A Study on the Spatial Variance in the Mechanics and Microstructure of Heart Valves

Samuel Jett, Colton Ross, Jacob Richardson, Cortland Johns, Devin Laurence, Yi Wu, Ph.D., and Chung-Hao Lee, Ph.D.

Biomechanics and Biomaterials Design Laboratory
School of Aerospace and Mechanical Engineering, The University of Oklahoma, Norman, OK

The University of Oklahoma
School of Aerospace and Mechanical Engineering

Valvular Heart Disease Background

- ***Valvular heart diseases (VHD)***, including regurgitation and stenosis, impair proper valve function and affect 2.5% of adults[1] (**Fig. 1b**). VHD can accompany alterations to the ***mechanics*** and ***structure*** of the heart valve.

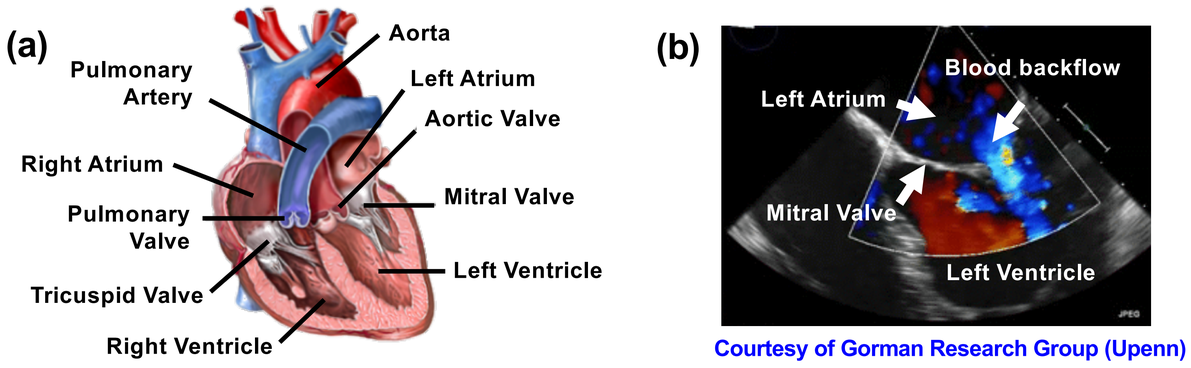

Figure 1. (a) Schematic of a heart with chambers, ***valves***, and major arteries labelled. (b) Echocardiogram showing mitral valve ***regurgitation***, i.e., backflow from atrium to ventricle.

Research Objectives

- While previous studies examined the center of the ***mitral and tricuspid valve*** (MV and TV) leaflets (**Fig. 2a**), our objective is to quantify the ***spatial variance*** in ***mechanics*** and ***microstructure*** of the MV and TV leaflets to inform ***computational models*** and ***material design*** for replacement valves.

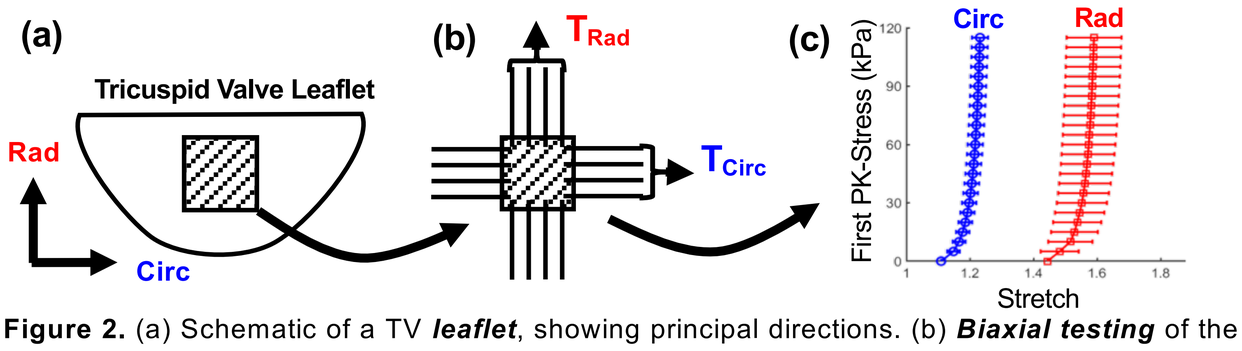

Figure 2. (a) Schematic of a TV ***leaflet***, showing principal directions. (b) ***Biaxial testing*** of the central region for quantification of (c) ***anisotropic*** and ***nonlinear*** mechanics of the TV leaflets.

