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جنت میں کھجور کا درخت لگائیں

حضور ﷺ کا فرمانِ عالیشان ہے کہ جو شخص یہ کہتا ہے

’سُبْحَانَ اللّٰهِ الْعَظِیْمِ وَبِحَمْدِهِ‘

’اللہ پاک ہے عظمت والا اور تمام خوبیاں اسی کیلئے ہیں۔

اسکے لئے جنت میں درخت لگا دیا جاتا ہے۔ (ترمذی)

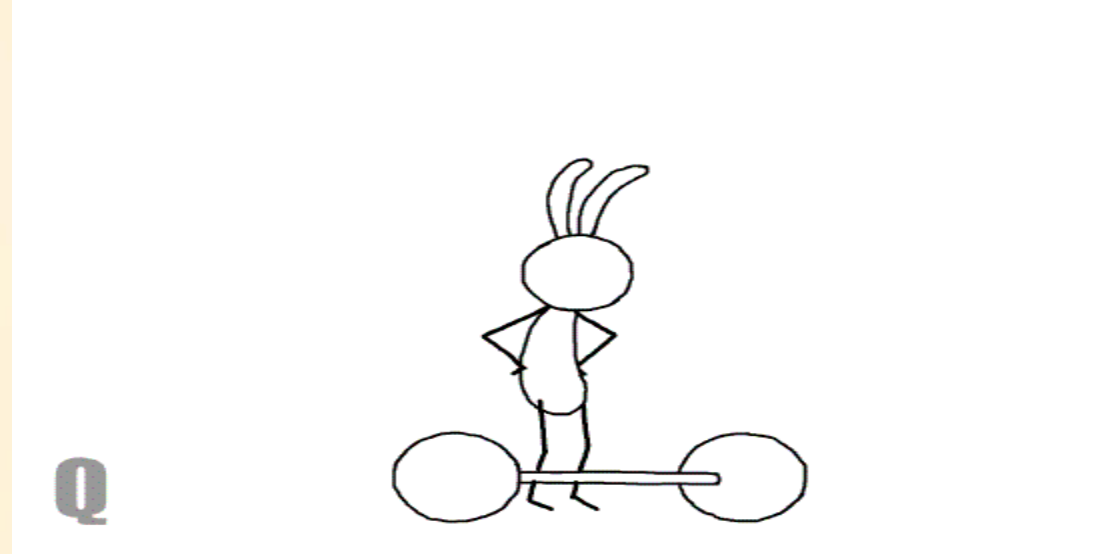




# Biomechanics of Tendon and Ligaments

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# Introduction



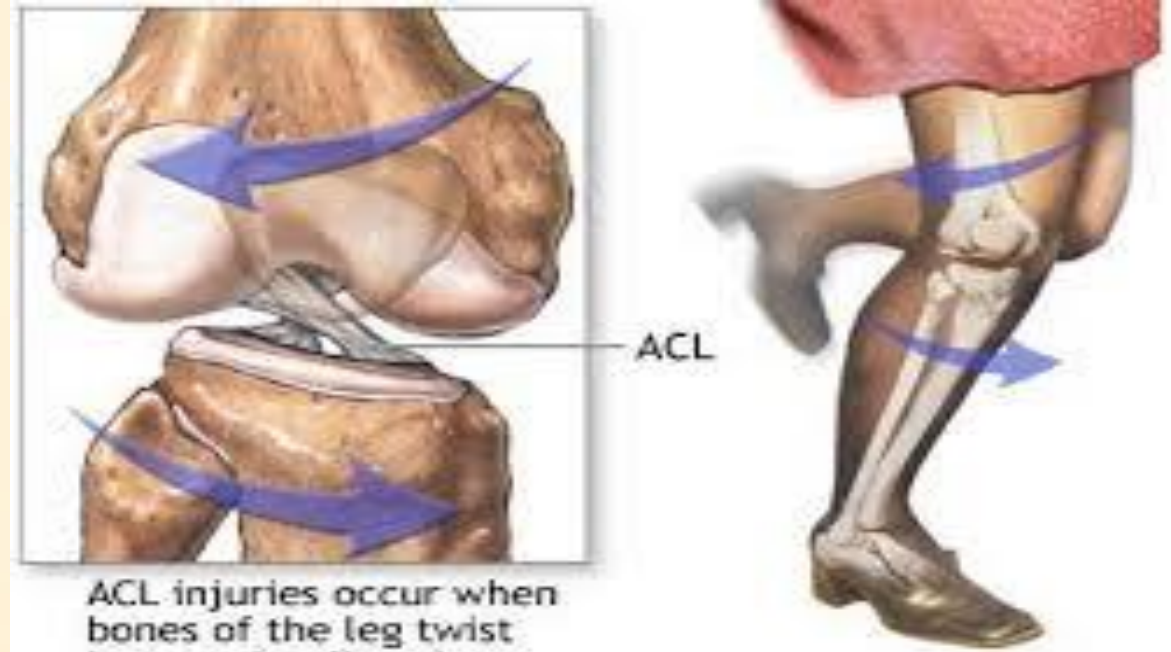
- Passive structures- tendons, ligaments, joint capsules.
- Ligament and joint capsule-prevention of excessive motion, enhance mechanical stability, guide the joint motion.
- Tendons- attach muscles to the bones and transmission of tensile loads.



- Tendons & ligaments govern joint motion and share load in synovial joints.

Increases in ratio of athletics and trauma has lead to increases in soft tissue injuries.

- Injury → changes in joint motion and wear → **premature joint degeneration** → increased morbidity



ACL injuries occur when bones of the leg twist in opposite directions under full body weight

ADAM

### Jumper's knee

Cross-section of knee in flexion

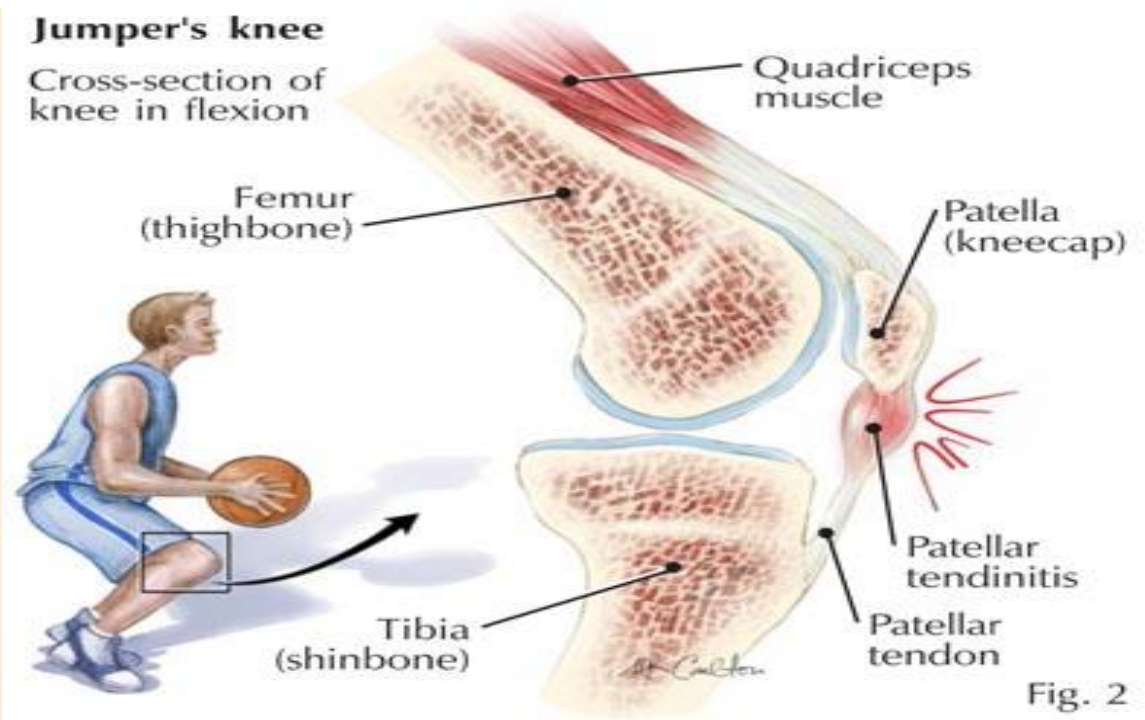


Fig. 2

## Tendons

## Ligaments

Dense connective tissues

Similar in structural composition and mechanical behavior

- load transfer structures
- Longer & narrower
- Connect muscle to bone
- Collagen more longitudinally arranged
- Load-bearing structures
- Shorter & wider
- connect bone to bone
- Less collagen & more ground substance
- Experiences more varied loading thus collagen arrangement more variable

# Structural components

| <b>Component</b>                      | <b>Ligament</b> | <b>Tendon</b>          |
|---------------------------------------|-----------------|------------------------|
| <b>Cellular material= fibroblasts</b> | <b>20%</b>      | <b>20%</b>             |
| <b>Extracellular matrix</b>           | <b>80%</b>      | <b>80%</b>             |
| <b>water</b>                          | <b>60-80%</b>   | <b>60-80%</b>          |
| <b>solids</b>                         | <b>20-40%</b>   | <b>20-40%</b>          |
| <b>Collagen</b>                       | <b>70-80%</b>   | <b>Slightly higher</b> |
| <b>Type 1</b>                         | <b>90%</b>      | <b>95-99%</b>          |
| <b>Type 3</b>                         | <b>10%</b>      | <b>1-5%</b>            |
| <b>Ground substance</b>               | <b>20-30%</b>   | <b>Slightly lesser</b> |



# Structural anatomy of tendon & ligaments

- **Collagen** is main structural protein in the extracellular space in the various connective tissues making 25% to 35% of the whole-body protein content.
- Collagen consists of amino acids wound together to form triple-helices of elongated fibrils. It is mostly found in fibrous tissues such as tendons, ligaments, and skin.
- Depending upon the degree of mineralization, collagen tissues may be rigid (bone), compliant (tendon), or have a gradient from rigid to compliant (cartilage).
- It is also abundant in corneas, blood vessels, the gut, intervertebral discs, and the dentin in teeth.
- In muscle tissue, it serves as a major component of the **endomysium & epimysium**. Collagen constitutes one to two percent of muscle tissue and accounts for 6% of the weight of strong, tendinous muscles. The fibroblast is the most common cell that creates collagen.





