BME 5210 Musculoskeletal Biomechanics (4)

Structure and Function Articular Cartilage

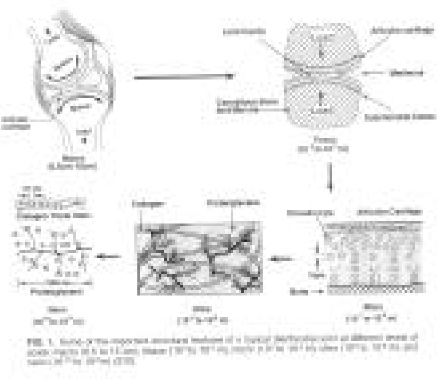
Winter Semester, 2002

Overview

Type	Appearance	Location
Hyaline cartilage	Glassy smooth, glistening	Covers long bones, growth plate
Fibrocartilage	Dense	Intervertebral disks, TMJ, meniscus
Elastic cartilage	Yellowish opaque	Epiglottis, eustachian tube

Structure Diarthrodial Joints

- Enclosed in fibrous capsule
- Lined with synovium (secretes synovial fluid/provides nutrients)
- Articular cartilage lines each end of articulating bone
- Joint cavity formed from synovium and articular cartilage



Geometric features

- Anatomic forms of the articulating surfaces – dictates type of motion possible
- Thickness contours of the cartilage layers – dictates the types and magnitude of stresses

Composition

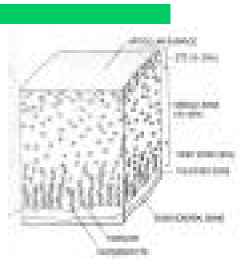
- Fluid phase: H_2O and electrolytes
- Solid phase: chondrocytes (cells), collagen fibers (Type I and II), proteoglycans & other glycoproteins
  - collagen: key structure within connective tissue, hair like, helical molecule
  - proteoglycan:protein with 1 or more glycosaminoglycan (GAG) chains attached by covalent bonds

Interstitial Water

- 60-87% of articular cartilage is water
- 30% of this water is found in intrafibrillar space of collagen
- Amount of water present depends on
  - FCD – fixed charge density
  - Organization of collagen network
  - Strength and stiffness of network (resistance to swelling)

Chondrocytes

- 10% of tissue volume
- Manufacture, secrete and maintain components of matrix
- Arrangement depends on location within articular cartilage



Collagen

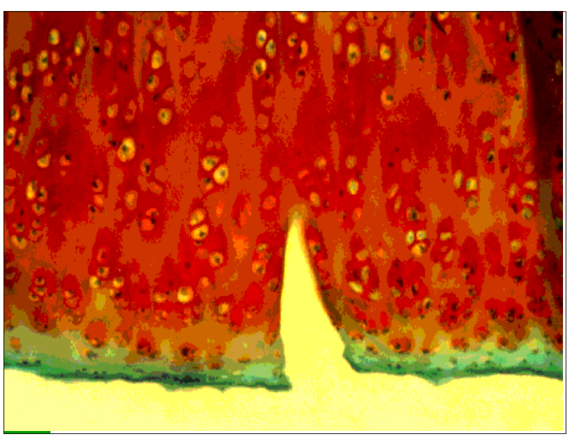
- Most abundant protein in body
- High level of structural organization – appears to provide tensile properties to the tissues
- Little resistance to compression

Collagen

- Type I: typical in meniscus (90%), intervertebral disk, skin, tendon, ligament
- Type II: typical in articular cartilage
- Type III: present in scar tissue

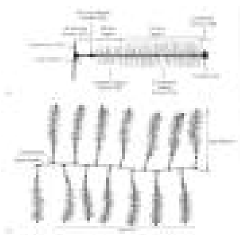
Articular Cartilage Structure

- Collagen
  - dense at surface, parallel to surface
  - fine fibers at surface, larger below
  - middle zone random
  - calcified cartilage
  - perpendicular thick fibers at calcified cartilage



Proteoglycan

- Hyaluronic acid (HA)
- link protein
- keratan sulfate chain
- chondroitin sulfate chain
- protein core

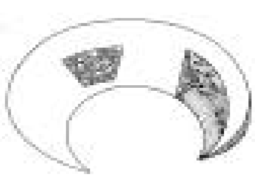


Collagen-Proteoglycan Interactions

- Collagen-collagen: covalent (x links) and noncovalent
- proteo-proteo or collagen-proteo: noncovalent interaction between the collagen which provides a mesh to contain the proteoglycans (PGs), also + charged collagen interact with - charged PGs

Meniscus Structure

- Surface: fine mesh of collagen fibers, smooth
- Internal: rope like collagen fibers circumferentially, smaller radial fibers
- Inner radius: random fibers and PGs
- PGs 1-2% wet weight



Material Characterization

- Material vs. Structural:
  - material: describes intrinsic properties, influenced by composition, ultrastructure, NOT influenced by specimen size or shape
    - elastic modulus, Poisson's ratio
  - structural: influenced by size and shape, reflect the function of the tissue as a whole
    - stiffness

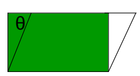
Basic Mechanics

- Material properties
  - relate stress σ and strain ε

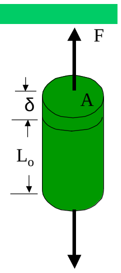
(constitutive equation)

σ = force/area (N/m^2)

$\varepsilon=\delta/L_o$

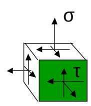


$\gamma=\theta$ in radians



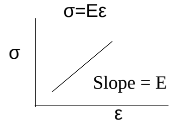
Stresses

- Stress at a point (idealized as a cube)
  - 3 normal stresses
  - 3 shear stresses (in the plane of the face)



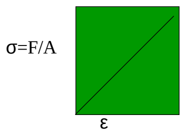
- Material properties are defined as numbers that relate stress to strain
  - these relations are called constitutive relations

$\sigma=E\varepsilon$



Linear Elastic

- Linear: stress varies linearly with strain
- Elastic: material follows the same stress/strain curve during loading and unloading therefore no energy is lost, material returns to its original shape



$E_{cartilage}$ = 0.3 -1.0 MPa (N/mm[2])

$E_{meniscus}$ = 0.1 - 0.6 MPa

E_{bone} = 2,400 - 3,50 MPa

E_{steel} = 193,000 MPa

Material Models for Articular Cartilage

- Early: isotropic, linear elastic
  - doesn't describe time variation of response
- Later: viscoelastic (springs and dampers)
  - doesn't consider influence of fluid (loss in compression, swelling)
- Later still: poroelastic, biphasic
  - doesn't consider viscous solid, ion effects
- Most recent: biphasic poro-viscoelastic, tri-phasic theories

Questions?