Biological Tissue Response To Loading

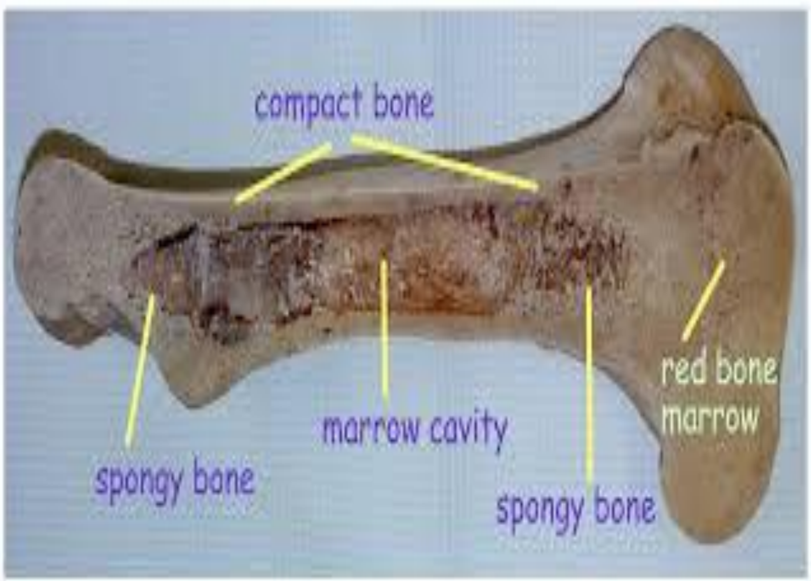
- **Bone response to loading**
- **Viscoelastic material response**

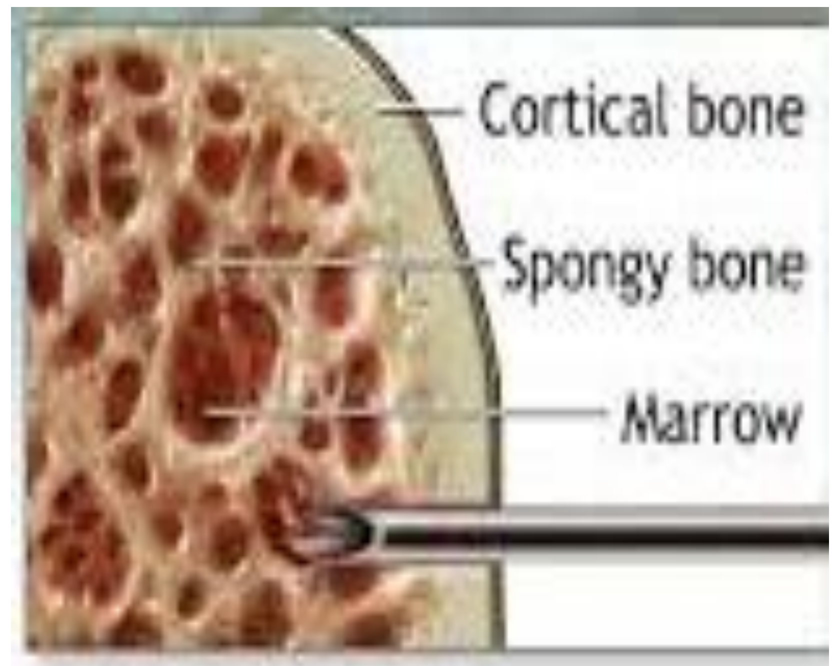
Intended learning outcomes

- **By the end of this lecture student will be able to:**
- Identify the mechanical characteristics of bone response to loading.
- Differentiate between cortical and cancellus bone response to loading.
- Identify the mechanical characteristics of cartilage response to loading
- List the functions of articular cartilage in synovial joint
- Apply the normal characteristics of tissue response to loading in clinical situations

