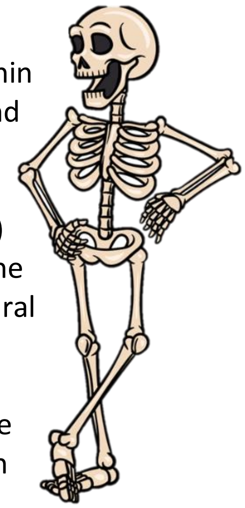
Anatomy Lecture Notes Section 2: The Skeletal System

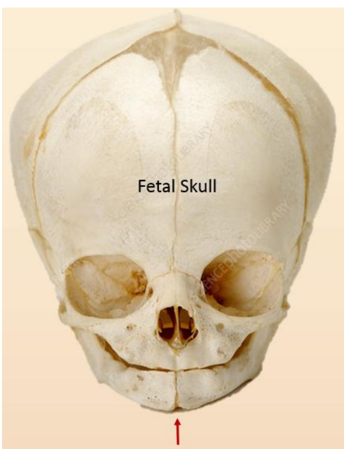
What is the Skeletal System?



The very framework of the human body is created by our **skeleton**. The skeletal system within our body consists of both fused and individual **bones** which are supported and supplemented by associated connective tissue, such as **cartilage**, **tendons** and **ligaments**.

The body's skeletal system accounts for about 20% of body weight. Osseous tissue (bones) is very dynamic and can change in accordance with body activity and nourishment. Our bone tissues are richly supplied with blood and use plenty of oxygen (O_2) and have natural metabolic waste products, especially during childhood growth.

The skeletal system literally gives us our basic shape and framework. At birth humans have about 270 bones. However, this number typically decreases to **206** bones in fully grown adults, as several of the developing bones fused together and become one bone.



For example, the **mandible** in the fetal and newborn skull is different even from a baby's skull after only about a year. In the developing fetus and at birth, the mandible is composed of **two separate bones**. See the photo at left of the fetal skull, the red arrow shows the mandibular symphysis, a transient type of immovable articulation holding the 2 separate halves of the mandible together. During the first year after birth, ossification (meaning 'becoming bone) of this joint occurs and fusion of the mandibular symphysis occurs resulting in a one single mandible bone. The faint remnant of the mandibular symphysis can sometimes be seen a subtle midline ridge of the mandible.

Do you notice any other bone in the photo of the fetal skull that is two bones that become one later in life? Hint: The forehead is made of the frontal bone, and adults only have one frontal bone.

Osseous Tissue and Skeletal Structure

What are the Functions of Bone? – There are many roles of the skeletal system.

1. Provides Support and a Structural Framework for body.

2. Protection of more delicate tissue. For example, the bony thoracic cage protects the heart and lungs; the skull protects the brain; the pelvis protects some internal organs.

3. Storage in the Body. Bone provides mineral storage in the body, mostly calcium and phosphorus. Yellow bone marrow is also stored in the medullary cavity of long bones. This is primarily adipose (fat) tissue, and adipocytes store triglycerides that can be used as Energy in the body.

4. Blood cell Production. The red bone marrow (myeloid tissue) stored in the medullary cavity of some bones is responsible for making all the cells found in blood, a process called *hematopoiesis*.

5. Movement of Body in conjunction with articulations and the skeletal muscle attachment to bones.

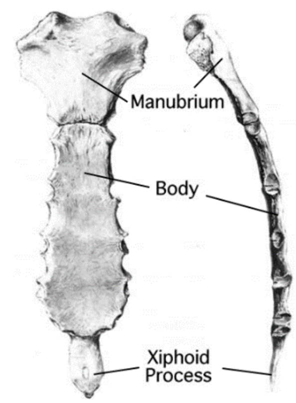
Classification of Bones by Shape

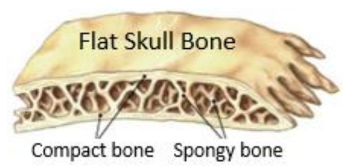
1. Long bones – are bones such as the femur, humerus, tibia, radius, metacarpals, metatarsals, phalanges, all share the similar basic anatomical arrangement including having:

a. a diaphysis (shaft);
b. both proximal and distal epiphyses;
c. a medullary cavity lined with endosteum containing either red or yellow (fatty) bone marrow.

