American Journal of Applied Sciences 5 (8): 1052-1058, 2008
ISSN 1546-9239

Abdominal and Thoracic Aortic Aneurysm Modeling

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Abstract: Modeling is a beneficial tool for understanding cardiovascular system functioning and pathophysiology of the system. The present study is concerned with left ventricle Pressure-Volume diagrams obtained by modeling of aortic aneurysms using the cardiovascular electronic system. In addition, these graphs were compared with a normal condition. The electrical circuit of the cardiovascular system consists of 42 segments including the main arterial vessels. Anatomical and physiological data for circuit parameters have been extracted from medical articles and textbooks. The pressure-volume graphs were obtained for fusiform and saccular aortic aneurysms at different values by using Matlab software. The results show that hypertension is a major symptom of these diseases. By increasing in amount of aneurysm, the blood pressure increases considerably, moreover, the amount of stroke work could be obtained from the graphs. Also, the diagrams show that the amount of cardiac function in every severity of the diseases.

Key words: Cardiovascular system, Pressure-Volume Loops, Abdominal Aortic Aneurysm (AAA), Thoracic Aortic Aneurysm (TAA)

INTRODUCTION

The aortic aneurysm is a dilatation of the aortic wall which occurs in two saccular and fusiform types. Most of the aortic aneurysms are fusiform (concentric radial dilatation) but infrequently may be saccular (eccentric radial dilatation). The abdominal aortic aneurysm is the most common form of the aneurismal disease[1,2]. In the former 30 years, the occurrence of Abdominal Aortic Aneurysms (AAA) has increased threefold. Approximately, one in every 250 people over the age of 50 will die of a ruptured AAA[3]. Aneurysms which involve the ascending aorta, aortic arch and descending thoracic aorta are termed thoracic aortic aneurysms. Aneurysms in these regions are prone to rupture once they reach a certain size. Fifty percent of patients who experience a rupture of a thoracic aortic aneurysm die before reaching the hospital. Furthermore, surgical repair of ruptured thoracic aneurysm carries 25-50% mortality as opposed to 5-8% mortality when such aneurysms are treated electively[4,5,6]. The method of modeling the cardiovascular system has previously been applied to the study of system pathologies by a number of authors[7,8,9,10,11]. The aortic aneurysm has primarily been probed and the earliest research was carried out by Long[12] and Morris[13] who investigated the compliance of aortic aneurysms and observed the effects of the pathology. More recent studies have used the clinical statistics to investigate the aortic aneurysms[14,15,16].

In this study, we have tried to present the cardiac pressure-volume loops for aortic aneurysms with different diameters by utilizing electronic cardiovascular modeling.

- A brief review of the electronic cardiovascular system[17]
- Performing mathematical method to present the left ventricle pressure-volume loops with the pathological data
- Comparing the loops with the relevant experimental and clinical observations in order to confirm the results

MATERIALS AND METHODS

The electronic cardiovascular system review: The equivalent model of the system including the pulsatile heart and the arterial tree are illustrated in Fig. 1. The electronic parameters are correlated to their mechanical parameters as follows: voltage (1 volt) is analogous to pressure (1 mm Hg), capacitance (1000 μF) to compliance (1 mL Pa^{-1}), resistance (1 kΩ) to resistance (1 Pa.s mL^{-1}) and inductance (1 μH) to inertance (1 Pa.s2 mL^{-1}).