Procollagen

Secretion  
↓

Cleavage  
↓  
Collagen monomer/  
propeptides

Cross-linkage  
↓  
Fibril formation

Collagen fibrils



Cell membrane

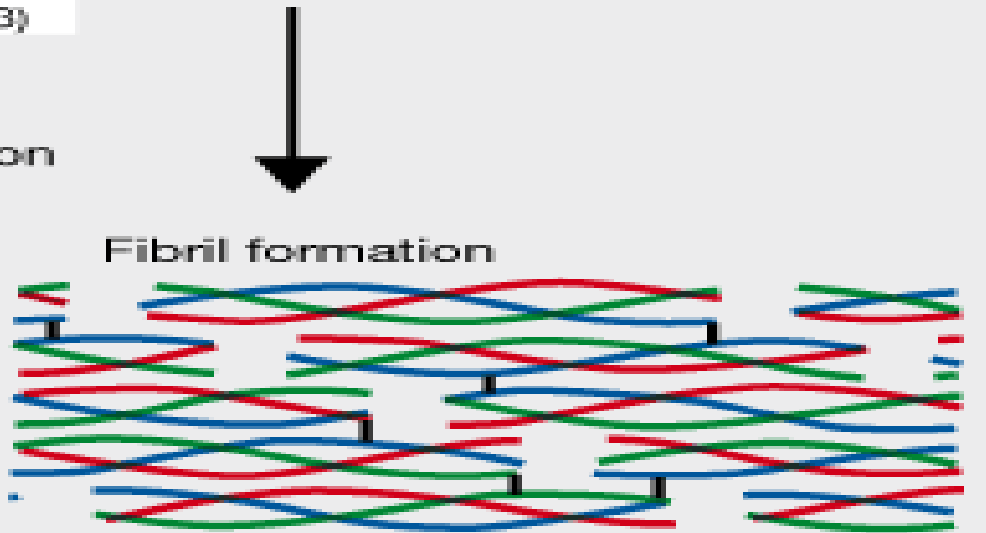
Procollagen III secretion  
↓



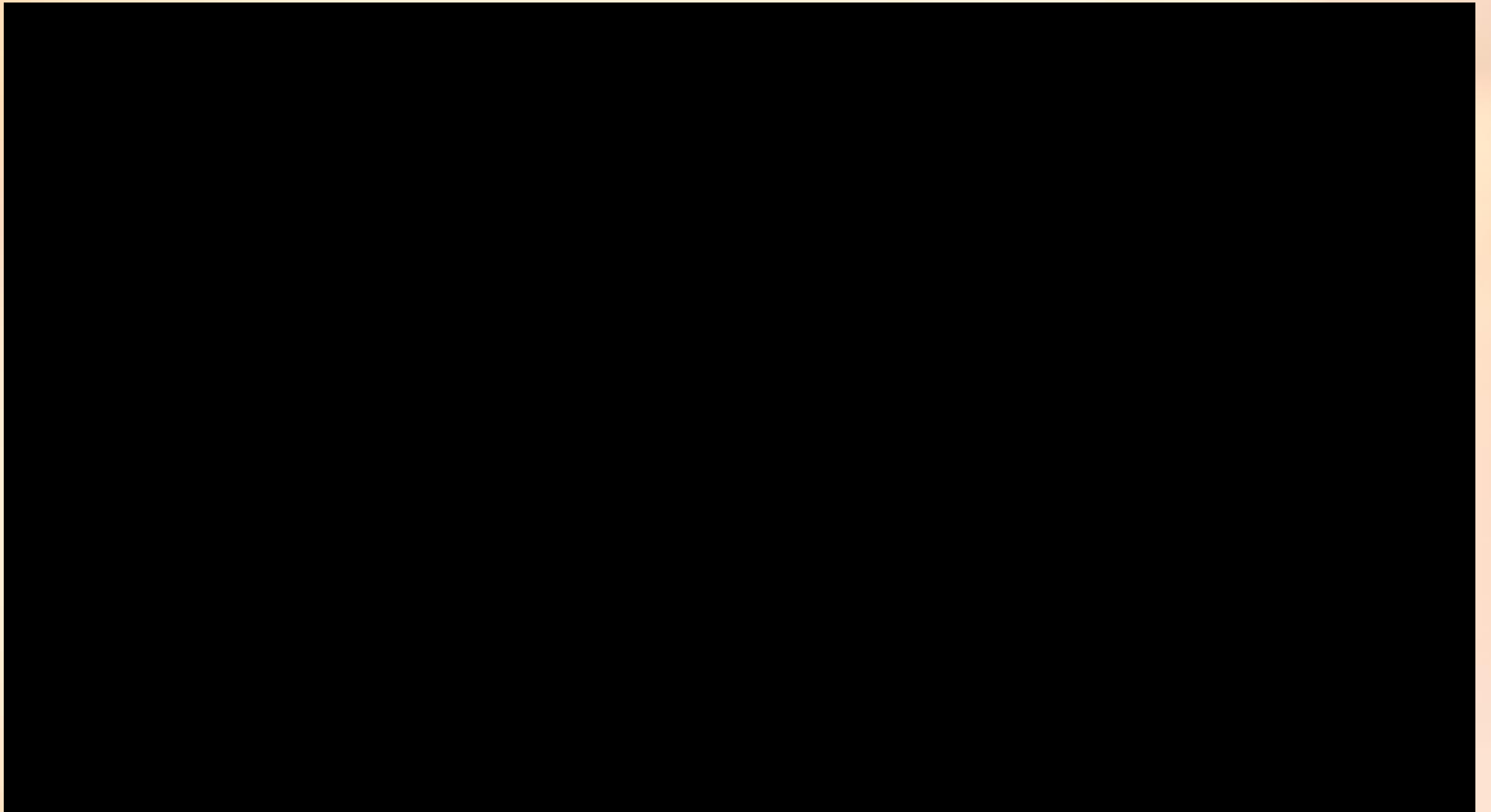
P III P  
(Col 1)  
↑

P III P  
(Col 1-3)  
↓

Circulation



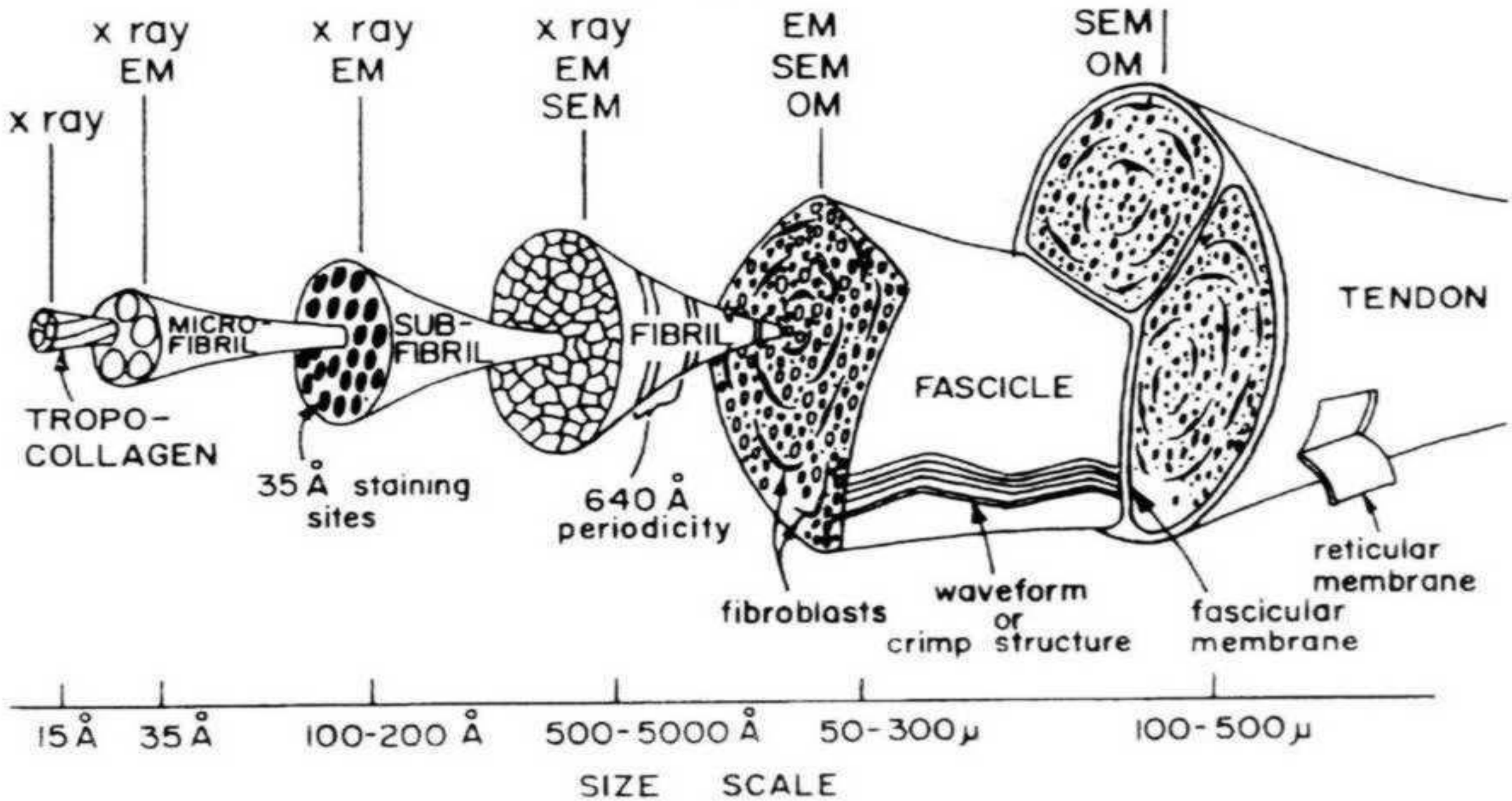
- ❖ 2/3 of collagen molecule consist of 3 amino acids, glycine, 33%, proline 15% & 15%hydroxyproline
- ❖ every third amino acid in each chain is glycine, and repetitive sequence essential for triple helix.
- ❖ Small size of glycine allows tight helical packing of collagen molecule, & enhances the stability of molecule by forming hydrogen bonds among three chains.
- ❖ Hydroxyproline and proline also form hydrogen bond.

