Parametric Anatomical CAD Model Generation with Silicone Phantom Fabrication Tools for Validation Studies

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Introduction

Adaptable shape models of critical cardiovascular anatomy sections have been developed to accelerate population-oriented studies of pathological morphology. To investigate aortic valve function, **a parametric model of the left ventricular outflow tract-to-ascending aorta (LVOT-to-AA) region was developed utilizing Dassault Systemes' modeling software SolidWorks**. This parametric model facilitates incremental changes for studying patient population variances and disease progression. The LVOT-to-AA model was dissected using a novel geometry-specific method so that mold-sets could be developed. Fabricating these mold-sets using 3D-printing techniques allowed the model to be cast in parts. **A LVOT-to-AA silicone phantom was produced using transparent silicone for use in a mock circulatory system (MCS) for analysis**. An aortic root silicone phantom investigation box was fabricated out of transparent acrylic plate and fittings to allow for particle image velocimetry (PIV) flow analysis.

Materials and Methods

- LVOT-to-AA sparse spatial data was received from the Visible Human Project (VHP).
- This model was used to generate a clinical data-based parametric model of the structure, allowing for incremental structural changes useful for studying (1) time-dependent structural progression due to age or disease and (2) structural variation from population to population.

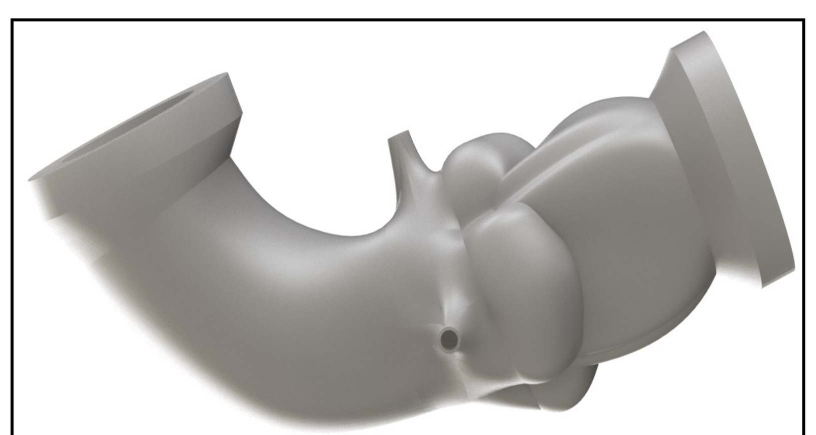


Figure 1— LVOT-to-AA Model

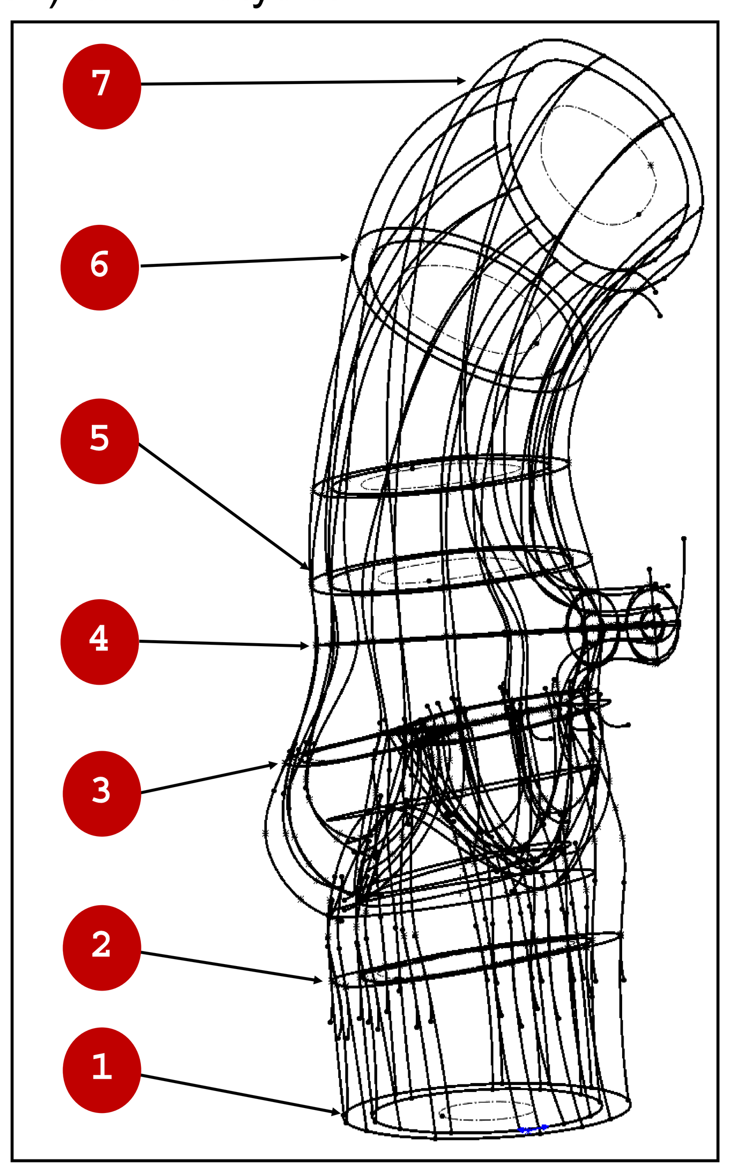


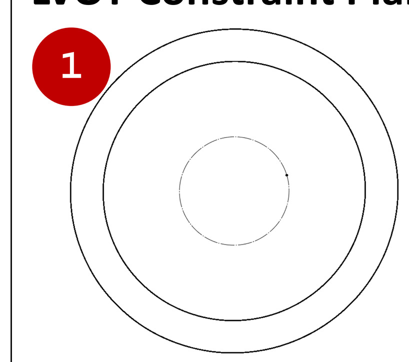
Figure 2—Parametric Model Lofted Curves

Table 1—Dimension Predictor Formulas Derived from Published Data

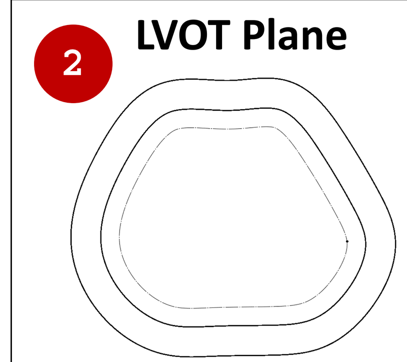
Vriz et al.		
Components	Data-Driven Predictor Formulas for Males	Data-Driven Predictor Formulas for Females
Sinus Diameter, F_{1i}(age)	F_{1m} = (6/80*age+14)*BSA	F_{1f} = (4/80*age+14)*BSA
ST Junction, F_{2i}(age)	F_{2m} = (5/80*age+11)*BSA	F_{2f} = (5/160*age+12)*BSA
Ascending Aorta, F_{3i}(age)	F_{3m} = (7/80*age+11)*BSA	F_{3f} = (5/160*age+15)*BSA
Kruger et al.		
Centerline Scaled Length 18 < age <= 38, S_1(age)		S_1 = 0.0018*age+0.9273
Centerline Scaled Length 38 < age <= 99, S_2(age)		S_2 = 0.0029*age+0.886

