Multidimensional Imaging Based Model for Canine Cardiovascular Procedural Skills

BME 402 Spring 2025

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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 cardiology residents to learn and practice transcatheter procedures.

Motivation

- Pulmonary stenosis accounts for 31-34% of congenital heart disease in canines [1]
- Balloon valvuloplasty (BVP) is the most widely accepted treatment for pulmonary stenosis [2]
- Transcatheter procedures have steep learning curves
- Currently there are no simulation models for BVP

Objective: Build a 3D model for students to practice balloon valvuloplasty

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]

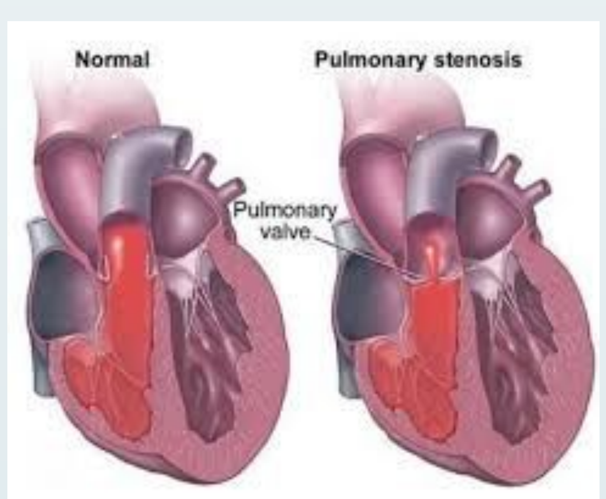

Figure 1: Pulmonary stenosis [6]

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

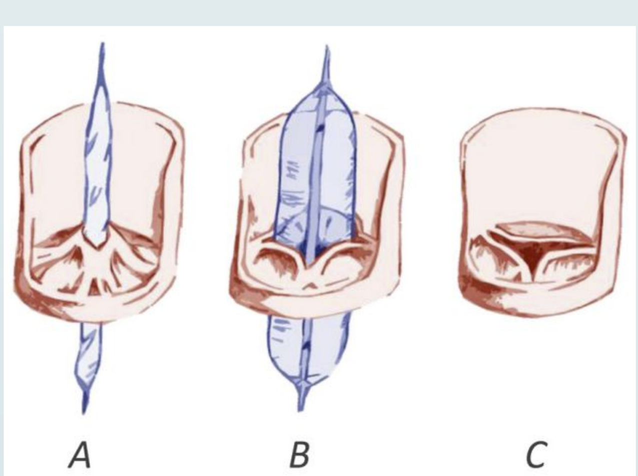

Figure 2: Balloon valvuloplasty [6]

Design Criteria

- Mimic fluoroscopy monitor display
- Elastic modulus similar to myocardium (0.17 MPa) – within 0.1 - 2 MPa [7]
- Transparent material
- Budget of $1000
- Realistic french bulldog heart anatomy
- Flow rate (~900 mL/min) to mimic cardiac output of french bulldog [8]
- Realistic navigation of the catheter during balloon valvuloplasty

Figure 3: French bulldog [9]