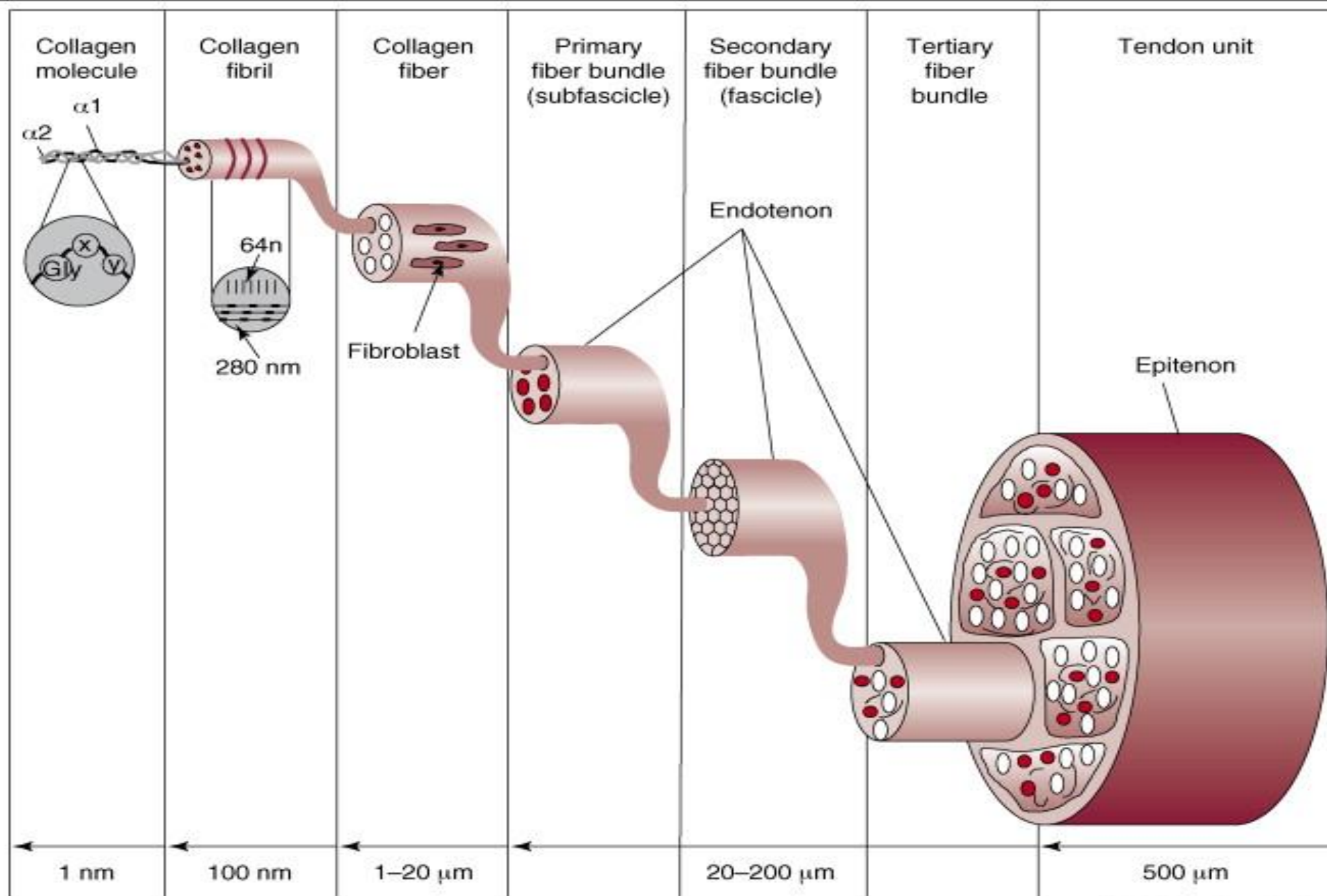


- 5 collagen molecules --→ Microfibril--→ Subfibril----→ Fibril--→ collagen fiber(1-20um in diameter)---→
- **Fascicle:....**Closely-packed, longitudinal, parallel bundles of fibrils bound together by proteoglycans and glycoproteins in association with water incorporated in a matrix. Fibroblasts are aligned in rows between these bundles.
- Fascicles held together by loose connective tissue, the **Endotenon**; containing thin collagen fibrils and elastic fibres.
- Allows longitudinal fascicle movement, and supports blood vessels, lymphatics and nerves
- The interstitial space within the fascia where the tendon is located is the **paratenon** a fatty areolar tissue.
- Groups of fascicles are bounded by the **epitenon or** Tendon itself surrounded by **epitenon**



Evidence :





- **The arrangement of collagen** in tendons and ligaments varies as in accordance with the function.

Parallel arrangement in tendons.... **which equips the tendons to handle the high unidirectional (uniaxial) tensile loads to which they are subjected during activity.**

- In ligaments not all in parallel direction and suited according to the function. As
- **The ligaments generally sustain tensile loads in one predominant direction but may also bear smaller (tensile loads in other directions;.**



## Factors effect the stability & strength



- **The arrangement of adjacent molecules aligns oppositely-charged acidic and basic Amino Acids makes a very stable construct, that takes a lot of energy to separate its molecules... However**
- In **newly** developed collagen the cross-linkage are few..
- the collagen are soluble in natural **salt and in acid** solution,
- cross linkage easily damaged with high **heat**, as well **aging**, decrease stability and strength.

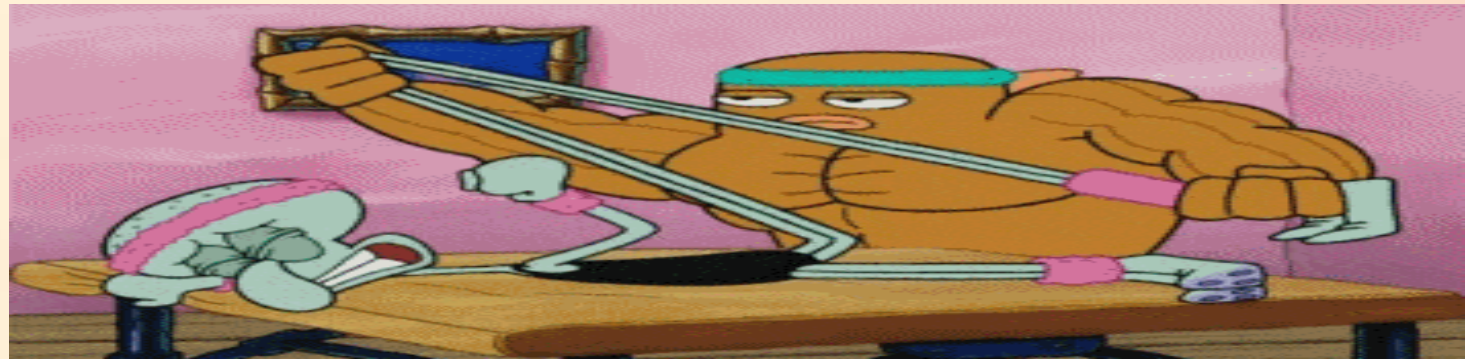


## • **Functions of tendon:**

- 1: Connect muscles to bone, functioning to transmit forces.
- 2: Tendons typically carry tensile forces covered by **Mesotenon joins epitenon & tension side of sheath**. This connection allows tendons to passively modulate forces during locomotion, providing additional stability with no active work.
- 3: Tendon act as cartilage:
  - At regions where tendons wrap around an articular surface, large compressive forces are generated. Tendons in these regions assume a cartilage-like appearance...
- **4: Acts as a pulley** & directs the path of the tendon AS it bends sharply, like the flexors in the hand, are enclosed by a tendon sheath that **made areolar tissue** located in skin binds outer layer of skin to muscle beneath.

