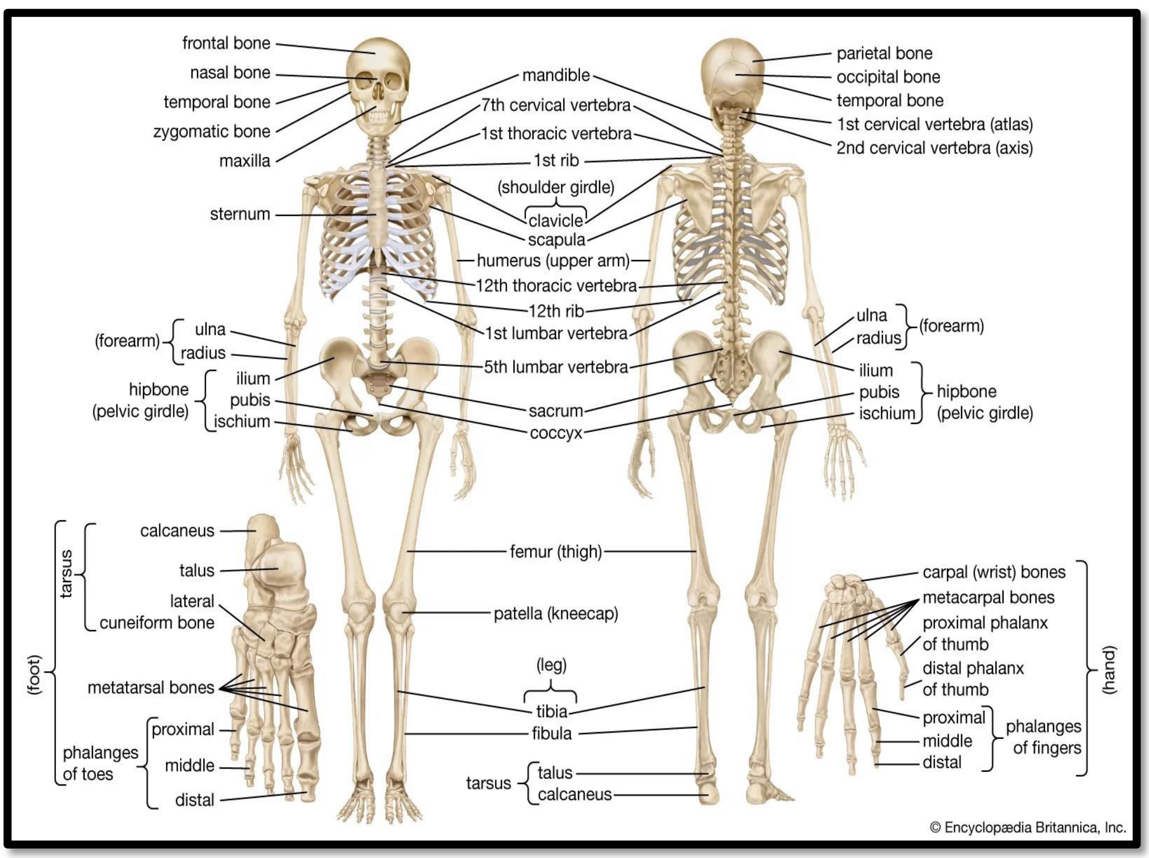
Physics of Skeleton

This organ system of the body appeals most to physical scientists because engineering type problems dealing with static and dynamic leading forces that occur during standing, walking, running, and lifting.

On the other hand, a number of medical specialists are concerned with problems of bone. Two medical specialties, dentistry and orthopedic surgery, are completely devoted to this area. Other medical specialists who have considerable interest in bones are rheumatologists, who specialize in problems of rheumatism and arthritis, and radiologists, who base many diagnostic decisions on x-ray images of bony structures. The various bones of the skeleton are shown in Figure below.