Dynamic structure of bone

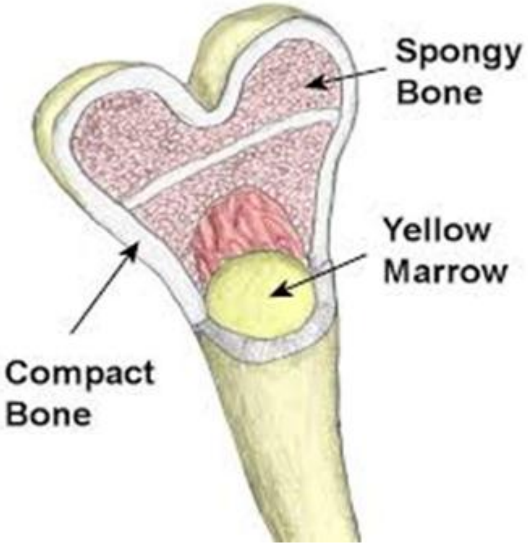
- Bone response to loading is primarily different in different types of bone.



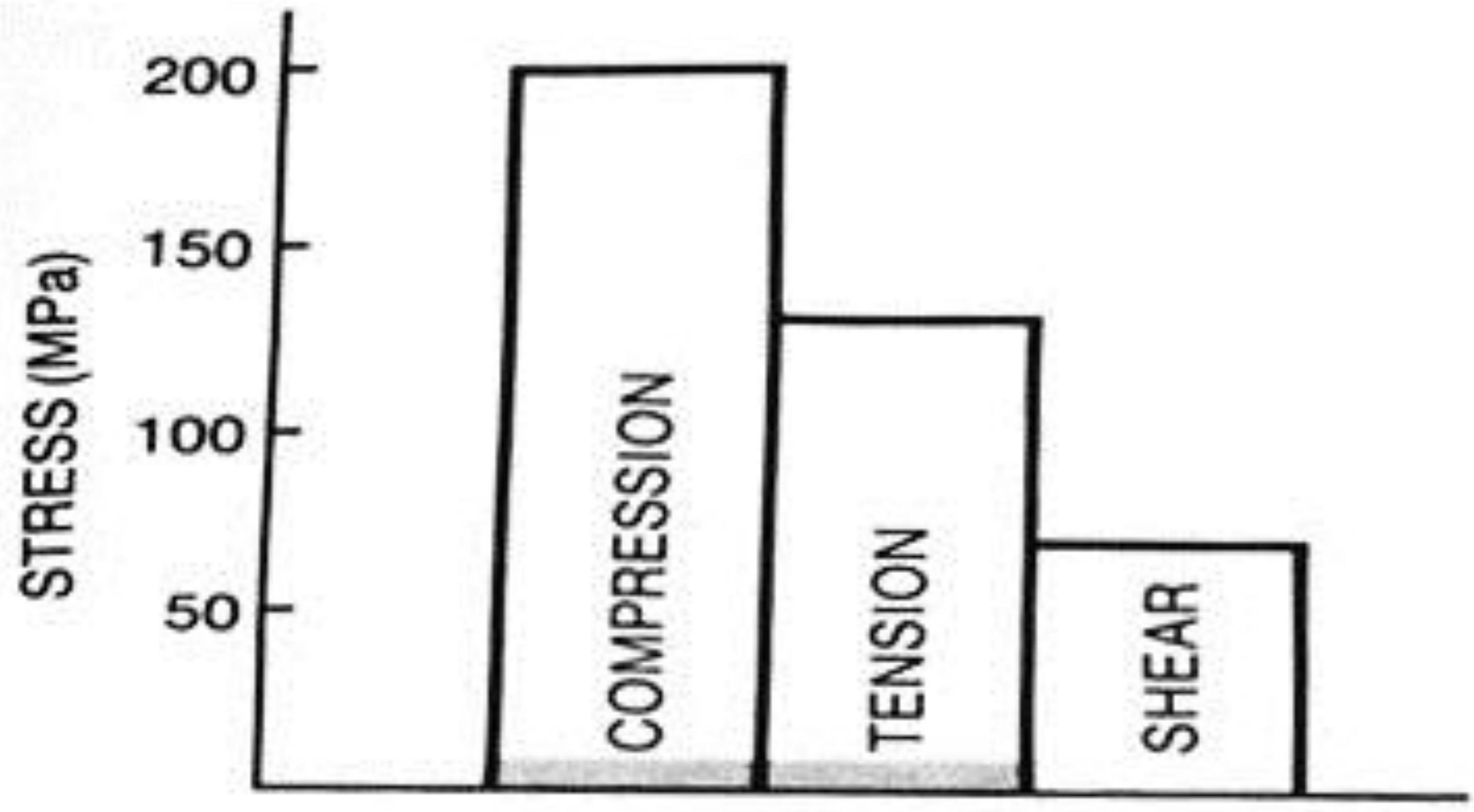


- The relative percentage of bone mineralization varies not only with the age of the individual but also with the specific bone in the body.

- The more porous the bone , the smaller the proportion of calcium phosphate and calcium carbonate, and the greater the proportion of nonmineralized tissue.

