount of movement available past the elastic barrier typically occurs postcavitation and has been classified as paraphysiologic movement. Movement of the joint beyond the paraphysiologic barrier takes the joint beyond its limit of anatomic integrity and into a pathologic zone of movement.  Both joint play and end-feel movements are thought to be necessary for the normal functioning of the joint. A loss of either movement can result in a restriction of motion, pain, and most likely, both. Active movements can be influenced by exercise and mobilization, and passive movements can be influenced by traction and some forms of mobilization, but end-feel movements are affected when the joint is taken through the elastic barrier, creating a sudden yielding of the joint and a characteristic cracking noise (cavitation). This action can be accomplished with deep mobilization and a high-velocity, lowamplitude manipulative thrust.

## ❖ APPLIED ANATOMY-

**Osteogenesis imperfecta (OI)** is a genetic disease in which bones do not form properly and therefore are fragile and break easily. It is also called brittle bone disease. The disease is present from birth and affects a person throughout life.

The genetic mutation that causes OI affects the body's production of collagen, one of the critical components of bone matrix. The severity of the disease can range from mild to severe. Those with the most severe forms of the disease sustain many more fractures than those with a mild form. Frequent and multiple fractures typically lead to bone deformities and short stature. Bowing of the long bones and curvature of the spine are also common in people afflicted with OI. Curvature of the spine makes breathing difficult because the lungs are compressed.

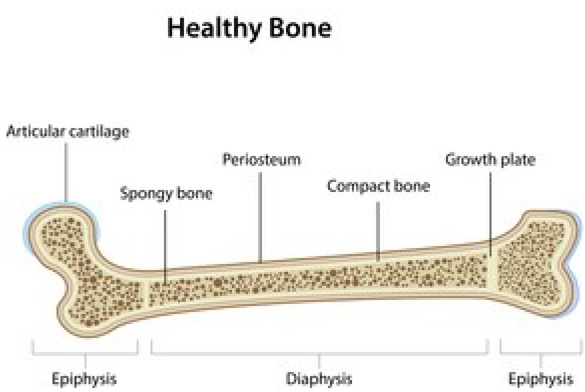



**Fig-62: Osteogenesis imperfecta**

### Cartilage Tears

Many aerobics devotees, encouraged to "feel the burn" during their workout, may feel the snap and pop of their overstressed cartilage instead. Although most cartilage injuries involve tearing of the knee menisci, tears and overuse damage to the articular cartilages of other joints is becoming increasingly common in competitive young athletes. Cartilage tears typically occur when a meniscus is subjected to compression and shear stress at the same time. Cartilage is avascular and it rarely can obtain sufficient nourishment to repair itself, so it usually stays torn.

Cartilage fragments (called loose bodies) can interfere with joint function by causing the joint to lock or bind, so most sports physicians recommend that the damaged cartilage be removed. Today, this can be done by arthroscopic surgery, a procedure that enables patients to be out of the hospital the same day. The arthroscope, a small instrument bearing a tiny lens and fiber-optic light source, enables the surgeon to view the joint interior.

