Articular cartilage is a 1-5 mm thick dense covering of articular surfaces. It is composed of "hyaline cartilage" as opposed to

_____.

Purpose:

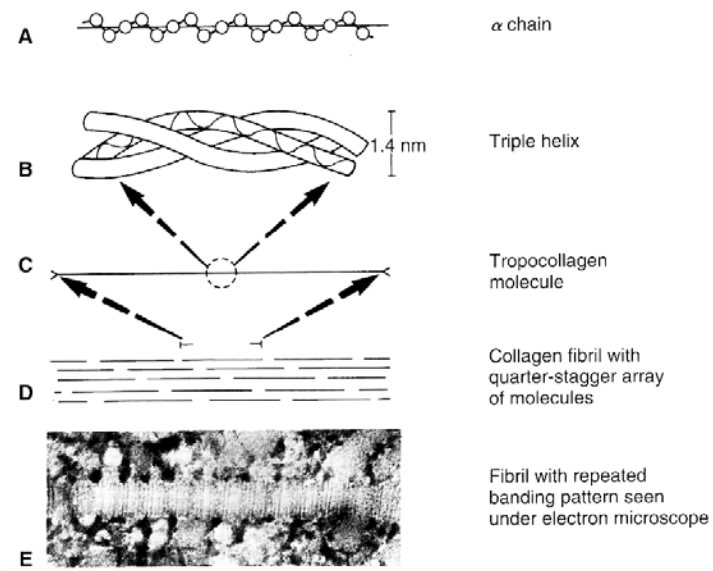
1. To decrease _____on articular surfaces by increasing _____.
2. To decrease _____on bones and allow relative movement of articular surfaces.

Composition:

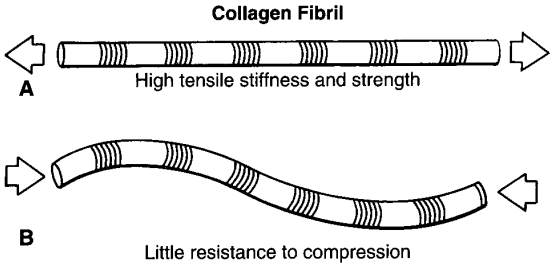
(Articular cartilage is devoid of _____, lymph channels and _____!)

1. Solid matrix _____ by weight
   a. Collagen fibers (mostly type II) _____
   b. Interfibrillar proteoglycan gel (PG) _____
   c. cells (chondrocytes) _____
2. water _____ by weight
   water can be squeezed out under load (part of "forced circulation")

Collagen



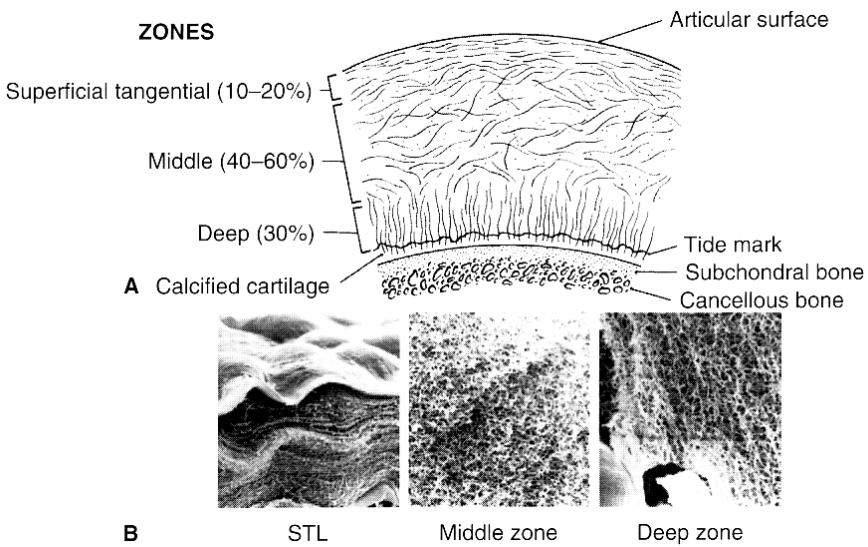
Collagen fibril is very resistant to tensile loads, but offers little resistance to compression.



