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Two-phase non-linear model for blood flow in asymmetric and axisymmetric stenosed arteries

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ABSTRACT

The pulsatile flow of a two-phase model for blood flow through axisymmetric and asymmetric stenosed narrow arteries is analyzed, treating blood as a two-phase model with the suspension of all the erythrocytes in the core region as the Herschel–Bulkley material and plasma in the peripheral layer as the Newtonian fluid. The perturbation method is applied to solve the resulting non-linear implicit system of partial differential equations. The expressions for various flow quantities are obtained. It is found that the pressure drop, plug core radius, wall shear stress increase as the yield stress or stenosis height increases. It is noted that the velocity increases, longitudinal impedance decreases as the amplitude increases. For asymmetric stenosis, the wall shear stress increases non-linearly with the increase of the axial distance. The estimates of the increase in longitudinal impedance to flow of the two-phase Herschel–Bulkley material are significantly lower than those of the single-phase Herschel–Bulkley material. The results show the advantages of two-phase flow over single-phase flow in small diameter arteries with stenosis.

1. Introduction

Blood is an important biofluid which is the suspension of red blood cells (RBCs), white blood cells (WBCs), platelets and a variety of lipoproteins in aqueous plasma. Plasma is an aqueous solution of various proteins, clotting factors and various ions [1]. Red blood cells are very numerous than white blood cells and are morphologically very simple. They contain hemoglobin which transports oxygen around the body [2]. Platelets are very small, but extremely important in relation to blood coagulation [3].

The clot formation occurs due to the causes like the endothelial injury, endothelial dysfunction, flow stagnation, etc. [4]. Clots are formed at the end of a series of interacting biochemical processes: platelet adhesion, activation and aggregation, coagulation (extrinsic and intrinsic), polymerization of fibrin monomers formed from fibrinogen, and cross linking of the fibrin polymer strands to form a fibrin network [5,6]. Fogelson [7] analyzed a continuum model for platelet aggregation and investigated its mechanical properties. Fogelson and Guy [8] further extended these continuum models to analyze the platelet–wall interactions of platelet thrombosis, using numerical solution.

Lawson et al. [9] analyzed the complex-dependent inhibition of factor VIIa by antithrombin III and heparin. Lawson et al. [10] developed an experimental model for the tissue factor pathway to thrombin. Attaullakhanov et al. [11] experimentally studied the spatio-temporal dynamics of blood coagulation and pattern formation. Mann et al. [12,13] developed models for blood coagulation and the dynamics of thrombin formation. Panteleev et al. [14] formulated mathematical models for the study of blood coagulation and platelet adhesion in their review and provided some clinical applications of the mathematical models.

As the significant devotion to the study of shear-thinning viscoelastic nature of blood, Thurston [15] investigated an extended Maxwell model for the one-dimensional flow of blood. Anand and Rajagopal [16] developed a shear-thinning viscoelastic fluid model for blood flow within a thermodynamic framework that takes cognizance of the fact that viscoelastic fluids can remain stress free in several configurations. Anand et al. [5] analyzed a viscoelastic model within the thermodynamic frame of reference for analyzing the mechanics of a coarse ligated plasma dot.

Blood flow through stenosed arteries has been investigated widely [17–19], because, fluid dynamics plays an important role in the progression of arteriosclerosis and infarcts. The development of arteriosclerosis in blood vessels is quite common, which may be attributed to the accumulation of lipids in the arterial wall or pathological changes in the tissue structure [20]. When an obstruction is developed in an artery, one of the most serious consequences is the increased resistance and the associated reduction of the blood flow to the particular vascular bed supplied by the artery [21]. Thus, the presence of a stenosis can lead to the serious circulatory disorder.

Several theoretical and experimental attempts have been made to study the blood flow characteristics due to the presence

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