Electrocardiographic Inverse Validation Study: In-vivo Mapping and Analysis

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Introduction

Reliable quantitative and objective assessment of regional electrocardiac function from non-invasive recordings at the body surface has been an area of extensive research by bioengineers and cardiologists for several decades. Several computational approaches that attempt to solve this electrocardiographic inverse problem have been developed, but to date their suitability for *in-vivo* and clinical situations is largely unknown. Before any inverse electrical imaging procedure can be used with confidence as a non-invasive diagnostic tool, it must first be validated so that recorded experimental observations can be faithfully reproduced.

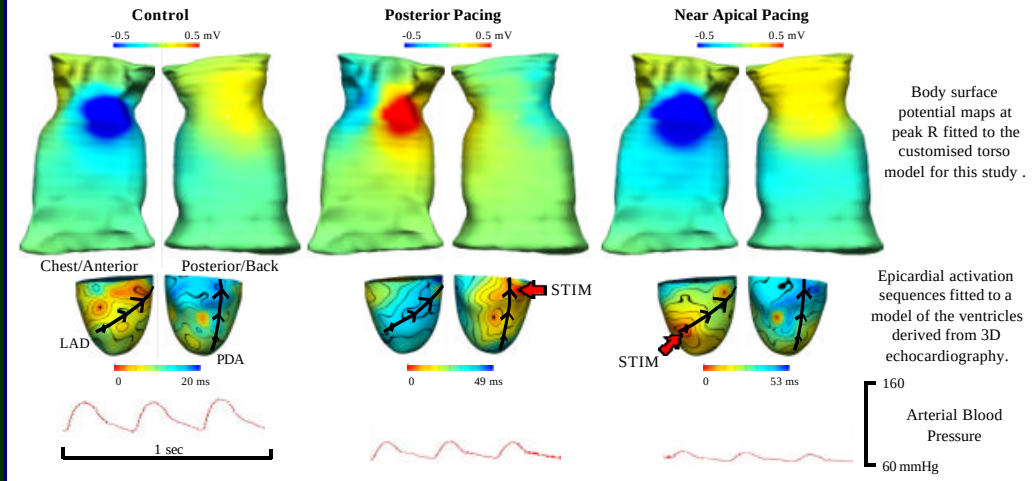
Objective: To simultaneously sample dense arrays of ventricular epicardial and body surface electropotential signals from anaesthetised pigs under control and pathological conditions.

Here we present recent data from three experimental case studies, for which we have investigated the effects of ventricular epicardial pacing, regional ventricular ischaemia and global hyperkalaemia on the ventricular activation sequence and associated electroactivity recorded from the body surface. These studies form part of our database of controlled interventions, which we plan use to comprehensively validate and refine the electrocardiographic inverse approach.

Methods: Surgery and Mapping

- domestic pigs were anaesthetised with α-chloralose (100 mg/kg i.v.), ventilated, thoracotomised and pericardectomised. The torso surface was shaved and washed.
- core temperature, fluid balance (*ca.* 100 ml/hr saline) and arterial blood gases were all maintained, while arterial blood pressure (ABP) and heart rate (HR) were monitored.
- heart location, size and orientation were determined using 3D echocardiography (HPSONOS 5500).
- unipolar torso and ventricular electropotentials were simultaneously recorded (sampling rate 2 kHz) using a 448 channel Unemap cardiac mapping system.
- ventricular epicardial signals were recorded using an elasticated electrode sock with 127 stainless steel electrodes (inter-electrode spacing *ca.* 5-10 mm).
- body surface potential signals were recorded using an elasticated electrode vest containing 256 ECG electrodes (inter-electrode spacing *ca.* 15 mm). As a non-invasive control, this was also performed prior to thoracotomy.
- concurrent mapping and geometrical model customisation methods are described further in an accompanying poster by Bradley *et al.* "Electrocardiographic Inverse Validation Study: Model Development and Methodology".

Study 1: Ventricular Epicardial Pacing



Body surface potential maps at peak R fitted to the customised torso model for this study .