Biaxial Mechanical Testing to Quantify Regional Variance in Leaflet Mechanics

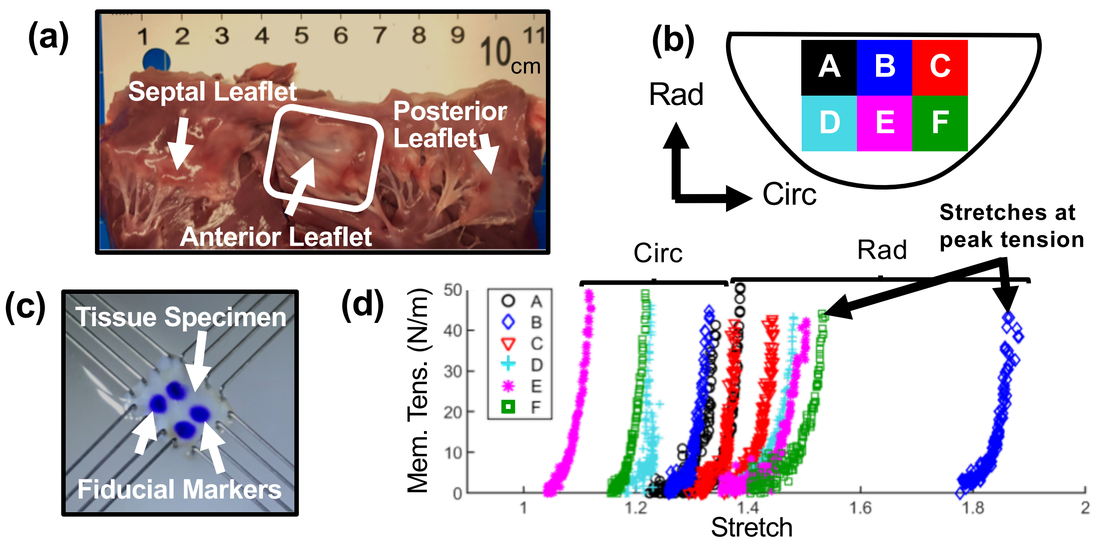

Figure 3. (a) Dissected and labelled TV. (b) Schematic of a leaflet showing regional specimen locations. (c) Specimen mounted on the ***biaxial tester*** with markers for ***optical strain tracking***. (d) Representative mechanical responses for the TVAL.

- In each region of the MV and TV anterior leaflets (**MVAL** and **TVAL**), the tissues were more compliant in the Rad than the Circ direction (**Fig. 4**).
- In the TVAL, we observed similar mechanics between regions **B**, **D**, and **E**, and between regions **A** and **C**, but unique mechanics in **F** (**Fig. 4a**).
- In the MVAL, we found increased Rad compliance and Circ rigidity in **B** and **E** compared to **A**, **C**, **D**, and **F** (**Fig. 4b**).

