An Experimental Model to Validate Electrocardiographic Inverse Algorithms

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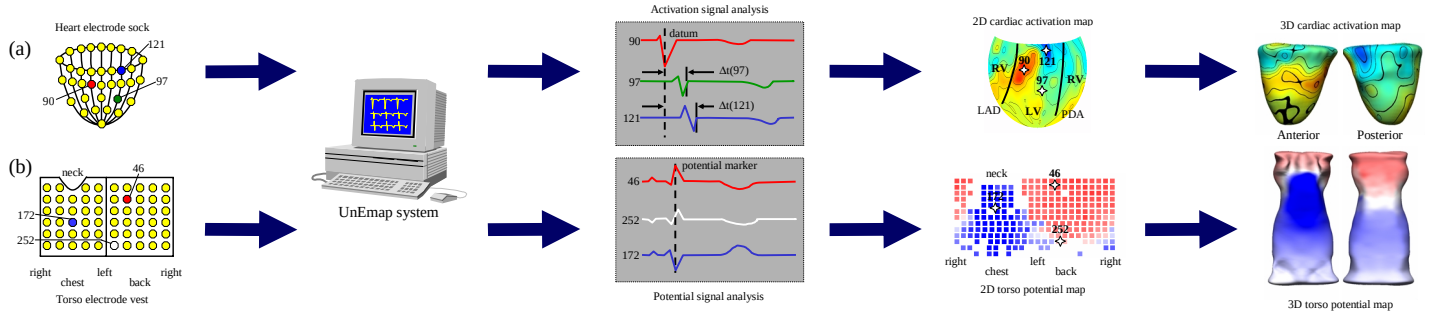
Introduction

The ECG is a fast and efficient procedure for initial diagnosis of cardiac dysfunction, although it has seen little in the way of development for several decades and cannot provide detailed quantitative information about regional cardiac activity. To obtain quantitative information about cardiac activity the inverse problem of electrocardiography must be solved. There are many algorithms available to solve the inverse problem but before these algorithms can be used practically they must be experimentally validated.

Our aim was to develop a combined experimental and computational framework for investigating the validity of inverse algorithms for electrocardiography. To achieve this we 1) concurrently mapped the electrical activity from the epicardium and body surface, 2) recorded the geometric position of the torso electrodes and a number of epicardial electrodes, 3) developed a visualisation system to process and display the recorded signals and 4) developed a computational framework based on customising a generic computational model of the porcine torso which is based on high-order boundary elements.

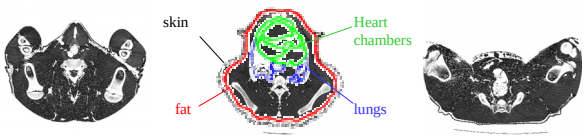
Method: Cardiac and Body Surface Potential Mapping



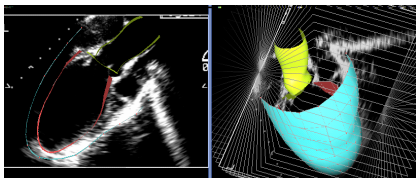
(a) Heart signals are recorded using an elasticated sock with 127 electrodes connected to a UnEmap cardiac mapping system. A single heart cycle is identified and the epicardial activation time for each electrode is determined using the most negative electropotential slope. An epicardial activation map is fitted to the electrode activation times and displayed using the 2D Hammer projection, where the left ventricle (LV) makes up the central portion of the projection, the right ventricle (RV) comprises the border regions and the apex is retained as a single point. This map can be further displayed by wrapping the 2D map around an anatomically accurate heart model to obtain a 3D cardiac activation map. For activation maps red and blue indicate regions of earliest and latest epicardial activation, respectively. LAD, PDA: left anterior and posterior descending coronary arteries, respectively.

(b) Torso signals are recorded using 256 electrodes sewn into an elasticated vest. A potential marker identifies the peak R wave of the ECG and torso electropotentials are displayed using a 2D representation of the body surface. The centre of the display reflects the left mid-auxiliary line and the left and right edges of the display the right mid-auxiliary line. This map can be further displayed by wrapping the 2D map around an anatomically accurate torso model to obtain a 3D torso potential map. For potential maps red and blue denote regions of positive and negative electropotential, respectively.

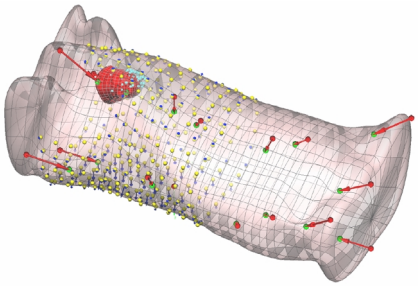
Method: Computational Model



To construct an anatomically accurate generic model of our experimental animal, a pig was placed in a CT scanner. The CT images were then digitised to provide 3D data sets for each anatomical surface (endocardium, epicardium, lungs, fat and torso). A non-linear optimisation procedure was used to obtain a parametric representation of each surface in 3D space. C^1 cubic Hermite elements were used to define the anatomical geometry. Full details of the fitting procedure may be found in Bradley *et al.*, *Annals of Biomed Eng*, **25**:96-111, 1997.



