Hemodynamic Analysis of Pigs Coronary Microcirculation with Detailed Anatomical Data

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1. Introduction

The function of the coronary network is to supply the heart with oxygen and nutrients and remove its waste. This is critical to the overall function of the heart. Additionally, the hemodynamics of the coronary circulation shows a number of interesting phenomena. For this reason, there have been many experimental and modeling studies in order to understand factors of influencing coronary circulation. There are two general theoretical approaches to study hemodynamics. The first use the mathematical models using morphometric and elasticity data. The other uses an electric circuit analog or lumped parameter model.

The heart muscle is perfused through the right coronary artery (RCA) and the left common coronary artery (LCCA). The LCCA bifurcates into the left anterior descending (LAD) artery and left circumflex (LCx) artery. A full set of data on RCA and LCCA were recently provided by Kassab *et al.*[1]. In the present study, our objective is to analyze the coronary artery blood of the pig's LCCA using the lumping parameter method and 1-dimensional numerical simulation and to understand hemodynamic conditions according to stenosis severity.

2. Methods

2.1 Lumping parameter method

The pressure drop, resistance, and volumetric flow of the Hagen-Poiseuille equation are analogous to the voltage, electrical resistance, and current in the electrical circuit, respectively. Pspice (Simulation Program with Integrated Circuit Emphasis), the commercial software was utilized to apply the lumping parameter method. Diverse physical analyses such as analyses of the pulsatile flows as well as easy analysis of coronary artery blood were investigated using the software.

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2.2 Mathematical Modeling

In order to analyze the coronary artery flow, Kassab's symmetric model was used[2] as shown in Fig.1. The branching ratio represents a ratio of the number of parent vessels divided by that of daughter vessels. The symmetric model is physically assumed to be that all the vessel elements in any order are in parallel, and the blood pressures at all of the junctions between specific orders of vessels are equal.

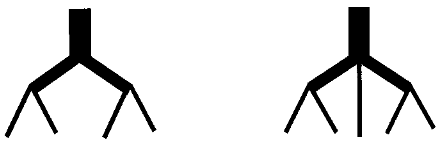
In the simplified circuit, the flow in each element of order n follows Poiseuille's equation

$$\dot{q}_n = \frac{\pi D_n^4}{128\mu_n L_n}(P_{n+1} - P_n) \tag{1}$$

in which q_n is the volumetric flow, D_n is the vessel lumen diameter, n is the coefficient of viscosity of blood, L_n is the length of the vessel element, P_n is the pressure of blood at the exit end of the vessel element, and P_{n+1} is that at the entry end of the vessel element, all in consistent unit.

In this study the new parameters of coronary compliance and blood rheology were introduced. The coefficient of viscosity was computed from Fahraeus- Lindqvist effect[3] and Albrecht et al.[4]. The second parameter, compliance is defined as the slope of the pressure -volume ($\triangle V/\triangle P$) or pressure-diameter ($\triangle D/\triangle P$) relation at any given pressure.

It was also reported that the compliance and distensibility are larger in the proximal than in the distal vasculature[5]. The compliances of the first three orders of porcine coronary arteries and epicardial capillaries were obtained in Kassab *et al*[6]. It is therefore, assu-



(a) (b)

Fig. 1 (a) Symmetric model (b) asymmetric Model

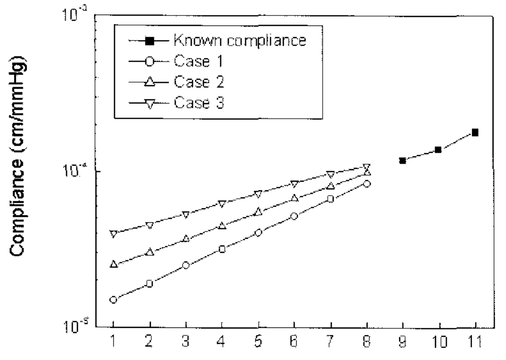


Fig. 2 Three cases of longitudinal compliance data

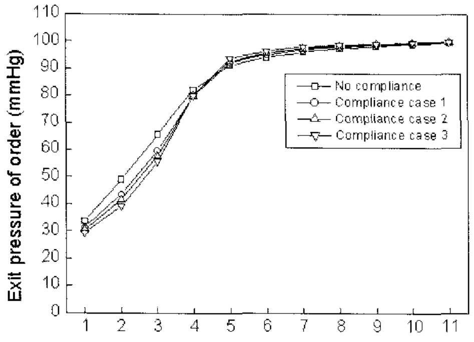


Fig. 3 Relationship between blood pressure at the exit of a blood vessel and the order number of the vessel of symmetric model for three compliance cases

med that the compliance of the other orders decreases by 22, 18, and 14 percent decrease rate per order with respect to the known compliance, respectively as shown in Fig. 2.

3. Results

The analytic solution to Eq. (1) for the symmetric model was determined. Fig. 3 shows the mean values of longitudinal pressure distributions with respect to the coronary blood flow per vessel in LCCA model. Distributions of blood pressure in coronary blood vessels show that the pressure drops in small arteries of orders 1 to 4 for three cases are larger than those of model without compliance.

The flow rates in coronary vessels are calculated according to the severity of stenosis in Fig. 4. Simulations were carried out for 30%, 50%, and 70% diameter stenosis at an order 11 blood vessel. Reduction in coronary blood flow (myocardial ischemia) may critically indicate the impairment of the mechanical beha-

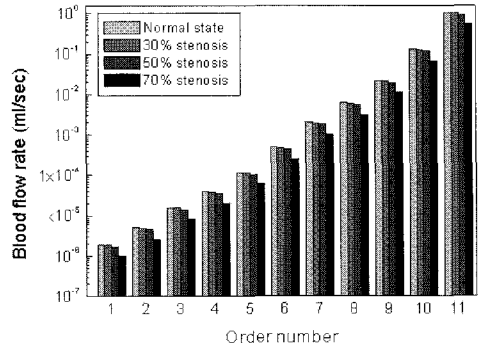


Fig. 4 Relation between blood flow per vessel element and the order number for the arterial branches of symmetric model for three degrees of stenosis

vior of the left ventricle. Nevertheless, there is intrinsic tendency of coronary circulation to maintain blood flow constant. Thus, the decreased flow due to stenosis causes the rise of aortic pressure. The increased aortic pressure may raise the wall shear stress on the surface of the stenosed vessel.

Acknowledgements

This work was supported (in part) by the Ministry of Science & Technology (MOST) and the Korea Science and Engineering Foundation (KOSEF).

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