

# An Electrical Perspective of the Human Circulatory System Using Four Terminal Model



## Engineering

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### ABSTRACT

*Modeling in medicine plays a very important and major role. Our main research objective is to develop the electrical model of the pumping heart coupled to lumped systemic and the pulmonary circulations of the human cardiovascular system using four terminal model approach. The cardio vascular system is a very complex system and consists of four chambers, two ventricles and two atria. The ventricles are guided by a time varying elastance functions where as the two atria are passive chambers separated from the ventricles by a mitral valve and tricuspid valve. Besides, the autonomic nervous system (ANS) is responsible for the regulation of the cardiovascular system (CVS) and influences its function. Therefore the model of the cardiovascular system should describe the behavior of each subsystem and take into account the interactions between them. The rate of change of volume of blood vessel is represented by the capacitive current.*

### 1-1 Introduction:

Medicine was once largely free of mathematics, but chemical trials call for mathematical statistics, circulation of blood is a topic for the hydro dynamist, carcinogenesis is a stochastic process, genetics is riddled with advanced algebra, the administration of hospitals is a subject for operations research, a study of the central nervous system involves a knowledge of cybernetics, radiotherapy makes demands on mathematical analysis, pharmacology includes bioassays, epidemics are described in terms of partial differential equations and so on.[5]

### 1-2 An overview on the cardiovascular system

The cardiovascular system consists of *heart, blood and blood vessels* and its main role is to bring oxygen and nutrients to every living tissue in the body and to remove wastes disposed of by lungs and kidneys. The propulsion of blood is performed by the heart. [11]

Functionally the circulatory system can be divided into two parts: a greater (*systemic*) and a lesser (*pulmonary*) circulation. The deoxygenated (venous) blood from the lower and upper body travels through the great venous trunks to the right atrium and then through the right ventricle and the pulmonary artery to the lungs (pulmonary circulation). The blood is enriched with oxygen in the lungs and flows through the pulmonary veins back into the left atrium of the heart. From there it reaches the left ventricle, which pumps the blood through the aorta into the greater circulation (systemic circulation). The blood is distributed through the whole body in the larger and smaller arteries and eventually reaches the terminal vessels, the capillaries. After exchanging substances and gases in the tissues, the blood returns to the heart through the venous part of the systemic circulation.[4]

### 1-3 Mathematical Model Block Diagram of Cardio Vascular System[4]

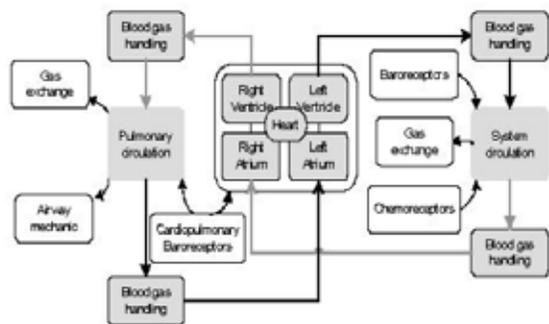


Figure 1 The model of cardiovascular control system[4]

### 2-1 Modeling of the Single Blood Vessel

The fluid dynamics of the cardiovascular system are extremely complex. Modeling it requires tools ranging from simple lumped parameters to sophisticated numerical techniques. Lumped parameter models based on an electrical circuit analogy provide a computationally simple way to obtain information about the overall behavior of the cardiovascular system. In these models, electric potential and current are analogous to the average pressure and flow rate, respectively. A particular vessel (or group of vessels) is described by means of its impedance, which is represented by an appropriate combination of resistors, capacitors and inductors. The resistors are used to model viscous dissipation, while the capacitors account for vessel compliance; the ability to accumulate and release blood due to elastic deformation. Finally, the inductors are used to model inertia terms. Regions of the vascular system can then be modeled and linked in a circuit network. These relationships are used to develop a set of nonlinear ordinary differential equations. As an example, the total resistance through a blood vessel can be computed by drawing an analogy between blood flow through an artery and current through a resistor: [6]

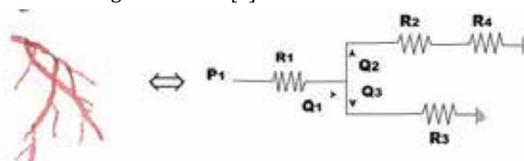


Figure 2: Analogy between blood flow through an artery and current flow through a resistor [7]

### 2-2 Four Terminal Model of the Segment of the Blood Vessel

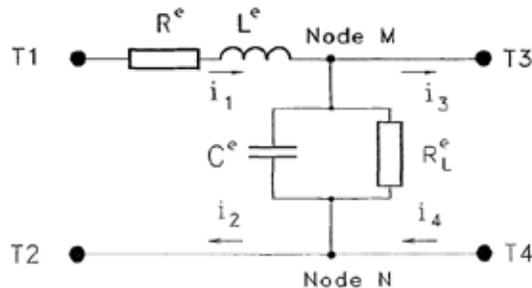


Figure 3; Four terminal model of a segment of a blood vessel[1]

