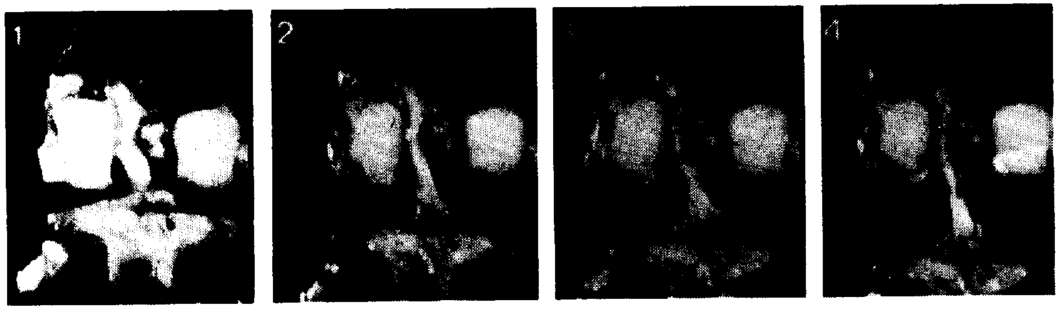
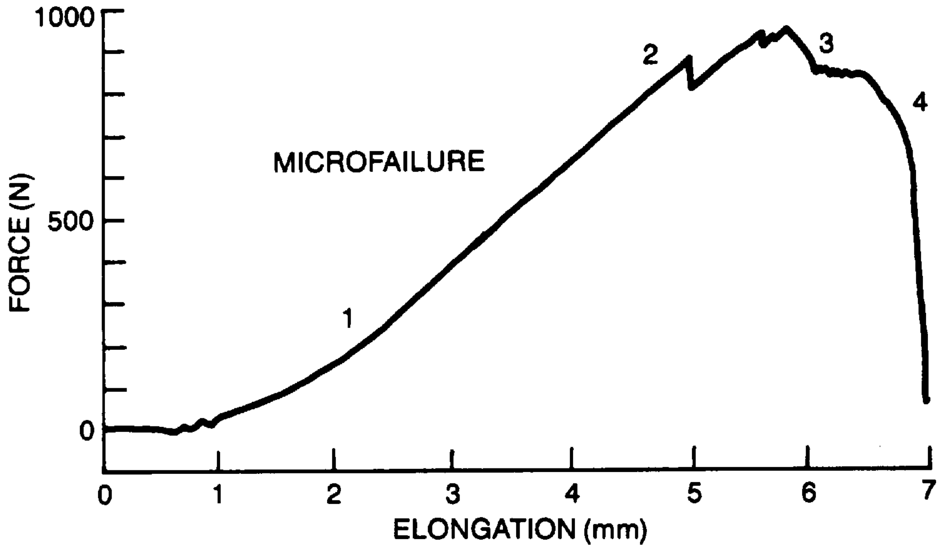
Ligament Biomechanics

