ME 411 / ME 511

Biological Frameworks for Engineers

Class Organization

- Lab 3 report due Fri, Nov 22
- HW6 due Mon, Nov 25
- *Tiny Workhorse* Project
  - Reports due Mon, Nov 25
  - Presentations on Wed, Nov 27
    - 9 min with 1 min Q&A
    - Check your laptops before class

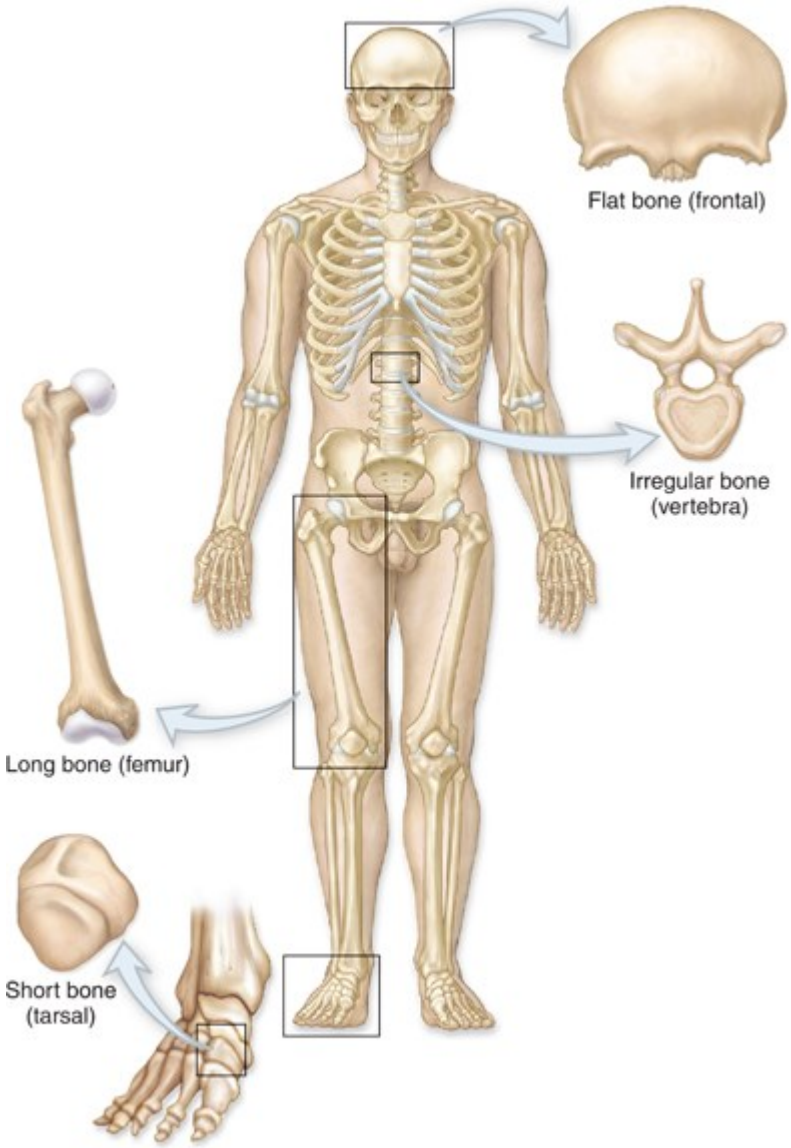
Biological Frameworks for Engineers

ME 411 / ME 511

Bone System

UNIVERSITY OF WASHINGTON

Bones



Living concrete:

Type 1 collagen

hydroxyapatite

$[Ca_3(PO_4)_2]_3 \cdot Ca(OH)_2)$

Functions:

Structural

Motion

Protection

Mineral Storage

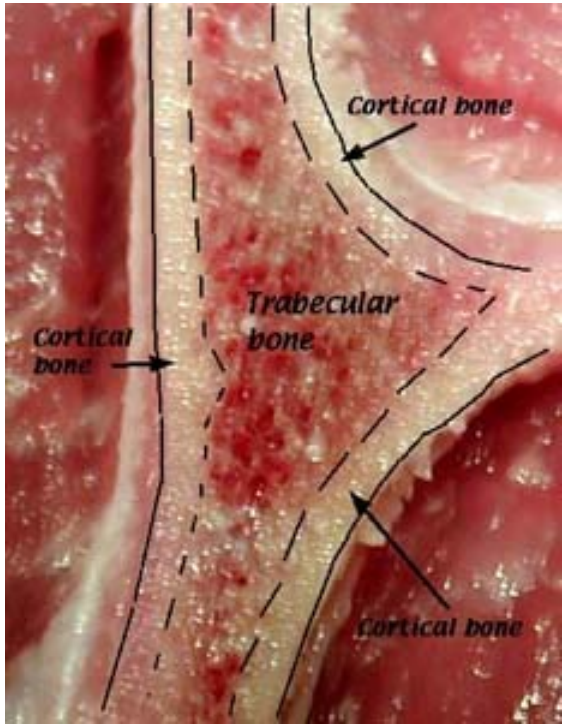
(Cell Factory)