## Functions of tendon:

- 5: As tendon contain elastic properties has ability to function as **springs**.
- 6: Not all tendons are required to perform the same functional role, with some **predominantly positioning limbs**, such as the fingers when writing (positional tendons)
- Others **acting as springs** to make locomotion more efficient (energy storing tendons).
- 7: Energy storing tendons can **store and recover** energy at high efficiency.
- **For example**, during a human initial stance, the Achilles tendon stretches as the ankle joint dorsiflex. During the last portion of the stance, as the foot plantar-flexes (pointing the toes down), the stored elastic energy is released propels foot forward.
- 8: Furthermore, because the tendon stretches, the muscle is able to function with less or even **no change in length**, allowing the muscle to generate greater force



**9:** Function also varied as according to converging of **tendon by different sheaths:** a

**Tendon sheath:** A layer of synovial membrane around a tendon. It permits the tendon to stretch and not adhere to the surrounding fascia.

It has two layers: 1: synovial sheath                      2: fibrous tendon sheath

- **9A: A synovial sheath:** The tendon invaginates the synovial sheath from one side so that the tendon is suspended from the membrane by mesotendon, through which the blood vessels reach the tendon, in places where the range of movement is extensive. The mesotendon disappears or remains in the form of narrow tendinous bands as threads known as vincula tendina.

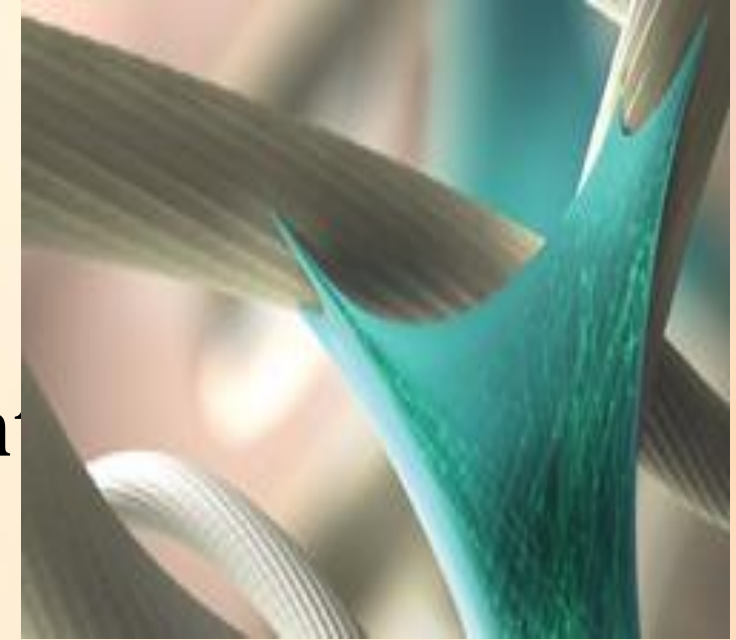
**Tendon in synovial sheath::** found where the tendon passes under ligaments and through osseofibrous tunnels (**function is to reduce friction between tendon & surrounding structure**). Synovial fluid released facilitates sliding of tendons in sheath.

**Example** common synovial sheath for the flexor tendons of the hand

- **9B:: Tendons not enclosed w/in synovial sheath** move in a straight line and are surrounded by a loose areolar connective tissue called the paratenon (continuous with tendon).

# Elastin

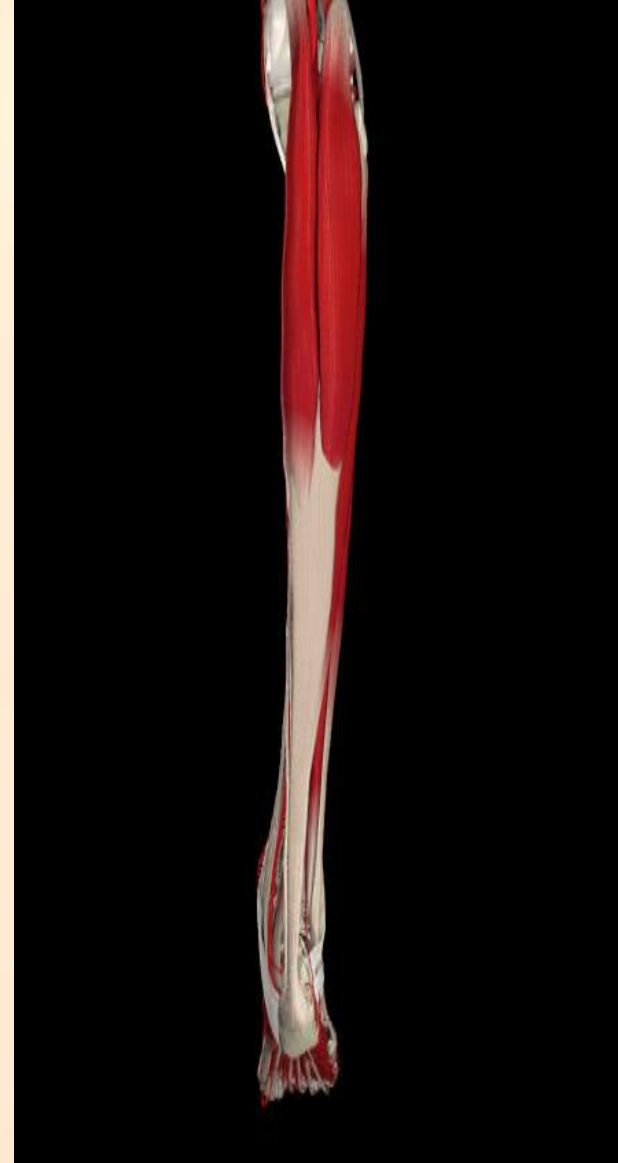
- Give Mechanical properties to tendon.
- present less in tendons and more in ligament
- **Ground substance::**
- GAG, WATER, GLYCOPROTEIN ,PROTEOGLYCAN
- PGs, Same structures as in AC.
- Forms gel like material and binds ligaments or tendons.
- Cement like properties provide structural stability.

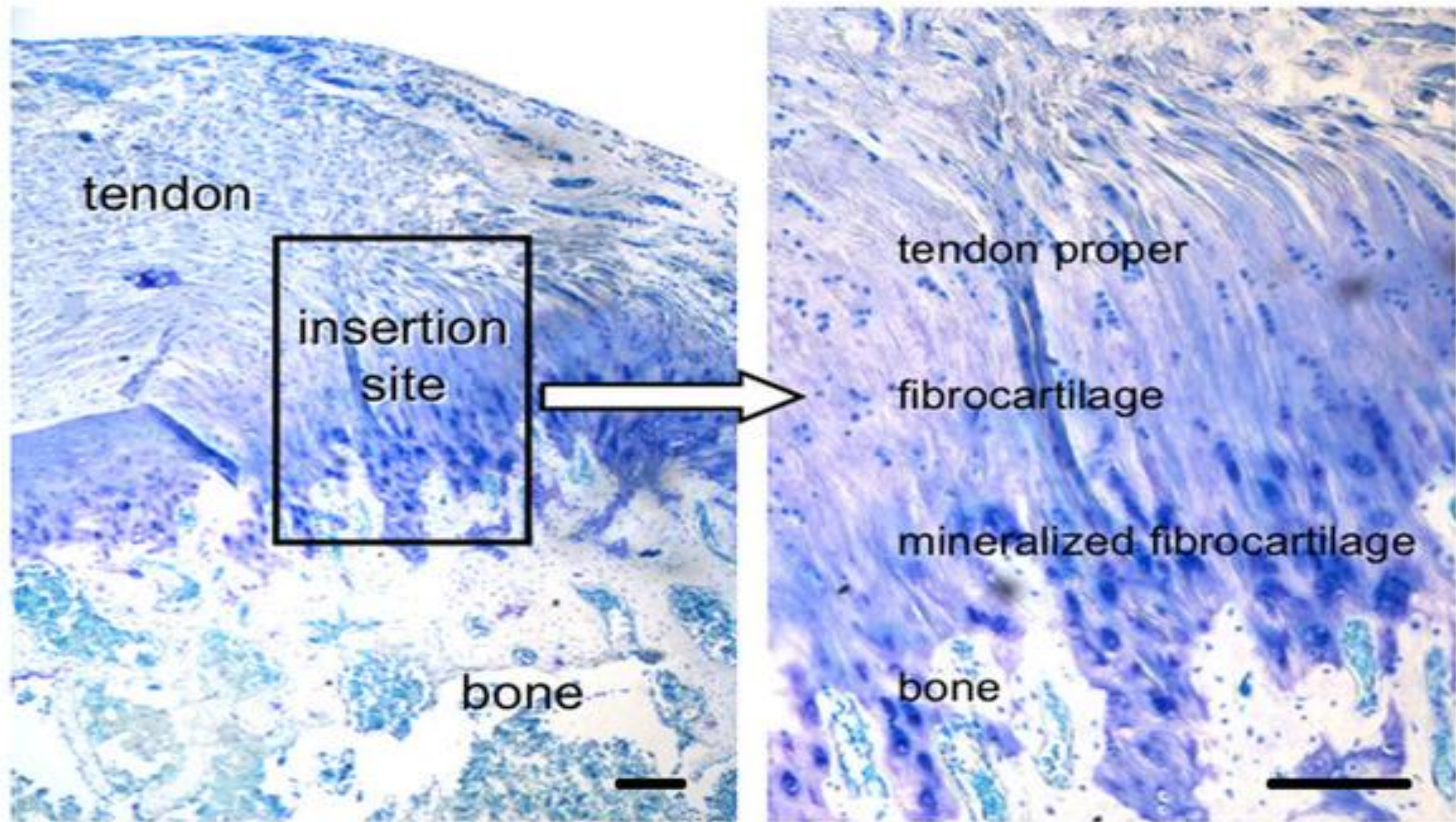




## Insertion into Bone

- At the tendo-osseus junction the collagen fibers of the endotenon continue into the bone as Sharpey's Fibers
- Then becomes continuous with the periosteum
- Zone I: end of tendon
- Zone II: collagen fibers intermesh with Fibrocartilage
- Zone III: fibrocartilage then gradually becomes mineralized fibrocartilage
- Zone IV: merge into cortical bone





