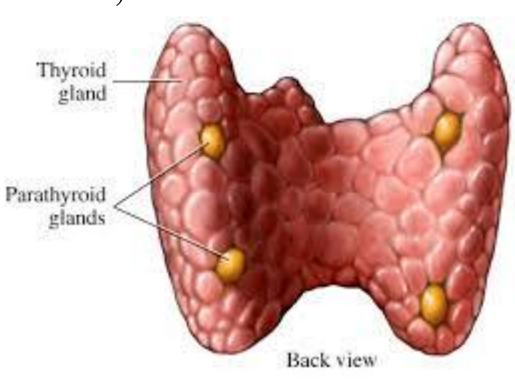
Karbala University-College of veterinary medicine

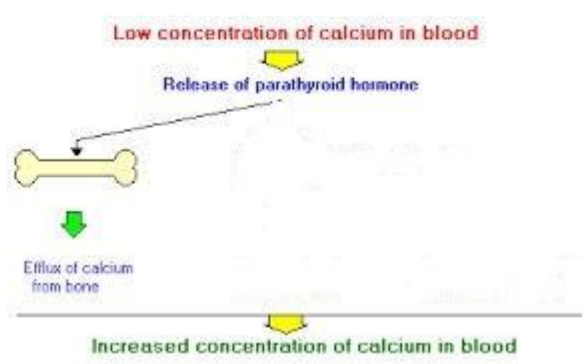
Medical Physics-Lecture (3)

Physic of the skeleton

Function of the bones in the body

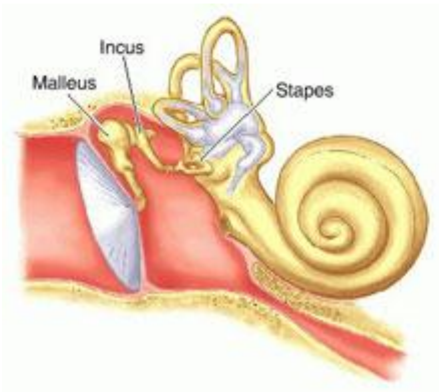
1) **Support (الدعم): -** The system of bones plus muscles (عضلات) supports the body.
2) **Locomotion (الحركة):**-Bone joints permit movement of one bone with respect to another. These hinges(المفاصل) are very important for walking as well as for many of the other motions of the body.
3) **Protection:**-The skull (الجمجمة) protects the brain and several of the most important sensory organs (eyes, and ears), the ribs(الأضلاع) protect heart and lungs, the spinal column (العمود الفقري) protects spinal cord(الحبل الشوكي).
4) **Storage of chemicals:**-Bones acts as a chemical bank for storing elements for future use by the body. For example, a minimum level of calcium is needed in the blood, if the level falls too low, the calcium sensor causes parathyroid gland to release more parathyroid hormone into the blood; this causes the bone to release the needed calcium

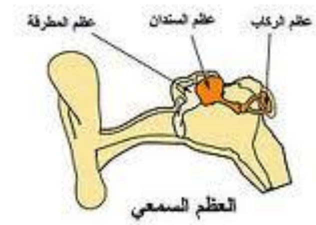




5) **Nourishment:-**Teeth are specialized bones that can cut food by incisors القواطع, tear it by canines الأنيابand grind it by molarsالأضراس and thus serve in providing nourishment for the body.

6) **Sound transmission:** The smallest bones of the body are Ossicles in the middle ear. the ossicles acts as levers ,its provide an impedance matching system for converting sound vibrations in air to sound vibrations in fluids.