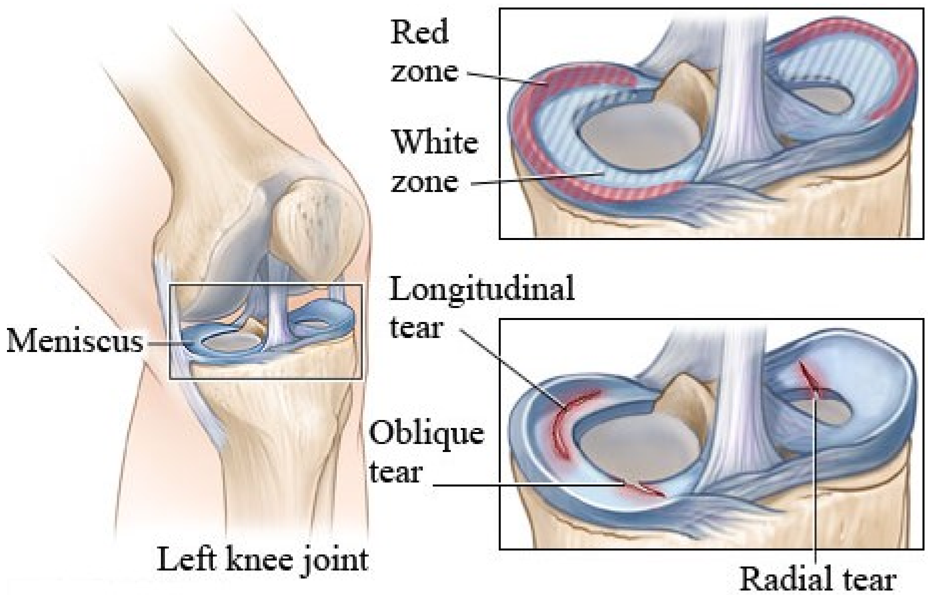



**Fig-63: Cartilage tears**

**Sprains**

In a sprain, the ligaments reinforcing a joint are stretched or torn. The lumbar region of the spine, the ankle, and the knee are common sprain sites. Partially torn ligaments will repair themselves, but they heal slowly because ligaments are so poorly vascularized. Sprains tend to be painful and immobilizing. Completely ruptured ligaments require prompt surgical repair because inflammation in the joint will break down the neighboring tissues and turn the injured ligament to “mush.” Surgical repair can be difficult: A ligament consists of hundreds of fibrous strands, and sewing one back together has been compared to trying to sew two hairbrushes together. When important ligaments are too severely damaged to be repaired, they must be removed and replaced with grafts or substitute ligaments. For example, a piece of tendon from a muscle, or woven collagen bands, can be stapled to the articulating bones.

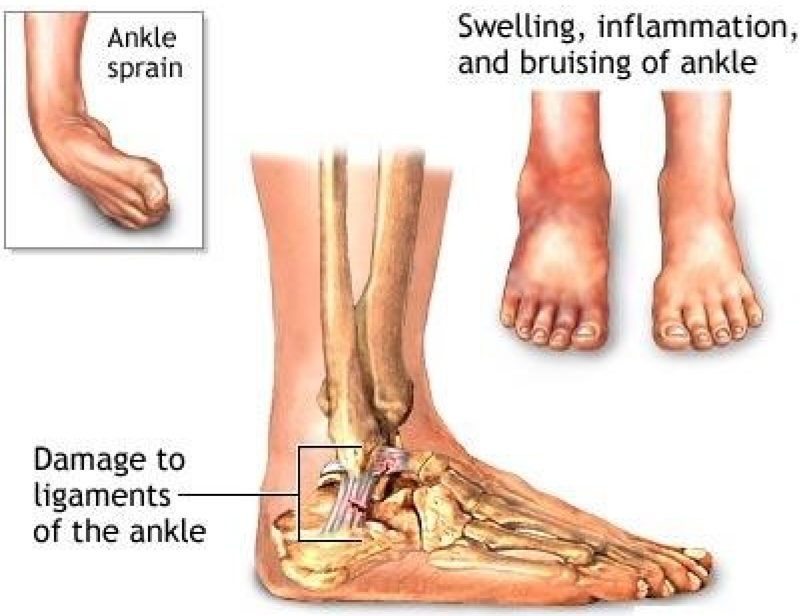



**Fig-64: Sprains**

**Dislocations**

A dislocation (luxation) occurs when bones are forced out of alignment. It is usually accompanied by sprains, inflammation, and difficulty in moving the joint. Dislocations may result from serious falls and are common contact sports injuries. Joints of the jaw, shoulders, fingers, and thumbs are most commonly dislocated. Like fractures, dislocations must be reduced; that is, the bone ends must be returned to their proper positions by a physician.

**Subluxation**

It is a partial dislocation of a joint. Repeat dislocations of the same joint are common because the initial dislocation stretches the joint capsule and ligaments. The resulting loose capsule provides poor reinforcement for the joint.

