Bone Mechanics

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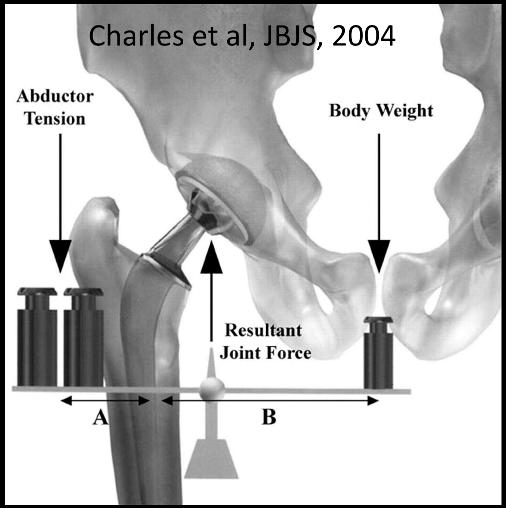
Orthopaedic Trauma Institute
UCSF + SAN FRANCISCO GENERAL HOSPITAL

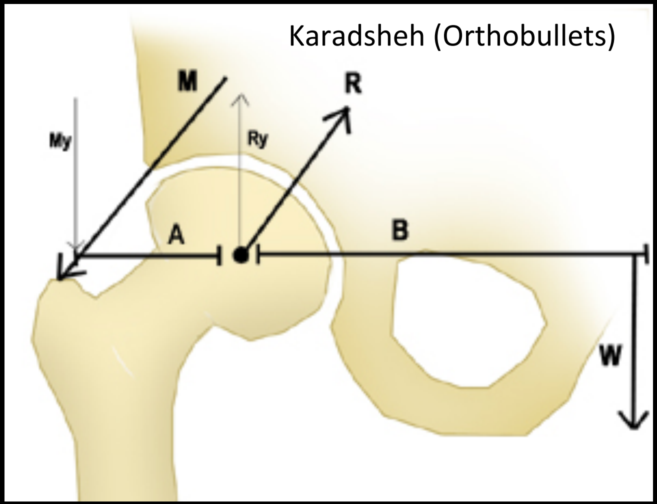
Bones

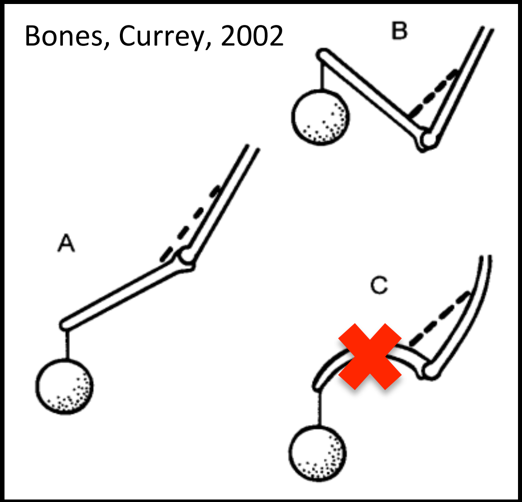
- Mechanical Function
- Adaptation to Loads
- Types of Mechanical Loading
- Mechanical Properties
- Causes of Fracture
- Fracture Risk Factors
- Research

Mechanical Function

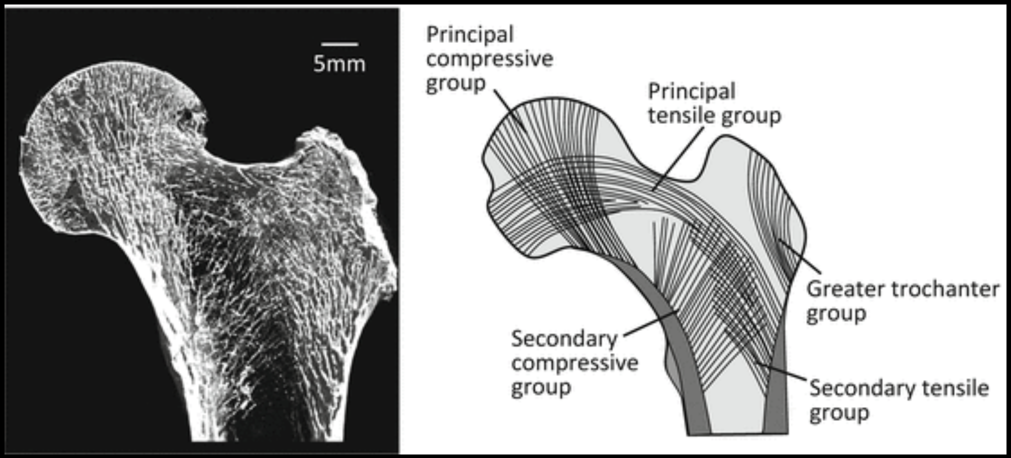
- The skeleton plays a critical structural role in bearing functional loads
  - Weight-bearing and muscle loads
  - Bones act as levers (rigid bodies) to help our musculoskeletal system perform a task