- **Two additional factors become important in in tensile loading of tendons:**

1. The amount of force produced by contraction of the muscle to which the tendon is attached ...

2. Cross-sectional area of the tendon in relation to that of its muscle.

- **The strength of a muscle depends on cross-sectional area.**

- **The larger the cross sectional area , the higher the magnitude of the force produced by the contraction and greater tensile load is transmitted.**

- **the larger the cross-sectional area of the tendon, the greater the loads it can bear**



THANKS



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# Mechanical Behavior of Tendon and ligaments

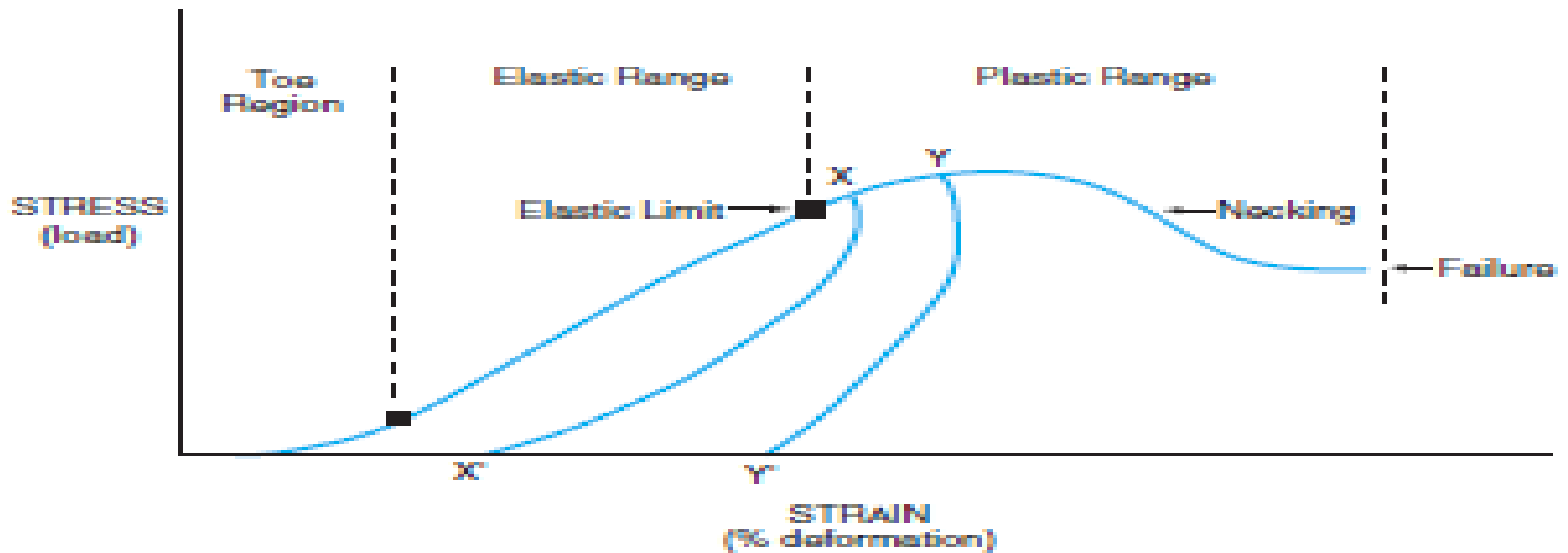
- Both are Viscoelastic tissues
- Visco - a small amount of load results in deformation (relative)
- Elastic - refers to Elastic Region
- can sustain high tensile loads for longer period but not as much as muscles can
- Flexible to allow changes in direction of muscle pull
- Prevent load injury for extended time period
  - When load is great enough to cause injury, damage is dependent on: rate and amount of load



# Mechanical Behavior of Tendon and ligaments

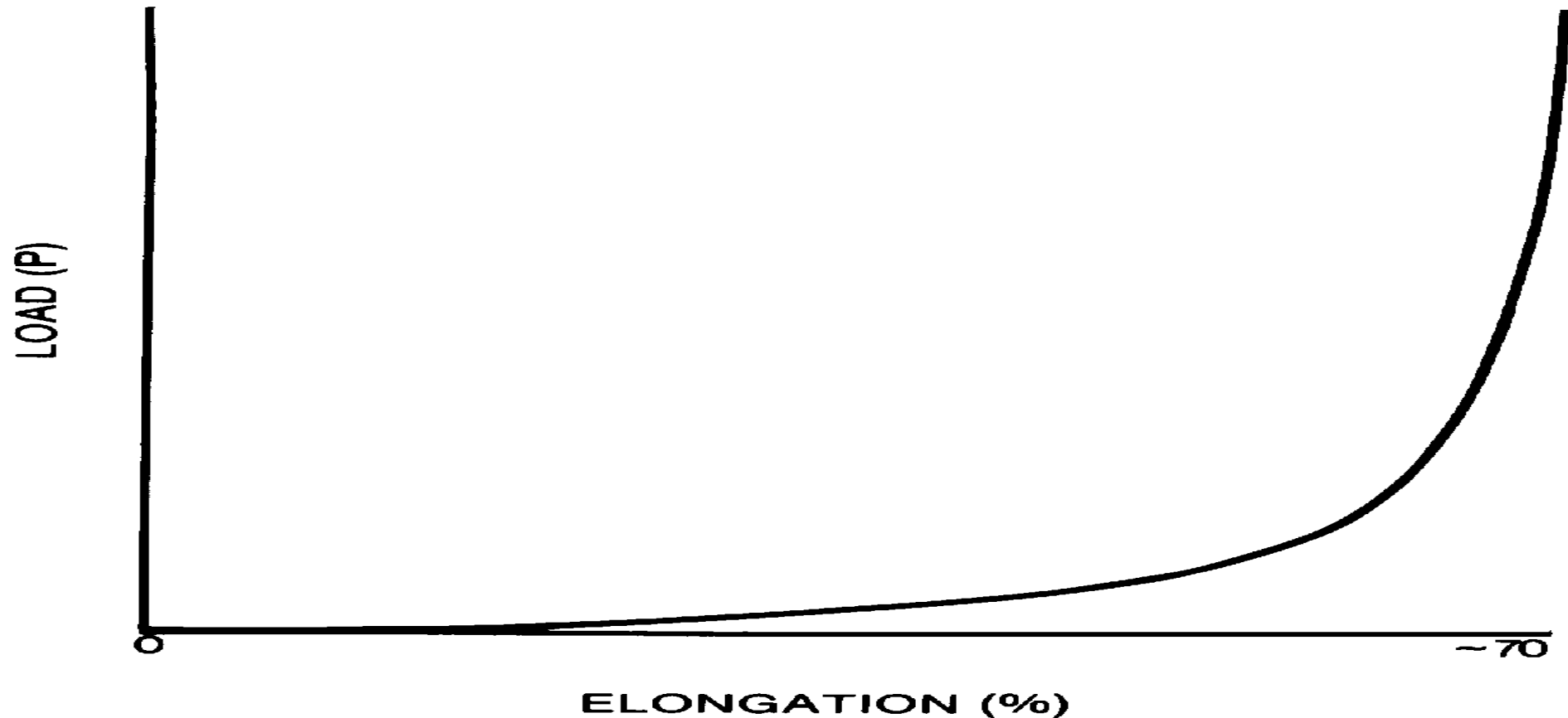
- Elastic region & limit
- Plasticity
- Stress relaxation
- Creep
- Curves for creep and stress relaxation
- Load Deformation curve variation(stress strain curve)
- Hysteresis
- Failure