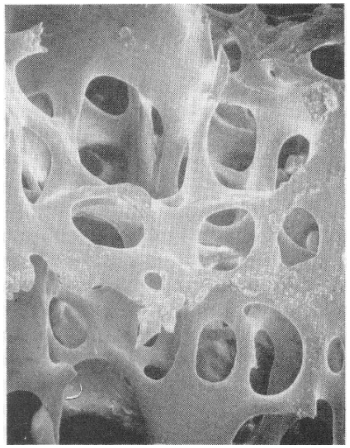
Extracellular Matrix

Table 9.2. Approximate composition of the extracellular matrix of bone tissue based on consensus values from several sources

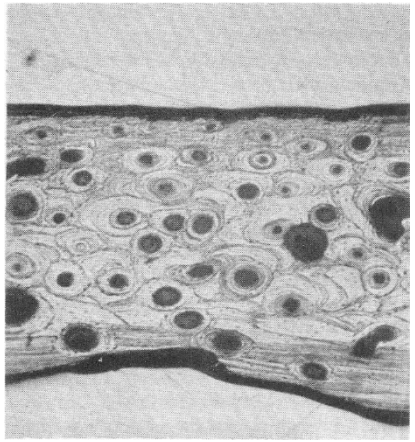
Component	Mass (%)
Mineral phase (hydroxyapatite)	70
Organic matrix (osteoid)	
Collagen (mostly type I)	18
Non-collagenous proteins and proteoglycans	2
Water	10

