

## Tissue Modeling and Characterization

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## Outline

- Tissue characteristics
- Tissue data sources
- Collecting and characterizing tissue properties
- Tissue damage
- Human sensitivity to stiffness

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## Tissue is Extremely Complex

- Nonlinear stress-strain relationship
- Large deformations possible before yield (Fung, 1993):
  - Tendons 2-5%
  - Muscle 15%
  - Skin 40%
  - Vessels 60%
  - Mesentary 100-200%
- Viscoelastic  
*Properties are function of time*
- Inhomogeneous  
*Properties vary through tissue thickness*
- Anisotropic  
*Properties vary with direction*

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## Tissue is Extremely Complex

- Properties change after removal from body
- Properties vary with:
  - species
  - age
  - sex
  - in vivo stress state
  - muscle activation
  - etc.

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## Sources of Tissue Data

- Biomechanics literature
- Ex vivo testing of animal or cadaver tissues
  - Allows precise control of sample geometry, multi-axial testing
- In vivo testing of animal or human tissue
  - Allows natural tissue state (in typical stress state, perfused with blood, with muscle activation)
- Force and position sensors on surgical instrument
  - Measure interaction forces too complex to model

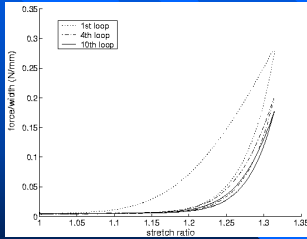
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## Data from Biomechanics Literature

- Sources: Fung, Yamada, Abe, etc.
- Ex vivo, from human or animal cadavers
- Tissue is “conditioned” by repeated cycling

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## Tissue Conditioning

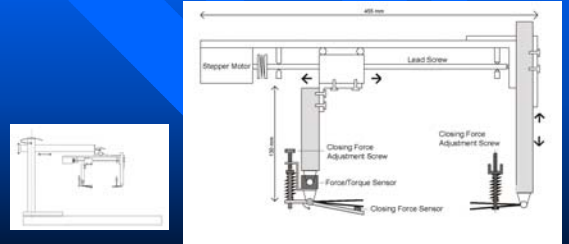


- Stress-strain characteristic changes as tissue is stretched for repeated cycles
  - Data in biomechanics literature is usually "conditioned" by multiple cycles
  - But tissue in vivo may not be in similar state!

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## Tissue Extension Device

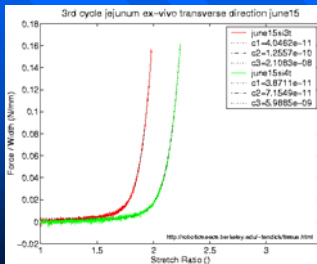
- Brouwer et al., 2000
- For in vivo or ex vivo testing of animal tissue



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## Tissue Uniaxial Extension

Load-displacement is exponential...



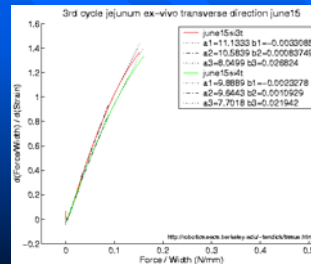
$$F(\lambda) = ae^{\beta\lambda}$$

where  $\lambda$  is the Lagrangian stretch ratio  $l/l_0$ .

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## Tissue Uniaxial Extension

... giving linear slope vs. load



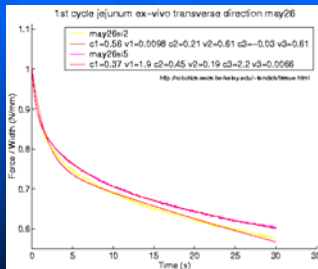
$$F(\lambda) = ae^{\beta\lambda}$$

$$\Rightarrow \frac{dF}{d\lambda} = \beta F$$

- Easier for fitting parameters

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## Viscoelasticity



$$G(t) = \frac{\sum C_i e^{-t/\tau_i}}{\sum C_i}$$

- Very difficult to fit: extremely sensitive to small changes in data
- But humans aren't very sensitive to slow changes anyway

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## Tissue Compression



Photo courtesy of Prof. Blake Hannaford, University of Washington

- Rosen et al., 1999
- Works for 3-D tissues and friable tissues that cannot be grasped for extension
- Valid for palpation tasks

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## Tissue Compression

- Ottensmeyer & Salisbury: device to measure indentation, including high frequency viscous properties
- Vuskovic et al.: suction device; analysis to extract modulus from measurements
- Carter et al.: puncture forces
- See also, here at MMVR:
  - Ottensmeyer talk, Friday a.m.
  - Brown poster, Thursday evening

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## Force Sensors on Instruments



Photo courtesy of Prof. Blake Hannaford, University of Washington

- Measure interaction forces too complex to model
- Force signatures during actual procedure
- Position tracking possible also
- See also, here at MMVR:
  - Rosen talk, Friday a.m.

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## Instrumented Scissors and Clamp

- One-axis force sensor measures cutting or spreading forces



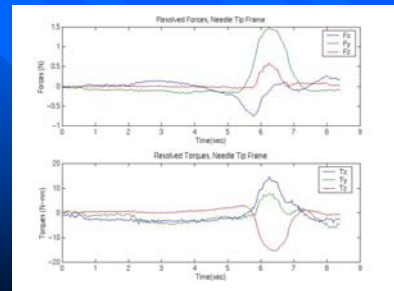
Curved Metzenbaum Scissors



Curved Kelly Clamp

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## Typical Data: Driving Needle Through Small Intestine



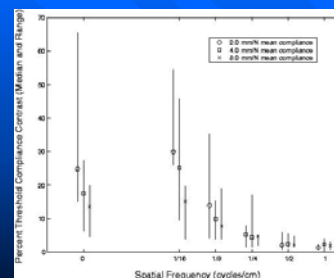
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## How to Predict Tissue Damage?

- Data in literature shows yield stress, but damage occurs prior to yield!
- Morimoto et al., 1997
  - Stretched pig tissues with clamp instrumented with force sensor
  - Macroscopic assessment of trauma
  - Microscopic histology
- More data needed!

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## How Sensitive are We to Changes in Tissue Stiffness?



- Dhruv & Tendick, 2000
- Can detect only 17-25% difference between two stimuli
- Spatial variation in surface stiffness from 1/16 to 1 cycle/cm
- Subjects scanned stimuli, for effective temporal frequency of 2 - 40 Hz
- Sensitivity improves to 1% at high frequencies
- Future research: how do expert surgeons predict tissue damage?

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