حدیث نبوی صلی اللہ علیہ وسلم

"آپ صلی اللہ علیہ وسلم کو جب کوئی مشکل درپیش ہوتی تو آپ صلی اللہ علیہ وسلم فوراً نماز کی طرف متوجہ ہو جاتے"۔

(ابوداؤد: حدیث نمبر: ۱۳۱۹)

The Biomechanics of Human Bone Growth and Development

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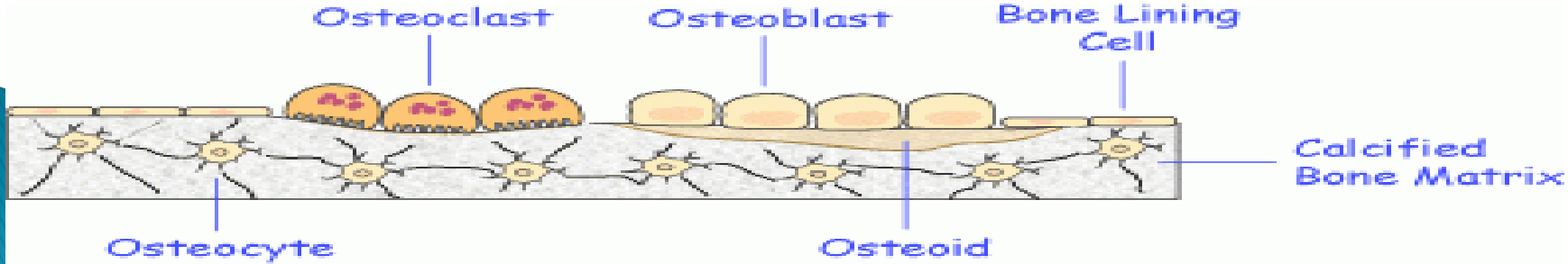
Types of Bone Cells

- **Osteoprogenitor cells**: located on the **external** surface of bone – Divide and proliferate to form osteoblasts
- **Osteoblasts:** Responsible for mineralization of bony matrix – Respond to stimuli and allow bone to remodel – When completely surrounded by osteoid matrix it becomes an osteocyte
- **Osteocyte** : Centre piece of bony matrix – Synthesize and resorb bony matrix to control blood calcium levels
- **Osteoclasts :** Phagocytic cell from bone marrow – Responsible for bone breakdown and removal

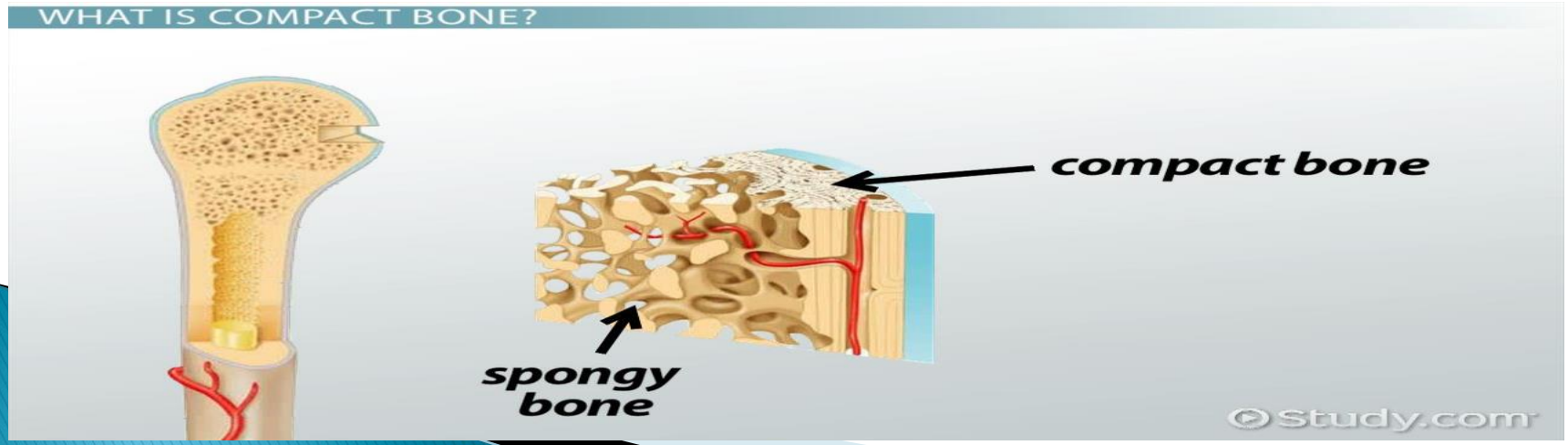


Adult Bone Development

- Balance between osteoblasts and Osteoclasts activity
- Increase in age yields progressive decrease in collagen and increase in bone brittleness.
- Greater in women

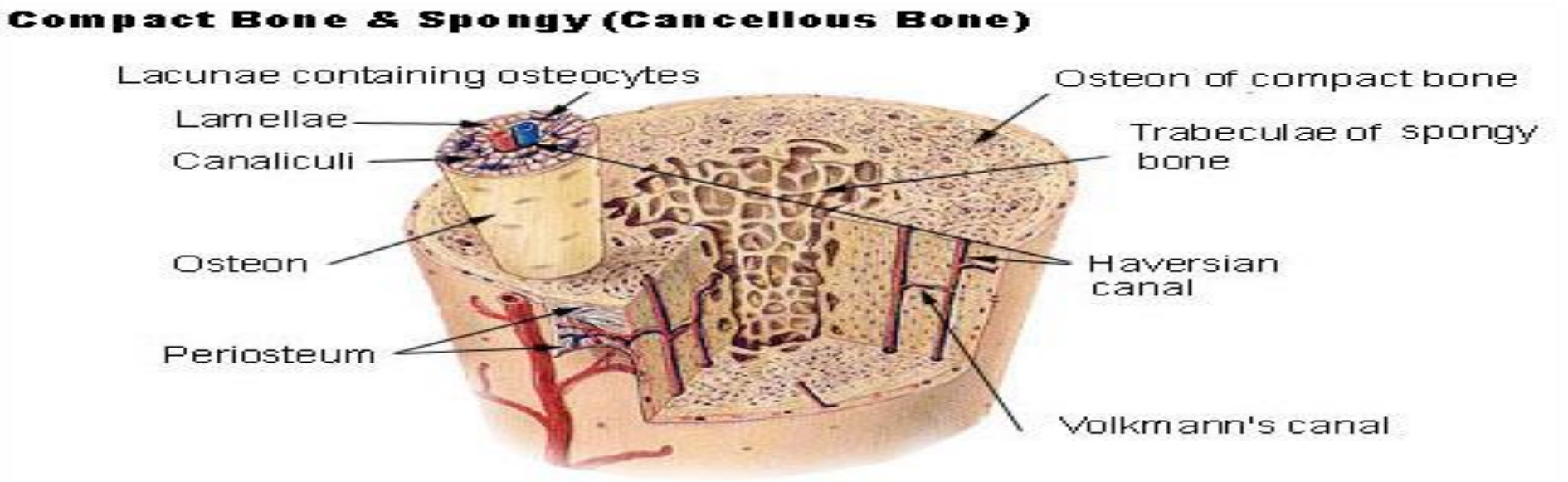
Types of Bone

- **Cortical (Compact):-** Forms outer shell of bone (cortex) – Very dense structure –
- Always surrounds Cancellous bone, but thickness varies depending on type of bone, age, diet, and functional requirements
- **Cancellous (Trabecular):-** Inside of bone – Thin plates arranged in a loose mesh structure – in a concentric layers with marrow between