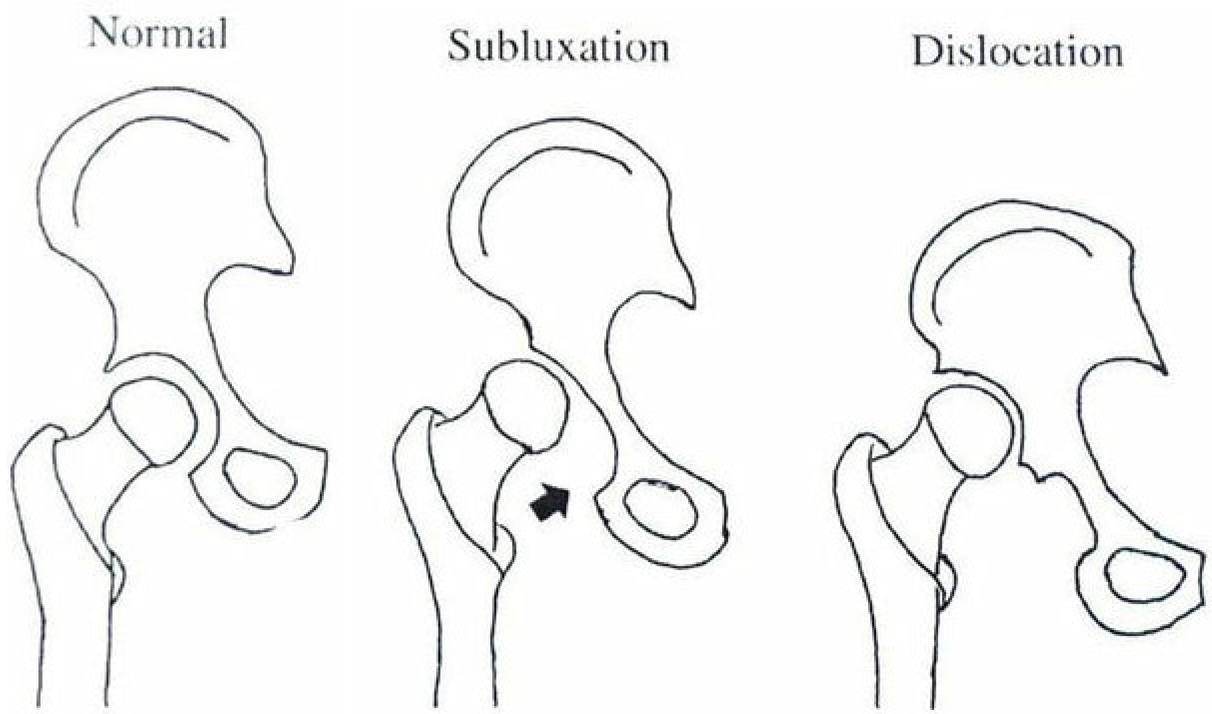



**Fig-65: Dislocation and Subluxation**

**Bursitis**

It is inflammation of a bursa and is usually caused by a blow or friction. Falling on one's knee may result in a painful bursitis of the prepatellar bursa, known as housemaid's knee or water on the knee. Prolonged leaning on one's elbows may damage the bursa close to the olecranon process, producing student's elbow, or olecranon bursitis. Severe cases are treated by injecting anti-inflammatory drugs into the bursa. If excessive fluid accumulates, removing some fluid by needle aspiration may relieve the pressure.

