

# Defibrillation Electrical Current Pathways in the Heart and Chest of a pig

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## 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 data with very little knowledge of the current flow inside the body. There is a concern, therefore, in the areas of patient safety and efficacy of the therapies as the applications continue to expand.

The lack of detailed electrical information inside the body is mostly due to the absence of appropriate imaging tools. Although there are several approaches such as mathematical modelling and surface/implanted electrode measurements, the complexity of tissue composition in the body prevents a comprehensive study using existing techniques. For example, it is nearly impossible to model every intricate detail within the human body with present computer technology. Therefore, it is clear that a non-invasive electrical imaging technique is needed to instigate safer and more effective treatments. One of the immediate areas of benefit include the defibrillation procedure where current pathway information can lead to an optimized electrode placement combined with minimal energy applied to the patient.

In this paper, we report that an imaging technique based on magnetic resonance imaging (MRI), called low-frequency current density imaging (LFCDI), has been used successfully to map electrical current flow inside the pig torso. LFCDI uses the MR imager to measure magnetic field created by the local current density (CD) at every point within the sample [1]. Using this technique, a complete three-dimensional current density vector map of the pig is obtained non-invasively.

## Method

Three Yorkshire pigs weighing between 3kg and 10kg were used for the study. Animals were anesthetized and euthanized immediately prior to the experiments. Since LFCDI requires three orthogonal rotations of the sample within the bore, lungs were inflated using a tracheal tube to minimize the movement of heart during imaging. Furthermore, an acrylic frame and an evacuable fixation cushion were used to secure the animal and to facilitate accurate rotations. Two pediatric-sized defibrillation electrodes (Heartstream corp., Seattle WA) were placed in a lateral-lateral position similar to human defibrillation procedures [2].



Figure 1 : Picture of the pig secured in an acrylic frame with the two electrodes attached to either side of the chest.

All experiments were performed on a GE Signa 1.5T imager located at Sunnybrook and Women's College Health Sciences Centre (Toronto, Canada). LFCDI was implemented using a modified spin-echo sequence (Figure 2) with a custom made current source. Bipolar current waveforms (200mA, 24ms) were applied to the electrodes during the sequence as indicated in figure 2. The voxel sizes were kept at 2mm<sup>3</sup> and 60 slices at 256 x 256 pixels were acquired. A typical scan took 90 minutes to collect data from all three orientations. Current density information was then calculated from the phase images using the following equations.

$$\vec{\Gamma} = \nabla \phi, \quad \vec{J} = \nabla \times \mathbf{H}$$

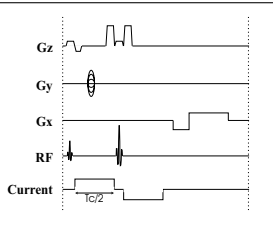


Figure 2 : Pulse sequence diagram for a typical LFCDI experiment. In this experiment, Tc (duration of the applied current) was set to 24ms.

## Results & Discussion

A total of 15 three-dimensional current density image sets were collected from the three animals. Figure 3 shows a reconstructed MR image indicating the approximate location and size of the electrodes. As expected, the majority of the current flow inside the pig torso was confined to the chest walls. In all three pigs, approximately 60% of the applied current was shunted through the skin and muscle layers in the chest. Figure 4 shows an example of current flow over the chest originating from one electrode flowing to the other. The highest current density was observed near the front chest over the third and fourth vertebrae (~250 A/m<sup>2</sup>).

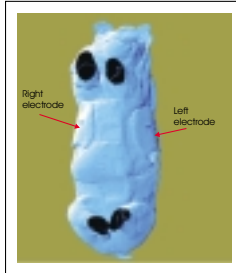


Figure 3 : A reconstructed image of the pig illustrating the locations of the defibrillation electrodes.

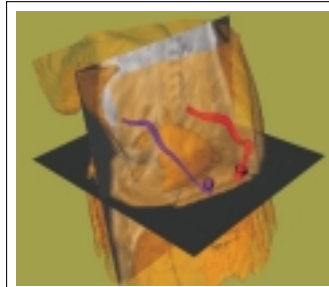


Figure 4 : Streamtubes across chest of pig showing current pathways from one electrode to the other.

Figure 5a and 5b show the current pathways in the heart. These pathways were complex and were very different from those in the chest. For example, current flow in the ventricles was almost orthogonal to the flow in the chest walls. Furthermore, direction of the current in two ventricles were opposite to each other (Figure 5a). Figure 5b shows current entering the heart through nearby

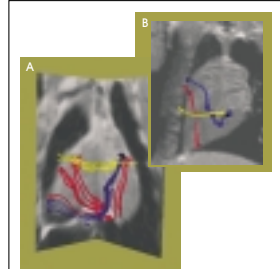


Figure 5 : Streamtubes through heart showing current pathways through the ventricles. A) Current flow within the ventricle. B) Examples of current entering the heart from chest walls.

intercostal musculature. These muscles along with connecting vessels (aorta, vena cava, etc.) were identified as the main current entry points to the heart.

This study, for the first time, accurately measured the current flow between two defibrillation electrodes inside the pig torso. The volumetric current density maps acquired from this study can be used to develop safer and more efficient defibrillation techniques in the future. The next phase of this study will include live animals to achieve results more relevant to real-life defibrillation scenarios.

## References

- [1] Scott G.C., Joy M.L.G., Henkelman R.M., In-vivo detection of applied electric current by magnetic resonance imaging, *Magnetic resonance imaging*, 7:89-94, 1989
- [2] Robertson C., Steen P., Adgey J., Bossaert L., Carli P., Chamberlain D., "The 1998 European Resuscitation Council Guidelines for Adult Advanced Life Support: A Statement from the working group on advanced life support, and approved by the executive"

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