

## Utilization of Esophageal Reference Electrode to Enhance Impedance Imaging

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### ABSTRACT

This paper presents an analysis of the expected improvement in distinguishability of target inhomogeneities when an "esophageal" reference electrode is located on the target-body interface. One dimensional (1D), two dimensional (2D) circular, and three dimensional (3D) spherical models are utilized for the evaluation. The results indicate an increase in the absolute value of the maximum difference between the voltages recorded with an insulating target present and no target present of: a factor of two for the 1D case and a factor of from two to more than ten for the 2D and 3D cases. The large enhancements for the 2D and 3D cases with small diameter targets may indicate that the "esophageal" reference electrode acts as a focusing mechanism.

### INTRODUCTION

The possibility of utilizing esophageal ultrasonic [1] and electrocardiographic [2] measurements for acquiring cardiac diagnostic signals has been advocated in recent years and was advocated much earlier by Patterson [3] for impedance based measurements of ventricular volume. These efforts have yielded developments which provide minimally invasive procedures for acquiring esophageal data. Recently, fairly good impedance images of the heart [4] and the lungs [5] have been acquired, and the idea of utilizing an esophageal electrode to enhance these images arose at a recent workshop [6]. The purpose of this paper is to quantitatively assess this idea by computing the maximum improvement in distinguishability one would expect from utilizing an esophageal reference electrode measurement.

### THEORY

Two dimensional, 1D, and 3D formulations are utilized in this study. The 2D model utilized is the Isaacson Formulation [7], i.e. a target of radius R and conductivity  $\sigma$  is centered in a circle of radius one and unity conductivity. For the 1D case the radius R and the unit circle are replaced by regions of the same width. For the 3D model the circles become spheres of the same radii.

The 1D model can be analyzed as a resistive network. Using the Isaacson [7] notation 1 and 2 to denote the presence and absence of a target, respectively, one can show that:

$$|V_1 - V_2|_{\text{max without esophageal reference}} = R |1 - \sigma| / \sigma \quad (1)$$

$$|V_1 - V_2|_{\text{max with esophageal reference}} = 2R |1 - \sigma| / \sigma \quad (2)$$

The 2D formulation follows directly from Isaacson [7] using his optimum current density. The 3D formulation follows directly from Geselowitz [8] with the point source and point sink replaced by an applied current density of the form  $j = \cos\theta$ , i.e. the optimum current density advocated by Isaacson [7].

### RESULTS

Examination of equations (1) and (2) reveals that the esophageal reference provides an enhancement factor of two for the 1D case.

For the 2D case, an enhancement in target distinguishability of approximately two with an esophageal reference electrode is obtained, but the enhancement is  $>6$  for a target radius of  $<0.1$ .

For the 3D case, the enhancement of approximately two is again present for large radius ( $>0.5$ ) targets. However, for small diameter targets the enhancement increases considerably and is  $>30$  for a target radius of  $<0.1$ . This may suggest a procedure for focusing static current fields, i.e. small diameter targets with proximal reference electrodes.

### REFERENCES

- [1] J.B. Seward, et al, *Proc.of the Mayo Clinic*, Vol. 63, pp.649-680, 1988.
- [2] H. Jadrar, J. Jenkins, and R. Arzbaecher, "Automated ECG Analysis During Esophageal Pacing Stress," *Proc. of the IEEE EMB Conf.* Vol. 1, pp.0018-0019, 1985.
- [3] R. Patterson, "Possible Technique to Measure Ventricular Volume Using Electrical Impedance Measurements with an Esophageal Electrode," *Med.Biol.Eng.&Comp.*, Vol. 25, pp.677-679, 1987.
- [4] B.M. Eyiüboğlu, B.H. Brown, and D.C. Barber, "In Vivo Imaging of Cardiac Related Impedance Changes," *IEEE EMB Magazine*, Vol. 8, No. 1, pp.39-45, 1989.
- [5] D. Isaacson and J.C. Newell, "Impedance Based Cardiovascular Measurements, Emerging or Fizzling Technologies?" *NSF/ERC Workshop, Duke University*, Apr.4 1989.
- [6] "Impedance Based Cardiovascular Measurements, Emerging or Fizzling Technologies?" *NSF/ERC Workshop, Duke University*, Apr.4 1989.
- [7] D. Isaacson, "Distinguishability of Conductivities by Electric Current Computed Tomography," *IEEE Trans.on Medical Imaging*, MI-5, pp.91-95, 1986.
- [8] D.B. Geselowitz, "An Application of Electrocardiographic Lead Theory to Impedance Plethysmography," *IEEE Trans. on BME*, Vol. BME-18, No. 1, pp.38-41, 1971.

### ACKNOWLEDGEMENTS

This work was supported in part by NIH research grant HL40092 and the NSF/ERC for Emerging Cardiovascular Technologies CDR 88-22201.

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