Babylon University

college of dentistry / first stage / medical physics

Lecture three : physics of the skeleton

Bones sort into various piles according to their shapes, so there are five piles: Shapes of bones

1-Flat, plate-like bones: shoulder blade (scapula), some bones of the skull, etc.

2-Long hollow bones: bones in the arms, legs, and fingers

3- Cylindrical bones: bones from the spine (vertebrae)

4-Irregular bones: bones from the wrist and ankle

5- Other bones: ribs, etc.

Functions of the bone

Bone is of interest to medical physics and engineers. Perhaps 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 , lifting , and forth. **Bone has at least six functions in the body:**

1- support, 2- locomotion, 3- protection of various organs, 4- storage of chemicals, 5- nourishment, and 6- sound transmission .(in the middle ear)

1- The support function of bone is most obvious in the legs. The body's muscles are attached to the bones through tendons and ligaments and the system of bones plus muscles supports the body.

2- Bone joints permit movement of one bone with respect to another . But the destruction of joints by arthritis can limit locomotion.

3- For protection , The skull ,which protects the brain and several of the most important sensory organs like eyes and ears .Also ribs form a protective cage for the heart and lungs.

4- The bones act a chemical " bank " for storing elements for future use by the body . The body can withdraw these chemical as needed .For example ,a minimum level of calcium is needed in the blood.

5- For nourishment the teeth are specialized bones that can cut food , tear it and grind it and thus serve in providing nourishment for the body.

6- For sound transmission the smallest bones of the body are the ossicles in the middle ear. These three small bones act as levers and use for converting sound vibrations in air to sound vibrations in the fluid in the cochlea.

Made of Bone

Note the large percentage of calcium (Ca) in bone , Since calcium has a much heavier nucleus than most elements of the body , it absorbs x- rays much better than the surrounding soft tissue. This is the reason x- ray show bones so well. Bone consists of two quite different materials plus **water : collagen** , the major organic fraction , which is about 40 % of the weight of solid bone and 60 % of its volume , and bone mineral , the so-called " inorganic " component of bone, which is about 60 % of the weight of the bone and 40 % of its volume. Collagen is apparently produced by the osteoblastic cells . Because of the small size of the crystals , bone mineral has avery large surface area. Bone mineral is believed to be made up of calcium hydroxyapatite $Ca_{10}(po_4)_6(OH)_2$.

Bone = collagen + bone mineral + water

Either of these components my be removed from bone, and in each case the remainder, composed of only collagen or bone mineral, will look like the original bone. The collagen remainder is quit flexible, some what a chunk of rubber, it bends easily if it is compressed. When the collagen is removed from the bone, the bone mineral remainder is very fragile and can be crushed with fingers.

Composition of Bone :

Collagen , Mineral Ca $_{10}(PO_4)_6(OH)_2$, Water

• Collagen makes bones flexible (elastic)

• Mineral makes bones rigid

• Water in interstitial spaces stores nutrients

HOW STRONG ARE YOUR BONES

Two Quite Different Types Of Bone. Solid Or Compact, Spongy, Bone Made Up Of Thin Thread –Like Trabecular- Trabecular Bone Is Found In The Ends Of The Long Bones, While Most Of Compact Bone Is In The Central Shaft. Trabecular Is Weaker Than Compact Bone Due To The Reduced Amount Of Bone In A Given Volume. What are the advantages of trabecular bone over compact bone. There are at least **two**, where a bone is subjected primarily to compressive forces, such as at the ends of the bones, trabecular bone gives the **strength** necessary with less material than compact bone, also because the trabecular are relatively flexible, trabecular bone can **absorb** more energy when large forces are involved such as in walking, running and jumping, on other hand, trabecular bone cannot withstand very well the bending stresses that occur mostly in the central portions of long bones.

All materials change in length when placed under tension or compression. When a sample of fresh bone placed in a special instrument for measuring the elongation under tension, a curve similar to that in (fig) is obtained. The strain $\Delta L/L$ increases linearly at first, indicating that is proportional to the stress (F/A) Hooks law. As the force increases the length increases more rapidly, and the bone breaks at stress of about 120 N/mm2. The ratio of stress to strain in the initial linear portion is Young's modulus Y. That is : $Y = (L\ F) / (A\ \Delta L)$