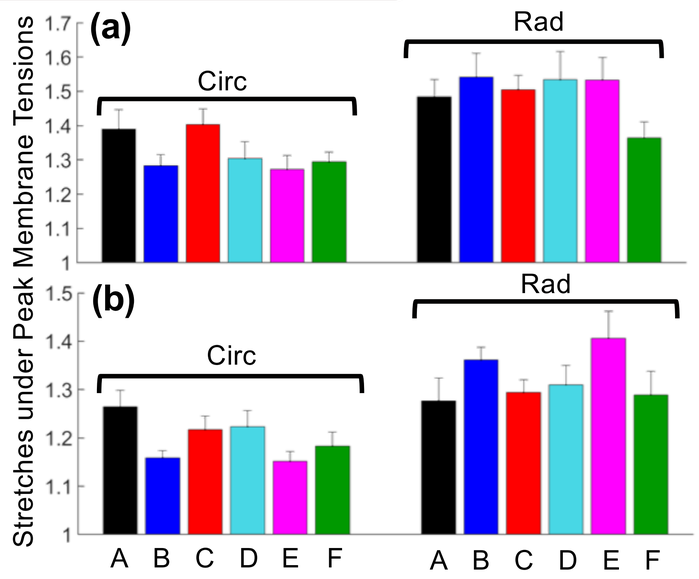

Figure 4. Comparisons of the ***stretches*** at peak applied ***membrane tensions*** in Rad and Circ directions for all regions of the (a) TVAL and (b) MVAL.

Analysis of Heart Valve Microstructure

- Our group developed a polarized Spatial Frequency Domain Imaging (pSFDI) system, (**Fig. 5a**) based on ***structural birefringence*** (**Fig. 5b**), to quantify ***local collagen fiber orientations*** (**Fig. 5c**) in heart valve tissue.

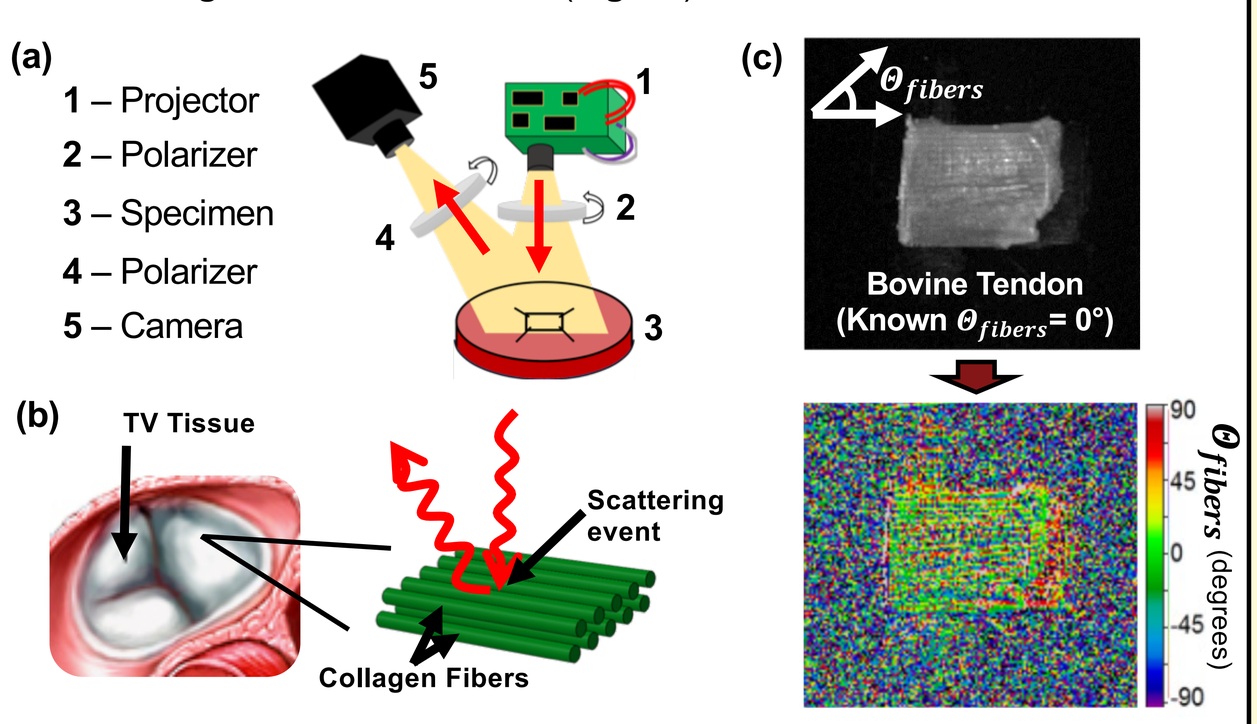

Figure 5. (a) Schematic of the ***PSFDI system*** showing major components. (b) Schematic showing the polarized ***light scattering*** off ***structurally birefringent*** collagen fibers in valve tissue. (c) Original and analyzed images of ***system validation testing*** on bovine tendon.

