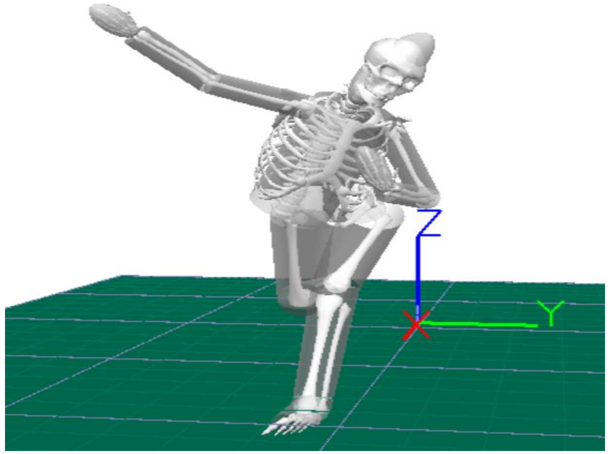
Biomechanics of bone



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Biomechanics of bone

- **Bone is a living tissue capable of altering its shape and mechanical behaviour by changing its structure to withstand the stresses to which it is subjected.**
- **Bones form the body's hard, strong skeletal framework.**
- **Each bone has**

1) a hard, compact exterior

2) surrounding a spongy, lighter interior.

- **Long bone has a central cavity contain bone marrow.**

Bones are the building blocks of the human skeleton.

