Patient-specific modelling of cardiovascular dysfunction: Identifying models of pulmonary embolism in pigs

T Desaive[1], J Revie[2], CE Hann[2], D Stevenson[2], S Heldmann[3], GM Shaw[4], B Lambermont[1], A Ghuysen[1],P Kolh[1], JG Chase[2]

[1]Cardiovascular Research Center, University of Liege, Belgium.
[2]Bioengineering Centre, Department of Mechanical Engineering, University of Canterbury, Christchurch, New Zealand
[3]Department of Mechanical Engineering, TU Darmstadt, Germany,
[4]Department of Intensive Care Medicine, Christchurch Hospital, Christchurch, New Zealand

Introduction

In an intensive care unit (ICU), cardiac assessment typically relies on a minimal set of measurements such as cardiac output (CO), arterial pressure, and electrocardiogram (ECG). However, significant patient variability that is very difficult to manage. Previous studies [1] have shown the potential for using lumped parameter models of the cardiovascular system (CVS) in a clinical environment. This paper extends the methods to allow robust patient specific modelling with a reduced data set that does not need the previously required ventricle volumes. The approach is validated on a porcine model of Pulmonary Embolism.

Method

An eight chamber model has been developed to describe the dynamics of the cardiovascular system. The measurements assumed in the identification method are arterial/pulmonary artery pressure, stroke volume and global end-diastolic volume. The left/right ventricle pressures and volumes were also available for validation. The cardiac model is personalised to each pig by using a proportional control to match outputs of the model to a minimal set of porcine measurements. The advantage of this method is that a global minimum is guaranteed once it converges. This method enables monitoring of patient specific indices like the contractile strength of the ventricles or the resistance of the heart valves. The identification and real-time tracking of these parameters provide a means for cardiac diagnosis and optimising therapy.

Results

All model outputs including left and right ventricle pressure and volumes matched the measured data to a mean and 90th percentile error of 4.2% and 16.3% respectively. A large increase in pulmonary resistance was identified in all the pigs consistent with the pathophysiological effects of pulmonary embolism. In addition, well known reflex responses such as increases in right ventricle contractility and systemic resistance were predicted, and the modelled right ventricle volume index (RVEDV/LVEDV) increased sharply in the pigs in a near death state as expected.

Conclusion

A robust patient specific modelling methodology was presented and validated on porcine measurements. A wide range of hemodynamics was captured within clinically acceptable error ranges. These results verify the potential for using the model in an ICU.

References

[1] Starfinger, C, Chase, JG, Hann, CE, Shaw, GM, Lambermont, B, Ghuysen, A, Kolh, P, Dauby, PC and Desaive, T (2008). "Model-based identification and diagnosis of a porcine model of induced endotoxic shock with hemofiltration," Mathematical Biosciences, Vol 216(2), pp. 132-139, ISSN: 0025-5564