The augmented FSI system for blood flow in viscoelastic vessels solved with IMEX schemes

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It is nowadays well-established that mathematical models are a powerful resource in the field of hemodynamics, being frequently adopted for various medical applications to obtain data that otherwise would require invasive measurements. The theory behind blood flow is closely related to the study of incompressible flow trough compliant thin-walled tubes. The correct numerical treatment of the fluid-structure-interaction (FSI) system of equations becomes even more challenging if we consider that veins are collapsible under certain circumstances. Recent works also showed the benefits of modeling the rheological behavior of the vessel wall using a viscoelastic law, considering in this manner that it manifests not only an instantaneous elastic strain but also a viscous damping effect, applied to pulse pressure waves, coupled to the definition of a relaxation time of the material. In this context, the purpose of this work is to propose an easily extensible 1D mathematical model able to correctly capture the FSI mechanisms inside both arterial and venous systems. The model is solved with an efficient and robust second-order numerical scheme with a time integration based on an Implicit-Explicit (IMEX) Runge-Kutta (RK) approach, proposed by Pareschi and Russo for applications to hyperbolic systems with stiff relaxation terms. The validation of the proposed model is done in different manners. Results obtained in Riemann Problems (RP), adopting a simple elastic tube law for the characterization of the vessel wall, are compared to available exact solutions. To validate also the contribute given by the viscoelasticity, a test problem for a modified non-linear system of equations that is a perturbation of the original system via a source term vector has been structured, applying it to a generic artery and to a generic vein. Specific tests have been chosen then to verify the well-balancing and the expected order of accuracy of the scheme. Finally, results obtained with different single-vessel configurations are compared to results obtained with other blood flow models and even with real medical measurements.

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