Evaluation of Mechanical Properties of Swine Tissue as it Relates to Atrial Fibrillation

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Background

Atrial Fibrillation (AF) refers to a disturbance in the natural cardiac rhythm.[1] It is a major problem throughout the population (over 2 million Americans have experienced these symptoms), and is also responsible for 15-20% of ischemic strokes.[2] A common treatment for AF is cardiac cryoablation and radiofrequency techniques. Ablation refers to the intentional controlled damage of tissue to restore a native cardiac rhythm. Anatomically, the esophagus is located behind the posterior wall of the left atrium in close proximity to the pulmonary veins, which are common targets for ablation. Thus, the locations of the esophagus, aorta, trachea, and diaphragm in relation to the heart makes them vulnerable to thermal damage during ablation procedures. Consequently, it is essential to understand the tensile properties of these tissues and how the anatomical changes from ablations may affect their intrinsic biomechanical properties. In order to understand the effects of the ablation procedures, baseline non-ablated data must be collected as well.

Objective

The purpose of this study is to evaluate the biomechanical properties of non-ablated swine tissue through data collection of the elastic modulus, peak avulsion forces, avulsion energy, tissue elongation, and force vs. cross sectional area of skeletal and cardiac swine tissue as a baseline data set for the ablated tissues.

Methodology

Figure 1.
- This figure represents the first portion of the experiment on a daily basis. Dissection of the various tissue (aorta in this image) into tissue bundles was imperative for performing tissue avulsions on the uniaxial pull machine.

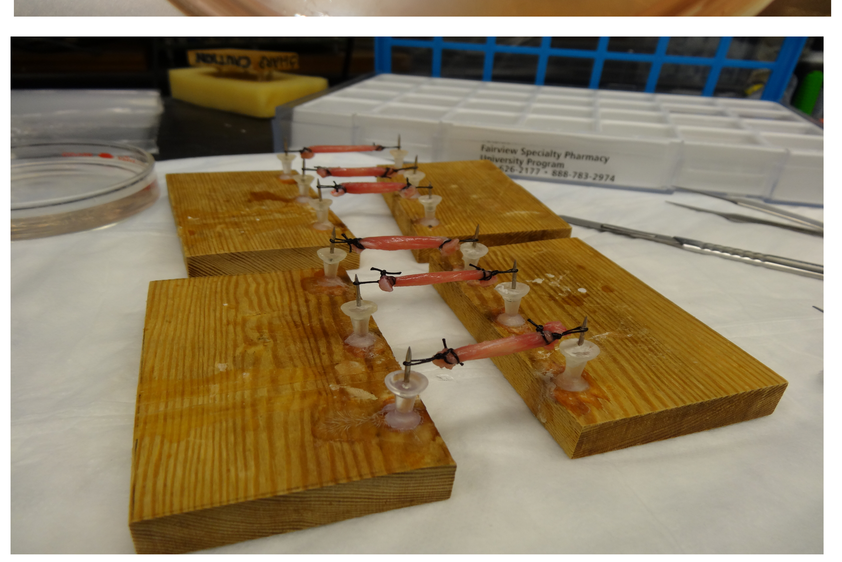


Figure 2.
- The portion immediately before tissue testing, the second phase is shown to the left. Tissue bundles approximately 20mm in length and 4 mm in diameter were mounted in this way. This allowed for placement of super glue at the sutures to limit tissue slippage.

