Numerical simulation of pulsatile flows in curved stenosed channels

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Abstract : Spatial and temporal variations of the hemodynamic features occur under pulsatile conditions in complex vessel geometry. Wall shear stress affected by the disturbed flow can result in endothelial cell dysfunction, which leads to atherogenesis and thrombosis. Therefore, detailed understanding of the hemodynamic characteristics in a curved stenosed channel is highly important when examining the pathological effects of hemodynamic phenomena on the progression of atherosclerosis. Distributions of wall shear stress and 3D vortex in the curved stenosed channels were estimated by conducting the numerical simulation. These results indicate that the curvature of the tube considerably influences the skewness of the flow, and the shear stress is intensified near the outer curvature wall due to centrifugal force. The results would be helpful in understanding the effects of geometrical factors on plaque rupture and severe cardiovascular diseases.

1. Introduction

Cardiovascular diseases (CVDs) such as atherosclerosis are a leading cause of death. Atherosclerosis is a complex disease characterized by thickening of the intima (plaque). In many previous studies, it has been suggested that hemodynamic and hemorheological features are closely related to cause, progression, and prognosis of atherosclerosis. Specifically, low and high wall shear stress (WSS) are related with the atherosclerosis.[1, 2]

Stenotic geometry produces regions with high and low WSS, flow separation, and recirculation.[3] Thus, investigation of the geometric structures and hemodynamic features is important to understand the roles of WSS on CVDs, including the development of secondary stenosis.[4] Previous studies have investigated the fluid characteristics around the curvature under pulsatile flows or in curved channel with stenosis in steady flows. However, the results under steady flow conditions are quite different from those under pulsatile conditions when the flow passes through the stenosed channels. In this study, numerical simulation was carried out to estimate the distributions of velocity and WSS and the 3D vortex structures in the curved stenosed channels.

2. Method

The numerical solutions of the fluid flow equations were carried out using CFX 16.1 (ANSYS, Inc., USA). Three types of stenosed models have 50% severity with different bend angles (0˚, 10˚, and 20˚) between the longitudinal axes at the upstream and downstream of the stenosis.[5] The vessel walls were assumed to be rigid. In this analysis, the flow was regarded as laminar and pulsatile flow with average Re = 160. Reynolds number was calculated

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using time-averaged velocity and the relevant Womersley number is 23. Open conditions with a relative pressure of 0 Pa was employed at the outlet of the channel. No-slip condition was applied to every wall. To minimize the influence of initial flow conditions, all simulations were carried out for eight cycles.

3. Results and discussion

The pulsatile flow characteristics were analyzed using numerical solutions for the straight and curved stenosed channels. As shown in Fig. 1, distribution of WSS appears differently depending on the geometry of the channel. In all cases, high WSS appears around the stenosis apex. However, in the 20° channel, noticeably high WSS also occurred at the outer wall. It means the high WSS occurred not only near the stenosed throat but also at the outer wall. As the bend angle increased, the axial flow became more skewed toward the outer wall due to centrifugal force. As a result, asymmetrical flow structures occurred in the curved models, while symmetrical flow structures occurred in the straight model. It means the centrifugal force resulting from the curved geometry induces skewed flow toward the outer curvature wall. Such asymmetrical WSS in a curved stenosed channel may be associated with thinning of fibrous cap, instability of the plaque, and eventual rupture associated with increased risk of heart attacks or stroke.

Acknowledgments

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (MSIP) (NRF-2016R1C1B 2014255)

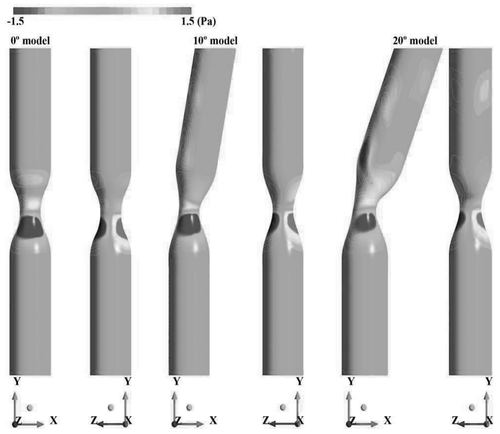

Fig. 1 The distribution of wall shear stress in 0°, 10° and 20° models with 50% severity stenosis

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