Physics of Skeleton

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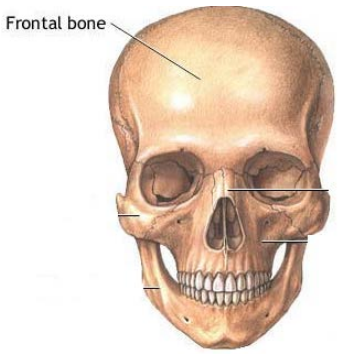
Function of bones:-

1. Supporting: The system of bones and muscles support the body. The muscles are attached to the bones through tendons and ligaments

Eg. Muscles and bones of legs and vertebrae

2. Locomotion: Eg. Bone joints which permit the movement of one bone with respect to another. These hinges or articulations are very important for walking as well as for many other motions of the body.

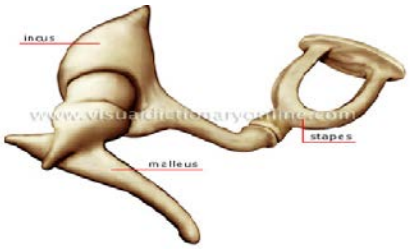
3. Protection: protection of delicate body parts is an important function of some of the bones. The skull, which protects the brain and several of the most important sensory organs (eye and ears), is extremely strong container while the ribs form a protective cage for the heart and lungs.



4. Storage of chemicals: The bones act as chemical bank for storing elements for future use of the body, then the bones can withdraw these chemicals as needed, for example if the level of Ca fall too low in the blood, a calcium sensor causes the parathyroid glands to release more parathormone into the blood, and this in turn causes the bones to release the needed Ca.

5. Nourishment: The teeth are specialized bones serve in providing nourishment for the body. Eg. Incisors, canines

6. Sound Transmission: The three smallest bones in the body are the Ossicles**.** -They act as ***levers*** which provide an ***impedance*** **matching.** -They form a system for converting sound vibration in the air into sound vibration in the *fluid* of the cochlea.



7- Red blood cells generation: The stem cells in the bone marrow generate the RBCs

Bone Composition:

The Bone is a living tissue which has blood supply as well as nerves with a special kind of cells distributed through the bone tissue; these cells are called ***"Osteocytes"***

The Octeocytes cells maintain the bone in a healthy condition. These cells make up about 2% of the volume of the bone, if these cells die (e.g. due to poor blood supply), the bone dies and it loses some of its strength. A series hip problem is caused by a condition called ***aseptic necrosis*** in which the bone cells in the hip die due to the lack of blood.

Bones consist of two quit different materials plus water:

1- Collagen: it is the major organic fraction of the solid bone. It is quite flexible, it has a fair amount of tensile strength so that it can bend easily if it's compressed. It forms about 40% of the weight of the solid bone and 60% of its volume.

2- Bone Minerals: it is the inorganic part of the solid bone. It is believed to be made up of caliciumhydroxyapatite [Ca10(Po4)6(OH)2]. It is very fragile and forms about 60% of the weight of the bone and 40% of its volume. The bone minerals crystals are rod shaped with diameters of 20 to 70 A_o. Because of the small size of the crystals, bone minerals have a very large surface area. Around each crystal is a layer of water containing in a solution many chemicals needed by the body. The large area exposed bone minerals permit the bone to interact rapidly with chemicals in the blood and other body fluids.

As described above bone is composed of small hard bone mineral crystals attached to a soft flexible collagen matrix. These components have vastly different mechanical properties. This combination provides a material that is strong as granite in compression and 25 times stronger than granite under tension.

The detailed chemical composition of the bone is given by the following table:

Element	% of the element in the bone
H	3.4
C	15.5
N	4
O	44
Mg	0.2
P	10.2
S	0.3
Ca	**22.2**
Miscellaneous	0.2

Bone remodeling:

Since the bone is a living tissue it undergoes a change through the life, a continuous process of destroying an old bone and building a new one is called ***"bone remodeling"***

Bone remodeling is performed by specialized bone cells, they are:

1- **Osteoclasts:** They are specialized cells which responsible for destroying the bone.