- **Goal** – Improve system ***resolution*** to provide accurate analysis of local fiber orientations in tissues with ***spatially-heterogeneous*** fiber networks.

Study Applications

- Our mechanical analysis will allow development of ***spatially-varied*** leaflet ***constitutive models*** (**Fig. 6a**) for use in ***computational models*** (**Fig. 6b**).
- Our results could eventually improve understanding of the ***complex relationship*** between tissue microstructure and mechanical behavior.

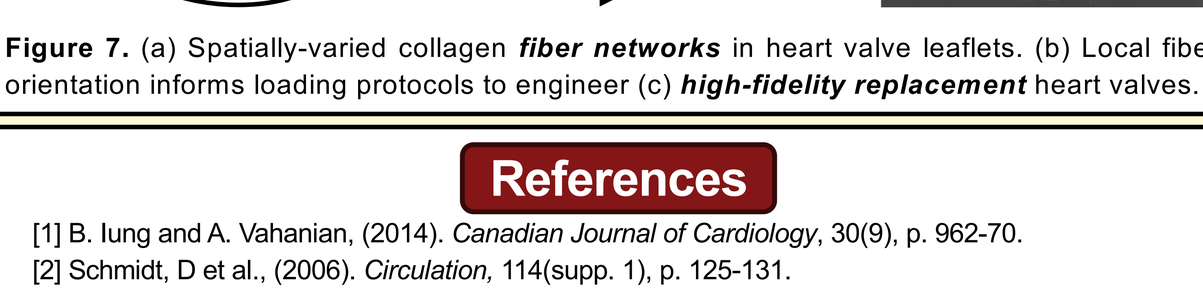

Figure 6. (a) The development of a ***spatially-varied*** material model to describe leaflet behavior for use in computational models of the MV and (b) ***TV closure*** and valvular function.

Future Research

- The microstructural quantification from this study could inform design of ***bioreactor protocols*** for ***tissue engineering*** biomimetic valves (**Fig. 7**).

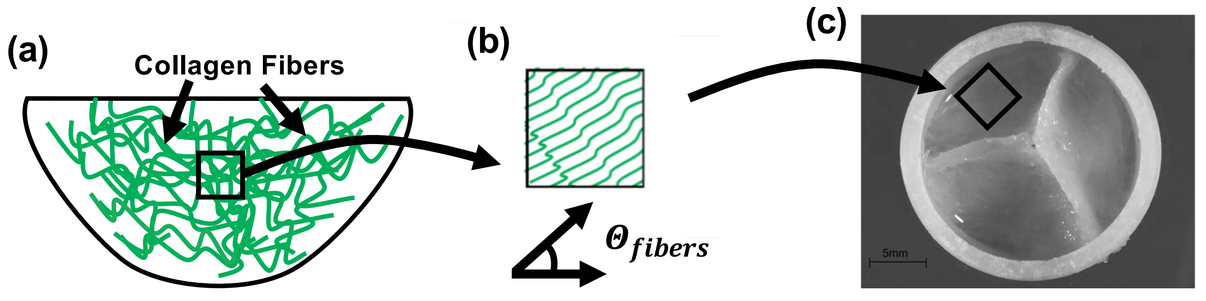

Figure 7. (a) Spatially-varied collagen ***fiber networks*** in heart valve leaflets. (b) Local fiber orientation informs loading protocols to engineer (c) ***high-fidelity replacement*** heart valves.

Acknowledgments

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References

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