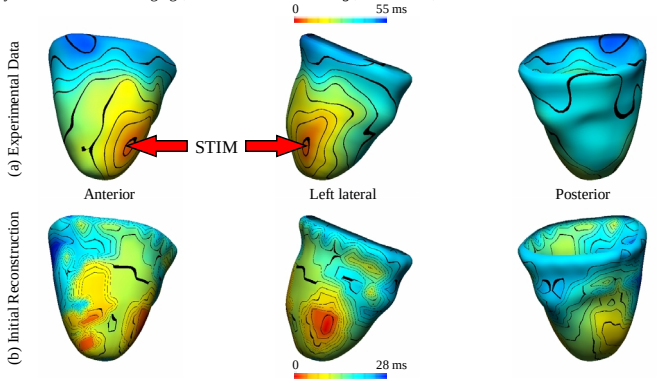
To obtain the size, orientation and location of the heart in the current experimental animal 3D ultrasound is used. The ultrasonic probe is mounted on a mechanical digitising (FARO) arm, and the position and orientation information generated by this arm is used to quantitatively register the ultrasound images with respect to the frame of reference used for the anatomical landmark positions. This allows the experimental heart geometry to be located inside the computational model. The left frame shows a traditional ultrasound view with overlays of the reconstructed epicardial, left ventricular endocardial and aortic surfaces. The right hand frame shows a 3D reconstruction of the porcine heart. Also shown in this view are the multiple ultrasound image planes from the 3D ultrasound probe.



For validation studies the generic model is customised to provide a computational model of each pig studied. The customisation of each pig is achieved by identifying a number of anatomical landmarks on the experimental animal using a mechanical digitising (FARO) arm. The same landmarks are located on the generic pig model and a non-linear fitting procedure which minimises the difference between the sets of anatomical landmarks is used to transform the generic model into a customised model. The FARO arm is also used to locate the torso electrodes and anterior epicardial electrodes. Shown on the computational model (above) are the torso electrodes (yellow spheres), errors from the torso electrodes to the customised pig model (blue arrows), generic pig landmarks (green spheres), customised pig landmarks (red spheres), deformation from the generic pig model to the customised model (red arrows) and anterior epicardial electrodes (cyan spheres).

Result: Preliminary Inverse

To illustrate the experimental data and computational model a preliminary inverse analysis is presented. Although the methodology is applicable to a variety of inverse algorithms, an activation based algorithm is used. Full details of the inverse algorithm can be found in G Husikamp and F Greensite, "A new method for myocardial activation imaging", *IEEE Trans. Biomed. Eng.*, **44**:433-446, 1997.



(a) Epicardial activation map obtained from stimulating down a sock electrode as indicated. The dispersion of activation (time from earliest to latest epicardial activation) was 55 ms.

(b) Preliminary inverse reconstruction obtained from the Husikamp and Greensite algorithm. The epicardial maps, in this instance, show the initial guess of the activation times obtained from the "Zero Crossing" function. This initial guess can be further refined by an optimisation technique which increases the initial dispersion of activation from 28 ms to 35 ms (based on minimising the differences between predicted and actual body surface magnitudes) or 54 ms (based on minimising the difference between predicted and actual body surface patterns).

Conclusions

We have successfully developed a combined experimental and computational framework for investigating inverse problems in electrocardiography. Preliminary results show that the Husikamp and Greensite algorithm can reconstruct the site of a focused activation (from pacing) although the resulting dispersion of activation is different than the measured dispersion of activation. This difference in dispersion can be improved with optimisation.

Future developments of this experimental and computational framework include obtaining better cardiac geometry and improved epicardial electrode localisation using a digital sonomicrometer system. The sonomicrometer system will be used to locate the 3D coordinates of a number of ultrasonic crystals sewn onto the epicardial sock. The positions of the crystals together with knowledge of the topology of the sock will then be used to find the *in-vivo* positions of the epicardial electrodes. The improved geometric knowledge will then allow us to further refine the inverse algorithms and investigate the validity and robustness of inverse algorithms for a variety of pathological conditions.

Acknowledgements

We would like to acknowledge the advice and expertise of Attila Kardos, Gerardo Sanchez-Ortiz and Jerome Declerck regarding the echocardiographic studies and analysis, and thank Chris Hirst and Vivienne Harris for their technical support.

Supported by: British Heart Foundation, The Wellcome Trust