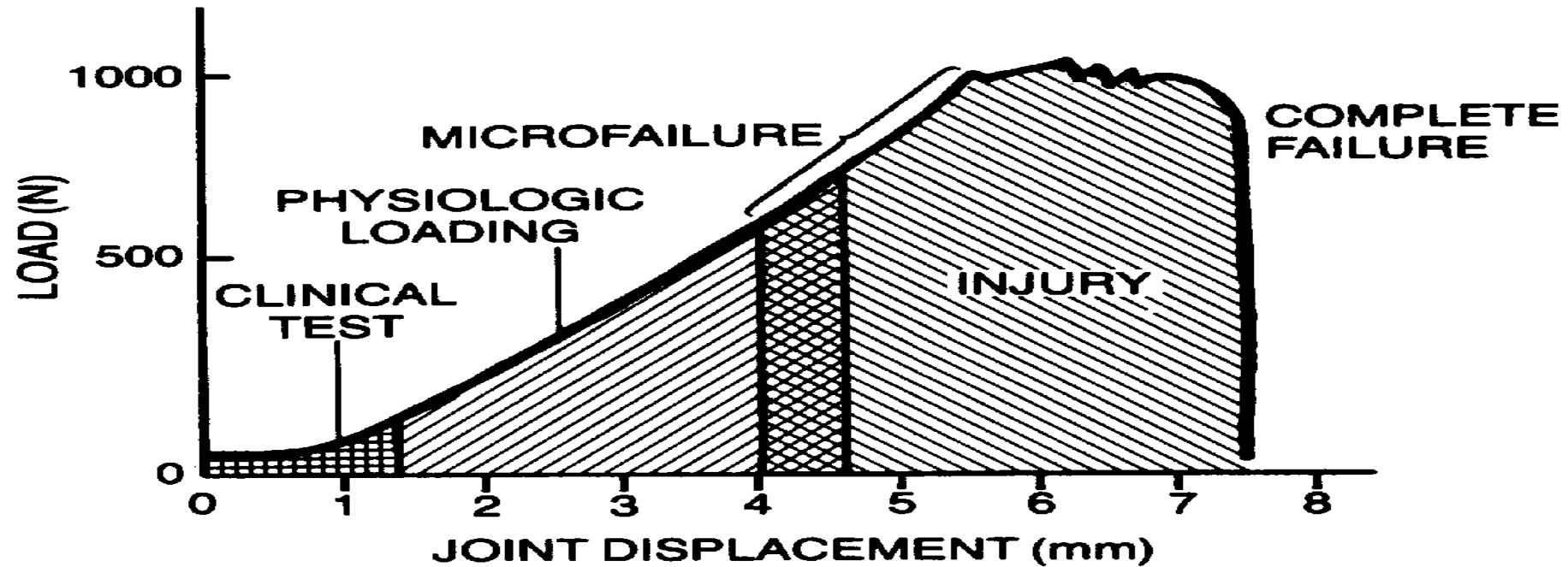
**FIGURE 4.6** Stress–strain curve. When stressed, initially the wavy collagen fibers straighten (toe region). With additional stress, recoverable deformation occurs in the elastic range. Once the elastic limit is reached, sequential failure of the collagen fibers and tissue occurs in the plastic range, resulting in release of heat (hysteresis) and new length when the stress is released. The length from the stress point (X) results in a new length when released (X'); the heat released is represented by the area under the curve between these two points (hysteresis loop). (Y to Y' represents additional length from additional stress with more heat released.) Necking is the region in which there is considerable weakening of the tissue and less force is needed for deformation. Total failure quickly follows even under smaller loads.

# Characteristic Stress-Strain Relation for Ligaments



Load-elongation curve for a human ligamentum flavum (60 to 70% elastic fibers) tested in tension to failure. At 70% elongation the ligament exhibited a great increase in stiffness with additional loading and failed abruptly without further deformation. (Adapted from Nachemson and Evans, 1968.)

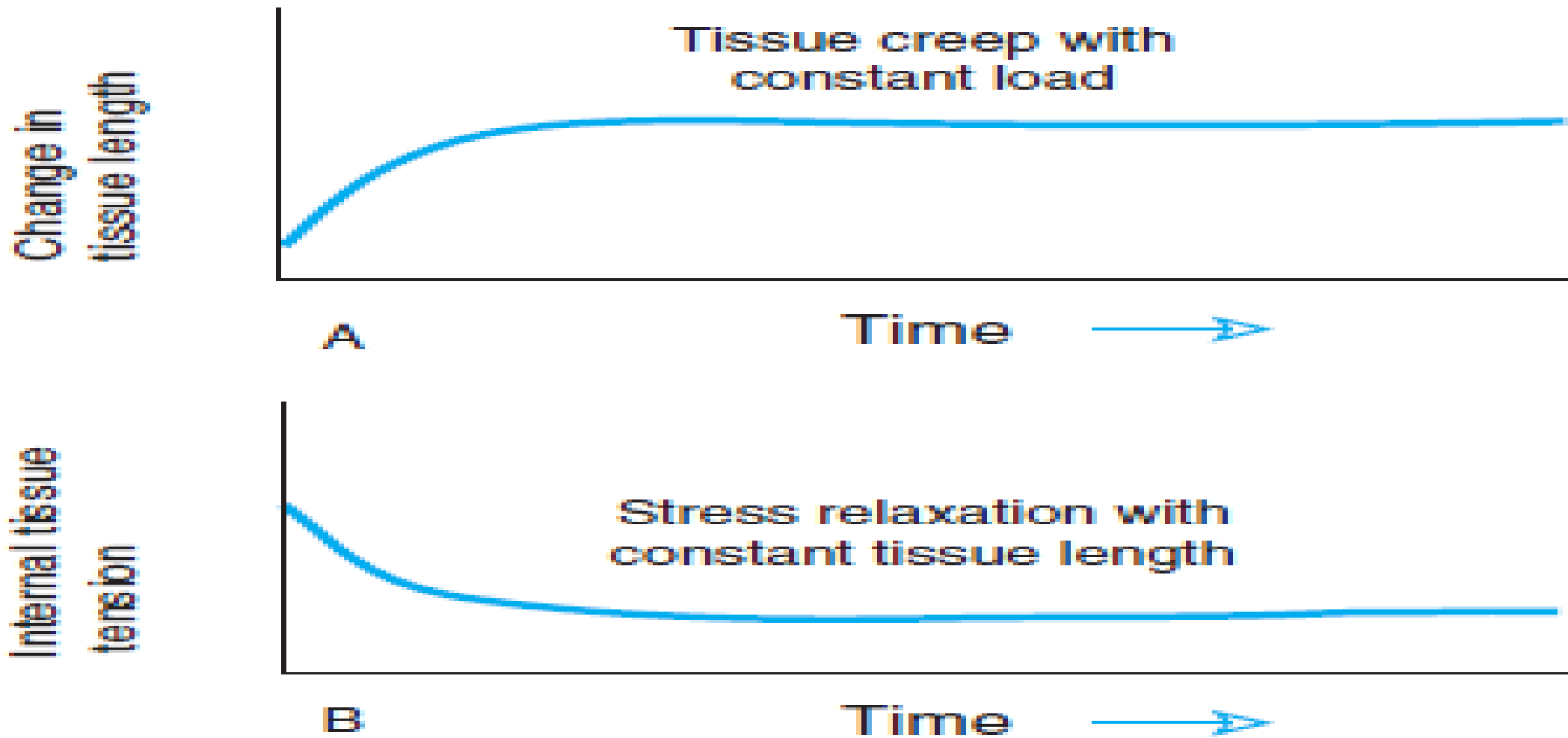
# Ligament and Tendon Injury curve (Mechanisms) (b)



The curve produced during tensile testing of a human anterior cruciate ligament *in vitro* (Noyes, 1977) (see Fig. 3–8) has been converted to a load-displacement curve and divided into three regions correlating with clinical findings: (1) the load imposed on the anterior cruciate ligament during the anterior drawer test; (2) that placed on the ligament during physiologic activity; and (3) that imposed on the ligament from partial injury to complete rupture. It should be noted that the divisions shown here represent a generalization. Microfailure is shown to begin toward the end of the physiologic loading region, but it may take place well before this point in any given ligament.



# Viscoelastic Behavior in Tendons and Ligaments



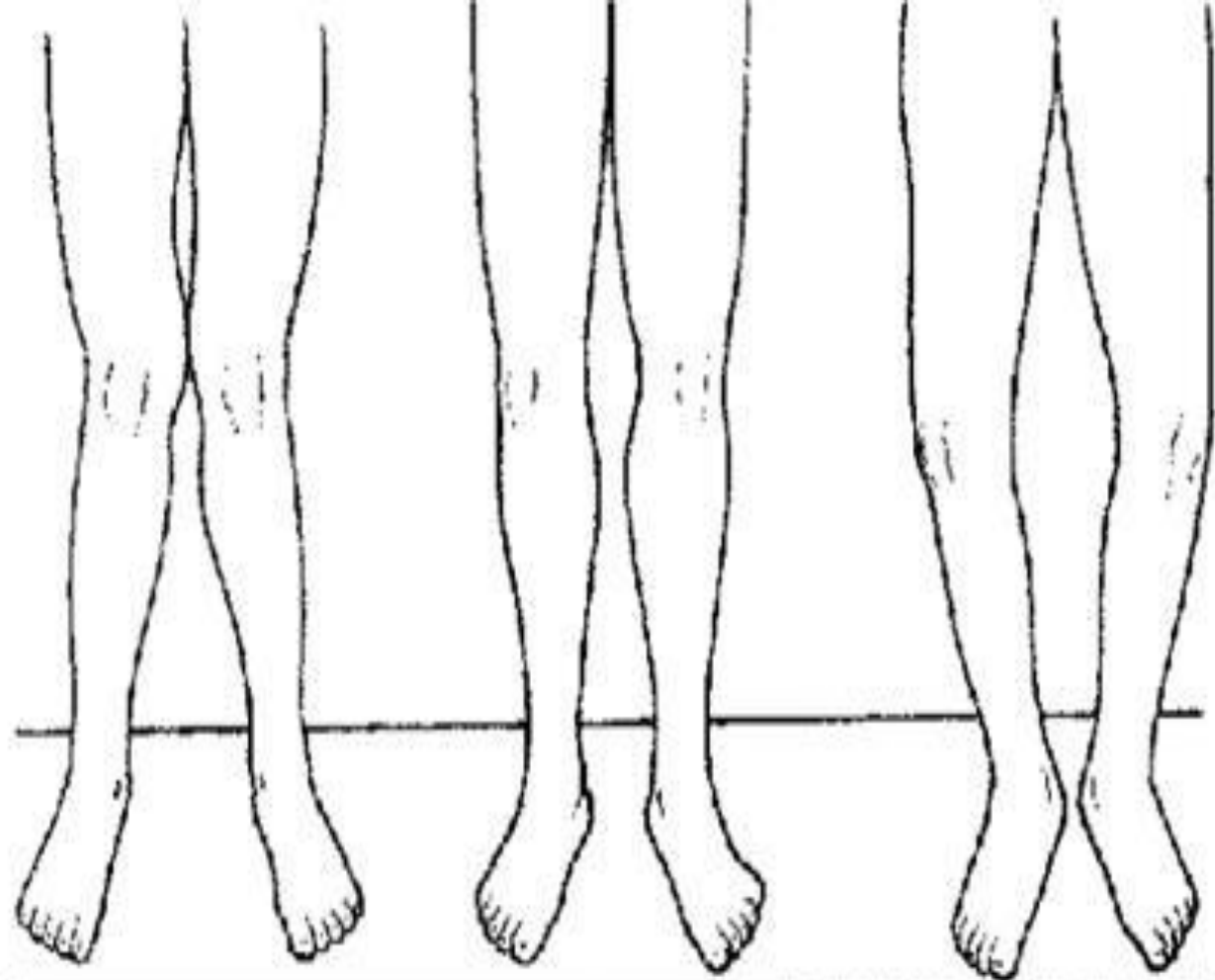
**FIGURE 4.7** Tissue response to prolonged stretch forces as a result of viscoelastic properties. (A) Effects of creep. A constant load, applied over time, results in increased tissue length until equilibrium is reached. (B) Effects of stress-relaxation. A load applied with the tissue kept at a constant length results in decreased internal tension in the tissue until equilibrium is reached.