Figure 1 shows the human skeleton

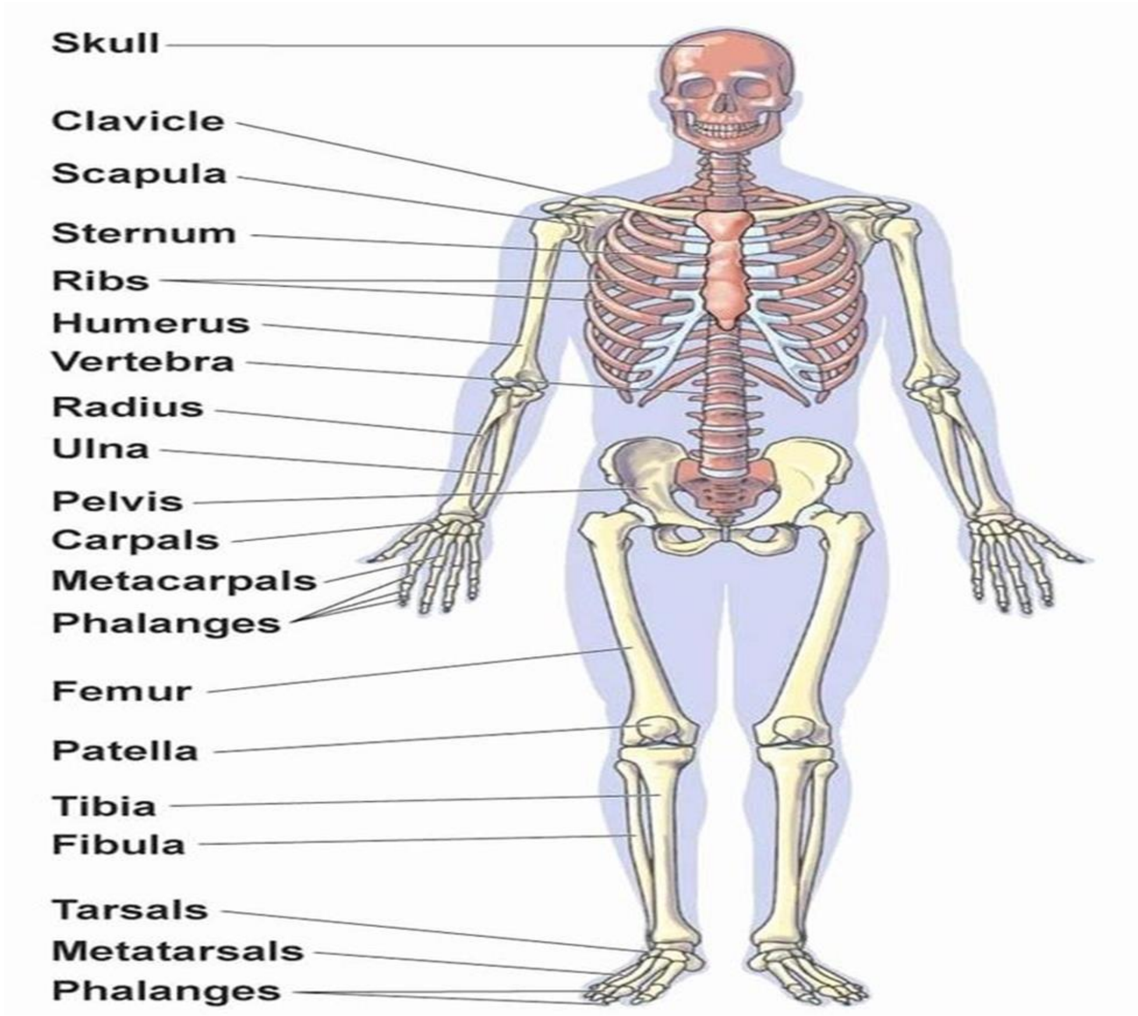


Figure 1 The human Skelton

- **Biomechanics is the study of the structure and function of biological systems such as humans, by means of the methods of mechanics.**
- **Bone consists primarily of calcium, phosphorous, water, and collagen fibers. Its hardness is attributed to mineral salts, comprising around two-thirds of its mass, while its elasticity stems from organic fibers. Being a living tissue, bone has the ability to self-repair if fractured and properly aligned.**

The major factors that decides the stress bearing capacities of bone

1. Bone composition.
2. Mechanical characteristics of bone tissue.
3. Bone size and shape.
4. Rate and direction of applied loads.

Classification of bones

The human skeleton comprises 206 bones, offering both rigidity and flexibility to facilitate a wide range of movements. Bones vary in shape and structure, contributing to their diverse functions:

A. Bone Shape:

1. **Plate (flat) bones, like those in the skull.**
2. **Long bones, such as the femur, tibia, fibula, humerus, ulna, and radius.**
3. **Irregular bones, including vertebrae.**
4. **Short bones, exemplified by tarsal and carpal bones.**
5. **Ribs, which don't fit precisely into the above categories.**

B. Bone Structure:

1. **Compact bone, found in solid sections like the shafts of long bones and vertebrae.**
2. **Trabecular bone, like the cancellous end of long bones, characterized by lower density due to less bone material.**

Functions of the bone

1. **Support:** The bone's support role is evident, especially in the leg, where it works in conjunction with tendons, ligaments, and muscles.
2. **Locomotion:** Bone joints, acting as hinges or articulations, facilitate movement.
3. **Organ Protection:** Bones safeguard various organs—like the skull protecting the brain and sensory organs (eyes, ears), ribs shielding the heart and lungs, and the spinal column guarding the spinal cord.
4. **Chemical Storage:** Bones help regulate calcium levels in the blood.
5. **Nutrient Supply:** Both deciduous (baby) and permanent teeth serve as sources of nourishment.
6. **Sound Transmission:** Ossicles within the middle ear aid in the transmission of sound.

COMPOSITION OF BONE

1. Bone is made of connective tissue. Bone is a composite material with 1) various solid and fluid substances, 2) besides cells, 3) an organic mineral matrix of fibers and 4) a ground substance,

-it has inorganic substances in the form of mineral salts which make it hard and relatively rigid. However, organic components provide flexibility and resilience.

2. The bones consist of two types of tissues. See Fig. 2

A- The compact bone tissue is a dense material forming the outer shell of bones and the diaphyscal region of long bones. The outer shell is called cortical.

B- The other tissue consists of thin plates (trabeculae) in a loose mesh which is enclosed by the cortical bone tissue. This is called cancellous, trabecular or spongy bone tissue.