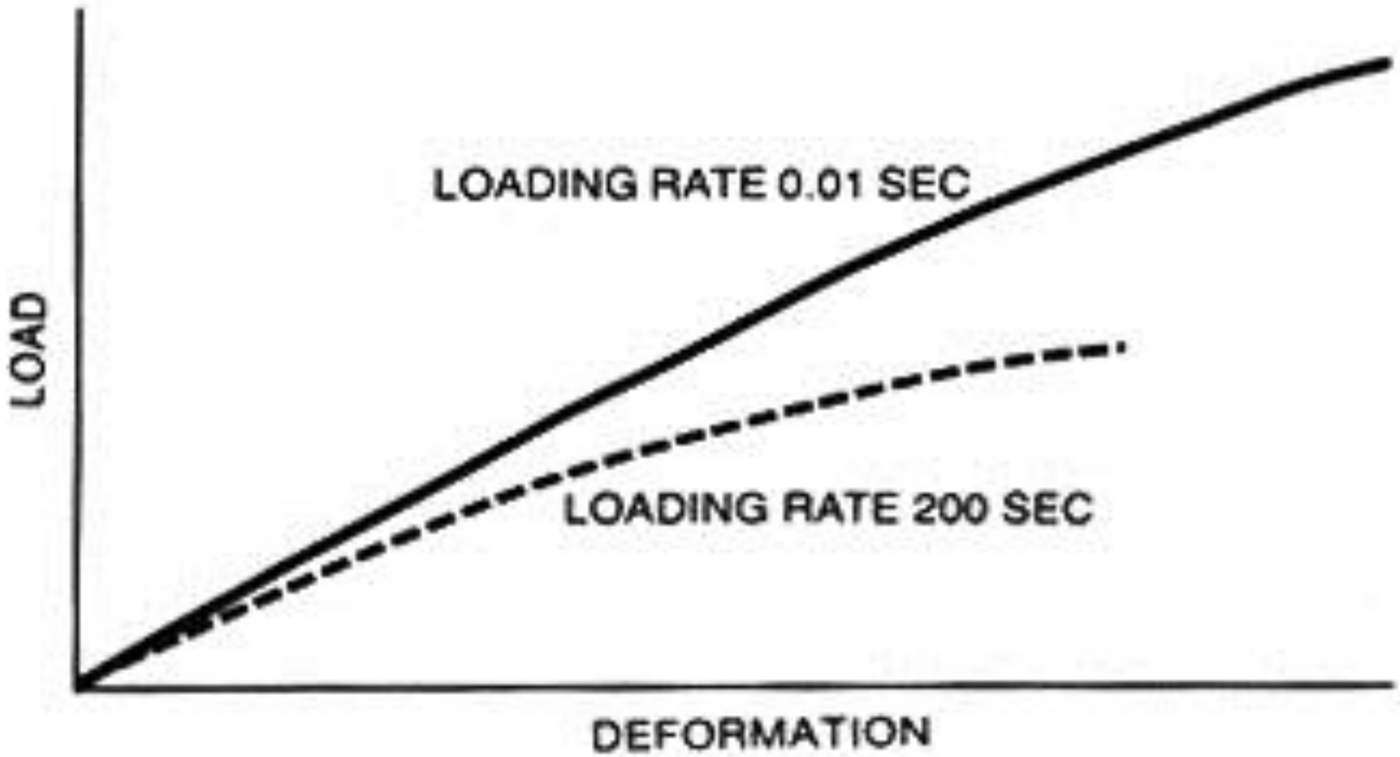


	Cortical	Cancellous
Porosity	5-30%	30-90%
Stiffness	Great	Less
Fracture	Occur when strain exceeds 2% its length	Occur when strain exceeds 7% its length
Type of material	Anisotropic	Anisotropic
Fracture toughness	Require more work to fracture	Require less work to fracture



Effect of various modes of loading on bone.

