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Non-Newtonian Effect on Hemodynamic Characteristics of Blood Flow in Stented Cerebral Aneurysm

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Abstract. Stent placement is considered as a promising and minimally invasive technique to prevent rupture of aneurysm and favor coagulation mechanism inside the aneurysm. Many scholars study the effect of the stent on blood flow in cerebral aneurysm by numerical simulations, and usually regard blood as the Newtonian fluid, blood, however, is a kind of non-Newtonian fluid in practice. The main purpose of the present paper is to investigate the effect of non-Newtonian behavior on the hemodynamic characteristics of blood flow in stented cerebral aneurysm with lattice Boltzmann method. The Casson model is used to describe the blood non-Newtonian character, which is one of the most popular models in depicting blood fluid. In particular, hemodynamic characteristics derived with Newtonian and non-Newtonian models are studied, and compared in detail. The results show that the non-Newtonian effect gives a great influence on hemodynamic characteristics of blood flow in stented cerebral aneurysm, especially in small necked ones.

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Key words: Cerebral aneurysm, lattice Boltzmann, non-Newtonian fluid, Casson model.

1 Introduction

Cerebral aneurysms are localized dilation or ballooning of the brain blood vessel caused by disease or weakening of the walls. They are particularly dangerous for the risk of permanent brain damage, disability or death when they rupture. A new therapy to treat aneurysm is implanting a porous stent across the neck of the aneurysm, which is viewed as a promising and minimally invasive treatment modality. Many hemodynamic factors,

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such as flow patterns, velocity and wall shear stress, are thought to play an important role in the pathogenesis and treatment of cerebral aneurysms [1].

Some studies have investigated the effect of the stent on hemodynamics by experimental methods [2–4]. Lieber et al. [2] investigated the influence of the stent filament size on the intra-aneurysmal flow dynamics in a sidewall aneurysm model *in vitro* using particle image velocimetry. Their results showed that stenting significantly reduces intra-aneurysmal vorticity and the reduction of mean flow circulation varies depending on the strut diameter. Liou et al. [3] investigated the effect of stent shapes (helix versus mesh) on the changes of intra-aneurysmal hemodynamics. They found both stents can induce favorable changes in the intra-aneurysmal flow stasis as well as direction and undulation of wall shear stresses, but the helix stent was more competitive.

Compared to experimental studies, more numerical works examining stent effects on hemodynamics also have been carried out in the past years [5–7]. Aenis et al. [5] conducted a finite element simulation of stented and nonstented aneurysm models in a three-dimensional configuration. The results of the stented versus the nonstented model showed a significant diminution of flow activity inside the stented aneurysm pouch. A high-pressure zone at the distal neck and the dome of the aneurysm prior to stenting decreases after stent placement. Hirabayashi et al. [6] investigated the effect of the stent structure and its positioning on hemodynamics using lattice Boltzmann method (LBM), and found the effects of strut diameter, positioning and aneurism geometry must be taken into account to fully quantify the role of the stent. Appanaboyina et al. [7] studied the effect of stent design, treatment options, stent positioning and partial stent modeling, demonstrated that their methodology based on unstructured embedded grids was useful in simulation of intracranial aneurysm stenting.

The aforementioned studies have provided valuable information on the flow in stented aneurysms, however, most of them assume blood flow to be a Newtonian fluid. It is well accepted that blood behaves as a Newtonian fluid in large arteries where the shear rates above 100 s^{-1} [8]. Nevertheless, the non-Newtonian effect may become important in aneurysms, especially in stented aneurysms with stagnant flow and low shear rates. Some studies have investigated the non-Newtonian effect on hemodynamics in nonstented cerebral aneurysm [9–11]. Bernsdorf et al. [9] simulated blood flow in cerebral aneurysms with lattice Boltzmann method, and showed that there was an overestimation of the wall shear stress results when the non-Newtonian effects were neglected. According to hemodynamic analysis of cerebral aneurysm models with realistic anatomies using Newtonian and non-Newtonian approximations, Cebral et al. [10] showed that the main flow characteristics are not significantly affected by the viscosity model. The results of Fisher and Rossmann's work [11] on the effect of non-Newtonian behavior suggested the blood's non-Newtonian behavior was considerable, but they were not as significant as various aneurysm morphologies, thus the assumption of Newtonian blood is quite reasonable. Furthermore, for stented aneurysm, Kim et al. [12] studied the effect of stent porosity and stent strut shape with a non-Newtonian fluid model for blood, but without a systematic comparison between Newtonian and non-Newtonian blood model.