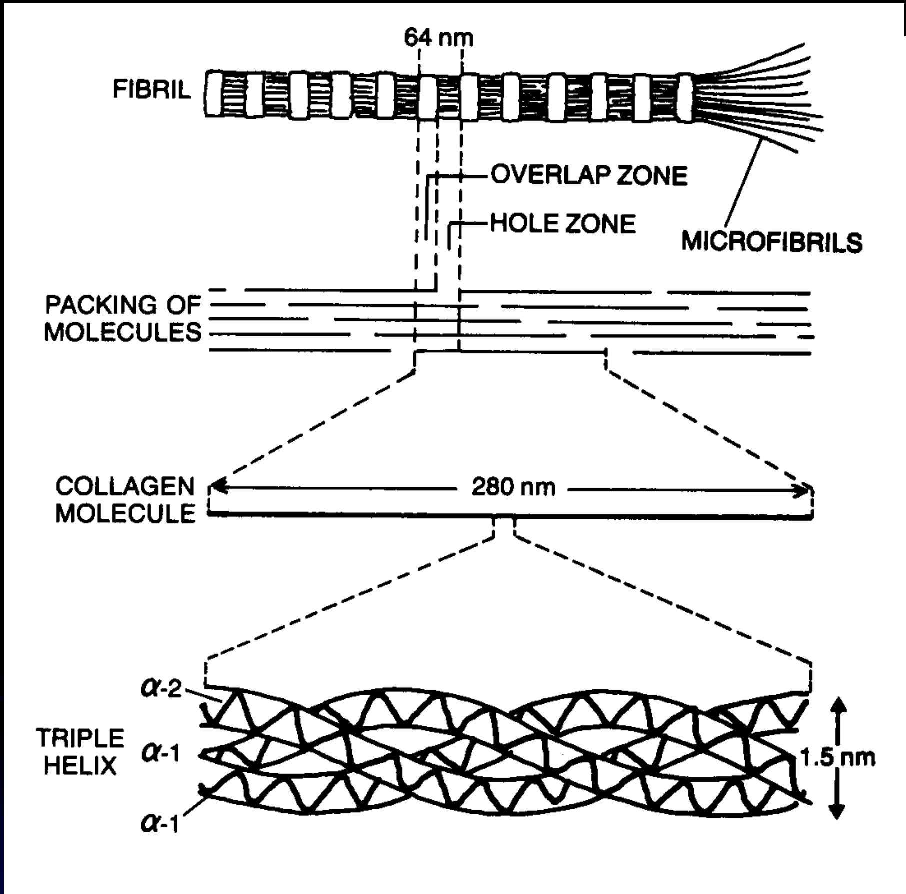
Ligament and Tendon Injury Mechanisms

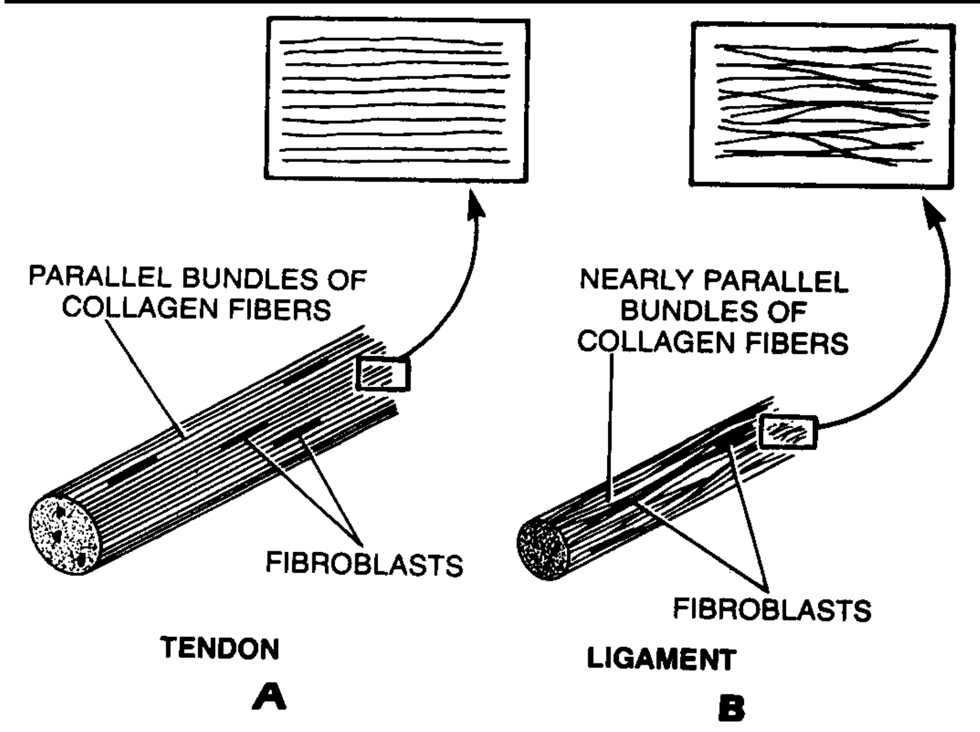


Progressive failure of the anterior cruciate ligament from a cadaver knee tested in tension to failure at a physiologic strain rate (Noyes, 1977). The joint was displaced 7 mm before the ligament failed completely. The force-elongation curve generated during this experiment is correlated with various degrees of joint displacement recorded photographically; photos correspond to similarly numbered points on the curve. (Courtesy of Frank R. Noyes, M.D., and Edward S. Grood, Ph.D.)



Composition and Structure of Tendons and Ligaments





Schematic diagram of the structural orientation of the fibers of tendon **(A)** and ligament **(B)**; insets show longitudinal sections. In both structures the fibroblasts are elongated along an axis in the direction of function. (Adapted from Snell, 1984.)