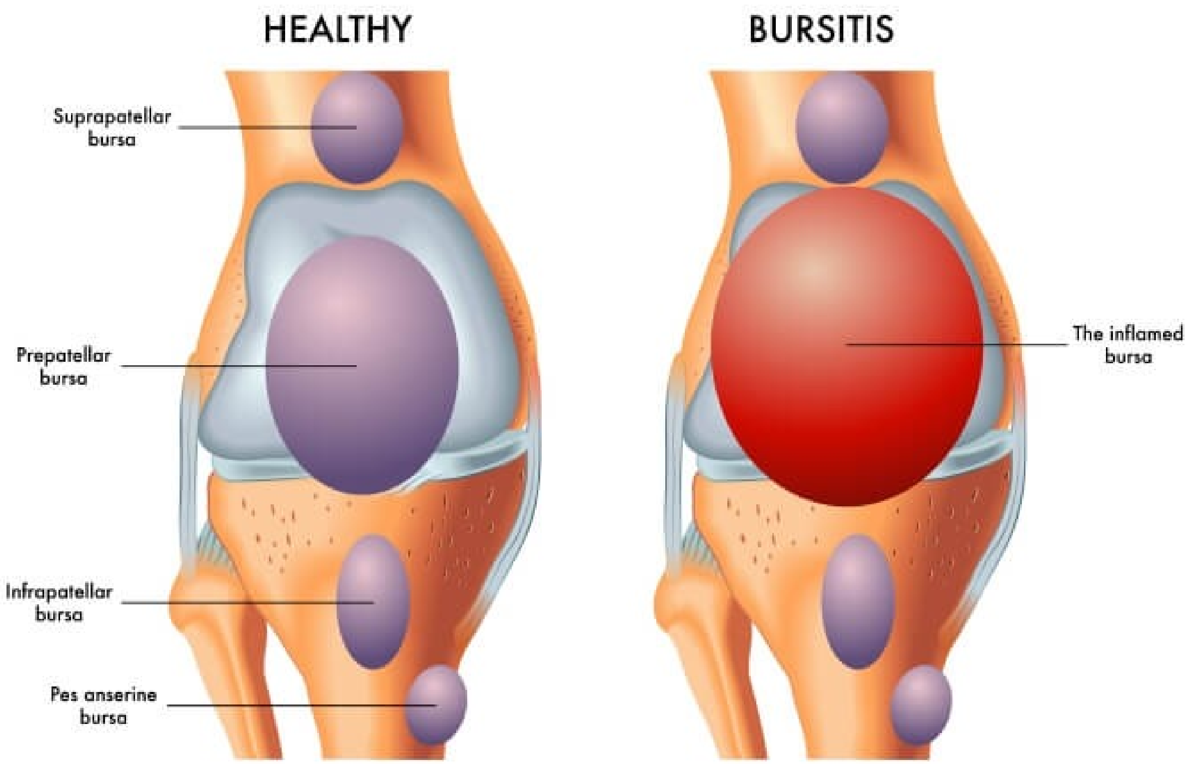



**Fig-66: Bursitis**

### Tendonitis

It is inflammation of tendon sheaths, typically caused by overuse. Its symptoms (pain and swelling) and treatment (rest, ice, and anti-inflammatory drugs) mirror those of bursitis.

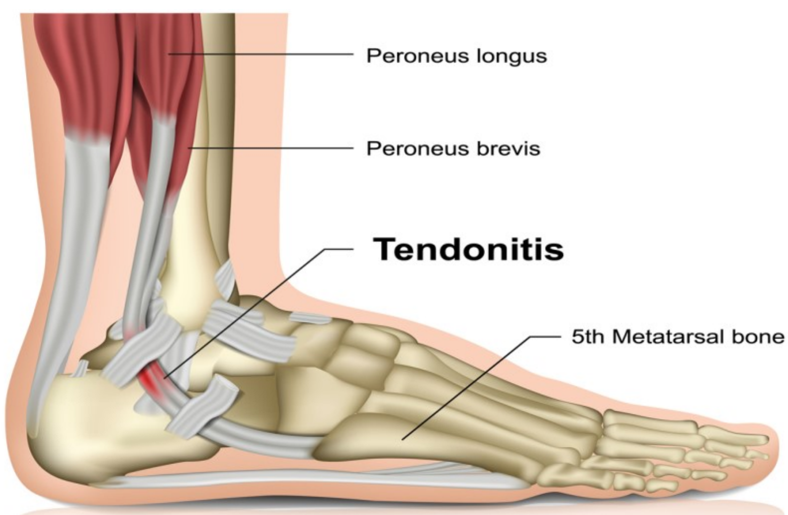



**Fig-67: Tendonitis**

**Arthritis**

The term arthritis describes over 100 different types of inflammatory or degenerative diseases that damage the joints. In all its forms, arthritis is the most widespread crippling disease in the United States. One out of seven Americans suffers its ravages. To a greater or lesser degree, all forms of arthritis have the same initial symptoms: pain, stiffness, and swelling of the joint. Acute forms of arthritis usually result from bacterial invasion and are treated with antibiotics. The synovial membrane thickens and fluid production decreases, causing increased friction and pain. Chronic forms of arthritis include osteoarthritis, rheumatoid arthritis, and gouty arthritis.

