Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **10**, No. 1, pp. 62-76

DOI: 10.4208/aamm.OA-2016-0146
February 2018

Numerical Simulation of Interaction Between Red Blood Cell with Surrounding Fluid in Poiseuille Flow

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Received 14 October 2016; Accepted (in revised version) 3 May 2017

Abstract. In this research, motion and deformation of a red blood cell (RBC) in a microchannel with stenosis is investigated by combined Lattice Boltzmann-Immersed Boundary method. The fluid flow occurs due to the pressure difference between the inlet and the outlet of the microchannel. The immersed boundary algorithm guaranteed that there is no relative velocity between the RBC and fluid. Therefore, mass transfer along the immersed border does not occur. It can be seen that the healthy RBC has more deformation and passes the stenosis easier while the sick one passes the stenosis with less deformation and returns to its initial state faster. Increasing the pressure gradient (i.e., increasing Reynolds number) would cause more deformation of the RBC. It is found that a healthy RBC moves faster than a sick one along the microchannel. Blood pressure increases due to the presence of stenosis and low deformable RBCs.It is the reason of many serious diseases including cardiovascular diseases. The results of this paper were compared to the previous valid results and good agreements were observed.

AMS subject classifications: 74F99, 76M25

Key words: Interaction, Poiseuille flow, lattice Boltzmann method, numerical simulation.

1 Introduction

Blood is a non-homogeneous fluid that mainly consists of blood cells, plasma, and nutrients. Blood circulation in microvessels delivers oxygen and nutrients to living tissues and removes metabolic wastes. Red blood cells (RBCs) have biconcave discoid shapes of 8 m diameter and form 40 to 45% of the blood volume [1]. When the diameter of RBCs are comparable with the vessel dimensions of capillaries, the co-interaction of RBCs and the interaction between RBCs and plasma significantly affects the overall properties of

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blood [2]. For instance, the deformed shape of blood cells or the changes in plasma viscosity is a symptom of various diseases, such as acute myocardial infarction, malaria, and sickle cell anemia [3–5]. The RBC membrane can undergo large deformations and the cell shape is squeezed to a diameter of 3m while flowing through the vessel. Deformed RBCs may increase blood viscosity and flow resistance, thus resulting in myocardial infarction and apoplexy [6].The circulation phenomenon can be aggravated under the presence of a pathological condition such as stenosis inside the microvessel, such as stenosis [7,8].

Recently, the lattice Boltzmann method (LBM) in combination with IBM has been used for simulating the motion and deformation of elastic bodies immersed in fluid flow including red blood cells (RBCs). The LBM is fast, accurate, relatively simple, compatible with the desired geometries and highly parallelizable. Zhang et al. [9,10] studied the dynamic behavior of RBC in shear flow and channel flow and investigated several hemodynamic and rheological properties, using a combination of LBM and IBM.. Cheng et al. [11] have proposed a proper model to simulate the fast boundary movements and a high pressure gradient occurred in the fluid-solid interaction. In their research mitral valve jet flow considering the interaction of leaflets and fluid has been simulated. Navidbakhsh and Rezazadeh [12] carried out a numerical study on the behavior of malaria-infected RBC. Vahidkhah and Abdollahi [13] simulated the motion of a massless elastic object in a two-dimensional viscous channel flow numerically using IBM-LBM. Dadvand et al. [14,15] investigated numerically the motion and deformation of a RBC in a viscous shear flow utilizing a combined LBM-IBM. Due to the advances in micro-machine technology, experiments have been done on RBCs in a micro-channel with constriction [16–18]. Eggleton and Popel [19] combined immersed boundary method (IBM) with finite element method to simulate three-dimensional deformation of a RBC in a shear flow. Pozrikidis [20] has used boundary integral method to study motion and deformation of RBCs in the shear flow and the flow in the channel. Zhao et al. [21] have studied the time variations of RBCs deformation and flow resistance in the stenosed microchannels having a diameter less than 10μm, using boundary integral method. Sun and Munn [22,23] have studied RBC deformation of two-dimensional RBC in a 20-40μm channel using lattice Boltzmann method (LBM). They modeled the RBCs as two-dimensional solid particles. Bagchi [8] simulated a suspension containing multiple cells in the range of vessel size 20-30μm and discharge hematocrit 10-60%, using IBM. Wang et al. [24] have used IBM with a spring model for simulating the blood flow in vessels with 8-11μm diameter and discharge hematocrit 10-41%. They have also studied hydrodynamic hemorheologic properties such as umbrella shaped cells, flat velocity profile and Fahraeus effect. Xiong [25] used LBM-IBM to examine changes in the wall shear stress induced by RBC passing through micro-channel with 5-11μm diameter. Li et al. [26] have used LBM for two-dimensional simulating of rigid particle suspensions in a stenosed microchannel. Hyakutake [27] conducted a two-dimensional simulation of the stenosed microvascular flow with rigid RBCs assuming primary pulmonary hypertension due to the stenosis of lung arteriole using LBM.

In the present article, motion and deformation of both healthy and sick RBC is inves-