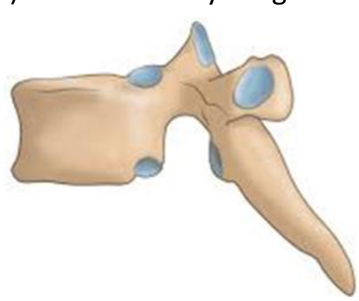
2. Short bones – are bones that are no longer than they are wide, they are sometimes referred to as 'boxy' bones. There are two main examples: 1) the carpal bones of the writs (except for the pisiform); and 2) tarsal bones of the foot.

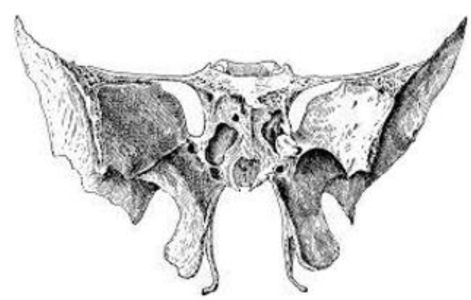
3. Flat bones – these are dense bones that have surface compact bone that encloses a thin spongy portion; e.g., the flat cranial bones like the frontal, parietal, and occipital bones of the skull. A perfect image of this description in bone is seen in the drawing below (center), this is what a typical flat 'roofing' done of the skull looks like. Also facial bones such as nasal, lacrimal and vomer are also examples of flat bones on the skull. Other flat bones include the sternum (shown at right) and the ribs of the thoracic cage (see left), the scapula, and bone of the ilium, ischium and pubis of the os coxae (also called the innominate bone).





4. Irregular bones – these types of bones have no definable shape, hence the term 'irregular'. There may be flat or long portions of the bone, but the most striking feature is that it is irregular and distinct in its shape. Bones in this category include all the vertebrae, plus the sphenoid, maxillary and temporal bones of the skull. Below (left) is a thoracic vertebra (it has the unique structures of facets for costal cartilage) and below (right) is the distinctly irregular sphenoid bone.

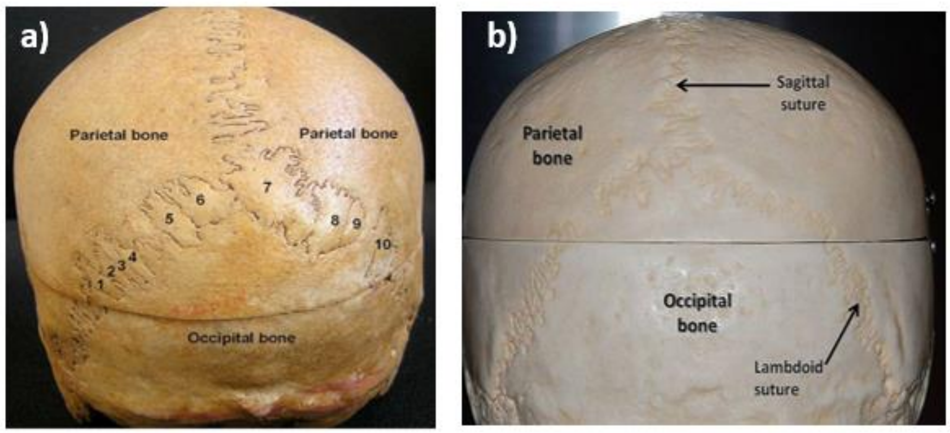




5. Sesamoid bones – these bones are like a "sesame seed" and are commonly found embedded in a muscle or tendon that is near a joint surface. The patella found within the quadriceps tendon and patellar ligament of the knee the largest and most consistent example in the human body. The pisiform of the carpal bone is also a consistent sesamoid bone in the flexor carpi ulnaris tendon that flexes the wrist. There are also hallux (big toe) sesamoids that act as a pulley system to ease stress in that area of the muscle or tendon (see right).

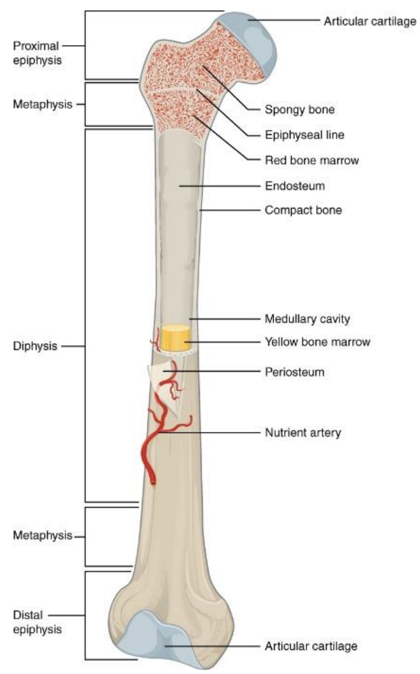
6. Sutural bones – these are also called Wormian bones (an eponym). These small bones form inside sutures of the skull, usually in the lambdoidal or sagittal sutures. They are inconsistent in number and shape, but are all very small. Sometimes they are not present in a skull at all.

