Multiphysics, multiscale, and computational models for simulating the human heart

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Abstract: We present recent contributions to multiphysics and multiscale modelling of the human heart. Specifically, we couple state-of-the art models for the electrophysiology, mechanical activation, and the passive mechanical response of the muscle, thus yielding a coupled electromechanical problem. Our multiscale model for cardiac electromechanics accounts for miscroscopic active force generation at the cellular level that exploits Machine Learning algorithms. In addition, our 3D electromechanical model is coupled with a 0D, closed-loop model of the systemic and pulmonary blood circulations, perfusion, and torso models. We consider the space approximation of the Partial Differential Equations therein involved by means of the Finite Element method. We numerically solve the coupled problem by means of partitioned-staggered schemes for realizing the numerical coupling. We present and discuss numerical simulations, obtained in the high performance computing framework, of cardiac electromechanics and fluid dynamics problems in the human heart, both in physiological and pathological conditions. We also present a Machine Learning method that enables real-time numerical simulations of cardiac electromechanics for the construction of cardiac digital twins.