Design Process

Heart Chambers

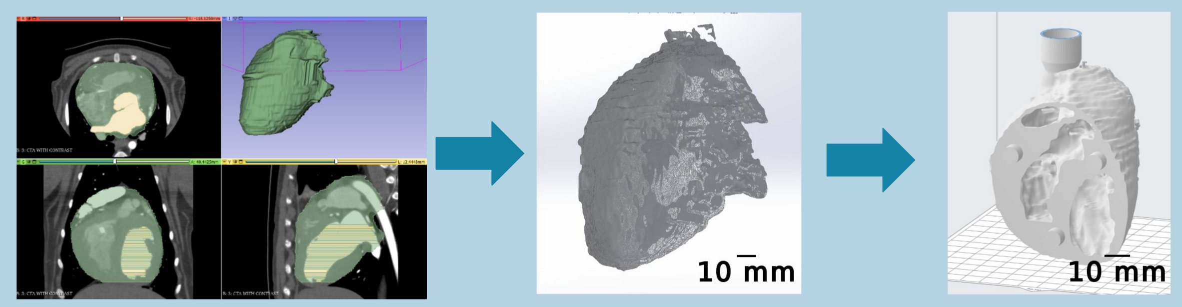

Figure 4. Segmentation of heart, 3D modeling, and heart connections

Jugular Vein

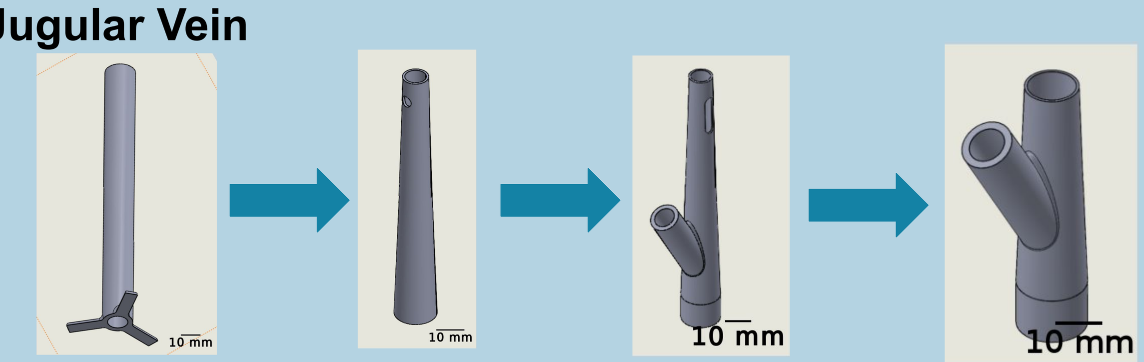

Figure 5. Jugular vein design iterations (chronological order, left to right)