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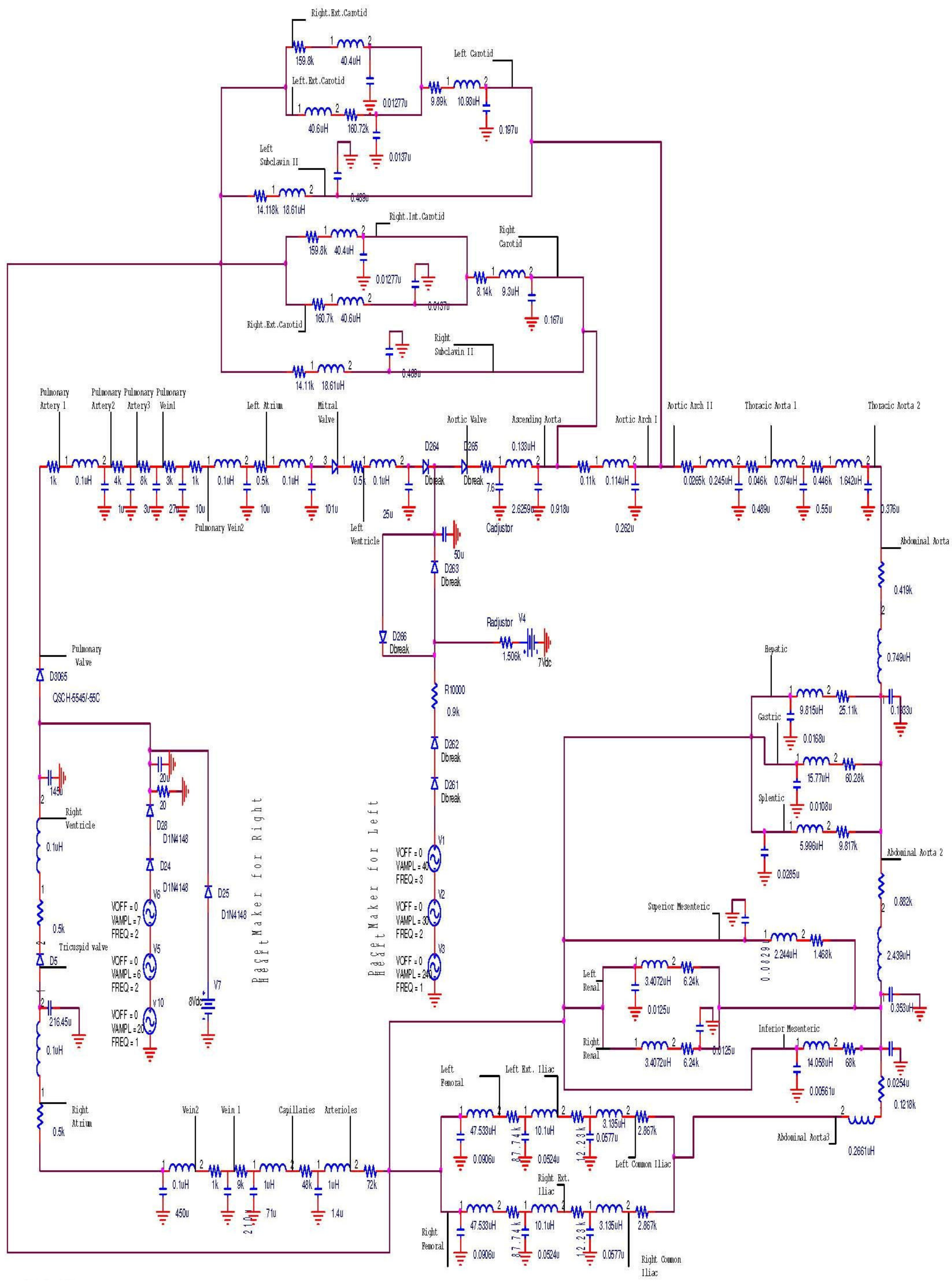