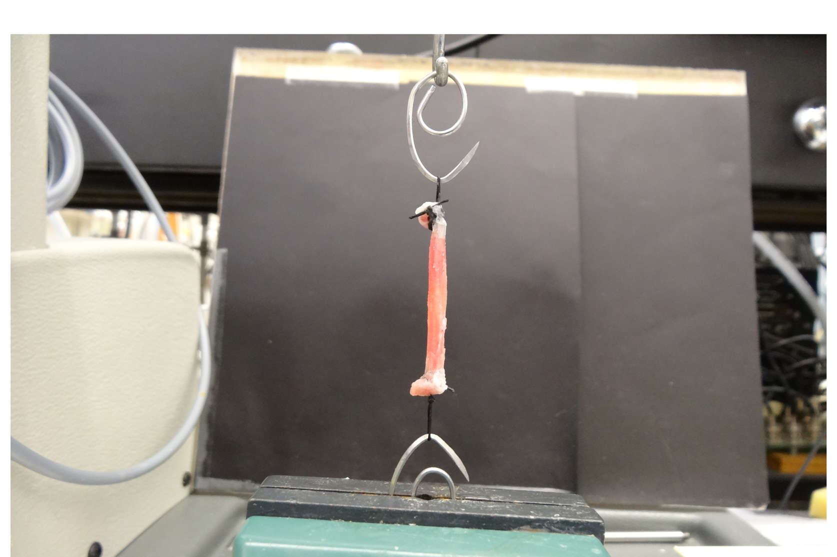
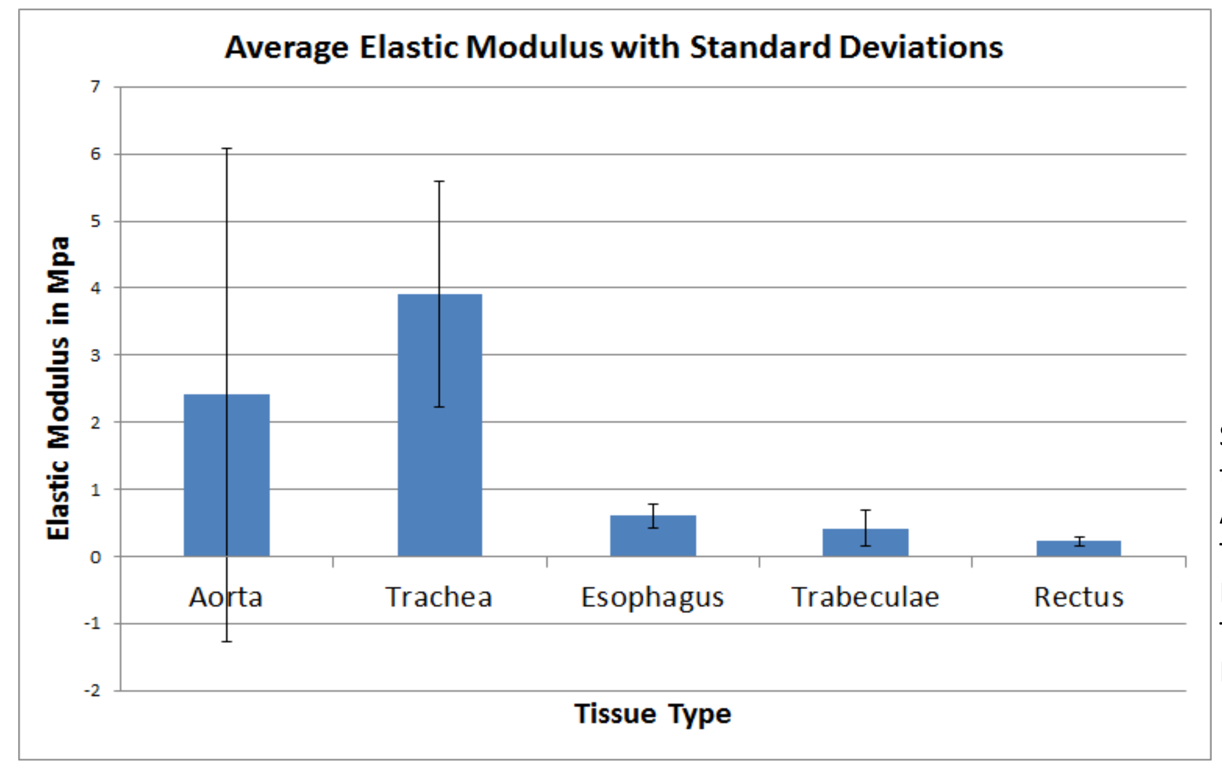


Figure 3.
- The uniaxial pull machine, utilized here to the left, was the final and most important part in the methodology. The machine pulled the tissue at a slow rate until avulsion (tissue breaking) occurred.
- The tissue being pulled here is esophageal tissue.

Results



Standard Deviation (avg of total samples)
Aorta - 3.67
Trachea - 1.67
Esophagus - 0.17
Trabecule - 0.26
Rectus - 0.07

Figure 4. One of the most important pieces of data collected through the use of Matlab software was the elastic modulus. After use of Matlab, the elastic modulus was found for each tissue. This is an overall average of the entire sample set for each tissue. There was 119 aorta, 56 trachea, 46 trabecule, 88 esophagus, and 45 rectus samples. The actual averages were : aorta – 2.42, trachea-3.91, esophagus-0.61, trabecule-0.43, rectus-0.23. (Units: N/mm^2).

Tissue	Mean Avulsion Force (in Newtons)	Standard Deviation of Avulsion Force (in Newtons)	Mean Avulsion Energy (in Joules)	Standard Deviation of Avulsion Energy (in Joules)	Average Elongation (in mm)	Standard Deviation of Elongation (in mm)
Aorta	7.05	1.46	30624.85	9602.49	20.81	3.67
Trachea	13.69	5.45	73280.23	41097.32	17.7	5.15
Esophagus	4.64	0.97	26673.29	9235.49	22.7	4.45
Trabecule	2.7	0.88	11244.31	5577.22	13.72	4.03
Rectus	1.91	0.66	11500.38	6389.66	19.2	5.85

Figure 5. This table outlines the total average data collected for each of the 5 different tissue types. The uniaxial pull machine data was analyzed through Matlab software.

