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Numerical Study on Sinusoidal Fluctuated Pulsatile Laminar Flow Through Various Constrictions

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Abstract. Numerical simulations have been carried out for laminar sinusoidal pulsating flow in a tube with smooth single constriction. A second-order finite volume method has been developed to solve the fluid flow governing equations on a non-staggered non-orthogonal grid. The effects of the Reynolds number, the Womersley number, the pulsatile amplitude, the constriction ratio and the constriction length on fluid flow in constricted tube will be investigated. It will be demonstrated that the dynamic nature of the pulsating flow greatly depends on the frequency of the flow changes. It is observed that the peak wall vorticity seems to increase with the increase of Reynolds number, the pulsating amplitude and the constriction ratio. The peak values of instantaneous wall vorticity are not greatly affected by the variation of Womersly number. The constriction length does not put a significant impact on the flow instantaneous streamline behaviors compared with other parameters. However, the peak wall vorticity increases monotonically with the decrease of the constriction length.

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1 Introduction

The problem of fluid motion in a given domain whose boundaries do not only consist of solid impermeable parts but also include the inflow and outflow parts we will call the 'flowing-through' problem (Moshkin and Mounnamprang, [24]). This problem is

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rather interesting for its applications, especially the flows inside constricted tubes are encountered in many engineering situations, for example fluid flow in pipes with fittings (Lee *et al.* [16]), fluid flow in heat exchangers (Suzuki *et al.* [32]), blood flow in arterial stenoses (Kleinstreuer, [14]), etc.

The research and engineering application of pulsatile fluid flows have been established as a major branch of fluid dynamics. The research on pulsatile flow includes wind energy conversion systems (Azoury, [1]), liquid and solid bulk transportation (Masry and Shobaky, [21]) and biomedical flow phenomena (Tucker, [34]). The principle of pulsatile laminar flow has been applied to practical heat transfer devices, since heat transfer can be enhanced at the incipience of flow instability (Niceno and Nonile, [26]). In biomedical engineering, the pulsatile flow has attracted more and more attention in the investigation of intracardiac flow (Nichols and O'Rourke, 1997 [27]) and blood vessel stenosis flow in recent years as mentioned in Ku [15] and Berger and Jou [2].

It is possible to simulate the flows in a constricted tube by the numerical solution of the unsteady Navier-Stokes equations (Tannehill *et al.* [33], Wesseling [36]). A considerable number of numerical algorithms have been developed for the solution of this equation. Although a large number of investigations has led to better understanding of the flow disturbances induced by a constriction or multiple constrictions, most of the theoretical, numerical and experimental studies have been performed under different simplifying assumptions; for example, the liquid is homogeneous and its viscosity is the same at all rates of shear, it behaves as a Newtonian liquid, the liquid does not slip at the wall, the flow is cylindrical in shape and is rigid.

Berger and Jou [2] reviewed the modeling studies and experiments on steady and unsteady, two- and three- dimensional flows in arteries, and in arterial geometries most relevant in the context of atherosclerosis. They also discussed the work that elucidated many of the pathways by which mechanical forces, primarily the wall shear stresses, were transduced to effect changes in the arterial wall at the cellular, subcellular and genetic level. Mittal *et al.* [22, 23] applied the technique of large-eddy simulation (LES) to the study of pulsatile flow through a modeled arterial stenosis. The inlet volume flux was varied sinusoidally in time in a manner similar to the laminar flow simulations of Tutty [35]. LES was used to compute flow at a peak Reynolds number of 2000 and a Strouhal number of 0.024. Liu and Yamaguchi [18] numerically studied the pulsatile influence on vortical fluid dynamics in the terms of waveform dependence on physiological pulsation with a two-dimensional model of unsteady flow in a stenosed channel. Bertolotti *et al.* [3] simulated three-dimensional unsteady flows through coronary bypass anastomosis by means of both experimental and finite element methods. The host artery included a stenosis shape located at two different distances of grafting. Mahapatra *et al.* [19] numerically solved unsteady Navier-Stokes equations by finite-difference technique in staggered grid distribution for a flow through a channel with locally symmetric and asymmetric constrictions. For flow through symmetric constriction the centerline vertical velocity exhibited finite oscillation behind the constriction at high Reynolds number. Mallinger and Drikakis [20] presented a computational investigation of instabilities