Preliminary Study in Characterizing Tissue Growth Through Residual Strain

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Background and Introduction

- Tissue engineering is used for the purpose of restoring and maintaining tissue and/or organ function[1].
- Currently, tissue engineering faces obstacles from the body rejecting the engineered tissue, mass transport limitations, and growth limitations.
- In order to succeed in restoring tissue function, engineered tissue should mimic native tissue as best as possible. To achieve this, the native behavior of the tissue must be thoroughly studied.

- An important application of this is for pediatric right ventricular outflow tract (RVOT) replacements.
- Currently, children who receive RVOT replacements will need multiple replacements as they grow because the engineered tissue being used is a non-living, foreign material with limited long-term function.
- What is desired is to be able to use an engineered tissue that can grow as the patient grows.

- Tissue growth can be characterized by residual strain, tissue geometry, structure, and mechanics.
- Residual strain is the strain present in a solid when all external loads have been removed[2].
- Residual strain homogenizes the stress distribution (circumferential, longitudinal, and radial stresses), which provides a uniform local mechanical environment for the vascular smooth muscle cells (VCSM). This uniform environment is desirable in the tissue since smooth muscle cells respond to stress and non-uniformity would cause changes in their activity.

*** My research focused on finding patterns in residual strain in porcine pulmonary trunks** (See Figure 1).

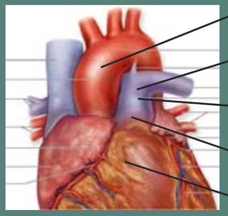


Figure 1: Diagram depicting the location of the pulmonary trunk with respect to the heart.

Methods

General:

- Rings were cut from the sinotubular junction and the bifurcation region.
- Two separate experiments were performed on each ring sample.

Residual Strain from Opening Angle and Circumferential Stretch:

- Residual strain can be characterized by the opening angle, and quantified by the circumferential stretch.
- Images were taken of the tissue rings before cut and for 30 minutes after cut (to allow tissue to equilibrate)
- Opening angle was calculated using the angle feature of the program *ImageJ* (see Figure 2b)
- Circumferential stretch was calculated by using the equation:

$$\lambda = \frac{l_{noload}}{L_{zerostress}}$$

Where $l_{no\ load}$ is the circumferential length in the no load state, and $L_{zero\ stress}$ is the circumferential length in the zero stress state (see Figure 2)

Residual Strain from Flexural Test:

- 3-point bending tests (see Figure 3) were also done on the cut ring samples.
- Bending was done both against and with curvature for each sample.

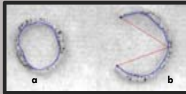


Figure 2: a) Shows the tracing of the circumferential length of the tissue in the no load state. b) shows the circumferential length of the tissue in the zero stress state (blue line) and the opening angle (red line)

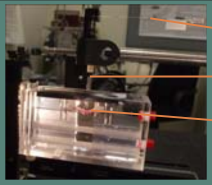


Figure 3: Picture of the bending device used to perform flexural tests.

Results and Discussion

Residual Strain from Opening Angle and Circumferential Stretch:

- As seen in Table 1, the OA for the sinotubular junction ring samples was consistently greater than that of the bifurcation region ring sample.
- Residual strain was calculated from the circumferential stretch using the equation for Green Strain:

$$E = \frac{1}{2}\left(\lambda^2 - 1\right)$$

• It can be seen from Table 2 that the residual strain of the sinotubular junction ring samples are greater than the bifurcation region ring samples.

*** Thus, a correlation between opening angle and residual strain can be inferred: a greater opening angle indicates greater strain.**

	Sinus OA (in degrees)	Bifurcation OA (in degrees)
PAT 10	143.9617	62.0137
PAT 11	68.7627	0.8030
PAT 12	85.7947	12.9927
PAT 17	82.8827	49.2370
Average	**95.3504**	**31.2616**

Table 1: *Summary of the average opening angles OA) of each pulmonary trunk sample of both sinotubular junction and bifurcation region samples.*

	Sinus λ	Bifurcation λ	Sinus E	Bifurcation E	S:B E Ratio
PAT 10	0.9005	0.9808	-0.0945	-0.0190	**4.9780**
PAT 11	0.9775	0.9901	-0.0223	-0.0099	**2.2581**
PAT 12	0.9843	0.9921	-0.0156	-0.0078	**1.9889**
PAT 17	0.9559	0.9831	-0.0431	-0.0168	**2.5693**
Average	**0.9546**	**0.9865**			
SEM	**0.0190**	**0.0027**			
% Error	**1.9909**	**0.2754**			

Table 2: *Summary of the average circumferential stretch and calculated strain values for each sample.*

Residual Strain from Flexural Test:

- Due to a small sample size, and the fact that they were procured from the slaughterhouse, and therefore are from varying backgrounds, it is difficult to see a clear trend.
- Preliminary data may suggest that stiffness going against curvature is greater than going with curvature, a characteristic possibly due to the mechanical makeup of the tissue.

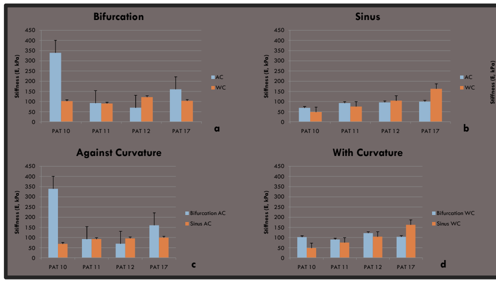
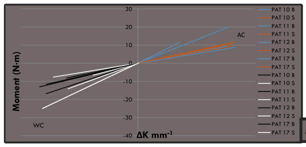


Figure 4: *Stiffness comparison between a) bifurcations samples: against and with curvature (AC, WC, respectively), b) sinotubular junction samples: AC and WC, c) bifurcation and sinotubular junction samples, AC, d) bifurcation and sinotubular junction samples, WC, and e) bifurcation, sinotubular junction, AC, and WC across all samples.*



- Plotting all data sets and comparing the effective stiffness (EI, independent of geometry) of bifurcation and sinus end samples, it may be justified to infer that the effective stiffness is fairly constant – this would be something to look into in the future with a greater number of samples.
- If true, this would correspond with the fact that residual strain homogenizes stress distribution along a vessel.

Figure 5: Comparison of Bifurcation and Sinus End Effective Stiffness

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