C- Dense fibrous membrane surrounds the bone and it is called periosteum (epithelium tissue) the periosteum membrane covers the entire bone except the joint surfaces which are covered with articular cartilage. It is the most sensitive part of the bone

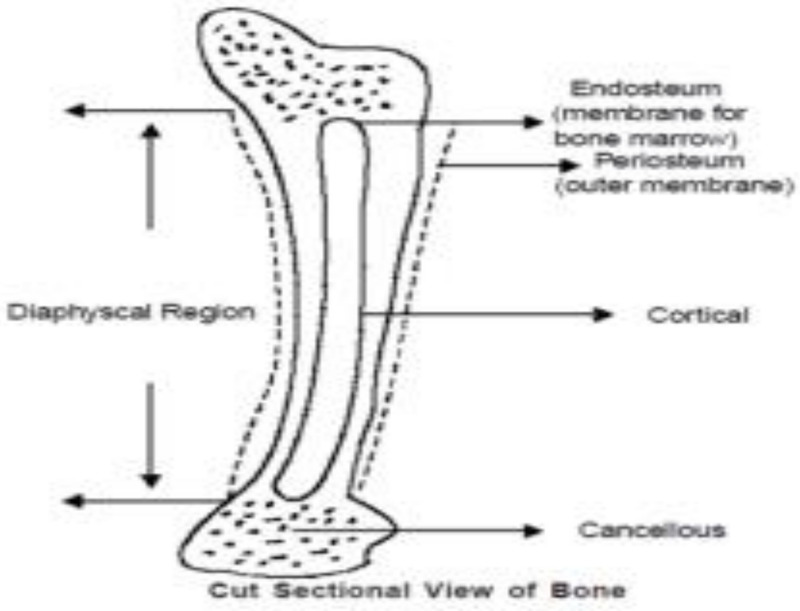
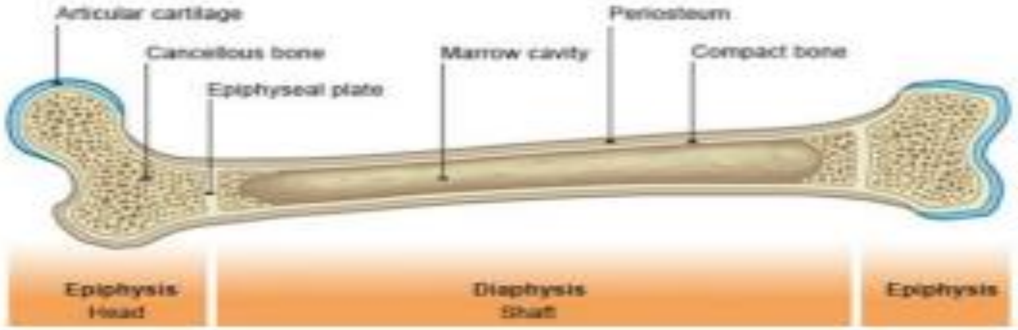
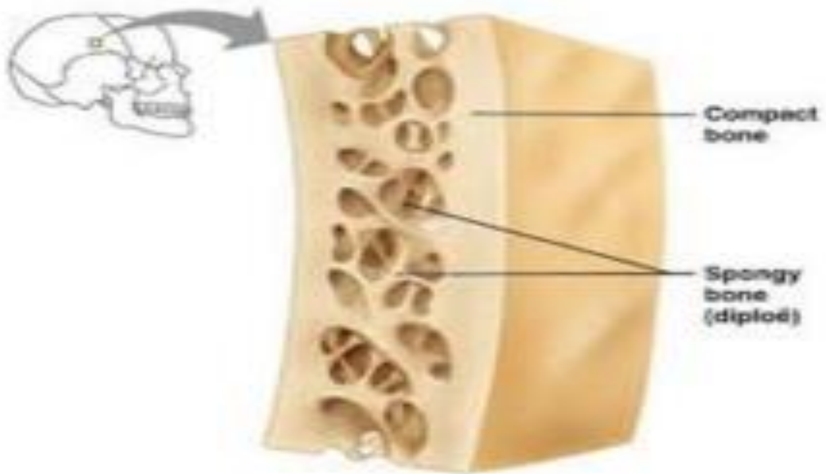


Fig.2 Cut sectional view of the bone





MECHANICAL PROPERTIES OF BONE

- Material can be A) homogeneous or B) nonhomogeneous.

  Homogenous material has same composition in all directions.

- Bone is a non homogeneous material as it has different compositions in different directions as it consists of various cells, organic and inorganic substances laid in uniform manner.
- Material can be A)isotropic having mechanical properties same in all directions or B) anisotropic with mechanical properties different in different directions.

Bone is anisotropic material as its mechanical response depends upon the direction of the applied load. For example compressive strength (the resistance of a material to breaking under compression) is more than tensile strength (the resistance of a material to breaking under tension), and tensile load capacity is more than transverse load capacity of the bone.