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○ Functions of the bones:

Bone has at least six functions in the body:

1. *Support:* The body's muscles are attached to the bones through tendons and the system of bones plus muscles supports the human body. this function of bone is most obvious in the legs.
2. *Locomotion:* In general, the function of the muscle is to pull the bone when contracted. Bone joints permit movement of one bone with respect to another. These articulations are very important for walking as well as for many of the other motions of the body.
3. *Protection:* the skull, which protects the brain and several of the most important sensory organs (eyes and ears), is an extremely strong container. The ribs form a protective cage for the heart and lungs. In additional to its support role, the spinal column provides a flexible shield for the spinal cord.
4. *Storage of chemical:* the bones act as a chemical "bank" for storing elements for future use by the body. The body can withdraw these chemicals as needed. For example, a minimum level of calcium is needed in the blood; if the level falls too low, a "calcium sensor" causes the parathyroid glands to release more parathormone into the blood, and this causes the bones to release the needed calcium
5. *Nourishment:* the teeth are specialized bones that can cut food (incisors), tear it (canines), and grind it (molars) and thus serve in providing nourishment for the body.
6. *Sound transmission*: the smallest bones of the body are found in the

middle ear. These three small bones act as levers and provide an

impedance matching system for converting sound vibrations in air to sound vibrations in the fluid in the cochlea. They are the only bones that obtain full adult size before birth.

○ Bone as a living tissue:

- Bone is a living tissue and has a blood supply as well as nerves.

- Osteocytes
  - o Cells that maintain the bone in a healthy condition
  - o 2% of the volume of bone
  - o Poor blood supply →osteocytes die →bone dies →loss of its strength.
  - o Aseptic necrosis: bone cells in the hip die →artificial joint.

- Bone remodeling by specialized bone cells
  - o Osteoclasts destroy the bone by about 0.5 g of calcium each day
  - o Osteoblasts build the bone by about 0.5 g of calcium each day
  - o Bones have about 1000 g of calcium → new skeleton in every seven years equivalently.
  - o Osteoblasts dominate until 35 to 40 years old.
  - o Osteoporosis: porous bones in older women → fractures.

○ Bone remolding:

It is a continuous process of destroying old bone by osteoclasts and building new bone by osteoblasts. Bone remodeling is slow. Each day the osteoclasts destroy bone containing about 0.5g of calcium. All body's bones have about 1000g of calcium so we have the equivalent of a new skeleton about every seven years.

1. Osteoclasts: cells specialized in bone destroying.
2. Osteoblasts: cells specialized in bone building.

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Young body is growing, and the osteoblasts do more than the osteoclasts, but after the body is 35 to 40 years old the activity of the osteoclasts is greater than that of the osteoblasts resulting in gradual decrease (1-2% per year) in bone mass that continues until death. This condition called osteoporosis. Osteoporosis can be diagnosed by the measurement of bone mineral density (bone densitometry). This faster in the women than in the men and leads to a serious problem of weak bones in older women.

- ## Chemical composition of bone:

Bone tissue consists of two non-living different materials in addition to water these materials are:

1. *Collagen:* It is an organic material form the bone framework and constitutes about 40% of the weight of solid bone and 60% of its volume. The collagen is flexible somewhat like a chunk of rubber.

2. *Bone Mineral:* (Inorganic component of bone) is about 60% of the weight of the bone and 40% of its volume. The bone mineral is very fragile and can be crushed with fingers. Bone minerals made up Ca2+ and PO43- salts, particularly calcium hydroxyapatite {Ca10(PO4)6(OH)2}. Similar crystals exist in nature is fluorapatite (common rock) differ from calcium hydroxyapatite in that fluorine takes the place of the OH. Fluorine in drinking water may prevent caries by turning microscopic areas of the teeth in to rock which more stable than bone mineral.

The functional component of the bone includes growth factors and cytokines. The hardness and rigidity of bone is due to the presence of mineral salt in the osteoid matrix, which is a crystalline complex of calcium and phosphate (hydroxyapatite). While the collagen makes bone flexible and bends easily with large tensile strength.

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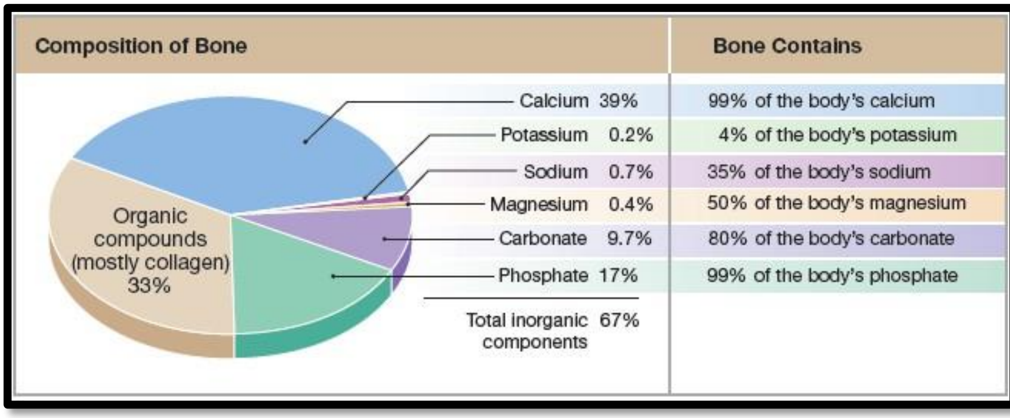
Calcified bone contains about 28 % organic matrix, 5 % water, and 67 % inorganic mineral (hydroxyapatite).