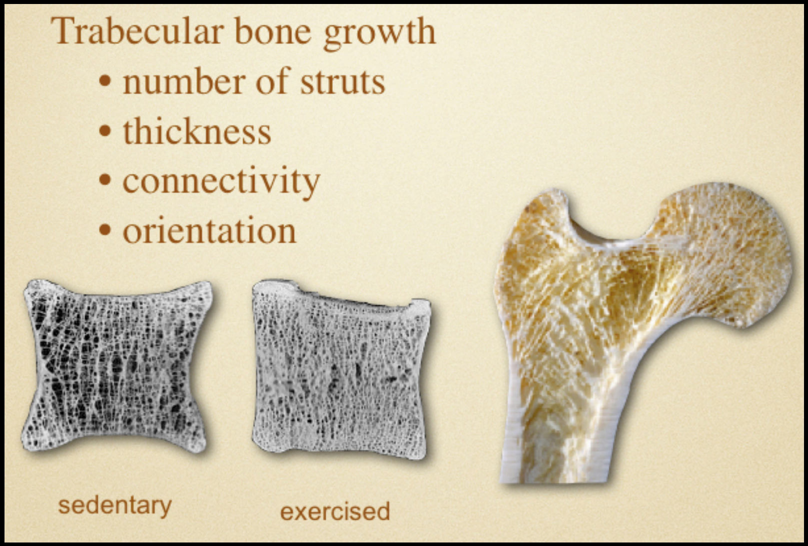


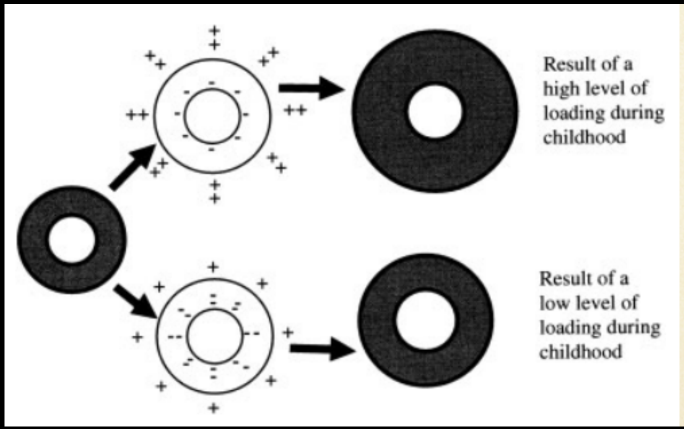


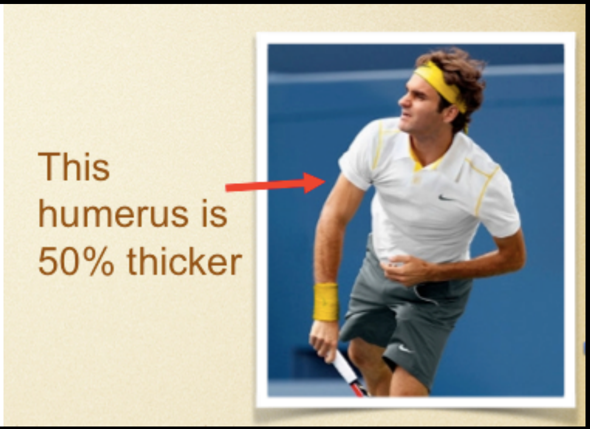


Structural Adaptation to Loads





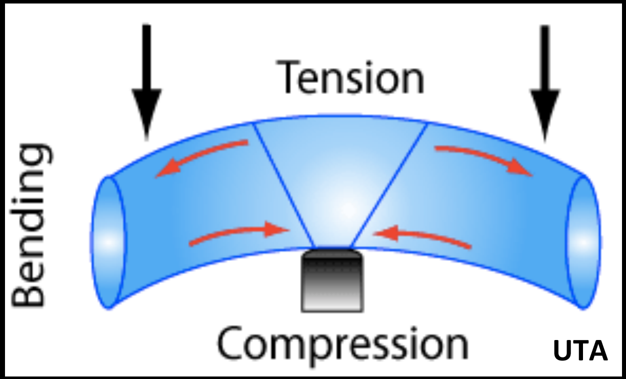


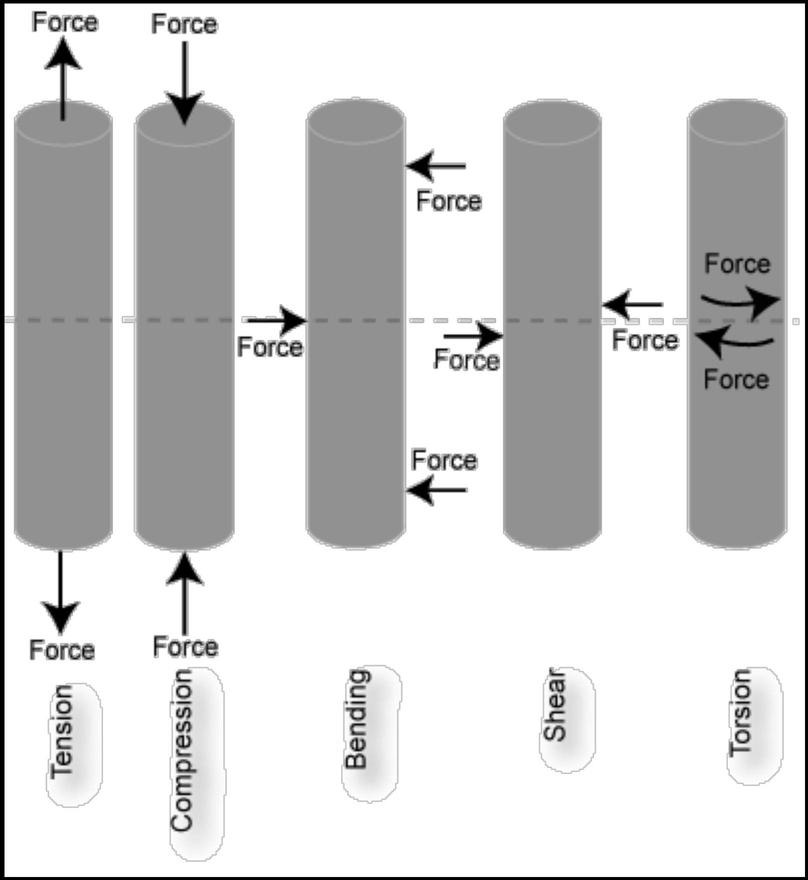


Simple Loads

Types of mechanical loading

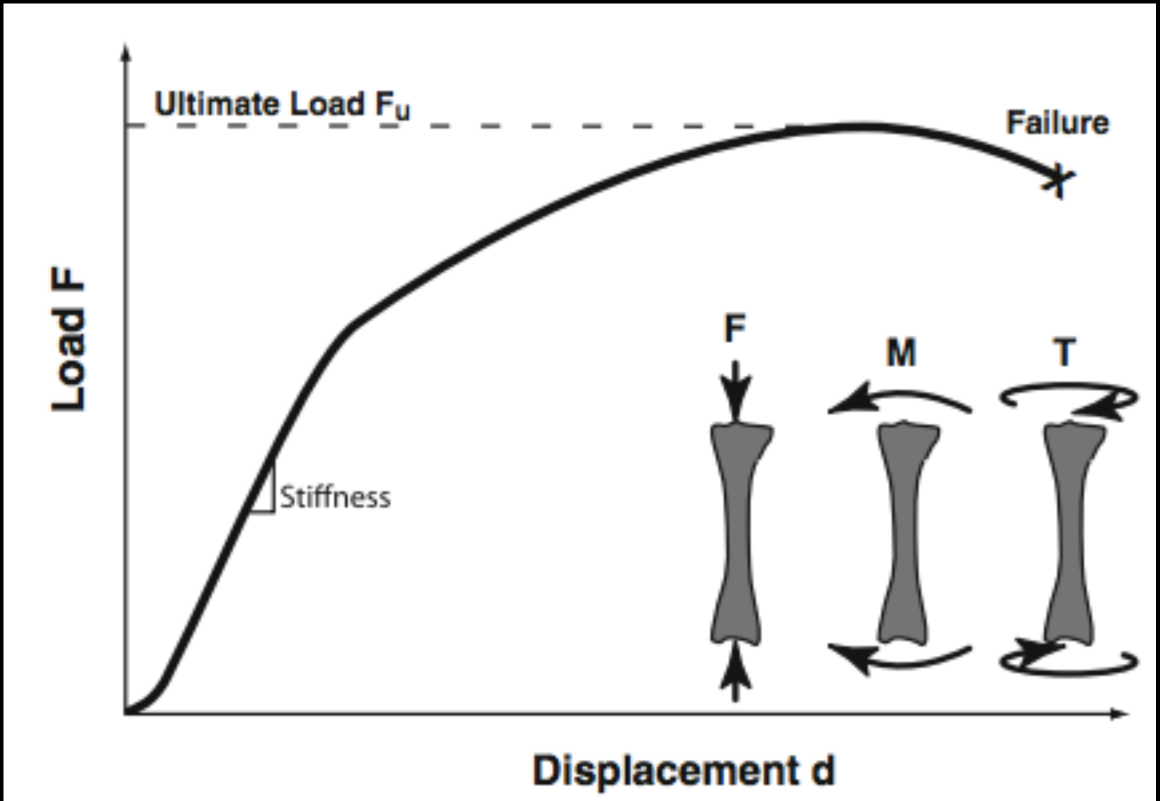
- Compression/Tension
- Bending
- Shear
- Torsion





Bone Mechanical Properties

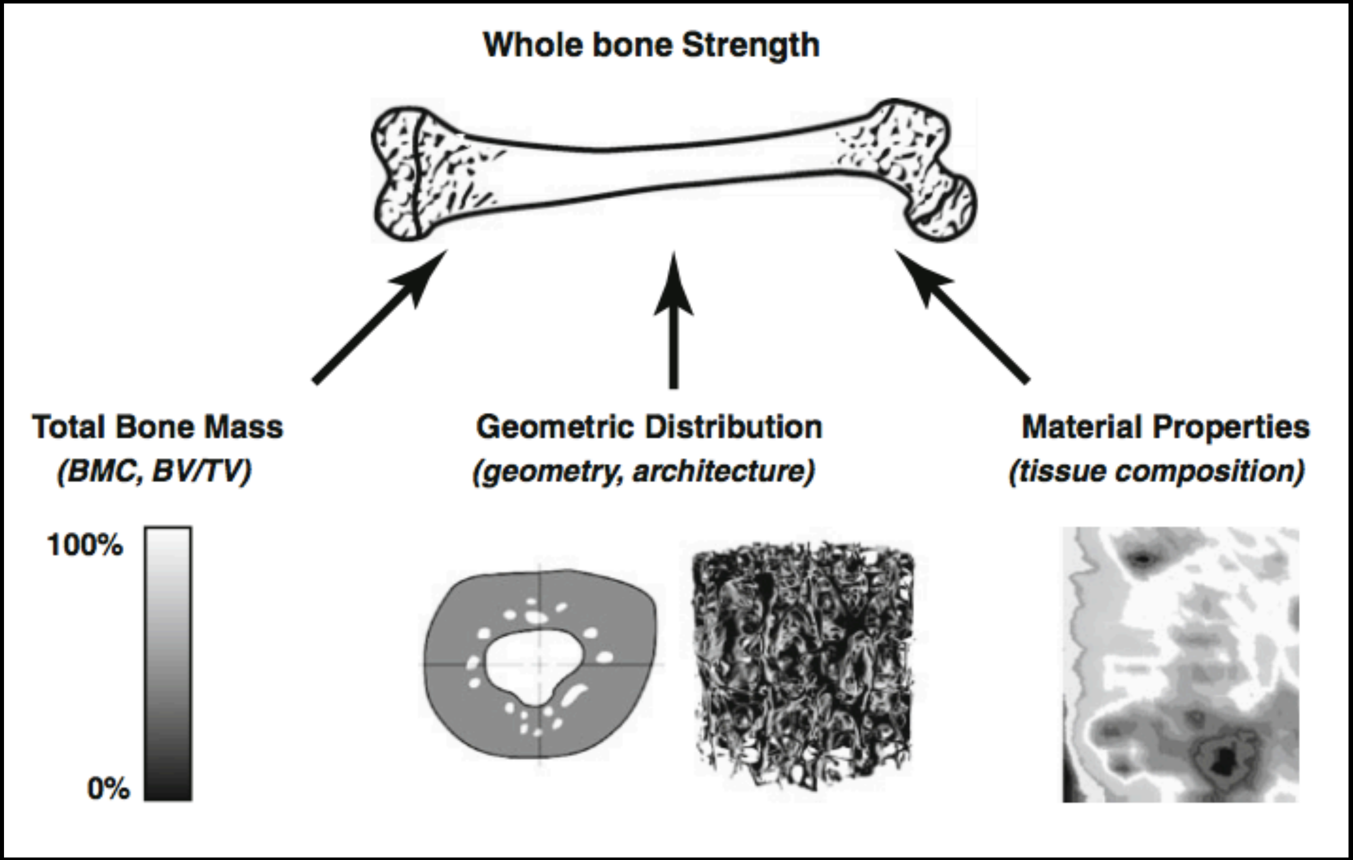
- **Strength** – load bone can bear before breaking
- **Stiffness** – deformation under load