Fig. 1: Cardiovascular electronic circuit

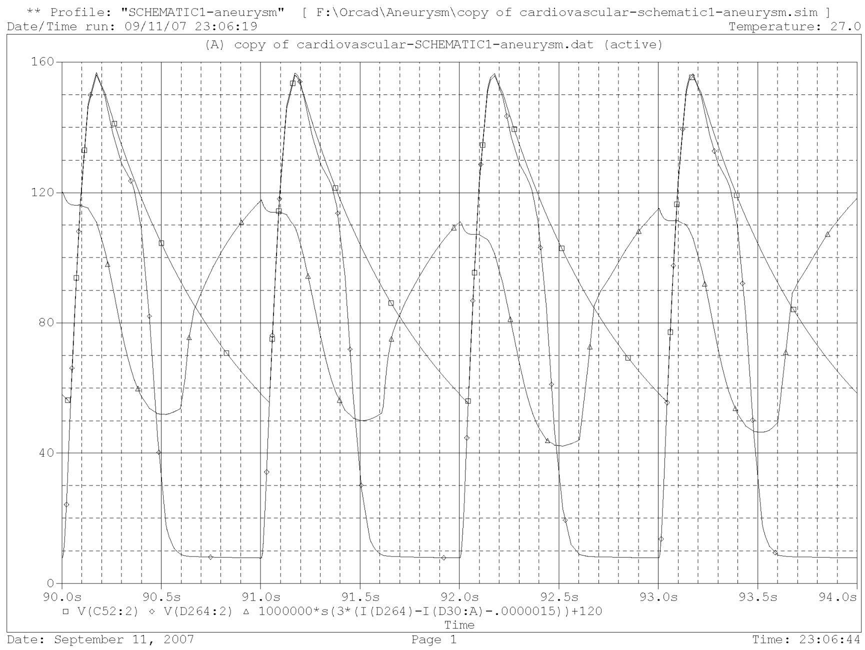

Fig. 2: Left ventricle pressure, aortic pressure and ventricle volume of 20% abdominal I aortic aneurysm in fusiform condition

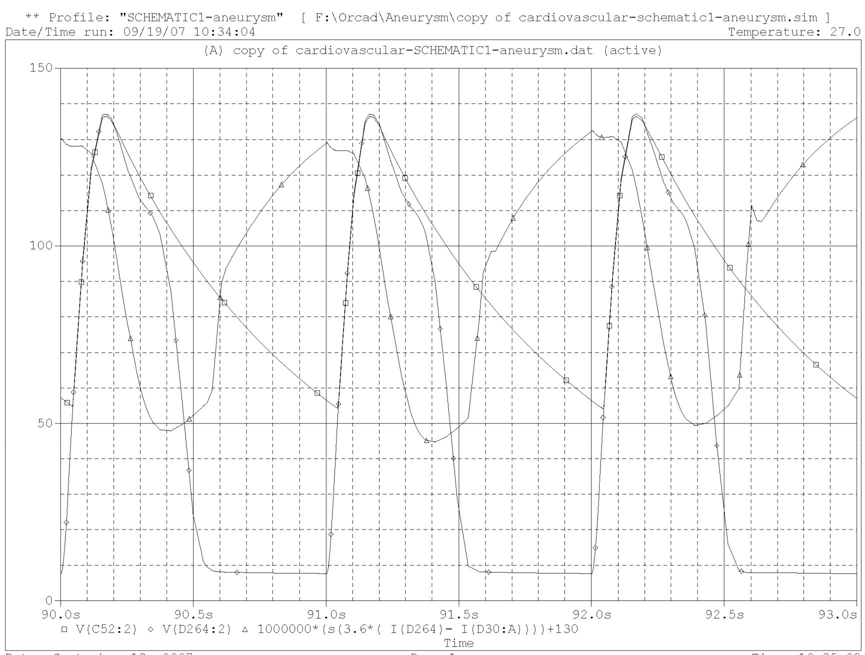

Fig. 3: Left ventricle pressure, aortic pressure and ventricle volume of 20% thoracic I aortic aneurysm in fusiform condition

Table 1: The parameters of the fusiform and saccular abdominal and thoracic aortic aneurysms with different diameter rates

Aortic Aneurysm	$\Delta P_{systole}$(Pa) (Eusiform)	$C_{aneurysm}$(mL Pa^{-1}) (Fusiform)	$\Delta P_{systole}$(Pa) (Saccular)	$C_{aneurysm}$(mL KPa^{-1}) (Saccular)	Diastole/Systole Pressure(mm Hg) (Fusiform)	Diastole/Systole Pressure(mm Hg) (Saccular)
Abdominal I (Diameter = 12.2 mm, L = 63 mm)						
20% Aneurysm	70.34	0.212	84.3	0.1985	55-150	55-155
40% Aneurysm	69.9	0.302	79	0.2038	55.2-149.7	55.3-154
50% Aneurysm	69	0.36	76.4	0.22836	56-149.7	55.2-153
70% Aneurysm	65	0.504	74.6	0.28677	56.8-148.7	56.1-152.1
90% Aneurysm	59.5	0.692	74.1	0.3587	58-148	56.8-151
Abdominal II (Diameter = 11.7 mm, L = 116 mm)						
20% Aneurysm	83.4	0.4785	87.9	0.4454	58-158	57-156
40% Aneurysm	75.73	0.805	85	0.5678	60-155	59-155
50% Aneurysm	74.8	1.0	84.2	0.6438	62-152	60-154
70% Aneurysm	62.4	1.385	83	0.745	64-148	61.5-152
90% Aneurysm	61.5	2.55	82.1	1.0625	70-147	63-150
Abdominal III (Diameter = 10.4 mm, L = 10 mm)						
20% Aneurysm	70.4	0.225	114	0.03184	55-151	55-163
40% Aneurysm	69.6	0.3099	110	0.0406	54-150	56-161
50% Aneurysm	69.1	0.362	105	0.04603	53.8-149.7	57-160
70% Aneurysm	64	0.489	100.8	0.0592	52-148	59-159.2
90% Aneurysm	58.37	0.65	97.6	0.07605	55.146	60-158.3
Thoracic I (Diameter =20 mm, L = 52 mm)						
20% Aneurysm	26.2	0.61475	-	-	53-135	-
40% Aneurysm	23.4	0.846	-	-	54-133	-
50% Aneurysm	21.9	0.9915	-	-	56-132.5	-
70% Aneurysm	21.5	1.347	-	-	56.5-132	-
90% Aneurysm	20.66	1.7984	-	-	59-130	-
Thoracic II (Diameter = 13.5 mm, L = 104 mm)						
20% Aneurysm	63.7	0.505	-	-	57-149	-
40% Aneurysm	51.05	0.918	-	-	61-147	-
50% Aneurysm	50.75	1.15	-	-	61.8-146.5	-
70% Aneurysm	44.05	1.775	-	-	66-143.5	-
90% Aneurysm	42.2	2.6259	-	-	68-142	-

