Porcine trial validation of model-based cardiovascular monitoring of acute pulmonary embolism

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Introduction
Diagnosis and treatment of cardiac and circulatory dysfunction can be error-prone and relies heavily on clinical intuition and experience. Computer-based approaches utilising measurements available in the Intensive care unit (ICU) can provide a clearer physiological picture of a patient’s cardiovascular status to assist medical staff with diagnosis and therapy decisions. This research tests whether in silico subject-specific cardiovascular system (CVS) models, identified using only measurements available in the ICU, can track disease dependent changes in a porcine model of acute pulmonary embolism (APE).

Validating the Subject-Specific Models
For validation, outputs of the subject specific models were compared to measurements from the porcine trials that were not used in the identification process, such as the ventricular pressure and volume waveforms. The model matched the maximum ventricular pressures and mean ventricular volumes to average absolute errors of 4.3% and 4.4% respectively which is less than the measurement noise of the experiment (~10%).

Porcine Measurements
Subject-specific CVS models were identified in five pig trials. Autologous blood clots were inserted every two hours to simulate APE and continuous measurements were recorded every 30 minutes of:
- Aortic and pulmonary artery pressures (Pao, Ppa)
- Left and right ventricular volumes (Vlv, Vrv)
- Left and right ventricular pressures (Plv, Prv)

Pao and Ppa were used to identify the CVS model while Vlv, Vrv, Plv, and Prv waveforms were only used to validate the accuracy of the model outputs.

Detecting Pulmonary Embolism
The following trends, indicative of APE, were observed by the CVS models:
- Increased pulmonary vascular resistance R=0.68 with experimentally calculated metric
- Increased right ventricular contractility
- A sharp drop in systemic resistance near death
- Increased RVEI (RVEDV/LVEDV) R=0.88 with measurements from the porcine trials

Conclusions
Personalised computer models of the CVS are capable of tracking disease dependent hemodynamic changes and monitoring the effectiveness of treatment in a porcine model of acute pulmonary embolism. Furthermore, the method...
- Has the potential to run in real time for continuous monitoring
- Is cheap and easy to implement as it only utilises equipment and measurements already available in the ICU
- Accurately estimates important CVS like preload (LVEDV, RVEDV), afterload (systemic and pulmonary resistance and stiffness), inotropy (left and right ventricular end systolic elastance).

These results suggest their may potential benefits in using computer models of the CVS to assist medical staff with diagnostic and therapeutic decisions.