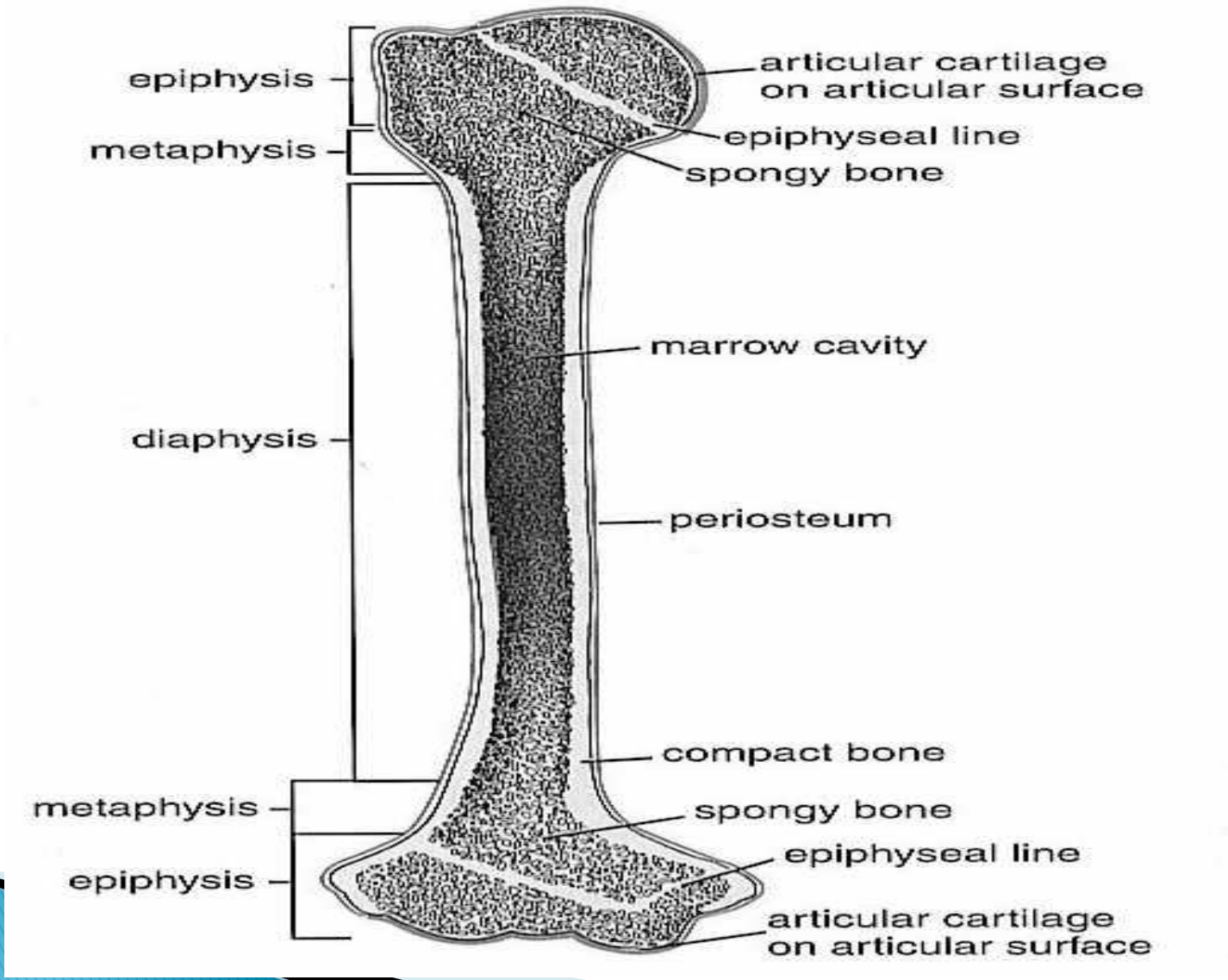


Structural Organization

- Bone mineralization ratio specific to bone
- **Two categories of bone**:
  - **Cortical bone(5-30% non mineralized)**
  - **Trabecular bone(30-90% non mineralized)**
- More porous bones have:
  - Less calcium phosphate
  - More calcium carbonate
  - Greater proportion of non-mineralized tissue