- **Osteoarthritis (Degenerative Joint Disease)**

Osteoarthritis (OA) is the most common chronic arthritis. A chronic (long term) degenerative condition, OA is often called "wear-and-tear arthritis." OA is most prevalent in the aged and is probably related to the normal aging process (although it is seen occasionally in younger people and some forms have a genetic basis). More women than men are affected, but 85% of all Americans develop this condition. Current theory holds that normal joint use prompts the release of (metalloproteinase) enzymes that break down articular cartilage, especially its collagen fibrils. In healthy individuals, this damaged cartilage is eventually replaced, but in people with OA, more cartilage is destroyed than replaced. Although its specific cause is unknown, OA may reflect the cumulative effects of years of compression and abrasion acting at joint surfaces, causing excessive amounts of the cartilage-destroying enzymes to be released. The result is softened, roughened, pitted, and eroded articular cartilages. Because this process occurs most where an uneven orientation of forces cause extensive microdamage, badly aligned or overworked joints are likely to develop OA.

As the disease progresses, the exposed bone tissue thickens and forms bony spurs (osteophytes) that enlarge the bone ends and may restrict joint movement. Patients complain of stiffness on arising that lessens somewhat with activity. The affected joints may make a crunching noise, called crepitus, as they move and the roughened articular surfaces rub together. The joints most often affected are those of the cervical and lumbar spine and the fingers, knuckles, knees, and hips. The course of osteoarthritis is usually slow and irreversible. In many cases, its symptoms are controllable with a mild pain reliever like aspirin or acetaminophen, along with moderate activity to keep the joints mobile. Rubbing a hot-pepper-like substance called capsaicin on the skin over the painful joints helps lessen the pain of OA. Glucosamine and chondroitin sulfate, nutritional supplements consisting of macromolecules normally present in cartilage, appear to decrease pain and inflammation in some people and may help to preserve the articular cartilage. Osteoarthritis is rarely crippling, but it can be, particularly when the hip or knee joints are involved.

- **Rheumatoid Arthritis**

Rheumatoid arthritis (RA) is a chronic inflammatory disorder with an insidious onset. Though it usually arises between the ages of 30 and 50, it may occur at any age. It affects three times as many women as men. While not as common as osteoarthritis, rheumatoid arthritis causes disability in millions. It occurs in more than 1% of Americans. RA is an autoimmune disease—a disorder in which the body's immune system attacks its own tissues. The initial trigger for this reaction is unknown, but the streptococcus bacterium and viruses has been suspect. Perhaps these microorganisms bear molecules similar to some naturally present in the joints (possibly glucosaminoglycans, complex carbohydrates found in cartilage, joint fluid, and other connective tissues), and the immune system, once activated, attempts to destroy both.