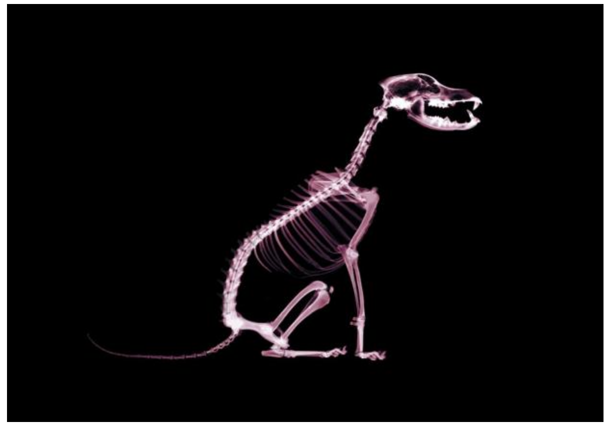




What is bone made of ?

H= 3.4%	Mg=0.2%
C=15.5%	P=10.2%
N=4.0%	S=0.3%
O=44.0%	Ca=22.2 %
Miscellaneous = 0.2%	

The detailed chemical composition of bone is given in the table above. Note the large percentage of calcium in bone. Since Ca has a much heavier nucleus than most elements of the body, it absorbs x-ray much better than the surrounding soft tissue (atomic number of Ca = 40). This is the reason x-rays show bones so well.



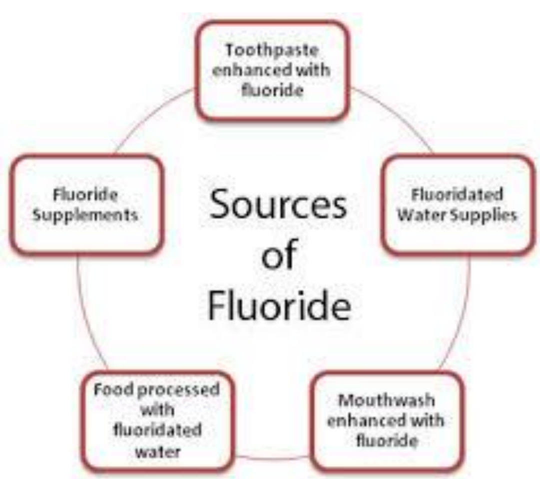
Bone consists of two different materials plus water: -

A- Collagen, the major organic fraction, which is about 40% of the weight of the solid bone and 60% of its volume.

B-Bone mineral, the so-called "inorganic" component of bone, which is about 60% of the weight of the bone and 40 % of its volume.

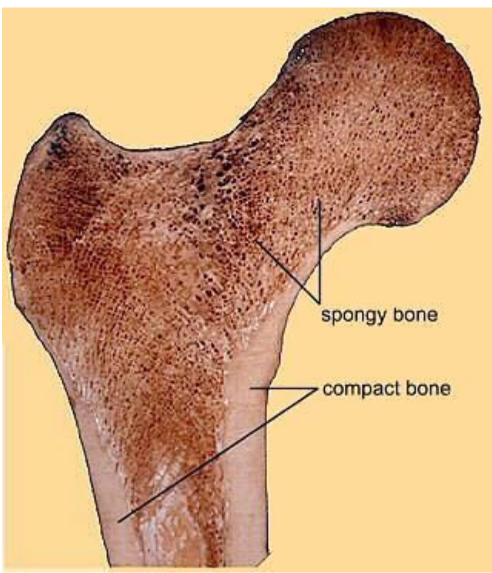
So the bone = water + collagen (organic material) + bone mineral (inorganic material)