- Bone has both liquid and solid constituent, hence it has viscoelastic properties which is time dependent i.e., the mechanical response of the bone is dependent on the rate of loading of the bone.
- Bone can stand rapidly applied loads much better than gradually applied loads

Mechanical properties of metals

.Mechanical properties of metals, concrete and polymers are found out by testing the specimen under 1) tensile, 2) compression and 3) bending load by universal testing machine and 4) torsional load by torsion testing machine.

- Similar tests can be performed on bone specimen for bulk properties. It can also be performed separately for cortical and cancellous part of the bone

3.The stress and strain diagram for the cortical bone under tensile loading is shown in Fig. 3.

The stress and strain diagram has three distinct regions. The part (OA) is elastic region and the slope of this line is equal to the elastic modulus (E) of the bone which is 17 GPa.

In the intermediate region (AB), the bone exhibits non linear elasto-plastic material behavior.

Now the bone does not retains its original length on removal of load (possible in region OA) and a permanent yielding takes place.

- **On removal of load, the specimen follows path BO’ instead BAO and there is a permanent strain of OO’. On loading the specimen will now follow path O’B which amounts to higher strength. This is known as strain hardening. The bone exhibits a linearly plastic material behavior in region BC after yield strength (Point B).**
- **The bone fractures when tensile stress is about 128 MPa for which the tensile strain is about 0.020.**