Cole and van der Meulen, 2011

Bone Mechanical Properties

- **Strength** – load bone can bear before breaking

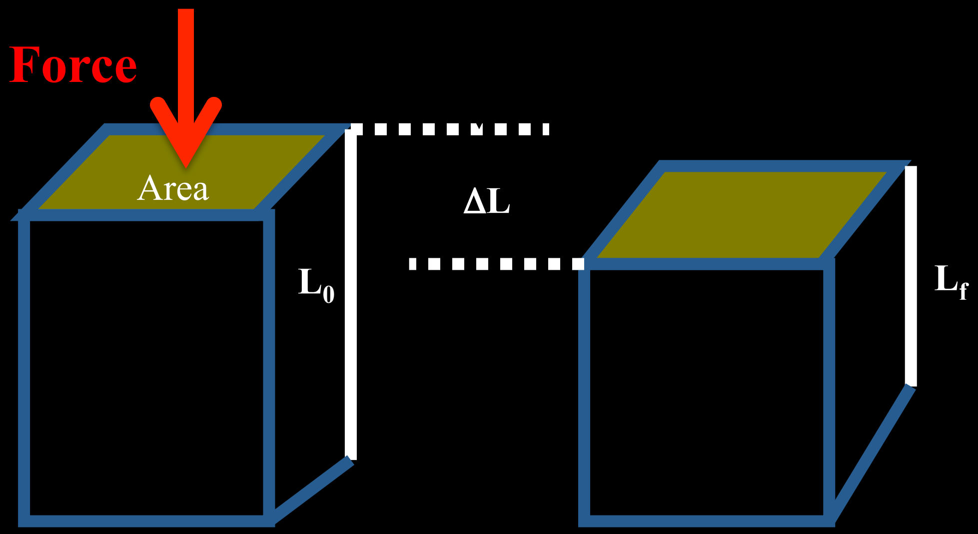


Cole and van der Meulen, 2011

Basic Mechanics

Stress & Strain

– Account for the geometry



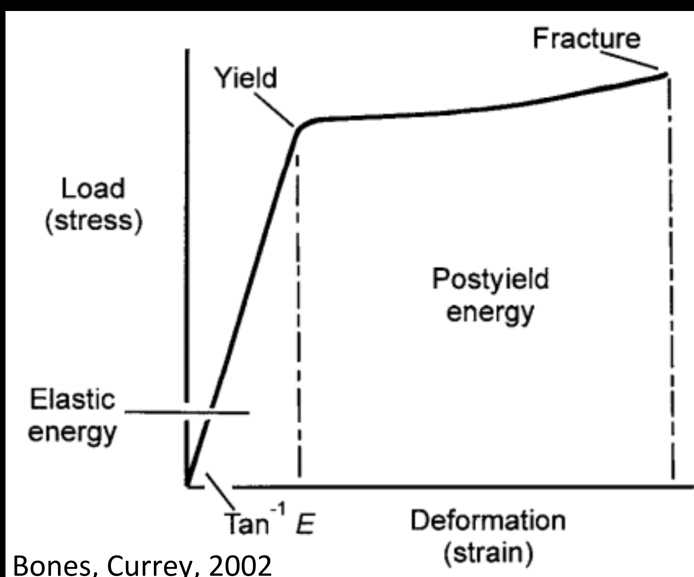
Stress = Force/Area

Strain = $\Delta L / L_0$

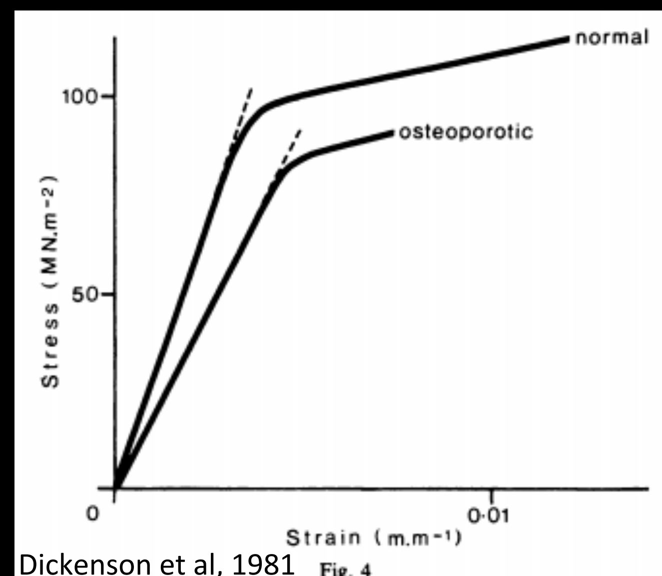
Adapted from Le, 2009, OTA

Stress-Strain Curve

- Standardized curves used to help quantify how a material will respond to a given load
  - Yield Stress
  - Ultimate Stress



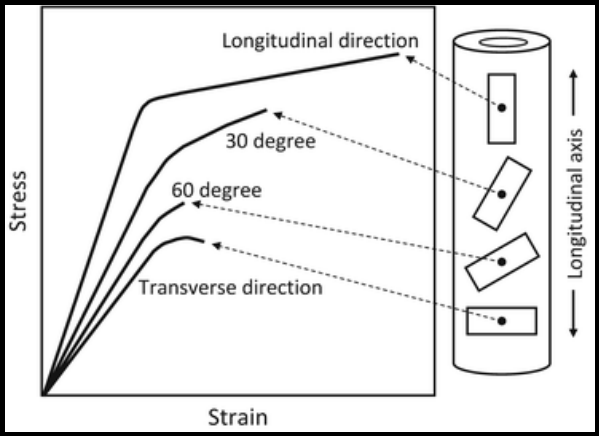
Bones, Currey, 2002



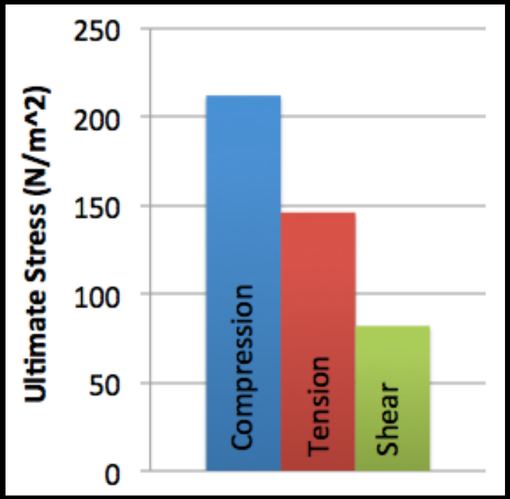
Dickenson et al, 1981 Fig. 4

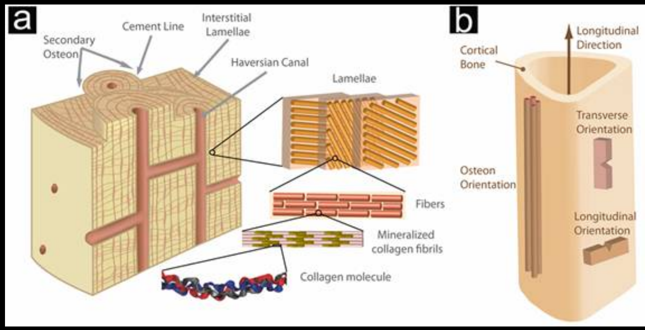
Anisotropy

- Isotropic
  - Same mechanical properties in all directions
  - Metals - stainless steel, titanium
- Anisotropic
  - Mechanical properties dependent upon direction of loading
  - Musculoskeletal tissues: bone, cartilage, muscle, ligament
  - Specifically oriented components



