A multi-scale mathematical model of the cardiovascular system for investigation of cardiac arrhythmias

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We present a multi-scale model of the entire cardiovascular system, by extending the heart-arterial approach proposed by Guala et al. [1]. The blood flow of the large-medium arteries is described through the 1D mass and momentum balance equations. This formulation well reproduces the wave propagation and reflection, which are due to the arterial bifurcations and discontinuities in the vascular mechanical properties. The 1D description of the arterial blood flow is suitable for characterizing the unsteady motion of a viscous incompressible fluid like the blood, which is subject to variable pulsating pressures and travels through a complicate pattern of anisotropic non-linear viscoelastic vessels. Some hypotheses (axisymmetric vessel geometry and flow field, laminar flow, longitudinally tethered arterial walls, homogeneous and Newtonian blood) simplify the model equations, still providing a sufficiently accurate solution of the whole arterial network. The micro-circulation regions, the venous return, the heart and pulmonary circulation are simulated by 0D models [2], consisting of a suitable combination of resistances, compliances and inductances, to reproduce the viscous, elastic and inertial effects, respectively. The motion of the cardiac valves is accounted for, according to the forces applied on the valve leaflets. A short-term pressure control is achieved through a baroreceptor mechanism, which modifies the heart rate, the cardiac contractility and the vascular tone, in response to the arterial pressure alterations. The present model is exploited to computationally reproduce single episodes of atrial fibrillation, AF, which is the most common cardiac arrhythmia. AF events lasting a few hours are simulated at different heart rates, obtaining the pressure and flow rate time-series throughout the whole domain and quantifying the magnitude of AF-induced alterations at different vascular regions (e.g., coronary circulation). Therefore, the proposed approach can offer new model-based insights into the rate and rhythm control strategy of AF.

References

[1] Guala, A. et al. 2015 *Modelling and Subject-Specific Validation of the Heart-Arterial Tree System.* Ann. Biomed. Eng. 43, 222–237.

[2] Scarsoglio, S. et al. 2014 *Impact of atrial fibrillation on the cardiovascular system through a lumped-parameter approach.* Med. Biol. Eng. Comput. 52, 905–920.