University of Al-Mustaqbal
College of Science
Department of Medical Physics

Medical Physics

Lecture 1: Physics of the Skeleton

Third stage

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Physics of the Skeleton

Skeleton comes from a Greek word meaning **dried up body**. Bone appears dead and dried up, but it is **not**! Bone is **living tissue.**

Parts of the skeletal system

- **Bones (skeleton)**
- **Joints**
- **Cartilages**
- **Ligaments (bone to bone) (tendon=bone to muscle)**

Functions of Bones

1. **Support** of the body (framework)
2. **Protection** of soft organs
3. Serve as **levers** (with help from muscles)
4. **Storage** of minerals and fats (calcium)
5. Blood cell **formation**

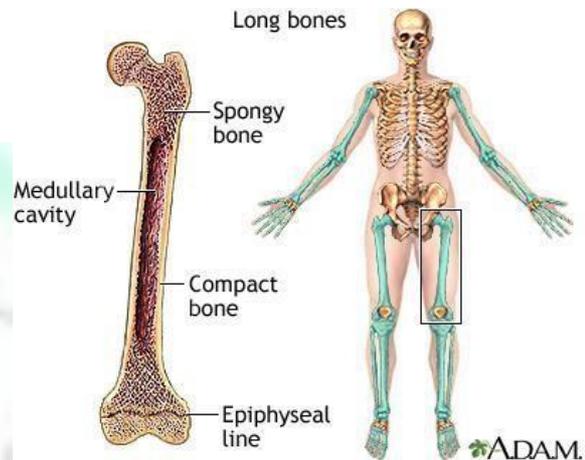There are <u>two</u> basic types of **bone tissue** in the human body.

1. **Compact bone** {**dense** and **hard**)
2. **Spongy bone** {Cancellous and Many open spaces}
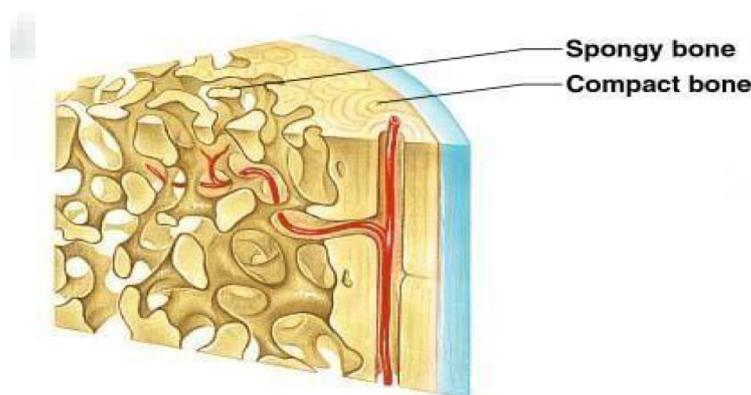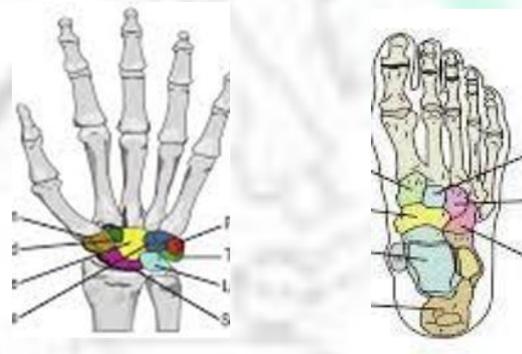
Classification of Bones

1. Long bones

- Typically, longer than wide.

- Have a shaft with heads at both ends.

- Contain mostly compact bone.

- Found in legs and arms.
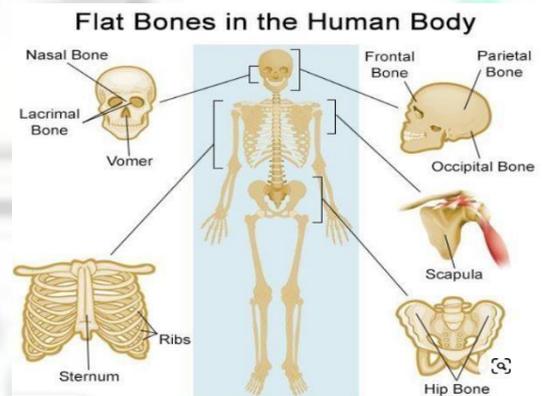
  - Examples: Femur, humerus.

2. Short bones

- Generally, cube-shape and small.

- Contain mostly spongy bone.

- Found in wrist, ankles, and toes.

