Al-Mustaqbal University

College of Technology and Health Sciences

Medical physics Department

Medical Physics

First Semester

3rd stage

Lesson 2

Physics of skeleton

Part 2

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How strong are the bones?

……….Continuation of Lesson 1

Bone mechanical properties is as same as any solid materials which its mechanical behavior may be determined by a simple stress–strain test in two principle ways in which the load may be applied; namely, tension and compression.

Now, we need to define stress and strain.

Stress is any load that exposed in the unit area, in other words, stress σ is defined by the relationship:

$$\sigma = \frac{F}{A}$$

in which F is the load applied perpendicular to the specimen cross section, in units of newton (N) and A is the original cross-sectional area before any load is applied.

Strain is the change in the dimension (elongation) produced by stress and we can write; strain ε is defined according to:

$$\varepsilon = \frac{\Delta l}{l_o}$$

in which l_o is the original length before any load is applied and Δl is the change in length.

Before fracture, the stress is proportional to strain;

$$\frac{F}{A} \propto \frac{\Delta l}{l_o}$$

$$\frac{F}{A} = Y\frac{\Delta l}{l_o}$$

$$Y = \frac{F l_o}{A\Delta l}$$

The proportional constant Y is called **Young's modulus** or modulus of elasticity. When the force increase, the bone breaks at stress of about 120N/m^2. The **elongation** from the above equations could be;

$$\Delta l = \frac{F l_o}{AY}$$

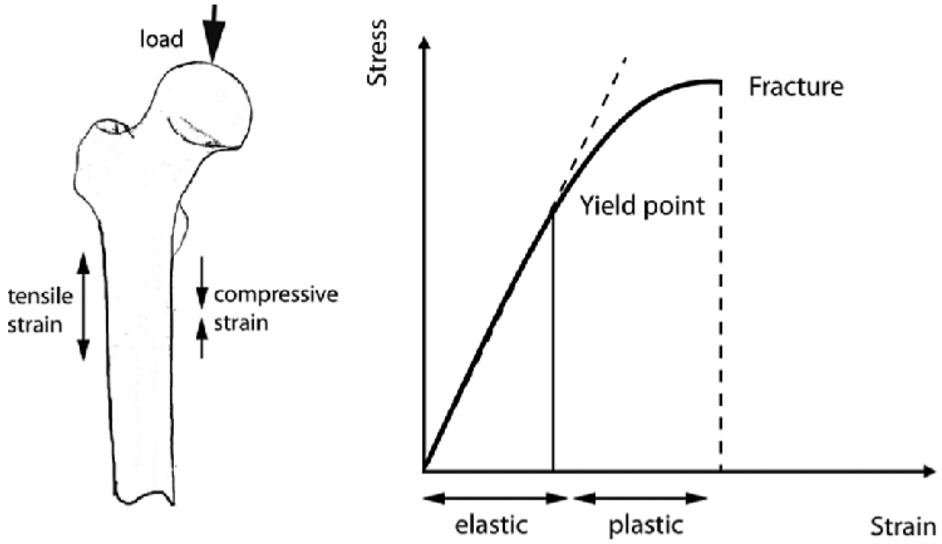

Figure 1.4. Stress/ Strain behavior of bones

When a piece of bone is placed under increasing tension, it's strain increase linearly at first (Hook's law) and then more rapidly just before it breaks.

Example: Assume a leg has 1.2 m shaft of bone with cross-sectional area of 3 cm^2 (3x10^{-4} m^2) what is the amount of shortening , when all of the body weight of 700 N is supported on it. Y= 1.8 x 10^{10} N/m^2

Solution;

$$\Delta l = \frac{F l_o}{AY}$$

$$\Delta l = \frac{700N \times 1.2m}{3 \times 10^{-4} m^2 \times 1.8 \times 10^{10}}$$

$$\Delta l = 0.15\ mm$$

The ability of the bones to support the body's weight without breaking is crucial to human. They support not only weight but also other forces such as; bending over to pick up something heavy, swimming, jumping, running and so on. In running the force on the hip bone when the heel strikes the ground may be four times the body's weight. In normal walking the force on the hip are about twice the body's weight.

