Mechanical Characterization of Human Prostate

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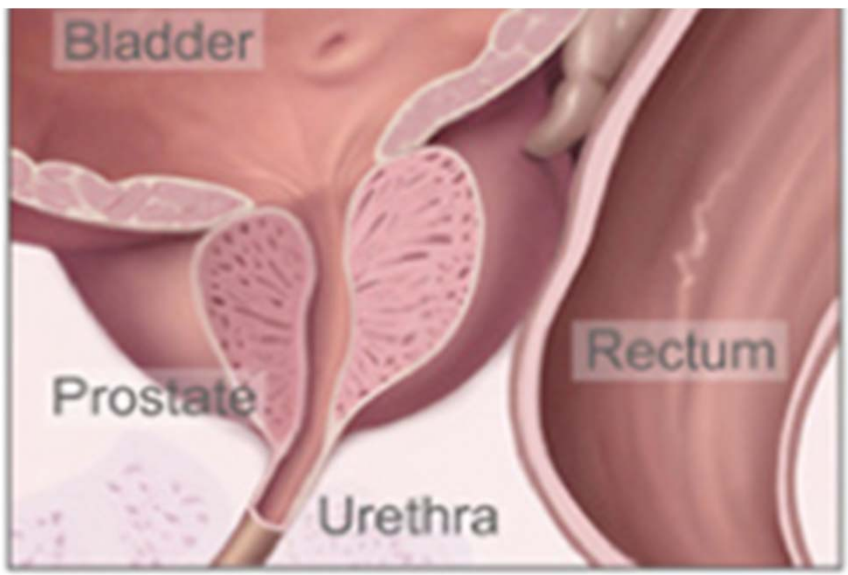
What is the Prostate?

- Part of male reproduction system
- Secret and store alkaline fluid that make up 20% semen volume
- Fluid help prolongs sperm survival
- Have smooth muscles to aid semen ejaculation



Wikipedia

Prostatic Fibrosis & LUTS

- Prostatic Fibrosis

1. Increase tissue stiffness
2. Common in aging man

- Lower Urinary Tracks Symptoms (LUTS)

1. Urgency, weak urinary stream, frequency
2. May lead to bladder dysfunction, urinary tract infections, and others

Purpose

- Prostate Fibrosis is an unexplored mechanism that may contribute to LUTS
- Profound interest using finite element modeling (FEM) to study biomechanical properties of the prostate
- Relate tissue response to disease symptoms

Overview of methods

- Tissue procurement

- Mechanical testing

1. Uniaxial loading-unloading test
2. Data processing

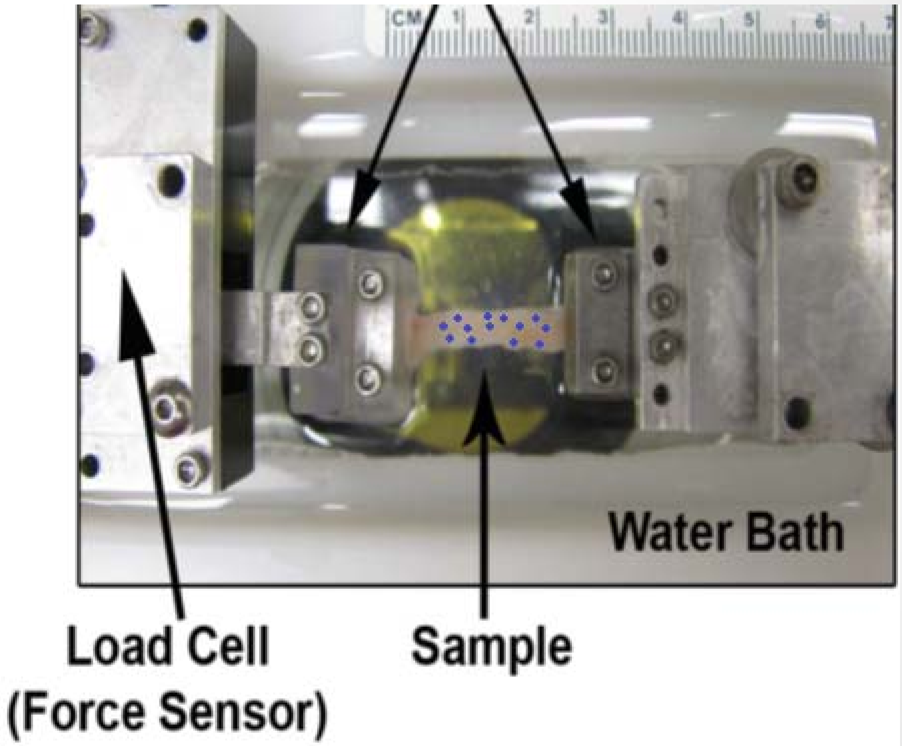
- Finite Element Modeling (FEM)