How strong is collagen compared with other materials?

Tested in tension	Tendons (80% collagen)	Steel	Aluminum

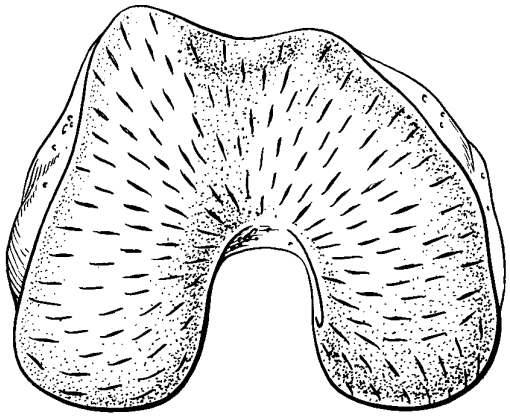
Distribution of collogen:



Note: collagen provides very little resistance to _____ or _____ stresses. However, compressive loads on cartilage surface tend to stretch the underlying collagen fibers, thereby creating _____ stresses in these fibers.

Surface of articular cartilage is anisotropic:

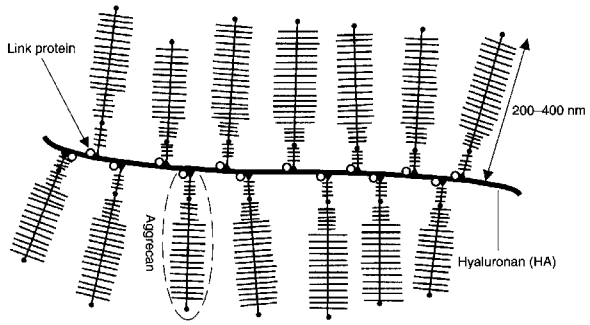
Split-line pattern of AC on distal femur

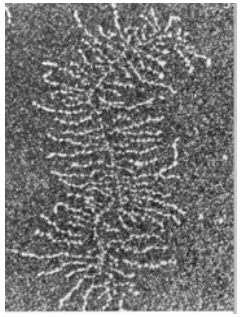


Split lines indicate strength and stiffness of AC are _____. What is the functional significance?

Proteoglycan gel

This portion of the solid matrix is closely tied with the flow of water in and out of the cartilage. "Bottlebrush" structure: Building blocks: glycosaminoglycans (_____)





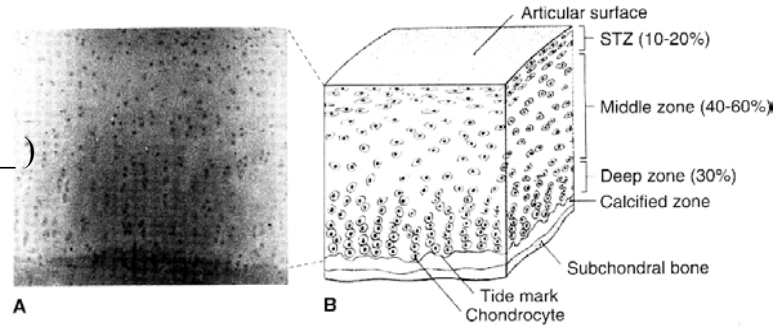
The "bristles" of the bottlebrush are _____ and tend to _____ each other. Compressive loads on the cartilage surface tend to "cramp" these bristles and move negative charges closer together. The bristles then try to push each other apart to reduce the _____ , hence resisting the compressive loads. This is the **first of two mechanisms** in which AC provides cushioning under load. This first mechanism does not require any fluid flow to work.