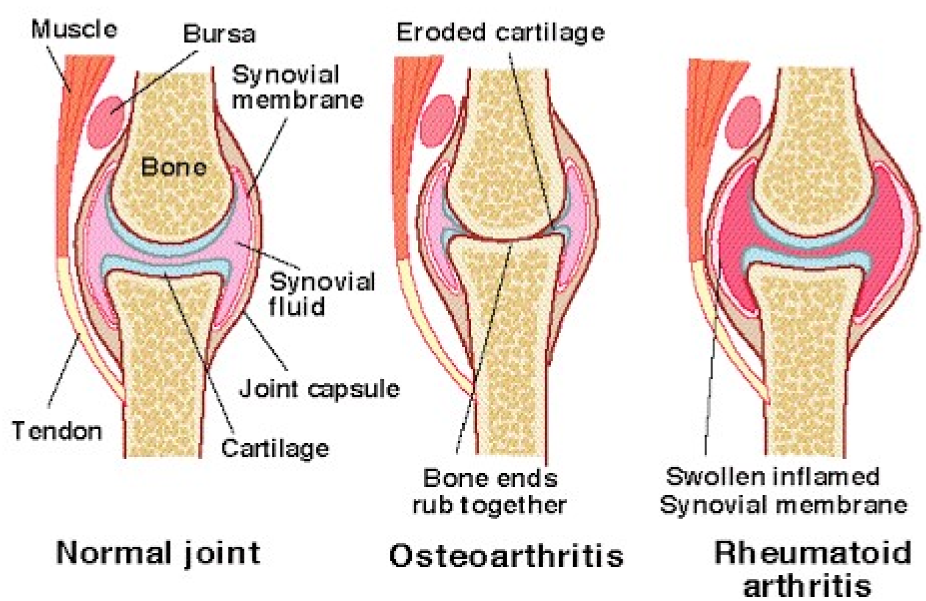



**Fig-68: Arthritis**

- **Gouty Arthritis**

Uric acid, a normal waste product of nucleic acid metabolism, is ordinarily excreted in urine without any problems. However, when blood levels of uric acid rise excessively (due to its excessive production or slow excretion), it may be deposited as needle-shaped urate crystals in the soft tissues of joints. An inflammatory response follows, leading into an agonizingly painful attack of gouty arthritis, or gout. The initial attack typically affects one joint, often at the base of the great toe.

Gout is far more common in men than in women because men naturally have higher blood levels of uric acid (perhaps because estrogens increase the rate of its excretion). Because gout seems to run in families, genetic factors are definitely implicated. Untreated gout can be very destructive; the articulating bone ends fuse and immobilize the joint. Fortunately, several drugs (colchicine, non steroidal anti-inflammatory drugs, glucocorticoids, and others) that terminate or prevent gout attacks are available. Patients are advised to drink plenty of water and to avoid alcohol excess (which promotes uric acid overproduction), and foods high in purine-containing nucleic acids, such as liver, kidneys, and sardines.

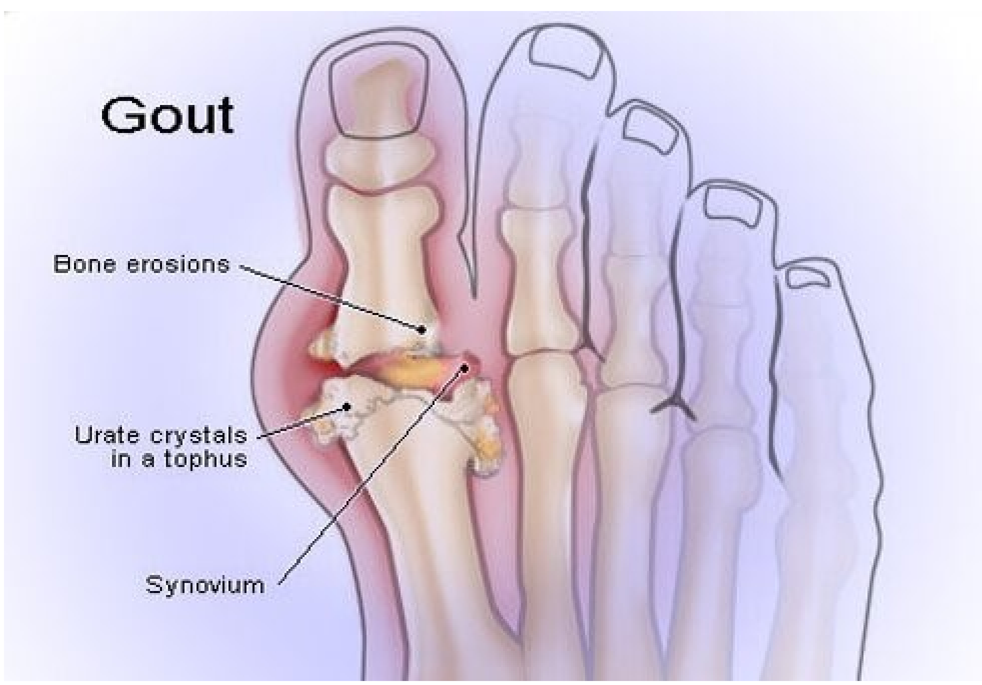



**Fig-69: Gouty Arthritis**

**Lyme disease**

Lyme disease is an inflammatory disease caused by spirochete bacteria transmitted by the bites of ticks that live on mice and deer. It often results in joint pain and arthritis, especially in the knees, and is characterized by a skin rash, flu-like symptoms, and foggy thinking. If untreated, neurological disorders and irregular heartbeat may ensue. Because symptoms vary from person to person, the disease is hard to diagnose. Antibiotic therapy is the usual treatment, but it takes a long time to kill the infecting bacteria. Currently, first generation vaccines have been approved by the U.S. Food and Drug Administration and it is hoped that these will prevent the rapid spread of new cases.