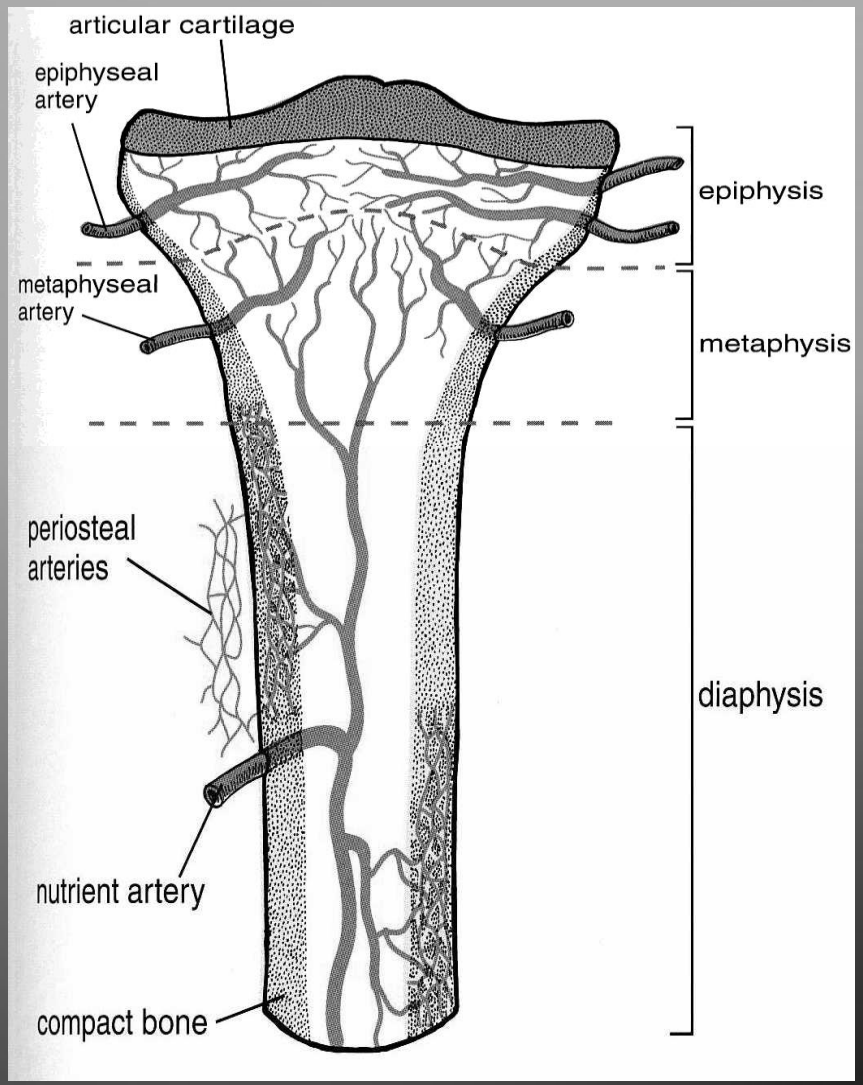
Gross Anatomy of Bone



Bone Regeneration

Depends upon

- Size
- Depth
- Location
- Maturity



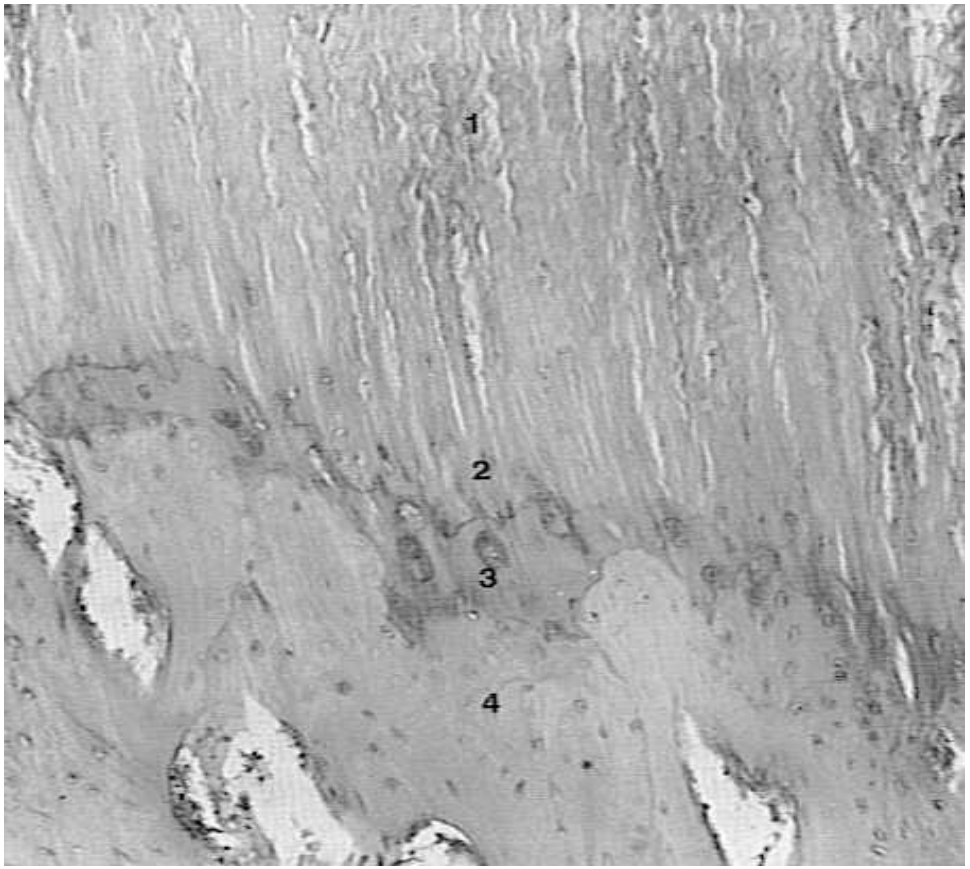
Bony Insertion

Zone 1 Parallel Collagen Fibers

Zone 2 Unmineralized Fibro cartilage

Zone 3 Mineralized Fibro cartilage

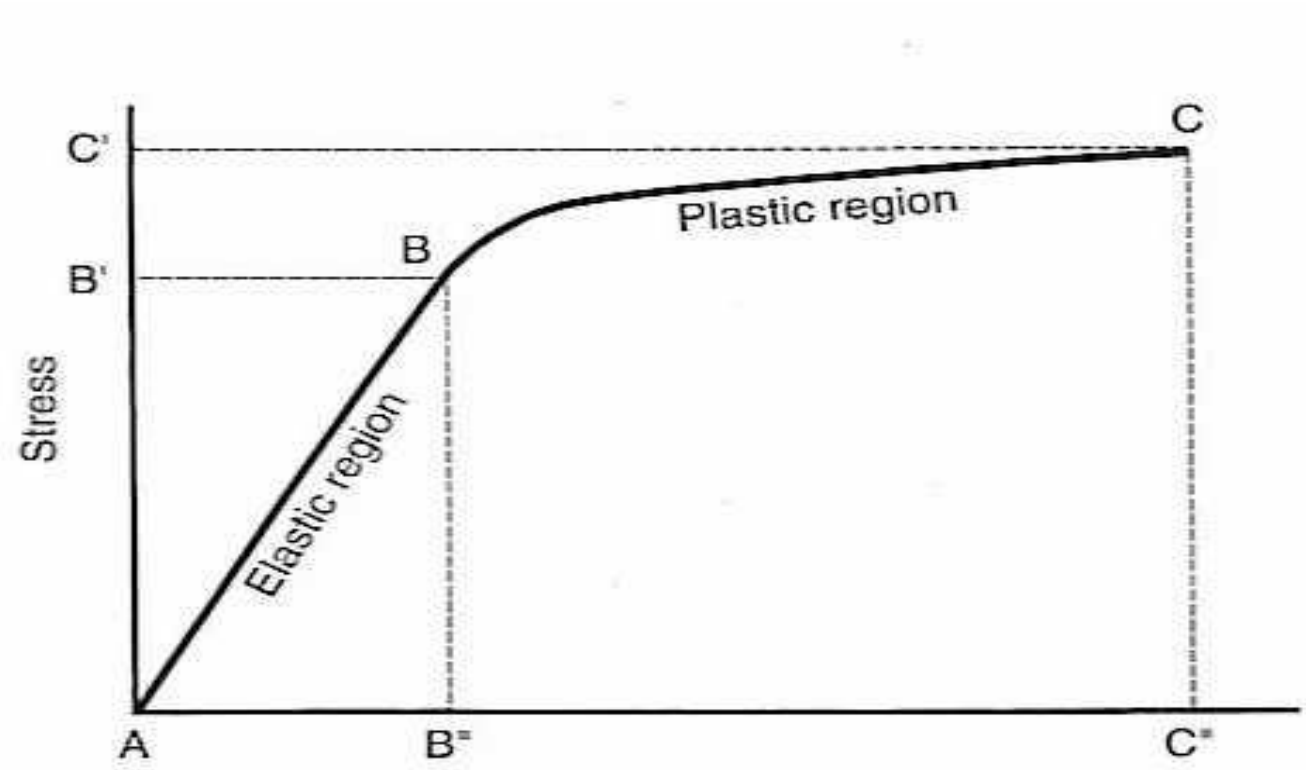
Zone 4 Cortical Bone



Biomechanical properties of bone

- **Biphasic material**: mineral as one component and collagen and ground substance as another.
- The most important properties are strength and stiffness.
- Behaviour under loading showed Hypothetical load deformation curve.

Stress – Strain Curve



(cortical bone in tension)

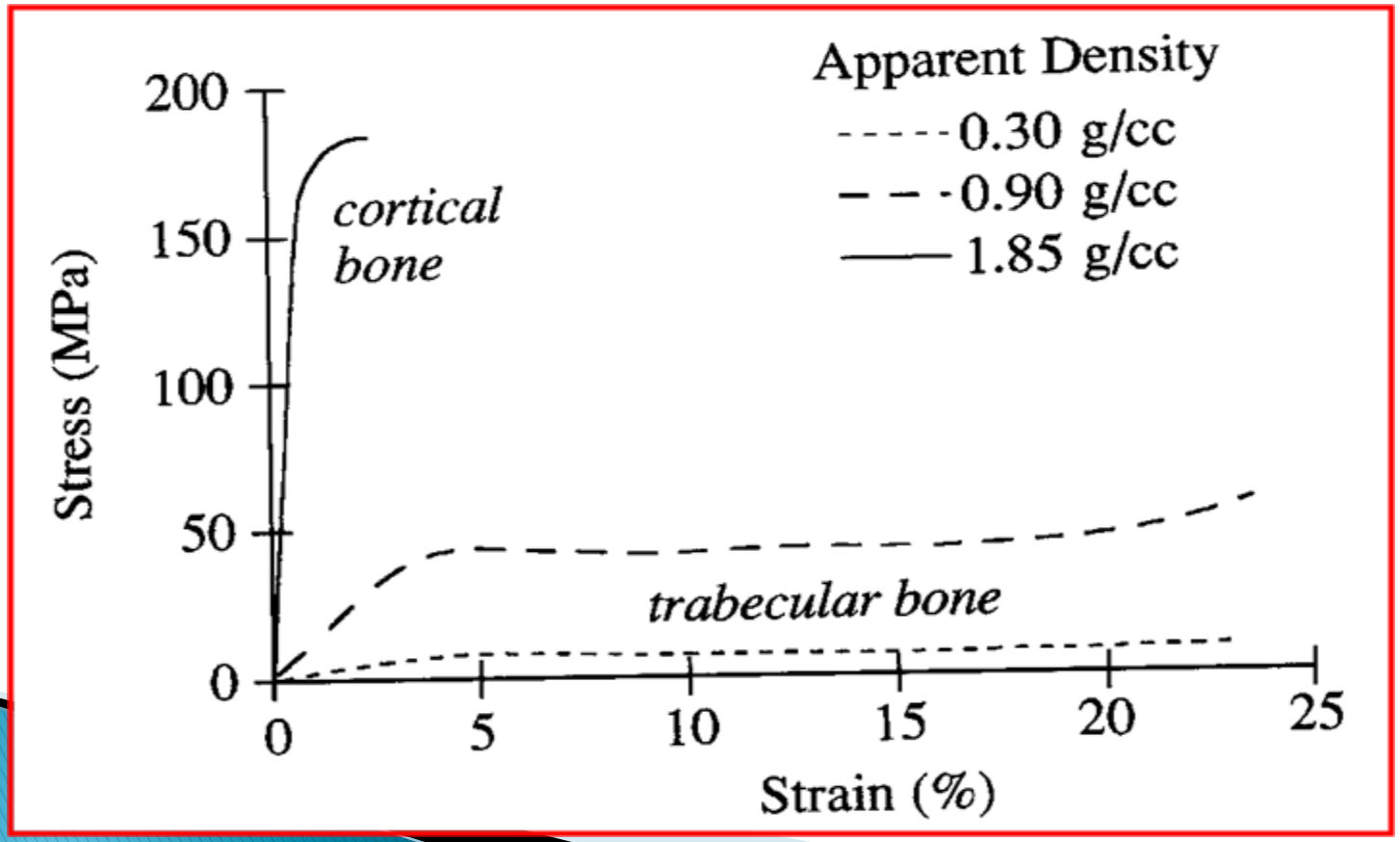
- **Three parameters for strength:**

– Load that it can sustain before failing

– Deformation that it can sustain before failing

– Energy that it can store before failing.

