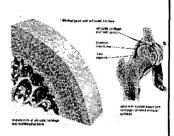
Articular Cartilage

Functional Anatomy & Biomechanics

Nam-Yong Choi, M.D.
Department of Orthopedic Surgery
Catholic University

Articular cartilage

- avascular
- aneural
- alymphatic



Articular cartilage

- highly organized & complex structure
- seemingly inert & homogenous
- can tolerate a tremendous amount of intensive & repetitive physical stress
- frequently lasts a lifetime
- · manifests a striking inability to heal

Articular cartilage

- immunoprivileged
- mechanical forces for biologic regulation
- supports 1-4Mpa(150-600lb / in²)
- average of 2million times each year

Articular cartilage

- lower collagen content & more complex ultrastructure
- less tensile modulus & strength
- anisotrophic material property "split-line" pattern varying collagen arrangement



Function

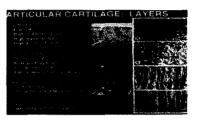
- load transmission & distribution
- shock absorption
- maintain contact stress at low level
- smooth, nearly frictionless

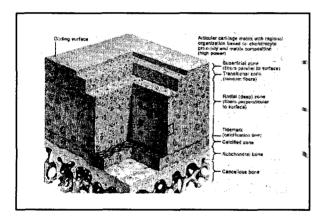
Response to injury

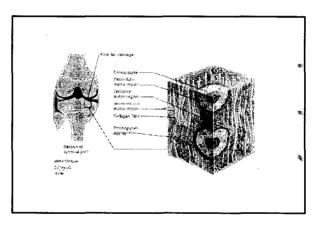
- avascularity
- immobility of chondrocyte
- limited ability to proliferate & alter their synthetic patterns

Structure & composition

• varies three-dimensionally, distance from surface & relation to distance from the cells

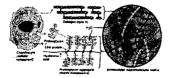






Composition

- chondrocytes
- functional extracellular matrix
 - collagens
 - proteoglycans
 - noncollagenous proteins
 - water: unique mechanical properties



-	of adult articular cartilage	
as % of total weight		
water	66-78%	
solids	22-34%	
as % of dry weight		
inorganic		
ash(HA)	5-6%	
organic ´		
collagen(type II)	48-62%	
proteoglycan	22-38%	
noncollagenous m	atrix proteins	
· ·	5-15%	
minor collagens	< 5%	
lipid	< 1%	
hyaluronate	< 1%	

Water

- 60-80% of its wet weight
- move freely in & of cartilage when loaded, 70% movable
- bound proteoglycan-collagen gel
- exchangeable w/ synovial fluid





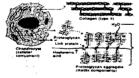
Water

- many free mobile cations(Na, Ca)
- contribute to its material properties joint lubrication nutrition of chondrocytes
- maintain the resiliency
- control surface deformation
 & mechanical behavior



Collagen

- 50% of dry wt.
- 90-95%: type II IX, XI, V, VI
- synthesized in chondrocyte ribosome
- slow turnover half life, > 3mo



Collagen

- structural framework
- counteracts the swelling pressure
- tangential orientation in gliding zone
- resists shear & surface wear





Proteoglycans

- synthesized by chondrocyte
- test-tube brush shape
- found in only AC & NP
- compressed by collagen framework
- damage to collagen: expand PG & absorb more water

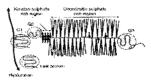




Proteoglycans

Composition

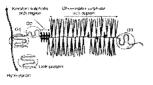
- : hyaluronate glycoprotein
 - glycosaminoglycan(GAG) side chains



Proteoglycans

GAG

- : chondroitin 4-sulfate, c-6-s, keratan-s
 - strong intra- & intermolecular repulsive force
 - creating a sustantial osmotic swelling pressure "pre-stress" even in absence of loads



Proteoglycans

- provide resiliency
- increased charge density
- occupy the largest possible domain
 - maximum separation of (-) charge
 - acts like a spring & resists deformation
- contribute to elasticity