**Fig-70: Lyme disease**

**Ankylosing spondylitis**

(Crooked, bent; spondyl= vertebra) A variant of rheumatoid arthritis that chiefly affects males; it usually begins in the sacroiliac joints and progresses superiorly along the spine. The vertebrae become interconnected by fibrous tissue, causing the spine to become rigid ("poker back").

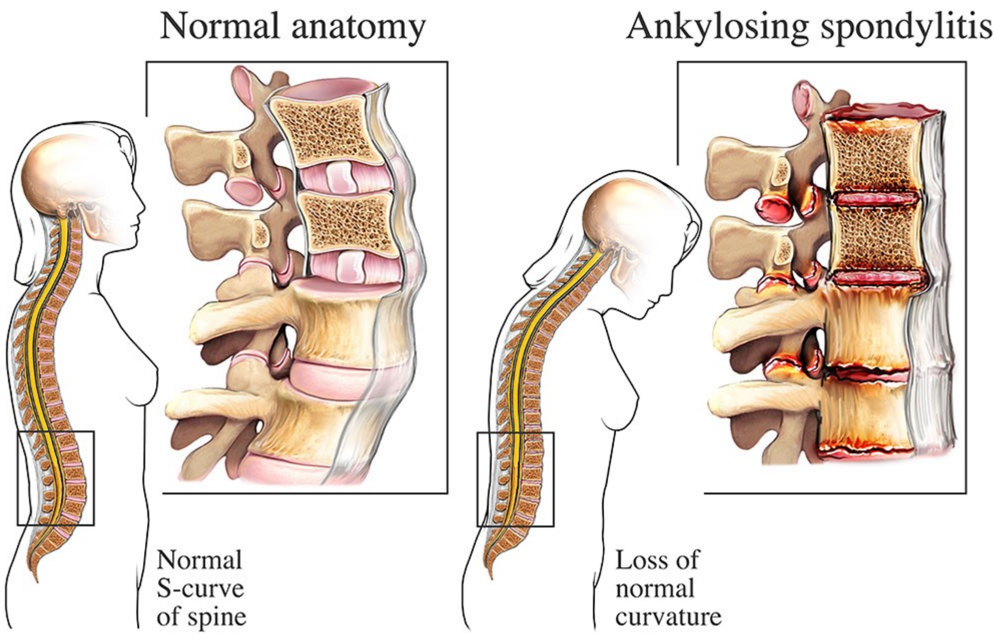



**Fig-71: Ankylosing spondylitis**

**Arthroplasty**

("Joint reforming") Replacing a diseased joint with an artificial joint. **Chondromalacia patellae** ("softening of cartilage by the patella") Damage and softening of the articular cartilages on the posterior patellar surface and the anterior surface of the distal femur; most often seen in adolescent athletes. Produces a sharp pain in the knee when the leg is extended (in climbing stairs, for example). May result when the quadriceps femoris, the main group of muscles on the anterior thigh, pulls unevenly on the patella, persistently rubbing it against the femur in the knee joint; often corrected by exercises that strengthen weakened parts of the quadriceps muscles.


**Fig-72: Arthroplasty**

**Synovitis**

Inflammation of the synovial membrane of a joint. In healthy joints, only small amounts of synovial fluid are present, but synovitis causes copious amounts to be produced, leading to swelling and limitation of joint movement


**Fig-73: Synovitis**

## *Review Questions-*

**Multiple choice questions-**

1. The joints between the articular processes of adjacent vertebrae can contribute to which movement?

a) Circumduction

b) Abduction

c) Lateral Flexion

d) Dorsiflexion

2. Which motion moves the bottom of the foot away from the midline of the body?

a) Elevation

b) Plantar Flexion

c) Eversion

d) Dorsiflexion

.