Types of Bone



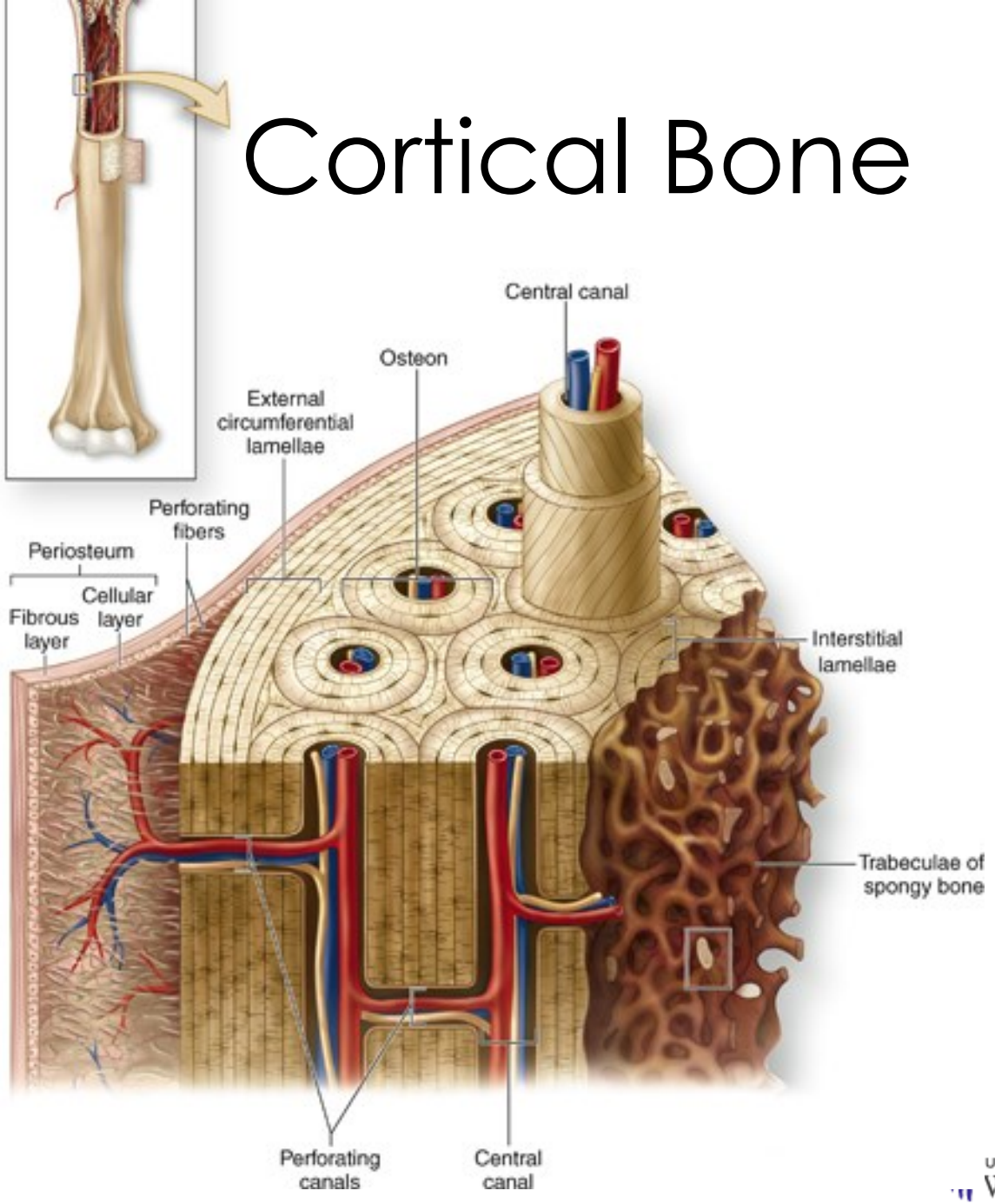


Trabecular

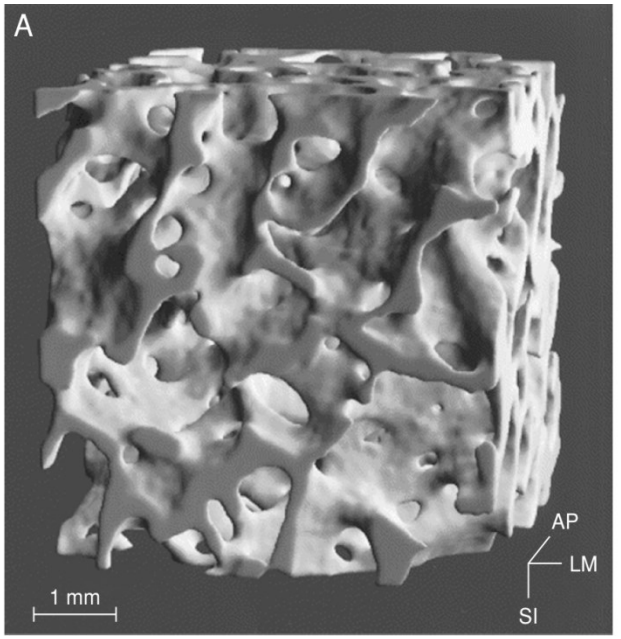


Cortical

Cortical Bone



Trabecular Bone



Biomechanics of Cortical

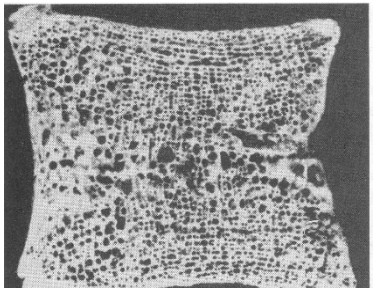
Table 9.3. Summary of mechanical properties of human cortical bone based on data from Reilly and Burstein, *Journal of Biomechanics*, **8**(1975), 393–405.

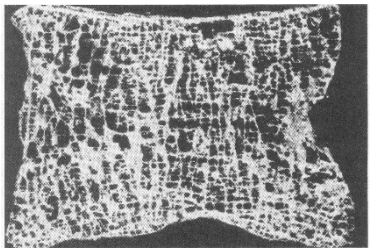
Parameter	Value
Modulus (GPa)	
Longitudinal	17.0
Transverse	11.5
Shear	3.3
Poisson's ratio	0.3–0.6
Ultimate strength: longitudinal (MPa)	
Tension	133
Compression	193
Shear	68
Ultimate strength: transverse (MPa)	
Tension	51
Compression	133