The **second mechanism** (requiring fluid flow) is as follows:

Within the GAGs the negative charges tend to attract _____ (e.g. Na+, Ca++, K+). The gel then tries to dilute itself via _____ to reduce the ionic concentrations. This produces a _____ within the cartilage as water flows into the cartilage from the joint synovial fluid. This produces a "swelling pressure" within the cartilage of about _____ even with no load applied. Now, when you apply external loads to the cartilage surface, water gets squeezed out into the joint space. This tends to _____ (of Na+, Ca++, K+). The cartilage then tries to _____ itself by drawing water back in. Eventually equilibrium is reached between the external pressure and the internal pressure and the loads are supported. These are the two mechanisms by which AC can resist _____on its surface.

Cells

(_____)

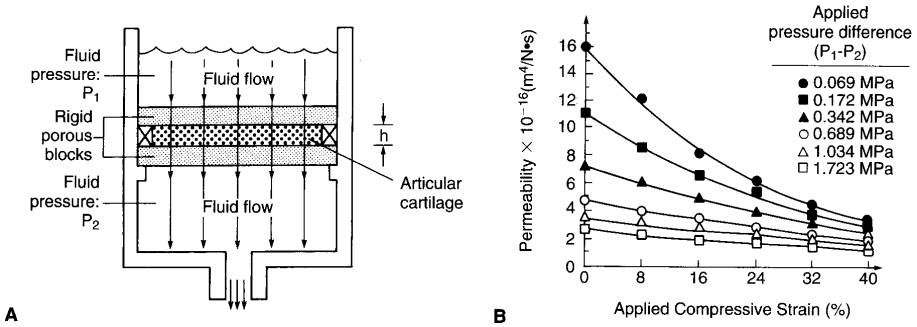


Water

Most abundant component of AC (_____ of total weight). Varies from _____ water at surface reducing to approximately _____ in deep zone. Water contains Na+, Ca++, K+ ions as mentioned previously. About 30% of the total water is tied up with _____. This leaves ~70% of the water free to move in and out of the cartilage. This movement of water is crucial to the cushioning properties of cartilage, but also to the general health of the cartilage. _____ to the cartilage and _____ are all done through the movement of water in and out of the cartilage through the _____.

Biomechanical Behavior of AC

Permeability: This relates to the ability of water to flow in and out of the articular cartilage. As load _____, permeability _____ so as to prevent total removal of water within the AC.

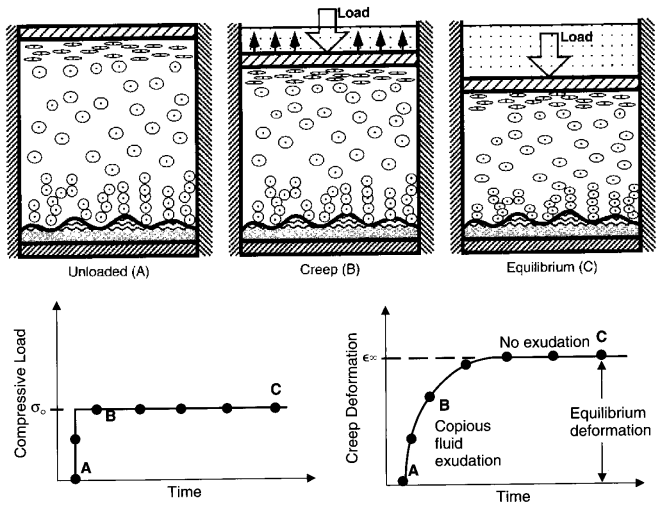


Under pathological conditions, this relationship can be disrupted, and the normal cushioning properties fail—tending to create high _____ and abnormally high _____ of the tissue.

Rate dependence of AC material behavior

1. Elastic behavior (time _____) occurs only with very rapid loading, no time for measurable fluid flow.
2. Viscoelastic behavior (time _____) for slower rates of loading, involves fluid flowing in and out of cartilage. Note: this is a simplification (i.e., making two categories). In reality, there is a continuum from fast to slow loading.

