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Changes of Blood Flow Characteristics due to Catheter Obstruction during the Coronary Angioplasty

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Abstract

Catheters are used to measure translesional pressure gradients in the stenosed coronary arteries. Uses of catheters during coronary angioplasty cause flow obstructions. A narrowed flow cross section with catheter effectively introduced a tighter stenosis than the enlarged residual stenoses after balloon angiplasty. Catheters in blood vessels cause pressure gradient rise and blood flow drop during the measurements. In this study, three dimensional computer simulations are conducted to investigate the flow blockage effects due to the catheter obstructions during the coronary angioplasty. The computer simulation models are generated by the data, which are measured by coronary angiogram, and the blood is treated as non-Newtonian fluid. The velocity, pressure, and wall shear stress variations are observed for the estimate of damages of blood vessel. This study is also extended to investigate the effects of stenotic vessel size, and shape and catheter size and location.

Key words: Catheter, Insertion, Pulsatile Flow, Stenosis, Blood Flow Characteristics

Introduction

As Korea are joined the ranks of advanced countries, a general person or a medical personnel's interest in Korea become larger about a geriatric diseases. These interests are increased due to the rapid Internet's tremendous popularity, and general people have been widely understanding about geriatric diseases. [1,2]

Additionarly, in the Korea as the standard of living were followed highly and the income came to be high with the Western society, the disease incidences increased together a lot. For the case where the person appeals the pain of the breast, the stenosis of the coronary artery sees with area ratio is the case which 70% over is already advanced. With relation diseases of the stenosis inside the coronary artery, namely angina pectoris and the myocardial infarction et al., there are is three methods to remedy these diseases. In these methods, the treatment for dispense drug is easily used.

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However, it is impossible to treat with the drug, when being judged that the intervention and the surgical operation is required. The balloon angioplasty, one of the mainly used methods for the intervention, is to measure the hemodynamic characteristics, translesional pressure gradient in various blood vessels using the catheter. After the stenosed vessel is enlarged or remodeled with the balloon or the stent, the balloon angioplasty operation is completed.[3,4]. Thus, the use of the catheter is very important for clinical side. So, many medical teams use it for a long time. The use of the catheter in a large coronary artery presents no particular problems. However, as the inner diameter of the artery approaches the size of the catheter (1.4 mm), blood flow is disrupted by the presence of the catheter and blockage effect occurs. Currently many researches are in progress to gain more information on changes in blood flow characteristics, phase relationships, and amplitude variation of the mean pressure caused by catheter obstruction.[5].

In order to investigate the of the occurred on blood flow blockage effect in the study, three-dimensional computational model of the stenotic coronary artery is idealized and constructed with velocity waveform collected from clinical data, and numerical analyses are focused on the variation of blood flow characteristics and the effects of catheter obstruction in the stenoted coronary artery.

Governing Equation

In order to investigate the blood flow characteristics with an angioplasty catheter in numerical analysis, the following equations were used to simulate unsteady and incompressible blood flow.

$$\frac{\partial u_j}{\partial x_j} = 0 \qquad (1)$$

$$\rho\left(\frac{\partial u_i}{\partial t} + u_j\frac{\partial u_i}{\partial x_j}\right) = -\frac{\partial p}{\partial x_j} + \eta\frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \qquad (2)$$

where ρ, u_i, p, η are density, velocity vectors, pressure and apparent viscosity, respectively. Velocity and pressure distribution of the blood and wall shear stresses within the vessel were then numerically calculated from the above equation (1) and (2). Carreau model of equation is used to represent apparent viscosity of blood in unsteady flow within a stenotic coronary artery.[5,6]

A HYBRID difference method is adapted for discretization of convective term in the governing equations representing pulsatile movement of blood in stenotic coronary artery. Discretization of pressure terms in the momentum equation was obtained from discretization equation of the continuity equation that took into account of the relationship between the pressure and the velocity vector by applying SIMPLE-C algorithm. Outlet condition is assumed to be pressure boundary condition.[7]

Stenotic Coronary Artery Model and Shape of Catherter

The shape of is very complicated. The use of catheters during coronary angioplasty in the stenosed coronary artery is as shown on Fig. 1[3]. In this case, the ratio of stenosis(stenosis throat area/inlet area) is approximately 65%. Fig. 1 shows magnitude of catheter probe in blood vessel, and centerline of the catheter is well corresponded with that of the blood vessel.

