CPM Specifications Document
Coronary Artery Bypass Grafting (CABG):

OSMSC 0109_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 bypass grafts are used to reroute blood to the heart when coronaries have significant narrowing.

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
0109_0000	CT	0.4883	0.4883	0.625	512	512	373	250	250	233.13

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

Table 2 – Available patient-specific clinical data

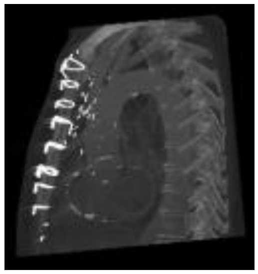
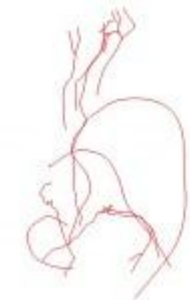
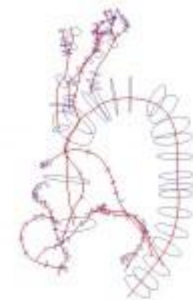
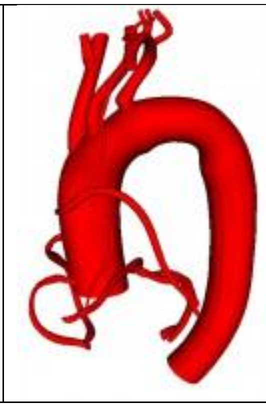
OSMSC ID	Age	Gender	HR (bmp)
0109_0000	63	M	61

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 ascending aorta to descending aorta before the phrenic artery, including the coronaries and vessels 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: OSMSC0109 subID: 0000 Age: 63 Gender: M				

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
0109_0000	1	15	236.91	460.12	18	171

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.

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 $g/cm \bullet s^2$
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).

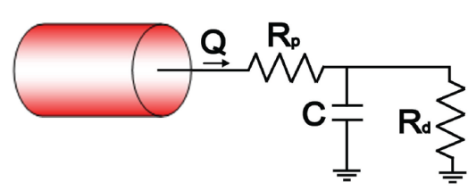


Figure 1 - Windkessel model

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.