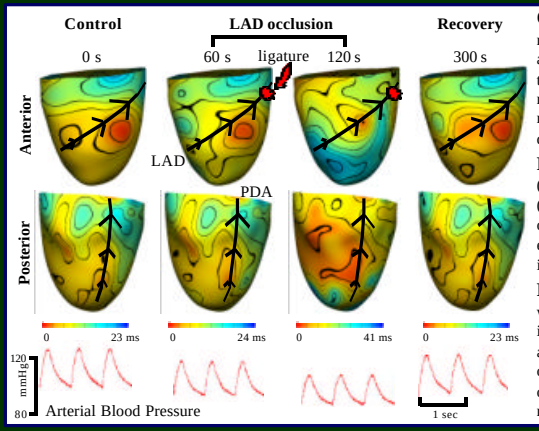
Epicardial activation sequences fitted to a model of the ventricles derived from 3D echocardiography.

Objective: Ventricular epicardial pacing was used to examine the effects of abnormal cardiac activation on the electrical activity at the body surface. A variety of pacing sites were used in order to provide a comprehensive set of paired epicardial and torso surface recordings, with which to assess the accuracy of the inverse approach.

Protocol: Posterior and near-apical ventricular epicardial sites were paced (amplitude 10 V; pulse width 2 ms; rate 200 pulses/min; baseline HR 182 beats/min), using selected sock electrodes, while epicardial activation and body surface potential recordings were sampled.

Result: In comparison to normal sinus rhythm, posterior epicardial pacing markedly altered the observed pattern of torso potentials at peak R. In contrast, the variation in ventricular activation due to near apical pacing did not drastically alter the peak R body surface map, although temporal and magnitude changes (not shown) were more pronounced.

Study 2: Regional Ventricular Ischaemia



Objective: To investigate the effects of regional myocardial ischaemia on the cardiac activation sequence. Our goal is to combine this with body surface potential recordings to non-invasively localise ischaemic region(s) of myocardium and to investigate various diagnostic indicators.

Protocol: The left anterior descending (LAD) coronary artery was ligated proximally (prior to placement of the electrode sock) and occluded for 2 minutes. Ventricular epicardial electropotentials were sampled at 60 s intervals.

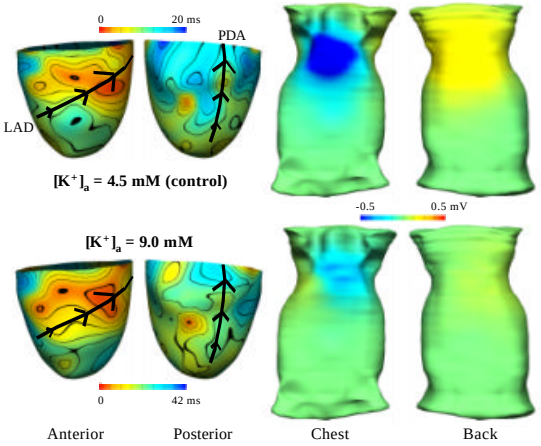
Result: The epicardial activation sequence was largely unchanged for the first minute of ischaemia, however gross changes in activation and signal amplitudes were observed following the subsequent 60 s of occlusion. Epicardial activation fully recovered after 3 minutes of reperfusion.

Study 3: Hyperkalaemia

Objective: To quantify the electrocardiac events associated with an increase in the circulating blood concentration of potassium ions ($[K^+]_a$).

Protocol: Potassium chloride (300 mM) was continuously infused (1 ml/kg/min, i.v.), while arterial blood samples were taken and analysed at 2-5 minute intervals. As each arterial sample was withdrawn, simultaneous epicardial and torso potentials were also recorded.

Result: Following approximately 40 minutes of infusion, arterial $[K^+]_a$ had increased from 4.5 mM to 10 mM. By this stage, speed of ventricular activation had clearly decreased, although the epicardial sequence remained somewhat similar. Associated with these myocardial changes was a marked decrease in the body surface potential signal amplitudes. These events were graded in response to elevated $[K^+]_a$.



Non-Invasive Reconstruction of Cardiac Activation

Now that we have established the experimental protocol to simultaneously record *in-vivo* epicardial and torso potentials, we aim to undertake a thorough validation study to investigate the inverse algorithm. This study will seek to determine the effect of geometry and individual variability by comparing the customised meshes with anatomically accurate meshes obtained from CT or MR. It will also seek to determine the level of accuracy and sensitivity with which electrocardiac events can be localised. The information gained from this validation study will help to determine the feasiablity of using body surface mapping as a clincal diagnostic tool.

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