Multidimensional Imaging Based Models for Canine Cardiovascular Procedural Skills

BME Fall 2024

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Problem Statement

The UW Veterinary School does not have a training model for students to practice balloon valvuloplasty procedures. The goal of this project is to create a 3D model of a canine heart to simulate pulmonary stenosis for students to practice transcatheter procedures.

Motivation

- Pulmonary stenosis (PS) is the most common congenital heart disease in canines (31-34%) [1]
- Transcatheter procedures are cheaper and have faster recovery times than surgical interventions to treat PS [2]
- Decreased caseload of patients with PS resulted in decreased training opportunity

Solution: Model for veterinary students to practice transcatheter procedures

Pulmonary Stenosis & Treatment

Pulmonary Stenosis:
Pulmonary valve leaflets are thickened or fused obstructing blood flow from heart to lungs [3]

Symptoms:
Exercise intolerance, collapsing, heart arrhythmias, congestive heart failure [3][4]

Balloon Valvuloplasty:
Balloon catheter inserted into jugular vein and fed through heart to pulmonary valve. Balloon inflated to expand leaflets to increase blood flow [5][6]

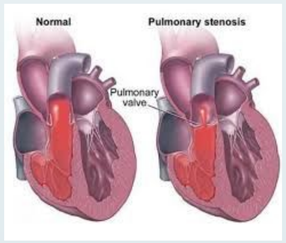

Figure 1: Pulmonary stenosis [6]

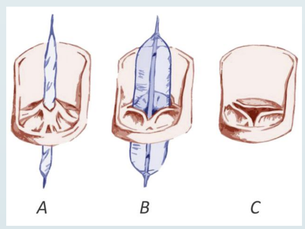

Figure 2: Balloon valvuloplasty [6]

Design Criteria

- Expected life cycle of 100 uses
- Valve must not deform more than 15% of original dimensions
- Transparent material
- Coefficient of friction within 20% of the native value (0.05)
- Elastic modulus within 10% of myocardium (0.17 MPa) and Jugular(1.16 MPa)
- Budget of $1000
- Tactile insertion and navigation through model is similar to native anatomy of french bulldog

Figure 3: French Bulldog

Design Process

Heart Chambers and Annulus

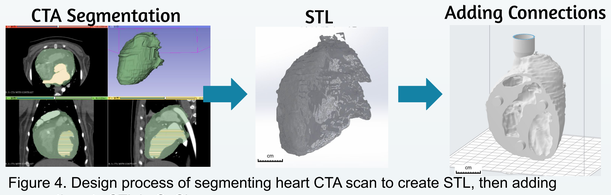

Figure 4. Design process of segmenting heart CTA scan to create STL, then adding connections to STL in OnShape

Jugular Vein

Figure 5. Jugular vein attached to heart model

- Created in SolidWorks
- Inner diameter 9-16 mm
- 1 mm wall thickness
- Hole for catheter insertion

Stand

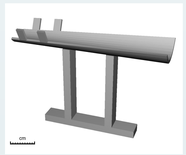

Figure 6. Stand to support jugular vein

- Stand to support jugular vein modeled in SolidWorks
- Box for heart using negative space from segmented heart

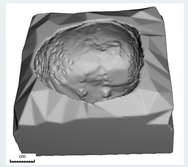

Figure 7. Box to hold heart model

Final Design

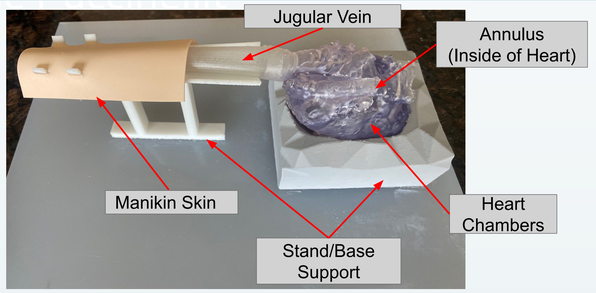

Figure 8. Final design assembly with component labels

- Final assembly includes the heart chamber halves, annulus, jugular vein, and stand
  - Three pegs and holes to connect heart chambers
  - Jugular fits into extruded cylinder around cranial vena cava
  - Annulus is press fit into heart half and fully enclosed
- Manikin skin allows for realistic insertion of catheter
- Base/stand ensures model stays in place during procedure