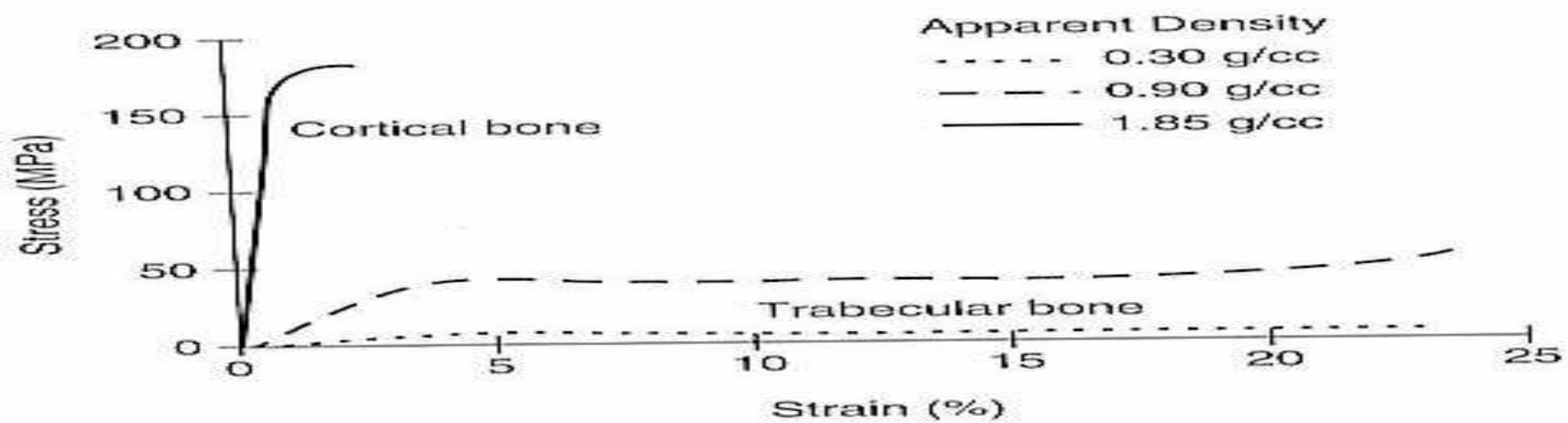
strength = area under the curve



- **Cortical Bone**
  - **Low porosity**
  - 5-30% bone volume is non-mineralized tissue
  - Withstand greater stress but less strain before fracturing
- **Trabecular Bone**
  - **High porosity**
  - 30 - >90% bone volume is non-mineralized tissue
  - Trabeculae filled with marrow and fat
  - Withstand more strain (but less stress) before fracturing

- Both cortical and Trabecular bone are anisotropic
- Bone function determines by structure of bone
- Strongest at resisting compressive stress
- Weakest at resisting shear stress

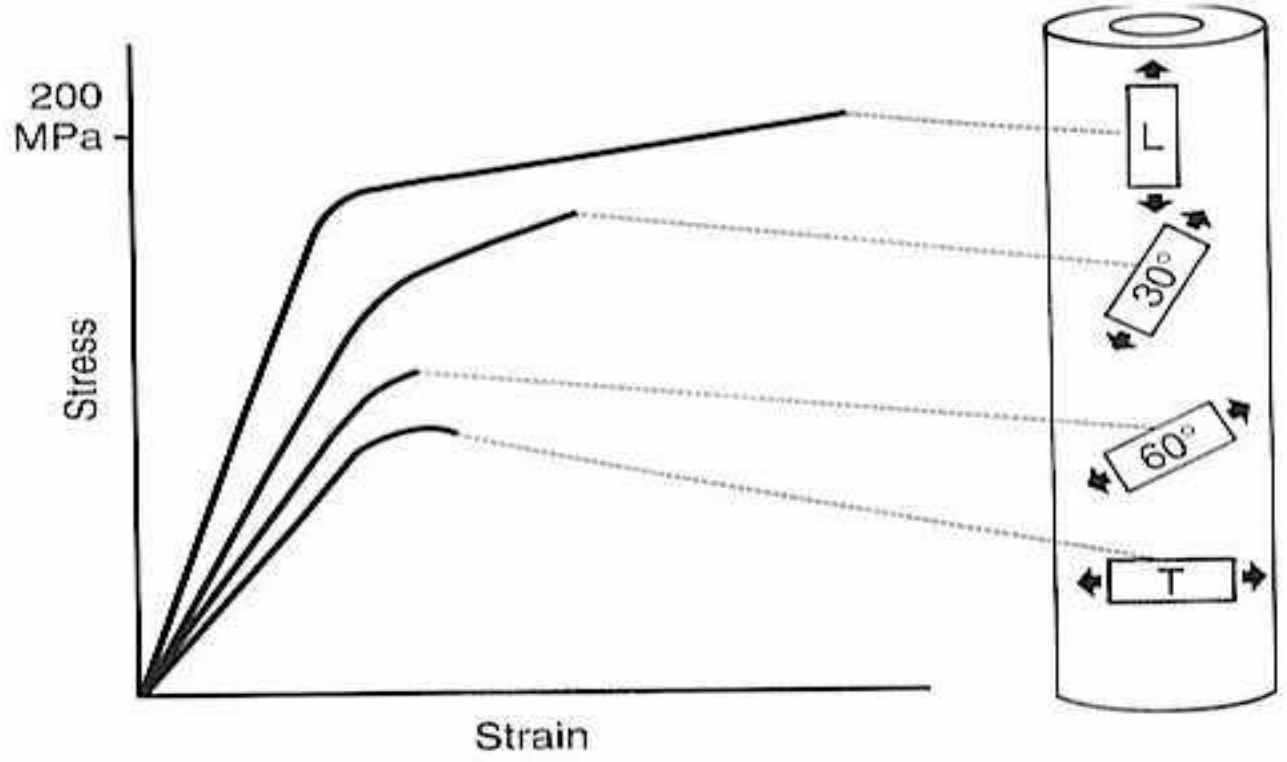
- **Physical difference** = apparent bone density= gm per cc
- **If Cortical and Trabecular bones tested under different bone densities and similar circumstances.**
- Elastic portion of the curve for cortical bone is not straight line hence not linearly curved and opposite for trabecular bone
- **Brittles or ductile** classified depending upon extent of deformation before failure.



- Structure of the bone is dissimilar in the transverse and longitudinal directions , it exhibits different mechanical properties when loaded under different axes, the property called as **ANISOTROPY.**

- Human femoral shaft sample tested under in four directions.

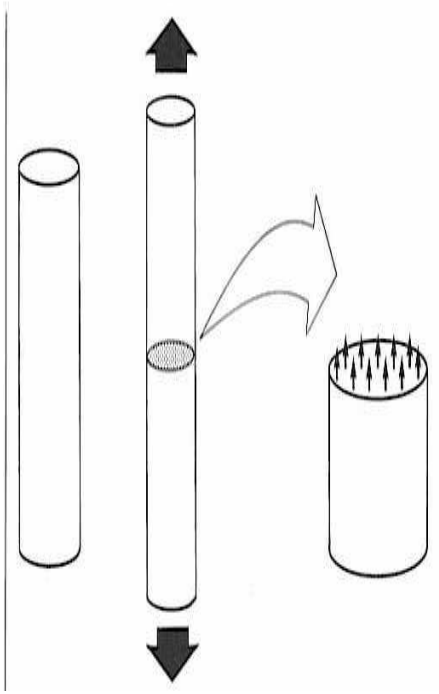
Anisotropic Nature of Bone



Bone loading and mechanical properties = complex
Strength and stiffness more in directions of daily loads.

