Cardiocirculatory model personalization through data-driven approaches and uncertainty quantification

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Abstract:
Mathematical cardiocirculatory models provide valuable insights into diagnostics and the impacts of cardiovascular diseases. Many models have been developed to account for the different components of the heart and cardiovascular system, encompassing ionic, electrophysiology, activation, mechanical and circulatory aspects[1].
With such sophisticated tools, the need for model personalization has arised to study the effects of various diseases on the cardiovascular system. Model personalization requires solving inverse problems. The calibration of model parameters is performed using noisy clinical data, which are related to the outputs of the cardiocirculatory models. Due to the high computational cost of solving inverse problems, neural networks efficiently handle these problems.
We investigated the effects of partial anomalous venous return using a 0D cardiovascular model[2]. The model determined the dependance of the shunt fraction (i.e. the fraction of blood bypassing the left atrium) on the pulmonary precapillary resistance. Additionally, we examined the relationship between shunt fraction and pulmonary vascular resistance, right ventricular passive elastance and right ventricular relaxation time for septal defects. The results demonstrated
consistency with clinical knowledge.
We updated the atrial and ventricular ionic models within a 3D-0D electromechanical model[1] to accurately represent the calcium ion transient driving cardiac contraction. The updated model was validated against healthy ranges of clinical quantities.
Finally, we developed a neural network methodology to solve inverse Bayesian problems. This approach enables the efficient computation of the maximum a posteriori parameter estimate and its uncertainty based on noisy observational data.

References

[1] Fedele M. et al. A comprehensive and biophysically detailed computational model of the whole human heart electromechanics. Computer Methods in Applied Mechanics and Engineering, 410:115983, 2023.

[2] Ferrero P., Tonini A., et al. Appraisal of partial anomalous pulmonary venous drainage through a lumped-parameter mathematical model: a new pathophysiological proof of concept. Interdisciplinary CardioVascular and Thoracic Surgery, 39(5):ivae175, 2024.