Biomechanics of Trabecular

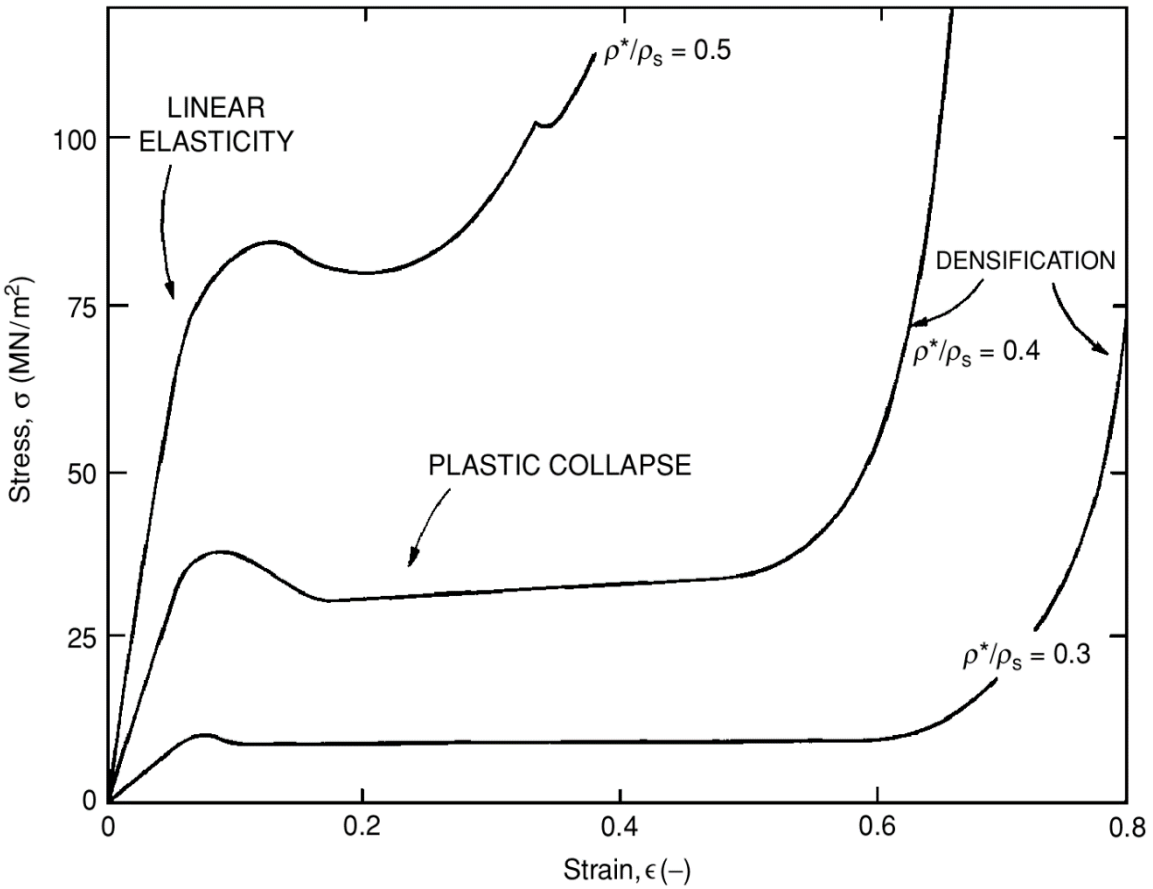
Table 9.4. Summary of mean compressive properties of human trabecular bone from different anatomic locations. Values in parentheses are standard deviations. Femur specimens were pooled from both the proximal and distal femur. The specimens from the tibia, distal femur, and spine were tested in the longitudinal (inferior-superior) direction. The proximal femur specimens were oriented along the neck of the femur. Adapted from Keaveny [11]. Copyright 2001 from *Bone Mechanics Handbook* by Cowin. Reproduced by permission of Routledge/Taylor & Francis Group, LLC.

Anatomic site	Relative density	Modulus (MPa)	Ultimate stress (MPa)	Ultimate strain (%)
Proximal tibia	0.16 (0.056)	445 (257)	5.33 (2.93)	2.02 (0.43)
Femur	0.28 (0.089)	389 (270)	7.36 (4.00)	Not reported
Lumbar spine	0.094 (0.022)	291 (113)	2.23 (0.95)	1.45 (0.33)





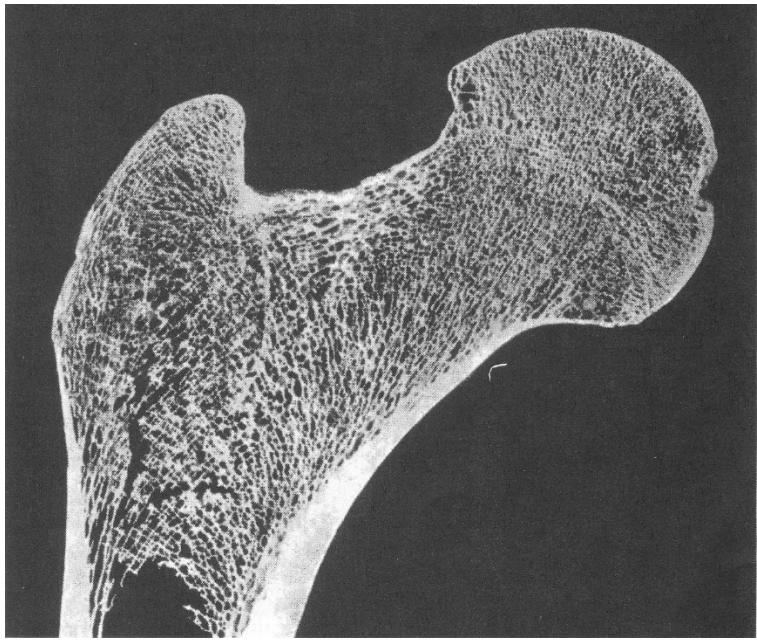
Biomechanics of Trabecular



Compressive stress–strain curves for trabecular bone of different relative densities. Relative density is the ratio of the apparent density (ρ^* in this figure) to the density of solid cortical bone (ρ_s).