# Creep

- ***When a load is applied for an extended period of time***, the tissue elongates, resulting in permanent deformation.
- It is related to the viscoelasticity of the tissue and is therefore time-dependent.
- Low-magnitude loads, usually in the elastic range for long periods, increase the deformation of connective tissue and allow gradual rearrangement of collagen fiber bonds (remodeling) and redistribution of water to surrounding tissues.

# stress relaxation

- ***When a force (load) is applied to stretch*** a tissue, and the length of the tissue is kept constant,
- after the initial creep there is a decrease in the force required to maintain that length, and the tension in the tissue decreases create relaxation



**Genu valgum**

**Normal**

**Genu varum**

Figure 1. Knee alignment can be categorized as genu valgum (knock-knee), normal or genu varum (bow legged)<sup>5</sup>



# Ponseti treatment of clubfoot





Before



After




**Braces halt the natural progression of the curve**





# Tendon Vascularisation

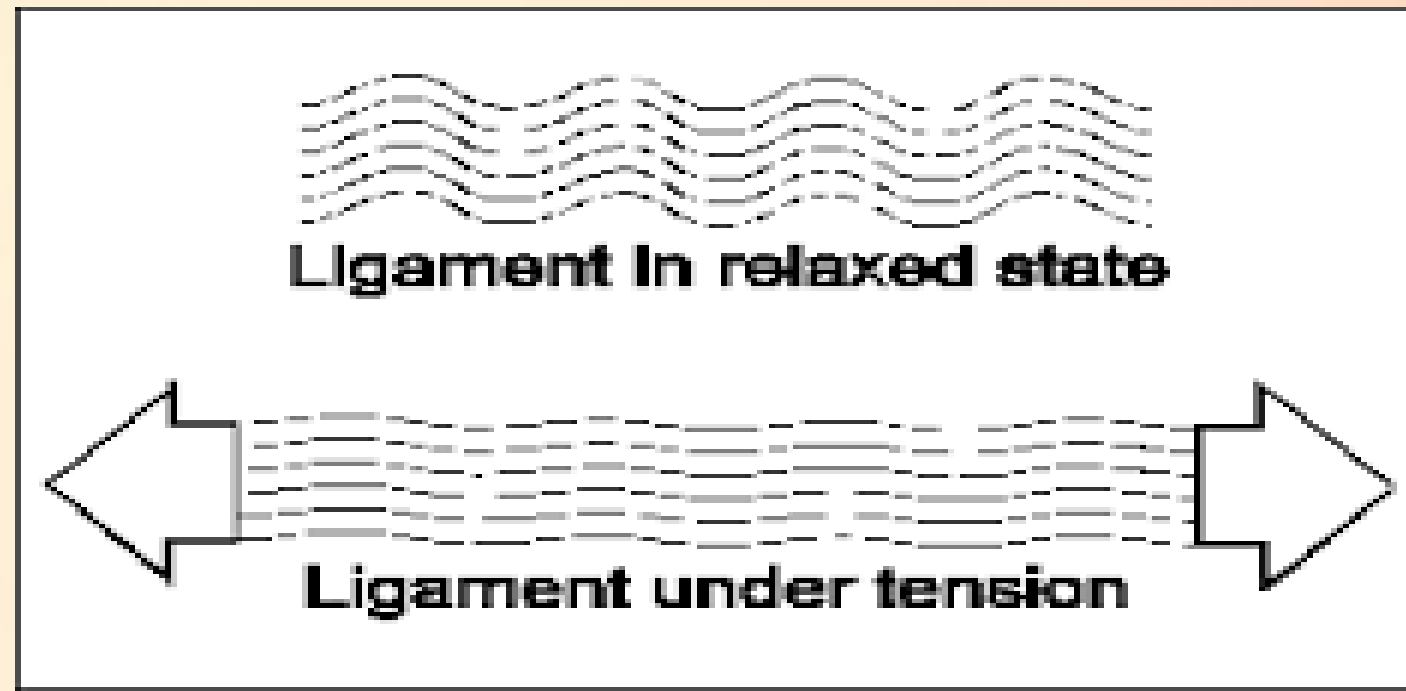
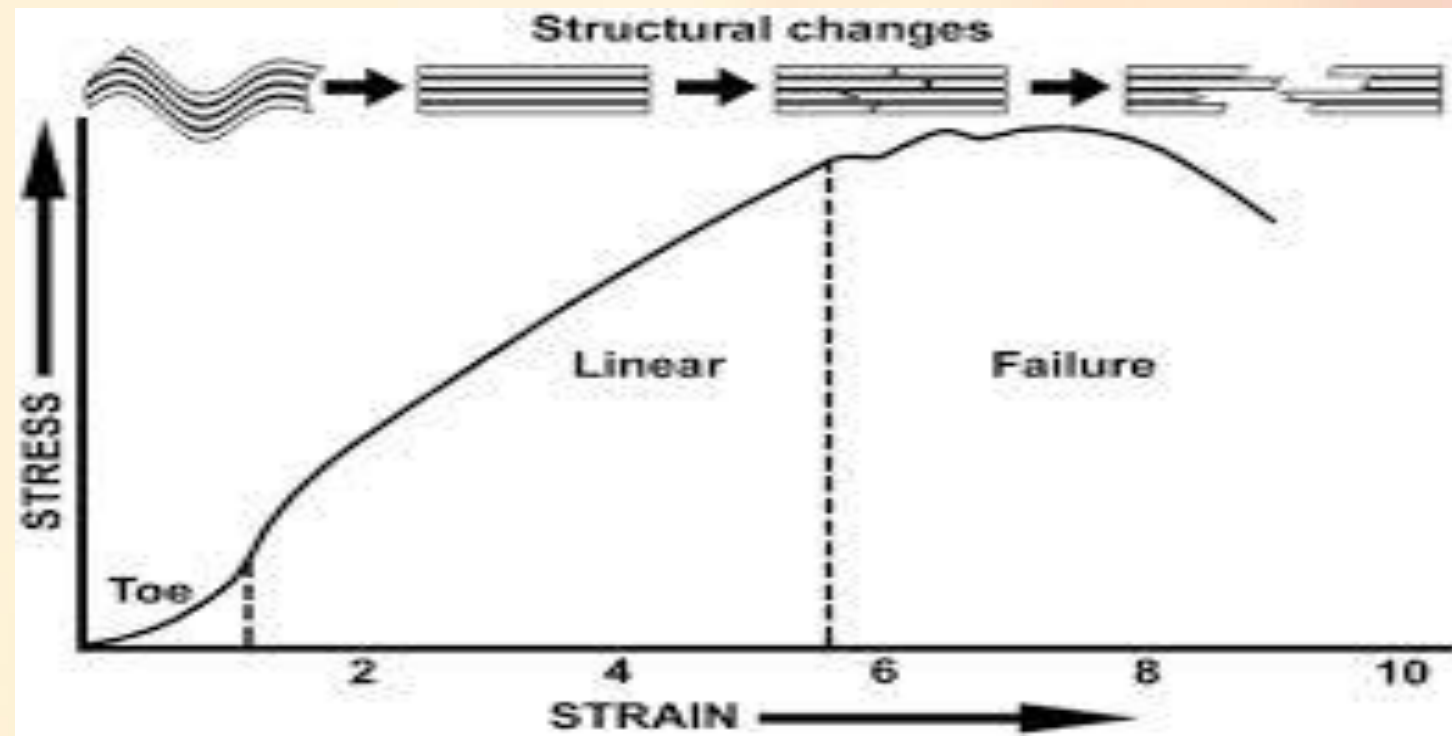
- **Limited vascularisation...low healing process & metabolic activity**
- Tendons blood supply from vessels in perimysium (mesotenon), periosteal insertion, surrounding tissues vessels in paratenon and mesotenon
- **Tendons with in paratenon sheath(vascular tendon)** Vessels enter from periphery and anastomose with longitudinal system of capillaries
- **Tendons covered by tendon sheath as avascular tendon:**
- avascularity in tendons adopt 
- Dual pathway for nutrition : vascular and synovial, i.e. diffusion → Clinically important is the implication that tendon healing can occur in absence of **adhesions**, that is blood supply.

# Ligamentous Vascularisation

- hypovascular compared to surrounding structures
- Uniform microvascularity from insertion sites(bones)
  - ❖ Flow is limited but essential to maintenance of cell population, matrix synthesis & repair.
- Variety of specialized nerve endings & mechanoreceptors( proprioception & nociception---  
→effect joint function.