- **Bone densitometry:**

There are two methods for bone mass measurement:

1. *Radiographic Absorptiometry:* In radiographic absorptiometry, which previously called photodensitometry, a radiograph of the hand and an aluminum step wedge is taken using a conventional X-ray unit. The optical densities of the radiographic images of the bone and aluminum wedge are measured using a device called an optical densitometer. The precision of such measurements is 2-4%.
2. *Dual Energy Absorptiometry, (DXA/DPA):* this enables the direct determination of bone mass by assessing the transmissions of two different energy beams through the body. Early dual photon absorptiometry (DPA) units used a radioactive material as the source of two distinct energy photon beams. In dual (energy) X-ray

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absorptiometers (DXA), an X-ray tube has replaced the radioactive source. The transmissions can be used to estimate the mass of bone at each location in the scan.

- **Bone shapes:**

According to their functions, the bone shapes are classified into five groups:

1. Plate like bones: Such as the scapula and some of the bones of the skull.
2. Long hollow bones: Such as those found in the arms, legs and fingers.
3. Cylindrical bones: Such as vertebrae.
4. Irregular bones: Such as the bones of wrist and ankle.
5. Bones such as the ribs that do not belong in any of the other groups.

- **Types of bone:**

Bone tissue in children and adults is of two types:

1. *Compact or cortical bone:* It makes up the outer layer of most bones and accounts for 80% of the bone in the body.
2. *Elastic properties of bone*: According to Hooke's Law, if a bone is placed under tension or compression, its length (L) is changed and the strain ($\Delta L/L$) increases linearly at first indicating that it is proportional to the stress (F/A)

- **Advantages of trabecular bone over compact bone:**

1. During compressive forces, the trabecular bone gives the strength

necessary with less material than compact bone.

2. Because the trabeculae are relatively flexible, trabecular bone can absorb more energy when large forces are involved such as in walking, running and jumping.

• The main disadvantage of trabecular bone, it cannot withstand the bending stresses that occur mostly in the central portions of long bones.

- **Physical properties of bone:**

1. *The density of the bone* is about 1.9 g/cm3 which stay constant through life. In old age, the bone reduced in strength because it is thinner (from inside) not because it is less dense.

2. *Elastic properties of bone*: According to Hooke's Law, if a bone is placed under tension or compression, its length (L) is changed and the strain (ΔL/L) increases linearly at first indicating that it is proportional to the stress (F/A)

where (F) is the applied forces and (A) is the cross sectional area of the bone. As the tensile force increase the length increase rapidly and the bone breaks at the stress of about 120 N/mm.2

Healthy bone is able to withstand a compression stress of about 170 N/mm2 before it breaks.

To calculate the change in length (ΔL) for a given force F, the above equation can be written as: ΔL =LF/AY.

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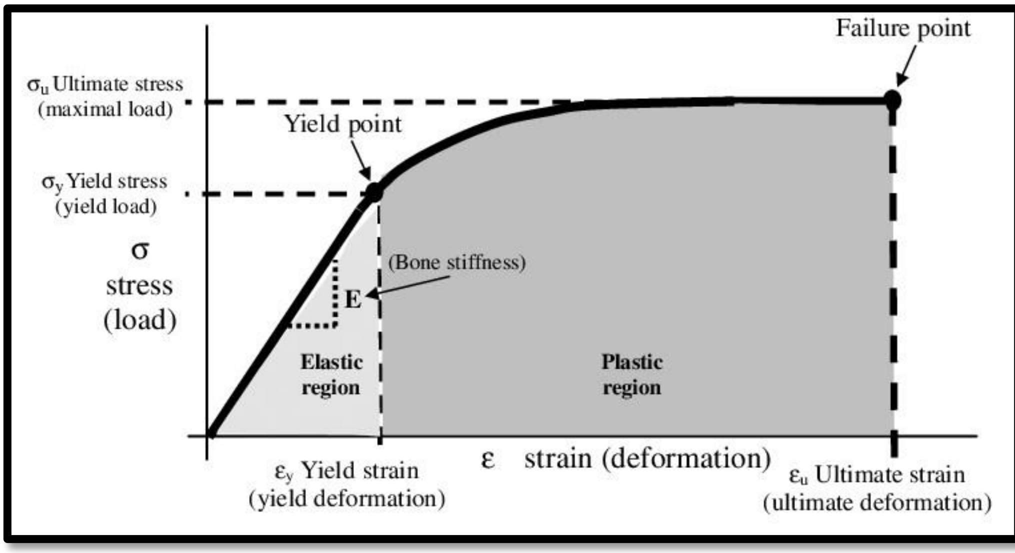