Franklin & Nordin, 1989



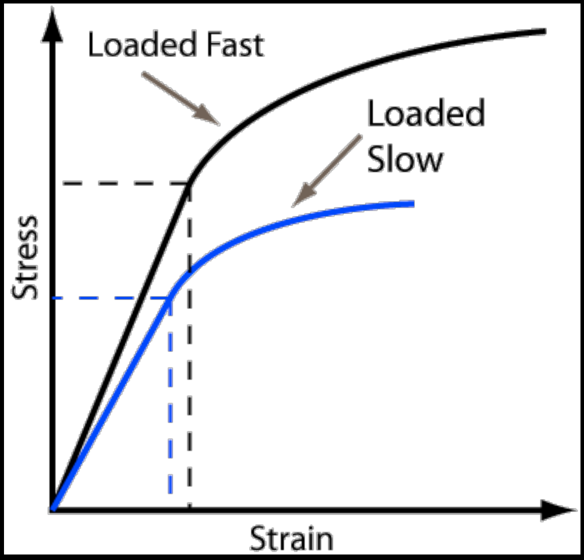


Ritchie, UC Berkeley

Viscoelasticity

- Stress-Strain character dependent upon rate of applied strain (time dependent)
- Viscous and elastic characteristics when undergoing deformation

  ↑ strain rate = ↑ stiffness, ↑ strength, ↑ energy



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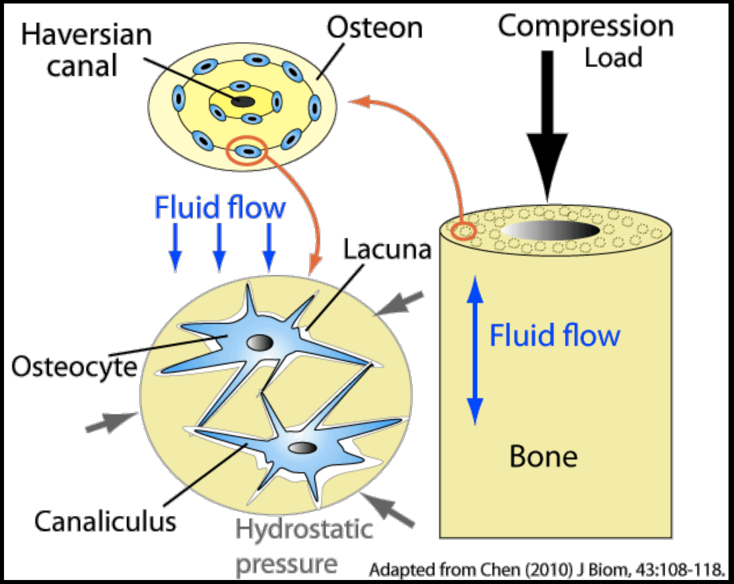
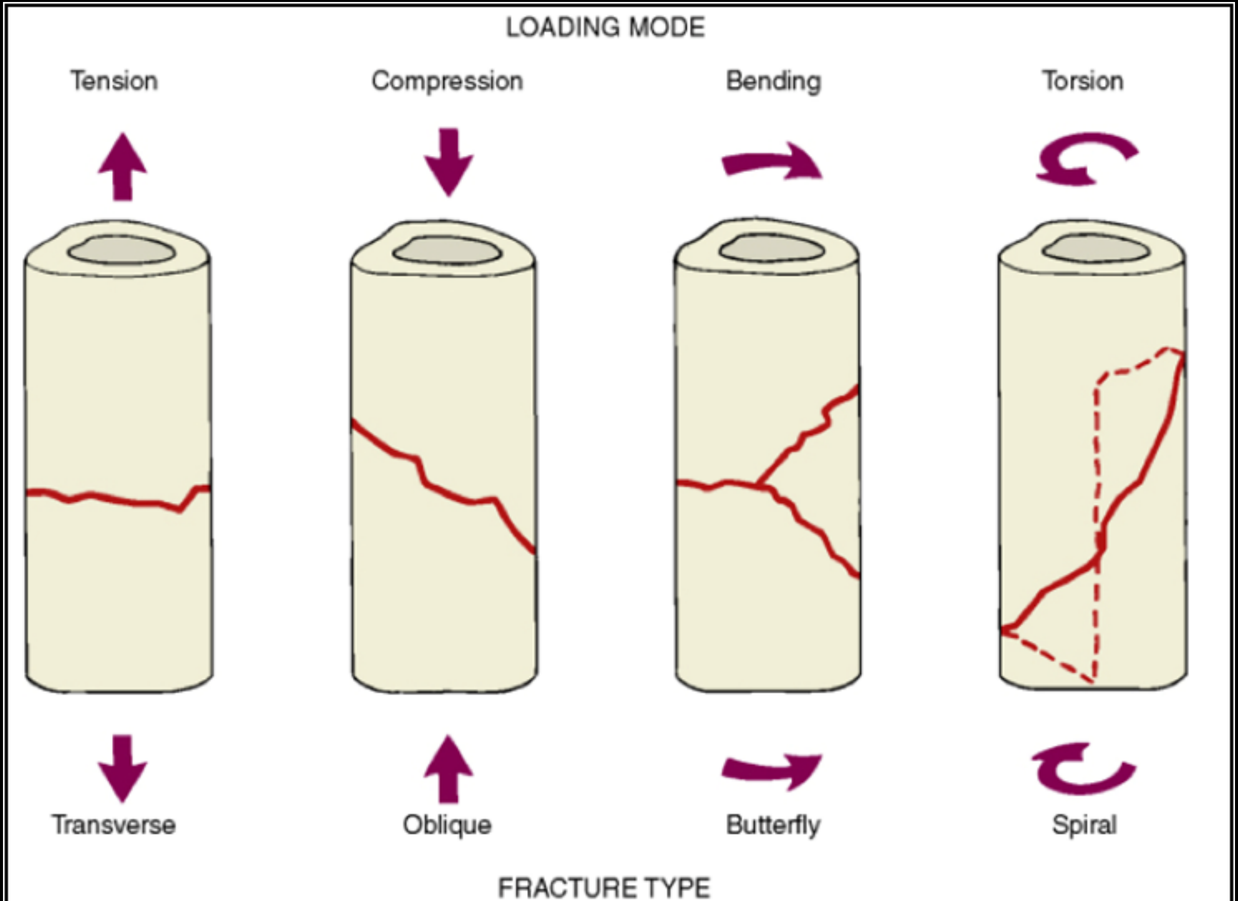


Bone Fractures

Simple Fracture Patterns



Browner et al. 2008

Common Causes of Fracture

1. Trauma
2. Fatigue
3. Pathologic

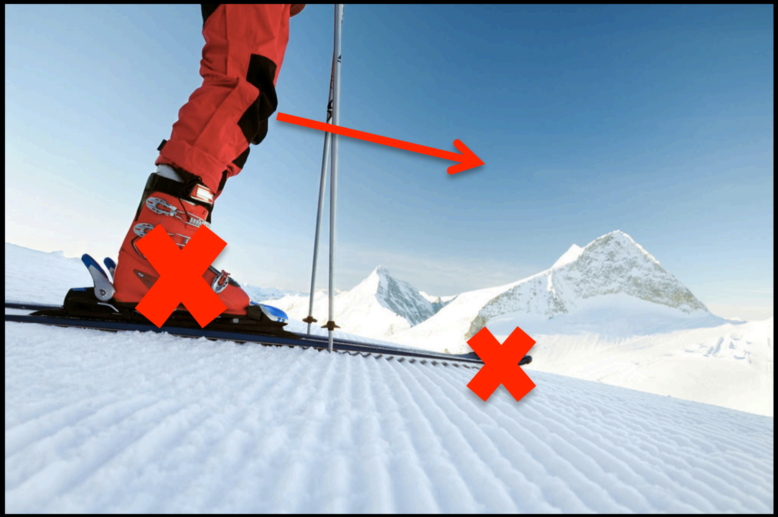
Traumatic Fracture

- Acute
- High energy
- Load exceeds strength of bone

Children's Orthopaedics of Atlanta

Common Examples

- Ski Boot Fracture
  - Falling forward
  - Binding malfunction
  - Loading Mechanism?
    - **Bending? Shear?**
  - 90% non-contact



