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The Dynamics of Suspended Rough Platelets in Shear Flows with Different Reynolds Numbers

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Abstract. The behaviour of platelet flows in plasma and the change of the platelet surfaces is studied by numerical simulations. In particular, the influence of the 2D platelets surface roughness and Reynolds number on the rotation of platelets is considered. Reynolds numbers Re vary from 0.4 to 50 and it is noted that if $Re = 50$, the 2D platelets stop rotating after 90° turn. If $0.4 \leq Re \leq 20$, the rotation period increases along with the increase of Reynolds number. The maximum angular velocity, the minimum angular velocity and the rotation period of platelets depends on their roughness. However, these characteristics are little affected by the roughness if the Reynolds number is close to 1. It is also worth noting that the torque of 3D platelets is greater than the torque of 2D platelets.

AMS subject classifications: 65M10, 78A48

Key words: Curvilinear immersion boundary method, platelets, Reynolds number, roughness.

1. Introduction

Numerical simulations expand traditional theoretical and experimental approaches to the phenomena that are almost imperceptible in the laboratory environment, thus increasing the capabilities of science and technology [7,24]. However, they often encounter computational challenges related to diverse spatial-temporal scales of multi-component biological and behavioral systems [14,19]. For example, cardiovascular diseases account for about 30% of all deaths worldwide, and severe ventricular dysfunction and hearing failure can be caused by acute thrombosis associated with myocardial infarction or by progressive intermittent atherosclerotic thrombotic events. At present, China has about 4.5 million patients with a heart failure. Moreover, the incidence of various cardiovascular diseases is on

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rise as patients get younger and younger. Thus the heart failure is a serious public health problem.

Blood is a concentrated suspension of red cells, white cells, and platelets. Each of them has a unique constitution and serves a different function. Red cells are highly deformable liquid capsules enclosed by a thin membrane whose resting shape is a biconcave disk, whereas white cells are viscoelastic spherical particles enclosed by a cortical spherical shell. In the inactivated state, platelets are oblate spheroids with the average aspect ratio close to 0.25 and the diameter close to 3 μm [9]. Similar to red cells, the platelets have no nucleus but analogously to white cells, they exhibits a low degree of flow-induced deformation.

The coagulation cascade of blood may be caused by platelet activation induced by blood flow, which promotes the formation of blood clots during artificial cardiovascular equipment and arterial diseases [1,2]. Although biochemical agonists can induce platelet activation, pathological blood flow patterns or high shear stress generated by cardiovascular equipment can increase the tendency of platelets to activate and initiate coagulation pathways, leading to thrombosis [21,25]. After activation, platelets undergo complex biochemical and rapid morphological changes, aggregate and adhere to the blood vessel wall to form thrombus. This complex process is described by a continuum-based simulation model, which treats blood as a continuum, and solves the Navier-Stokes equation controlling the viscous blood flow [29].

In this work, we focus on the dynamics of inactivated suspended platelets in the blood fluid. As early as 1922, Jeffery [18] research the motion of ellipsoidal particles immersed in a viscous fluid. A natural point of departure for describing the flipping motion of a platelet over a substrate is Jeffery's analysis of the motion of an ellipsoid in a general linear flow. When Jeffery' solution is applied to an oblate sphere in a simple shear flow, it executes a series of periodic trajectories parameterized by the initial inclination of the unit vector along the axis of the rotating particle. If the axis of rotation is perpendicular to the vorticity of the shear flow, the director rotates around the center of mass and changes with time, describing the angular velocity of the entire circle. Hsu and Ganatos [16] calculated the spherical motion of this configuration based on the direct boundary integral method for the separation of large and medium particles from the wall. Gavze and Shapiro [10,11] used similar calculations. In fact, the dynamics of inactivated suspended platelets in the blood fluid is a fluid structure interaction (FSI) problem. Such problems play an important role in many fields of science and engineering, but due to their strong nonlinear and multidisciplinary nature, it is still a challenge to carry out a comprehensive research on them [4]. For the majority of FSI problems, the analytical solution of the corresponding model equation is not known and the scope of laboratory experiments is limited. On the other hand, the basic physics of complex interactions between fluids and solids can be studied by numerical simulations. With the latest development of computer technology, the simulation of scientific and engineering systems becomes more and more complex and includes such fields as the particle assembly, aerodynamics, hemodynamics, and complex flows in irregular domains [5,12,15,17,22,23,31,32].

The FSI algorithm consists of three main numerical steps: