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Effect of abrupt preload reduction on left atrial and ventricular pressures in a multi-scale mathematical model of the cardiovascular system

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Purpose: The time-varying elastance theory has been widely used to describe left atrial and ventricular behaviors. However, the applicability of this theory to the left atrium is not fully established. Therefore, we used a different type of model, based on a description of sarcomere contraction. We aim to observe if the model behaves similarly to experimental observations during inferior vena cava occlusion (IVCO) experiments.

Methods: We used a multi-scale model of the cardiovascular system in which left ventricular and atrial pressures are inferred from a sarcomere model. In this model, we reproduced IVCO experiments by a fourfold increase of the vena cava resistance. As in experimental settings, we observed the variation of measurements before and 5 heartbeats after modification of the resistance. These measurements were: maximum a and v wave pressures, minimum and end-diastolic ventricular pressures, slopes of a and v waves and maximum transmitral pressure gradients during early and late ventricular filling.

Results: Among the 8 measurements, in the model, 7 followed a similar decrease as experimentally observed. The only measurement that increased is the slope of the v wave. A possible reason for this discrepancy could be that in experimental protocols, vena cava is obstructed far from the heart. In our model, since the vena cava is only represented by a windkessel model, this geographical difference cannot be accounted for.

Conclusion: The developed multi-scale model inferring ventricular and atrial contraction from a sarcomere model correctly represents the left atrial behavior and responds to IVCO experiments as physiologically expected.

Measurements before and after IVCO

Measurement	Units	Experiments		Model simulations	
		Baseline	IVCO	Baseline	IVCO
Maximum a wave pressure	mmHg	6.6	4.3	9.64	4.95
Maximum v wave pressure	mmHg	5.6	2.9	14.31	14.08
Minimum ventricular pressure	mmHg	1	−0.4	7.04	14.08
End-diastolic ventricular pressure	mmHg	6.5	3.8	10.24	4.95
Slope of the a wave	mmHg/s	60	37	54.88	29.16
Slope of the v wave	mmHg/s	21	13	18.74	41.05
Maximum early pressure gradient	mmHg	2.8	2.4	1.50	1.08
Maximum late pressure gradient	mmHg	1.2	0.9	2.43	1.70