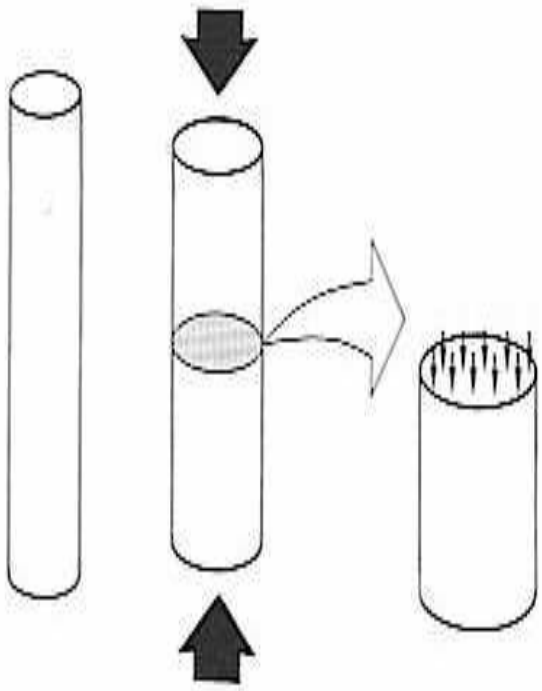
BIOMECHANICAL BEHAVIOUR OF BONE

- Mechanical properties , geometric characteristics, loading mode, direction of loading, rate and frequency of loading.
- Tension, compression, bending, shear, torsion, Combined loading.
- **Tensile loading**:
- During tensile loading equal and opposite loads are applied outward from the surface of bone and tensile stress and strain result inside the structure.
- Tensile stress can be thought of as many small forces directed away from the surface of the structure.
- Structure lengthens and narrows.



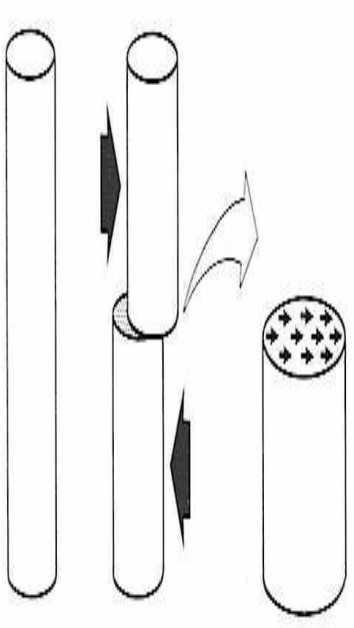
Compressive loading

- Equal and opposite loads are applied towards the surface of the bone; and compressive stress and strain result inside the structure.
- Maximal stress along perpendicular plane.
- Structure shortens and widens.
- **Example: Vertebral fracture.**



Shear loading

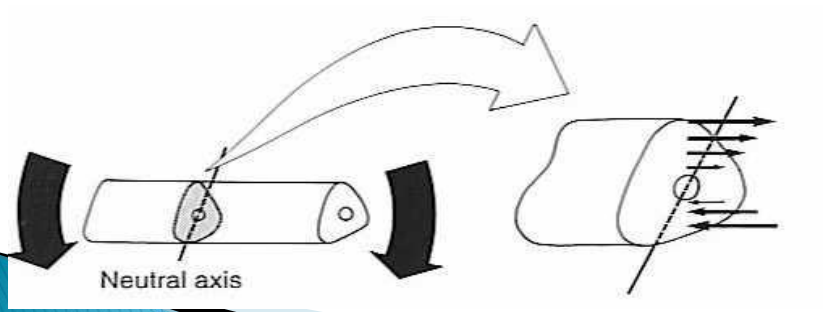
- Load is applied parallel to the surface of the structure and shear stress and strain result inside the structure.
- Deformation = angular manner.
- **Most often seen in Cancellous bone.**
- **Cortical bone**= withstands greater stress than strain than shear i.e. 190, 130, 70 M Pa respectively.
- Direction of stress failure results in general in stable fracture.

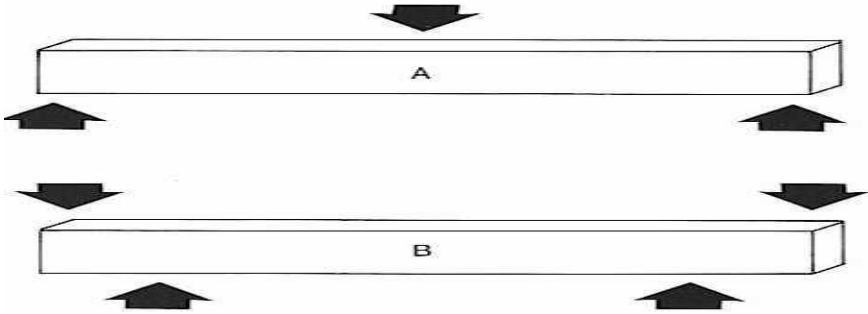


THANKS

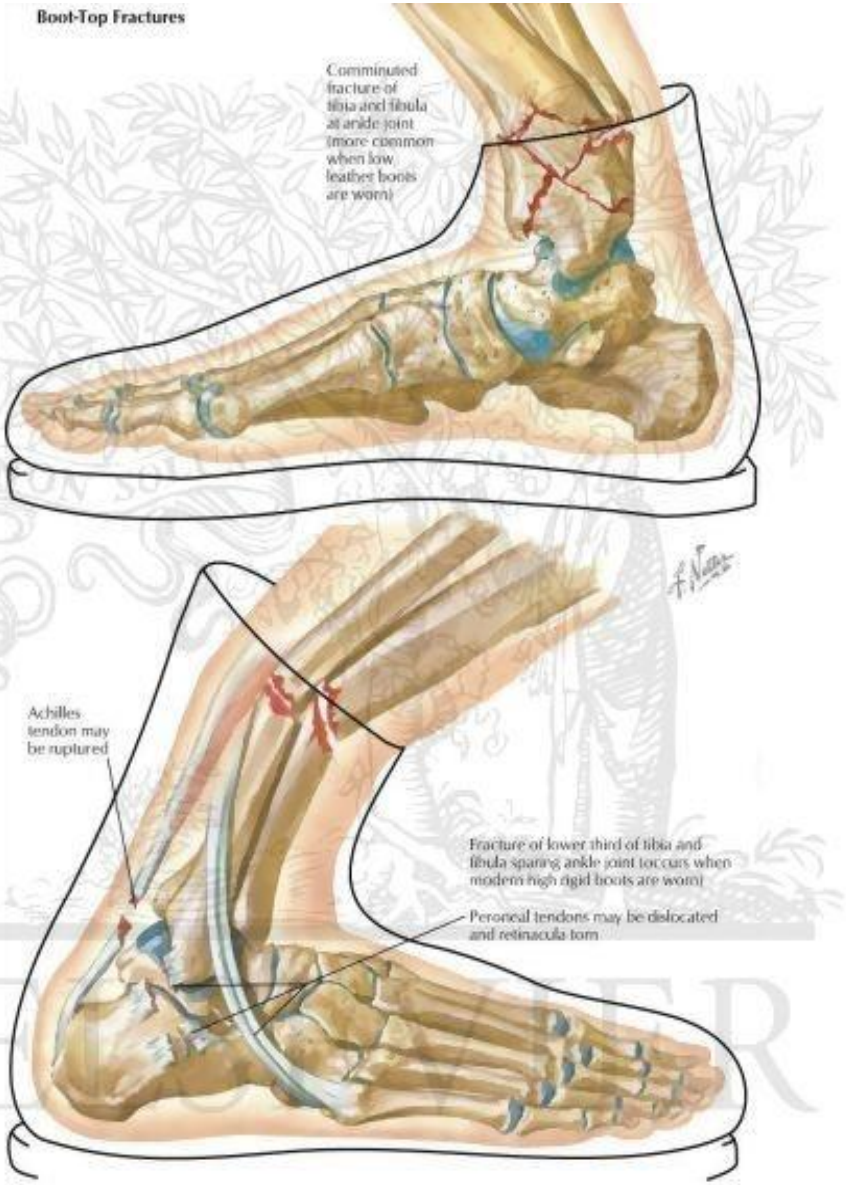
Bending

- Loads are applied to a structure in a manner that causes it to bend about an axis.
- Combination of tension and compression.
- Tensile stresses and strains on one side and compressive stresses and strains on other side.
- Three point bending= three forces acting to produce moments. **Bone breaks at the point of application of the middle force.**
- **E.g. boot top fracture** in skiers seen in Proximal tibia ,distal tibia and foot.
- **Four point bending= two force couples produce 2 equal moments.**
- Structure breaks at weakest point.
- **E.g. manipulation of postsurgical stiff knee joint.**