In multisegment electrical models of the circulation, two or more networks are connected in series. A typical four terminal model of the segment of a vessel is shown in Fig. There,  $L^e$  is an inductor representing the inertance of blood, and  $R_L^e$  repre-

sents a leakage resistor accounting for outflow through small branches. The four-terminal network has two input terminals: T1 and T2, and two output terminals: T3 and T4. The voltages and currents in terminals T1 and T3 and node M are appropriate representations of pressure and flows in the circulation, but the currents and voltages in the return, or ground wire connecting T2, N, and T4 do not have analogues in the circulation. Indeed, similar to the two-terminal model, when the four-terminal network is powered by one generator or terminated by a two-terminal network, the instantaneous forward input flow  $i_1$  and return input flow  $i_2$  are equal in magnitude and phase. Also the instantaneous forward  $i_3$  and return  $i_4$  output flows are equal. Thus, the currents  $i_2$  and  $i_4$  do not represent the venous circulation. The parallel connection of the leakage resistor  $R_L^e$  and the capacitance  $C^e$  in node N present the same problem as the connection of the systemic resistor and the capacitance in the two-terminal model. This connection makes appear that, rather than moving to the veins, the blood leaks to the outside of the vessel.[1]

**3-1 Mathematical Model of the Cardio Vascular System:**

The model presented in this paper consists of a pumping heart coupled to lumped descriptions of the systemic and the pulmonary circulations. The heart consists of four chambers: two ventricles and two atria. The ventricles are guided by a pair of time-varying elastance functions, whereas the two atria  $la$  and  $ra$  are passive chambers separated from the ventricles via the mitral valve MV and the tricuspid valve TV. The aortic AV and pulmonary PV valves are designed to allow a small amount of volume to flow back into the left  $lv$  and right  $rv$  ventricles (from the vasculature) before closure is completed, as observed in experiments. When the left ventricular pressure  $piv$  exceeds the root aortic pressure  $pas$ , the aortic valve opens and blood flows through the characteristic systemic resistance  $RQS$  into the arterial system consisting of three sections. The pressures in the arterial system include the root aortic

pressure  $pas$  and three pressures  $pa1$ ,  $pa2$ , and  $pa^A$ . The veins are described by two sections with the pressures  $pv1$  and  $pv2$ . The veins return the blood to the passive right atrium. When the right atrial pressure  $pra$  exceeds the right ventricular cavity pressure  $prv$ , the tricuspid valve TV opens and the right ventricle is filled with blood flowing through the resistance  $Rra$ . Subsequently, blood is ejected into the pulmonary circuit through the pulmonary valve PV and characteristic pulmonary resistance  $RQP$ . The architecture of the pulmonary circuit is a replica of the systemic one.[2]

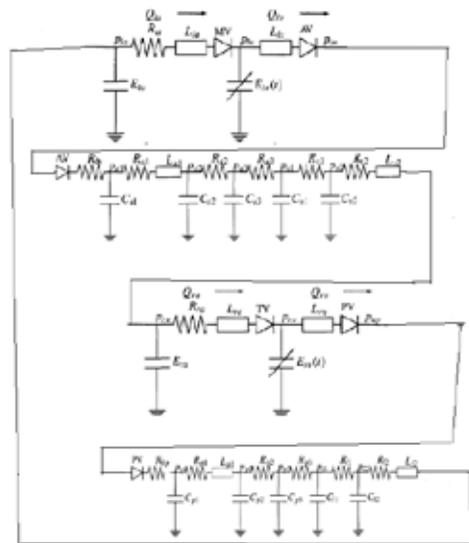


Figure 4: Electrical model of the circulatory system [2]

Conclusion: The overall mathematical model using electrical elements that is capacitor, inductors and resistors is thus studied and developed considering the pulmonary and systemic circulation.

**REFERENCE**

[1] Joshua E. Tsitlik, "Modeling the Circulation with Three-Terminal Electrical Networks Containing Special Nonlinear Capacitors", Annals of Biomedical Engineering, Vol.20, pp. 595-616, 1992, USA. | [2] Johnny T. Ottesen, Mette S. Olufsen, Jesper K. Larsen, "Applied Mathematical Models in Human Physiology", ISBN 0-89871-539-3, Siam, Society for Industrial and Applied Mathematics Philadelphia. | [3] A.A.Zadpoor, A.R. Arshi, Nikooyan, "A Bond Graph Approach to the Modeling of Fluid-Solid Interaction in Cardiovascular System's Pulsatile Flow", IEEE Proceedings of Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, 2005. | [4] Zhang Yanrul, Wu Xiaoming, Yuan Hengxin, Chen Lilin, "The Human Cardiovascular Model with the Baroreflex Control of Central Nervous System", published in IEEE/ICME International Conference on Complex Medical Engineering in 2007. | [5] Lucia MIRABELLA, "Numerical methods for cardiovascular problems: computational electrocardiology and fluid dynamics in moving domains Ph. D. course in Mathematical Engineering, 2010. | [6] J.N. Kapur, "Mathematical models in medicalsciences", Published by Taylor & Francis in International Journal of Mathematical Education in Science and Technology, in July 2006. | [7] website; ai.stanford.edu/mitul/me 382/web/spring-report 6.htm |