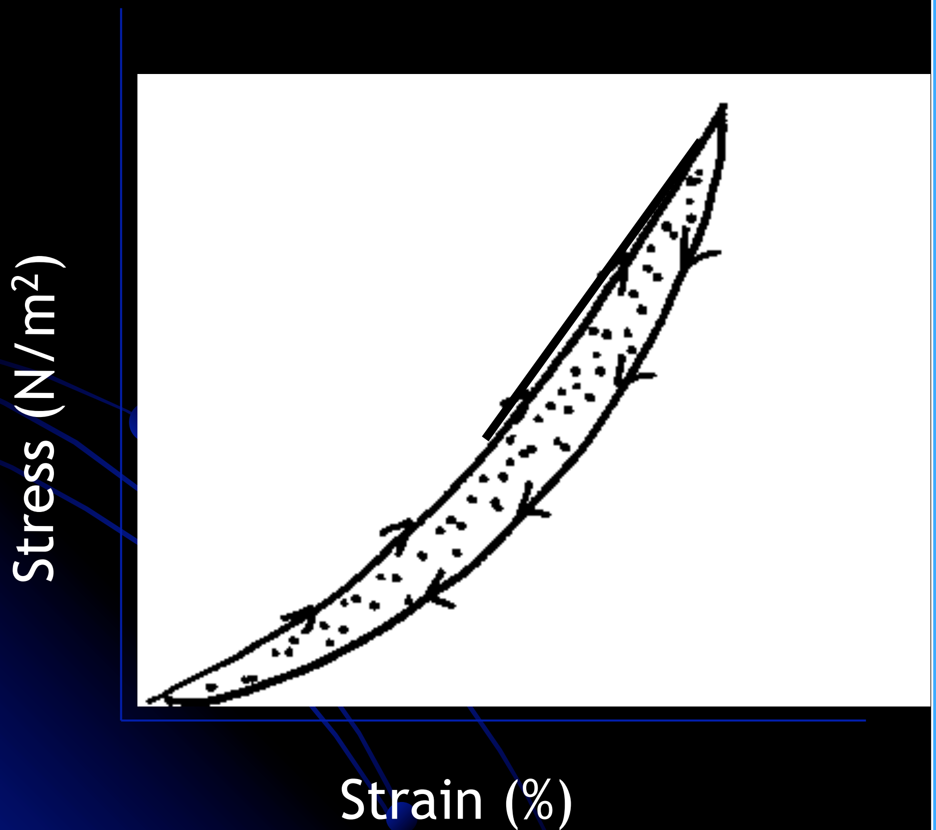
Mechanical properties of tendons

Modulus of Elasticity: 10^9 N/m^2

Hysteresis: 7%

For comparison, E for two other materials:

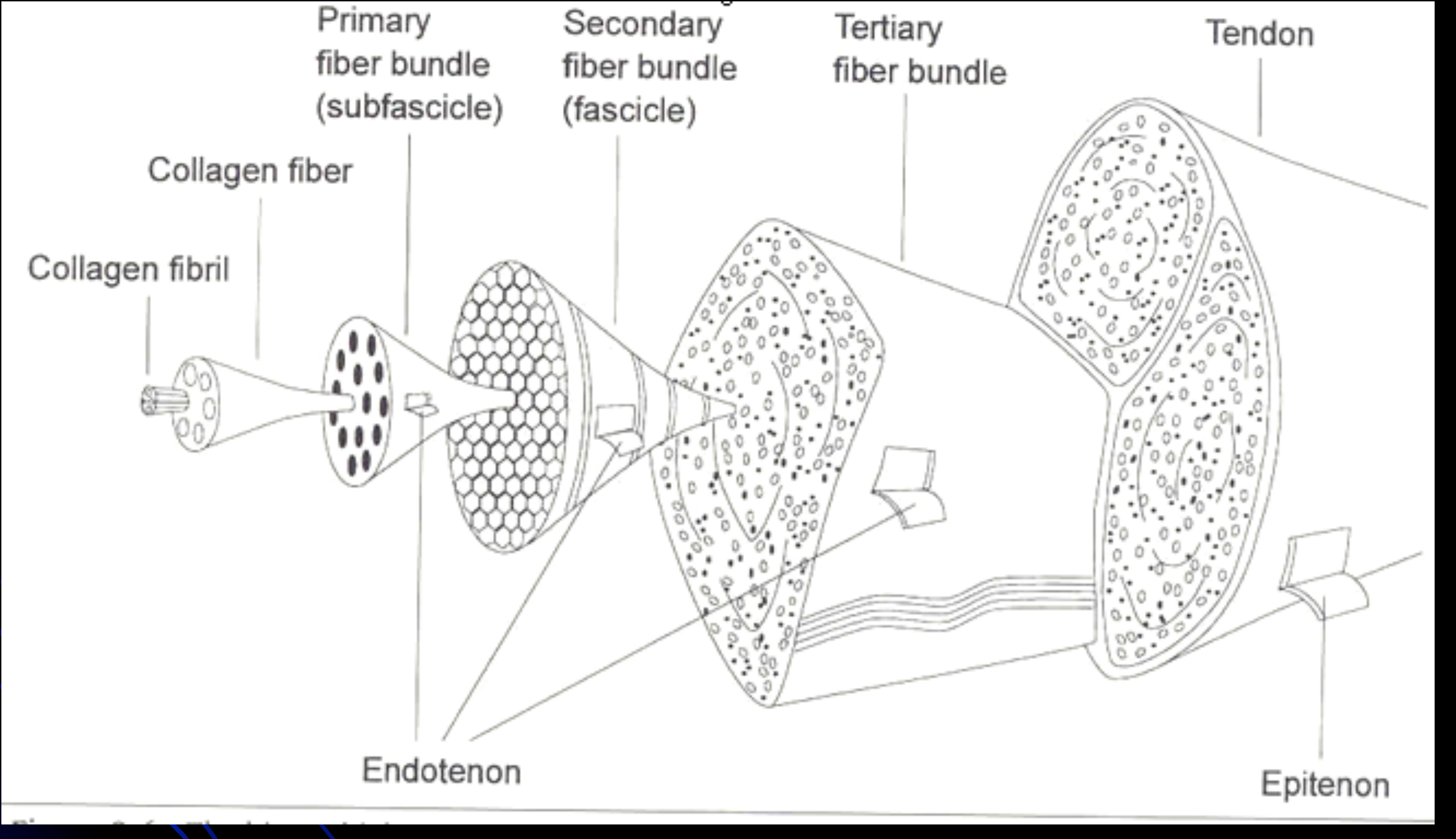
- rubber = 10^6 N/m^2
- steel = 10^{11} N/m^2