Table 2— Controlled Model Profile Curves

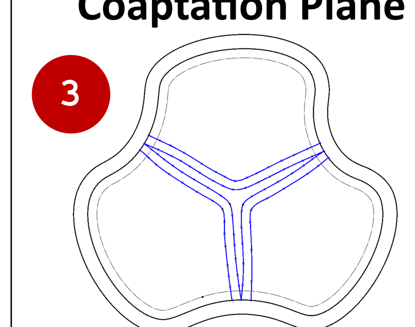
LVOT Constraint Plane



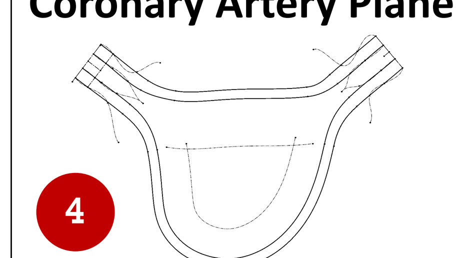
LVOT Plane



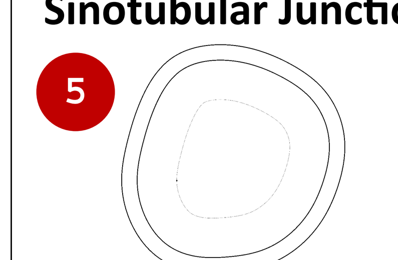
Coaptation Plane



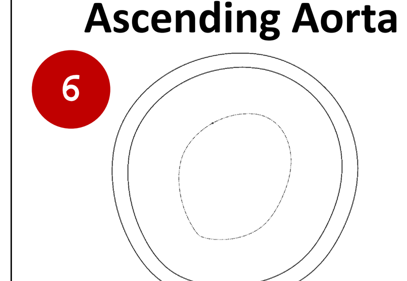
Coronary Artery Plane



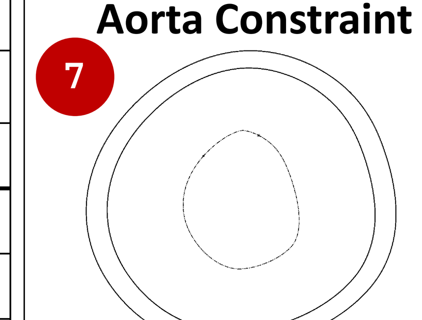
Sinotubular Junction



Ascending Aorta



Aorta Constraint



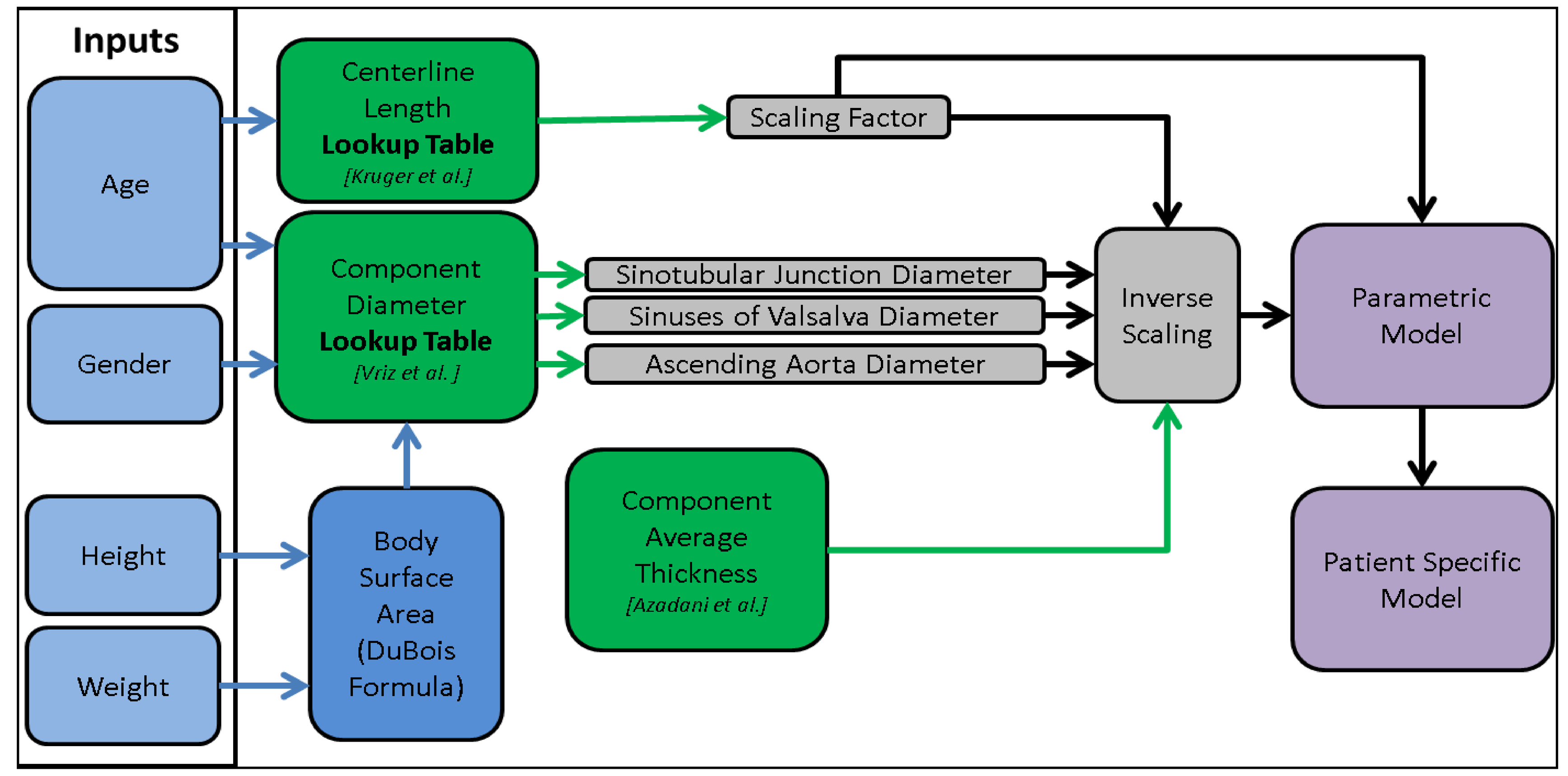


Figure 3—Patient-Specific Model Predictor Flow Diagram