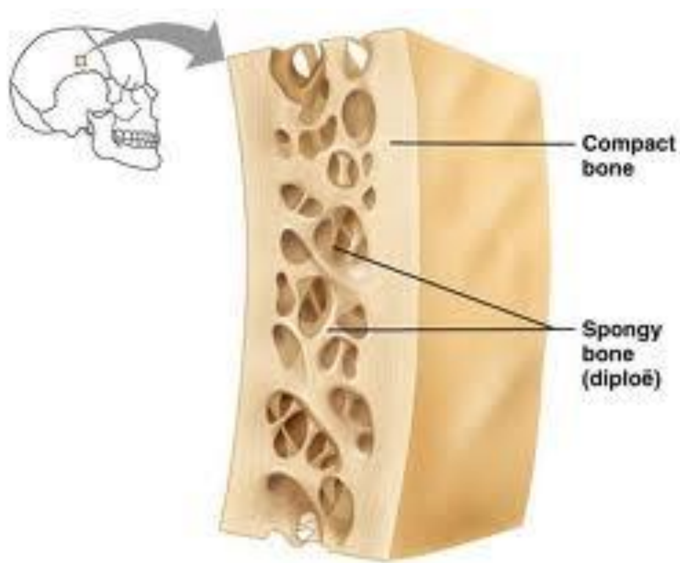
Bone mineral is believed to be made up of calcium hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$. Similar crystal exist in nature, fluorapatite, a common rock (صخرة) differs from calcium hydroxyapatite in that fluorine takes the place of the OH. Fluorine in drinking water may prevent caries (التسوس) by turning microscopic areas of teeth into the rock fluorapatite, which is more stable than bone mineral.



How strong are your bones?

If we cut the bones apart, we can find it's composed of one or a combination of two quite different types of bones Solid (compact) bone and Spongy (trabecular) bone

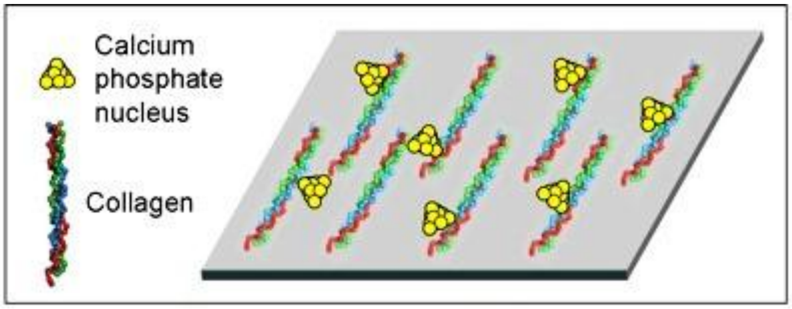




Note: Bone tissue is the same in the trabecular and compact bone

Mechanical properties of bone

The bone is composed of small hard mineral crystals attached to a soft flexible collagen matrix (شبكة).



These components have vastly (على نحو ضخم) different mechanical properties that also differ from those of bone. The combination provides a material that is as strong as granite in compression (ضغط) and 25 times stronger than granite under tension (سحب).

We can make some standard physics and engineering measurements on a piece of compact bone:

1) Density

The density of compact bone is constant through life at about 1.9 g/cm^3 (or 1.9 times as dense as water). In old age the bone become more porous and disappears from the inside or surface. The density of the remaining compact bone is still about 1.9 g/cm^3; it is reduced in strength because it is thinner, not because it is less dense.

2) Young's modulus of elasticity: All materials change in length when placed under tension or compression. When a sample of fresh bone is placed in a special instrument for measuring the elongation under tension, as show in figure1, the strain (ΔL /L) increases linearly at first, indicating that it is proportional to the stress (F/A) "Hook's law" .

As the force increases the length increases more rapidly, and the bone breaks at a stress of about 120 N/mm^2 (~17,000 lb/in.^{2}).The ratio of stress to strain in the initial linear portion is young's modulus Y. that is.