Area under curves

- Area **under** load curve: Energy **stored** in tendon
- Area **under** unload curve: Energy **recovered** from tendon
- Area **between** curves: Energy **lost** from tendon: **Hysteresis**

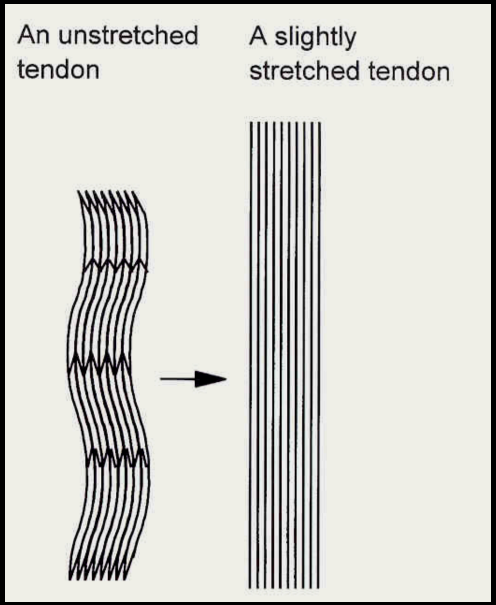
Tendon: Internal Architecture

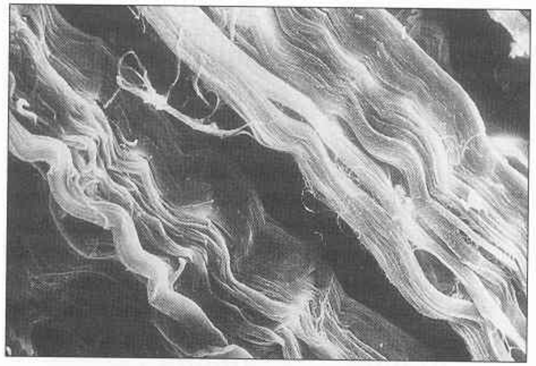


collagen fibril (20-150 nm), collagen fiber (1-50 μm), primary (15-400 μm), secondary (150-1000 μm), tertiary (1-3 mm), tendon(2-12 mm)

Tendon: Internal Architecture

- crimping of tendons:
  - a wavy formation within fascicles
  - varies and irregular along fibers
  - believed to result from crosslinking of proteoglycans
  - disappears when stretched and reappears when unloaded
  - removal of crimp dominates low strain range (<4%)





