**Introduction**

The basic tool in the non-invasive assessment of cardiac electrical activity is the 12 lead ECG. This is a fast and efficient procedure for initial diagnosis, but has seen little in the way of development for several decades. The diagnostic capability of an ECG can be improved by increasing the number of leads used to sample the cardiac electric field since this increases the amount of information available about the electrical source. Quantitative interpretation of this densely sampled data, in terms of the underlying cardiac electrical activity, is an electrocardiographic inverse problem. Over the last few decades various mathematical algorithms have been developed in an attempt to solve this problem. Unfortunately, unless the approach is posed in a particular manner, the inverse problem is not uniquely determined. The means that in the presence of noise, which always exists, a solution to the inverse problem can produce a result which bears no resemblance to that of the true electrical generator. Another approach to the inverse problem is to pose it in terms of the underlying activation sequence. This has significant advantages over the epicardial potential formulation, not least in that it deals directly with the underlying physiological process governing the generation of the body surface potentials, namely a progressing wave of cardiac activation. Another approach to the inverse problem is to pose it in terms of the underlying activation sequence. This has significant advantages over the epicardial potential formulation, not least in that it deals directly with the underlying physiological process governing the body surface potentials. Recently, a new algorithm based on this activation imaging approach has recently emerged (F. Greensite and G. Huiskamp, An improved method for estimating epicardial potentials from the body surface, IEEE Trans. Biomed. Eng., 45:1-17, 1998 and G. Huiskamp and F. Greensite, A new method for myocardial activation imaging, IEEE Trans. Biomed. Eng., 44:439-446, 1997). “Aim of this study is to quantitatively evaluate and validate this new algorithm for solving the inverse problem by comparing mathematical results against in-vivo experimental data (consequent epicardial and body surface potentials) recorded from a number pigs.”

**Theory: Inverse Algorithms**

Determining the electrical state of the heart from remote measurements of the electrocardiographic potential field at the body surface is of considerable medical interest. The inverse problem of electrocardiography is a general name that encapsulates all methods that attempt to compute the time-varying transmembrane and intracellular currents on the surface of the heart (denoted \( \phi (t, x, y) \)) from the recorded potentials with 20-40 electrode locations at remote locations on the body surface (denoted \( \mathbf{V}(t, x, y) \)).

In a macroscopic sense, the relationship between the electrocardiographic and its intracellular current sources is well understood; via the bidomain field equation:

\[
\nabla \mathbf{V}(t, x, y) = \mathbf{G}(t, x, y) \nabla \phi(t, x, y) + \mathbf{G}_i(t, x, y) \nabla \phi_i(t, x, y),
\]

where \( \mathbf{G}(t, x, y) \) and \( \mathbf{G}_i(t, x, y) \) are the extracellular and intracellular conductivity tensors, respectively. Two meaningful approaches for solving the inverse problem will be quantitatively investigated and validated.

**Epicardial Potential Imaging**

The electric field in the source-free region between heart and body surfaces is determined by Laplace's equation, with boundary conditions given by the vanishing of the normal component of current density on the body surface and the known epicardial potentials. The result is a linear relationship between the body surface and epicardial potentials. The full approach is given in Greensite et al., IEEE Trans. Biomed. Eng., 45:1-17, 1998.

**Myocardial Surface Activation Imaging**

This approach first produces a series of signals at every myocardial surface point \( \mathbf{V}(t, x, y) \) on the outer surface of the heart (denoted \( \phi (t, x, y) \)) from intracardiac current sources. The geometric locations of the torso electrodes are obtained by direct measurement using a mechanical digitising arm.

**Method: Cardiac and Body Surface Potential Mapping**

**Method: Porcine Model Construction**

To construct an anatomically accurate generic model of the pig pig was placed in a CT scanner and a sequence of cross-sectional images obtained. These were then digitized to provide 3D data sets for each anatomical surface (endocardium, epicardium, lungs, fat and torso). A non-linear optimization procedure, which incorporated non-linear constraints and smoothing, was used to obtain a parametric representation of each surface in 3D-space. CUBA Monte Carlo elements were used to define the smoothly continuous anatomical geometry. Full details of the fitting procedure may be found in Bradley et al., Annals of Biomed. Eng., 25:9-111, 1997. Approximately 2-10 hours of CPU time were required to fit each surface. For validation studies the generic model is customised to provide a computational model of each pig studied. TheCustomisation 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 set of anatomical landmarks is used to transform the generic model into a customised model. To obtain the size, orientation and location of the heart 3D ultrasound is used. The ultrasonic probe is mounted on a cardiac digitising arm. A 3D reconstruction of the torso surface is seen in this view as the multiple ultrasound images planes from the 3D ultrasound probe. The position and orientation of the ultrasound probe is encoded using a mechanical digitising arm in order for this reconstructed heart to be located within the computational mesh.

**Results: Sample Simulation**

The figures to the right shows an example of the activation inverse solution using the porcine computational model. (a) Shows the model heart with a prescribed activation sequence. This sequence was then used to generate body surface maps viewed from the anterior (b) and posterior (c). (d) Shows the activation sequence obtained from the activation inverse algorithm using the calculated body surface potentials with 20 (µV RMS) noise added. (e) Shows the reconstructed activation sequence obtained when 100 (µV RMS) noise is added. On the heart, blue represents activated myocardium and red represents resting tissue. For the body surface, blue represents negative potential and red represents positive potential.

For further information see the recent paper by Nash et al. “Electrocardiographic Inverse Validation Study: In-vivo mapping and analysis”.

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