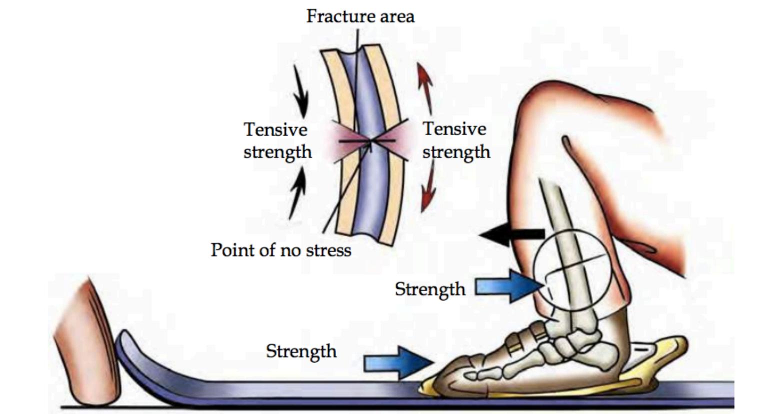
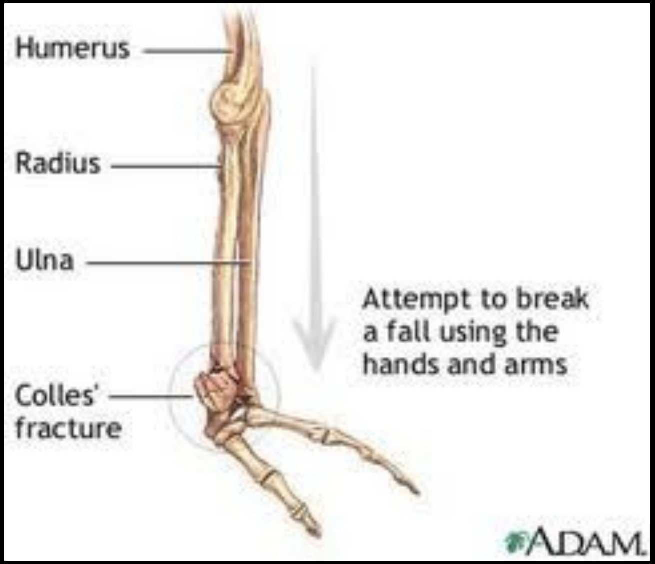


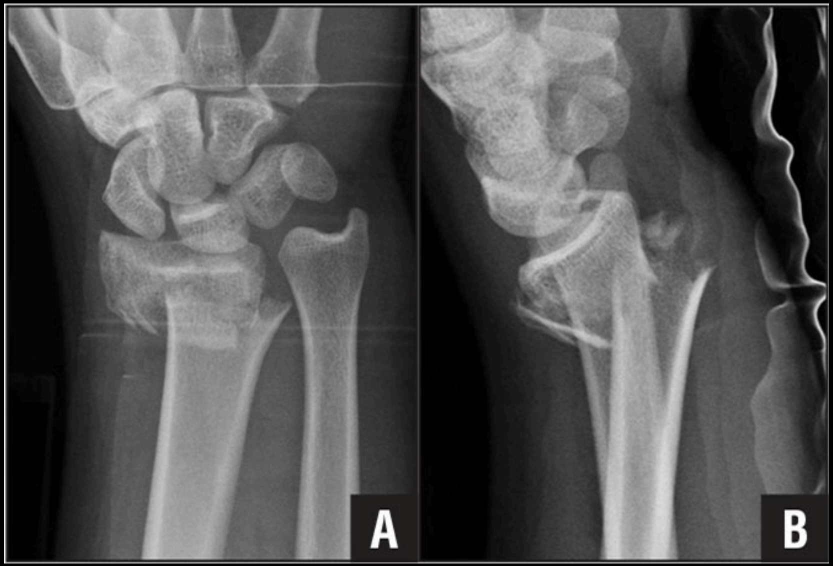
Fig. 1.21. A bending load at three points creates fracture in ski boots and occurs when the ski is detained abruptly. A compressive strength is created in the anterior tibia and a tensile strength is created in the posterior tibia. The tibia fracture is usually on the back. Bankoff (2007, p. 132).

Tibial Fractures in Alpine Skiing and Snowboarding.
Stenroos et al, 2016

Common Examples

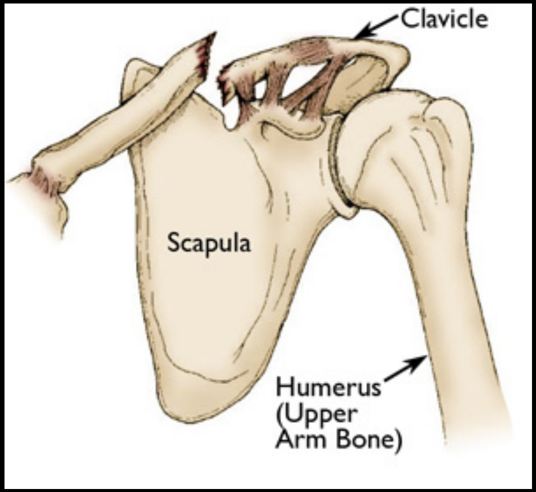
- Distal Radius
  - Falling on an outstretched hand
  - Loading Mechanism?
    - Compression

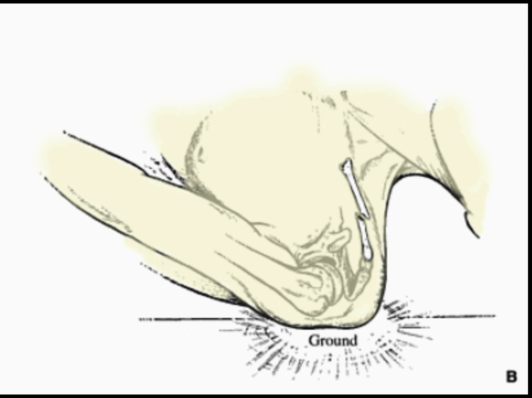


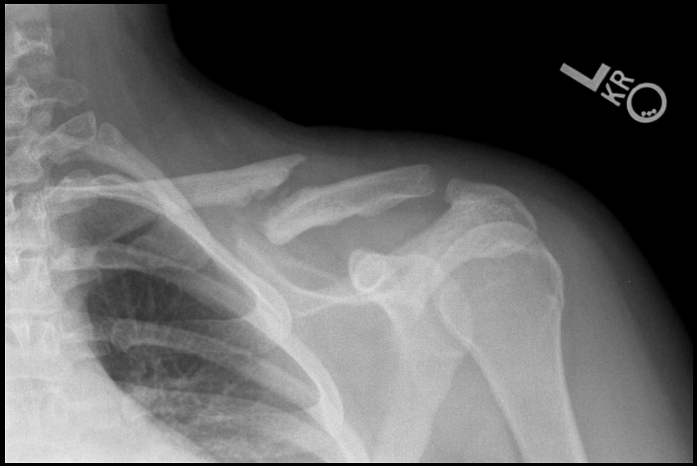


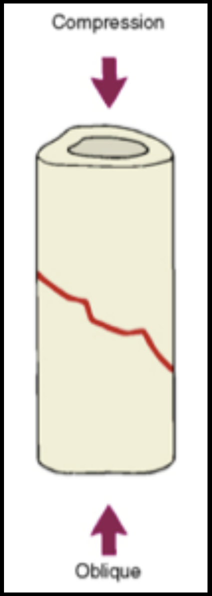
Common Examples

- Clavicle Fracture
  - Loading Mechanism?
    - compression (oblique pattern)