(3-point vs. 4-point)


Boot-Top Fractures
Comminuted fracture of tibia and fibula at ankle joint (more common when low leather boots are worn)
Achilles tendon may be ruptured
Fracture of lower third of tibia and fibula sparing ankle joint (occurs when modern high rigid boots are worn)
Peroneal tendons may be dislocated and retinacula torn
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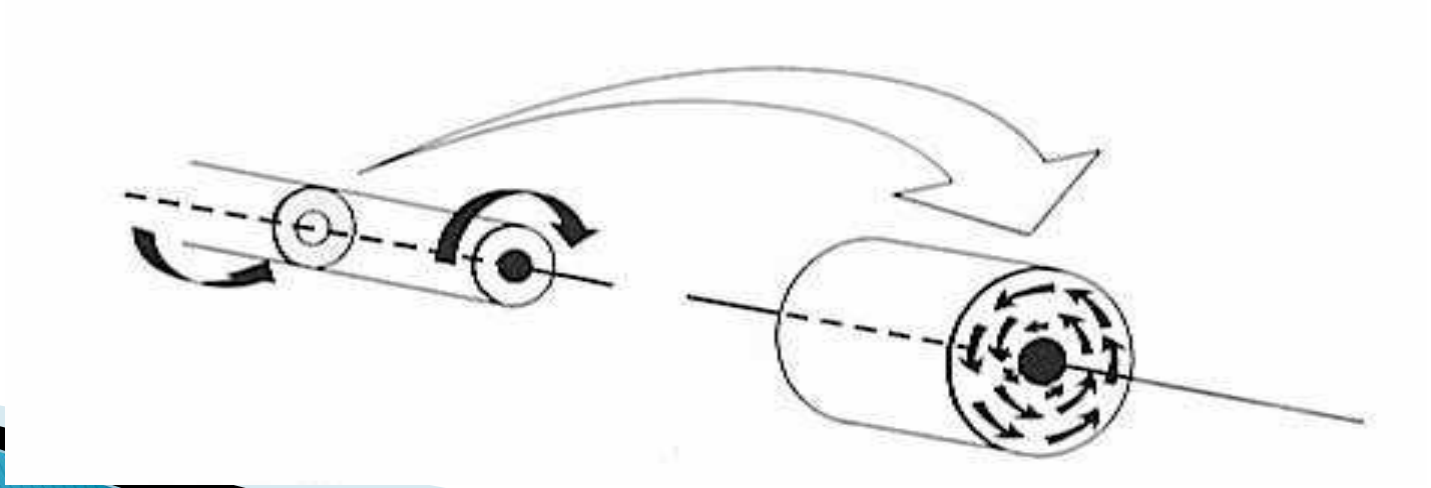
torsion

- load is applied to structure that causes it to twist about an axis and torque is produced within the structure.
- **Combination of shear, tension and compression.**
- Initial crack parallel to the neutral axis, second crack along plane of maximal tensile stress.



Combined loading

- Walking , jogging = complexity of the loading patterns.

Normal walking:

heal strike- compressive

Stance phase-tensile

Push off- compressive

Later phases- shear stresses.

JOGGING:

- Toe strike- compressive
- tensile – push off
- More stresses and strains on tibia from slow walking to jogging.

Influence of Muscle Activity on stress distribution within bone

- Muscle contractions alter the stress distribution.
- Decrease or eliminate tensile stress on bone by producing compressive stress.
- E.g. Compression on anterior surface / tension on posterior surface.
- Increases bone strength.

Strain Rate Dependency in Bone

- 1::: **Showed Viscoelastic material** –but behaviour varies with the rate it is loaded
- 2:::: **Stiffer** – loads applied at high rates, but also stores more energy
- Bone stronger for brisk walking as compared to slow walking i.e. 30 % more.
- But implications of brisk loading increase chances of for fractures and the type of secondary damage.

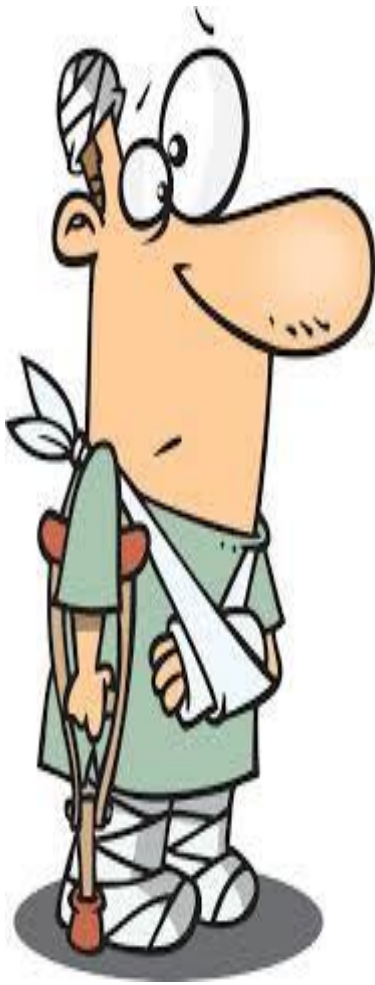
- **Low loading rate=if resulted in fracture then** energy dissipation through formation of single crack fracture.

  bones and soft tissues relatively intact and no displacement of bony fragments.
- **High loading rate:**

  Greater energy ,more for single crack,

  Comminution of bone and extensive soft tissue damage.
- Three general categories depending upon amount of energy released.

1) **Low energy: ski fracture**
2) **High energy: automobile accidents**
3) **Very high energy fractures: high velocity gun shot**



Fatigue Rate of Bone under repetitive loading

- Fatigue Produced by few repetitions of a high load or numerous repetitions of a low load.
- **Bone fatigues** rapidly when the load approaches its "yield' point.
- **Fatigue determined by**: – Amount of load – number of repetitions – number of repetitions in a given time period (frequency of load).
- **Remodelling process becomes outpaced by the fatigue process.**
- Activity results in muscle fatigue that changes how bone is loaded.

- Resistance to fatigue is greater in compression than in tension.
- 5000 cycles of experimental loading= number of steps in 10 miles of running.
- 1 million cycles correspond to = 1000 miles.
- A total distance of less than 1000 miles could cause fracture of cortical bone tissue.
- Common sites: Lumbar vertebrae, the femoral head, and proximal tibia.

Influence of bone geometry on biomechanical behaviour.

- 1::In ***tension and compression*** : load to failure and stiffness are proportional to the **cross-sectional area of bone**.
- Larger the area , the stronger and stiffer will be the bone.
- ***2::In bending:*** cross section of the bone as well as Distribution of bone around a central/ neutral axis= **AREA MOMENT OF INERTIA or Length of the bone**

- Larger moment of inertia and increased length = stronger and stiffer bone in bending.
- Long bones of skeleton.
- ***In Torsion:*** same factors as in bending, **polar moment of inertia**.
- Proximal and distal sections of tibia= fracture common in distal portion.
- ***Fracture healing:*** **callus formation(Woven Bone).= increased area and polar moment of inertia.**

- Certain surgical procedures or bony defects in which weakness in the bone setermined especially in torsion.
- **Types of defects**

  stress raisers = **length less than the diameter of the bone** = a small piece of bone removed or screw inserted = stress prevented from being distributed evenly = decrease concentration of stress around the defect. 60% decrease in torsional loading.

  open section defects = **length exceeds the bone diameter. e.g.** cutting a slot during bone biopsy. Outer section no longer continuous.

Reduced ability to sustain loads especially torsional.90% reduction in torsional loading.