2- Osteoblasts: They are specialized cells which responsible for building a new bone

We have the equivalent of a new skeleton about every seven years, each day the osteoclasts destroy bone containing about (0.5 gm) of calcium, osteoblasts build a new bone by using about the same amount of calcium.

While the body is growing and young the osteoblasts do more than osteoclasts, but after the body is 35 to 40 years old the activity of osteoclasts is greater than that of osteoblasts, resulting in a gradual decrease in the bone mass that

continuous until death. This decrease is apparently faster in women than in men and leads to serious problems of weak bones in older women. This condition called ***Osteoporosis***. It is one of the bone diseases which is produced by the reduction of the amount of Ca as a result:

- The ***mass*** of the bone ***decrease***
- The ***volume decrease***
- The ***density*** of ***the bone = mass /volume*****= 1.9 kg/cm^3** it s remain constant.

Bone Strength:

If you cut the bones apart, you would find that it composed of two quite different types of bones:

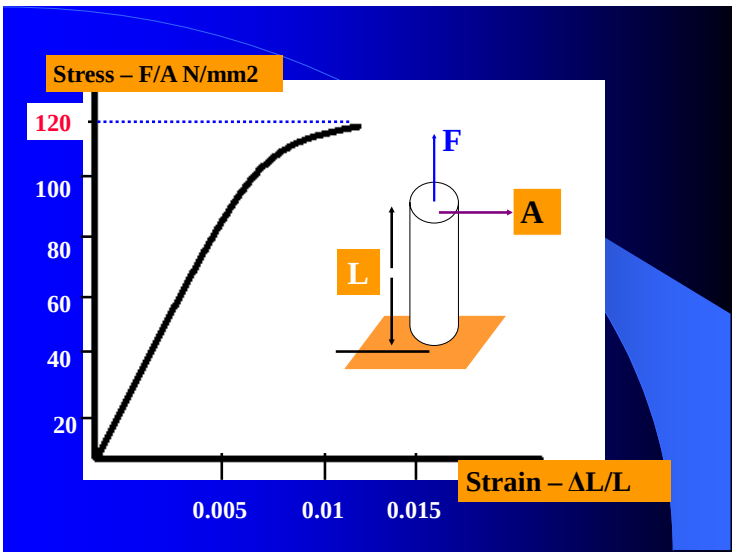
1- Solid (compact) bone: This is found in the central shaft of the bone.

2- Spongy (cancellous) bone: This is made up of thin thread-like trabeculae (trabecular bone). It is predominantly found at the ends of the long bones. Trabecular bone is considerably weaker than compact bone due to the reduced amount of bone in a given volume. Therefore the trabecular bone has two advantages over the compact bone:

- Where the bone is subjected primarily to compressive forces, such as at the ends of the bones and the spine, trabecular bone gives the strength necessary with less material than the compact bone.
- Because the trabecular is relatively flexible, it can absorb more energy when large forces are involved such as in walking, running and jumbing.

  Note: Trabecular bone cannot withstand very well the ***bending stress*** that occurs mostly in the central portion of long bones.

Hook's Law: The strain (Δ L/L) increases linearly, at first indicating that it s proportional to the stress (F/A), as the force increase the length increase more rapidly, and the bone breaks at a stress of about 120 N/mm^2.



The ratio of stress to strain in the initial linear portion is the ***Young's modulus,*** that is***:***

$$\text{Young's modulus} = \frac{F/A}{\Delta L/L}$$

Where L= the length of the bone (mm)

F= the force exerting on the bone (N)

A= the cross section area of the bone (mm^2)

The compressive breaking stress of the compact bone is 170 (N/mm^2), while the tensile breaking stress is 120 (N/mm^2), Young's modulus of the compact is about 179 x 10^2 (N/mm^2).

