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An efficient approach to study the pulsatile blood flow in femoral and coronary arteries by Differential Quadrature Method

Seiyed E. Ghasemi [a], M. Hatami [b], J. Hatami [c,*], S.A.R. Sahebi [d], D.D. Ganji [e]

[a] Young Researchers and Elite Club, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran
[b] Department of Mechanical Engineering, Esfarayen University of Technology, North Khorasan, Iran
[c] Garmsar Health & Care Center, Semnan University of Medical Sciences, Garmsar, Semnan, Iran
[d] Department of Mechanical Engineering, Islamic Azad University, Sari Branch, Mazandaran, Iran
[e] Department of Mechanical Engineering, Babol University of Technology, Babol, Iran

HIGHLIGHTS

- Flow analysis for blood in coronary and femoral arteries is simulated numerically.
- Differential Quadrature Method (DQM) and Crank Nicholson Method (CNM) are used.
- Blood is considered as the third grade non-Newtonian fluid.
- Modeling is performed under periodic body acceleration.

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ABSTRACT

In this paper, flow analysis for a non-Newtonian third grade blood in coronary and femoral arteries is simulated numerically. Blood is considered as the third grade non-Newtonian fluid under periodic body acceleration motion and pulsatile pressure gradient. Differential Quadrature Method (DQM) and Crank Nicholson Method (CNM) are used to solve the Partial Differential Equation (PDE) governing equation by which a good agreement between them was observed in the results. The influences of some physical parameters such as amplitude, lead angle and body acceleration frequency on non-dimensional velocity and profiles are considered. For instance, the results show that increasing the amplitude, A_g, and reducing the lead angle of body acceleration, ϕ, make higher velocity profiles in the center line of both arteries.

1. Introduction

Non-Newtonian fluids have many applications especially in biomedical science. For example, blood can be a non-Newtonian fluid whose physical properties are presented by Abdel Baieth [1]. Blood which is composed of plasma, red and white blood cells, platelets, etc., can be considered as one of the most important multi-component mixtures occurring in nature. Ogulu and Amos [2] modeled the pulsatile blood flow in the cardiovascular system employing the Navier–Stokes equation and found an increase in the wall shear stress when the porosity of the medium was increased. In an experimental

* Corresponding author. Tel.: +98 9157186374; fax: +98 9157186374.
E-mail addresses: ghasemi.seiyed.e@gmail.com (S.E. Ghasemi), m.hatami2010@gmail.com (M. Hatami), javad.hatamy@gmail.com (J. Hatami).

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study Praveen Kumar et al. [3] investigated the effect of gold nanoparticles in blood from biomedical view point which can be used in drug delivery applications. Recently, Hatami et al. [4] studied the third grade non-Newtonian blood conveying gold nanoparticles in a porous and hollow vessel by two analytical methods called Least Square Method (LSM) and Galerkin Method (GM). They considered temperature dependency for blood by Vogel's model and investigated the effect of Brownian motion and magneto-hydrodynamic on nanoparticles in blood flow. Moyers-Gonzalez et al. [5] on the modeling of oscillatory blood flow in a tube, observed that as the frequency of the (constant amplitude) pressure gradient oscillations increases, the peak values of the velocity field and shear stress decrease. The characteristics of flow and heat transfer of the second-grade viscoelastic electrically conducting blood in a channel with oscillatory stretching walls in the presence of an externally applied magnetic field are investigated by Misra et al. [6]. Massoudi and Phuoc [7] modeled blood as a modified second-grade fluid where the viscosity and the normal stress coefficients depend on the shear rate. They considered Fahraeus–Lindqvist effect which assumes that the blood near the wall behaves as a Newtonian fluid, and in the core as a non-Newtonian fluid. In a pioneer study, Majhi and Nair [8] mathematically modeled pulsatile blood flow subjected to externally-imposed periodic body acceleration by considering blood as a third grade fluid using numerical Crank Nicholson Method (CNM).