A skull **a)** with, and **b)** without sutural bones



The Anatomy of a Long Bone - A long bone consists of several sections:
Diaphysis - the long central shaft of the bone.

Epiphysis - the ends of the long bone.



Metaphysis - this is the area between the diaphysis and epiphysis and contains either the epiphyseal plate or the epiphyseal line. It is the site of length-wise growth of long bones.

Epiphyseal Plates - are the growth plates of bones which allow for the length-wise growth of long bones to occur during childhood. This growth plate is composed of hyaline cartilage and once the cartilage plates ossify (become bone tissue) it fuses into the epiphysis and then it becomes the bony *epiphyseal line*, which serves as a remnant of the growth plate. Once there is an epiphyseal line, there is no more length-wise growth. Typically, long bones stop their length-wise growing between the ages of 18 and 26.

Articular Cartilage - this is a special type of hyaline cartilage that covers the ends of epiphyses. This provides a smooth surface which forms a movable articulation (joint) with another bone, so that friction is minimized. This is a very thin but firm layer of flexible resilient hyaline cartilage, said to have distinct viscoelastic properties that helps reduced friction at the site of the articulation and can also provide shock absorption to the joint. This tissue has no neural or vascular supply.

Medullary Cavity – this is also called the marrow cavity. It is the central hollow area of the diaphysis (shaft) where **red** (myeloid tissue) and/or **yellow** bone marrow (adipose tissue) is stored. The medullary cavity has walls composed of spongy (cancellous) bone and is lined with a thin, vascular membrane called the **endosteum**.

Endosteum - the inner lining of the medullary cavity of long bone. It is in contact with the bone marrow.

Periosteum - is the outer covering around bone. It has 2 layers: An outer fibrous layer composed mostly of fibroblasts that make collagen fibers; and an inner cellular layer, composed mostly of osteoprogenitor cells which will be able to differentiate into osteoblasts. The periosteum provides a good blood supply to the bone and a point for muscular attachment.

Sharpey's Fibers - also called perforating fibers, this is connective tissue consisting predominantly of bundles of strong collagen fibers connecting the periosteum to a bone. They are the outer fibrous layer of periosteum that enters into the outer circumferential and interstitial lamellae of compact bone tissue. They are also used to attach muscle to the periosteum of bone by merging with the fibrous periosteum and underlying bone as well.

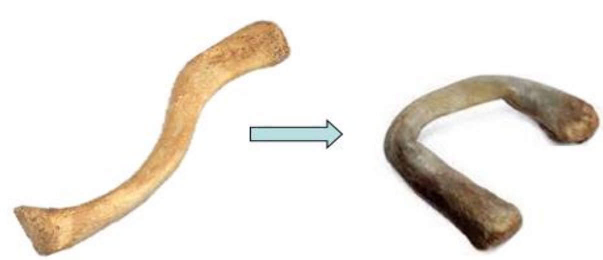
The Constituents of Bone Tissue

What exactly makes up the material that we see as bone? There are two main components of bone: **1)** the organic material, which are cells, protein fibers and some organic molecules; and **2)** the inorganic elements which are essentially the mineral salts that are so critical to giving bone its rigid quality which is fundamental to many of its important roles in the body. It may surprise some to know that only about 1/3 of bone is composed of organic material, and about 2/3 of bone is composed of inorganic material.