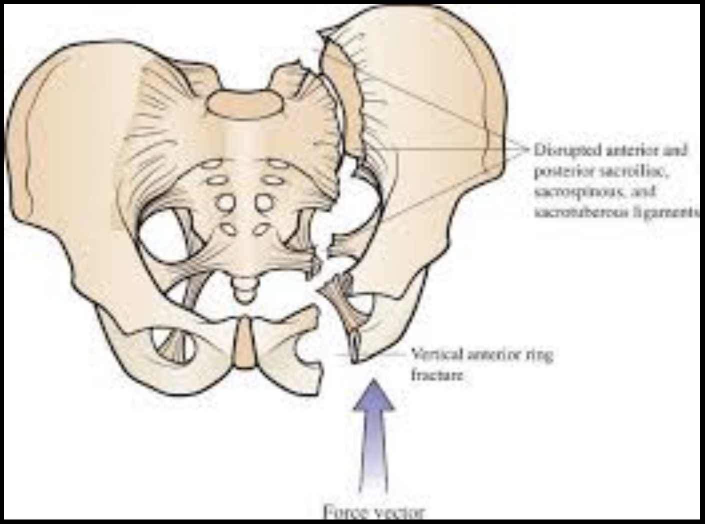


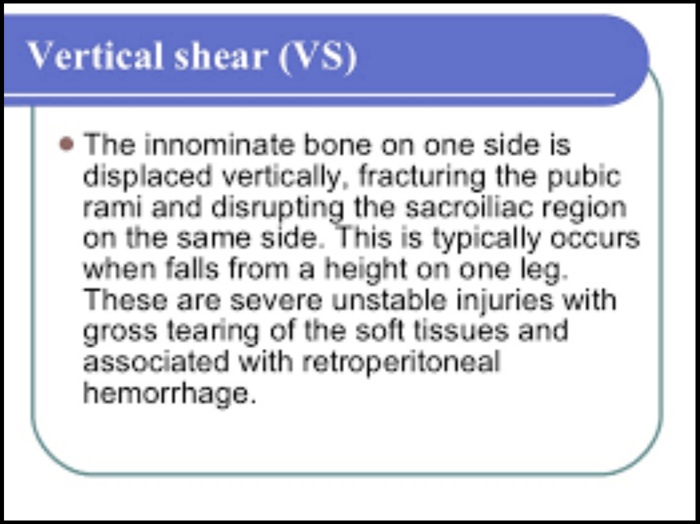


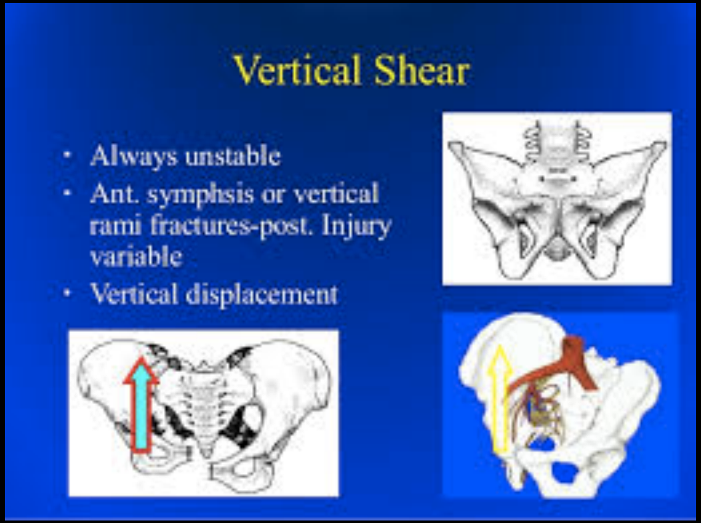


Common Examples

- Pelvis
  - Loading Mechanism?
    - Shear







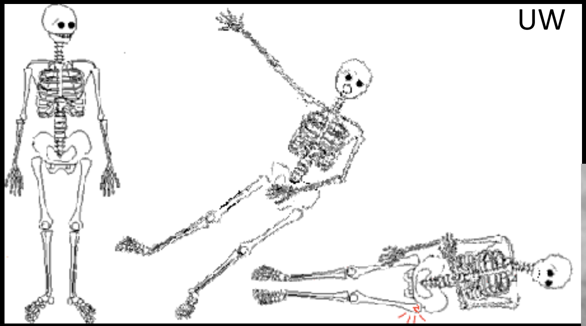
Stress Fractures

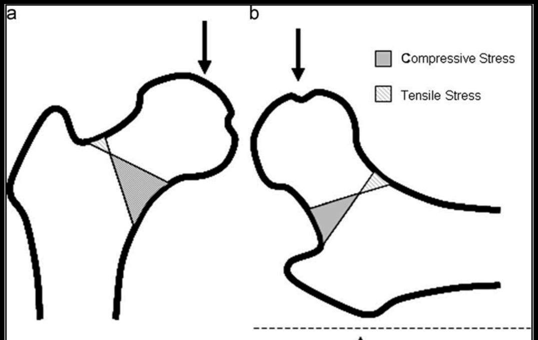
- Hairline/Fissure/Fatigue-induced fracture
  - Overuse injury
  - FATIGUE - result of accumulated trauma from repeated loading (less than strength of bone)
  - Not accidental loads

AAOS OrthoInfo

Pathologic Fractures

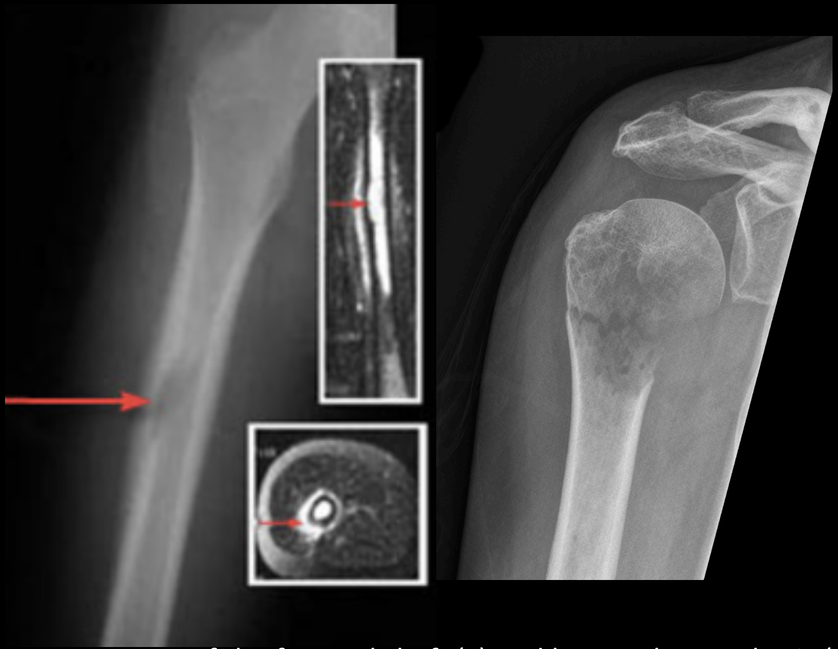
- Caused by condition/disease that led to weak bone
  - Low energy
  - Most common cause – Osteoporosis
  - Other conditions: cancer, infection, bone disorders, bone cyst





De Bakker et al, 2009

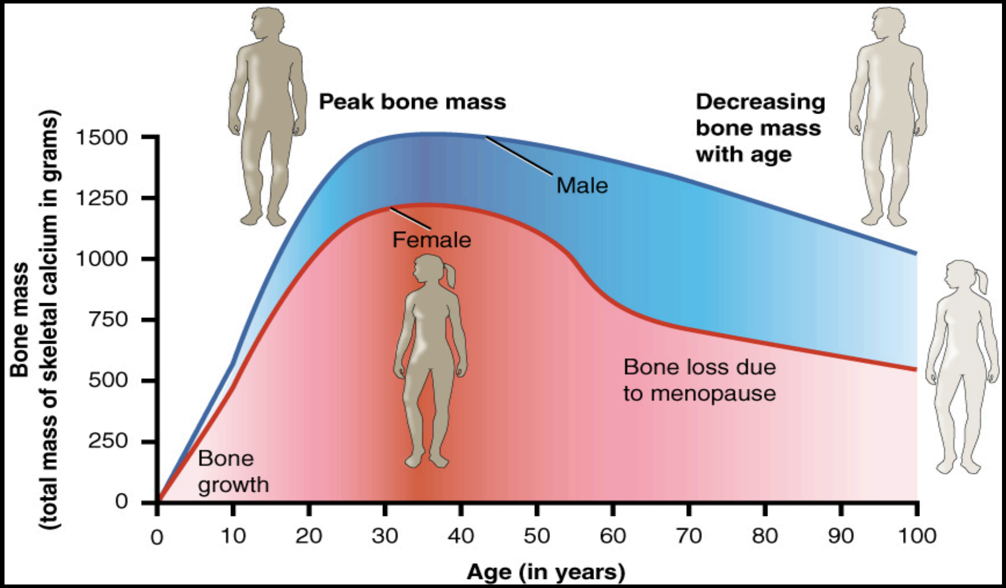
Fragility Fracture



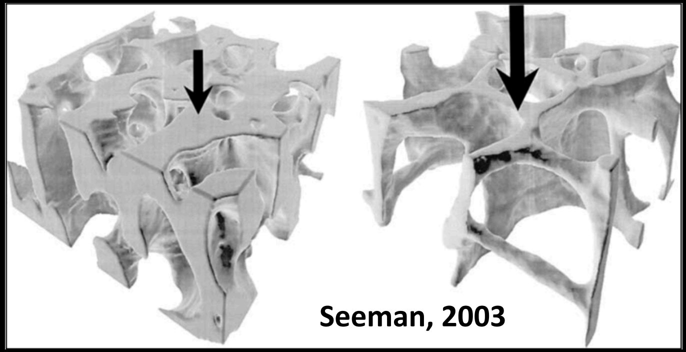
Bone tumors of the femoral shaft (L) and humeral metaphysis (R)
AAOS OrthoInfo