Rate dependency in bone



Rate dependency of bone

Characteristic of bone response to loading

- Bone strength is the strength provided by the body of a bone against any compression load.
- The more the compression load, the more will be the compression strength of that bone.

- Bone is stronger and stiffer when load is applied in the longitudinal direction (direction of osteon orientation) than in horizontal direction.

- Bone is an anisotropic material (explain?)

- Living bone is seldom loaded in only one mode.

- Ultimate strength of bone is *greater in compression than in tension.*

- Bone resist rapidly applied load better than slowly applied load (Why)as it will absorb more energy.

- Bone with large cross section resists forces more than smaller bones (G R)as stress at any location of the large bone will be less than in a small bone loaded under similar conditions.

- Cortical bone is stiffer than cancellous bone. It can withstand greater stress but less strain before failure.

- Failure of bone occurs when there is accumulation of bone micro damage exceeds bone's ability to repair the damage (fatigue fracture).

- Failure of bone occurs at its weak point when it is subjected to load that may cause this failure.

- Activity of the muscles reduces the tensile stress on the bones. Its fatigue causes increase of stresses on certain areas of the bone and as a result failure occurs.

- Spongy bone e.g. ribs fails first and quicker when subjected to the same load than composite bones.

- Fracture produced by tensile loading is usually seen in cancellous bone.

e.g. fracture of calcaneous at the attachment of gastrocnemius.

- Fracture produced by compressive loading causes oblique crack e.g. fracture of vertebra.

- Fracture produced by shear loading occurs in cancellous bone e.g. fracture of the femoral condyle and the tibial plateau.

Influence of muscle activity on stress distribution in bone

- When bone is loaded with muscular contraction attached to the bone, it alters the stress distribution in the bone.
- This muscular contraction decreases or eliminates tensile stress on the bone by producing compressive stress that neutralizes it either partial or totally.
- Thus the muscle contraction allows the bone to sustain higher loads than would be expected.