According to the stress types, studies showed that bones are not as strong under tension as they are in compression. However, bone is stronger under tension than many common materials as presented in the following table 1.3.

Table 1.3. Compression, Tension and Young Modulus of some materials

Materials	Compressive breaking stress (×106 N/m2)	Tensile breaking stress (×106 N/m2)	Young's modulus (×108 N/m2)
Steel	552	827	2070
Rubber	-	2.1	0.01
Granite	145	4.8	517
Concrete	21	2.1	165
Compact bone	170	120	179
Trabecular bone	2.2	-	0.76

Any bone can be exposed to an external force. For example, if you jump and hit the ground with stiff-legged landing, the force generated is too high on the ankle but the bone can withstand a large force for a short time without breaking. While, the same force over long period will fracture it. That means the short term force is not as dangerous as the same force applied over longer period of time. This property is called ***viscoelasticity.***

When bone is fractured, the body can repair it but the details of the growth are not well understood. The local electrical fields may play a role. When bone is bent it generates an electrical charge on its surface. This phenomenon is called ***piezoelectricity.*** Experiments with animal bone have shown that bone heals faster if an electrical potential ia applied across the break. This technique has not been used at human yet.

Lubrication of Bone Joints

Studies show that two-third of the cadavers had a joint problem in the knee and one-third had the same problem in the hip. Generaly, there are two kind of diseases that affect the joints;

- **Rheumatoid arthritis** – Results in overproduction of synovial fluid and cause swollen joints
- **Osteoarthritis** – A disease of the joint itself.

The main components of a joint is shown in figure 1.5.

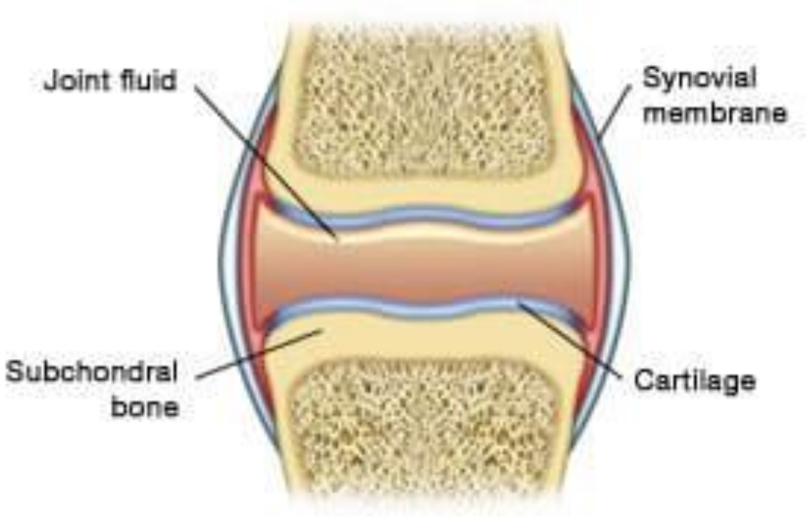

Figure 1.5. The main components of a joint

The lubricating properties of a fluid depend on its viscosity; thin oil is less viscous and better lubricant than thick oil.

The viscosity of synovial decreases under stress found in the joint.

The good lubricating properties of synovial fluid are thought to be due to the presence of hyaluronic acid and mucopolysaccharide of molecular weight 500000 which deform under load.

Measurement of Bone Mineral in the body

The strength of bone depends on the mass of bone minerals, and the most striking feature in osteoporosis is the lower than normal bone mineral mass. Since bone mineral mass decreases very slowly, 1 to 2% per year, a very precise technique were needed to show changes and so detect the possible fracture before it can occur.

The idea of using an x-ray image to measure the amount of bone mineral is an old idea. The major problems of using an ordinary x-ray (Figure 1.6) are;

1. The usual x-ray beam is heterogeneous - has many different energies.
2. The scatter in the image.
3. The film is not reproducible detector.