1. Arruda-Boyce constitutive model
2. Mechanical testing simulation
3. Prostate gland modeling

Mechanical Testing

- Uniaxial load-unload mechanical testing

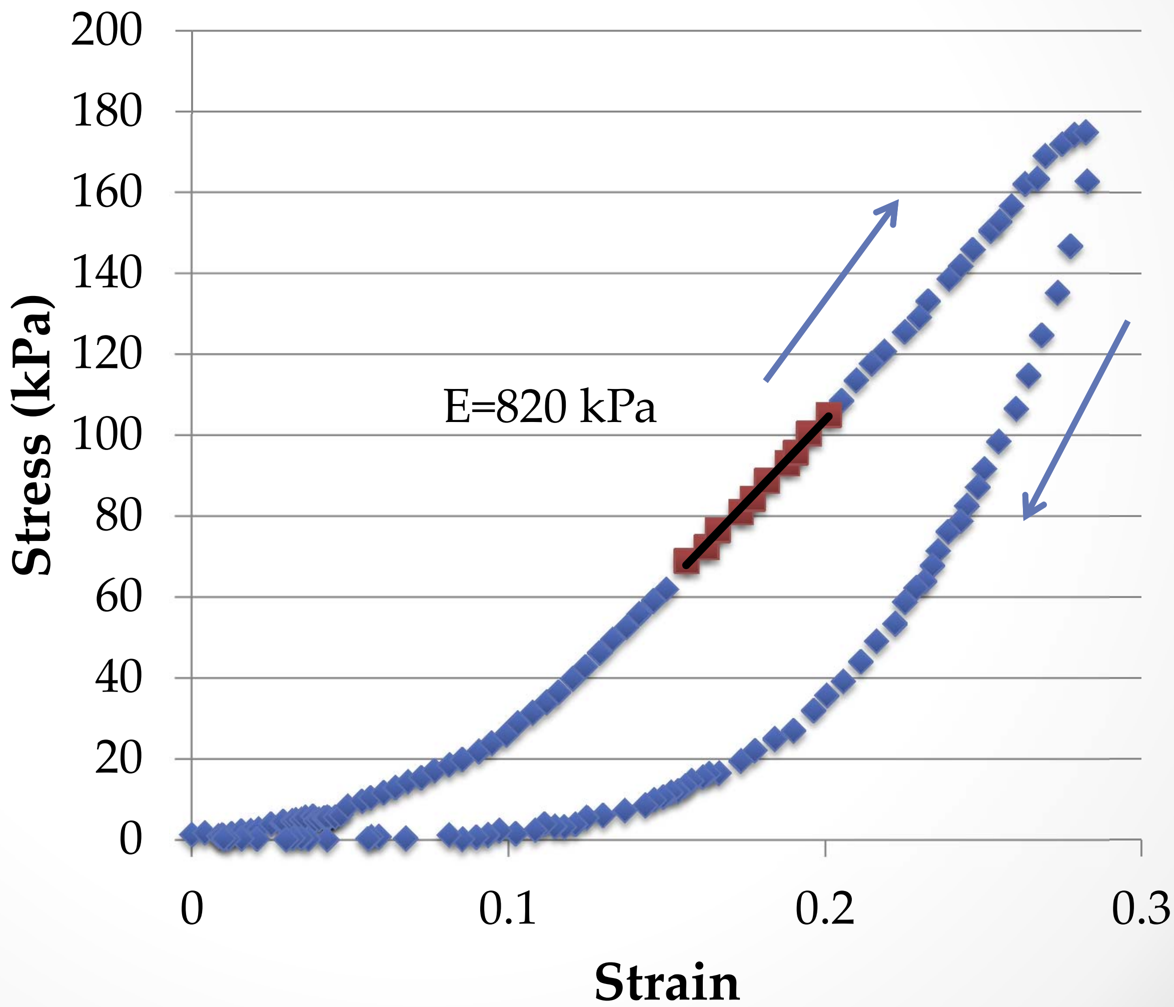
1. Prostate specimen gripped and submerged in saline
2. Brushed with 25 µm diameter glass beads
3. Loading at 0.01/sec strain
4. Data acquisition using video camera (displacement) and tensiometer (force), controlled and synchronized using LabVIEW