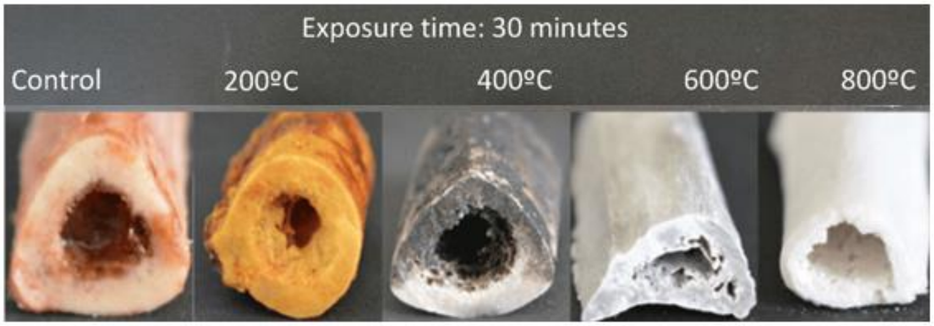
Organic Components (1/3)	**Inorganic Components (2/3)**
Collagen Fibers (proteins)	Calcium Hydroxyapatite (80%) (Ca^{2+} and PO_4^{3-})
Specialized Bone Cells (4 cells)	Calcium Carbonate (15%)
Glycosaminoglycans (GAGs)	Other trace minerals (Mg, Na, Zn, Cr, Cu, etc.)
Give Bone Flexibility	***Gives Bone Rigidity***

Calcium Hydroxyapatite is a natural mineral form of apatite, the chemical formula is $Ca_{10} (PO_4)_6$. 2OH, or can be expressed by 2 units of $Ca_5 (PO_4)_3$ (OH). If the components of bone were measured by volume, it consists of **40%** of the inorganic calcium hydroxyapatite component, **25%** water and **35%** organic component (proteins). About 90% of the organic component are collagen type I, the cells of bone and the remaining 10% non-collagenous proteins and molecules.

Experiments have shown that soaking a bone in vinegar for a few days will dissolve the calcium mineral salts (calcium hydroxyapatite) out of the bone, leaving only the organic components (mostly collagen) to remain. The bone become soft and rubbery, such that it can be bent (see the collar bone below), and if they the bone is long enough, it can even be tied into a knot.



Heating bone destroys the protein fibers but leaves behind a hard material mostly calcium and phosphorus. However it is brittle without the organic elements, and although minerals gives bone hardness, without the proteins, it breaks easily. Bone in our bodies is very watery and dense, and not dry like the bones we may see in an anatomy bone box in lab. The image below shows the difference between a control bone (no heat) and when it is heated at successively higher temperatures, what When bones are heated Heating caused the bone to become brittle



Bone itself as a material is a superior conductor of heat than the muscle that is attached to it. As we have seen, bone is not completely solid, not only is there a medullary cavity in the middle of long bones, but all bones have that honeycomb-like structure of spongy bone, and this areas contains many air spaces. These air spaces guard against temperature fluctuations and bone in this way acts protect the muscle and other tissues in close proximity to it.

Specialized Cells of Bone

Bone tissue is derived from the primary germ layer the **Mesoderm**. The **osteoprogenitor** cells are the stem cells of bone tissue and this is where the cell lineage for bone tissue starts. These cells continue to differentiate (become more specialized in structure and function) to become the second and third type of bone cell. The final type of bone cell, the osteoclast, comes from a separate lineage, derived from a type of white blood cell called a monocyte.

The Four Bone Cells

1. **Osteoprogenitor cells**: The stem cell of bone tissue, resides in the periosteum and endosteum. This is the only cell with "mitotic potential", that is, the only bone cell that is able to multiply.

2. **Osteoblasts**: This cell cannot multiply (or divide), but it makes the calcified bone matrix called osteoid tissue. It lays down the various lamellae and trabeculae of bone. It is found in endosteum and in the inner cellular layer of the periosteum.

3. **Osteocytes**: These are the mature cells of bone that are located inside a lacuna. They can no longer make bone matrix but now maintain the bone matrix with canaliculi (extensions of the plasma membrane) that reach out into the lamellae and maintain this tissue.