$$Y = \frac{LF}{A\Delta L} \qquad \Delta L = \frac{LF}{AY}$$

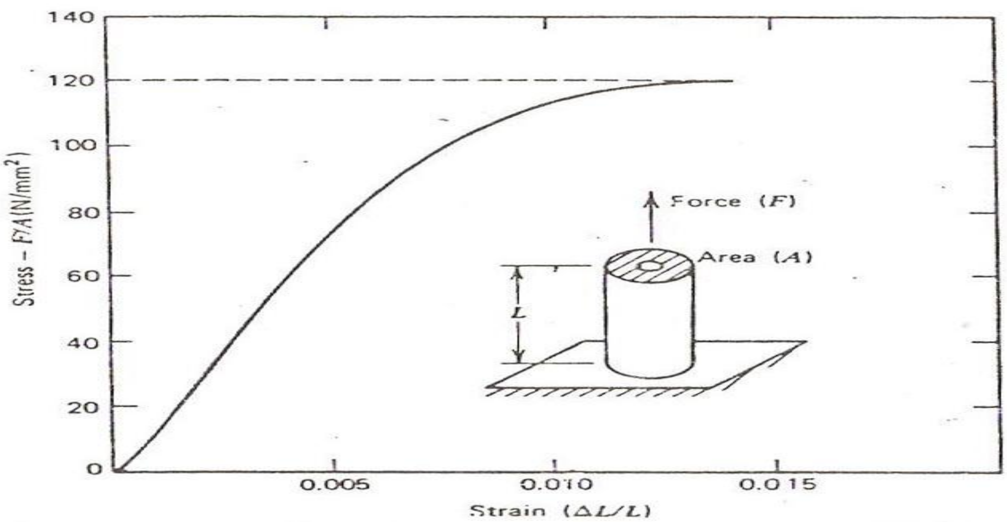


Figure 1: A piece of bone is placed under increasing tension

Example:- Assume a leg has a 1.2 m shaft of bone with an average cross-sectional area of 3 cm^2 ($3\times10^{-4} m^2$) what is the amount of shortening when all of the body weight of 700 N is supported on this leg? Young's modulus of bone is (1.8×10^{10} N/m^2)

$$\Delta L = \frac{LF}{AY} = (1.2m)\,(7\times10^2 N)/\,(3\times10^{-4}\, m^2)\,(1.8\times10^{10} N/m^2)$$

$$=1.5\times10^{-4}\, m = 0.15mm$$

The ability of the bones to support the body's weight without breaking is crucial to man's well-being. Healthy compact bone is able to withstand (يقاوم) a compressive stress of about 170 N/mm^2 before it fractures, the mid shaft of the femur (عظم الفخذ) has a across-sectional area of about 3.3 cm^2(0.5 in^2); it would support a force of about 5.7×10^4 N(12,000 lb,or 6 tons).

The bones are not as strong under tension as they are in compression; a tension stress of about 120 N/mm^2 will cause a bone to break.

3) Viscoelasticity: bone can withstand a large force for short period without breaking, while the same over a long period will fracture it. That is, the short-term force developed when you fall or jump, while possibly exceeding the maximum compressive strength of bone, is not as dangerous as the same force applied over a longer period of time.

Measurements of bone mineral in the body

In this section we describe several physical systems for studying the bones in vivo (in the living body). There are many other physical techniques for studying bone, but most are used on excised bone samples (مستأصلة من الجسم).

The strength of bones depends on the mass of bone mineral present. Since bone mineral mass decreases very slowly, 1-2% per year, a very precise (دقيق) techniques are needed to show changes:

1) X-ray image: - The idea of using an X-ray image to measure the amount of bone mineral is an old one (figure2).

The major problems of using an ordinary X-ray are:

a. The usual X-ray beam has different energies and the absorption of the X-ray by Ca^{+2} varies rapidly with energy in this range of energies.

b. Large beam contains much scattered radiation when it reaches the film

c. The film is poor detector for making quantitative measurements since it is non linear with respect to both the amount and the energy of X-ray.

