Abstract

One-dimensional models have been extensively used to study the arterial hemodynamics due to their relative ease of application to a larger arterial network and ability to supply more accurate boundary conditions to the higher dimensional models. These models require a priori assumed axial velocity profile function across the cross section. The comparison of flow characteristics predicted using different a priori assumed or evolving cross-sectional velocity functions has not been reported in the literature. In the present thesis, such a study is undertaken with the main contributions as investigation on the influence of three different a priori assumed cross-sectional velocity profiles on the blood flow characteristics, development of a computationally efficient finite element formulation to eliminate the requirement of a priori assumed cross-sectional velocity profile, formulation of a wave propagation model for blood flow simulation considering a more realistic multi-layered arterial wall wherein each layer is modeled using a viscoelastic material model and investigation on the blood flow characteristics considering blood as a Non-Newtonian fluid.

Partial differential equations, mathematically representing the physical phenomena of blood flow in the compliant blood vessels, are discretized in the spatial domain by finite element method and in time domain by implicit Crank-Nicolson or Galerkin time integration technique. For the one-dimensional model with a priori assumed axial velocity profile, a 3-noded finite element with flow rate (q), pressure (p) and cross-sectional area (A) as nodal degrees of freedom is used for the discretization along the arterial axis. For the computationally efficient axisymmetric formulation, a 9-noded element is used for the interpolation of axial velocity (u) along length and radius of the artery. The pressure (p) and arterial wall radius (R) are interpolated using a 3-noded element along the length. The radial velocity is assumed to be linear along the radial direction and related to the arterial wall radial velocity. The arterial wall is modeled as single layer elastic, single layered viscoelastic and two-layered (considering media and adventitia) viscoelastic material. A velocity boundary condition is prescribed at the inlet of a single/arterial network and outlet boundary condition is prescribed in terms of 3 parameters based Windkessel model. The radial velocity of the arterial wall is equal to the radial velocity of fluid at the fluid-solid interface. The axial velocity u of solid and fluid at the interface is taken as zero. The inner radius of the deformable arterial wall is taken as equal to the outer radius of fluid domain and this condition is implemented by updating the radial nodal coordinates of fluid domain at every iteration within a time step. The fluid pressure at the fluid-solid interface is taken as internal pressure acting on the arterial wall. The flow characteristics and the velocity profile function are found to be in good agreement with the 3-dimensional computational results available in the literature. The axial velocity profile is found to be changing with time and axial coordinate of the artery. The present study finds a phase difference between the shear stress at the wall and the flow rate. The magnitude of shear stress τ_{rz} is significantly smaller than the circumferential normal stress $\sigma_{\theta\theta}$ in the arterial wall. The flow characteristics obtained using the axisymmetric formulation for more realistic multi-layered viscoelastic arterial model differ significantly compared to those predicted using 1D model with a priori assumed velocity profile functions. The blood constitutive models considered predict nearly the same flow rate/pressure variation with time with a little noticeable difference in the flow rate prediction using Newtonian and non-Newtonian blood models at diastolic state. Some difference in the flow rate prediction through the Newtonian and non-Newtonian models is observed at diastolic state.

Keywords: Blood flow, layered arterial structure, Finite element method, Non-linear axisymmetric model, viscoelasticity, Non-Newtonian blood models