Study of current pathways in porcine heart using current density imaging

Richard S. YOON[1]**,** Tim P. DEMONTE[1], Dawn JORGENSON[2], Michael L.G. JOY[1]
[1]University of Toronto, Department of Electrical and Computer Engineering, Institute of Biomaterials and Biomedical Engineering, Toronto, Ontario Canada; [2]Agilent Technologies, Heartstream Operation, 2401 4th Ave., Suite 500, Seattle, WA U.S.A.;

Introduction

Defibrillation of the heart is an application of electrical current to the excitable tissues of myocardium. Its purpose is to stop the fibrillating heart which is the cause of sudden cardiac arrest. The effectiveness of defibrillation has been demonstrated over 50 years of clinical use, yet there is no comprehensive study of the electrical current distribution/pathways inside the body during defibrillation. Presently, implanted surface electrode technique is the only available means of determining the electrical activity inside the body [1]. Although this technique provides a direct electrical measurement, it suffers from a poor spatial resolution and is highly invasive. In this study, Low frequency current density imaging (LFCDI) technique is used to make a 3 dimensional current density (CD) map of the pig torso area during electrical stimulation.

Methods

Two pigs weighing 13 kg and 10 kg were used. The animal was anesthetized with Ketamine (IM, 30 mg/kg) and euthanized by a lethal injection of Euthanyl (IV, 2ml/4.5kg). Following an abrasive skin preparation, specially constructed pediatric-sized cardiac defibrillation electrode (copper; Agilent Co., Seattle, WA) was applied to each side of the chest to a position similar to the human defibrillation technique. That is, one electrode was applied to the upper right chest area, while the other electrode was applied to the lower left chest area. An adhesive conductive gel was used to secure the electrodes to the skin. Furthermore, a tracheal tube was inserted and the lung was kept at an inflated position to minimize movement of heart during the experiment. The animal was then secured to a plastic frame in order to facilitate an accurate 90° rotation required by the LFCDI technique.

A standard LFCDI technique was implemented on a GE®Signa 1.5T imager (55 cm bore) [2]. A body coil was used for both trasmit and receive mode due to the size of the animals (65 cm and 53 cm). A modified spin echo sequence was used with the following key parameters: TE = 30 ms, TR=1600ms, FOV=48cm, 2mm voxel size, 16 to 41 slices. For the LFCDI, 150 mA bipolar (DC) pulses were applied to the electrodes for 24 ms. Each imaging sequence took 7 to 16 minutes to acquire one orientation. All data sets were archived and post-processed to extract the current density information.

Results

Nine sets of images were gathered and the CD was computed for all the cases. However, due to the large size of the first animal (63 cm), only one component of the current density was measured from two orientations (5 image sets). Moreover, care was taken to align the dominant current direction with the CD measurement direction. For the second animal, smaller size allowed for a collection of all three orientations of data (4 image sets). Therefore, it was possible to generate a complete three dimensional CD data for the second animal. Each experiment took approximately 45 min to an hour to complete.

Proton density magnitude images collected along with the current information revealed a clear location of the heart inside the chest cavity (Figure 1). It is also possible to delineate myocardium from blood filled ventricles and atrium, and these magnitude images were used as a guide while analyzing the CD images.

A preliminary analysis of the CD data indicated that the high percentage (up to 60 %) of the current was flowing through the chest wall (Figure 2). However, a much less, yet substantial amount of current (up to 20%) was observed inside the chest cavity, in the myocardium. Furthermore, it was also observed that the current pathways inside the heart were very complex. For example, each chambers of the heart exhibited a different directions of current flow within the same image slice (Figure 2). This complex pattern of current flow within the heart changed, as the image slice was moved from the chest wall towards the spine. In addition, a large current shunt across the abdomen area was observed in the second animal that was not seen in the first animal.

Figure 1 Proton density image of the pig

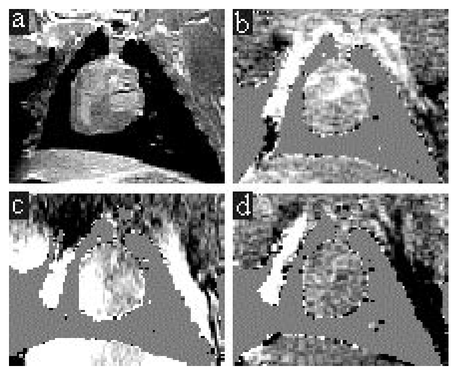

Figure 2 Magnitude image(a) is shown along with the three current components, Jx(b), Jy(c) and Jz(d).

Discussion

This study demonstrates that LFCDI is able to measure current density in a complicated and inhomogeneous tissue such as pig's body. Furthermore, this study has proved that LFCDI is an effective tool to study the efficacy of defibrillation techniques. Although this is only a preliminary study, the depth and details of information regarding the current distribution inside the pig chest is astounding. This amount of information has not been available from any other modalities of imaging.

The strength of the current used in this study is much less than the typical defibrillation current used in a clinical setting(150 mA vs. 15 A). In future studies, better instrumentation can provide a higher current level to represent the clinical situation more closely. Moreover, an *in-vivo* study can minimize changes in tissue properties such as conductivity due to the blood drainage following death.

References

[1] Konings K. T., et Al., Circulation, Vol. 89, 1994, pp 1665-1680
[2] Joy M.L.G, et Al., IEEE Trans. Biomed., Vol. 46 (9), 1999, pp 1139-1149