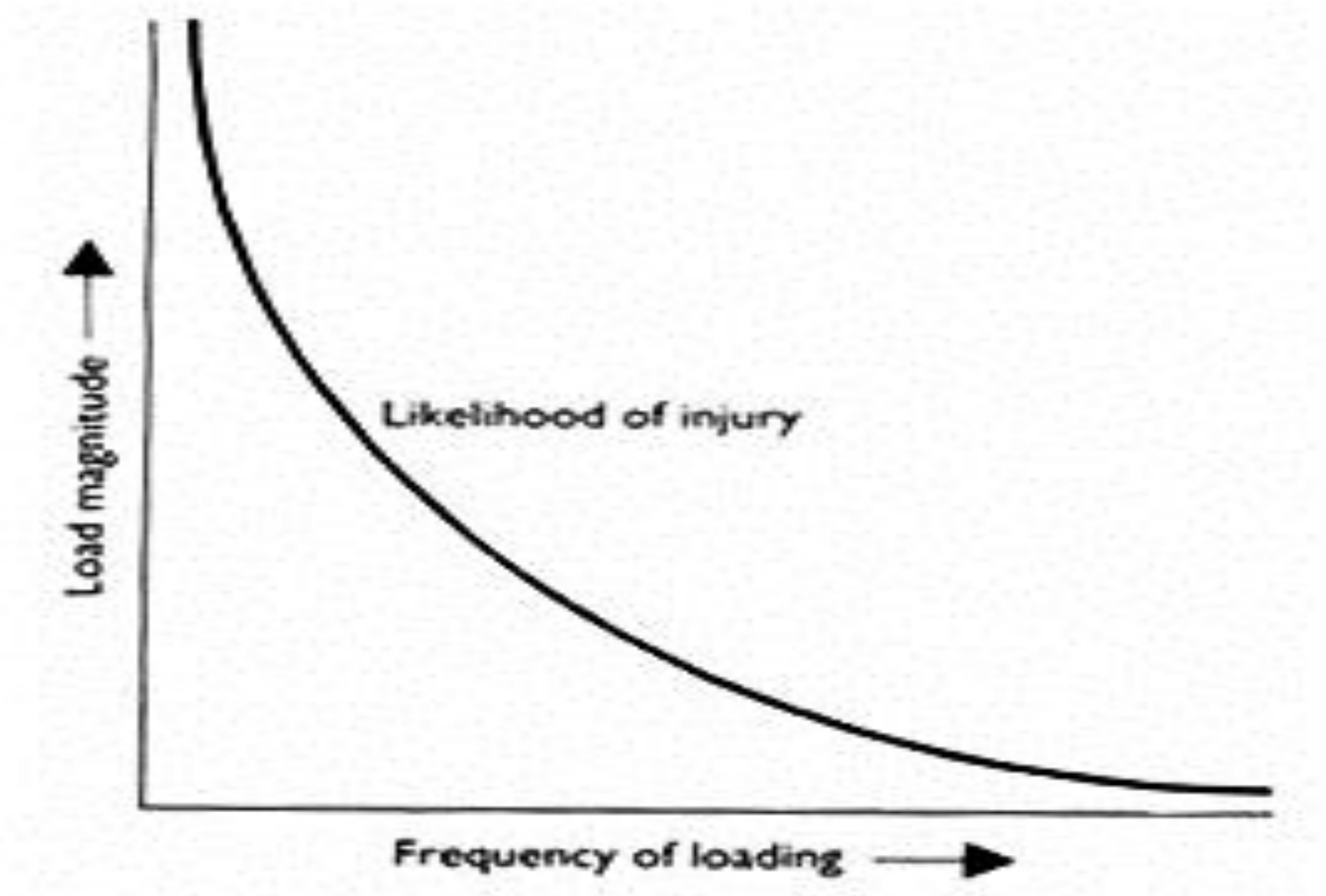
Fatigue of Bone under repetitive loading

Fractures caused by repeated applications of a lower load called fatigue fracture and is typical produced either:

- *few repetition of a higher loads*
- *Or many repetition of a relatively normal load*

In repetitive loading of living bone , the fatigue process is affected by:

- the amount of load
- the number of application of the load within a given time (frequency of loading) .



Bone response to repetitive loading

Bone modeling and remodeling

- Stresses result in changes that occur in living bone throughout the lifespan are unrelated to normal growth and development.

- Bone responds dynamically to the presence or absence of different forces with changes in size ,shape ,and density.

- **When strain exceeds modeling threshold ,the process of bone modeling occurs ,with bone mass and density increased.**

- **When strain magnitudes stay below a lower remodeling threshold, bone remodeling occurs, with bone removed close to the marrow.**

- Remodeling can occur in either "conservation mode," with no change in bone mass, or "disuse mode" with a net loss of bone .

- Mass characterized by an enlarged marrow cavity with thinned cortex.

- **The modeling and remodeling processes are directed by osteocytes**

cells embedded in bone that are sensitive to changes in the flow of interstitial fluid through the pores resulting from strain on the bone.

In response to detected strain levels, osteocytes trigger the actions of osteoblasts and osteoclasts ,the cells that respectively form and resorb bone.

- A predominance of osteoblast activity produces bone modeling, with a net gain in bone mass.

- Bone remodeling involves predominance of osteoclast activity ,with associated maintenance or loss of bone mass.

- Approximately 25% of the body's trabecular bone is remodelled each year through this process
- strains resulting from an activity such as walking are sufficient to provoke bone turnover and new bone formation.

- Thus ,bone mineralization and bone strength in both children and adults are a function of stresses producing strains on the skeleton.

