Vector Analysis of Current Pathways in Post-mortem Pig Torso

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Abstract

Although electrical therapy is commonly used in clinical settings, the pathways of electrical current through the body remain poorly understood. In this study, Low frequency current density imaging (LFCDI) is used to measure the 3-D current density inside a pig torso during an external current application. Vector analysis (using streamlines) of the data revealed complex current pathways inside the thorax including several pathways leading into and out of the heart and the connecting vessels. This study demonstrates that the LFCDI technique can be used to measure the current pathways inside the body to improve our understanding of electrical therapy.

Introduction

The effects of electric current on biological systems have been recognized for several hundred years, and is a basis for many electrical therapies currently used in clinical settings. These therapies cover a wide range of applications including electrical muscle stimulation, defibrillation, cardiac pacing, and electroconvulsive therapy. However, most of the therapies are based on empirical knowledge with a very little current flow information inside the body. Therefore, non-invasive electrical imaging technique can expand our understanding of these therapies significantly.

Low frequency current density imaging (LFCDI) uses an MR imager to measure the magnetic field caused by an externally applied electrical current [1]. This magnetic field information is encoded in a phase image which is then processed to calculate corresponding current density values at every pixel using the following equations.

$$\Gamma = \gamma B_J T_c \quad \Big| \quad \mathbf{J} = \nabla \times \mathbf{H}$$

As a result, the LFCDI technique offers a unique non-invasive approach to image electrical current flow in the body. In this study, LFCDI is used to measure the current flow information in a post-mortem pig torso.

Method

Three Yorkshire pigs weighing 3kg to 10kg were used in the study. Animals were anesthetized and euthanized immediately prior to the experiments (Ketamine 30mg/kg; Euthanyl 2ml/4.5kg). Following euthanization, the lung was inflated using a trachael tube to minimize movement of the heart during imaging. Furthermore, the animal was secured to an acrylic frame to facilitate accurate 90° rotations within the bore (3 orthogonal rotations are required for LFCDI). Two pediatric-sized defibrillation electrodes were place on either side of the chest, mimicking *anterior-anterior* position used during human defibrillation procedures.

LFCDI was implemented on a GE Signa LX 1.5T imager (55cm bore size), using a modified spin-echo sequence. 60 to 77 slices (2mm slice thickness) were acquired using 256 x 256 resolution at 48cm FOV, keeping the voxel size roughly at 2mm^3. A typical scan took 90 minutes to collect data in all three orientations. Current density information was then calculated from the phase images using aforementioned equations.

Data analysis was performed using visualization software (MayaVi [2]) through the use of streamlines to indicate current pathways. Streamlines representing the current flow were calculated by integrating the current density along the curve *s*, which satisfied the following equation.

$$ds = \left(\frac{dx}{J_x}\right) = \left(\frac{dy}{J_y}\right) = \left(\frac{dz}{J_z}\right)$$

Results

Total of 15 three-dimensional current density image sets were collected. In all three animals, approximately 60% of the applied current was observed in the skin and muscle layers of the chest. The highest current density was measured near the front chest over the fourth and fifth vertebrosternal ribs in the range of 250 A/m^2. As expected, the current pathways over the chest flowed from one electrode to the other along the chest wall (Figure 1). Although the general pathways over the chest wall were similar in all animals, some minor variations were observed with different electrode locations.

The amount of current reaching the heart was approximately 20% of the total applied current. Current density inside the heart was generally lower than the chest wall, exhibiting a peak current density of 60 A/m^2. Furthermore, the general direction of current flow inside the heart was orthogonal to that seen in the chest wall (Figure 1). This orthogonal direction of the current flow inside the heart was consistent in all animals, regardless of the size or the electrode location. The magnitude of the current flow within the heart, however, varied in relation to the underlying structures (e.g. ventricles, atria, etc.) and the chest wall proximity. Majority of the current seen in the heart entered/exited via the closest points in chest wall and through the liver in some cases.

In addition, current flow was also observed in the connecting vessels of the heart including Aorta and Vena Cava. These vessels exhibited similar peak current density to the heart, in the range of 60 A/m^2. However, the actual amount of current flowing through these vessels was small, often less than 5mA in total.

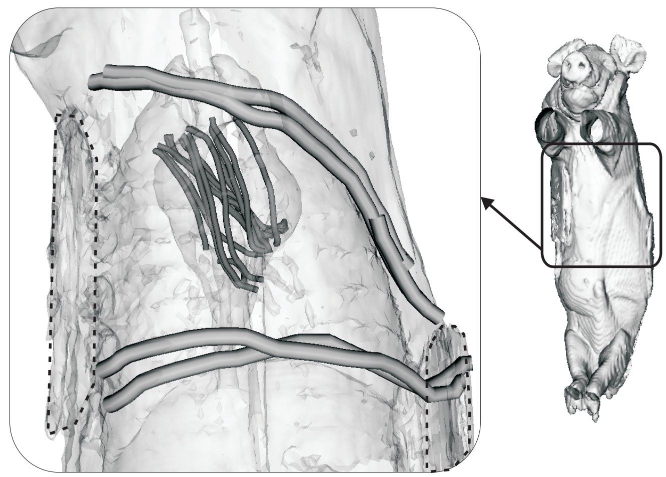

Figure 1. Streamline analysis of the current flow over the chest walls (thicker line) and within the heart (thinner line). Current was applied to two electrodes on either side of the pig (outlined with

Conclusion/Discussion

This study demonstrates that LFCDI can be used to image 3D electrical current density within the body non-invasively. Furthermore, the streamline analysis provides an effective tool to extract current pathway information from the 3D current density map. Using the streamline analysis of LFCDI data, current pathways over the chest walls and the entry/exit points of the heart were clearly identified. For the first time, electrical current pathways in the body during defibrillation like procedures were measured and identified.

References

[1] G.C. Scott, et al., Measurement of Non-Uniform Current Density by Magnetic Resonance, *IEEE Transactions on Medical Imaging*, **10**, 362-374, 1991

[2] http://mayavi.sourceforge.net//index.html