The wave velocity distributions in the left coronary artery are quite different from those in the aorta, showing systolic-diastolic pattern of a cardiac cycle. During systole blood flows out from the left ventricle toward the aorta and the coronary arterial sinus is occluded so that blood flow decreases in the coronary artery. During diastole with the coronary sinus being opened, blood flows in the left coronary artery. It is very important to differentiate the velocity waveform of the coronary artery from that of aorta. In order to comprehend the flow characteristics of blood in the coronary artery, more suitable waveforms of velocity and pressure for diastolic and systolic coronary flow should be employed. The inlet velocity waveform of the physiological coronary blood flow, which is quite different from that of the aortic flow, is represented in Fig. 2.

The present study aims to examine the effect of blockage by the catheter on coronary artery for 4 types of insert location of catheter as shown on Fig. 3. In the Fig. 3(a), CASE 1 showed when catheter was inserted into the stenosis region. Second case (Fig. 3(b)) in throat area of stenosis region. Third case (Fig. 3(c)) is when passing the throat area. In fourth case (Fig. 3(d)), catheter is inserted until fully passing the stenosis region.

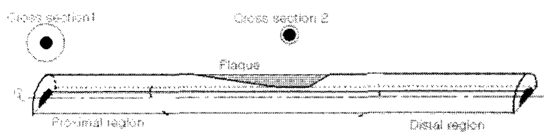


Figure 1. Geometrical configuration of the stenotic coronary artery

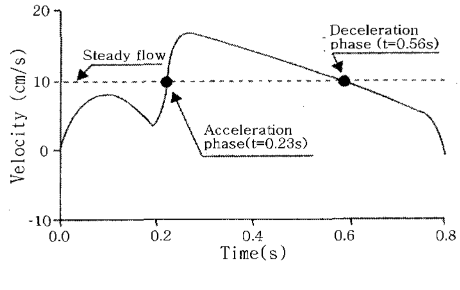
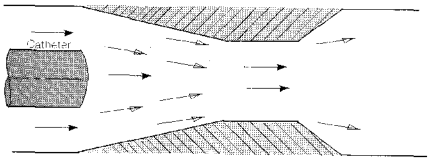
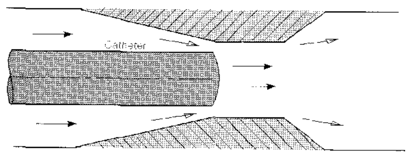


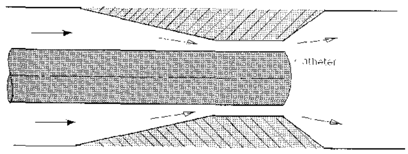
Figure 2. Physiological waveform of phasic coronary blood flow



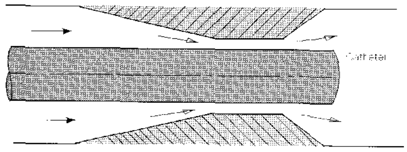
(a) Case 1



(b) Case 2



(c) Case 3



(d) Case 4

Figure 3. Inserting positions of catheter in the stenosed coronary artery

Results and Discussion

Hemodynamic characteristics variations with insertion of catheter

In the Fig. 4 and Fig. 5, it is investigated the variation of velocity and pressure in the centerline of the stenoted blood vessel for the fully insertion of catheter case as shown on Fig. 3 (d) and case of without catheter for the acceleration and the deceleration phase.

For the Figs 4 and 5 the maximum velocities for the catheter-inserted case are 4.8 times as long as those in acceleration phase and 2.8 times as long as those in deceleration phase of those without catheter case, respectively. Also, It is found those maximum pressure drops are than 10 times as long as those in acceleration phase and 2 times as long as those in deceleration phase of those without catheter case, respectively.