- Since body weight provides the most constant mechanical stress to bones, bone mineral density generally parallels body weight , with heavier individuals having more massive bones.

Bone Modeling and Remodeling:

-**Bone is a very dynamic tissue, with the modeling and remodeling processes continuously acting to increase, decrease, or shape bone.**

-**Stresses result in changes throughout the lifespan are unrelated to normal growth and development.**

-Bone responds dynamically to the presence or absence of different forces with changes in size, shape, and density.

-The bone elements place or displaced themselves in the direction of functional forces and increase or decrease their mass

--The modeling and remodeling processes are directed by osteocytes, cells embedded in bone that are sensitive to changes in the flow of interstitial fluid through the pores resulting from strain on the bone.

-bones deform or strain with larger loads producing higher levels of strain.

-When strain exceeds **modeling** threshold, the process of bone modeling occurs, **with bone mass and density increased.**

-When strain magnitudes stay below a lower remodeling threshold, **bone remodeling occurs**, with **bone removed close to the marrow.**

-**Remodeling can occur in either "conservation mode," with no change in bone mass**, or '**'disuse mode'' with a net loss of bone mass characterized by an enlarged marrow cavity with thinned cortex**.

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- Adults who gain or lose weight tend to also gain or lose mineral density however a given individual's physical activity profile ,diet, lifestyle, and genetics can also dramatically influence bone density.

- Factors such as lean body mass, muscle, strength, and regular participation in weight bearing exercise have been shown to exert stronger influences on the bone density

Osteoporosis

Bone resorption exceeds bone deposits in osteoporosis.

The symptoms of osteoporosis often begin to appear in the elderly, especially postmenopausal women.

Osteoporosis may begin earlier in life, when bone mineral density decreases.

When bone decomposition cannot keep up with bone resorption, bone mineral mass decreases, resulting in reduced bone density accompanied by loss of trabecular integrity and loss of stiffness.

- **Both of these losses create the potential for a much greater incidence of fracture, ranging from 2 to 3.7% in nonosteoporotic individuals and almost doubling to 5 to 7% in osteoporotic individuals.**
- **Mild or moderate exercise can increase bone mineral content in the elderly .**
- **In one study, bone mineral content in runners aged 50 to 72 was shown to be greater than in subjects who did not run.**
- **There was also a decreased rate of age related bone loss: 4% over 2 years for the runners and 6 to 7% over 2 years for the non-runner group.**

- When the runners stopped running or moved to walking as an alternative exercise, bone loss increased substantially to 10 to 13%. Therefore, it is suggested that a substitute activity for running is one that provides high intensity loads and low repetitions, such as weight lifting.
- Lifestyle and activity habits play an important role in the maintenance of bone health. In one study, the incidence of osteoporosis was 47% in a sedentary population compared to only 23% in a population whose occupations included hard physical labor.
- It is clear that the elderly may benefit from some form of weight-bearing exercise even though the exercise intensity and durations have not been determined.
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Injury and loading

- Whether or not a bone incurs an injury as a result of an applied force is determined by the critical strength limits of the material and the loading history of the bone.
- These limits are primarily influenced by the loading on the bone.
- The loading of the bone can be increased or decreased by physical activity and conditioning, immobilization, and skeletal maturity of the individual.
- The rate of loading is also important because the response and tolerance of bone is rate sensitive.
- At high rates of loading, when bone tissue cannot deform fast enough, an injury can occur.

Muscular activity and loading

- Muscular activity can also influence the loads that bone can manage. Muscles alter the forces applied to the bone by creating compressive and tensile forces.
- These muscular forces may reduce tensile forces or redistribute the forces on the bone.
- Since most bones can handle greater compressive forces, the total amount of load can increase with the muscular contribution.
- If muscles fatigue during an exercise bout, their ability to alleviate the load on the bone diminishes.
- The altered stress distribution or increase in tensile forces leaves the athlete or performer susceptible to injury.