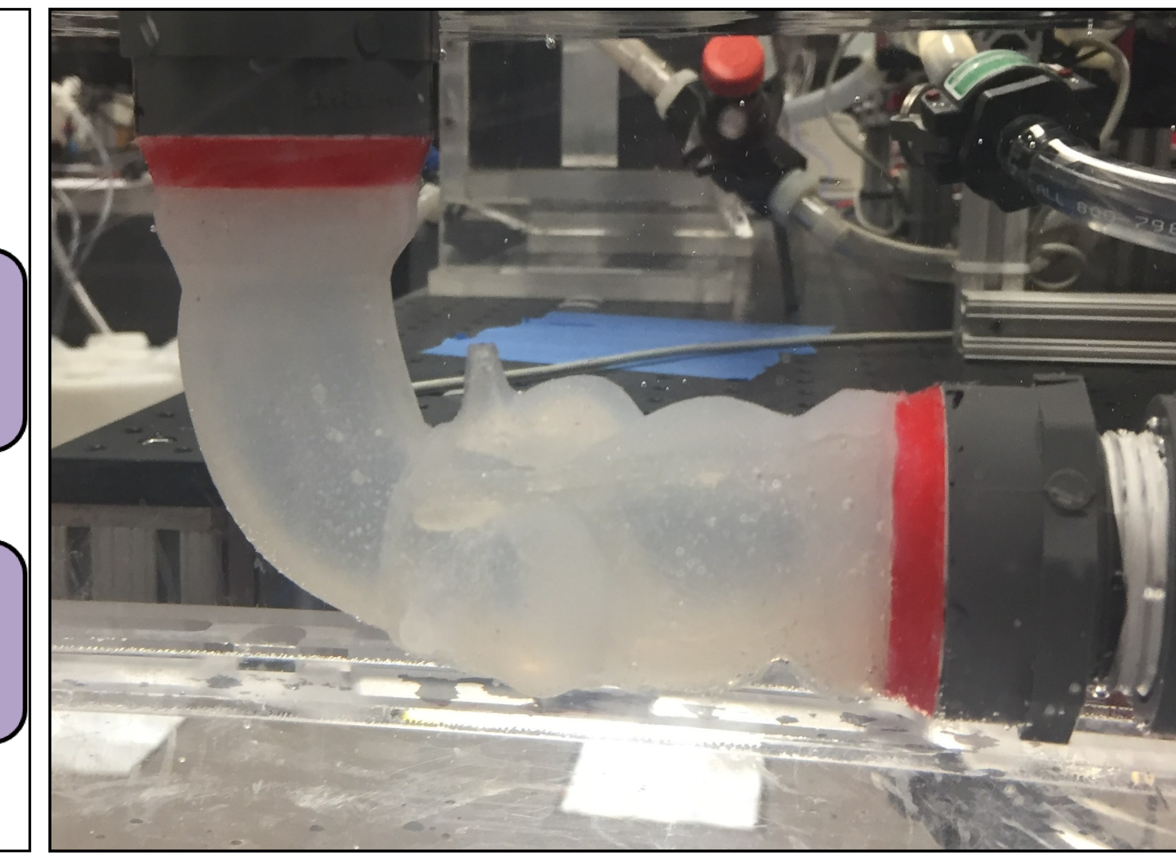


Figure 7—Silicone Phantom Integrated into the MCS

Table 3—Prediction Parameters for Three Patient States

	Patient 1	Patient 2	Patient 3
Age	18	48	99
Gender	Male	Male	Male
Height (m)	1.8	1.9	1.8
Weight (kg)	90	95	75
BSA (m^2)	2.1	2.23	1.94
Scale	0.96	1.03	1.17
Ascending Aorta (mm)	28.54	30.66	29.9
Sinotubular Junction (mm)	27.85	28.19	28.19
Sinuses of Valsalva (mm)	38.99	38.21	38.21
Annulus (mm)	28.53	28.8	29.74
Centerline Length (mm)	101.12	100.45	100.85

