April 17, 2017
Lecture 24
Tissue biomechanics: tendons/ligaments

BIOE/ME 481: Whole body musculoskeletal biomechanics
Tendon models in locomotion

- Decline in energy $\rightarrow$ stored as elastic energy
- Reduces peak power input $\rightarrow$ shock absorber

4 zones at interface with bone ("enthesis")
As force is developed and the tendon stretches the muscle fibre can change its angle of pennation.
Hysteresis

- Below failure region
- Does not follow same curve during loading & unloading
- Area inside = amount energy lost ($W_d$)
- due to internal friction
Stress relaxation

- Constant displacement
- Force decreases over time
- Strain rate sensitive
- Higher rate: larger peak force & greater relaxation
Creep

- Constant load
- Length of tissue increases over time

**Input**

**Output**

\[ F \]

\[ t_o \] \[ t \]

\[ \text{displ} \]

\[ t_o \] \[ t \]
Strain rate sensitivity

- Damage affected by rate & load magnitude
  - Slow: bone avulsion
  - Fast: ligament tearing
Basic definitions

(Linear) Spring:

depends on deformation $x_s$

$F_s = k \times x_s$, where $k =$ spring stiffness

(note, $x_s$ is the total displacement, $\Delta x = x_s - 0$)

(Linear) Dashpot:

depends on velocity $x_d$

$F_d = b \times x_d$, where $b =$ damping coefficient
Maxwell Model

Spring in series with dashpot

\[ b \quad k \quad F \]
Kelvin-Voigt Model

Spring in parallel with dashpot

\[ F \]

\[ k \]

\[ b \]
Standard linear solid (SLS) model
Excised tissues

- Functional units
  - Tendon: muscle – tendon – bone
  - Ligament: bone-ligament – bone
  - Cartilage – cartilage - bone

BMEN 90022 - Comp Biomech - Tendon, Ligament, & Cartilage
Ligaments connect bone to bone with a transition zone.

Ligament function

- Joint stabilizer
  - Ligament – defines boundary of normal motion
  - Muscles – drive the path
- Ligament = joystick case, muscle = hand
Ligament imaging

[Images of ligament imaging on MRI and histology]

zencaroline.blogspot.com

http://silver.neep.wisc.edu/~lakes/links601lig.html
Ligament fiber orientation

- Ligaments connect bone to bone with a transition zone
- Fibers can be parallel, oblique or spirally oriented

- Largest and strongest?
  - Iliofemoral ligament

http://academic.uofs.edu/faculty/kosmahle1/courses/pt245/fibers.htm
Ligament testing

- Apparatus for manipulation knee joint
- Load cell
- Motion capture system
Ligament properties

- Depends on the ligament
- Iliofemoral Tensile strength = 3.5kN

Failure strains of ligaments can be close to 60% (recall tendon was 4-10%)

Achilles E: 0.67-1.07 GPa
Knee ligament E: 0.13-0.18 GPa
The shape of this curve will be different depending on the tissue.
Stress-strain curve
Mechanical tests

- Toe region
- Exponential relationship
- Most physiological range in which tissues function
Mechanical tests

- Linear region
  - Collagen alone: strain 2-5 %
  - Whole ligaments/tendons: 20-40%
  - Due to organization of fiber bundles
  - Functional E is measured here
+ Mechanical tests

- Non-linear $\rightarrow$ failure
  - Reserve strength of tissue
  - Max elongation $\sim 10$-$15\%$
  - Area where fibers start to rupture until complete failure
Anterior cruciate ligament (ACL)

- ACL:
  - Primary role:
    - anterior tibial displacement restraint
    - 85% of forward resisting force
  - Secondary role:
    - Interior tibial rotation restraint
    - No restraint to posterior tibial displacement
- ACL injury (tear or rupture):
  - tibia driven forward
- Clinical test:
  - anterior drawer test
**Preconditioning specimens**

- Stress strain curve can change over time under the same loading conditions. Why?
- **Hysteresis**
- **Internal structural changes** that occur until equilibrium point is reached
- Specimens preconditioned for 10 cycles (min) prior to testing