# Crimping

- Fibrils appear in sinusoidal pattern under microscopy
- influences biomechanical behavior of tendons and ligaments
- **Tensile resistance occurs once crimp pattern is straightened (toe region)**
- Load-deformation non-linear



# Ligament Failure and Tendon Injury Mechanism

## GRADES

- **Grade I injury:**
- Negligible clinical symptoms... pain & swelling
- no joint instability
- Micro failure of the collagen fibers



## Grade II injury:

- severe pain and some joint instability
- Movement stop with increased pain during activity
- Progressive failure of the collagen fibers --→ partial ligament rupture.
- The strength and stiffness of the decreased by 50% or >50%,
- The clinical test for joint stability is usually performed with the patient under anesthesia or **without anesthesia**





## Grade III

- Severe pain at trauma
- less/**no** pain after trauma,
- joint completely unstable.
- Most collagen fibers ruptured, but a few still be intact, though it is unable to Support any loads.
- Ligament or joint capsule rupture produces abnormally high stresses on the articular cartilage.
- early osteoarthritis in humans and in animals.



# *Factors That Affect the Biomechanical Properties of Tendons and Ligaments*

- Maturation and aging
- Pregnancy and the postpartum period
- Mobilization and immobilization
- Diabetes mellitus
- Steroids
- Nonsteroidal anti-inflammatory drugs
- Hemodialysis (hyperlaxity/amyloids)
- Grafts



# Maturation and aging

- During maturation (up to 20 years of age), the number and quality of cross-links in collagen & ground substance increases resulting in increased tensile strength of the tendon and ligament
- Aging results in a decline in the mechanical properties of tendons and ligaments, i.e. their strength, stiffness, and ability to withstand deformation.



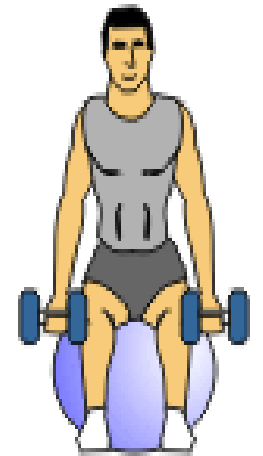
## Pregnancy and the Postpartum period

- A common clinical observation is the increased laxity of the tendons and ligaments especially in the pubic area during later stages of pregnancy and the postpartum period.
- Stiffness of these structures decreased in the early postpartum period but was later restored.



# Mobilization and immobilization

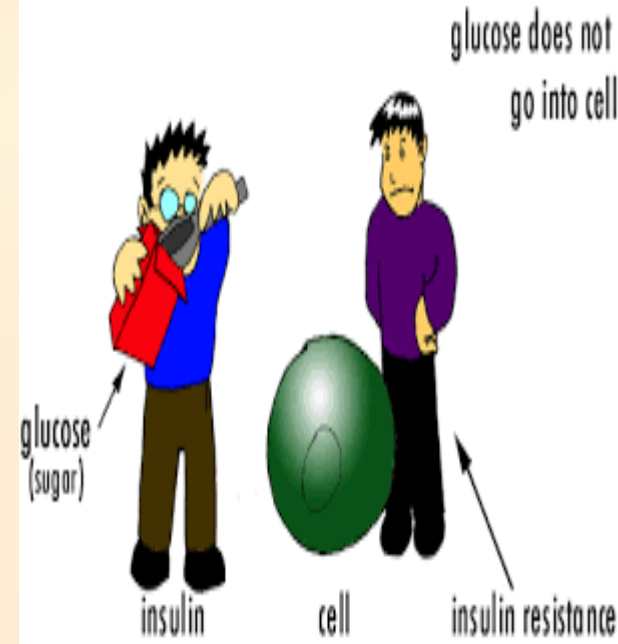
- Like bone, ligament and tendon appear to remodel in response *to the mechanical demands* placed on them;
- they become stronger and stiffer when subjected to increased stress; weaker & less stiff when the stress is reduced(normal aging process).
- Physical training has been found to increase the tensile strength of tendons and of Ligament. immobilization decrease the tensile strength of ligaments.
- stress-strain characteristics after remobilization return to normal but that the energy-absorbing capabilities or the bone-ligament complex improved but **did not return to normal**





# Diabetes Mellitus

- Diabetes mellitus is a metabolic disorder in which the ability to oxidize carbohydrates is more or less completely lost.
- This is usually caused by pancreas insufficiency and a disturbance of the normal insulin mechanism, resulting in **hyperglycemia, glycosuria, and polyuria**. Diabetes mellitus is known to cause musculoskeletal disorders due to decrease strength of collagen fiber and delay healing process after injury.
- Diabetics compared with non-diabetics show higher rates of tendon contracture (29 VS. 9%), tenosynovitis (59 vs. 7%), joint stiffness (40 vs. 9%), and capsulitis (16 vs. 1%).
- Diabetes also causes **osteoporosis**.
- Difference in mode of failure(early on stress-strain curve)



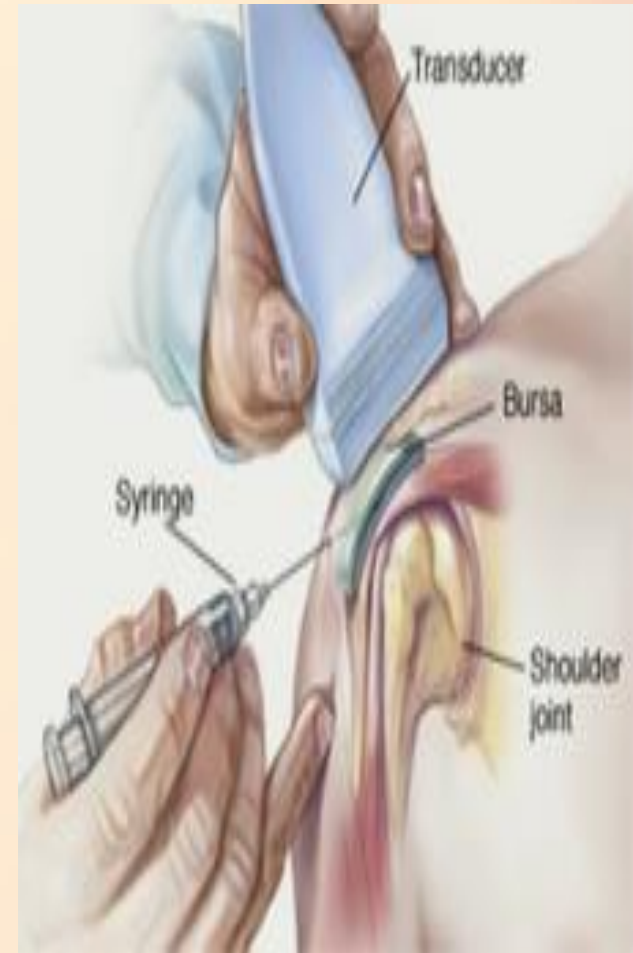
## Steroids

- Corticosteroids, when applied immediately after injury, may cause significant improvement of biomechanical and histological properties in tendons but not on ligaments.
- Corticosteroids also are known to inhibit collagen synthesis when use for long run.
- Helpful for shorter use.



# Nonsteroidal Anti-inflammatory Drugs

- NSAIDs (which include aspirin, acetaminophen, and indomethacin) are frequently used in the treatment of various painful conditions of the musculoskeletal system.
- NSAIDs are also widely used in the treatment of soft tissue injuries such as inflammatory disorders and partial ruptures of tendons and ligaments.
- Animal studies suggest that short term administration of NSAIDs would not be deleterious for tendon healing but instead would increase the rate of biomechanical restoration of the tissue. Not good for long term use.



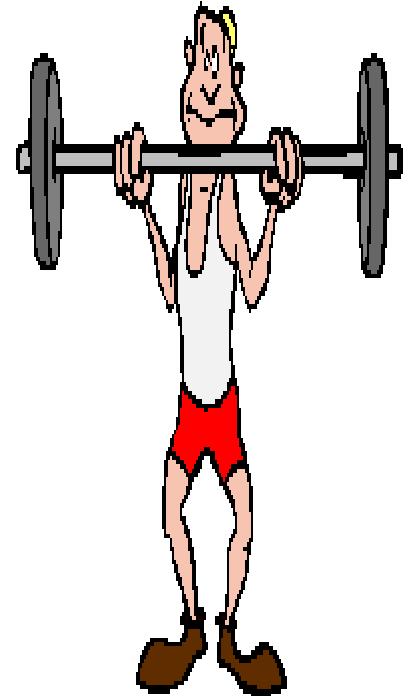
# Hemodialysis

- Tendinous failure resulting from chronic renal failure does occur at different ratios in individuals receiving continuous hemodialysis.
- **Tendon rupture** almost 36% *among* individuals receiving hemodialysis.
- **Hyperlaxity** of tendons and ligaments was found in 74%, *patellar* tendon elongation in 49%, and *articular hypermobility* in 51 % of individuals receiving long-term hemodialysis
- Dialysis-related **amyloidosis** may cause the deposition of amyloid in the synovium of tendons



# Grafts

- Grafts derived from different individuals of the same species are called allografts.
- Grafts derived from the same individual are called autografts.
- Heterografts: graft from separate species
- Patellar bone, and Achilles tendon are usually used as allograft tissue.
- Central tissue of the patellar tendon is commonly used as autografts tissue.
- Allografts and autografts are useful in ligament reconstruction but material properties do not return completely to normal levels.







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