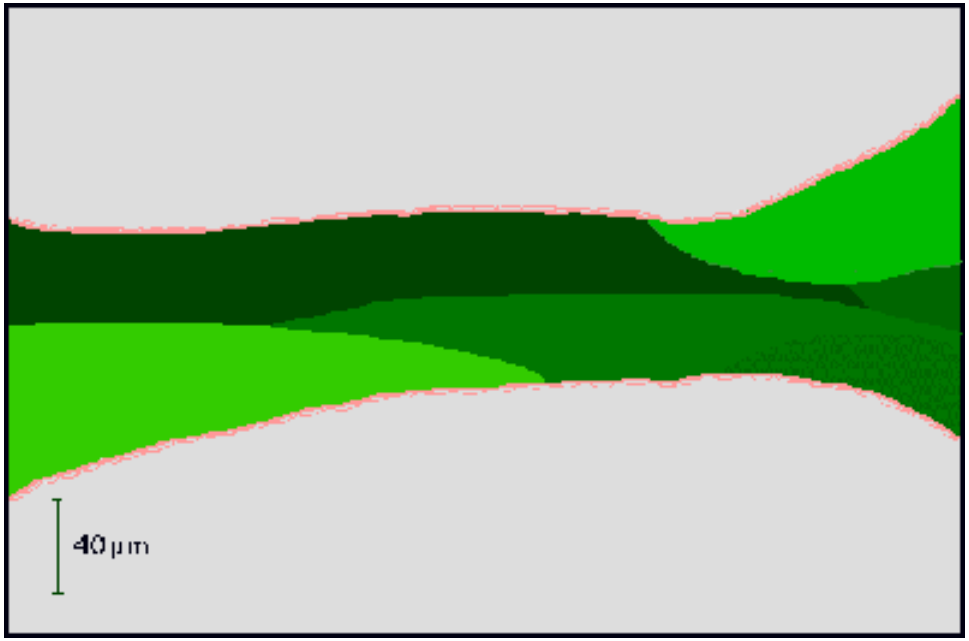
Bone Remodeling

- Maintenance of mineral homeostasis
- Reconstruct in the face of mechanical stimulation
- Maintain structural integrity in the face of accumulated microdamage
- Enhance healed bone



Remodeling

- Osteoclasts 
  - Recruited to dissolve bone
- Osteoblasts 
  - Recruited to synthesize bone
- Lining Cells 
  - Reside on surface of bone tissue
- Osteocytes 
  - Reside permanently inside bone tissue
  - Long branches sense pressures or cracks and direct osteclasts

