jargon-free title

Mechanical Properties of Biological Tissues

Using Volume Controlled Cavity Expansion (VCCE) to Inform Constitutive Modeling and Failure Prediction in Blood Clots

Massachusetts Institute of Technology ---

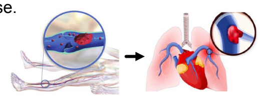
pitch should
1. say something everyone cares about
2. explain gap in knowledge
3. explain what you did
4. show meaning of results
5. overall significance

bolded blue text highlights important takeaways

INTRODUCTION

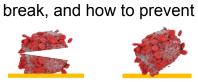
1

Blood clot dislodgement can cause significant disease.



A patient with a clot risks downstream disease if the clot is dislodged without warning.

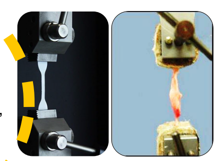
How much **force** or **energy** is required to stretch and break a clot is a **solid mechanics** question. We need more information to understand how blood clots break, and how to prevent it.



Clots may fail due to bulk fracture or stretch and peeling.

2

Standard **mechanical testing** does not work well on soft materials and biological tissues because tissues are:
- soft,
- irregular shape,
- inhomogeneous,
- difficult to hold on to,
- scarce,
- strain stiffening.

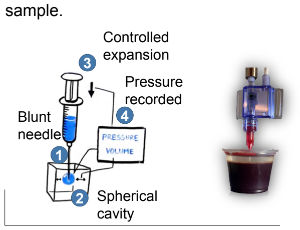


Tension testing of metal vs tendon.

METHODS

3

Volume Controlled Cavity Expansion (VCCE) probes the local mechanical properties within a soft sample.

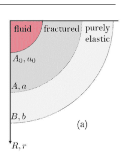


Calculate material parameters
- μ: stiffness
- τ: relaxation times
- Gc: fracture energy

Assume constitutive model for material: $W(\lambda, \mu, \tau)$

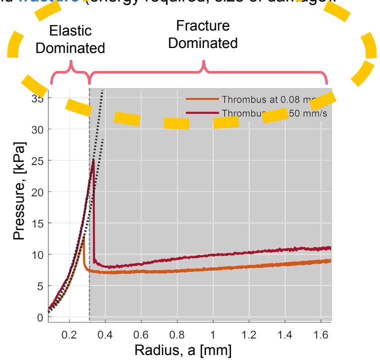
Cavity pressure from W, λ: $\frac{p}{\mu} = \int_{\lambda_a}^{\lambda_b} \frac{\bar{W}'(\lambda_\theta)}{1-\lambda_\theta^3} d\lambda_\theta$

Minimize incremental invested energy δU: $U = U_E + U_F$



DATA ANALYSIS

Separate data regimes to obtain material properties connected to **elasticity** (stiffness, relaxation times) and **fracture** (energy required, size of damage).



Pressure recorded during cavity expansion in a whole blood clot at two radial expansion speeds.

Elastic regime: One-term Ogden material model

Modulus, μ
Stiffening, α

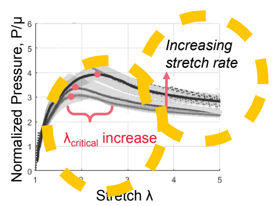
$$W(\lambda) = \frac{2\mu}{\alpha}(2\lambda^\alpha + \lambda^{-2\alpha} - 3)$$

$$U_E = 4\pi\mu A^3(1-\lambda_a^3)\int_{\lambda_a}^{\lambda_b} \frac{\bar{W}(\lambda_\theta)}{(1-\lambda_\theta^3)^2}\lambda_\theta^2 d\lambda_\theta$$

Fracture regime: Fracture energy is a function of rate ($\dot{\lambda}$)

$$U_F = 2\pi(A^2 - A_0^2)NG_c(\dot{\lambda})f(\lambda, \dot{\lambda})$$

Iterative incorporation of **additional physics**

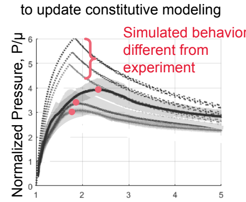


Perform experiment: Observe key trends

Analyze data: Fit material parameters μ, τ, G_c

Simulate and compare: Deviation from experiment used to update constitutive modeling

Hypothesis: Propose a constitutive model $W(\lambda, \mu, \tau)$, $U_F(G_c)$

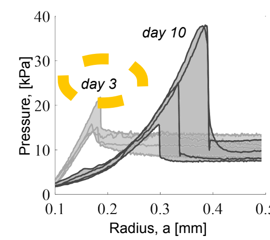


RESULTS

4

***I.* VCCE is a valuable characterization tool**

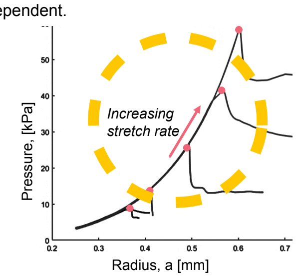
The method can detect **mechanical property change** in blood clots.



A clot made from blood on day 10 is softer but more difficult to fracture than one made on day 3.

***II.* VCCE enables study of fracture in soft materials**

The **fracture energy** in blood clots is rate dependent.



Increasing the stretch rate leads to fracture occurring at larger deformation and higher pressures.

explain significance of plots, in a way that is more accessible to a broader audience than in a paper

5

SIGNIFICANCE

I. Understanding the transition between elasticity and failure of blood clots will allow for **clinically relevant recommendations** around caring for patients.

II. A **more comprehensive constitutive model** that quantifies the effect of rate on the fracture energy of clots will enable **highly accurate digital twins.**

REFERENCES

- "Large deformation isotropic elasticity–on the correlation of theory and experiment for incompressible rubberlike solids," Ogden. 1972.
- "Probing local nonlinear viscoelastic properties in soft materials" Chockalingam et al. 2021.
- "The intimate relationship between cavitation and fracture" Raayai-Ardakani, Earl, Cohen. 2019.

Learn more about VCCE with this video.

refers audience to more material

section arrangement was required by conference to facilitate judging off rubric