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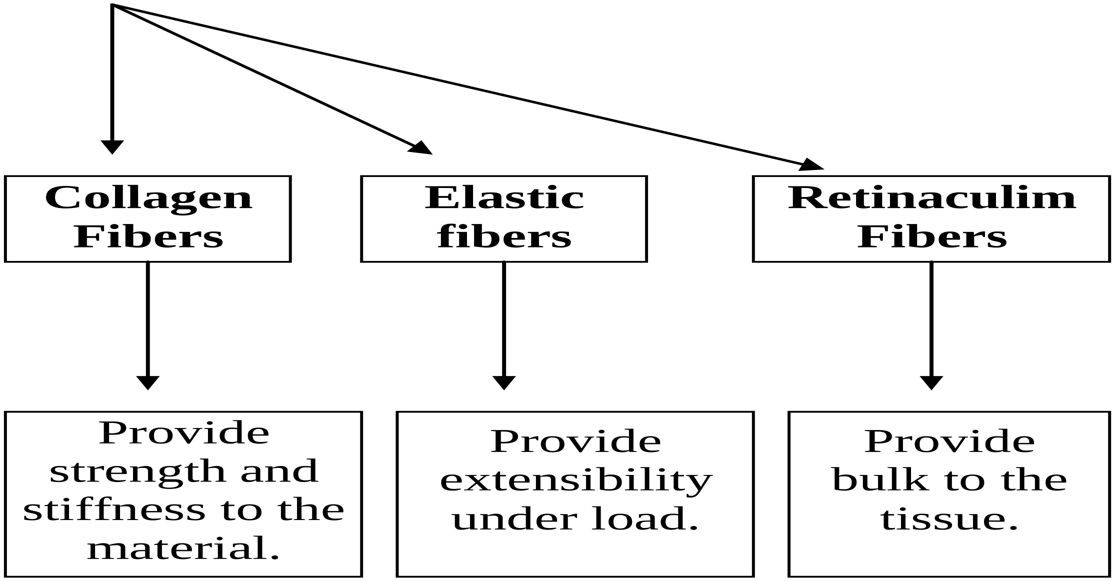
Stress fractures

- A stress fracture occurs when bone resorption weakens the bone too much and the bone deposit does not occur rapidly enough to strengthen the area.
- Stress fractures in the lower extremity can be attributed to muscle fatigue that reduces shock absorption and causes redistribution of forces to specific focal points in the bone.
- In the upper extremity, stress fractures result from repetitive muscular forces pulling on the bone. Stress fractures account for 10% of injuries to athletes.

- The typical stress fracture injury occurs during a load application that produces shear or tensile strain and results in laceration, fracture, rupture, or avulsion.
- Bone tissue can also develop a stress fracture in response to compressive or tensile loading that overloads the system, either through excessive force applied one or a few times or through too frequent application of a low or moderate level of force.
- The relationship between the magnitude and frequency of applications of load on bone is presented in. The tolerance of bone to injury is a