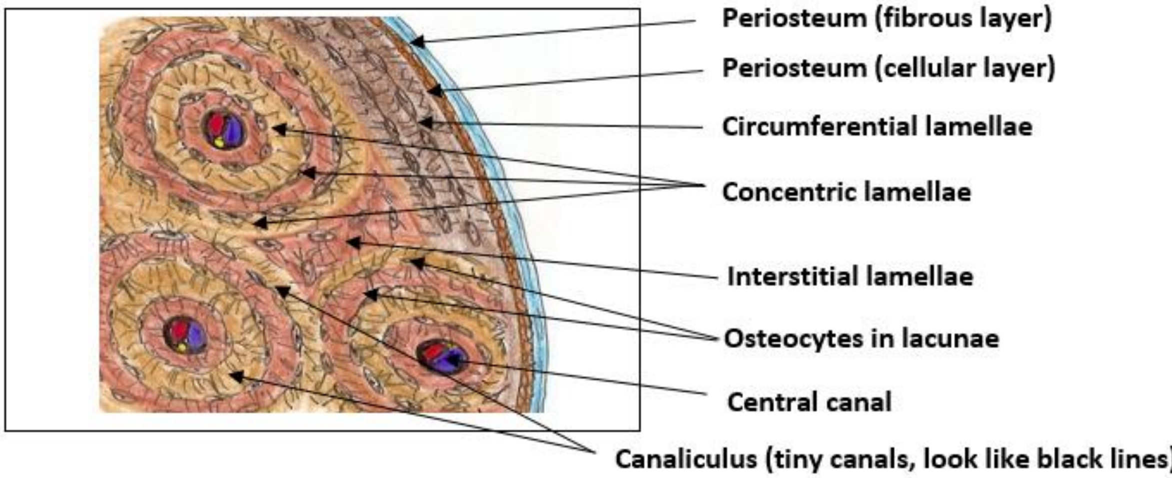
4. **Osteoclasts**: These are very large multinucleated cells, often made from a fusion of up to 50 monocyte nuclei, and have a ruffle border on one aspect of the cell where they release their powerful degradative enzymes. These cells are the **dissolvers** of bone matrix. By dissolving bone matrix they liberate the calcium ions (Ca^{2+}) stored there, and since calcium is such an important ion in regulating may physiological pathway, this is highly regulated process in the body.

The activities of the ***osteoblasts*** (the bone maker) and the ***osteoclasts*** (the bone breaker) are how we change the shape and thickness of bone tissue in the body - a process referred to as **remodeling** of bone.

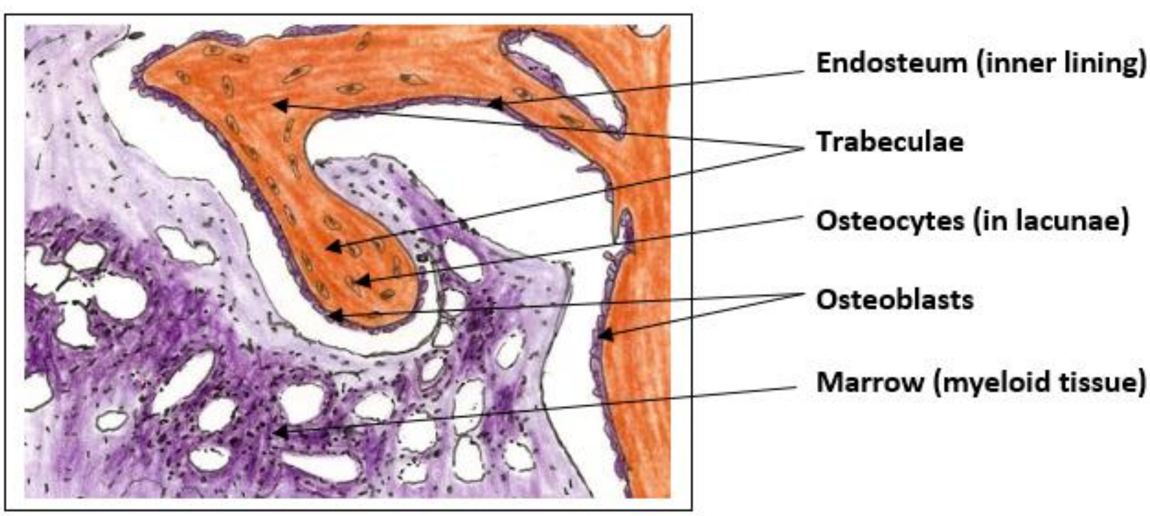
Bone Histology

Compact Bone – The **Osteon Unit** is the functional unit of compact bone, it consists of:

A. Concentric rings of calcified lamella that are arranged around the central canal.
B. Central (Haversian) canals in the middle of an osteon.
C. Perforating (Volksmann) canals which connect the various central canals.
D. Lacunae ('lagoons') are spaces in the lamella in which osteocytes reside.
E. Canaliculus (singular) and canaliculi (plural) means 'tiny canals', they are actually extensions of the plasma membrane of osteocytes that are penetrating the surrounding calcified matrix, permitting the maintenance of bone via diffusion of nutrients, wastes, etc.
F. Collagen fibers in the mineral matrix give strength and flexibility to the bone.
G. All compact bone is covered by periosteum, which has an outer fibrous layer and an inner cellular layer.