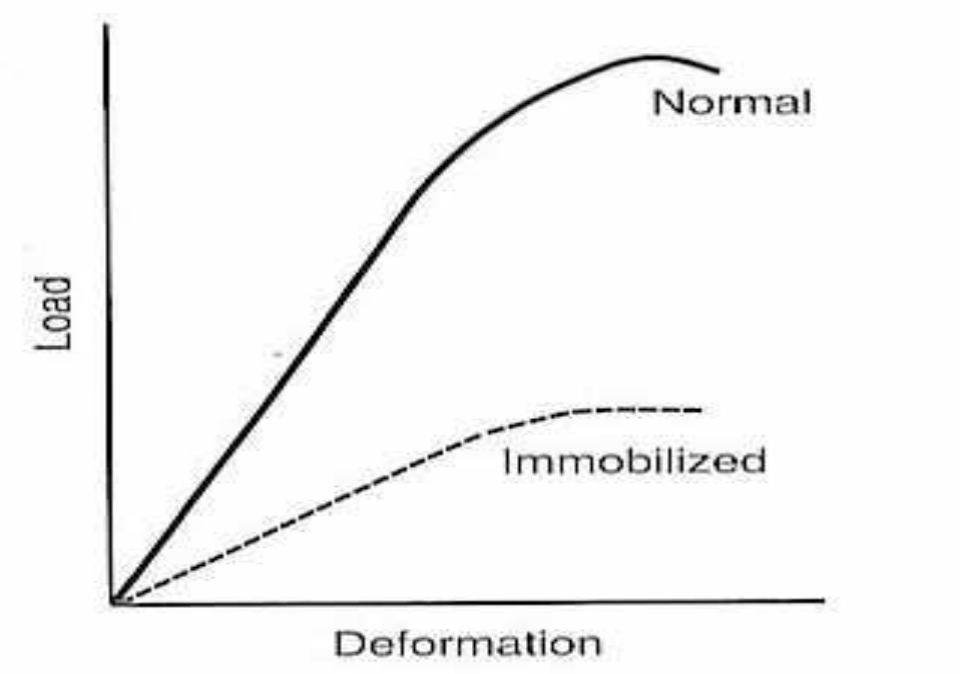
THANKS

Bone Remodeling

- **Wolff's Law – Remodeling of bone is influenced and modulated by mechanical stress.**
- Bone will alter its size, shape and structure to meet the mechanical demands placed on it.
- Accomplished by either: – Gravity (influenced by body weight) – Muscle activity
- Positive correlation between bone mass and body weight.
- Weightlessness during space travel.

- Careful consideration during facture healing:
  – Immobilization – **Metal implants**
- Bed rest bone mass decrease by 1% per week.
- **Immobilization**= decrease in strength and stiffness of bone.
- Rigid plates should be removed shortly after fracture has healed.

Fatigue Curve (Load vs. Repetition)



Degenerative Changes in Bone associated with Aging.

- Ageing process= loss of bone density= Longitudinal Trabeculae become thinner and transverse are absorbed.
- Marked reduction in Cancellous bone and thinning of cortical bone.
- Brittleness and reduced energy storage capacity with progressive age.
- Many factors affect the bone loss.
- **Can be prevented by :Regular physical activity.**

Types of Bones

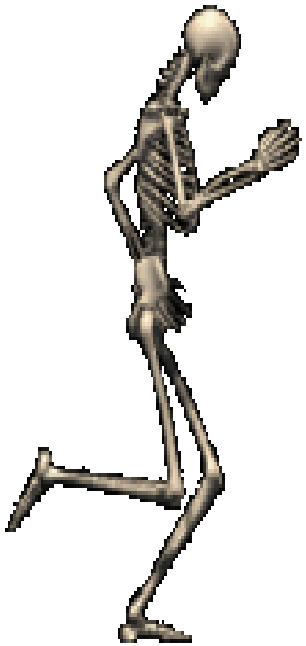
- Axial Skeleton
- Appendicular Skeleton
- Short Bones
- Flat Bones
- Irregular Bones
- Long Bones
- Articular Cartilage

Bone Growth & Development

- **Longitudinal Growth**
  - At epiphyses or epiphyseal plates
  - Stops at 18 yrs of age (approx.)
    - can be seen up to 25 yrs of age
- **Circumferential Growth**
  - Diameter increases throughout lifespan
  - Most rapid growth before adulthood
    - Periosteum build-up in concentric layers

Bone Response to Stress

- Wolf's Law
  - Indicates that bone strength increases and decreases as the functional forces/stress increase and decrease on bone.
- **Bone Modeling and Remodeling**
  - Mechanical loading causes strain
  - **Bone Modeling**
    - If Strain > modeling threshold, then bone modeling occurs.

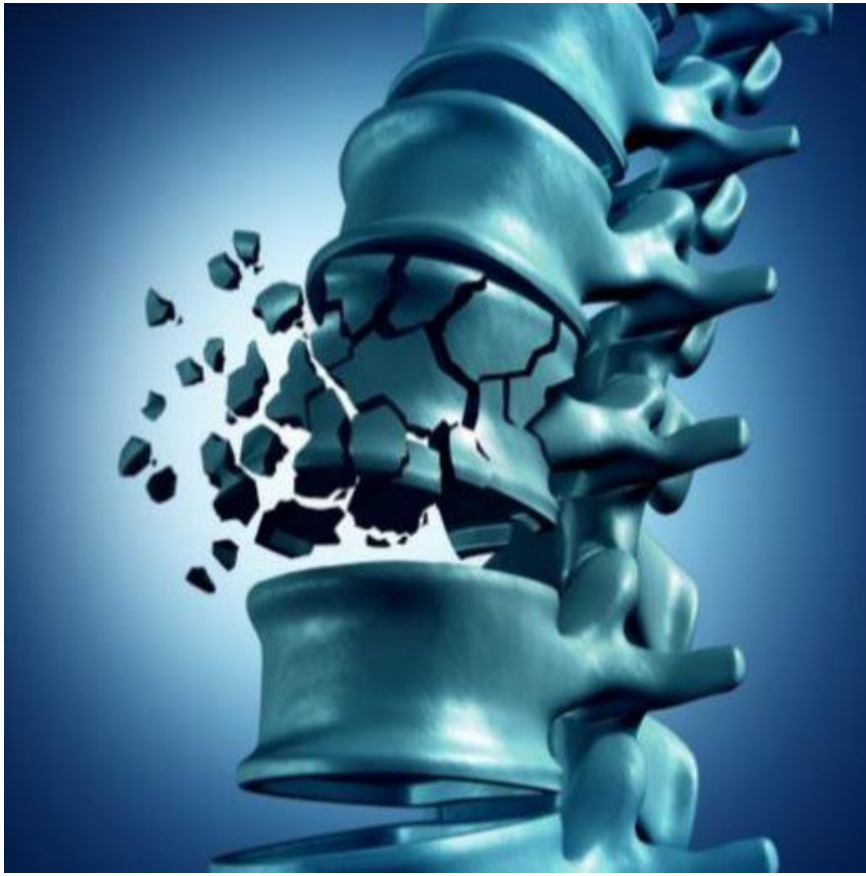


Bone Response to Stress

- **Bone Remodeling**
  - If Strain < lower remodeling threshold, then bone remodeling occurs.
    - at bone that is close to marrow
  - "**conservation mode**": no change in bone mass
  - "**disuse mode**": net loss of bone mass
- **Osteocytes: imp role in bone loss.**

Bone Response to Stress

- Bone mineral density generally parallels body weight
  - Body weight provides most constant mechanical stress
  - Determined by stresses that produce strain on skeleton
  - **Think:** weight gain or loss and its effect on bone density



Bone Hypertrophy

- An increase in bone mass due to predominance of osteoblast activity.
- Seen in response to regular physical activity
  - Ex: tennis players have muscular and bone hypertrophy in playing arm.
- The greater the habitual load, the more mineralization of the bone.
  - Also relates to amount of impact of activity/sport

Bone Atrophy

- A decrease in bone mass resulting form a predominance of osteoclast activity
  - Accomplished via remodeling
  - Decreases in:
    - Bone calcium
    - Bone weight and strength
- Seen in bed-ridden patients, sedentary elderly, and astronauts