3. Movement in a circular motion at a condyloid joint is what type of motion?

a) Rotation

b) Elevation

c) Circumduction

d) Abduction

4. Supination is the motion that moves the ________.

a) Foot so that the bottom of the foot faces the midline of the body

b) Hand from the palm backward position to the palm forward position

c) Scapula in an upward direction

d) Hand from the palm forward position to the palm backward position

5. Movement at the shoulder joint that moves the upper limb laterally away from the body is called ________.

a) Elevation

b) Eversion

c) Abduction

d) Lateral rotation

- **Short note questions-**

1. Briefly define the types of joint movements available at a ball-and-socket joint.

2. Discuss the joints involved and movements required for you to cross your arms together in front of your chest.

3. Discuss about the general features of Synovial joints

## *Solutions*

**Mcq's**

**Answer- 1-  ©**

**Answer- 2- ©**

**Answer- 3- ©**

**Answer- 4- (b)**

**Answer- 5- ©**

**Answers for Critical Thinking Questions**

1. Ball-and-socket joints are multiaxial joints that allow for flexion and extension, abduction and adduction, circumduction, and medial and lateral rotation.
2. To cross your arms, you need to use both your shoulder and elbow joints. At the shoulder, the arm would need to flex and medially rotate. At the elbow, the forearm would need to be flexed.
3. Given in text

## Glossary

**Abduction**

Movement in the coronal plane that moves a limb laterally away from the body; spreading of the fingers

**Adduction**

Movement in the coronal plane that moves a limb medially toward or across the midline of the body; bringing fingers together

**Circumduction**

Circular motion of the arm, thigh, hand, thumb, or finger that is produced by the sequential combination of flexion, abduction, extension, and adduction

**Depression**

Downward (inferior) motion of the scapula or mandible

**Dorsiflexion**

Movement at the ankle that brings the top of the foot toward the anterior leg

**Elevation**

Upward (superior) motion of the scapula or mandible

**Eversion**

Foot movement involving the intertarsal joints of the foot in which the bottom of the foot is turned laterally, away from the midline

**Extension**

Movement in the sagittal plane that increases the angle of a joint (straightens the joint); motion involving posterior bending of the vertebral column or returning to the upright position from a flexed position

**Flexion**

Movement in the sagittal plane that decreases the angle of a joint (bends the joint); motion involving anterior bending of the vertebral column

**Hyperextension**

Excessive extension of joint, beyond the normal range of movement

**Hyperflexion**

Excessive flexion of joint, beyond the normal range of movement

**Inferior rotation**

Movement of the scapula during upper limb adduction in which the glenoid cavity of the scapula moves in a downward direction as the medial end of the scapular spine moves in an upward direction

**Inversion**

Foot movement involving the intertarsal joints of the foot in which the bottom of the foot is turned toward the midline

**Lateral excursion**

Side-to-side movement of the mandible away from the midline, toward either the right or left side

**Lateral flexion**

Bending of the neck or body toward the right or left side

**Lateral (external) rotation**

Movement of the arm at the shoulder joint or the thigh at the hip joint that moves the anterior surface of the limb away from the midline of the body

**Medial excursion**

Side-to-side movement that returns the mandible to the midline

**Medial (internal) rotation**

Movement of the arm at the shoulder joint or the thigh at the hip joint that brings the anterior surface of the limb toward the midline of the body

**Opposition**

Thumb movement that brings the tip of the thumb in contact with the tip of a finger

**Plantar flexion**

Foot movement at the ankle in which the heel is lifted off of the ground

**Pronated position**

Forearm position in which the palm faces backward

**Pronation**

Forearm motion that moves the palm of the hand from the palm forward to the palm backward position

**Protraction**

Anterior motion of the scapula or mandible

**Reposition**

Movement of the thumb from opposition back to the anatomical position (next to index finger)

**Retraction**

Posterior motion of the scapula or mandible

**Rotation**

Movement of a bone around a central axis (atlantoaxial joint) or around its long axis (proximal radioulnar joint; shoulder or hip joint); twisting of the vertebral column resulting from the summation of small motions between adjacent vertebrae

**Superior rotation**

Movement of the scapula during upper limb abduction in which the glenoid cavity of the scapula moves in an upward direction as the medial end of the scapular spine moves in a downward direction

**Supinated position**

Forearm position in which the palm faces anteriorly (anatomical position)

**Supination**

Forearm motion that moves the palm of the hand from the palm backward to the palm forward position

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