Current Density Impedance Imaging in Porcine Heart

W. Ma[1], D. Wang[1], T. DeMonte[1], A. Nachman[1], D. Jorgenson[2], M. Joy[1]
[1]University of Toronto, Toronto, Ontario, Canada, [2]Heartstream operation, Phillips Medical System, Seattle, Washington, United States

INTRODUCTION: Current density impedance imaging (CDII) can non-invasively measure the internal conductivity of an object [1][2]. It utilizes the current density imaging (CDI) technique and Maxwell's equations to derive an explicit expression for conductivity σ . The purpose of this study is to demonstrate the CDII technique in biological tissues such as the porcine heart. Reliable impedance images would be invaluable in the study of cardiac defibrillation.

THEORY: The technical basis of CDII is CDI, which images current density distributions using an MRI scanner [3]. Suppose CDI measures two disparate current density distributions $\mathbf{J}_1$ and $\mathbf{J}_2$ inside the subject. From Maxwell's equations for static electromagnetic fields, the gradient of the logarithm of conductivity σ is expressed as:

$$\nabla \ln \sigma = \frac{\nabla \times \mathbf{J}_2 \cdot (\mathbf{J}_1 \times \mathbf{J}_2)}{|\mathbf{J}_1 \times \mathbf{J}_2|^2}\mathbf{J}_1 + \frac{\nabla \times \mathbf{J}_1 \cdot (\mathbf{J}_2 \times \mathbf{J}_1)}{|\mathbf{J}_1 \times \mathbf{J}_2|^2}\mathbf{J}_2 + \frac{\nabla \times \mathbf{J}_1 \cdot \mathbf{J}_2}{|\mathbf{J}_1 \times \mathbf{J}_2|^2}\mathbf{J}_1 \times \mathbf{J}_2 . \quad (1)$$

This expression requires $\mathbf{J}_1 \times \mathbf{J}_2 \neq \mathbf{0}$. When $\nabla \ln \sigma$ is obtained, the conductivity is calculated through an integration operation.

METHOD: A three-electrode scheme was used to establish current injections: apex, anterior and posterior electrode were attached to the small pig (Figure.1). Different combinations of the electrodes will result in different current injection pathways. In our study, $\mathbf{J}_1$ used apex-anterior (AA) electrodes, and $\mathbf{J}_2$ used apex-posterior (AP) electrodes. This configuration guarantees that $\mathbf{J}_1 \times \mathbf{J}_2 \neq \mathbf{0}$ in most regions of the heart.
The MRI images shown here were obtained immediately obtained after death. The imaging system is a 1.5 Tesla GE® EXCITE MR scanner. The voxel size is $3.8 \times 3.8 \times 3.8\,\mathrm{mm}$. The injected current pulse is $140\,\mathrm{mA} \times 4.7\,\mathrm{ms}$. The total imaging time was about 30 minutes. After $\mathbf{J}_1$ and $\mathbf{J}_2$ were measured, the conductivity distribution was calculated using equation (1).

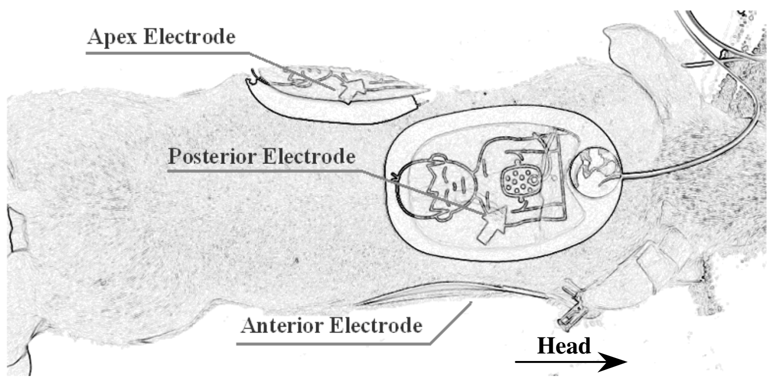
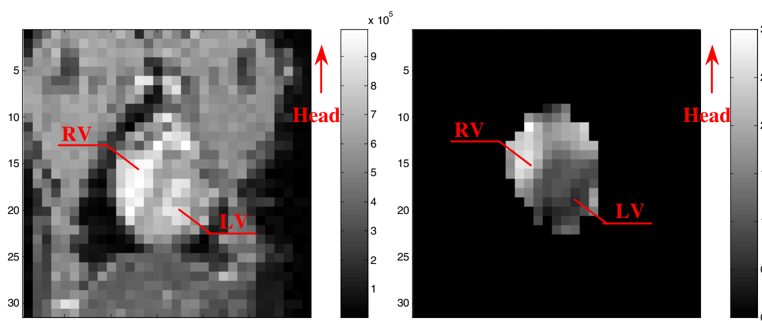


Figure1. Electrode configuration: three electrodes are attached to the pig. The current is injected by establishing voltage difference between electrode pairs. Among all available electrode-combinations, apex-anterior (AA) and apex-posterior (AP) positions were used in this study.

RESULTS: Figure 2.a is the magnitude image of the porcine heart. Figure 2.b shows the reconstructed relative conductivity distribution. Brighter regions indicate higher conductivities. The relative conductivity values could be made into absolute values if the conductivity at one point within the region was known. Pulmonary tissues outside the heart region were masked out due to low SNR in lungs. Some voxels on the boundaries of the heart were also masked out due to derivative calculations using templates [3].

DISCUSSION AND CONCLUSIONS: From Figure 2.b, we can see that the conductivity in the right ventricle is 2-3 times higher than that in the left ventricle. This abrupt change could be explained by more blood accumulation in the right ventricle. Overall, the myocardium shows a significant lower conductivity compared to the conductivity of the blood. This observation is consistent with the data in [4].
However, according to [4], in the working frequency range of CDII, 10 to 100 Hz, the difference between the conductivity of blood and myocardium is slightly higher than the CDII-measured contrast between the bright and dark regions. Possible reasons of this discrepancy are the gelling of blood that causes a decrease in blood conductivity and the degradation of tissues that may result in conductivity increase of tissues in the myocardium after death.
In conclusion, CDII demonstrates its capability of non-invasively imaging the conductivity of biological tissues, and provides relevant information for the bioelectricity research.



(a) (b)
Figure 2. Comparison of the MR magnitude image and the conductivity image. (a). MR magnitude image; (b).conductivity distribution of the same slice. The brightness indicates the relative conductivity.

REFERENCES:
[1] K. Hasanov *et al. Proc.26th IEEE EMBS*, p.1321-1324, 2004.
[2] M. Joy *et al*. Proc. 12th *ISMRM*, 2004.
[3] G. Scott *et al*. *IEEE Trans. Med. Imag,* Vol. 10, p. 362-374, 1991.
[4] S. Gabriel, *et al. Phys. Med. Biol.* Vol. 41, p. 2271-2293, 1996.
This work was supported by NSERC and Phillips Medical Systems.