Loading-Unloading Example

Stress=Force/Area

Strain=Current Disp./Original Total Length



Finite Element Modeling

Arruda-Boyce Hyperelastic model

- Based on Langevin chain statistics: Models material cube with eight chains in diagonal directions
- Chains mimic collagen and elastic fiber, soft tissue's main constituents
- Reflects physics of macroscopic deformation from microscopic components

Liu et. Al 2004

Finite Element Modeling

Form of Arruda-Boyce strain energy function used in ABAQUS software

The parameters used are *μ_0, λ_m, D*

$$U = \mu\left\{\frac{1}{2}(\bar{I}_1 - 3) + \frac{1}{20\lambda_m^2}(\bar{I}_1^2 - 9) + \frac{11}{1050\lambda_m^4}(\bar{I}_1^3 - 27) + \frac{19}{7000\lambda_m^6}(\bar{I}_1^4 - 81) + \frac{519}{673750\lambda_m^8}(\bar{I}_1^5 - 243)\right\} + \frac{1}{D}\left(\frac{J_{e\ell}^2 - 1}{2} - \ln J_{e\ell}\right),$$

$$\mu_0 = \mu\left(1 + \frac{3}{5\lambda_m^2} + \frac{99}{175\lambda_m^4} + \frac{513}{875\lambda_m^6} + \frac{42039}{67375\lambda_m^8}\right).$$

$$\bar{I}_1 = \bar{\lambda}_1^2 + \bar{\lambda}_2^2 + \bar{\lambda}_3^2,$$

$$K_0 = \frac{2}{D}.$$

Finite Element Modeling

- Start with an estimation of parameters, then trial and error to approach test data average

1. $\mu\_0=E/3$, since material assumed to be incompressible

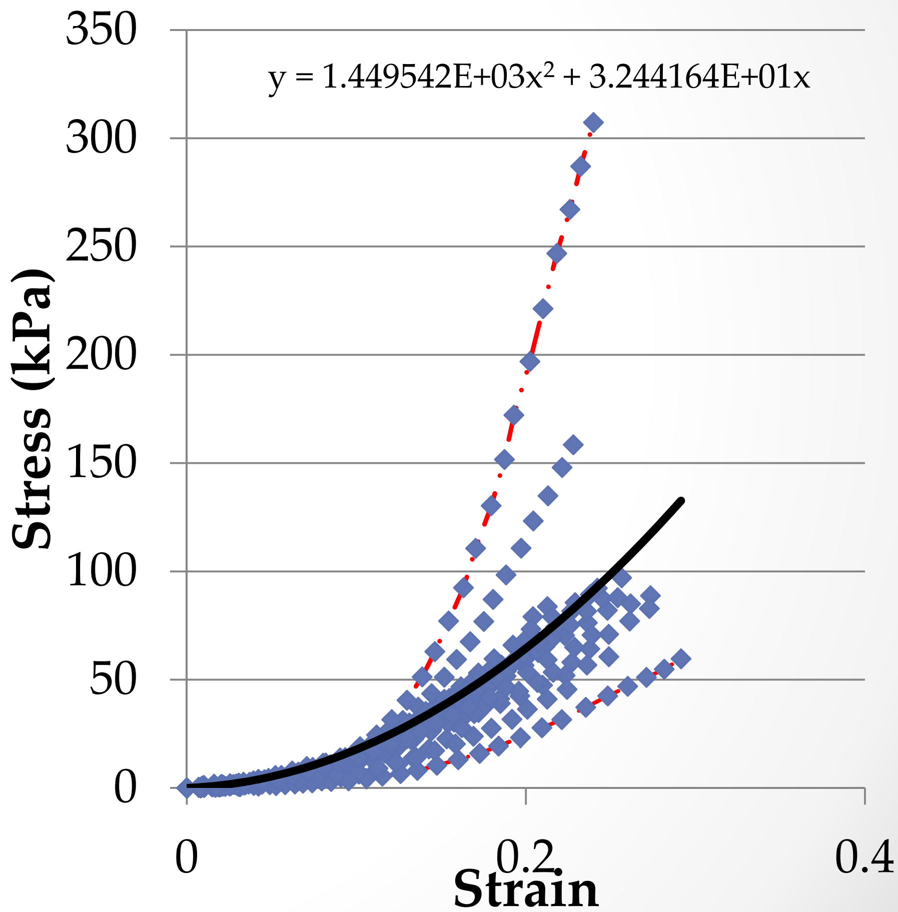
μ_0=[20, 30, 40, 60, 100kPa]