The electronic model consists of forty two elements represented the left and right ventricles, systemic arteries and veins and pulmonary arteries and veins. Each element consists of a conduit for viscous blood flow characterized by a linear resistance and a volume storage element specified by a linear capacitor. The inertance of each element is featured by a linear inducer. The reference pressure is atmosphere pressure (or ground in electronic model).

The energy of systolic contraction is modeled by superposing of three voltage suppliers and two ideal diodes. The voltage suppliers vary periodically over time and are responsible. We could state the following three components in this study:

The Computerized and mathematical method: The pressure and volume graphs of the left ventricle for both normal and aneurismal conditions were obtained by using ORCAD Software. Figure 2 shows the left ventricle pressure, ventricle volume and aorta pressure graphs with 20% fusiform aneurysm in the abdominal I aorta. Also, Fig. 3 shows the left ventricle pressure, volume and aorta pressure graphs with 20% fusiform aneurysm in the Thoracic I aorta.

The fusiform and saccular abdominal and thoracic aortic aneurysms with different diameters were applied according to Table 1[18]. Figure 4 to 9 illustrate left ventricle pressure-volume with the abdominal aortic aneurysms for increasing rate of 20, 40, 50, 70 and 90%. Figure 10 and 11 illustrates left ventricle pressure-volume with both conditions of normal and the aortic aneurysms of thoracic I and II for increasing values of 20, 40, 50, 70 and 90%.

RESULTS

Figure 4 presents Pressure-Volume loops for fusiform abdominal I aortic aneurysm. The blood pressure reaches to 156 mm Hg approximately, however, the stroke volume increases nearly to 4 mL at its maximum value. Likely, the other figures represent the same stroke values. Figure 5 shows the abdominal I aortic aneurysm in saccular condition. It can be understood that maximum increase in left ventricle pressure is about 161 mm Hg.

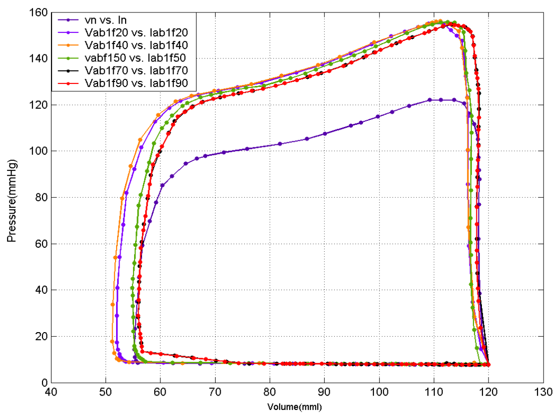

Fig. 4: Cardiac pressure-volume loops of abdominal I aortic aneurysm in fusiform condition

