CPM Specifications Document
Anomalous Origin of the Coronary Arteries:

OSMSC 0121_0000

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Version 1

Open Source Medical Software Corporation

1. Clinical Significance & Condition

Coronary heart disease (CHD), also known as coronary artery disease is the leading cause of death in the U.S., causing about 25% of total deaths in the U.S [1, 2]. Coronary artery stenosis and occlusion is caused by plague build up, often fatty materials resulting in atherosclerosis, in the arteries supplying blood to heart muscle resulting in ischemia. Coronary Artery aneurysms are also caused by atherosclerosis or other disease; however coronary artery aneurysms are less common with incidence varying from 1.5-5% [3]. The most common sites for coronary aneurysms, in order of highest to lowest frequency are the: (1) proximal Left anterior descending artery (LAD) and right coronary artery (RCA), (2) left main coronary artery (LMCA), (3) left circumflex artery (LCX), (4) and lastly the junction between the RCA and right posterior descending artery (RPD) [4]. Understanding blood flow may serve as the basis for understanding coronary artery disease and aneurysm formation and considering therapeutic options.

2. Clinical Data

Patient-specific volumetric image data was obtained to create physiological models and blood flow simulations. Details of the imaging data used can be seen in Table 1. See Appendix 1 for details on image data orientation.

Table 1 – Patient-specific volumetric image data details (mm)

OSMSC ID	Modality	Voxel Spacing			Voxel Dimensions			Physical Dimensions		
		R	A	S	R	A	S	R	A	S
0121_0000	CT	0.4883	0.4883	0.6250	512	512	280	250	250	175

Available patient-specific clinical data collected can be seen in Table 2.

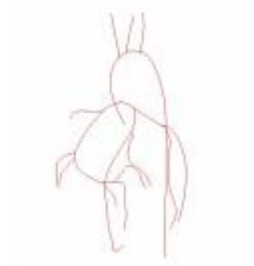
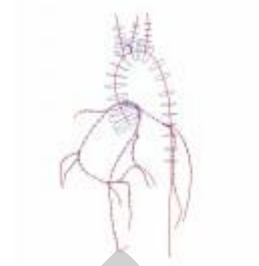
Table 2 – Available patient-specific clinical data

OSMSC ID	Age	Gender	Height (m)	Weight (kg)	BSA (m^2)	HR (bmp)	Psys (mmHg)	Pdia (mmHg)
0121_0000	10	F	1.46	40.1	1.2	64	103	56

3. Anatomic Model Description

Anatomic models were created using customized SimVascular software (Simtk.org) and the image data described in Section 2. The models extend from the ascending aorta to the descending aorta, including the coronary arteries and branches off the aortic arch. See Appendix 2 for a description of modeling methods. See **Error! Reference source not found.** for a visual summary of the image data, paths, segmentations and solid model constructed.

Table 3 – Visual summary of image data, paths, segmentations and solid model.

OSMSC ID	Image Data	Paths	Paths and Segmentations	Model
ID: OSMSC0121 subID: 0000 Age: 10 Gender: F				

Details of anatomic models, such has number of outlets and model volume, can be seen in Table 4.

Table 4 – Anatomic Model details

OSMSC ID	Inlets	Outlets	Volume (cm^3)	Surface Area (cm^2)	Vessel Paths	2-D Segmentations
0121_0000	1	14	23.06355	96.20649	14	218

4. Physiological Model Description

In addition to the clinical data gathered for this model, several physiological assumptions were made in preparation for running the simulation. See Appendix 3 for details.

5. Simulation Parameters & Details

No simulation results available.

6. Simulation Results

No simulation results available.

7. References

[1] American Heart Association, "Coronary Artery Disease -The ABCs of CAD," 14 February 2012. [Online]. Available: http://www.heart.org/HEARTORG/Conditions/More/MyHeartandStrokeNews/Coronary-Artery-Disease---The-ABCs-of-CAD_UCM_436416_Article.jsp#.T3yHFat8B8E. [Accessed 4 April 2012].

[2] Centers for Disease Control and Prevention, "Healthy, United States, 2010: With Special Feature of Death and Dying," U.S Government Printing Office, Washington, DC, 2011.

[3] M. Syed and M. Lesch, "Coronary artery aneurysm: a review," *Prog Cardiovasc,* vol. 40, no. 1, pp. 77-84,

1997.

[4] J. W. Newburger, "Diagnosis, Treatment, and Long-Term Management of Kawasaki Disease: A Statement for Health Professionals From the Committee on Rheumatic Fever, Endocarditis and Kawasaki Disease, Council on Cardiovascular Disease in the Young, American Heart Association," *Circulaton,* vol. 110, pp. 2747-2771, 2004.

Appendix

1. Image Data Orientation

The RAS coordinate system was assumed for the image data orientation. Voxel Spacing, voxel dimensions, and physical dimensions are provided in the Right-Left (R), Anterior-Posterior (A), and Superior-Inferior (S) direction in all specification documents unless otherwise specified.

2. Model Construction

All anatomic models were constructed in RAS Space. The models are generated by selecting centerline paths along the vessels, creating 2D segmentations along each of these paths, and then lofting the segmentations together to create a solid model. A separate solid model was created for each vessel and Boolean addition was used to generate a single model representing the complete anatomic model. The vessel junctions were then blended to create a smoothed model.

3. Physiological Assumptions

Newtonian fluid behavior is assumed with standard physiological properties. Blood viscosity and density are given below in units used to input directly into the solver.

Blood Viscosity: 0.04 g/cm•s^2
Blood Density: 1.06 g/cm^3

4. Simulation Parameters

Conservation of mass and Navier-Stokes equations were solved using 3D finite element methods assuming rigid and non-slip walls. All simulations were ran in cgs units and ran for several cardiac cycles to allow the flow rate and pressure fields to stabilize.

5. Outlet Boundary Conditions

5.1 Resistance Methods

Resistances values can be applied to the outlets to direct flow and pressure gradients. Total resistance for the model is calculated using relationships of the flow and pressure of the model. Total resistance is than distributed amongst the outlets using an inverse relationship of outlet area and the assumption that the outlets act in parallel.

5.2 Windkessel Model

In order to represent the effects of vessels distal to the CFD model, a three-element Windkessel model can be applied at each outlet. This model consists of proximal resistance (R_p), capacitance (C), and distal resistance (R_d) representing the resistance of the proximal vessels, the capacitance of the proximal vessels, and the resistance of the distal vessels downstream of each outlet, respectively (Figure 1).

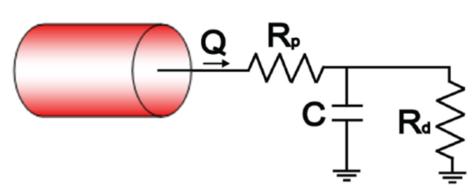


Figure 1 - Windkessel model

First, total arterial capacitance (TAC) was calculated using inflow and blood pressure. The TAC was then distributed among the outlets based on the blood flow distributions. Next, total resistance (R_t) was calculated for each outlet using mean blood pressure and PC-MRI or calculated target flow ($R_t=P_{mean}/Q_{desired}$). Given that $R_t=R_p+R_d$, total resistance was distributed between R_p and R_d adjusting the R_p to R_t ratio for each outlet.