- Examples: Carpals, tarsals

3. Flat bones

- Thin and flattened Usually curved

- Cover organs and provide surface for leg muscle

- Thin layers of compact bone around a layer of spongy bone
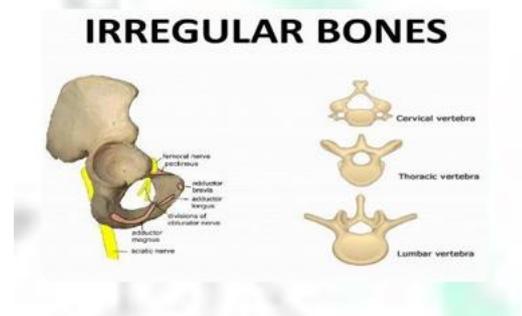
- Examples: Skull, ribs, sternum

3. **Sesamoid Bones**

- The sesamoid bones get their name for resembling a sesame seed.

4. **Irregular bones**

- The irregular bones get their name for their odd shapes that do not fit the other categories of long, short, flat, or sesamoid.

What Are Bones Made of?

☒ **Periosteum**: The outer surface of the bone; a thin, dense membrane that contains

nerves and **blood vessels** that nourish the bone!

☒ **Compact**: This is the next layer; it is very **smooth** and very **hard**. It is the part you see when you look at a skeleton!

☒ **Cancellous**: Many layers within the compact bone; these look like sponges! Not as hard as compact bone, but it is still very hard. In many bones, the **cancellous** bone **protects** the **innermost** part of the bone.

☒ The **bone marrow**: It is sort of like a thick jelly, and its job is to make blood cells.
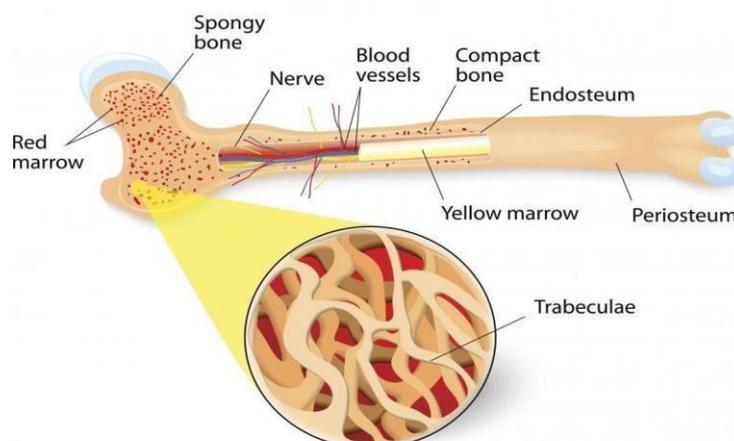
Composition of compact bone: Table 1 where Large percentage of **calcium** with heavier **nucleus** (high x-ray absorption**).**

Table 1. Composition of Compact Bone"	
Element	Compact Bone, Femur (%)
H	3.4
C	15.5
N	4.0
O	44.0
Mg	0.2
P	10.2
S	0.3
Ca	22.2
Miscellaneous	0.2

Generally, Bone = collagen + bone mineral + water

- **Collagen**

Collagen which is the major organic fraction, 40% of the weight of solid bone and 60% of its volume. {**flexible and bends easily, large tensile strength**. Produced by **osteoblastic** cells.

- **Bone mineral**

Bone mineral: inorganic component 60% of weight 40% of its volume. Formed on the collagen. Made up of calcium hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$. Very large surface area of 4×10^5 m^2 ⇒ rapid interaction with chemicals in the blood and other body fluids.

Physics of the Skeleton (part 2)

How Strong Are Your Bones?

We mentioned in the previous lecture that there are two types of bones. so, what are the advantages of sponge (trabecular) bone over compact bone?

1. Where a bone is subjected primarily to compressive force, such as at the ends of the long bones and the trabecular bone give the strength necessary with less material than compact bone.

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

Mechanical properties of bones

1. **Density**

   The density of compact bones is constant = 1.9 gm/cm^3 (or 1.9 times as dense as water). It is independent of age.

   In old age, the bone becomes more porous and thinner due to reduced strength.

2. **Bone elongation under tension and shortening under compression:**

   According to Hook's law below a sample (e.g bone) under a tensional force (F) will increase in length (ΔL) as the force increases, and the bone breaks at a stress of about (120 N/ mm2) Healthy compact bone is able to with stand a compressive stress of about 170 (N/mm2), as in the Fig below.

   Hooke's law:

   $\sigma = Y \xi$, *(stress-strain)*

How can derive Young's Modulus ?

According to the definitions for : <mark>Stress</mark> (the force (F) per unite area (A) of the sample)

$$\sigma = F/A$$

- **Tension**: pulling it apart
- **Compression**: pushing it together

<mark>Strain</mark> fractional change in **length** due to **stress** (the ratio of the change in the length (ΔL) of the sample (e.g bone) to the original length (L_O))

$$\xi = \Delta L / L$$

<mark>Young's modulus:</mark> is the relationship between stress and strain

$$Y = \sigma / \xi = LF/A\Delta L$$

EX: Assume leg has a (1.2 m) shaft of bone with an average cross- sectional area of (3 cm^2) what is the amount of shortening when body weight 0f (700 N) is supported on the leg? (Y.M=1.8x10^{10} N/m^2).

