NC STATE UNIVERSITY

# Multiscale Interactions of Mechanics, Microstructures, and Composition of Heart Valve Tissues

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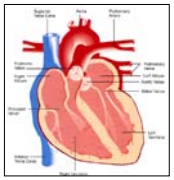
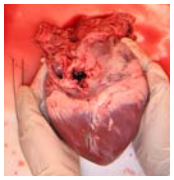
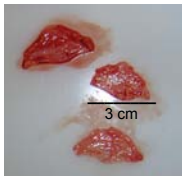
## Introduction and Background

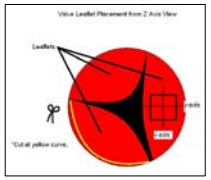
- Approximately 250,000 heart valve disease in USA in 2010[1]. Stenosis and insufficiency are the most common heart valve diseases, which are related to the mechanics of heart valves.
- Objective: Investigated the relationship of mechanical property, collagen fibers microstructure, and collagen concentrations in aortic and pulmonary semilunar valves.


Anatomy of the heart[4]


Porcine heart



Pulmonary valve leaflets

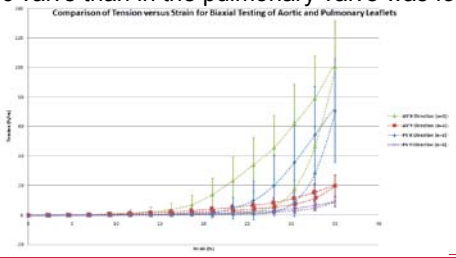

Method of dissection

- Function of heart valves:
  1. allow blood to flow through the heart smoothly.
  2. prevent retrograde flow of blood.
- Method of dissection:
  1. Each valve has three leaflets. Cartesian coordinate system was set before dissection.
  2. Leaflet samples were relaxed in HBSS for the physiological condition.

## Method and Results

### Mechanical Testing

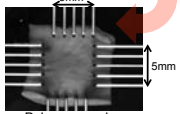
- Biaxial testing was conducted via a BioTester 5000 (CellScale, Waterloo, CAN).
- ~7mm x 7mm sample were cut from leaflets.
- Samples were mounted and tested circumferentially (x-axis) and radially (y-axis).
- Evenly distributed boundary conditions were provided, which eliminates the variability between sample sizes.
- Aortic valves are stiffer in the circumferential direction.
- A greater variance in the directional strength of the aortic valve than in the pulmonary valve was found.



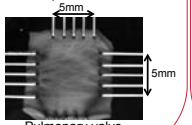


BioTester 5000


Tungsten BioRakes



Pulmonary valve sample, relaxed

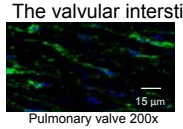


Pulmonary valve sample, stretched

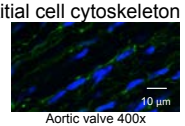
### Cellular Analysis

- Tissue-Level:
  - Histology were prepared with Masson or H&E stains. Photomicrographs were obtained via Leica DMLB Microscope.
  - Circumferential aligned collagen fibers were notable in aortic valve leaflets.
- Cellular-Level:
  - Immunohistochemical samples were prepared for a confocal microscope.
  - Direction of actin filaments follows the nuclei long-axis.

The valvular interstitial cell cytoskeleton



Pulmonary valve 200x

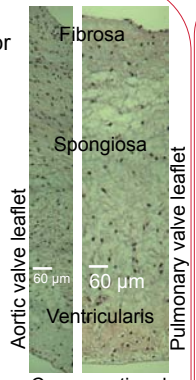


Aortic valve 400x

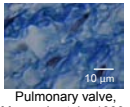
The valvular interstitial cell cytoskeleton. Actin filaments are shown in green and the cell nuclei are in blue.


Aortic valve, en-face, 400x


Pulmonary valve, en-face, 400x



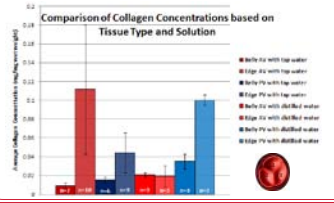
Cross-sectional view 400x



Pulmonary valve, Masson's stain, 1000x

### Biochemical Analysis

- Collagen extracted from a leaflet sample into solution (0.5M acetic acid: distilled water = 0.029:1 & 50mg Pepsin A), dyed, centrifuged, and dissolved in Alkali reagent.
- A spectrophotometer and standard curve were used to calculate the concentrations.
- Use of distilled water and collagen extraction time may have substantial effects on results
- Higher collagen concentrations were observed on edge regions than on belly regions of PV leaflets (AV leaflets provided inconsistent location-dependent results)




## Discussion

- A relationship exists between the mechanical strength, collagen fiber microstructure, and collagen concentration of a valve leaflet.
- Semilunar valve tissues have nonlinear anisotropy material properties due to the heterogeneous collagen fiber microstructure.
- A higher collagen concentration may be related to greater mechanical strength and may be location dependent.
- The mechanical property of semilunar valve tissues do not depend only on collagen concentration but how collagen fibers are arranged structurally at the microscopy level.

[1] American Heart Association.
[2] Courtesy of Chung, M.K., and Rich, M.W. *Alcohol Health and Research World 14(4):269–276, 1990.*

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