2. Bulk modulus (K) 100 to 1000 times of shear modulus, D=2/K

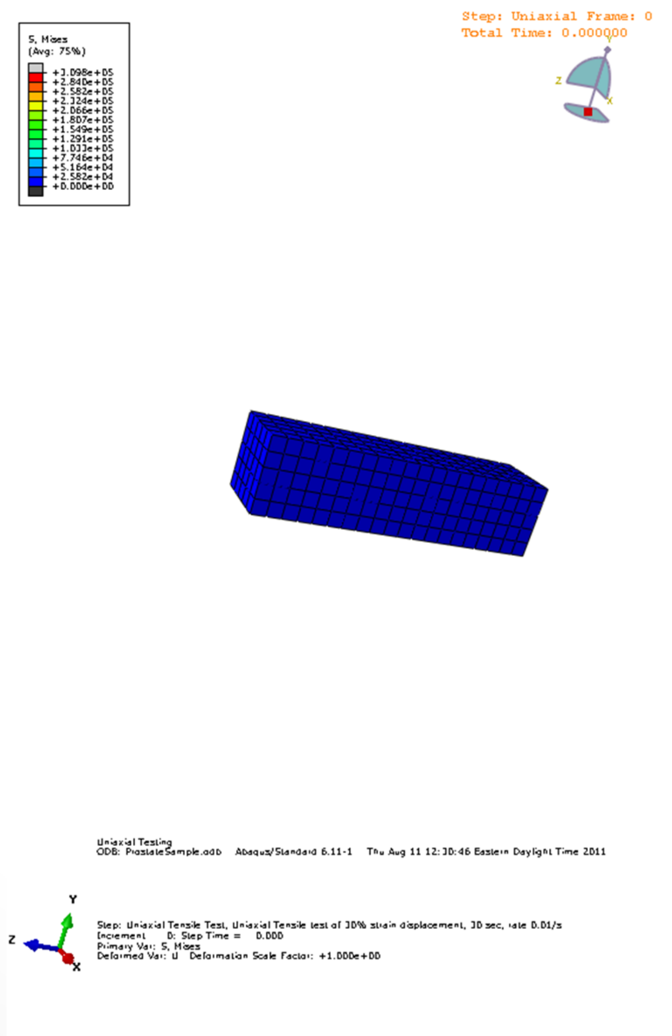
D=[1E-6, 1E-7, 1E-8]

3. λ_m=1.05, 1.01, in reference to previous studies.

λ_m=[1.05, 1.01, 1.001, 1.0001]

