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Numerical Simulation of Red Blood Cell Suspensions Behind a Moving Interface in a Capillary

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Abstract. Computational modeling and simulation are presented on the motion of red blood cells behind a moving interface in a capillary. The methodology is based on an immersed boundary method and the skeleton structure of the red blood cell (RBC) membrane is modeled as a spring network. As by the nature of the problem, the computational domain is moving with either a designated RBC or an interface in an infinitely long two-dimensional channel with an undisturbed flow field in front of the computational domain. The tanking-treading and the inclination angle of a cell in a simple shear flow are briefly discussed for the validation purpose. We then present and discuss the results of the motion of red blood cells behind a moving interface in a capillary, which show that the RBCs with higher velocity than the interface speed form a concentrated slug behind the moving interface.

AMS subject classifications: 65M60, 76M10, 76Z05

Key words: Red blood cells, moving domain, immersed boundary method.

1. Introduction

The rheological property of the red blood cells (RBCs) is a key factor of the blood flow characteristics at the microchannel level, especially the particulate nature of the blood becomes significant when studying blood drop through a glass capillary within miniature blood diagnostic kit. The penetration of the blood suspension in a perfectly wettable capillary has been analyzed in [1, 2]. The failure of such penetration is attributed to three RBCs segregation mechanisms: (i) corner deflection at the entrance, (ii) the intermediate deformation-induced radial migration and (iii) shear-induced diffusion within a packed slug at the meniscus. The key mechanism responsible for penetration failure is the deformation-induced radial migration, which endows the blood cells with a higher velocity than the meniscus to form the concentrated slug behind the

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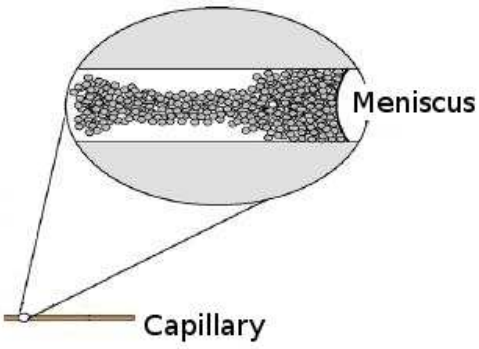

Figure 1: Schematics of the BRCs moving behind a meniscus.

meniscus (see Fig. 1). The results in [1,2] shed light on making the smallest microfluidic kit and loading microneedle that require the least amount of blood sample.

Nowadays *in silico* mathematical modeling and numerical study of RBC rheology have attracted growing interest (see, e.g., [3,4]). The immersed boundary method developed by Peskin, e.g., [5–7], has been one of the popular methodologies for numerically studying the RBC rheology due its distinguish features in dealing with the problem of fluid flow interacting with a flexible fluid/structure interface. For example, in [8–17], immersed boundary methods have been combined with different RBC membrane models to simulate the motion of RBCs and vesicles in fluid flow. We have successfully combined an immersed boundary method with a spring model developed in [18] to simulate the motion of RBCs in shear flows and Poiseuille flows in [15–17]. To simulate the RBCs aggregation behind a moving interface considered in [1,2], we have extended the aforementioned methodology since the typical setting of the periodic boundary condition in the channel wall direction is not well suited anymore. As by the nature of the problem, the computational domain has to be focused on the marching frontier, which has no counterpart to go periodic. Instead we have the computational domain moving with a interface (see, e.g., [26,27] and references therein for adjusting the computational domain) in an infinitely long two-dimensional channel with an undisturbed flow field in front of the domain. This approach extends the range of the methodology from still focus to moving focus. To mimic the motion of the RBCs behind a meniscus in a capillary, we have considered a flat interface moving with a given constant speed in this paper. The simulating results of the motion of red blood cells behind a moving interface show that the RBCs with higher velocity in the channel central region than the interface speed form the concentrated slug behind the interface, which resembles the motion of the RBCs observed in [1,2]. The structure of this paper is as follows: We discuss the elastic spring model and numerical methods in Section 2. In Section 3, the tanking-treading and the inclination angle of a cell in a simple shear flow are briefly discussed for the validation purpose. We then present and discuss the results of the motion of red blood cells behind a moving interface in a capillary. The conclusions are summarized in Section 4.