The ratio of stress to strain in the initial linear portion is Young's modulus (Y). That is:

$$Y = \frac{L.F}{A.\Delta L}$$

Y= Young's modulus L= Original length F=Force A= area and ΔL= change in length.

3. *Viscoelasticity:* The property of bone to withstand a large force for a short period of time without breaking (such as in jumping), while the same force over a long period may fracture it. This is because the stress in bone does not depend only on the current value of strain, but on how fast that strain was applied.

4. *Piezoelectricity:* The property of bone to generate electrical charge on its surface when it bent. It has been suggested that this phenomenon may be the physical stimulus for bone growth and repair.

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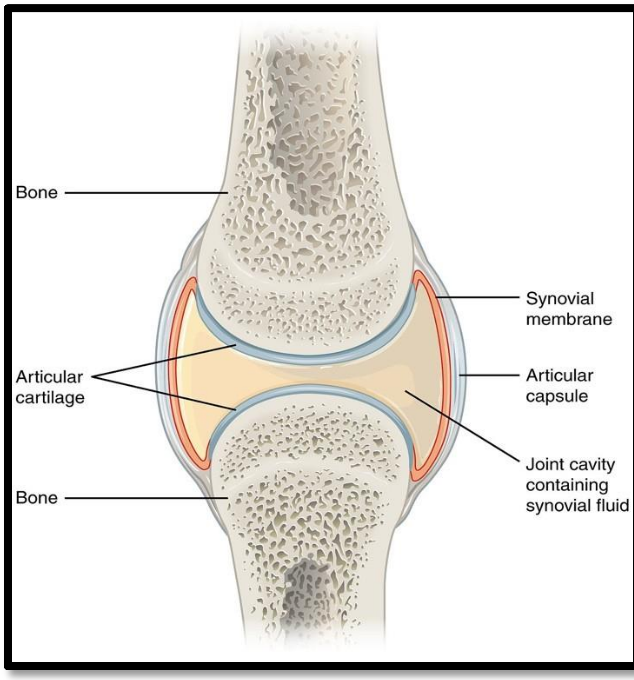
○ Lubrication of Bone Joints

The main components of joint are:

1. The synovial membrane encases the joint and retains the lubricating synovial fluid.



2. Articular cartilage: A smooth rubbery material that is attached to the solid bone. The surface of the articular cartilage is not very smooth. The roughness plays a useful rule in joint lubrication by trapping some of the synovial fluid.

• The lubrication properties of a fluid depend on its viscosity, thin oil is less viscous and better lubricant than thick oil. The viscosity of synovial fluid decreases under the large shear stresses found in the joint.

Example 1: Assume a leg has 1.2 m shaft of bone with an average cross-Sectional area of 3x10-4m^2. What is amount of shortening when all the body weight of 700 N is supported on this leg, Assume the Young's modulus (Y) =

1.8x1010N/m^2.

Sol:

$$\Delta L = \frac{L.F}{A.Y} = \frac{(1.2m)(700N)}{(3x10^{-4}m^2)(1.8x10^{10}N/m^2)} = 1.5x10^{-4}m = 1.5mm$$

Example 2: In regions of the cardiovascular system where there is steady laminar blood flow, the shear stress on cells lining the walls of the blood vessels is about 20 N / m2. If the shear strain is about 0.008, estimate the shear modulus for the affected cells.

Sol:

$$Y = \frac{stress}{strain} = \frac{()}{).))+} = 25\ x10^{(}\ N / m^{(}$$

H.W: Assume a leg has 0.6m shaft of bone with an average cross-sectional area of 1.5x10^{-4}m^2. What is amount of shortening when all the body weight of 350 N is supported on this leg, Assume the Young's modulus (Y) = 1.8x10^{10}N/m^2.

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