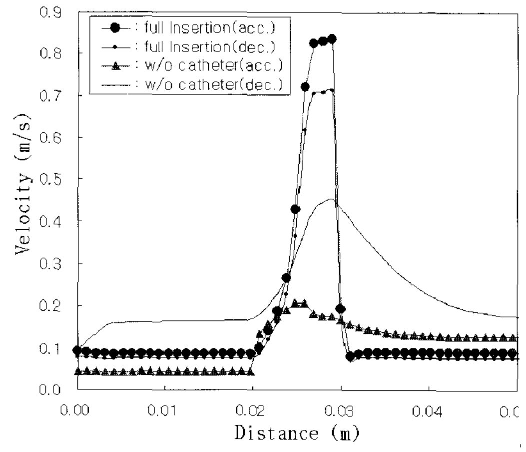


Fig. 4 Velocity variations along the centerlines in the stenosed coronary artery

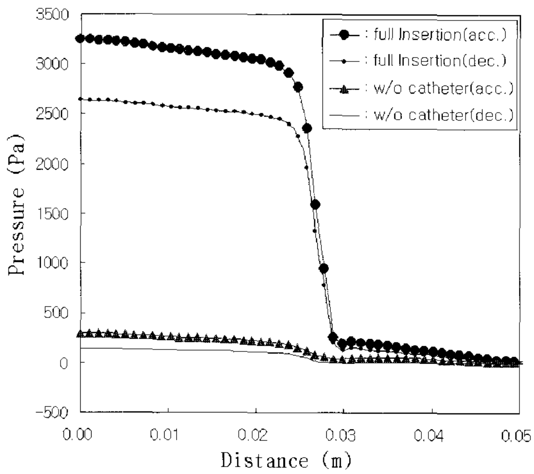


Fig. 5 Pressure variations along the centerlines in the stenosed coronary artery

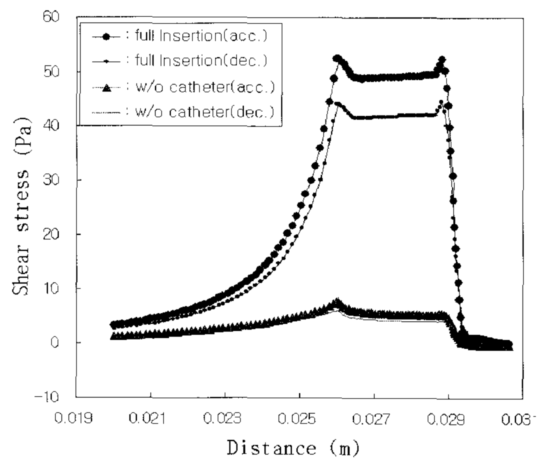


Fig. 6 Wall shear stress variations along the outer wall of the stenosed coronary artery

It is found that 10 times of blockage effects occurred due to the catheter insertion in the small stenosed coronary vessel, which is similar with diameter of the catheter. Such results could be examined at variation of wall shear stresses as shown on Fig. 6. Therefore, increases of wall shear stresses by rapid inserted catheter are strongly presses down on harden stenosed areas. Thus, the morphology of atherosclerotic plaque were crushed and ruptured by the increased wall shear stress. It is might be possible that the fragments of plaque are transported to distal site of blood vessel and prevented from blood flow.

Hemodynamic characteristics variations with location of catheter insertion

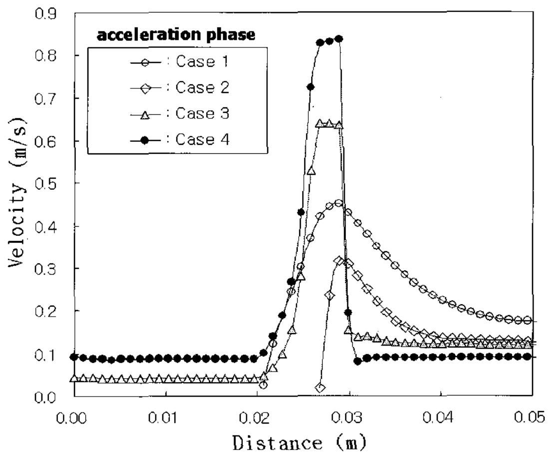
In the 4.1 clauses, it was found that the velocity, the pressure and the wall shear stresses are rapidly increased by the inserted catheter. However, it is not abrupt inserted to catheter. Real insertion is progressively executed such as shown in Fig. 3. Thus, the pressure and the wall shear stress will be varied with the changes of flow pattern by repeating acceleration and deceleration phase and the decreased shape for diameter of blood vessels by the inserting catheter. But in this study didn't consider that the catheter is located on all coronary artery on real time. It is indicated the variation of velocity, pressure drop, wall shear stress and apparent viscosity at the most clinical point of view in Figs 7～11.

In Fig. 7, the variations of velocity for the acceleration and decelerationphase are increased with inserted catheter into the stenosed section. However, the reason for velocity variations of Case 1 is greater than those of Case 2 are occurred in separation region at frontal catheter area with inserted catheter