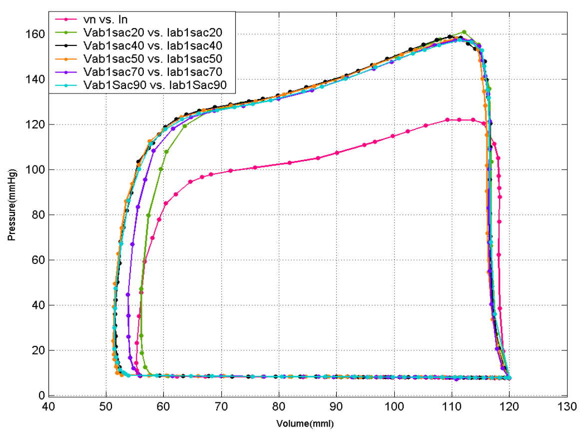

Fig. 5: Cardiac pressure-volume loops of abdominal I aortic aneurysm in saccular condition

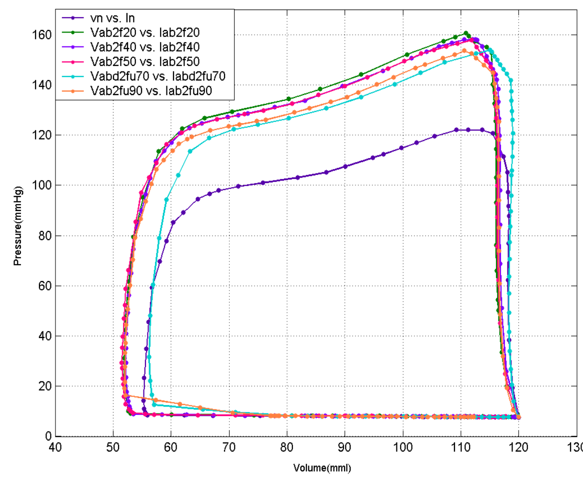

Fig. 6: Cardiac pressure-volume loops of abdominal II aortic aneurysm in fusiform condition

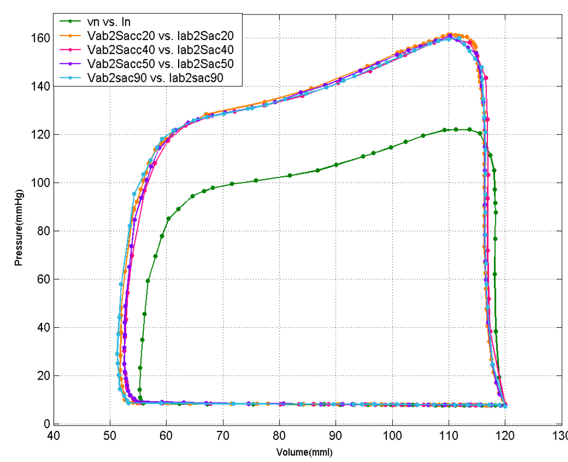

Fig. 7: Cardiac pressure-volume loops of abdominal II aortic aneurysm in saccular condition

Aneurysm of abdominal II in Fusiform condition was exihibited in Fig. 6. The blood pressure peak was demonstrated approximately 160 mm Hg. The blood pressure of saccular condition of abdominal II was similar to its fusiform condition in Fig. 7. Abdominal III aortic aneurysm in fusiform condition was presented in Fig. 8. Left ventricle Pressure reaches about 157 mm Hg. Fig. 9 shows the abdominal III aortic aneurysm in saccular condition, as it can be seen the blood pressure highest level is close to 168 mm Hg.

Figure 10 shows left ventricle diagrams for normal condition as well as thoracic I aortic aneurysm in fusiform condition with different values. As it can be clearly observed from diagram, stroke volume maximum variations in aortic aneurysm of thoracic I are about 4 mL whereas blood pressure reaches to almost 140 mm Hg at highest level.

Figure 11 presents cardiac pressure-volume diagrams for both normal and aortic aneurysm of Thoracic II in fusiform condition with different values. It can be understood that stroke volume variations are similar to thoracic I aortic aneurysm. However, the blood pressure increases to 155 mm Hg at its maximum level. Thus we can state that the increase in blood pressure which is caused by Thoracic II aortic aneurysm is higher than the one caused by Thoracic I aortic aneurysm.

We have shown that the stroke volume of the left ventricle does not change significantly due to aortic aneurysms. Furthermore, the cardiac output does not change as it has been referred by clinical observations.