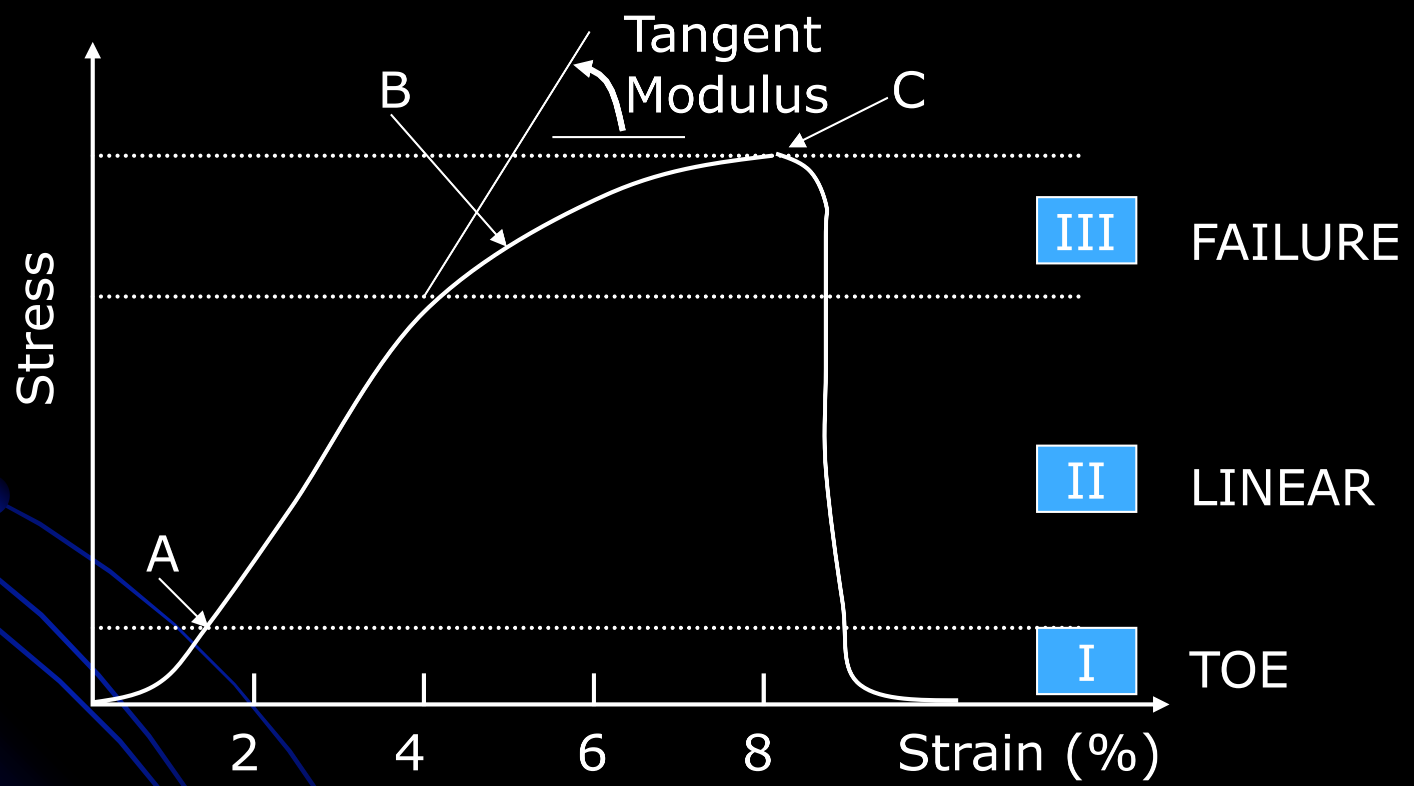
■ **Figure 2.19** Varying wavy formations or crimping of the collagen fibers of a human Achilles tendon (x6000, SEM).