Proteoglycan aggregates

- · adding structural rigidity
- store more energy than monomer
- greater rupture strength
- · hold water osmotically
- some resistance to flow of water



Chondrocyte

- 1-2% of total volume
- at surface: flatter, smaller greater density
- occupy lacuna



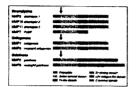
Chondrocyte

- synthesis & maintenance extracellular matrix
- metabolic activity & ability of cells
 - related to age
- stimulates matrix synthesis: IGF-1, bFGF, TGF-β

	Aging	OA
water	decreased	increased
collagen II	unchanged	unchanged
НА	increased	decreased
link proteins	fragmented	
PG content	unchanged	decreased
extractibility	decreased	increased
monomer size	decreased	decreased
aggregation	decreased	decreased
chondroitin sulfate		
content	unchanged	decreased
chain length	decreased	decreased
c-4-s/c-6-s	decreased	increased
keratan sulfate	increased	decreased

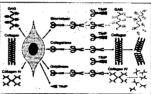
Matrix metalloproteinases (MMPs)

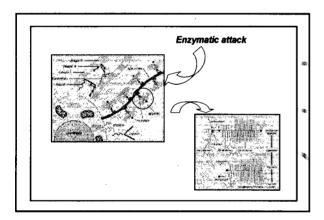
- degradative enzymes destroy aggrecan
- Collagenase
- Stromelysin
- Gelatinase

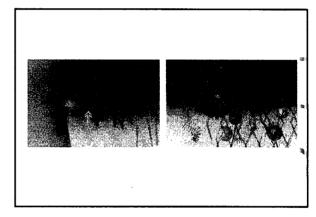


Matrix metalloproteinases (MMPs)

- secreted by chondrocytes as a proenzyme under influence of IL-1 or TNF
- suppressed by TIMP (tissue inhibitor of MMPs)







Proinflammatory cytokines

- IL-1
- : in chondrocyte stimulates collagenase & stromelysin inhibits collagen & PG synthesis, & TGF-β
- TNF-α & TNF-β
- : in synoviocyte induces collagenase & PGE2

Antiinflammatory cytokines

- IL-4 inhibits TNF-α, IL-1 & PGE2 synthesis
- IL-6 stimulates TIMPs

Loss of matrix proteoglycans

- loss of compressive stiffness & elasticity: transmission of greater mechanical stress to chondrocytes
- increase in hydraulic permeability: greater loss of interstitial fluid affect cartilage self-lubrication

Role of subchondral bone

initiation & progression of cartilage damage

- stiffening of subchondral bone precedes & causes articular cartilage degeneration
- progression of cartilage degeneration requires stiffening of subchondral bone

Mechanical properties Biphasic : solid(porous) & fluid(imcompressible) phases

Mechanical properties

Viscoelastic materials

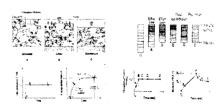
time dependent deformation
 & recover

Viscoelastic response two mechanisms

- intrinsic viscoelastic p. of macromolecules
- frictional drag arising from flow of interstitial fluid (biphasic v.)

Mechanical properties

• Biphasic creep response & stress-relaxation response

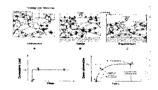


Tensile properties

- highly nonhomogenous
- varying w/ depth
 - higher in superficial zone
- far less than tendon & ligament

Behavior in compression

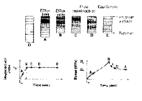
 Biphasic creep response caused by exudation of interstitial fluid creep equilibrium: human 4-16 h rabbit 1h





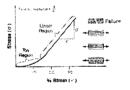
Behavior in compression

• Biphasic stress-relaxation response result of fluid redistribution within matrix



Behavior under tension

- stretched at extremely slow rate
- tensile stress-strain curve
- failure at strain greater than 30%
- strain increases w/ increasing depth



Behavior in shear

- middle zone
- no pressure gradient or vol. change
- compression stiffens cartilage in shear
- resists high shear stress at uncalcified-calcified junction

Thank you for your attention!