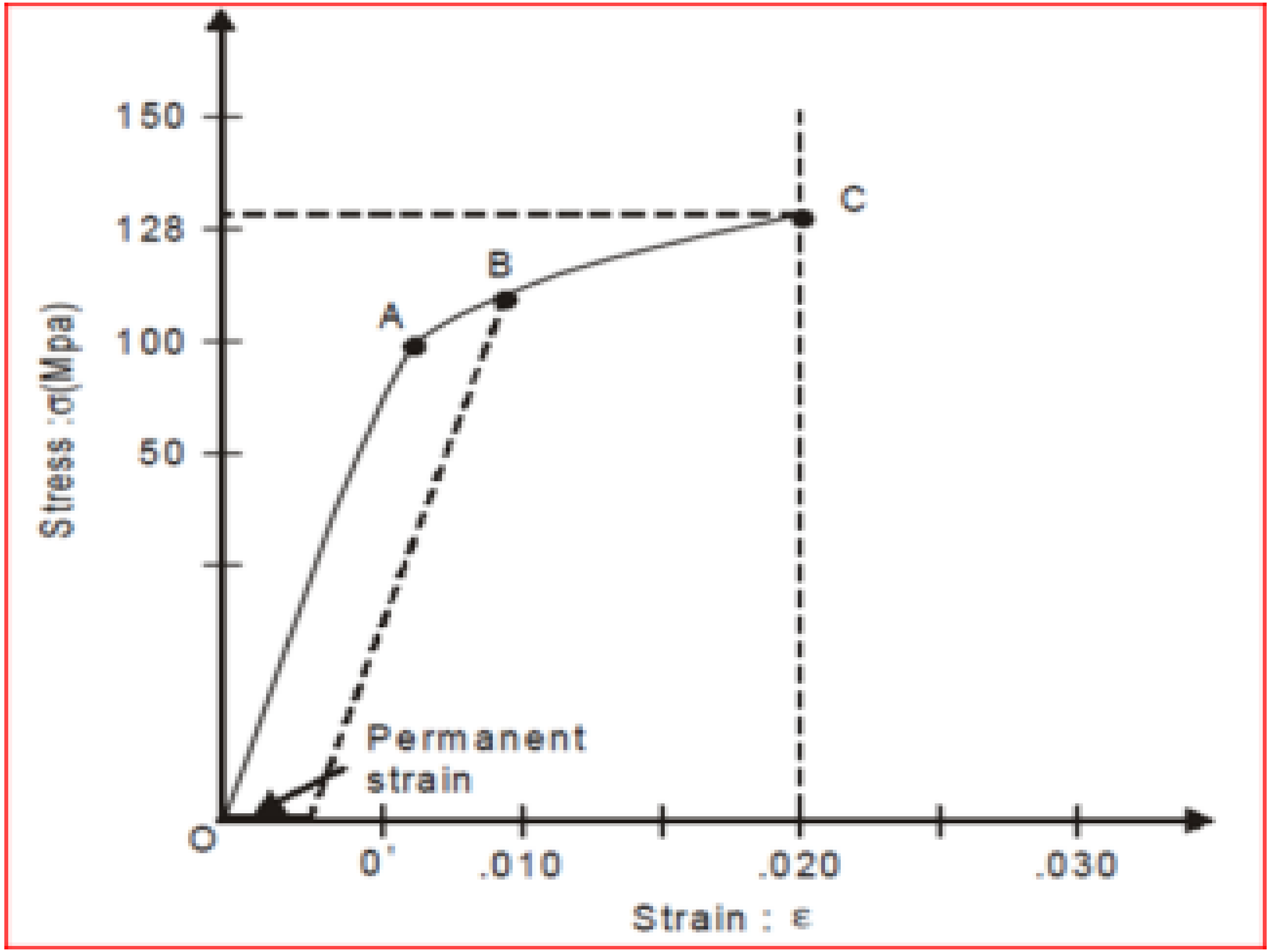


Fig. 3 Stress and strain of the cortical bone during tensile loading

- It has been seen that a specimen of bone which is loaded rapidly, has a greater elastic modulus and ultimate strength than a specimen which is loaded slowly. This has been shown in the figure 4 . We also know that resilience energy is the area under the stress and strain diagram.
- resilience is the ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading.

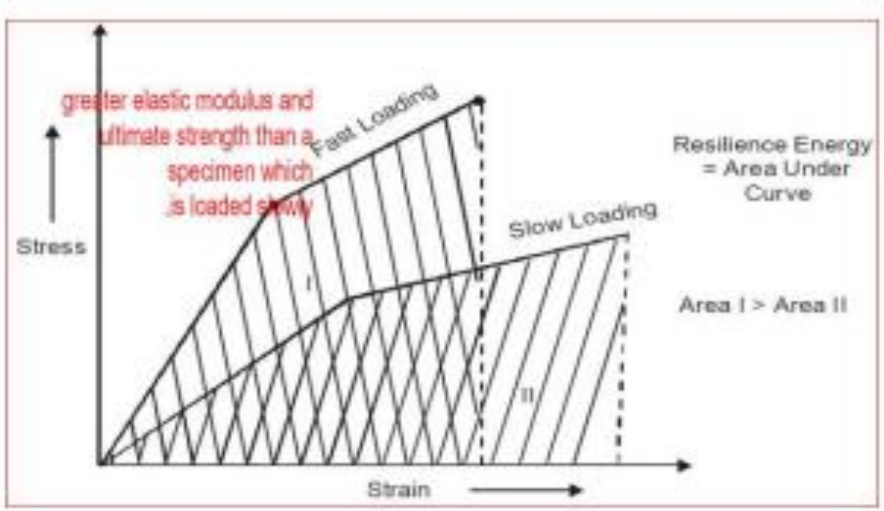


Fig. 4 Fast and Slow Loading of the bone

4. Bone is an anisotropic material. Hence its stress-strain behavior depends upon the orientation of bone with respect to the direction of loading.

- Bone is stronger (larger ultimate strength) and stiffer (larger elastic modulus) in longitudinal direction (along long axis) than transverse direction (vertical to long axis).
- Fig. 5 shows Longitudinal and Transverse Loading
- Bone fails in brittle manner at lower load during transverse loading as compared to the longitudinal loading