An improved technique based on the physical principles called photon absorptiometry is shown in (Figure. 1.7). The three problems with x-ray technique were largely eliminated by using

1. Monoenergetic x-ray or gamma source
2. Narrow beam to minimize scatter
3. A scintillation detector

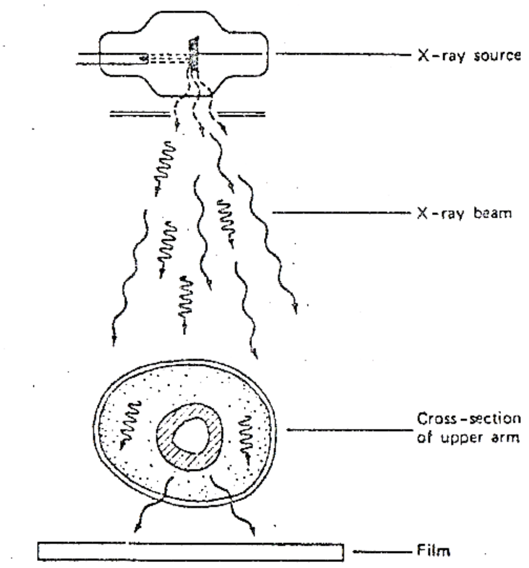

Figure 1.6. The ordinary x-ray

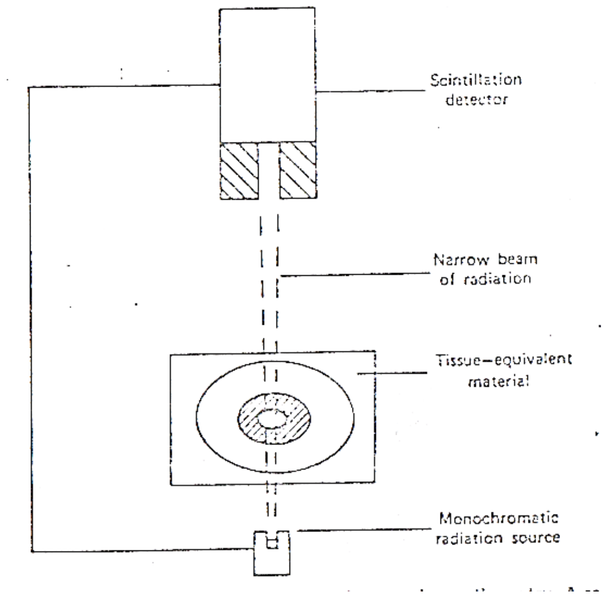

Figure 1.7. The basic component used in the photon absorptiometry

The photon absorptiometry technique depends on the intensity absorption of beam by the bone mineral. The I_o is the intensity of beam before entering the bone and I is the intensity of the transmitted beam.

The bone mineral mass (BM) is proportional to log (I_o/I) and given by;

BM (g/cm²) =K log (I_o/I) ……….. where K is a constant.

Exercises

1 The elongation of bone under stress could be given by the following relation'

(a) $\Delta l = \frac{ml_o}{AF}$

(b) $\Delta l = \frac{Fl_o}{AY}$

(c) $\Delta l = \frac{F}{AY}$

(d) $\Delta l = \frac{l_o}{l}$

(e) $\Delta l = \frac{AY}{Fl}$

2 In running the force on the hip bone when the heel strikes the ground may be

(a) four times the body's weight

(b) double the body's weight

(c) eight times the body's weight

(d) only the body weight

(e) half the body weight

3 Viscoelasticity means;

(a) the long term force is not as dangerous as the same force over short time

(b) bones cannot withstand with short term forces

(c) bones afford heavy loads for long time

(d) the short term force is not as dangerous as the same force over longer time

(e) None of them

4 When bone is bent it generates an electrical charge. This phenomenon is

(a) Osteoporosis

(b) Piezoelectricity

(c) X-ray imaging

(d) Photoelectric effect

(e) Spongy bone

5 The presence of hyaluronic acid and mucopolysaccharide

(a) Results in good lubricating properties of synovial fluid

(b) Causes bone diseases

(c) Helps absorb the X-ray

(d) Produces calcium

(e) Results in bad lubricating effect