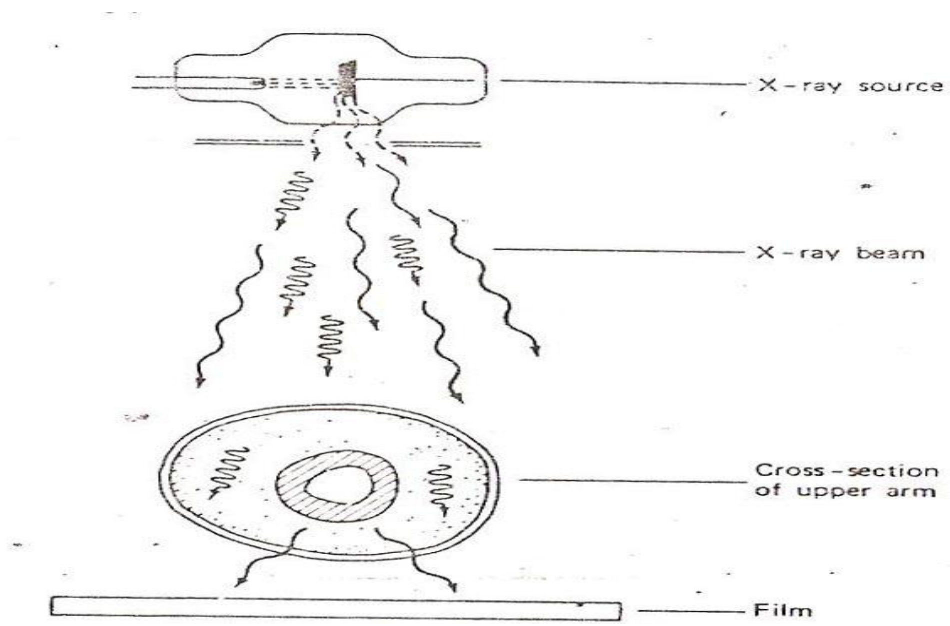


Figure2: conventional X-ray imaging

A large change in bone mineral mass (30% to 50%) must occur between the taking of two x-rays of the same patient before a radiologist (طبيب الأشعة) can be sure that there has been a change.

2) ***Photon absorptiometry***

The problems with the X-ray technique were largely eliminated by using photon absorptiometry (figure 3.) in which we use:

a) Monoenergetic X-ray or gamma rays source.

b) A narrow beam to minimize scatter.

c) Scintillation detector that detects all photons and permits them to be sorted and counted individually.

To determine of bone mineral mass:

Bone mineral mass (BM gm/cm) =K log I_o/I.

Where: K is a constant that can be determined experimentally.

I (intensity of X-ray that transmits the bone).

I_o (intensity before the beam enter the bone),

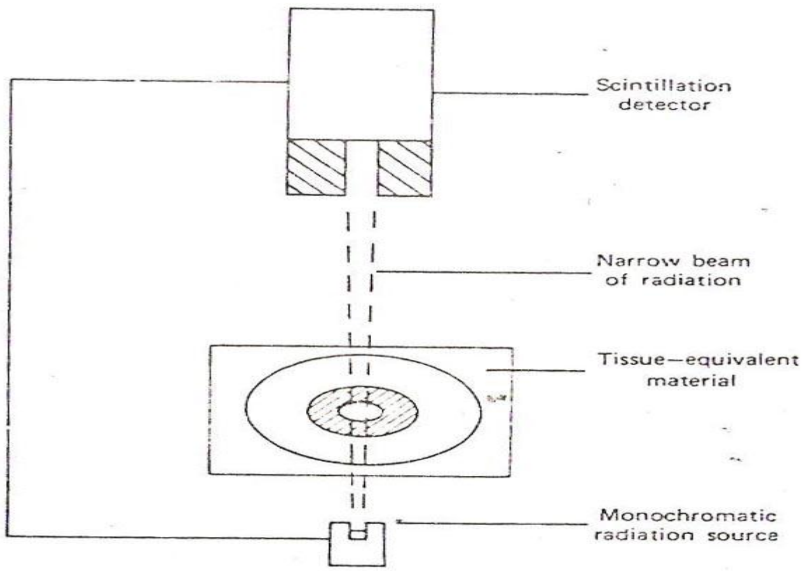


Figure 3: The basic components used in photon absorptiometry

3) ***In vivo activation*** : whole body is irradiated with energetic neutrons that convert a small amount of the Ca^{+2} and some other elements into radioactive form that give off energetic gamma rays then detected and counted. The gamma rays from radioactive Ca^{+2} can be identified by their unique energy and the number of them indicates the amount of Ca^{+2} in the body.

Disadvantages of this technique

1-Expensive technique.

2-Hazard of large radiation exposure.