Stress: force per unit area , $\sigma = F / A$

Strain: fractional change in length due to stress , $\varepsilon = \Delta L / L$

Hooke's law: $\sigma = Y \varepsilon$, stress-strain diagram

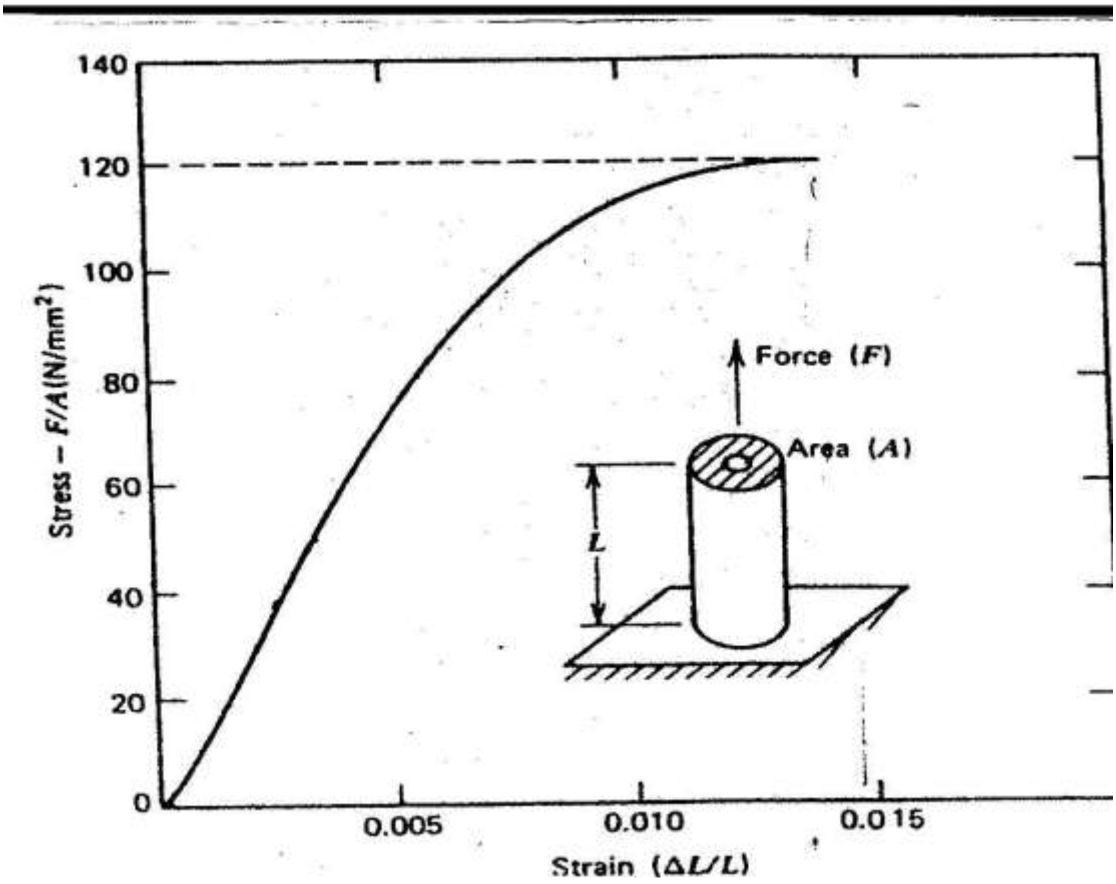

Figure. When A Piece Of Bone Placed Under Increasing Tension, Its Strain ΔL/L Increases Linearly At First (Hooks Law) And Then More Rapidly Just Before It Breaks In Two At120 N/Mm2

Young's modulus of elasticity :-

How much forces is needed to break the bone by compression , tension and twisting . When the bone placed under tension or compression there is change in its length from the stress – strain curve in fig.

Stress = $\frac{F}{A}$ = N/mm^2

Strain = $\frac{\Delta L}{L}$

Stress = 120 N/m^2

$\frac{\Delta L}{L} \Rightarrow 0.015$ at fracture

The strain $\frac{\Delta L}{L}$ increase linearly at first with the stress $\frac{F}{A}$ (hook's law)

If F increases the L increase more rapidly and the bone breaks at stress of 120 N mm^{-2} .

$\therefore$ The ratio of stress to strain in the initial linear portion is called young's modulus Y

Y = $\frac{LF}{A\Delta L}$, **Y_{bone} = 1.8 x 10^{10} N/m^2** .

Example : Man with mass of (100 Kg) standing on the one leg has a (1 M) shaft of bone with average cross-sectional area of (3 cm^2) find :-

1-The pressure in Pa .

2-The amount of shortening in this bone .