“Crimp” in an unloaded ligament

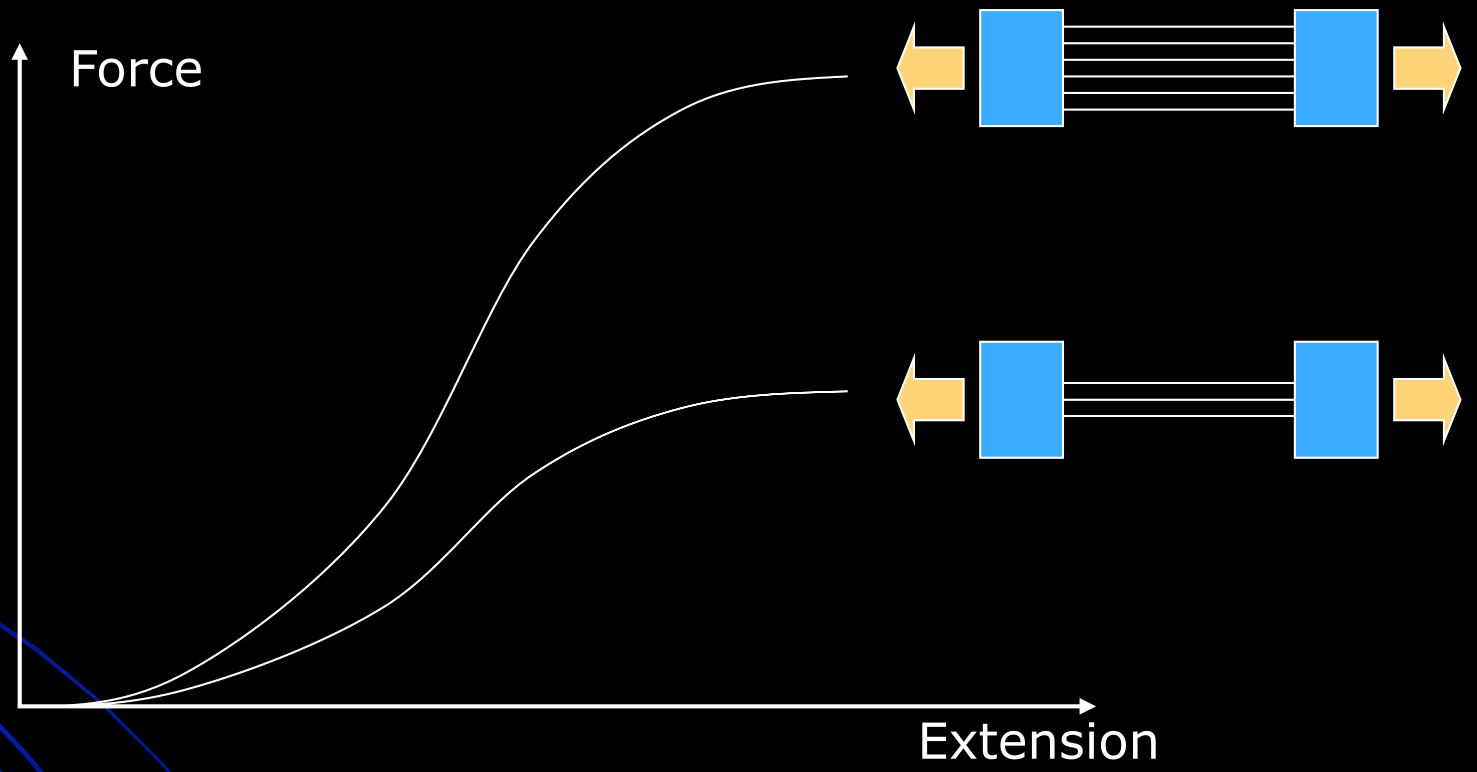
Tendon: Biomechanics

- Biomechanical characteristics of tendons:
  - tensile strength: due to molecular and supramolecular organization of collagen
  - adequate flexibility: elastin fibers
  - inextensibility: efficient transmission of force from muscles to bones
  - inferior resistance again shear and compressive forces
- Adaptation
  - tension in all directions: fibers interwoven
  - tension along one axis: parallel ordering