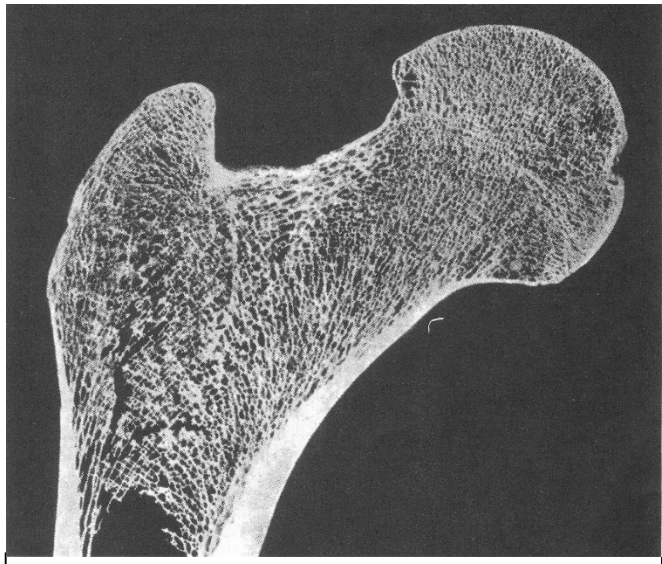


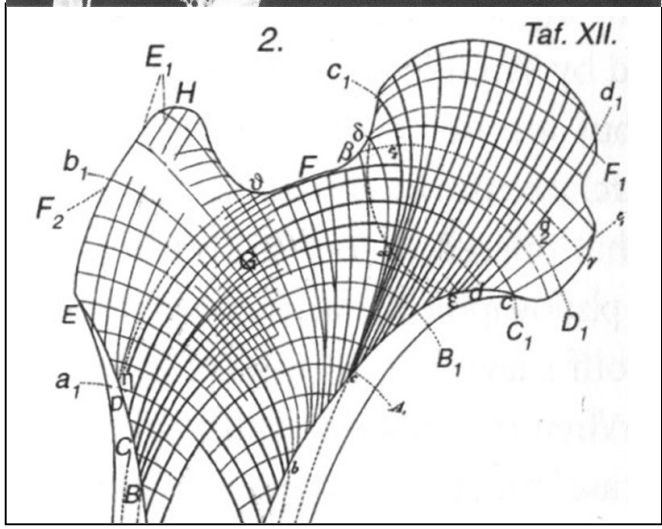
Mechanobiology

Wolff's Law:

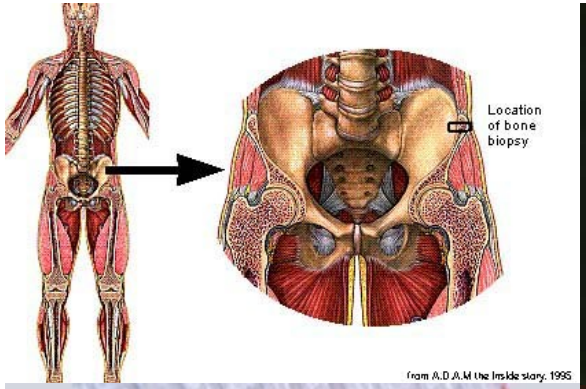
"Every change in the form and the function of a bone or of their function alone is followed b certain definite changes in their internal architecture, and equally definite secondary alterations in their external confirmation"

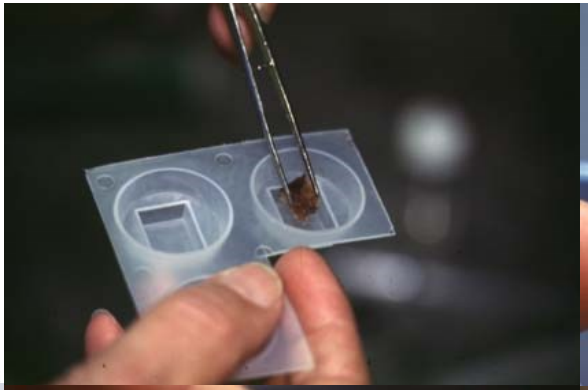
…bone will adapt its internal architecture in response to external constraints and loads.