Spongy (or Cancellous) Bone – is the bone tissue that is made first and the **trabeculae** (plates or struts) are the functional unit of spongy bone. Osteocytes are still located in lacunae in spongy bone and the osteoblasts are found on the surface of the trabeculae within the endosteum. This is also where the very large osteoclasts cells are located. The trabeculae provide internal spaces in bone which can contain red bone marrow where blood cells are made.



<u>Bone Formation and Growth</u>

There are two types bone formation or ossification in the body; **intramembranous ossification** and **endochondral ossification**.

1. <u>Intramembranous Ossification</u>: In this process, bone tissue forms inside a membrane from an ossification center and grow peripherally. Bone tissue replaces the membranous model and the resulting bones are often called 'dermal' bones. Since all connective tissue arises from the middle primary germ layer, the mesoderm, it is the mesenchymal cells that are the stem cells for all connective tissue. These stem cells differentiate into the stem cell for bone tissue called the osteoprogenitor cells. These cells continue to differentiate and become osteoblasts or the bone makers. Finally, they become trapped inside lacunae and become the mature cells of bone, the osteocytes. In a simplified but accurate pathway the bone tissue arises in the progression shown below:

Mesoderm –> Mesenchymal cells –> Osteoprogenitor cells –> Osteoblasts –> Osteocytes

This process is not the way most bones in the body are formed in the body, so there are just a few examples and they are; the flat roofing bones of the skull, such as the frontal and parietal bones; the mandible, clavicle and patella are also made by intramembranous ossification.

2. <u>Endochondral Ossification</u>: This is the way that most bones in the body are formed. In this type of bone formation, bone replaces a cartilaginous model (hyaline, of course). The cartilage model of bone is found in long and short bones and in those parts of irregular bones which are preformed of cartilage (cartilage bones). The resulting bone is histologically identical to intramembranous ossification.

A brief summary of the basic process of endochondral ossification starts after the cartilage model of the bone is complete. Blood vessels grow and migrate into the center of the cartilaginous structure, invading the cavities left by dying chondrocytes. Mesenchymal cells come with the blood vessels and differentiate into Osteoblasts. Osteoblasts replace cartilage matrix with spongy bone, this becomes the **primary ossification center**. This results in spongy bone in the shaft of the bone which will later be remodeled (by osteoclasts) into a marrow cavity, with outer compact bone.

Secondary ossification sites begin later at each epiphysis of the bone, that is at the proximal epiphysis and distal epiphysis; this is called the **secondary ossification center**. This arrangement leaves a cartilage band within the metaphysis and this is called the epiphyseal plate, which is the growth plate. The length-wise growth of long bones occurs at this site as the reserve cartilage reproduces itself; the chondrocytes enlarge and become more active metabolically, thus causing minerals to precipitate. Eventually the cartilage reserve itself ossifies creating the epiphyseal line indicating the end of bone growth. Increase in girth (width) is called appositional bone growth and occurs as osteoclasts remodel bone from the medullary cavity as the osteoblasts add more bone matrix to the outside.

The balance in activity between the osteoblasts (bone makers) and osteoclasts (bone dissolvers) can be referred to a **bone remodeling**. For normal bone growth, maintenance and repair to occur, remodeling of bone is continuous throughout one's lifetime.

Disorders of Bone Tissue

Osteoporosis: A significant reduction in bone mass that impairs function. It results from too little mineralization of bones for any of several reasons:

1) Decrease in hormone levels, e.g., loss of estrogen at menopause decreases calcium absorption.
2) Deficiency of mineral in youth resulting in too little to begin with.
3) Imbalance of activity of osteoblasts and osteoclasts.

Osteopenia: A reduction in bone mass with age.

Osteomalacia: This is a defective mineralization of bone, resulting in too much flexibility. Most commonly due to a deficiency in vitamin D levels in the Body. Called rickets in children.

Osteophyte: also called a bone spur, is an outgrowth of bone occurring along the edges of a bone. Can form in any bone but most commonly found in joints and where ligaments or tendons attach to the bone.

Osteoarthritis: Wear and tear arthritis, this is due to the heavy normal use of a joint throughout a lifetime. The most common joints having wear are the knee and finger joints.

Osteoma: Cancer of bone tissue.

Bone Fractures

Fractures of Bone involve a break or crack in bone. As we will see below, there are many different types of bone fractures, primarily based on the pattern of damage that occurs to the bone

Firstly, there are two basic categories for any kind of bone fracture, and that is **Simple** and **Compound**.

Simple (Closed) Fracture – the skin remains intact (not broken). Although the bones are broken they remain within the body and do not penetrate the skin.