<u>Solution:</u>

$L_O = 1.2$ m ,   A = 3 cm^2,   F = 700 N, ΔL =?

A=3 cm^2 → 3 x10^{-4} m^2

$$Y = LF/A\Delta L$$

$= (1.2 \times 700) / (3 \times 10^{-4} \times 1.8 \times 10^{10})$

   $\Delta L= 0.000155$ m

<u>H.W</u> Calculate the change in length of a bone the original length is (40 cm) exposed to a limited stress (2.33×10^3 N/m^2)? Knowing that (Y.M.=1.8x10^{10} N/m^2).
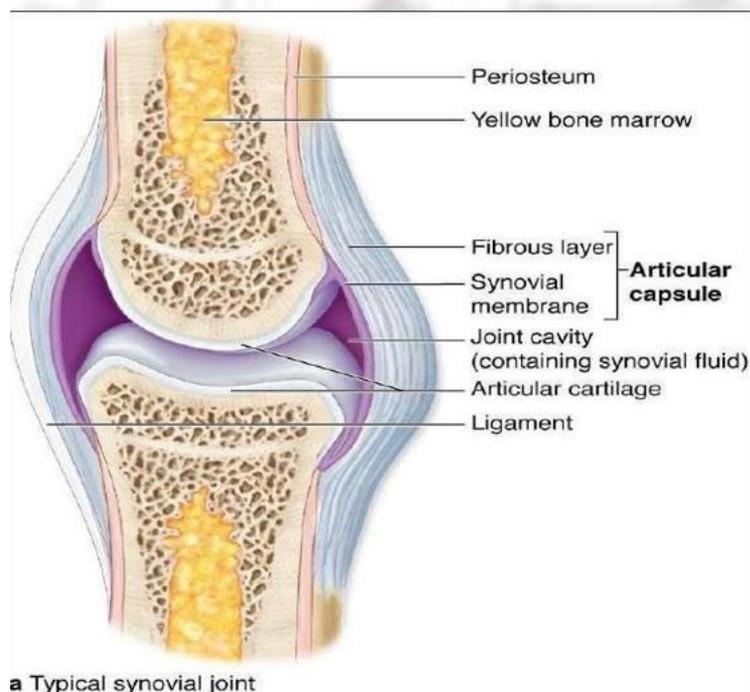
Lubrication of Bone Joints

Joints are places in the body where two bones come together. Each bone ended with synovial fluid, and the joints made most of the body movement The surface of the articulate cartilage does not smooth the roughens of the cartilage but plays a useful role in joint lubrication by trapping some of the synovial fluid and because of its porous nature, another lubricating material is squeezed into the joint when it is under great test stress when it needs the most lubrication.

When the pressure increases on the joint, the lubrication threads squeeze out of the cartilage into the joint in one end each lubricating thread remains in the cartilage, and as the pressure is reduced the threads pull back into their holes. The viscosity of the synovial fluid decreases under the large shear stresses found in the joint.

The coefficient of friction of a healthy joint was found to be 0.01.

<p style="text-align:center;color:red;">Viscosity α 1 / Lubrication</p>

Periosteum
Yellow bone marrow
Fibrous layer ⎤
Synovial membrane ⎦ — Articular capsule
Joint cavity (containing synovial fluid)
Articular cartilage
Ligament

a Typical synovial joint

Measurement of bone mineral

A few years ago, osteoporosis was difficult to detect until a patient appeared with broken hip or crushed vertebra. At that time it was too late to use preventive therapy. The strength of bone depends on the mass of bone mineral present. The physical techniques for studying bones are:

1- x-ray image: to measure the bone mineral , its an old one. There are some problems of using x-ray, these are : x-ray beam has different energies and the absorption of x-ray by Ca varies rapidly with energy, scattered radiation when it reaches the film, the film is a poor detector for making quantitative measurements
•The three problems are eliminated by using

1- Mono energetic x-ray or gamma ray source.

2- a narrow beam to minimize scatter

3- a scintillation detector that detects all photons

2- photon absorptiometry technique: the determination of bone mineral mass by using

MB=K Log (Iº/I)

MB: bone mineral , Iº: initial intensity , I : final intensity , k: constant

3- Activation technique: take the fact that nearly all of calcium in the body is in the bones. The whole body is irradiated with energetic neutrons that convert a small amount of calcium and some other elements into radioactive forms that given off gamma rays, and the emitted gamma rays then detected and counted,the gamma rays from radioactive calcium can be identified by their unique energy