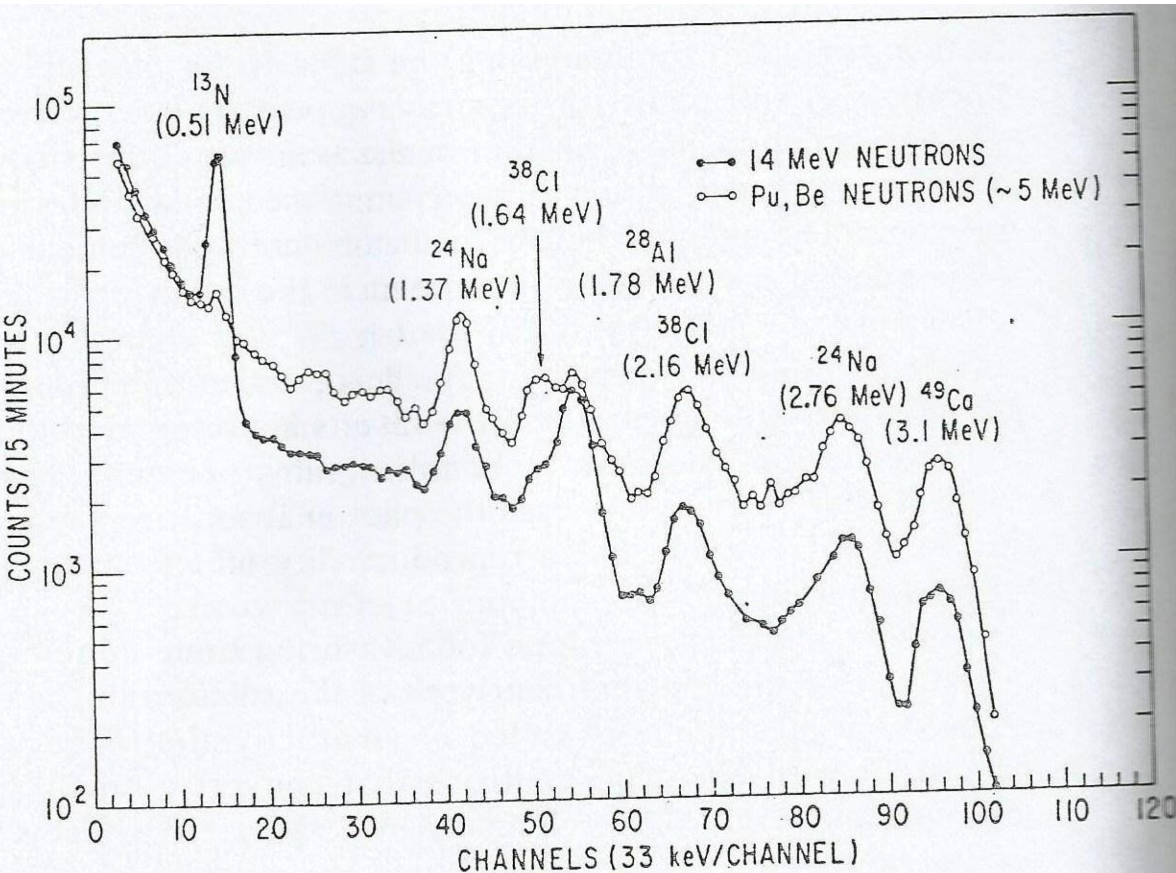


Figure 3.17. A graph of the gamma ray intensities from the body as a function o energy (channels) after whole body irradiation with 14 MeV and about 5 MeV neu- trons. The radioactive elements causing the main gamma ray peaks and their ener- gies are given. Note the peak at the right caused by radioactive calcium (^{49}Ca). The area under this peak indicates the amount of calcium (and thus the amount of bone mineral) in the body. (Reprinted from S.H. Cohn, K.K. Shukla, C.S. Dombrowski, and R.G. Fairchild, *Journal of Nuclear Medicine*, Vol. 13, No. 7, with permission of the publisher.)