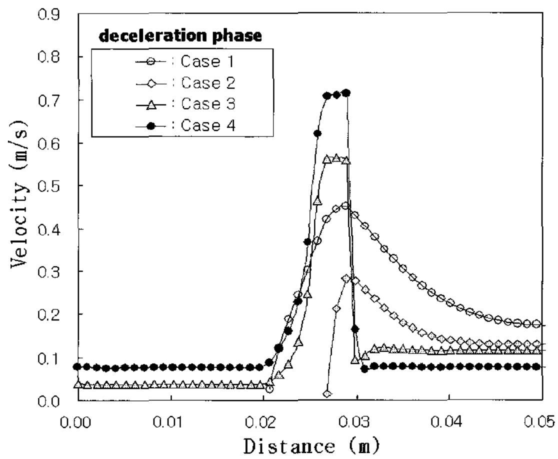
Increased velocity is brought the increase of pressure drop shown on Fig. 8. For the acceleration and deceleration phase, the pressure drops are increased as catheter inserted into all stenosed site. Especially, magnitude of pressure drop is more than twice when the catheter is passing the stenosed site, where between the Case 2 and the Case 3. Thus, these tendencies are could be interrupted the blood flow for intervention operation. In order to investigate the effect of inserted catheter, pressure coefficient($\Delta p / 0.5 \rho U_m^2$) is calculated and compared with 4 types of Cases in the Fig. 9. In the Fig. 9, the largest case of pressure coefficient is inserting the catheters into stenosed site more than fully inserted the catheters into stenosed site.

In order to investigate the viscosity variation of each Case with acceleration and deceleration phase, the variation of apparent viscosity was shown in Fig. 10.

The apparent viscosities of each case have constant value before stenosed region. After passing the stenosed region, it showed the increasing tendency. The reason is the velocity gradient is reduced from the recirculation or flow separation region before inserted catheter into stenosed region. After catheter was fully inserted stenosed region, the apparent viscosities of each case have constant value.

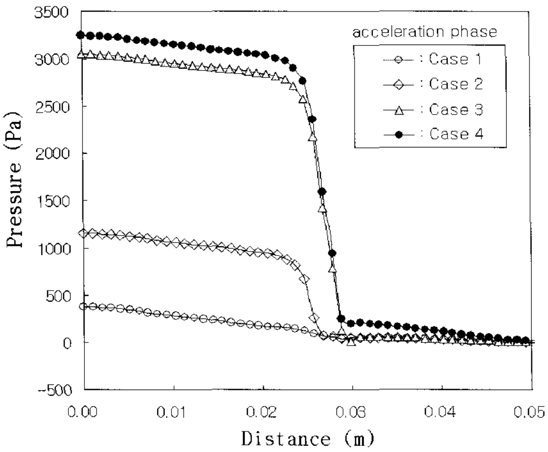


(a) acceleration phase(t=0.23s)

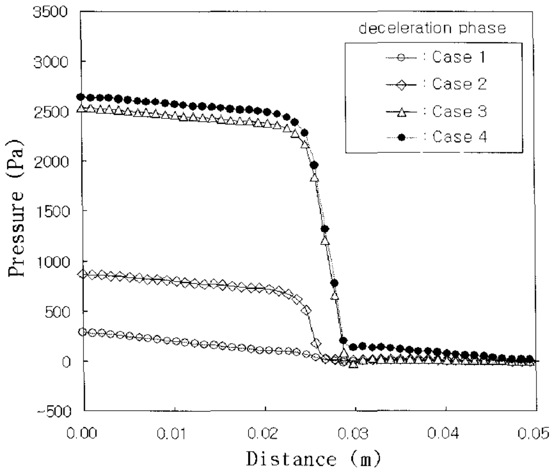


(b) deceleration phase(t=0.56s)

Figure 7. Velocity variations along the centerline for different inserting cases in the stenosed coronary artery



(a) acceleration phase(t=0.23s)



(b) deceleration phase(t=0.56s)

Figure 8. Pressure variations along the centerlines for different inserting cases in the stenosed coronary artery