Aging

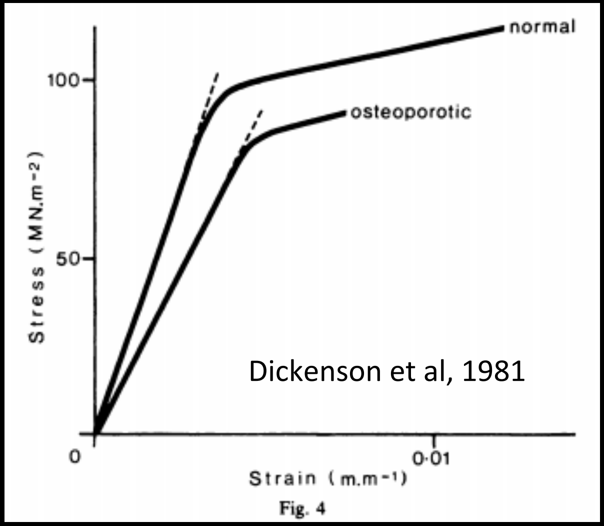
- ↓ bone mass, ↓ strength, ↑brittle = ↑ fracture risk



Anatomy & Physiology, 2013



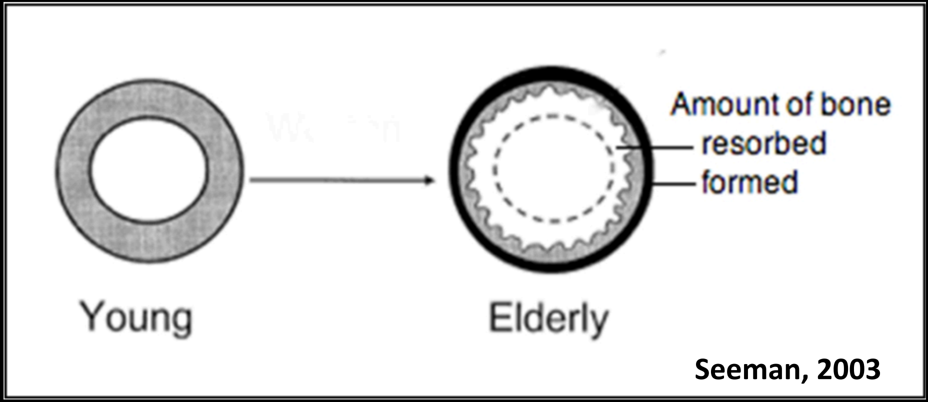
Seeman, 2003



Dickenson et al, 1981

Aging

- Bone remodeling = mechanical compensation
  - shifting effective bone to periphery
    - ↑ moment of inertia as the cortex thins
    - ↑ resistance to bending and torsion (Bouxsein & Karasik, 2006)



Seeman, 2003

Osteoporosis & Fragility Fractures

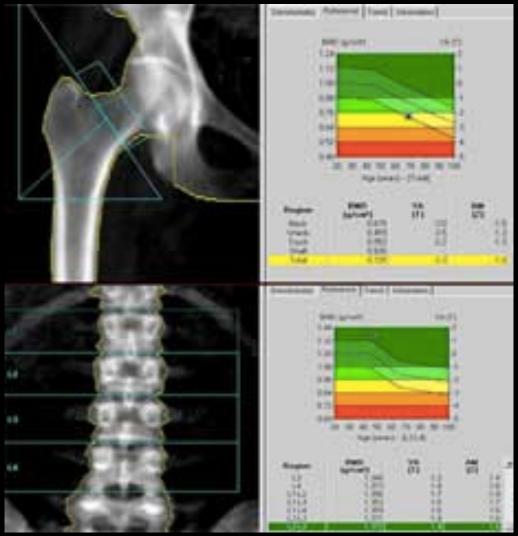
- Osteoporosis
  - Disease characterized by low bone mass + structural deterioration
  - ↑ bone fragility & fracture risk
  - > 25% of women 80+ yrs old (NIH, 2011)
  - Leads to 9 million fragility fractures annually worldwide (Johnell & Kanis, 2006)
- Most common fragility fractures - spine, hip, wrist

Bone Fracture Risk

- Factors increasing risk of fragility fractures
  - Age
  - Gender - 70% of hip fractures occur in women
  - **<u>Physical inactivity – weight-bearing exercise is good!</u>**
  - Nutritional problems – lack of calcium and Vitamin D
  - Chronic medical conditions – endocrine & intestinal disorders
  - Glucocorticoids (Cortisone)
  - Tobacco & alcohol use
  - Previous fracture
  - Family history of osteoporosis

Osteoporosis

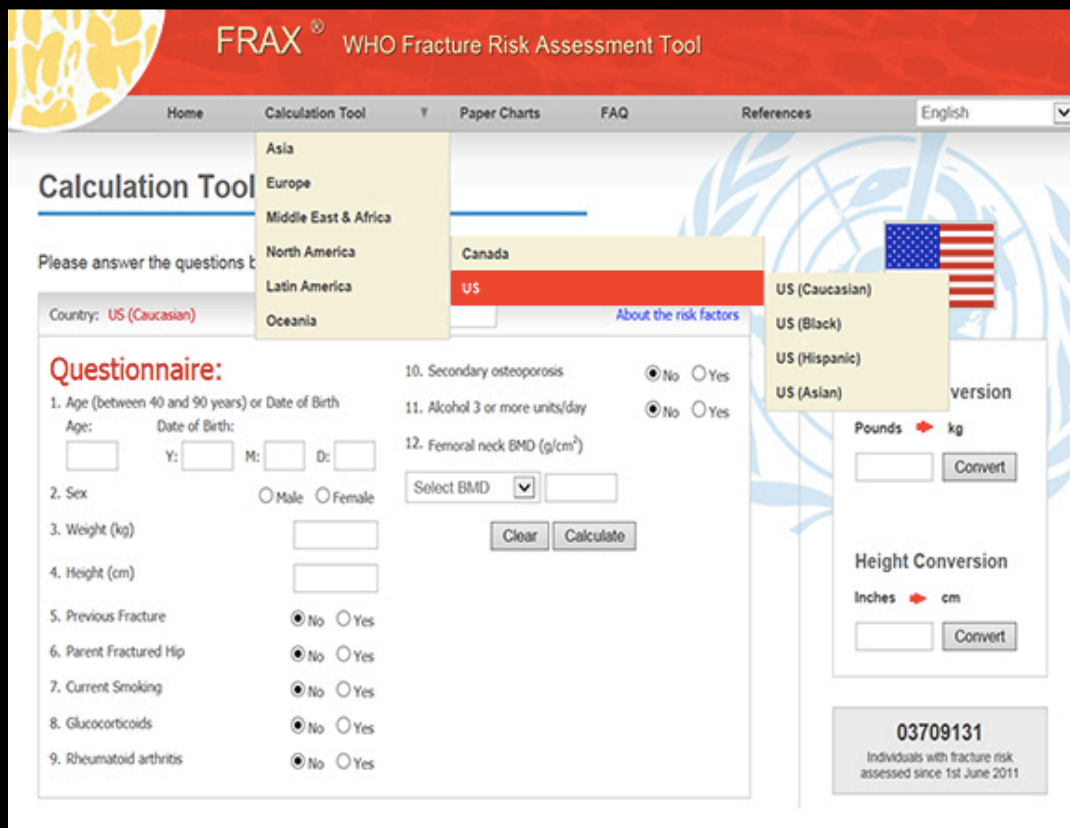
- Bone Density Test
  - Clinical standard:
    Dual-energy X-ray absorptiometry (DXA)
  - Uses X-rays to measure bone mineral density & determine if you have osteoporosis
  - Anatomic locations: hip, spine, forearm
  - Results: T-score and Z-score
    - T-score ≥ -1 Normal
    - T-score: -1 to -2.5 Osteopenia
    - T-score ≤ -2.5 Osteoporosis