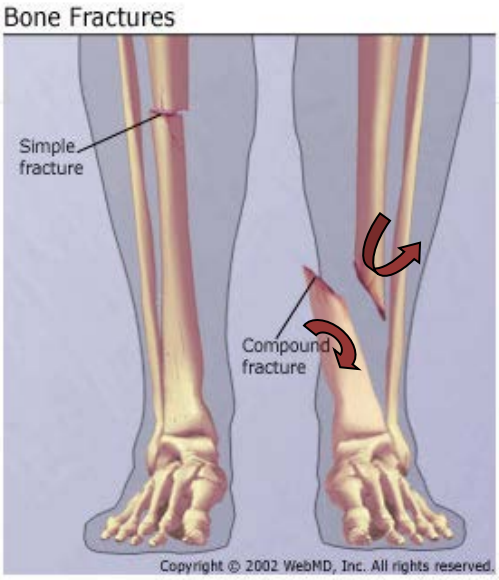
Bone Fracture:

There are many types of fractures, but the main categories are:

1- Simple Fracture: It is also called a closed fracture, the bone breaks but there is no open wound in the skin.

2- Compound Fracture: It is also called an open fracture, the bone

breaks through the skin; it may then recede back into the wound and not be visible through the skin.



The bones don't normally break due to compression; they usually break due to shear or under tension. A common cause of shear is catching the foot and then twisting the leg while bone is apt to puncture the skin, this type of fracture is compound.

Physical factors affecting the degree of bone fracture:

1- The amount of the exerting force during collision or falling

Therefore, the shorter the duration of impact, the greater the force. To reduce the force and thereby the likelihood of fracture, it is necessary to increase the impact time. In both falling down or jumping from elevation, the impact time can be increased significantly by simply rolling with the fall or jumping, thereby spreading the change of momentum of the body over longer time.

2- The direction and the type of the exerting force (Tension, Compression, and Twisting).

3- The age, Broken bones are very common in childhood, though

children's fractures are generally less complicated than fractures in adults. Older people, whose bones are more brittle, are more likely to suffer fractures from falls that would not affect younger people.

Measurement of bone mineral in the body

Osteoporosis is the most common disease in elderly women and the most common feature of it is lower bone mineral mass ,bone mineral mass decrease 1-2% per year, thus precise technique was needed to show the changes .

The first tried is using an ordinary X-ray but it forced many problems

- X-ray beam has many different energies and the absorption of x-ray by calcium varies with energy .
- X-ray beam contain much scattered radiation when reach the film .
- The film is a poor detector for quantitative measurement .

Then ordinary x-ray can't detect the change in bone mineral until its lost 30-50% of density, at this time it was too late use preventive therapy .

Photon absorptiometry

A develop technique measured the bone density consist of

- Monoenergetic x-ray or gamma ray source .
- Narrow beam to minimize scatter radiation .
- Scintillation detector that detect all photons.
- The bone mineral mass (BM) calculated electronically and given by (g/cm^2) it's use radioactive source gradually decay .

A single energy photon beam is passed through bone and soft tissue to a detector the amount of mineral in the path is then quantified .

The problems of photon absorptiometry are

- The radioactive source must be replaced after time .
- To measure the bone need uniform thickness of soft tissue ,therefor it can't measure hip and spine .

To solve the problems developed a new technique , it's called **Bone density scan (DXA).**

Bone density scan (DXA)

It's also called dual energy X-ray absorptiometry, DXA widely used for measuring bone mineral density (BMD).

There are two types : central device and peripheral device.

Central DXA device measure bone density in the hip and spine .

Peripheral device measure bone density in wrest ,heel and finger.

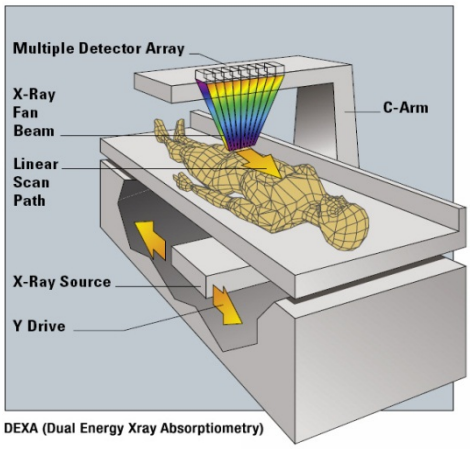
Central DXA consist of :

-Large flat table and an arm suspended overhead.

-X-ray source mounted under the flat table and x-ray detector mounted in suspended arm.

-special software for processing data, monitor to display the results.