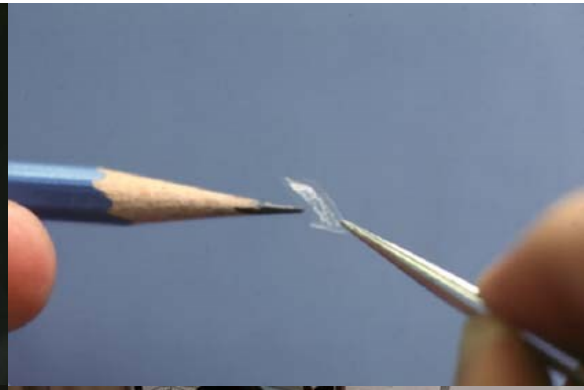


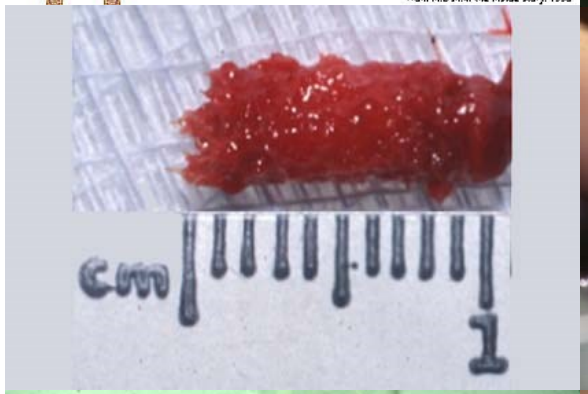


Histology

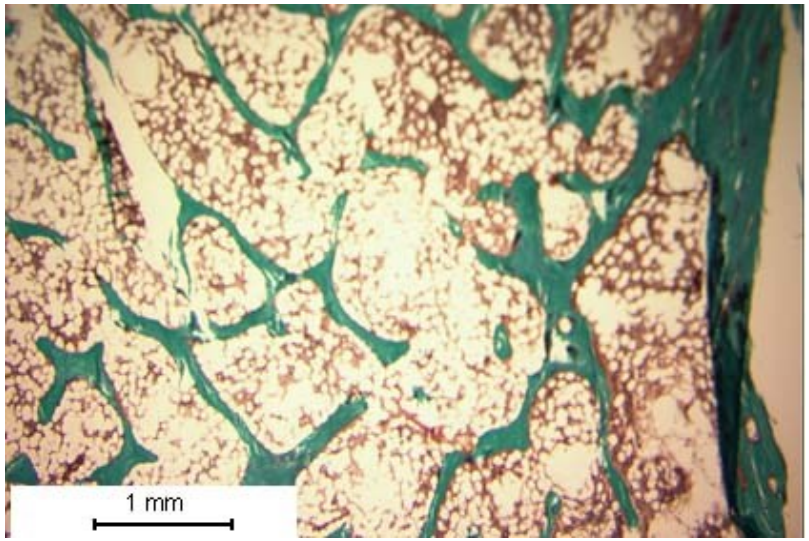




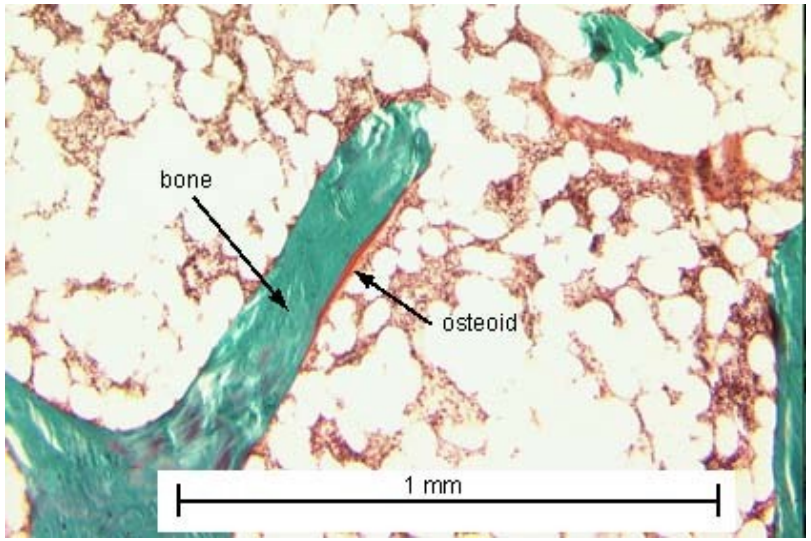


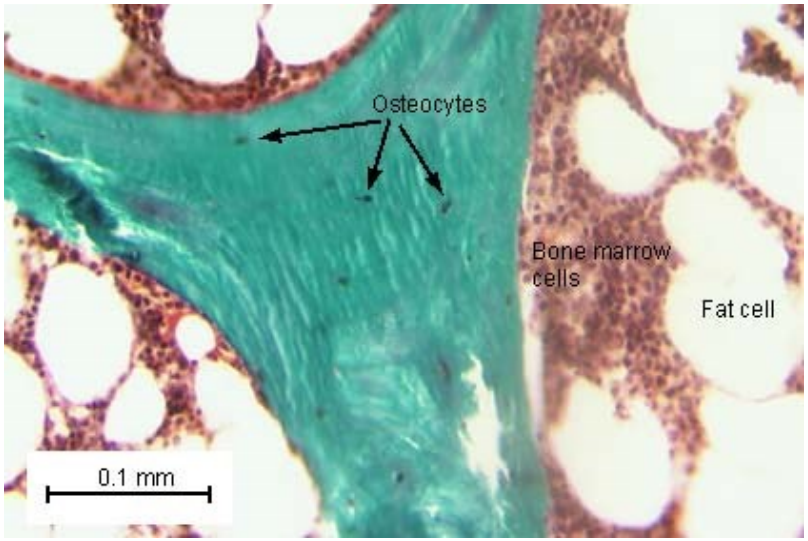


Normal Bone



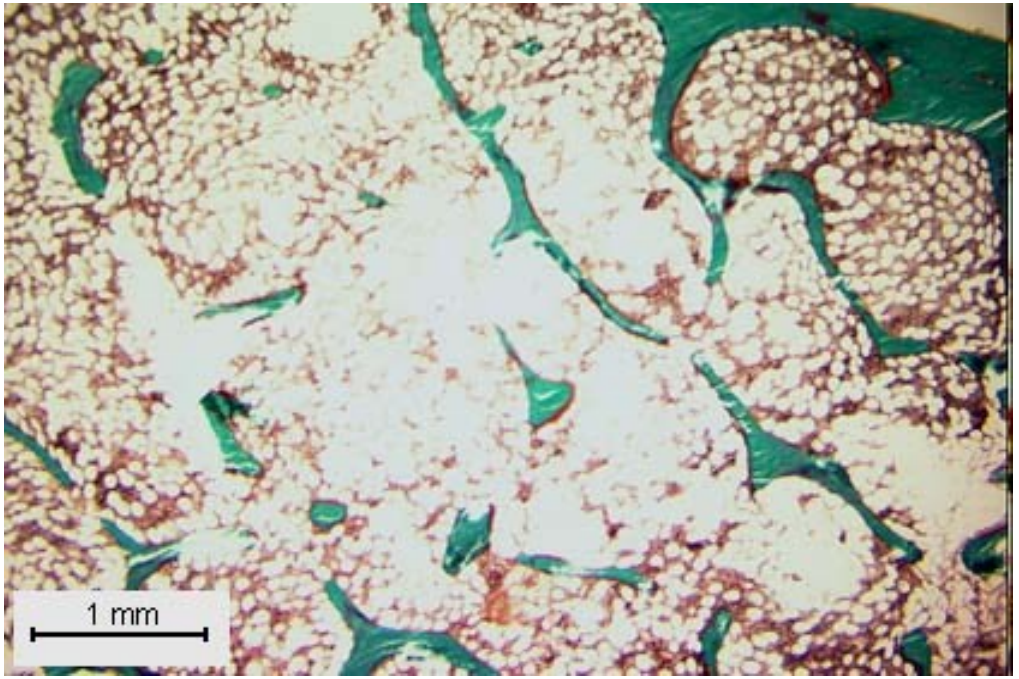
- Calcium is green.
- Fat cells in bone marrow are white
- Dark Red are other bone marrow cells
- Osteoid is new collagen





Bone Pathologies

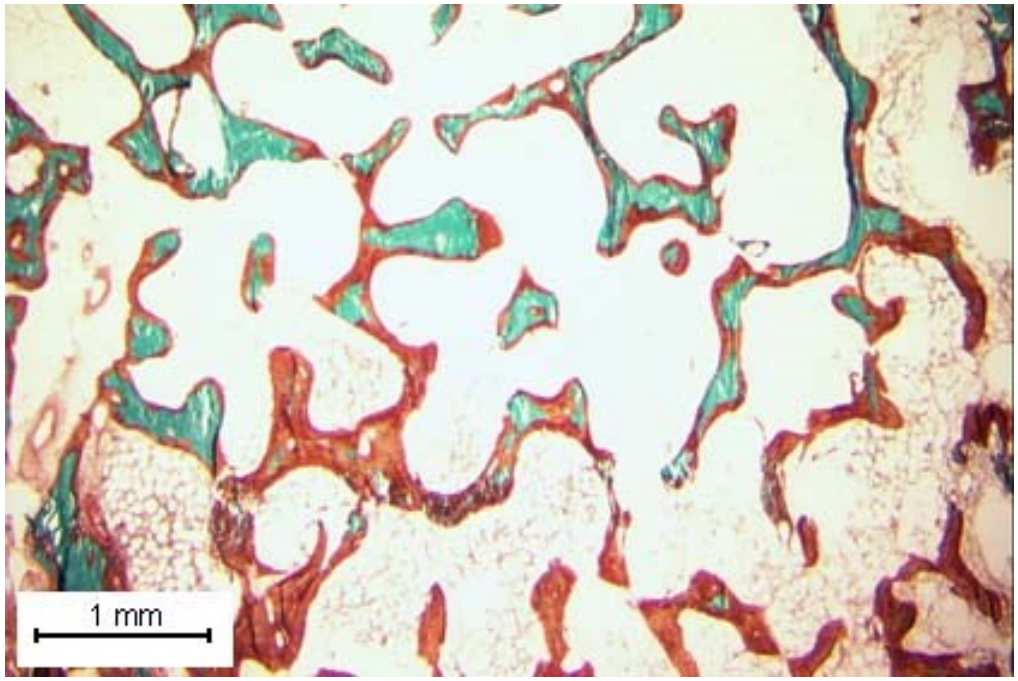
- Osteoporosis
  - Loss of bone mass per unit volume
  - Ratio of mineral to organic phase maintained



  - Decreased strength, density, and stiffness
  - True osteoporosis is accompanied by fracture
  - Bone loss without fracture is osteopenia

Bone Pathologies

- Rickets (*Osteomalacia*)
  - Mineralization of the matrix of the skeleton is defective
  - Cannot metabolize Calcium or Vitamin D
  - Lack of calcium → collagen does not stain "green"
  - Decreased strength, density, and stiffness



Questions?