Viscoelastic materials

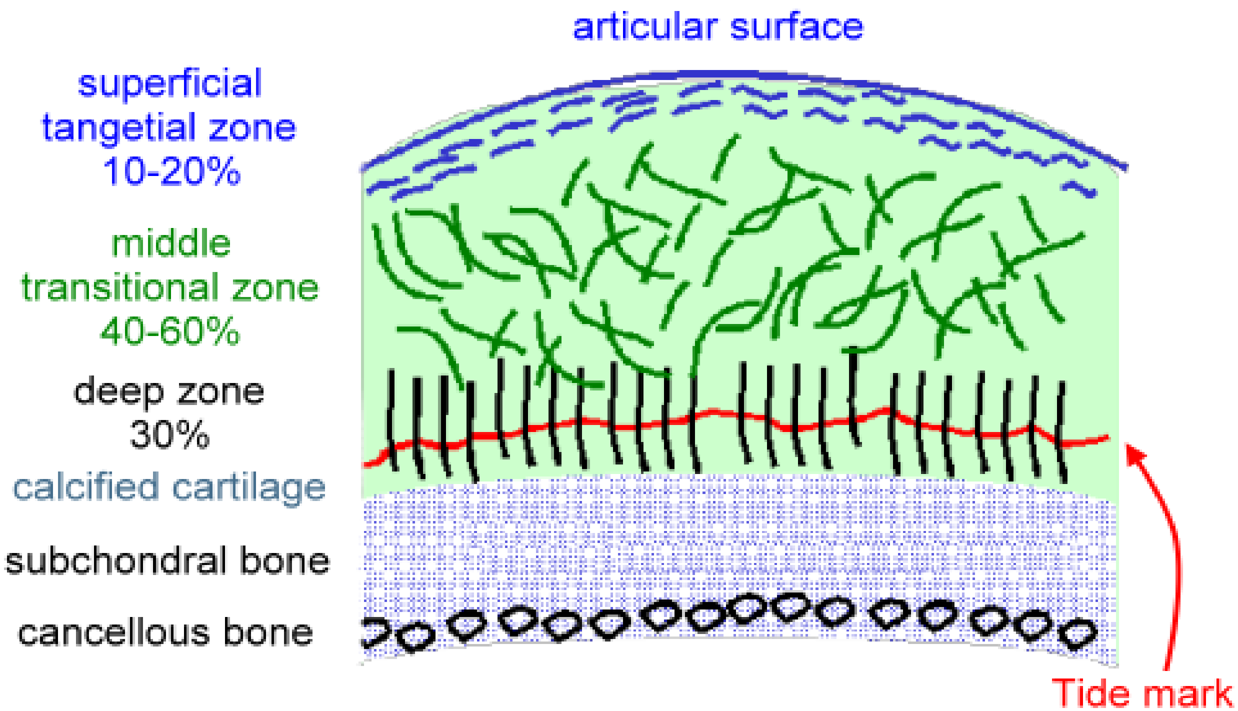


- **ARTICULAR CARTILAGE**
- **Composition:**
- ***1- Solid matrix 20-40%***
- - Collagen: 60%
- Provide strength and stiffness
- Resist stresses and strength to articulation
- - Proteoglycan: 40%

2- Water 60-80%

- **Arrangement of the collagen fibers in the cartilage**
  Superficial zone: represents 10-20% of total thickness (resist tensile strain)
- - **Middle zone:** represents 40-60% (50%)
- - **Deep zone:** represents 30% (resist compression)

Articular cartilage



Collagen Arrangement of the Articular Cartilage

Nature Of articular cartilage viscoelastisity:

- The response is a combination of the response of a viscous fluid and an elastic solid
- The two fundamental responses of a viscoelastic material are creep and stress relaxation.
- Creep occurs when subjected to the action of a constant load.
- Responds with a rapid initial deformation followed by a slow (time-dependent) progressively increasing deformation known as creep, until an equilibrium is reached.
- Respond with a high initial stress followed by a slow (time dependent) progressively decreasing stress required to maintain the deformation .This phenomenon is known as stress relaxation.

- **Mechanical response of cartilage to loading:**
- The tensile stiffness decreases with increase of distance
- Cartilage is perfectly elastic for a small load applied for a short time.
- Cartilage becomes deformed when exposed to constant stresses. (So ,,,
- It assumes its shape during rest.
- The larger the cartilage is loaded, the greater is the impairment of its elasticity.
- Increase of the frequency and the magnitude of load lead to articular cartilage degeneration.

Functions of the articular cartilage:

- Increases the area of load distribution
- Provide a self-lubrication feature that operates under normal physiologic joint loading conditions.
- Decreases the stresses on the joint surfaces by distributing the loads over large areas.
- Allows relative movement of the opposing surfaces with minimal friction and wear.

- **Factors affecting cartilage degeneration:**
- Magnitude of stresses
- Frequency of stresses
- Disorders of the metabolism
- The structure of the cartilage.

- Damage to articular cartilage, can disrupt the normal load-carrying ability of the tissue and thus the normal lubrication process operating in the joint.
- Lubrication insufficiency may be a primary factor in the etiology of osteoarthritis

Strength of ligaments

- Medial collateral ligament
- The ligament can sustain force of 115 kg/cm2 and a stretch of 12.5 %of its length before rupture.
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- Lateral collateral ligament
- The ligament can sustain force of 276 kg/cm2 and a stretch of 19% of its length before rupture.

Thank You