The procedure of work :



DEXA (Dual Energy Xray Absorptiometry)

The X-ray source sends a thin

Invisible beam of low dose,

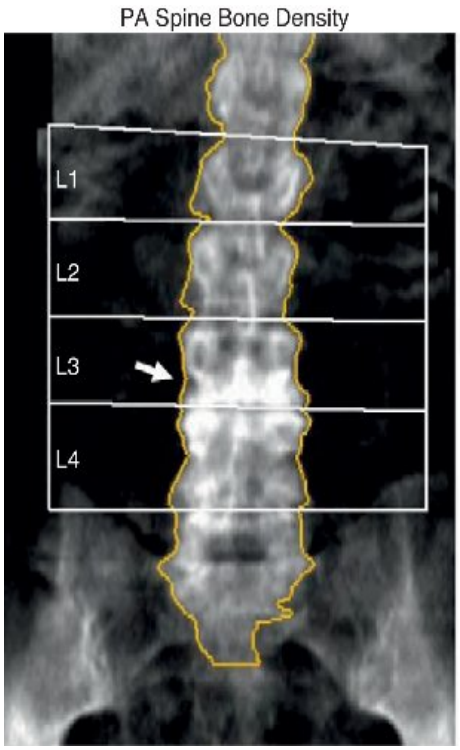
with two distinct energy peak

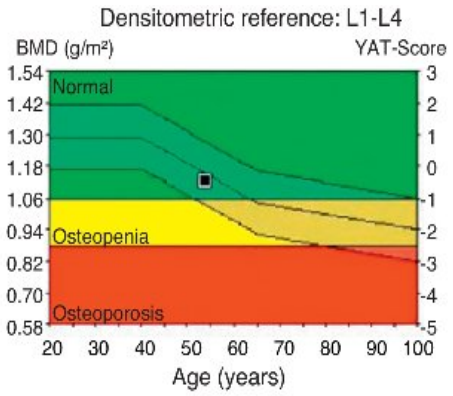
through bones being examined,

one peak is absorbed by soft tissue

and the other by bone. The soft tissue amount can be subtracted from the total and what remains is patients bone mineral density. The DXA machines feature a special software that compute and display the bone density measurements on computer monitor.

How dose DXA report interpret :





Region	BMD [1] (g/m²)	Young adult [2] (%)	T-score	Adj. to age [3] (%)	Z-score
L1	0.883	78	-2.1	80	-1.8
L2	0.991	83	-1.7	85	-1.5
L3	1.326	111	1.1	113	1.3
L4	1.217	101	0.1	104	0.4
L1-L4	1.122	95	-0.5	97	-0.3
L2-L4	1.184	99	-0.1	101	0.1

The plot diagram for lumber bone density (BMD) (g/cm^2) which is the amount of calcium in bone expressed as number of grams per square centimeter, against the age and compare it with normal bone density represented by T-score.

The T-score:

The "young normal" or T-score indicates how your BMD compares to that of a healthy 30 year-old. Peak bone density is reach by age 30.

T-score numbers interpreting as the following

- Above (-1) considered normal.
- Between (-1 and -2.5) its osteopenia.
- Below (-2.5) indicates osteoporosis.

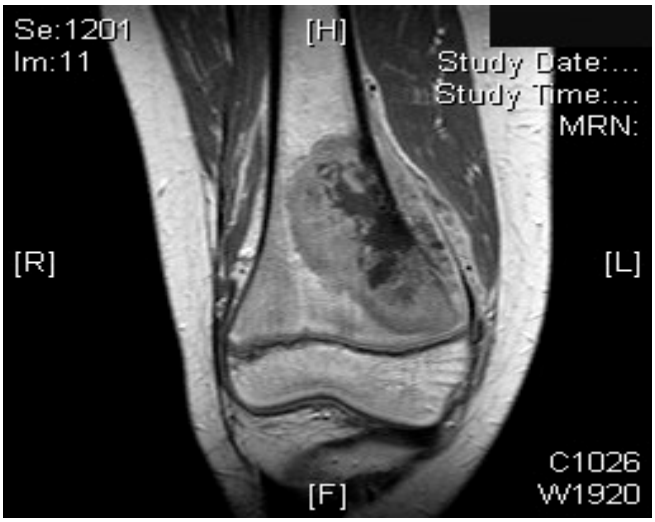
The Z-score:

The "age-matched" or **Z-score** compares your BMD to what might be expected in someone your age, sex, weight and ethnic.

