Simulation studies of the ischemic vulnerability of the subendocardium

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Abstract—Changes in the subendo–subepi flow ratio were studied by using a simple electronic circuit model of the coronary vessel consisting of a resistor, capacitor and field effect transistor in order to provide a better understanding of the ischemic vulnerability of the subendocardium. The simulated subendo–subepi flow ratio was found to be approximately 1.2 under normal condition. Changes in the flow ratio were observed while varying the main arterial resistance, mean arterial pressure and intramyocardial pressure individually. The mean flow in the subendocardium was found to decrease at a rate faster than that in the subepicardium with the increase in the septal arterial resistance and the intramyocardial pressure. The same tendency was also observed while the arterial pressure was lowered. This decrease in the mean subendocardial flow is considered to be the effect of higher end-systolic resistance in the subendocardial venule compared to that in the subepicardial venule. These results would be helpful in understanding the vulnerability of the subendocardium to ischemia and in providing clinical treatment to patients with that disease.

Key words: Field effect transistor; dynamic simulation; coronary circulation; ischemia; subendo–subepi flow ratio.

1. INTRODUCTION

The heart propels the blood through the vascular system. It thereby maintains the delicate balance between the functions of different organs in our body by transporting nutrients and waste products. The mechanical work needed for
pumping blood is performed by the heart muscle or myocardium. When the blood flow through the myocardium, generally known as coronary circulation, is obstructed due to some obstacles to the flow, the heart loses its normal functionality and, as a result, the activities of the body are hampered. In most heart diseases, myocardial ischemia is known to be maximal in the endocardial muscle, i.e. in the innermost layer of the left ventricular wall rather than the outermost layer, known as the epicardium [1]. These ischemic events are usually associated with an absolute or relative decrease in blood flow to subendocardial muscle as compared to more superficial muscles. A subendo–subepi flow ratio of approximately 1.25 has been reported by clinical researchers conducting experiments on conscious dogs under resting physiological conditions [2]. This ratio is an important factor in determining the vulnerability of the subendocardium to ischemia and, hence, a study of the way it changes with various physiological conditions is required. We have already proposed an electronic circuit model of the coronary vessel using a resistor, capacitor and field effect transistor (FET) [3]. Using this model, we could observe the two main characteristics of the coronary vessel, i.e. dominant diastolic blood flow in the main artery and early systolic reverse in the epicardial vein [3]. In this paper, we made use of this model in order to study the causes of the ischemic vulnerability of the subendocardium by observing the changes in the subendo–subepi flow ratio with the changes in some parameters of the left coronary circulation. We assumed that the coronary vessel is collapsible at the distal end and that the collapse is gradual. We further assumed that the intramyocardial pressure is generated solely by the contraction of the cardiac muscle and in no way directly connected to the left ventricular pressure [3].

2. THE MODEL OF LEFT CORONARY CIRCULATION

The left coronary circulation system and its equivalent electronic circuit model are shown in Fig. 1a and 1b, respectively. In order to study the changes in the flow ratio, the model of the left coronary circulation was divided into two parts, i.e. the subepicardium and subendocardium. As in the real system, both of these sections consist of segments of the artery, arteriole, capillary, venule and vein. Each of these segments was constructed using the hardware circuit model of the coronary vessel [3] consisting of electronic components such as a resistor, capacitor and FET. A brief description of the FET and how it works in the model is presented at the end of this section for those unfamiliars with its characteristics. As shown in the circuit model of left coronary circulation (Fig. 1), the arterial pressure and the intramyocardial pressure in the subepi- and subendocardial layers are represented by $P_a$, $P_{mepi}$ and $P_{mendo}$, respectively, and were used as input signals to this circuit. An analogy was made between the quantitative units of the hydrodynamic systems and those of the electrical systems in order to convert the electrical units into hydrodynamic units. This analogy is shown in Table 1. In this study, we considered a conical shape of the myocardium [2] in which these vascular