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Pathologies in the Left Atrium Reproduced Using a Low-Order Synergistic Numerical Model of the Cardiovascular System

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Abstract : Pathologies of the cardiovascular (CV) system remain a serious and deadly health problem for human society. Computational modelling provides a relatively accessible tool for diagnosis, treatment, and research into CV disorders. However, numerical models of the CV system have largely focused on the function of the ventricles, frequently overlooking the behaviour of the atria. Furthermore, in the study of the pressure-volume relationship of the heart, which is a key diagnosis of cardiac vascular pathologies, previous works often evoke popular yet questionable time-varying elastance (TVE) method that imposes the pressure-volume relationship instead of calculating it consistently. Despite the convenience of the TVE method, there have been various indications of its limitations and the need for checking its validity in different scenarios. A model of the combined left ventricle (LV) and left atrium (LA) is presented, which consistently considers various feedback mechanisms in the heart without having to use the TVE method. Specifically, a synergistic model of the left ventricle is extended and modified to include the function of the LA. The synergy of the original model is preserved by modelling the electro-mechanical and chemical functions of the micro-scale myofiber for the LA and integrating it with the microscale and macro-organ-scale heart dynamics of the left ventricle and CV circulation. The atrioventricular node function is included and forms the conduction pathway for electrical signals between the atria and ventricle. The model reproduces the essential features of LA behaviour, such as the two-phase pressure-volume relationship and the classic figure of eight pressure-volume loops. Using this model, disorders in the internal cardiac electrical signalling are investigated by recreating the mechano-electric feedback (MEF), which is impossible where the time-varying elastance method is used. The effects of AV node block and slow conduction are then investigated in the presence of an atrial arrhythmia. It is found that electrical disorders and arrhythmia in the LA degrade the CV system by reducing the cardiac output, power, and heart rate.

Keywords : cardiovascular system, left atrium, numerical model, MEF
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