DXA device is most used in :

- Diagnosis of osteoporosis, which involves a gradual loss of calcium, as well as structural changes causing bones to become thinner, more fragile and more likely to break.
- Tracking the effect of treatment of osteoporosis and other conditions cause bone loss.
- Assess an individual's risk of developing fractures.

Bone Scan:



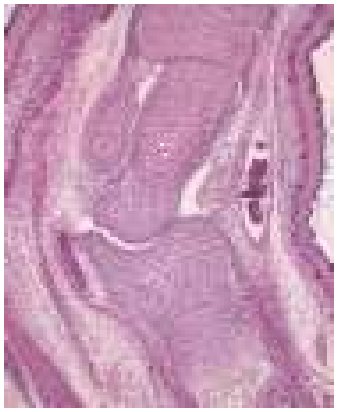
- Bone in a bone tumor is being destroyed somewhat like a brick house being torn down at a time.
- When radioactive fluorine (F^{18}) is injected into a patient, it will be distributed through the bones of his body.
- When the radioactive fluorine atoms come in contact with the partially destroyed bones, they find many places that they can fit in more so than in normal bone.
- The increased radiation from the tumor area signals the possibility of a bone tumor.

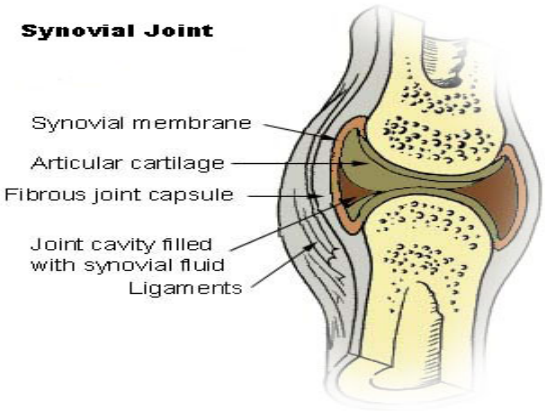
Bone Joints

Joints are placed in the body where two bones come together; the joints make most of the body movement possible. In this type of joint, the ends of the opposing bones are covered with hyaline cartilage, the articular cartilage, and they are separated by a space called the joint cavity. The components of the joints are enclosed in a dense fibrous joint capsule, also called an articular capsule. The outer layer of the capsule consists of the ligaments that hold the bones together. The inner layer is the synovial membrane that secretes synovial fluid into the joint cavity for lubrication.

Because all of these joints have a synovial membrane, they are sometimes called synovial joints.

The types of bone joints are:





1. ***Ball and socket*** which allows circular motion. (Hip and shoulder)

2. ***Hinging joints*** which allow back and forth movement. (Knee and elbow)

3. ***Pivot joints*** which allows back and forth turning motion. (Vertebrae of neck)

4. ***Gliding joints*** which allow sliding and twisting movement. (Bones of wrist and ankle)

5. ***Fixed joints*** which don't allow movement.

   (Bones of the skull)

Bone Joints Lubrication Mechanism:

- Each bone ended with porous and not very smooth cartilage lubricated with the ***Synovial fluid.***
- The roughness of the cartilage plays useful role in joint lubrication trapping some of the synovial fluid and because of its porous nature, other lubricating material is squeezed into the joints.
- Pressure causes lubricating threads to squeeze out of the cartilage into the joints, one end of the each lubricating thread remains in the cartilage, and as the pressure is reduced the threads pull back into their holes
- Under a large sheer stress the ***viscosity*** of the synovial fluid ***reduces.***

- The ***coefficient of friction*** of the healthy joints was found to be 0.01 i.e: when 100 N of force exert on a joint, only 1N of force is needed to move it, it is the least friction in the nature.

Joints Diseases

There are two major diseases affect the joints:-

- ***Rheomatoid arthritis:*** It results from the overproduction of the synovial fluid in the joints and commonly causes swollen joints.

- ***Osteoarthrosis***: it is the disease of the joint itself. Its occur when cartilage or cushion between joint breaks down leading to pain, stiffness and swelling.