Tendon: Mechanical Properties

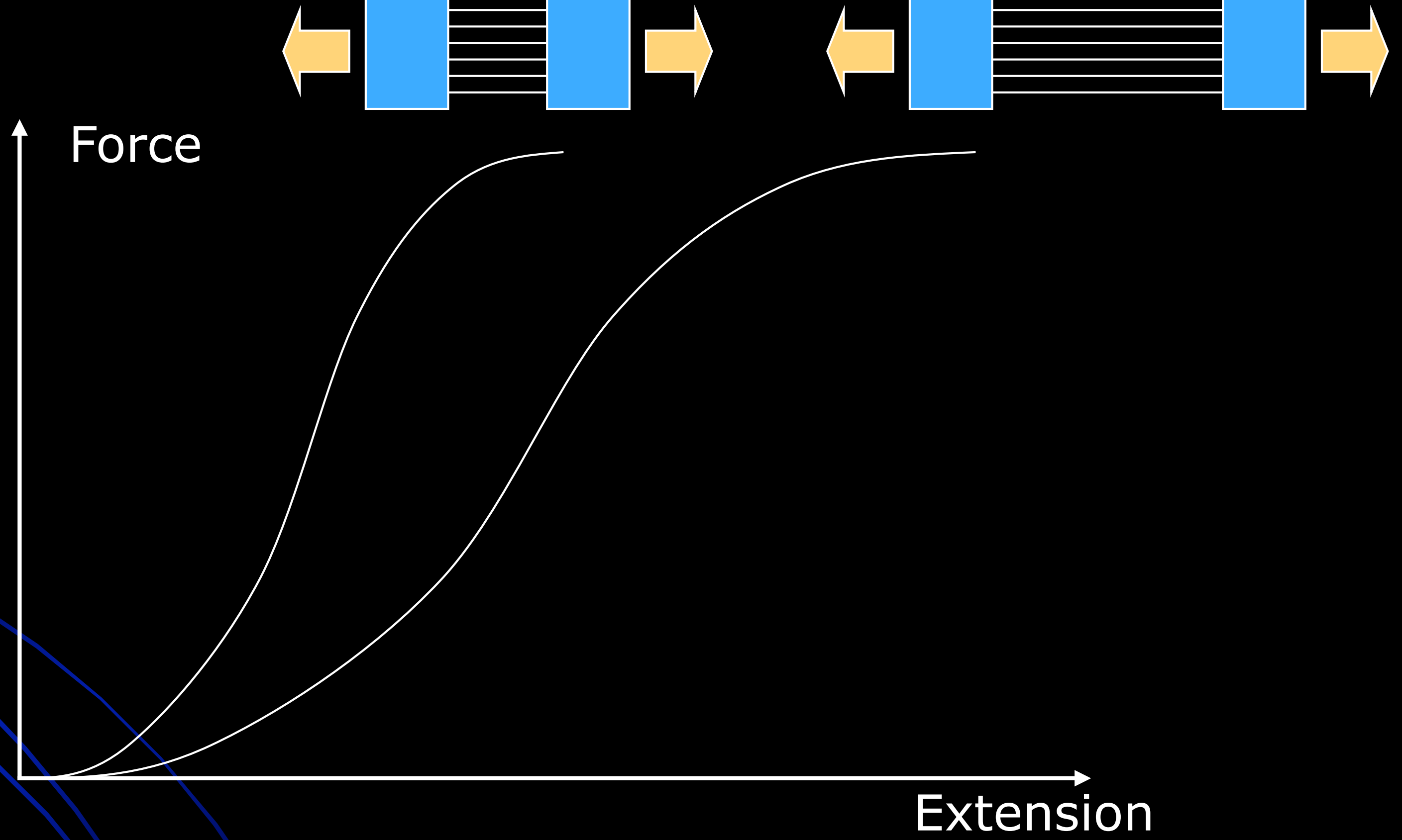


Tendon: Biomechanics



- Effect of increasing tissue cross-sectional area on load-extension: greater load, greater stiffness

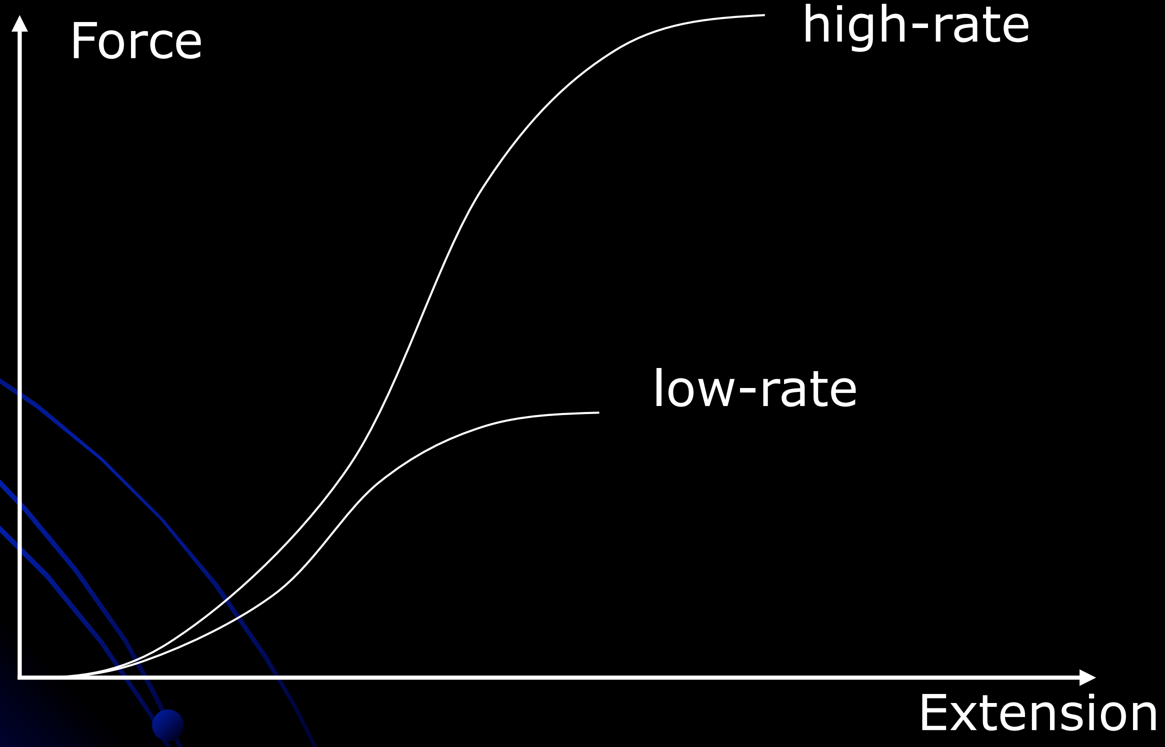
Tendon: Biomechanics



- Effect of increasing tendon length on load-extension: less stiff, similar strength

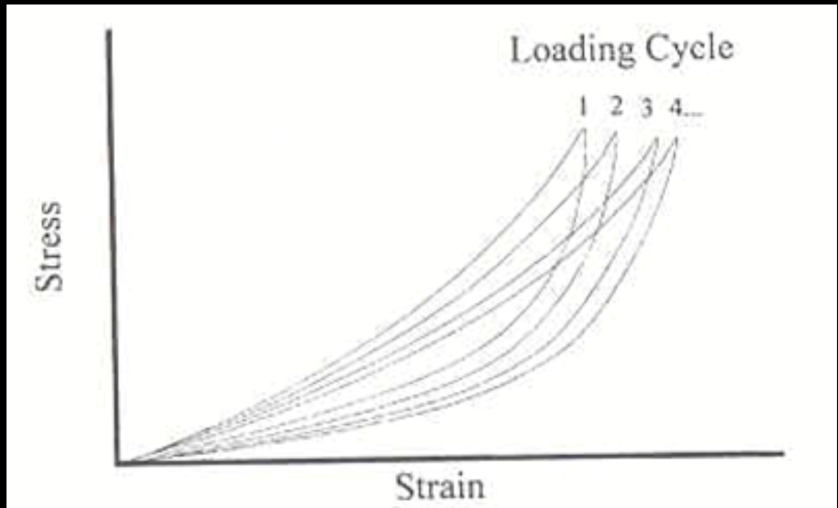
Tendon: Viscoelasticity

Rate dependency (rat tail tendon):