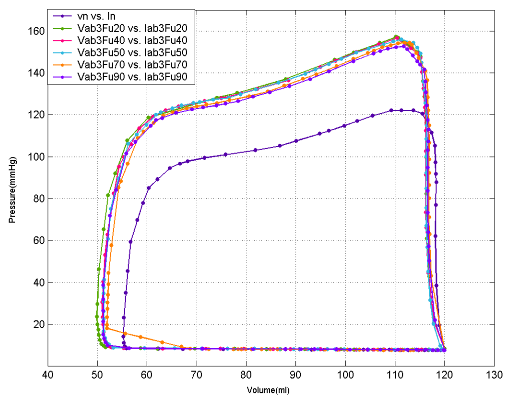

Fig. 8: Cardiac pressure-volume loops of abdominal III aortic aneurysm in fusiform condition

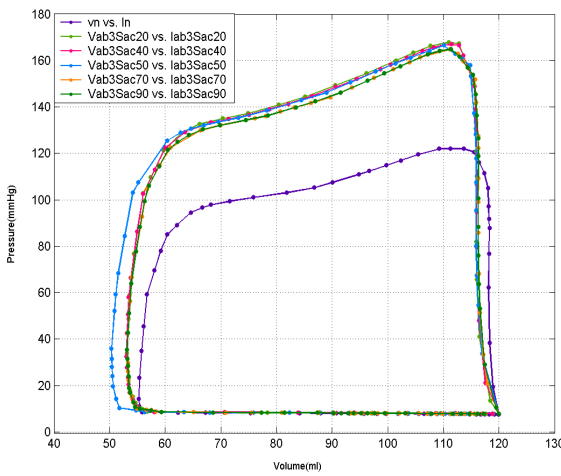

Fig. 9: Cardiac pressure-volume loops of abdominal III aortic aneurysm in saccular condition

Comparatively, there is significant increase in pressure both in thoracic and abdominal aortic aneurismal condition, therefore it can be understood that the hypertension could be principal symptom of these diseases as clinical studies can approve that[19,20,21,22].

CONCLUSION

This study has made an excellent illustration of the cardiac Pressure-Volume cycle in normal or diseased states of the living heart which indicates amount of cardiac work for physicians and scientists in order to comprehend deeply the cardiovascular system and related diseases.

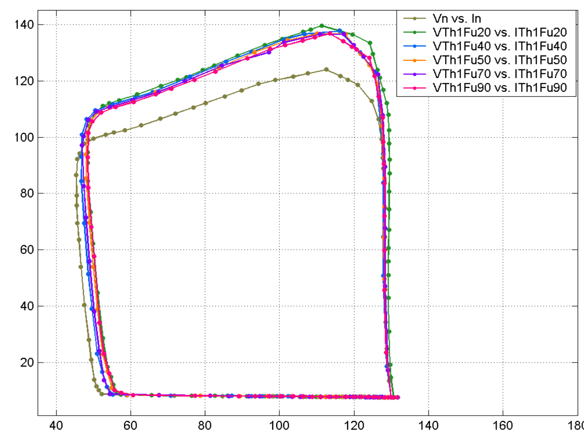

Fig. 10: Cardiac pressure-volume loops of thoracic I aortic aneurysm in fusiform condition

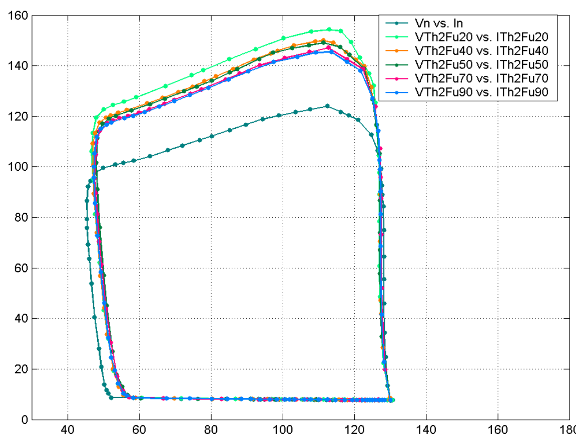

Fig. 11: Cardiac pressure-volume loops of thoracic II aortic aneurysm in fusiform condition

ACKNOWLEDGEMENT

I would like to thank Professor Stephen Wood for his kind guide for understanding the physiological concept of cardiovascular system and his early help in editing this text.

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