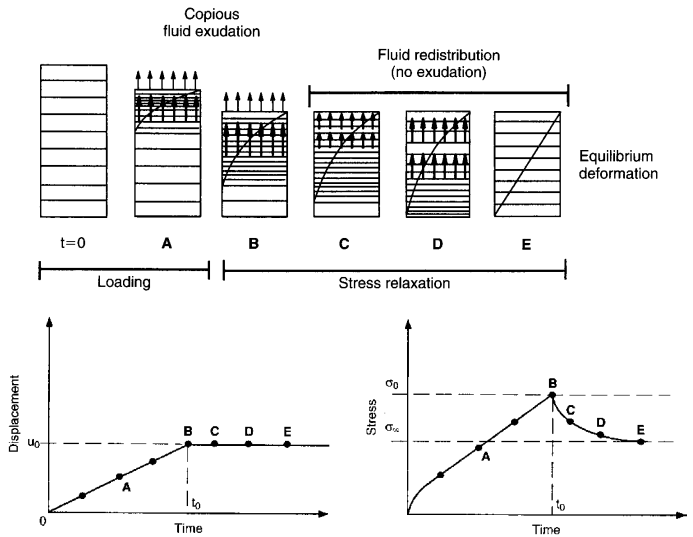
a. Creep test



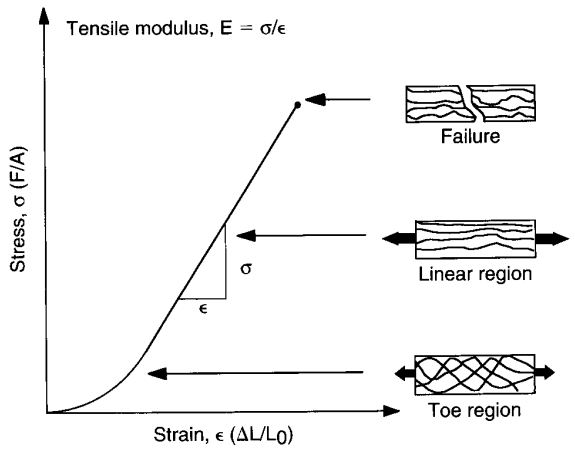
_____ is held constant, _____ changes over time. Can use creep test to determine the strength and stiffness of the _____. Stiffness of this solid matrix is called the _____ of the cartilage.

b. Stress-relaxation test

_____ is held constant and, after an initial peak, _____ decreases over time. This behavior is consistent with creep response mentioned above, just a different way of measuring the viscoelastic behavior.



Behavior of AC under uniaxial tension



Cartilage is _____ when tested at the surface as opposed to deeper (closer to the bone). Also, cartilage is stronger and stiffer when tested _____ _____ split lines. Overall, the surface of AC can be described as a " _____."

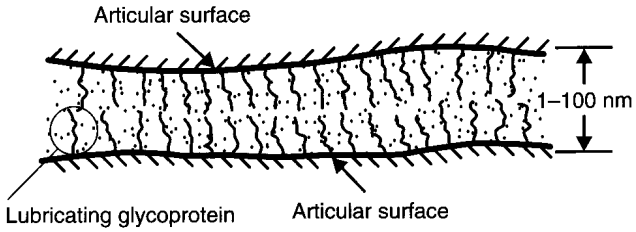
Lubrication of AC

Basic mechanisms:

1. A relatively thick fluid film exists (under normal conditions) that acts to lubricate the joint for the sliding and squeezing of one surface against the other. Thickness: _____ .
2. Under _____ loads or under _____ gliding conditions, the thickness of the film decreases (_____). There is evidence that suggests that fluid squeezed out of the cartilage matrix us the mail contributor of this fluid film. Dynamically here's what happens: the fluid is squeezed out (extruded) in front of and beneath the loaded contact area. Once the area of peak stress has passed any given point on the cartilage, the fluid will start to be reabsorbed, ready for the next

cycle of movement. This _____ is good for the cartilage. It gets its nutrients from the synovial fluid.