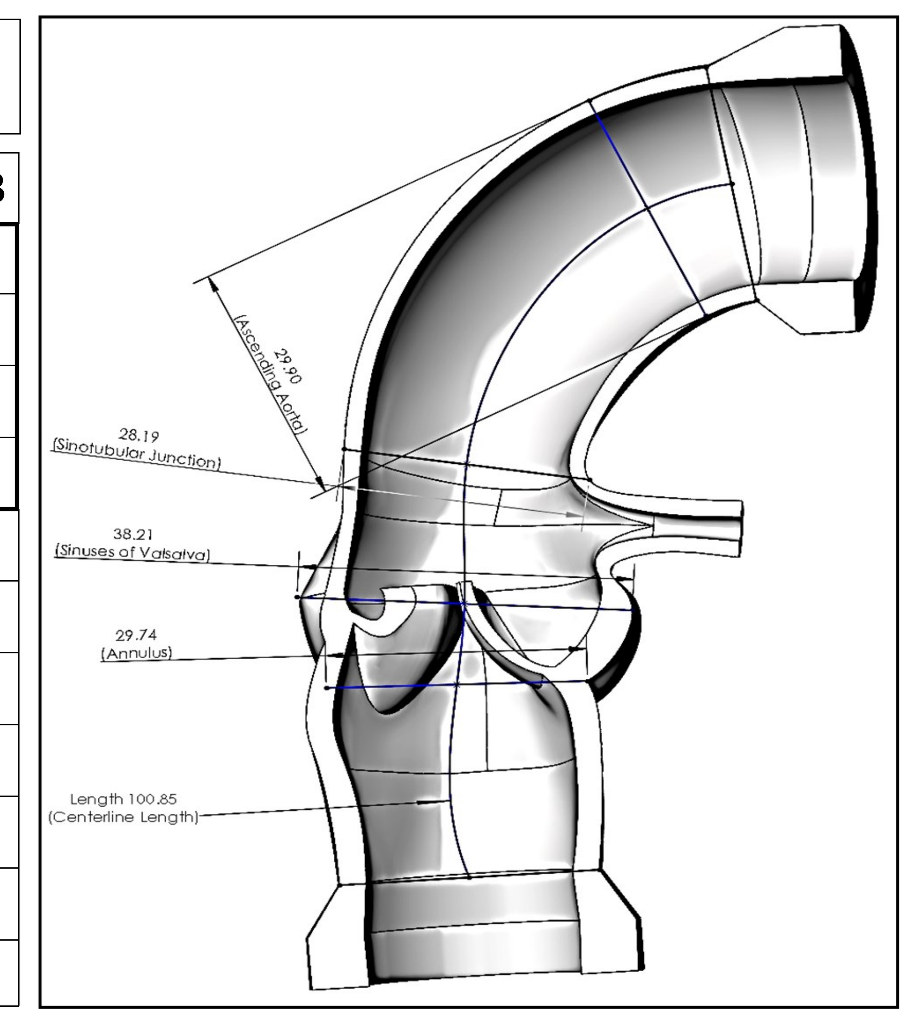


Figure 4—Patient 3 Predicted Model

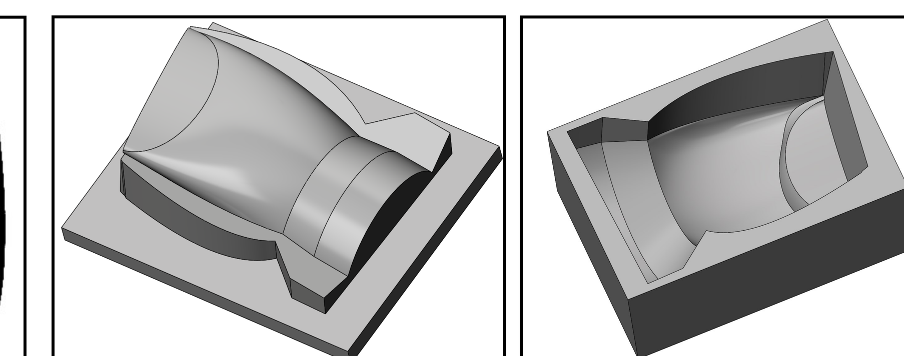


Figure 5—Mold Set Model Example

Figure 6—Silicone Phantom

Results

Using published data, correlation equations were derived and implemented to allow for prediction of aortic valve structure, based on gender, age, height, and weight. Mold sets were fabricated so that a silicone phantom could be created. A visualization system acrylic box module was fabricated in order to integrate silicone phantoms into a mock circulatory system for use with particle image velocimetry for data acquisition.

Conclusion

A method of generating a continuous LVOT-to-AA parametric model has been successfully developed and carried out.

Future Research

Broadening the functionality of the parametric valve would allow for more accurate prediction models by allowing greater control over the various components of the LVOT-to-AA model. Applying a unified and comprehensive data set, describing the anatomical structure dimensions as a function of time, to the parametric model design table would allow for improved modeling ability.

References

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