Compound (Open) Fracture – the skin is broken by the fractured bone. The broken bone has penetrated through the skin and exposed the bone and deep tissues to the exterior environment.

For the most part, a compound fracture involves increased risks in the following ways:

1) Increased risk of infection (due to compromised skin barrier), leaving a region of our body vulnerable to exposure, and

2) Increased risk of blood loss. The pressure within the body is higher than the lower pressure externally and this means it is easier for blood loss to occur, there can be a greater possibility of blood loss compared to internal bleeding from a simple fracture.

Another important basic category for fractures is whether it is displaced or non-displaced, which is referring to the normal anatomical alignment of the fractured bone.

Non-displaced Fracture: This is when a bone breaks but retains its normal anatomical alignment within the body. This is seen the oblique fracture on the far left. In nondisplaced fractures, often they only require bracing, booting or casting for treatment.

Displaced Fracture: This is when there is a displacement of a bone fragment or section caused by the fracture. The bone breaks into two or more sections and it is moved out of its normal anatomical alignment. In other words, the bone pieces are not lined up properly any longer. This kind of fracture often requires a “re-alignment” of the bone prices prior to setting a cast or braces. This can be a very painful experience because it involves a re-adjusting injured tissue.

Below is a list of some basic types of fractures. Also see lecture PPT slides or the textbook.

Comminuted fractures are severe fractures that involve the shattering of a bone into many smaller pieces.

Transverse fractures occur across the bone, perpendicular to the longitudinal axis of a bone and are the result of a force applied at a right angle to the bone.

Greenstick fracture is when the bone partly fractures on one side, but does not break completely because the rest of the bone can bend. More common among children, whose bones are softer and more elastic. The bone is like a green stick; it won’t snap and break all the way through, but rather it bends and splinters on one side because it is flexible.

Hairline fracture is a partial fracture of the bone. Often this type of fracture is harder to detect.

Avulsion fracture is a muscle or ligament pulls on the bone, fracturing it. These fractures may be caused by overexertion of muscles or sudden traumatic pulling.

Oblique fractures are slanted fractures that occur when a force is applied at any angle other than a right angle to the bone.

Spiral fractures are the result of an extreme twisting force being exerted on a bone. These are commonly found in sporting injuries.

Compression (crush) fracture - generally occurs in the spongy bone in the spine. For example, the front portion of a vertebra in the spine may collapse due to osteoporosis.

Impacted fracture - when the bone is fractured, one fragment of bone goes into another.

Segmental fractures - happen when a bone is broken in at least two places, leaving a segment of bone that is totally separated by the breaks. These fractures are often seen in car accidents.

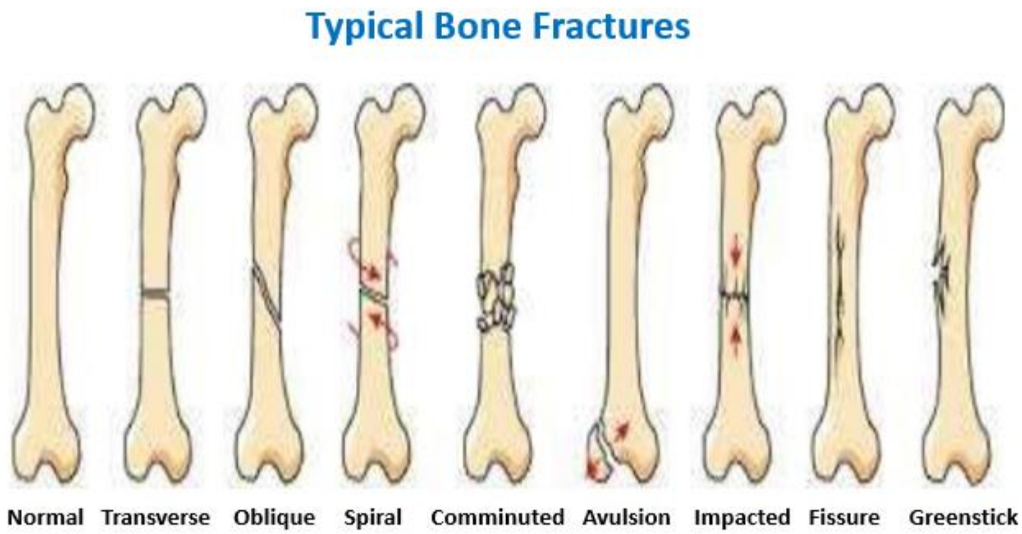
Longitudinal fracture - the break is along the length of the bone.