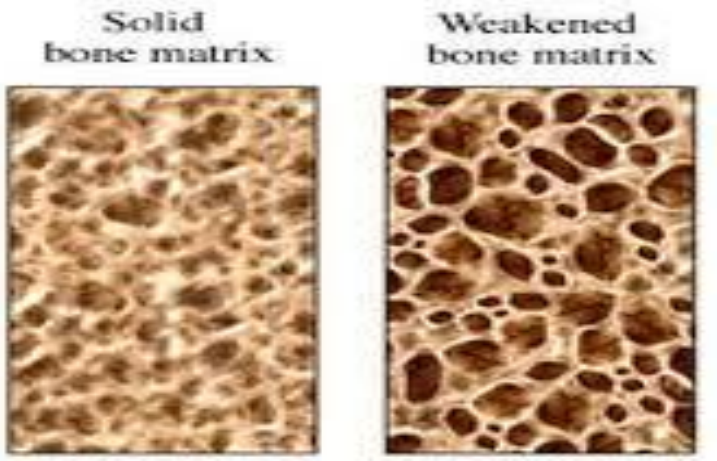
Bone Atrophy

- Affect on Astronauts
  - Overall cause is unknown
  - Tend to have negative calcium loss
    - Decrease of intestinal Ca^{2+} absorption
    - Increase in Ca^{2+} excretion
  - **One hypothesis:**
    - Changes in bone blood flow due to difference in gravitational field

THANKS

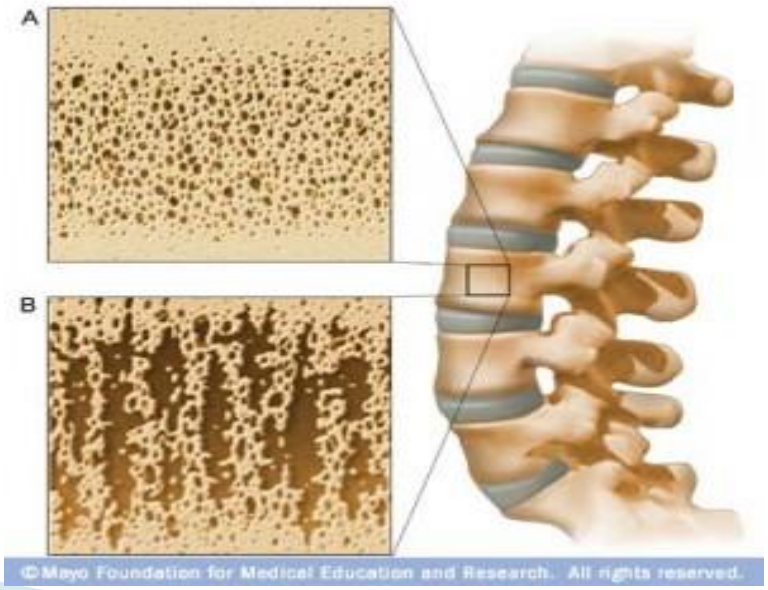
Osteoporosis

- Porous bone (loss of bone density) resulting from decreased bone mass and micro-damage to the bone structure that results in a susceptibility to fracture
- metabolic bone disease, Large prevalence, most common in postmenopausal women.
- **Etiology** :- Negative calcium balance….diet – Hormonal changes (estrogen) – Sedentary lifestyle



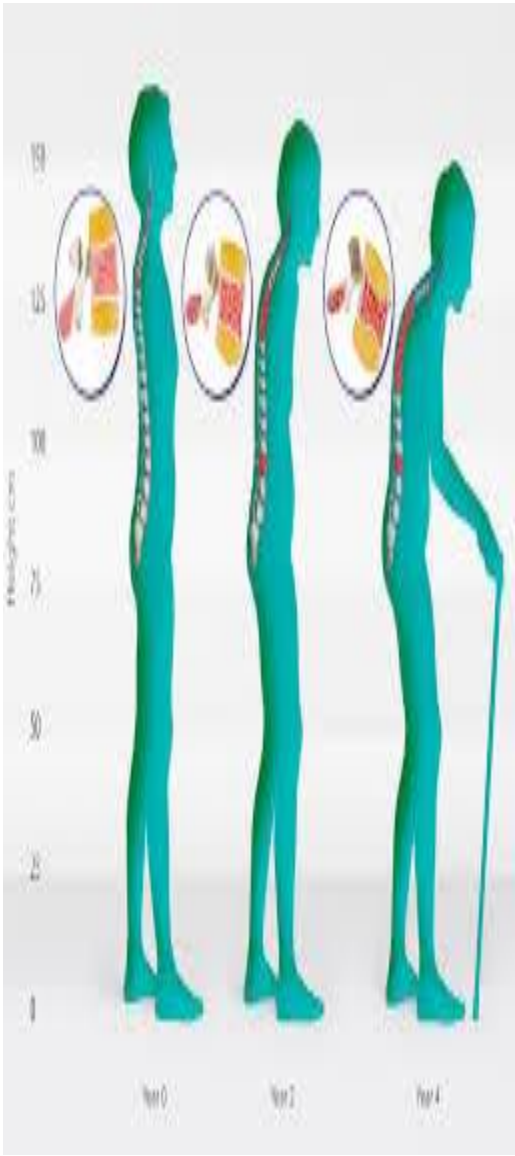
Osteoporosis

- A disorder involving decreased bone mass and strength with one or more resulting fractures.
- **Found in elderly**
  - Mostly in postmenopausal and elderly women
  - Causes more than 1/2 of fractures in women, and 1/3 in men.
- Begins as osteopenia



Osteoporosis

- Type I Osteoporosis = Post-menopausal Osteoporosis
  - Affects about 40% of women over 50
  - Gender differences
    - Men reach higher peak bone mass and strength in young adulthood
- Type II Osteoporosis = Age-Associated Osteoporosis
  - Affects most women and men over 70



Osteoporosis

- **Symptoms:**
  - Painful, deforming and debilitating crush fractures of vertebrae
    - Usually of lumbar vertebrae from weight bearing activity, which leads to height loss
      - Estimated 26% of women over 50 suffer from these fractures

Osteoporosis

- Men have an increase in vertebral diameter with aging
  - Reduces compressive stress during weight bearing activities
  - Structural strength not reduced
  - Not known why same compensatory changes do not occur in women

Female Athlete Triad

- 1) Eating Disorders affect 1-10% of all adolescent and college-age women.
  - Displayed in 62% female athletes
    - Mostly in endurance or appearance-related sports
- 2) Amenorrhea is the cessation of the menses.
- 3) Osteoporosis is the decrease in bone mass and strength.

Amenorrhea & Osteoporosis

- Primary Amenorrhea
- Secondary Amenorrhea
- Prevention
- Impact activities and moderate intensity resistance training beneficial.
- 3 times per week for at least 10-20 minutes, twice a day.

Anorexia Nervosa

- Is an eating disorder characterized by refusal to maintain a healthy body weight and an obsessive fear of gaining weight, often couple with a distorted self image which may be maintained by various cognitive biases.

Bulimia nervosa

- Is an eating disorder characterized by restraining of food intake for a period of time followed by an over intake or binging period that results in feelings of guilt and low self-esteem. Self created vomiting.

Osteoporosis Treatment

- Hormone replacement therapy
- Estrogen deficiency damages bone
- Increased dietary calcium
- Lifestyle factors affect bone mineralization
- Risk factors for osteoporosis:

Osteoporosis Treatment

- Future use of pharmacologic agents
  - May stimulate bone formation
  - Low doses of growth factors to stimulate osteoblast recruitment and promote bone formation.
- Best Bet:
  - Engaging in regular physical activity
  - Avoiding the lifestyle (risk) factors that negatively affect bone mass.

Common Bone Injuries

- Fractures
  - Simple
  - Compound
  - Avulsion
  - Spiral
  - Bending Moment
- Stress Reaction
- Impacted
- Depressed
- Greenstick
- Stress

Common Bone Injuries

- Bone stronger in resisting compression than tension, so the side loaded with tension will fracture first.
  - Acute compression fractures (in absence of osteoporosis) is rare
- Stress Fractures occur when there is no time for repair process (osteoblast activity)
  - Begin as small disruption in continuity of outer layers of cortical bone.

Epiphyseal Injuries

- Include injuries to:
  - Cartilaginous epiphyseal plate
  - Articular cartilage
  - Apophysis
- Acute and repetitive loading can injure growth plate
  - Leads to premature closing of epiphyseal junction and termination of bone growth.

Epiphyseal Injuries

- Osteochondrosis
  - Disruption of blood supply to epiphyses
  - Associated with tissue necrosis and potential deformation of the epiphyses.
- Apophysitis
  - Osteochondrosis of the apophysis
  - Associated with traumatic avulsions