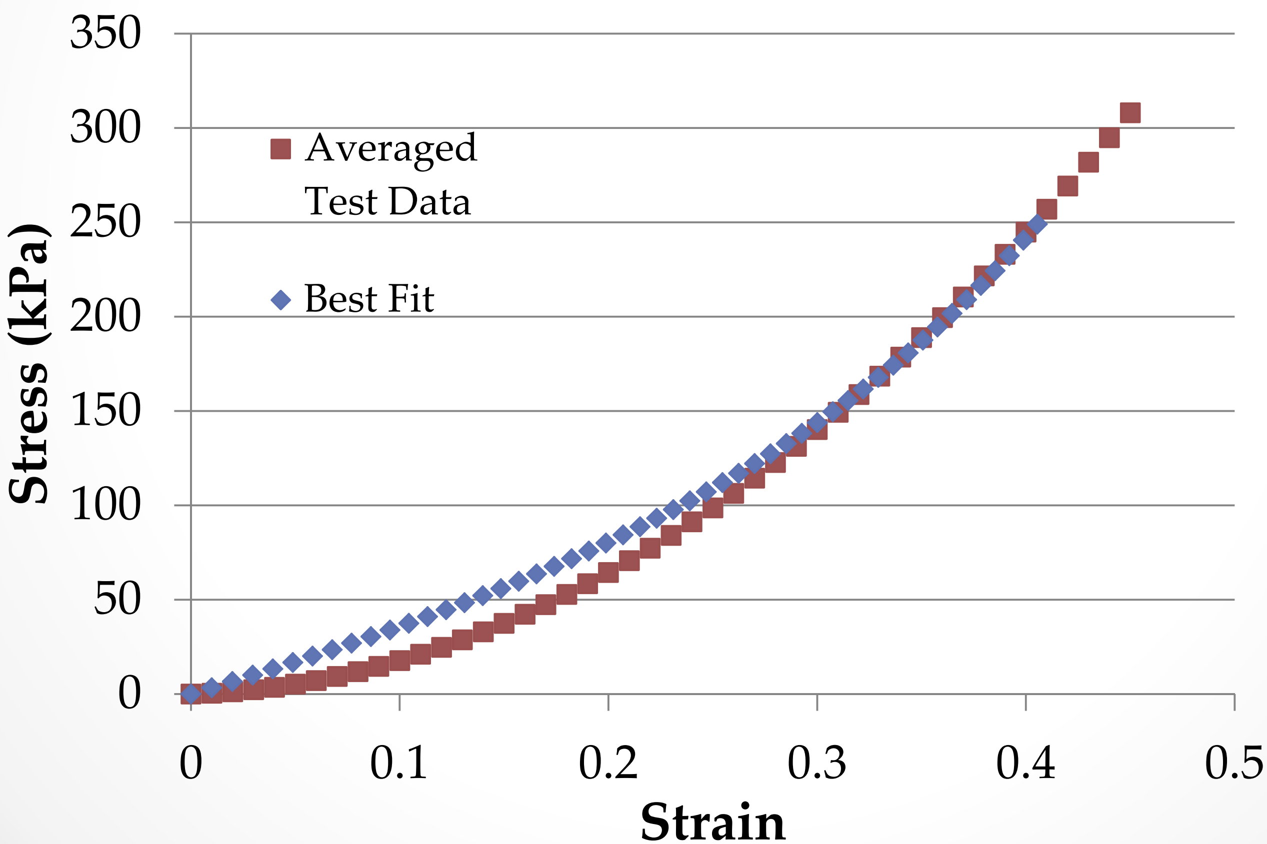


Uniaxial Loading Simulation

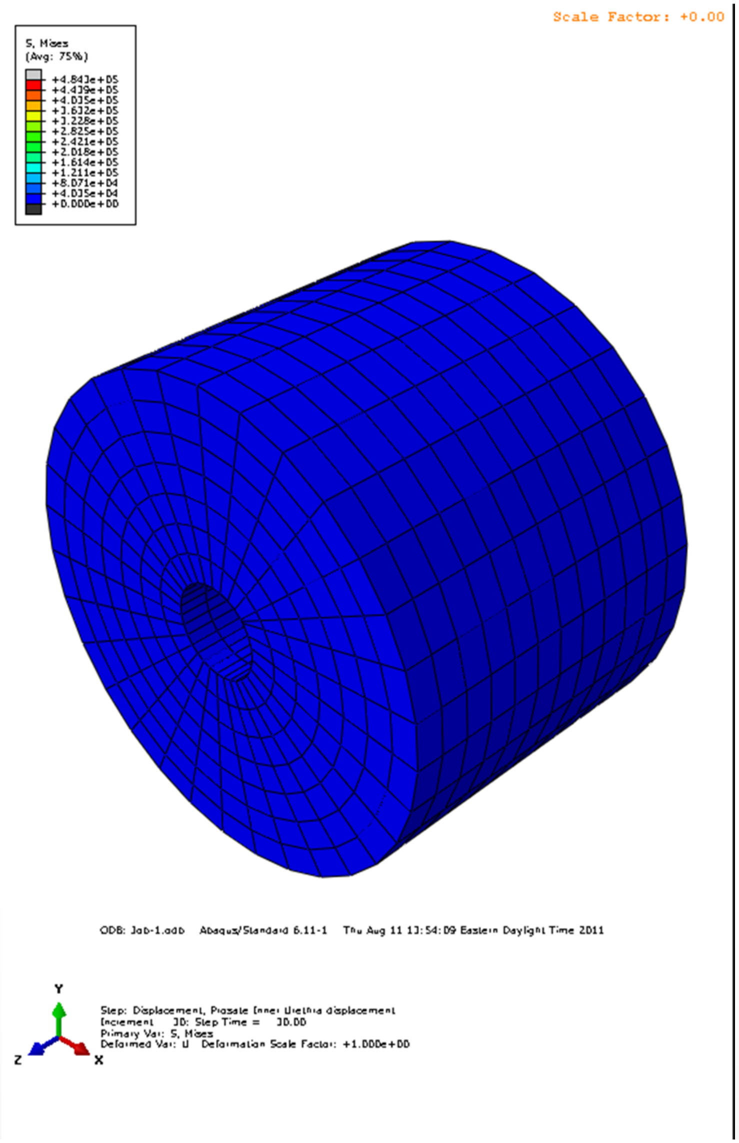


Results

- Prostate samples are viscoelastic and hyperelastic
- Best Fit: $\mu_0 = 33kPa, \lambda_m = 1.001, D = 1E - 8$



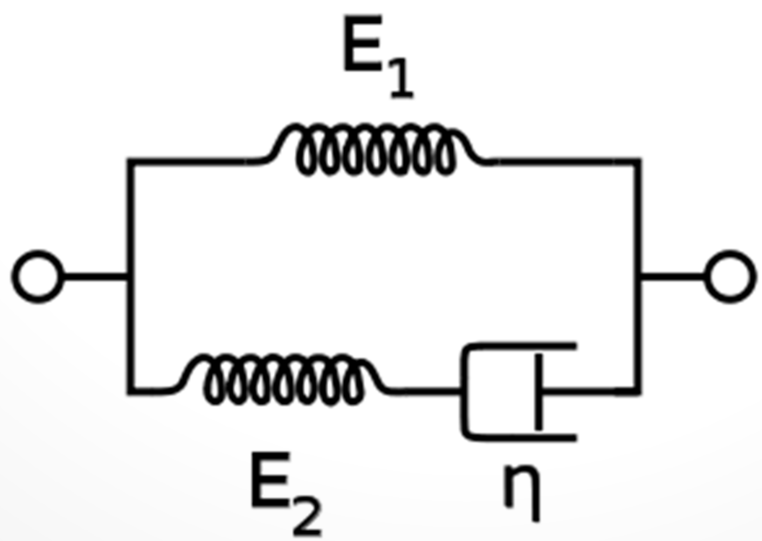
Prostate FEM



Discussion and Future Works

- Need to implement viscoelastic part into model

1. Difficult to realize curvature at lower strain levels, may be because lack of visco element or we need to apply a different nonlinear model to match initial curvature
2. May possibly implement standard solid model with nonlinear springs instead of linear springs in the future



Discussion and Future works

- Diseased prostate modeling

1. Test diseased prostate samples in the future
2. Expect less deformation, since prostate with fibrosis is stiffer
3. Comparison between reactions of healthy and diseased models will enable us to observe the biomechanical effect of fibrosis and relate that to Lower Urinary Track Symptoms (LUTS)

Discussion and Future Works

- Improvement in prostate model shape

1. Current simple model is appropriate for analyzing response of only tissue around urethra
2. Need accurate representation to include geometrical effects over whole prostate
3. Magnetic Resonance Imaging (MRI) pictures could be used to reconstruct model with accurate dimensions

Thank you for listening!