P = $\frac{F}{A}$. F = M * g = 100 x 10 = 10^3 N

$\therefore$ P = 10^3N/ 3 x $10^{-4}$$m^2$

= $\frac{1}{3}$ x 10^7 Pa

= 3 x 10^6 Pa

$$\Delta L = \frac{LF}{AY} = \frac{1x10^3}{3x10^{-4}x1.8x10^{10}} \approx 10^{-4} \text{ m}$$

Y = $\frac{LF}{A\Delta L}$ tension elongate in L due to $\frac{F}{A}$ stress

$\Delta L = \frac{LF}{AY}$ compression

Shorting in the length of the bone of its length (L)

Young’s modulus

$$Y = \frac{\sigma}{\varepsilon} = \frac{LF}{A\Delta L}$$

<u>EXAMPLE</u>. Assume a leg has 1.2m shaft of bone with an average cross-sectional area of $3x10^{-4}m^2$. What is amount of shortening when all of the body weight of 700 N is supported on this leg.

<u>Sol</u>.

$$\Delta L = \frac{L\,F}{A\,Y} = \frac{(1.2m)(7x10^{2}N)}{(3x10^{-4})(1.8x10^{10}N/m^{2})} = 1.5x10^{-4}m = 0.15mm$$

LUBRICATION OF BONE JOINTS

- There are **two** major diseases that affect the joint-rheumatoid, arthritis, which results in over production of the synovial fluid in the joint and commonly causes swollen joints, and osteoarthritis, a disease of the joint itself. The synovial membrane encases the joint and retains the lubricating synovial fluid. The lubricating properties of a fluid depend on its viscosity . The viscosity of synovial fluid decreases under the large shear stresses found in the joint .

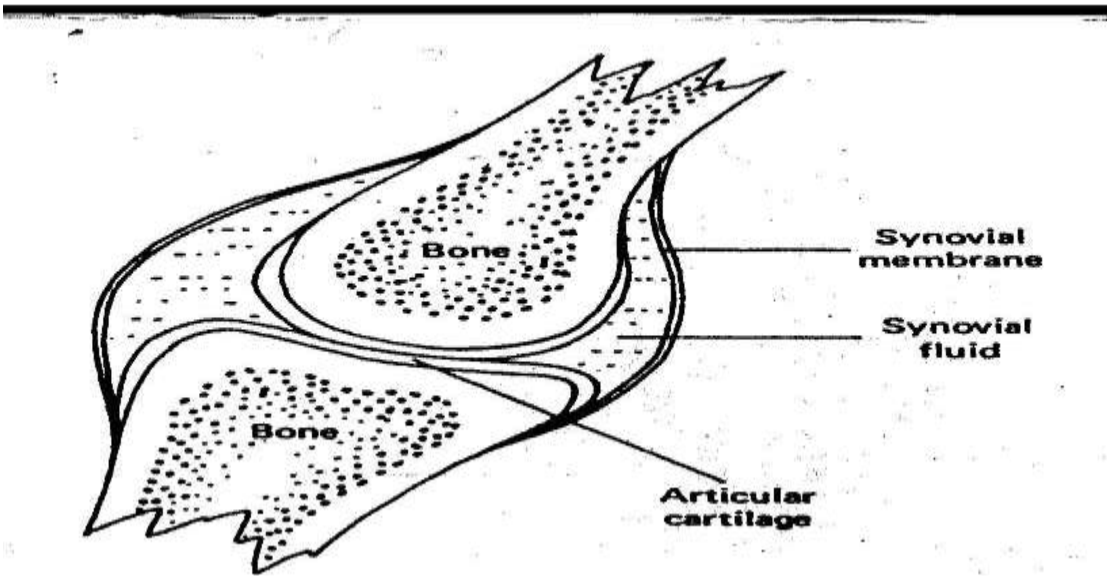

Figure. The main components of a joint.

Example : Assume a leg has a (1.2 m) shaft of bone with an average cross- sectional area of (3 cm^2) or (3*10exp – 4 m^2). What is the amount of shortening when all of the body weight of (700 N) is supported on this leg ?

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

•$MB=K \, Log \, (I^o/I)$

MB: bone mineral , I^o: 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.

Example :Using the information in figure below to:

a)Calculate the maximum tension a bone with a cross-sectional area of (4) cm^2 could withstand just prior to fracture .

b)Determine how much a bone (35) cm long would elongate under this maximum tension.

c)Calculate the stress on this bone if a tension force of (10^4)N were applied to it .How much would this bone lengthen?