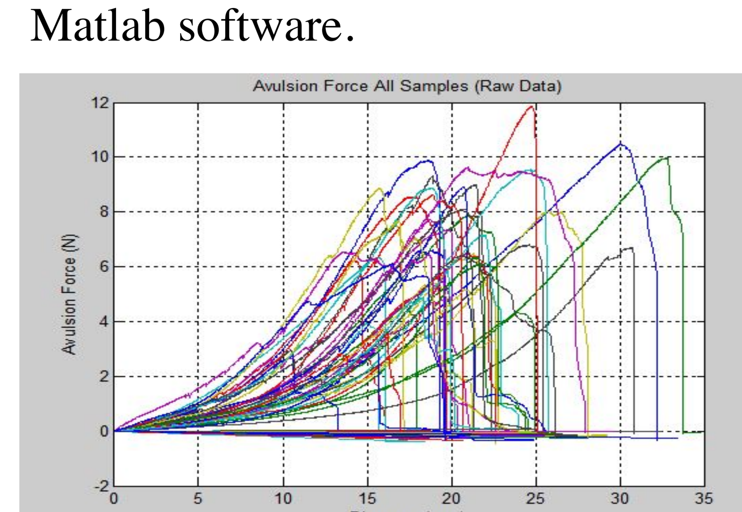


Figure 6. The figure to the left shows the force in newtons vs. the distance pulled in mm produced by the uniaxial pull machine. The linear line before the peak represents the elastic modulus. This is the data set representing the 43 "good samples" of the aortic tissue.

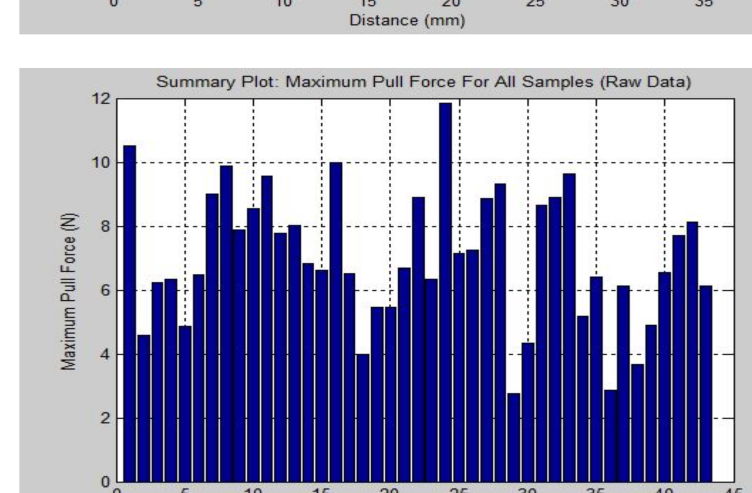


Figure 7. The figure to the left shows the maximum pull force for the 43 "good samples" of the aortic tissue. A consistent trend shows that the majority of the samples surpassed the 6 Newton mark, showing the stiff tensile properties of the aortic tissue.

Interpretation

There was a consistent trend throughout the majority of the experiments, and this relates to the cross sectional area of the tissue being tested. A linear relationship existed between the cross sectional area and the elastic modulus. As the cross sectional area increases, the avulsion forces increases as well. This was seen for all of the tissues tested. A comparison data set was performed by Ambroise Duprey, at the University of Michigan. The data collected by their team evaluating the BAV human aortic tissue was 2.30 MPa +/- 0.3.[3] They used a uniaxial pull machine, similar to the Chatillon machine that I used. Moreover, their team dealt with the issues of tissue slippage by use of sandpaper at the edges.[3] These results are very similar to the results obtained by myself in testing. As seen in the Figure 4, the overall average for the swine aortic tissue's elastic modulus was 2.42 Mpa +/- 3.67. The variance in the standard deviation outlines the difficulty in maintaining a consistent avulsion for the aortic tissue. The innate stiffness in the tissue often lead to breaks at the suture sites on the ends of the sample. The glue at the sutures acted as a pair of scissors as the force increased across the length of the aorta, finally cutting through the tissue at the top or bottom suture sites. As seen in Figure 5, the avulsion forces for trachea and the aorta were the highest, showing a parallel between the elastic modulus and maximum avulsion forces.

Conclusion

The elastic modulus is a primary mechanical property used to outline the properties of various tissue. The five different tissues examined show a variance of elastic modulus, as seen in Figure 5. The aortic and esophageal tissues have the most samples, adding validity to the results. A unique aspect not shown in the results section is the issue of good samples vs. bad samples. The good samples are samples that did not avulse near the suture sites. A good sample actually avulses in between the two sutures, specifically revealing the mechanical properties of the tissue only, minimizing the possibility of error due to incorrect avulsions. Other properties such as cross sectional area vs. force, elongation vs. volume, energy vs. force, and force vs. tissue volume were explored as well. These are additional, necessary mechanical properties used to define the tissue. The primary focus was on the aorta and esophagus, tissues that are in close proximity of ablation procedures. Thus, this data set is a supplemental data set to Ashish Singal's PhD work, in which ablated tissue properties are evaluated, relating to Atrial Fibrillation.

References

1) Reiffel, J. *Cardioversion for Atrial Fibrillation: Treatment Options and Advances*. (Online). 2009. PACE-Pacing and Clinical Electrophysiology.
2)CDC-Division for Heart Disease and Stroke Prevention-*Atrial Fibrillation Fact Sheet*. Center for Disease Control and Prevention. 2010.
3) Duprey, Ambroise. *Mechanical Properties of the Aorta: Annual Report to the European Society for Vascular Surgery*. Vascular Mechanics Laboratory, University of Michigan. 2007-2008.

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