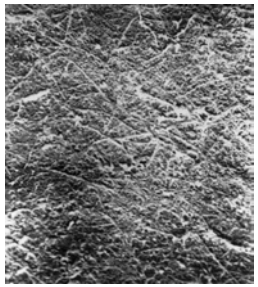
3. Under extreme loading conditions, a thin boundary layer exists on the surfaces that acts as a lubricant. Thickness: _____ (1 nm = _____ m). This layer is believed to be 1 molecule thick. Here, this results from the fluid being nearly completely squeezed out.

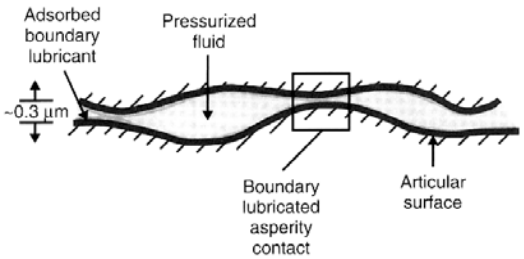


This can happen from prolonged static loading conditions, e.g., standing for very long periods of time without moving at all. It is believed that this thin boundary layer arises from either the synovial fluid being _____* on the articular surface or from an _____ _____ of the synovial fluid into a thin gel on the surface.

*Definition: "Said of solids, to condense and hold a gas on the surface."

Mixed lubrication:





Wear in AC

Under most conditions there is very little, if any, wear on cartilage surfaces. _____ refers to "the removal of material from solid surfaces caused by mechanical action."

Two components of wear

1. _____ results from the interaction of the two surfaces. Fragments from one surface may be adhered to the other one (_____) or the softer surface may be scraped away by the harder one (_____).
2. _____ results from deformation of contacting bodies.

Since normal young joints rarely show any rates of wear, this suggests that either

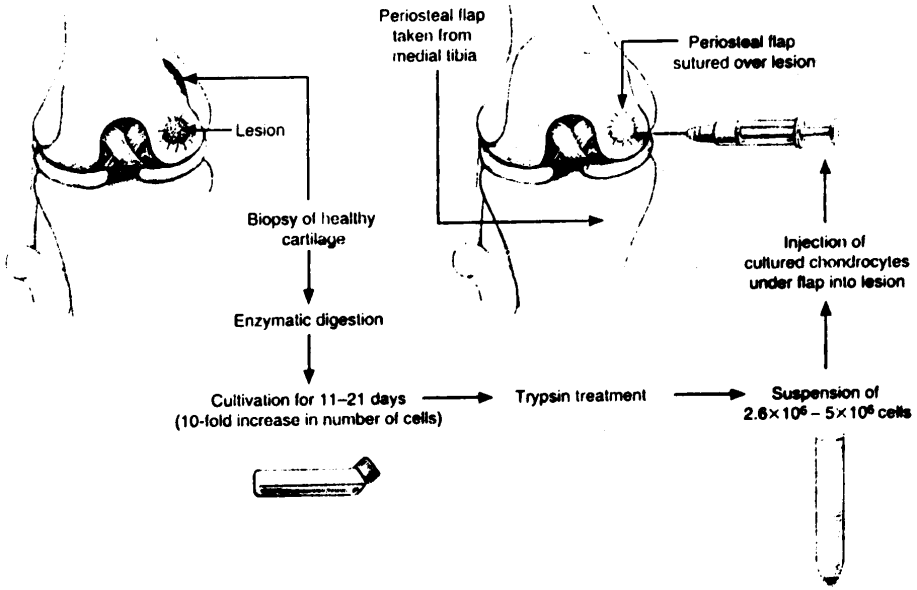
1. the joint surfaces rarely or never contact each other, or
2. _____ of the surface is possible.

Healing of AC

Can AC heal itself?

Can healing be promoted surgically?

Example: "Chondrocyte Transplantation"



(Source: *New England Journal of Medicine*, 1994, p. 890.)