Stress fracture is more common among athletes. A bone breaks because of repeated stresses and strains in a particular area of bone.

Impacted fracture is also called a **torus** or **buckle** fracture. This can occur when a bone is compressed and pressure is applied on an area, causing parts of the bone to crumble under the impact of the force. The bone deforms but does not really crack. This is more common in children

Colle's fractures are of the distal radius that usually occur as the result of a fall onto an outstretched hand. They consist of a fracture of the distal radial metaphyseal region with dorsal angulation and impaction.

Pott's fracture involves one of the bony parts of the ankle called the malleoli, of either the tibia - the medial malleoli on the inside or the fibula - the lateral malleoli on the outside.



The 4 Essential things required for Normal Bone Growth, Repair and Remodeling

For bone tissue to engage in normal functions such as growth, remodeling of bone tissue and any repairs of bone tissue, it needs to have these four main elements in balance.

1) Adequate Minerals:

Plenty of Ca^{2+} and PO_4^{2-}. Are required, absolutely necessary for normal bone activity. As we have seen, bone will be too flexible without adequate minerals. Also extremely important to bone and the entire body, are the trace minerals, there are about 80 of them, all can be gained in sea salt or Himalayan salt.

2) Adequate Vitamins:

We need these Vitamins: **D**, **K2**, **C**, and **A**. Vitamin D is needed for the proper mineral depositions in bone, called the 'mineralization' of bone. Vitamin K2 activates 2 proteins in the body, matrix Gla protein (MGP) and osteoclacin. These both work in sequence to remove excess calcium from the blood (MGP), and put it in the bone osteocalcin. Vitamin C stimulates collagen production in the body and plenty of collagen is required for normal bones. Vitamin A improves bone density and is proposed to protect bone.

3) Appropriate Hormone Levels:

All of the hormones we have discussed in class that effect osteoblasts, osteoclasts or the levels of calcium in body fluid will have an impact on normal bone growth and repair and so must be maintained at adequate levels. These hormones include: Human Growth Hormone (hGH), Thyroxine, Calcitriol, Parathyroid Hormone, Calcitonin, and Sex Hormones.

4) Weight Bearing Exercise:
Bone is very dynamic tissue that responds very quickly to use or disuse. Accordingly, bone tissue will **atrophy** (get smaller and become less dense) from lack of use, and will **hypertrophy** (get larger and thicker and more dense) from increased use.

Bone Markings and Bony Landmarks

Markings on bone are frequently caused by stress on the bone from the blood vessels or the muscles that are literally sitting on the bone, or are present as articulations or passageways for other structures.

Articulating Surfaces:
1. Head is a large, expanded, rounded projection on one end of a bone.
2. Condyle is a smaller projection which articulates with another bone. Some will have specific names, for example, the trochlea of the humerus (means a pulley-like articulation feature) or the capitulum of the humerus (meaning a bowed head shape).
3. Facets are small articulating surfaces that are slightly concave or convex.

Depressions:
1. Fossae are usually shallow depressions in bone, though some can be deeper.
2. Sulcus is a shallow groove in bone (often made by tendons or blood vessels).
3. Fovea is a shallow pit in bone.
4. Alveolus is the ‘tooth socket’, the depression in bone where a tooth sits.
5. Neck is the constriction below the head of a bone.

Passageways:
1. Foramen is a hole through a bone, usually with smooth edges.
2. Meatus is a hole into, but not through a bone, as the ear hole.
3. Fissure is an irregular crack, usually between two bones.
4. Sinus (antrum) in the skeletal system, it is a cavity or chamber within a bone.

Extensions and Projections:
1. Process is any projection from the surface of a bone, frequently for muscle attachment, a handle.
2. Ramus is a branch, or an abutment (plural is rami).
3. Trochanter exists only on the femur (greater and lesser), very large projections for muscle attachment.
4. Tubercle is a much smaller projection from a bone, usually somewhat rounded, as muscle attachment.
5. Tuberosity is a roughened result of muscle stress, easier felt than seen, as the texturing on a basketball.
6. Crest, as the name indicates, an elevated ridge on a bone, like the ridge of a mountain range.
7. Line is a small or sharp ridge similar to a crest but less prominent, the walkway along a hillside.
8. Spine is a pointy projection for muscle attachment.
9. Styloid refers to a needle-like projection, as in an old time record player stylus.