Jugular Stand and Heart Box

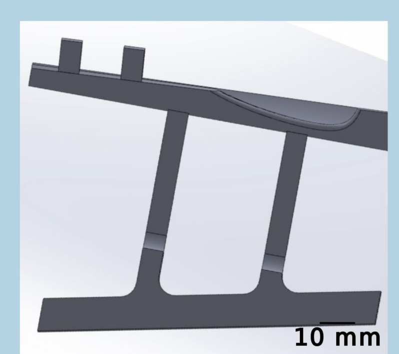

Figure 6. Jugular vein stand

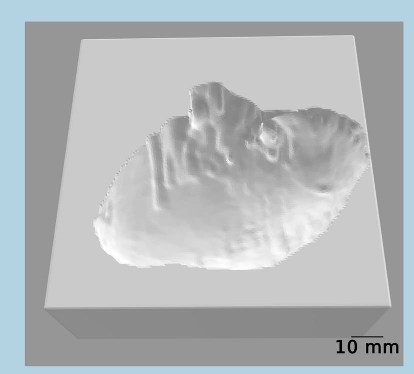

Figure 7. Heart box

Peristaltic Pump

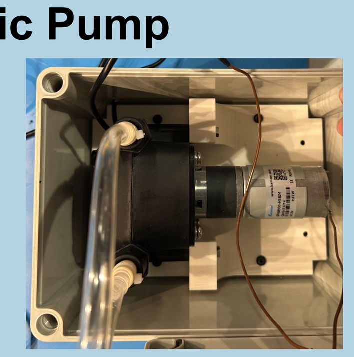

Figure 8. Inside of pump

Figure 9. Outside of pump

Final Design

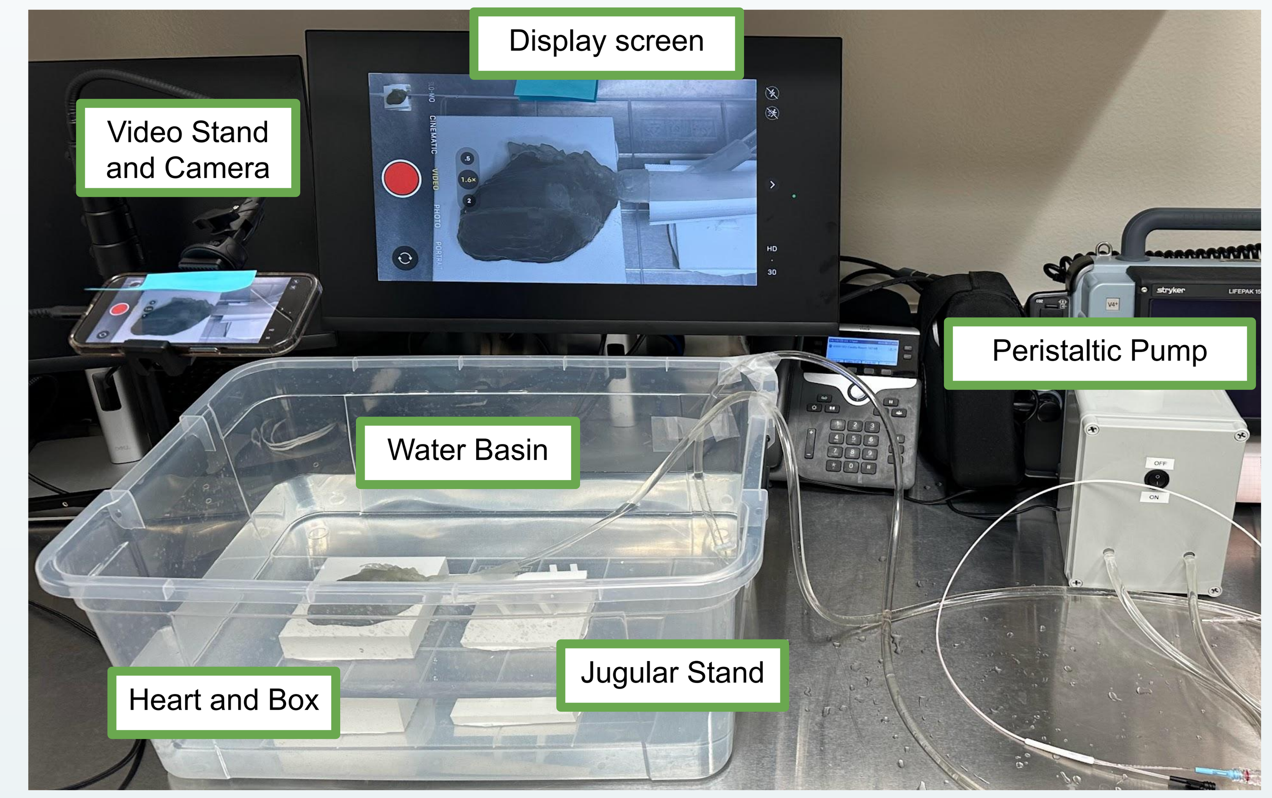

Figure 11. Full model assembly

- **Heart and Jugular Vein Material:** Formlabs Elastic 50A
- **Display Screen:** mimics fluoroscopic view
- **Dyed Water**: simulates contrast used in fluoroscopy
- **Peristaltic Pump:** Flow rate matches cardiac output of french bulldog (~900 mL/min)
- **Petroleum Jelly:** coated on heart walls to reduce friction

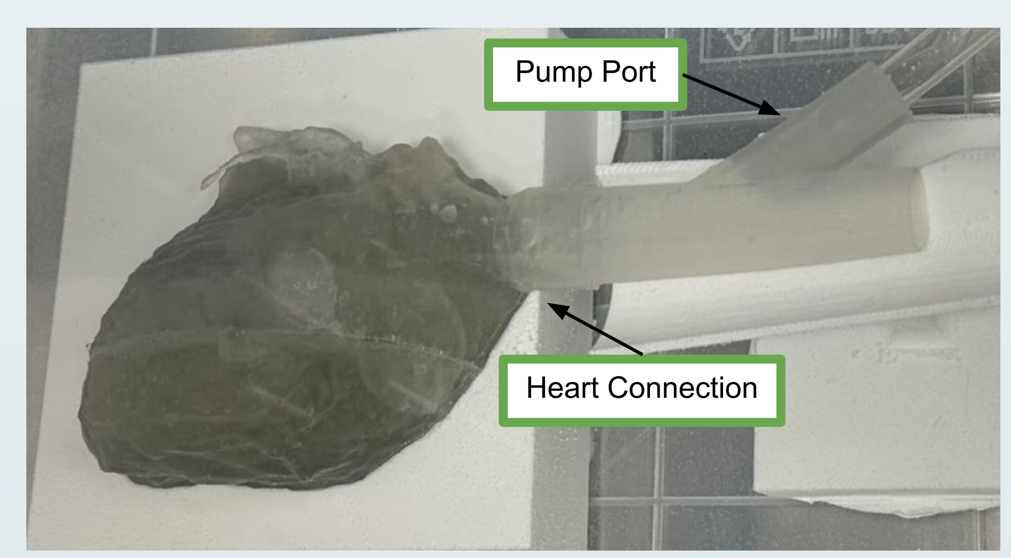

Figure 14. Heart in Heart Box + Jugular Vein in Stand + Pump Tubing attached to Jugular Vein