Nandakumar et al. [9] studied on Pulsatile flow of a shear-thinning model for blood through a two dimensional stenosed channel. They investigated the effects of percentage stenosis and Reynolds number on steady flow, and Womersley number on pulsatile flow, of blood through a two-dimensional channel with stenosis, and the results were compared with the Newtonian case. Misra and Chauhan [10] reported the results of a study of pulsatile blood flow in a tube with pulsating walls where blood was modeled as a two-layered fluid. Chen and Lu [11] investigated the non-Newtonian pulsatile blood flow in a bifurcation model with a non-planar branch numerically. The objective of their study was to deal with the influence of the non-Newtonian property of fluid and of out-of-plane curvature in the non-planar daughter vessel on wall shear stress, oscillatory shear index, and flow phenomena during the pulse cycle. Craciunescu and Clegg [12] studied numerically the effect of blood velocity pulsations on temperature distribution and heat transfer within rigid blood vessels and assumed the entrance velocity to be a simple sinusoidal function of time. A mathematical model for the pulsatile blood flow in a small vessel in the cardiovascular system with a mild stenosis was analyzed by Prakash and Ogulu [13]. They modeled blood as a power law fluid and the differential approximation for the heat flux was invoked in the energy equation. They discussed about the effect of heat transfer on the velocity.

Razavi et al. [14] simulated the blood pulsatile flow in a stenosed carotid artery numerically using different rheological models. Their results showed that the power-law model produces higher deviations, in terms of velocity and wall shear stress in comparison with other models while generalized power-law and modified-Casson models are more prone to Newtonian state.

EL-Shahed [15] studied the pulsatile flow of blood through stenosed porous medium in the presence of periodic body acceleration.

Unsteady pulsatile flow of blood through porous medium in an artery has been studied under the influence of periodic body acceleration and slip condition in the presence of magnetic field considering blood as an incompressible electrically conducting fluid by Eldesoky [16]. He obtained an analytical solution of the equation of motion by applying the Laplace transform. The wall temperature distribution in atherosclerotic plaque and cooling effect of pulsatile blood flow in the right coronary artery have been studied in presence of multi-directional magnetic field by Ghaffari et al. [17]. They obtained the results using a coupled FEM–FVM numerical procedure.

Tian et al. [18] used a simplified model to simulate a pulsatile non-Newtonian blood flow past a stenosed artery caused by atherosclerotic plaques of different severity. Their focus was on a systematic parameter study of the effects of plaque size/geometry, flow Reynolds number, shear-rate dependent viscosity and flow pulsatility on the fluid wall shear stress and its gradient, fluid wall normal stress, and flow shear rate.

The dynamic mathematical model of pulsatile blood flow through a stenosed tapered artery in the presence of a catheter has been studied by Ramana Reddy et al. [19]. They modeled blood as a homogeneous and incompressible couple stress fluid.

Third grade non-Newtonian blood flow containing nanoparticles in porous arteries in the presence of magnetic field was simulated analytically and numerically by Ghasemi et al. [20]. They used the Collocation Method (CM) and the Optimal Homotopy Asymptotic Method (OHAM) to solve the Partial Differential Equation (PDE) governing equation, and a good agreement between the two methods was observed in their results.

Differential Quadrature Method (DQM) is a numerical technique which was first developed by Richard Bellman and his associates in the early 1970s [21]. The differential quadrature method (DQM) is a rather efficient numerical method for the rapid solution of linear and nonlinear partial differential equations involving one dimension or multiple dimensions [22–24]. Compared with the standard methods such as the finite element and finite difference methods, the DQM requires less computer time and storage. The essence of the DQM is that a partial derivative of a function is approximated by a weighted linear sum of the function values at given discrete points. Its weighting coefficients do not relate to any special problem and only depend on the grid spacing. Thus, any partial differential equation can be easily reduced to a set of algebraic equations using these coefficients. The DQM needs only applying a few grid points in order to get high-precise solutions, a good convergence and it requires only less computational workload, the advantage of the DQM lies in the ease of its implementation and more flexibility to choose grid points [25,26]. The DQM applications were rapidly developed by thanks to the innovative works in computation of weighting coefficient by other scientists and recently this method was applied in many engineering problems [27–31].