Bone Fracture Risk

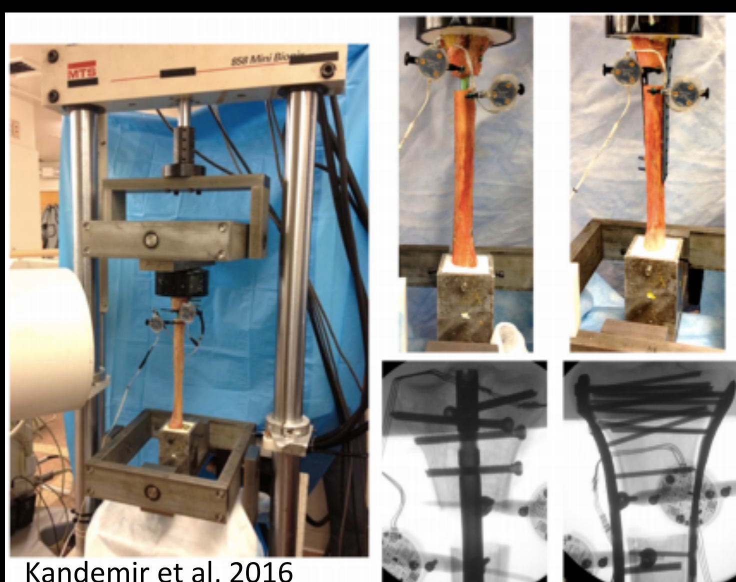
FRAX® Fracture Risk Assessment Tool

- Developed by WHO in 2008
- Prediction tool for assessing individual's risk of bone fracture

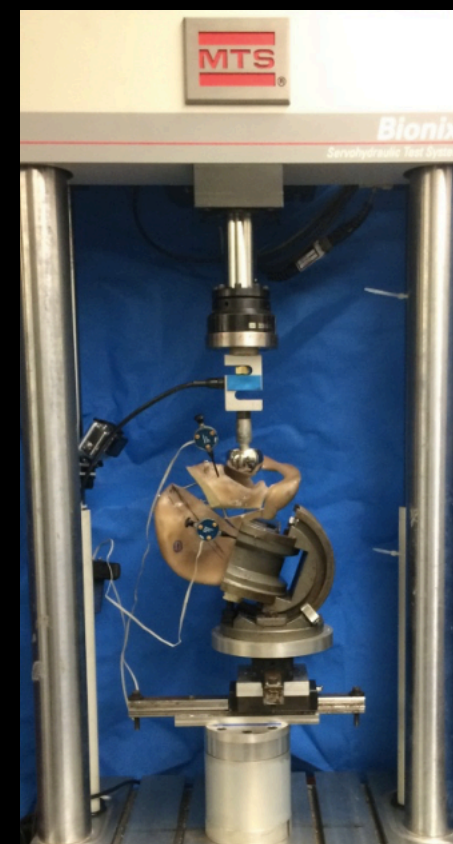


Research

- Biomechanical evaluation of fracture fixation strategies
  - Experimental testing
    - Using artificial or cadaveric bones
    - Create physical fracture fixation constructs
    - Apply physiologic loads
    - Measure strength, stiffness, fatigue life

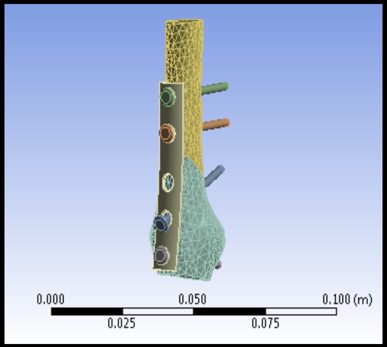


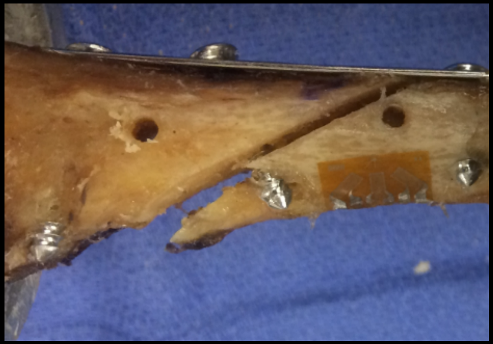
Kandemir et al, 2016

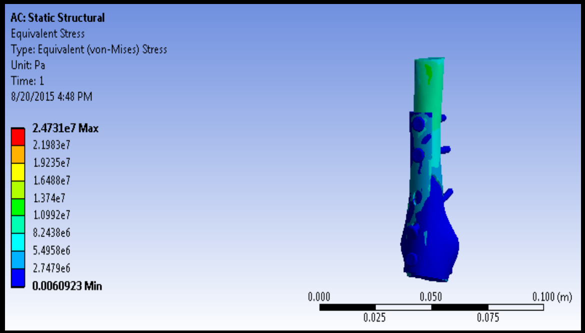


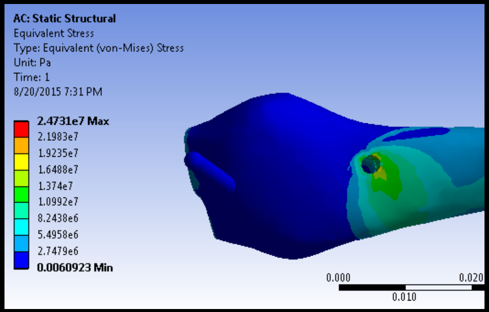
Research

- Biomechanical evaluation of fracture fixation strategies
  - Finite element analysis
    - Virtual surgery
    - Simulation of mechanics









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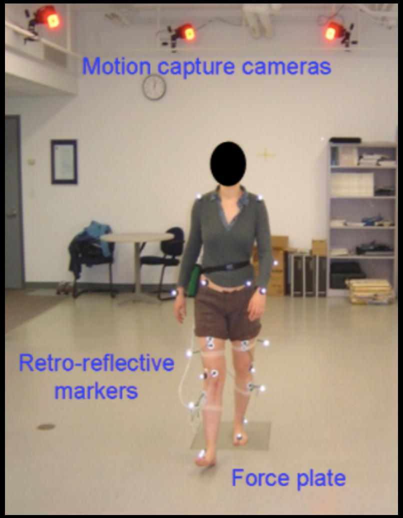
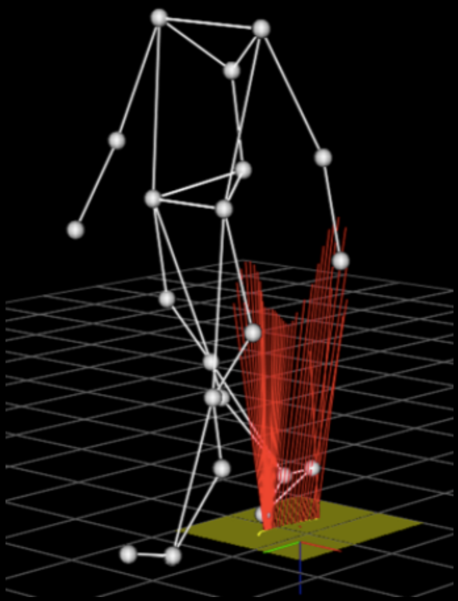
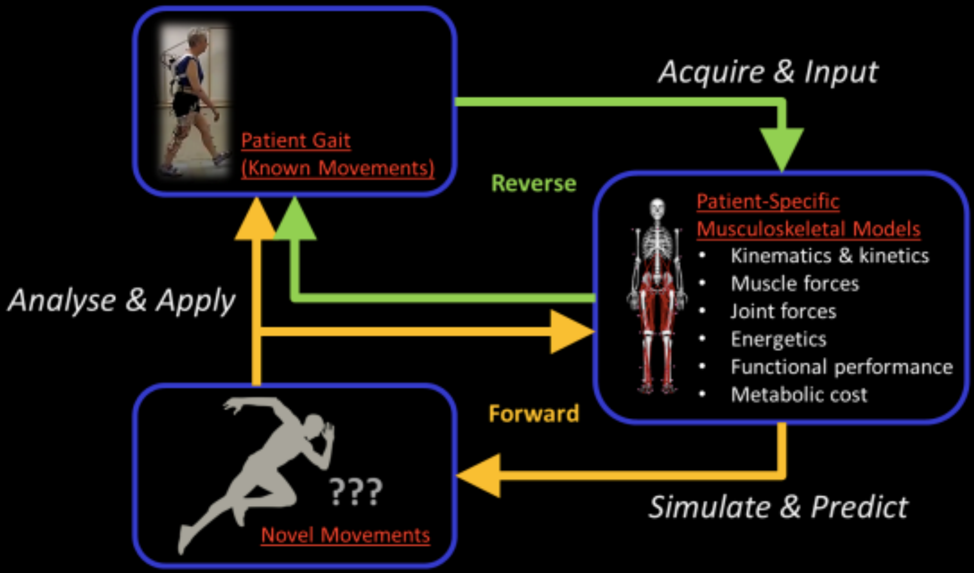
Calculation of Joint Loads from Gait Lab Measurements

- 3D Motion Analysis (Kinematics)
- Ground reaction forces (Kinetics)
- Use Inverse Dynamics to calculate joint loads
- Musculoskeletal Modeling







The Biomechanist

Direct Measurement of Joint Loads Using Instrumented Implants