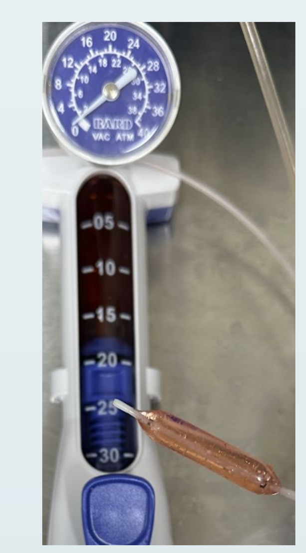

Figure 13. Indeflator with balloon and dyed water

Testing

BVP Testing Procedure - IRB Exempt

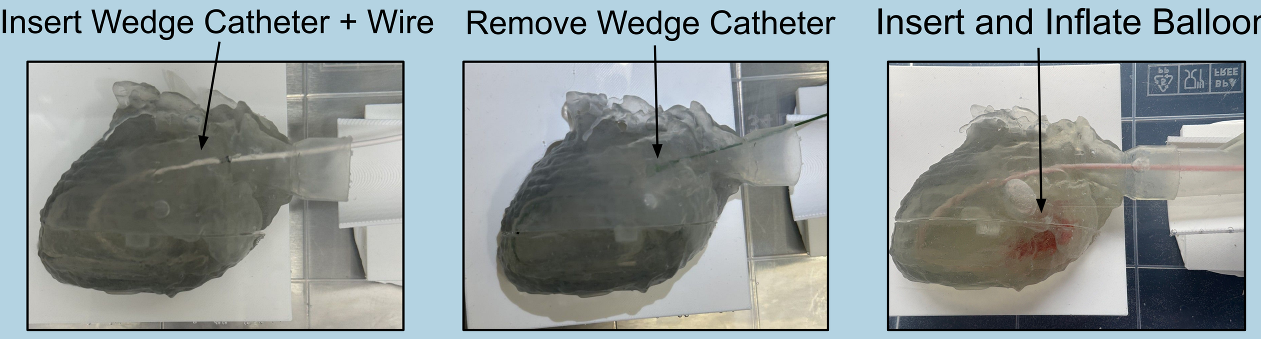

Figure 10. BVP testing cycle

Subjects

3 Cardiology Attendings
3 Cardiology Residents
3 Non-Cardiology Residents

Analysis

Wilcoxon Rank Sum Test
Group 1: BVP Experienced (n=5)
Group 2: No BVP Experience (n=4)

Likert Surveys

Pre + Post Test Assessing:

1. Experience with BVP
2. Confidence in BVP
3. Knowledge of Anatomy
4. Improvement in Skill
5. Model Accuracy
6. Recommendation for Use

Post - Testing Survey Results

5/9
Realistic Fluid Flow
100% attendings agree
No difference in groups
p = 0.9

7/9
Increased Confidence in Anatomy + BVP
100% inexperienced agree
No difference in groups
p = 1 and p = 0.09

8/9
Realistic Anatomy + Catheter Navigation
No difference in groups
p = 1 and p = 0.96

9/9
Realistic Fluoroscopy Replication
No difference in groups
p = 0.24

9/9
Recommend Model for Training Students
No difference in groups
p = 0.56

Discussion

Material Validation

- MTS Testing:
  - Formlabs Elastic 50A 3D resin has an elastic modulus of 1.68 MPa
- Client Validation:
  - Material has sufficient transparency and compliance

Human Subjects Testing

- Significant difference in pre-testing BVP confidence and knowledge
- No significant difference in post-testing responses
- Heart anatomy and navigation of catheter through heart is realistic
- Video display accurately mimics fluoroscopy screen
- All attendings feel the fluid flow from pump is realistic
- All inexperienced users had an increase in confidence in BVP and improved understanding of cardiac anatomy

100% of users believe the model will be a beneficial addition to the current training program at the University of Wisconsin - Veterinary School

Future Work

1. Increase transparency of heart to improve catheter visualization
2. Focus video display more closely on model to replicate fluoroscopy and prevent users from seeing their hands
3. Improve heart box tolerancing to secure heart halves together
4. Secure pump tubing to water basin
5. Combine valve and heart into a single print and perform fatigue testing on model

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