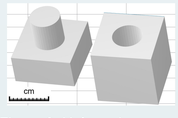

Figure 9. Hole and peg connector of heart halves

Figure 10. Jugular vein connection piece

Results

Material Stiffness Characterization

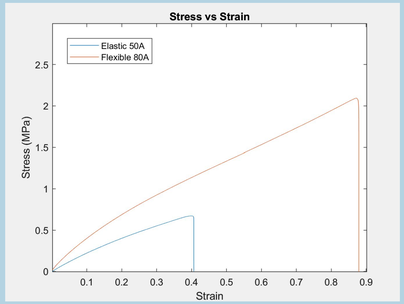

Figure 11. Stress vs strain curve for Elastic 50A and Flexible 80A

<u>Elastic 50A Modulus:</u> 1.68 MPa +- 0.84
<u>Flexible 80A Modulus:</u> 2.51 MPA +- 0.32

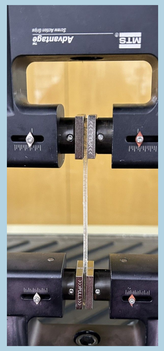

Figure 12. Flexible 80A material sample in MTS

Annulus Valve Fatigue Test

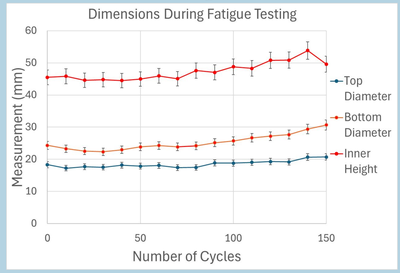

Figure 13. Dimensions of annulus during fatigue testing

<u>Top diameter:</u> 13.2% increase
<u>Bottom diameter:</u> 26.0% increase
<u>Height:</u> 9% increase

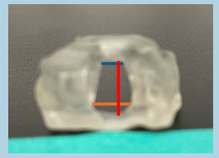

Figure 14. Annulus dimension measurements

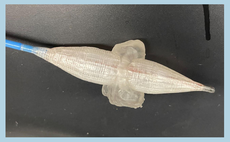

Figure 15. Inflated balloon catheter through annulus

Full Model Functionality Test (5 Criteria)

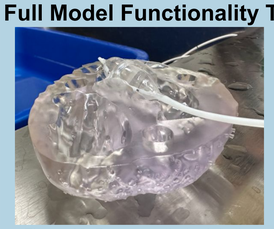

Figure 16. Balloon catheter inflating valve inside heart model

<u>Movement of Leaflets:</u>
- Meets expectations

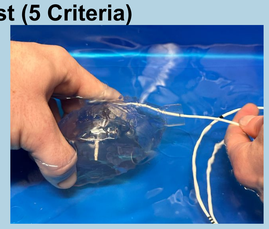

Figure 17. Heart model submerged in water

<u>Transparency:</u>
- Meets expectations

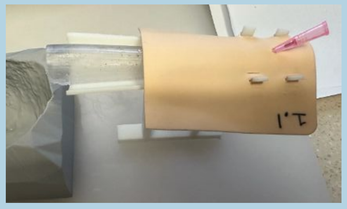

Figure 18. IV needle inserted into jugular vein

<u>Insertion Process:</u>
- Meets expectations

<u>Ease of Use:</u>
- Partially meets expectations
- Increase heart mold clearance

<u>Model Compared to Native Anatomy:</u>
- Needs improvement
- Client unable to traverse catheter to valve

Discussion

Material Characterization
<u>Elastic 50A:</u> 41% error from jugular vein stiffness
- Client satisfied with stiffness

<u>Flexible 80A:</u> 2231% error from myocardial stiffness
- Heart walls insufficiently compliant

Annulus Valve Fatigue Test
- Heart valve may expand with use
- Annulus will be confined within heart – may minimize stretch observed
- Provide multiple annuli to replace when fatigued

Full Model Function Test
- Movement of valve leaflets stretched as client expected compared to native anatomy
- Catheter visible through model when in water tank - implement dyed water in balloon catheter
- Insertion process matches expected toughness of skin
- Model assembly easy to use by singular user
- Model anatomy too challenging - enlarge right ventricle and remove ridges on interior of ventricle

Future Work

- Print heart chambers in Elastic 50A
- Implement the model into a fluid filled system with pump to simulate blood flow
- Make anatomical edits such as enlarging the right ventricle and smoothing edges for easier model use
- Create video platform and projection to mimic procedure conditions

Acknowledgements

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BME Department

References

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