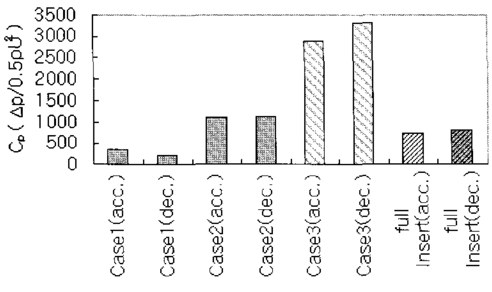
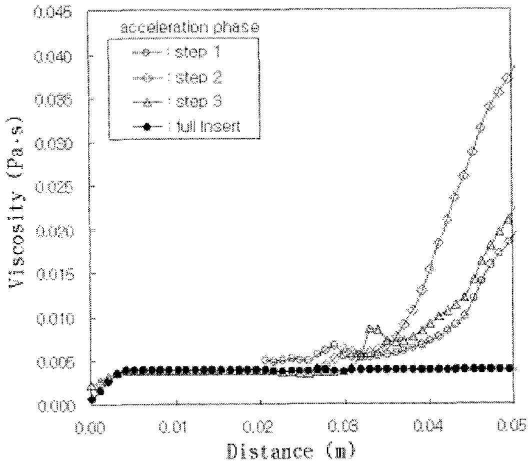
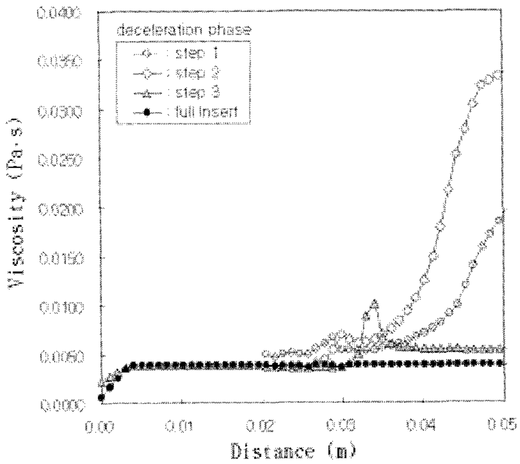


Figure 9. Comparison of Cp for different inserting positions

The all shear stress variations along the outer and inner walls for different inserting cases in the stenosed coronary artery are depicted in Fig. 6. As shown in the figure, it has shown only the wall shear stresses of outer



(a) acceleration phase(t=0.23s)



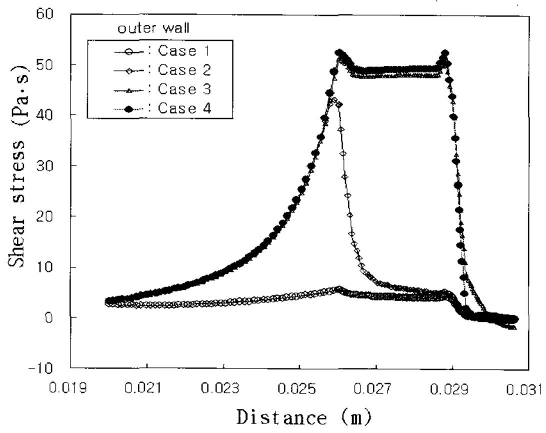
(b) deceleration phase(t=0.56s)

Figure 10. Viscosity variations along the centerlines for different inserting cases in the stenosed coronary artery

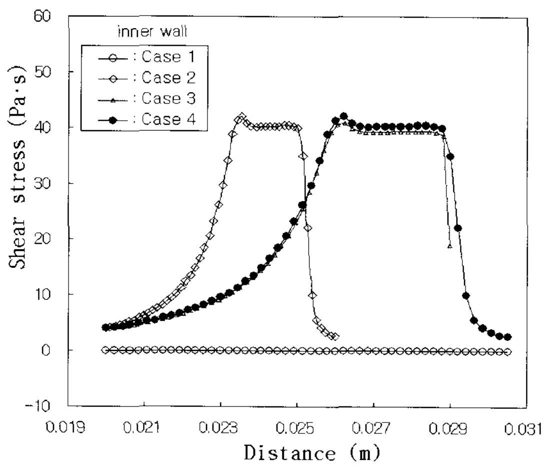
wall for acceleration phase and those of inner wall for deceleration phase. As illustrated before clauses, catheter was inserted into stenosed region, the wall shear stress are rapidly increased. For the inner wall, the value is on the wall of the catheter. And as the catheter is continuously inserted into the stenosed region, the value is decreased.

Conclusions

The blood flow characteristics in the stenotic coronary artery due to the catheter insertion are studied by computer simulation. The these results are summarized as follow;



(a) outer wall



(b) inner wall

Figure 11. Wall shear stress variations along the outer and inner walls for different inserting cases in the stenosed coronary artery

(1) The maximum velocities for the catheter-inserted case are greater than 4.8 times for acceleration phase and 2.8 times for deceleration phase of those without catheter case, respectively. Also, It is found those maximum pressure drops are than 10 times for acceleration phase and 2 times for deceleration phase of those without catheter case, respectively.

(2) The approximately maximum 10 times of blockage effects occurred due to the catheter insertion in the small stenosed coronary vessel, which is similar with diameter of the catheter.

(3) The magnitude of pressure drop is more than twice when the catheter is passing the stenosed region, where between the Case 2 and the Case 3.

(4) The largest case of pressure coefficient is inserting the catheters into stenosed region more than fully inserted the catheters into stenosed site. Thus, these tendencies are could be interrupted the blood flow for intervention operation and it also shown suddenly abnormal symptoms

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