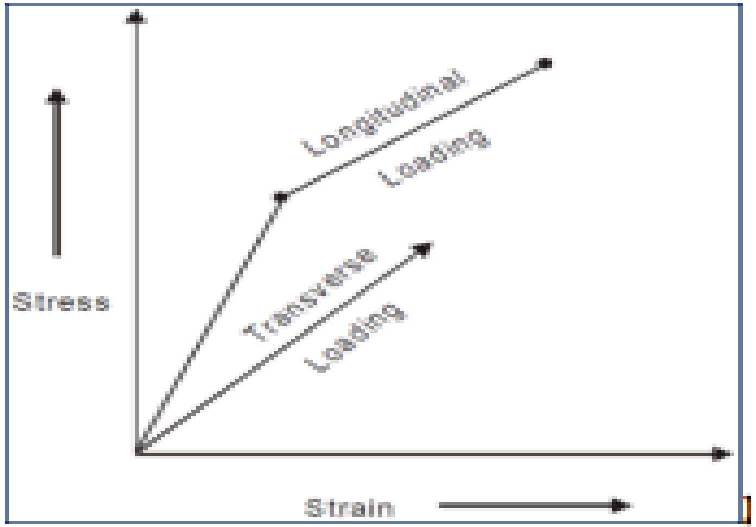


Fig. 5 Longitudinal and Transverse Loading

5. Cancellous bone: The distinguishing characteristics of the cancellous bone is its porosity. Hence cancellous bone has lower density depending upon porosity. The stress-strain of cancellous bone depends upon

1) porosity and

2) the mode of loading.

Factors affecting strength

Factors affecting the strength or structural integrity of bone are:

(a) Area: : Larger is the bone, the larger is area upon which the internal forces are distributed and the smaller is the intensity of stresses.

- **stress (σ) = Force/Area= F/A or Force = $\sigma \times$ Area of bone**
- **Strain: fractional change in length due to stress, $\varepsilon = \Delta L / L$**
- **Hooke's law: $\sigma = Y\varepsilon$, stress-strain diagram Hence, bone with larger area can withstand more force for a given value of maximum permissible stress.**

Example 1

Assume a leg as a 1.2 m shaft of bone with an average cross-sectional area of 3 cm^2. What is the amount of shortening when all of the body weight of 700 N is support on this leg?

Solution:

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

$$= 1.5 \times 10^{-4}\text{ m} = 0.15\text{ mm}$$

(b) Geometry of bone: The bone can be solid or hollow tube.

(c) Reduction in Density: The strength of bone decreases with reduction of density which may result due to skeletal conditions such as osteoporosis, with ageing or after period of disease. Certain surgical treatments may alter the geometry of the normal bone which may reduce the strength of the bone. Screw holes or other defects in the bone also reduce the load bearing capacity of the bone as stress concentration at these locations of defects increases loading to failure.

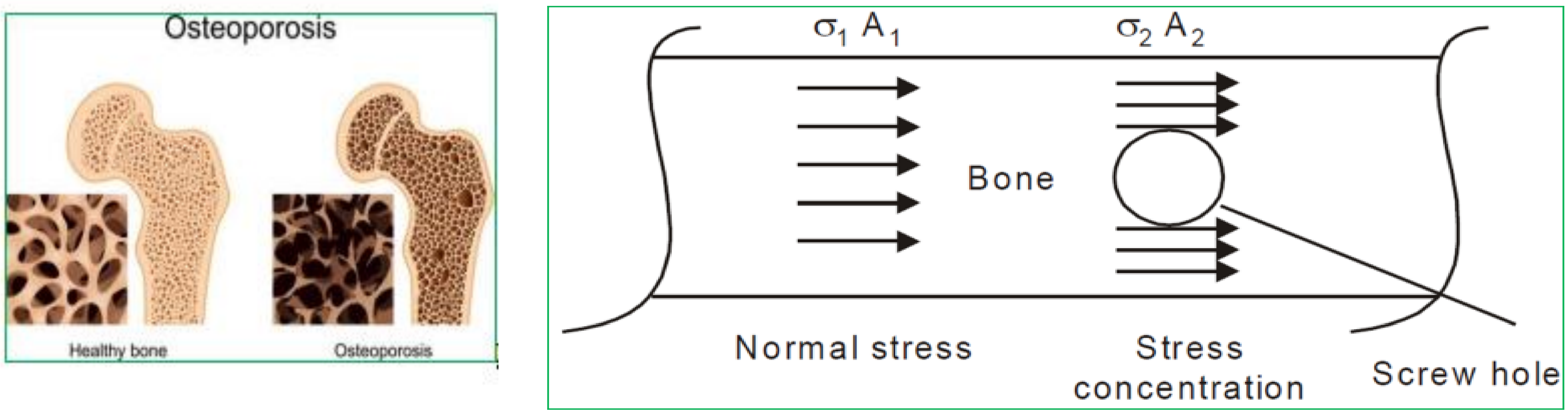


Fig. 7 Bone with osteoporosis