Tendon: Viscoelasticity

Preconditioning



Steady state develops after 10-20 cycles

Disuse, ligaments

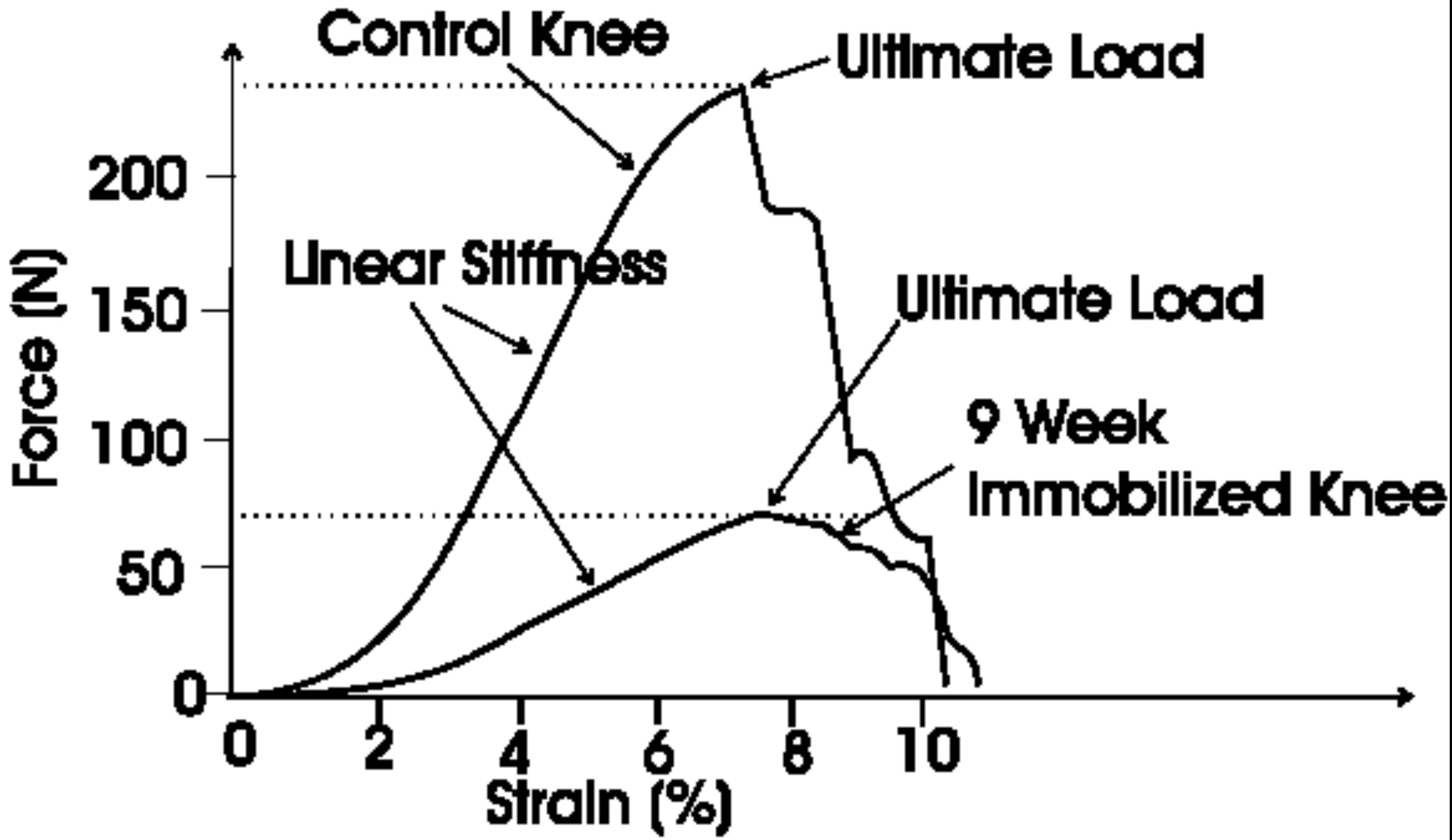


Figure 9 - Effects of 9 weeks of joint immobilization on the rabbit medial collateral ligament. Ultimate failure load decreases along with tissue stiffness and the energy absorbed prior to failure.