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Constitutive Modelling of Jugular Vein Tissue

Nayyan Kaul and Hsiao-Ying Shadow Huang
Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC

Introduction and Background

Motivations :

- Highly Non Linear Stress - Strain behavior Mechanical Anisotropy, Large Deformations, Viscoelastic nature of the material.
- Veins (ubiquitous throughout the body) affected by numerous diseases like CVI, Thrombosis; used in valve replacement, vein reconstruction .etc., but without any proper study.
- Material Properties are not known.

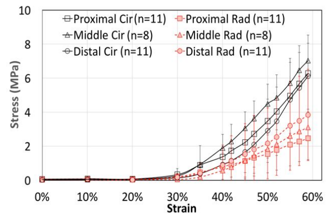

Fig. 1: General stress – strain behavior of jugular vein valve tissue showing high degree of anisotropy from a previous study. Results are averaged for number of samples due to high sample variability.

Focus :

I. To determine suitable phenomenological strain energy based constitutive relation for JV valve and JV wall tissue.

II. Determination of material parameters required to implement the model numerically in FEM environment.

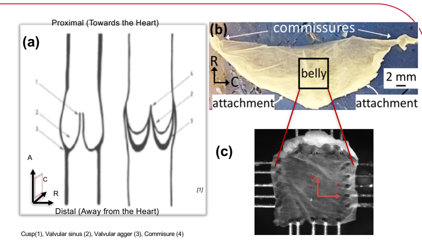

Fig. 2: Schematic showing the position of the tissue used for experimental tests: (a.) Position of the wall tissue. (b.) Position of the valve tissue sample from the belly region. (c.) Valve sample mounted on the biaxial testing apparatus with hooks attached for holding all 4 sides with no in plane shear.

Methods and Results

Constant Invariant Testing and Strain Energy based Constitutive Relation :

- Constant α and Constant I_1 Tests for 16 wall samples and 8 valve samples were conducted to study the behavior of strain energy derivatives.
- Response curves (Fig. 3) were plotted based on the experimental data.
- Separate strain energy descriptor were selected based upon the behavior.
- Wall Tissue:

$$W = c_1(\alpha-1)^2 + c_2(\alpha-1)^3 + c_3(I_1-3) + c_4(I_1-3)(\alpha-1) + c_5(I_1-3)^2$$

- Valve Tissue :

$$W = c_0(exp^{(c_1(I_1-3)^2 + c_2(\alpha-1)^4)} - 1)$$

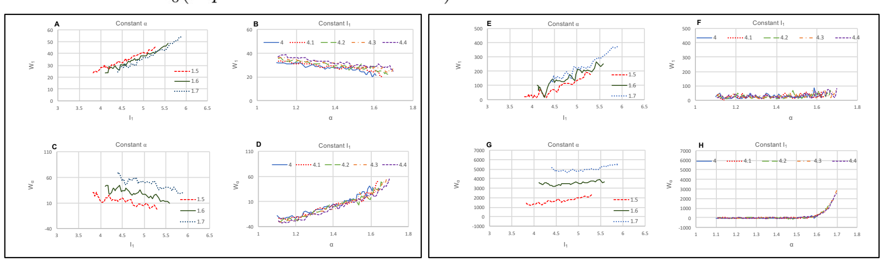

Fig. 3: Response curves generated from the constant invariant tests for wall (A-D) and valve (E-H) samples.

Material Model Parameter estimation :

- Using Powell's Method Algorithm to minimize the square of residuals between experimental and model predicted stress value.

$$\chi^2 = \sum_{i=1}^{N} [y^i - t^i]^2$$

- Data from equibiaxial and off biaxial displacement controlled testing (with a maximum strain of 70%) was using for parameter estimation.
- 5 different protocols were used to collect data at 1Hz with 8 cycles of tissue preconditioning.

Sample	c_1	c_2	c_3	c_4	c_5
Proximal Wall Tissue	30.655	27.957	1.968	-17.916	5.205

Sample	c_0	c_1	c_2
Jugular Vein Valve Tissue	112.281	0.059	1.09

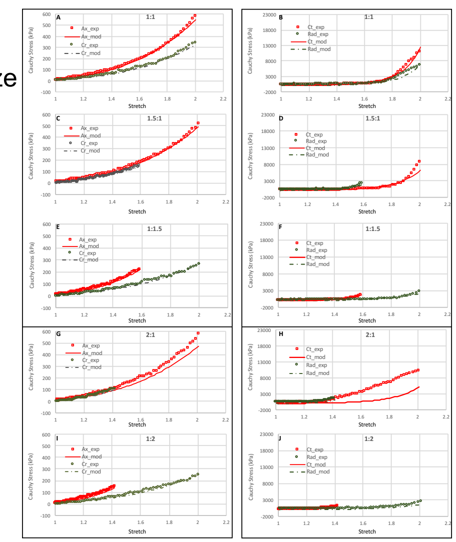

Fig. 4: Experimental vs Model Predicted Stress – Stretch data for wall (left panel) and valve (right panel) tissue for all 5 biaxial testing protocols.

Discussions and Conclusion

- Material models presented for the wall & valve tissue were able to emulate the behavior of tissue under experimental testing, evident from high correlation coefficients.
- The study also provides investigators with representative material parameters to form a continuum model when such is required for numerical analyses and computational simulations.
- Additionally, it can be of great help during the primary stages of bio prosthetic designs, valve-replacement surgeries, and when investigating valvular diseases.

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