IMAGING OF GASTRIC EMPTYING WITH ELECTRICAL IMPEDANCE TOMOGRAPHY

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Abstract - Electrical Impedance Tomography uses surface electrical measurements to image changes in the conductivity distribution within a medium. This technique was applied to the measurement of gastric motility by imaging conductivity changes in the abdomen after ingestion of liquid. Preliminary results show good correlation with typical clinical measurements.

Introduction

Electrical Impedance Tomography (EIT) is an imaging technique which calculates the electrical conductivity distribution within a medium from electrical measurements made from a series of electrodes on the medium surface. A low amplitude alternating current is successively injected across pairs of electrodes while the voltage differences produced on the remaining electrodes are measured. Using this data, the conductivity distribution is estimated by the resolution of a non-linear system of equations. We are particularly interested in dynamic EIT (i.e. the measurement of changes in the conductivity distribution, rather than the conductivity itself) because it is better able to compensate for measurement errors, and is more sensitive to small conductivity changes.

EIT promises to be of interest in studying physiological processes which modify the electrical conductivity of the body, resulting from the movement of liquids or gasses (e.g. cardiac, respiratory, and gastric activity.) In this paper we present results obtained from initial investigation into the measurement of gastric motility using EIT.

Clinical Problem

Many pathological conditions are associated with delayed gastric emptying; common causes are gastroparesis secondary to diabetis, surgery, gastric ulcer, or gastritis. Currently, the most accurate clinical methods for evaluation of gastric motility are radionucleotide techniques, which involve labelling the solid or liquid phase of a meal with a standard isotope like ^{99m}Tc and ^{111}In. A test meal is ingested and imaging is performed by measuring the activity in the region of interest every 15 minutes for up to 3 hours. The meal volume, composition, and caloric content have a large effect on the gastric motility.

Experimental Procedure.

Our EIT data acquisition system[1] uses 16 electrodes for both current injection and voltage measurement, and is able to read the induced voltage at all electrodes for one injection pattern in 40 ms. In this experiment, a current injection of 1 mA at 13 kHz was used (this is approximately 10% of the threshold for cutaneous perception.) In order to reject any conductivity changes due to cardiac activity, all data acquisition was gated at 100 ms after the QRS peak.

The electrodes were evenly spaced around the abdomen of the subject, at the level of the stomach. The experiment was begun three hours after the subject had finished his meal. A reference set of measurements was acquired, and subsequently a conductivity change was induced by the subject drinking 355 ml of Coca-Cola. Over the next hour, a set of measurements was acquired every five minutes. Using this data the conductivity changes associated with his gastric activity were calculated.

Image Reconstruction

Reconstruction of conductivity changes was accomplished using the modified Newton-Raphson algorithm[3]. From our measured data we construct a matrix of voltage ratios $\boldsymbol{f}$, such that

$$f_{ij} = \frac{v_{ij}^{k\ \mathrm{min}}}{v_{ij}^{\mathrm{ref}}},\ \text{for } 1 \le i,j \le 16,$$

where v^{ref} represents measurements before the conductivity change, and $v^{k\ \mathrm{min}}$ represents the measurements taken k minutes later.

Using the finite element technique we simulate the matrix of voltage ratios, F, produced by a change in log conductivity, $\mathbf{r}$,

$$F(\mathbf{r})_{ij} = \frac{V(\mathbf{r})_{ij}}{V(0)_{ij}},\ \text{for } 1 \le i,j \le 16,$$

where $V(\mathbf{r})$ is the voltage produced by log conductivity distribution $\mathbf{r}$. Image reconstruction involves finding the change in conductivity distribution which produces an $F(\mathbf{r})$

which best approximates f while meeting certain smoothness criteria.

A reconstructed value of $\mathbf{r}$ may be interpreted as the conductivity ratio

$$\frac{\sigma_a}{\sigma_b} = e^{\log\sigma_a - \log\sigma_b} = e^{\mathbf{r}},$$

where σ_b and σ_a are the conductivities before and after, respectively.

Results and Discussion

Figure 1 shows an image of the change in conductivity distribution between the reference measurements and those immediately after ingestion; the images calculated at other times after the ingestion differed only in amplitude. In the left frontal region there is a region of decreased conductivity which corresponds to the position of the stomach. The average value of $\mathbf{r}$ in this region is 1.75±20%, indicating a conductivity ratio (σ_a/σ_b) of 0.17. The measured conductivity of Coca-Cola is 125±5% S/m, and the average conductivity in the abdomen 600 S/m [2], giving a conductivity ratio of 0.21, which is well approximated by our estimate.

The gastric activity is shown in figure 2. Curve A shows the conductivity change in the region of interest normalised with respect to the initial change as a function of the time after ingestion. Curve B and C represent typical maximum and minimum gastric motility measured using radionucleotide techniques following injection of 300-400 ml orange juice[4]. Our measurement follows the maximum motility curve closely during the first 30 minutes, after which it tends more closely toward the minimum motility curve. This behaviour can be explained by the fact that EIT is sensitive to conductivity changes far outside of the measurement plane. We are therefore still measuring the liquid after it has moved into the intestines, and out of the range of the radionucleotide imaging.

These results seem to indicate that EIT shows promise as a physiological imaging technique. Much more work, however, is still required to demonstrate the applicability of these results.

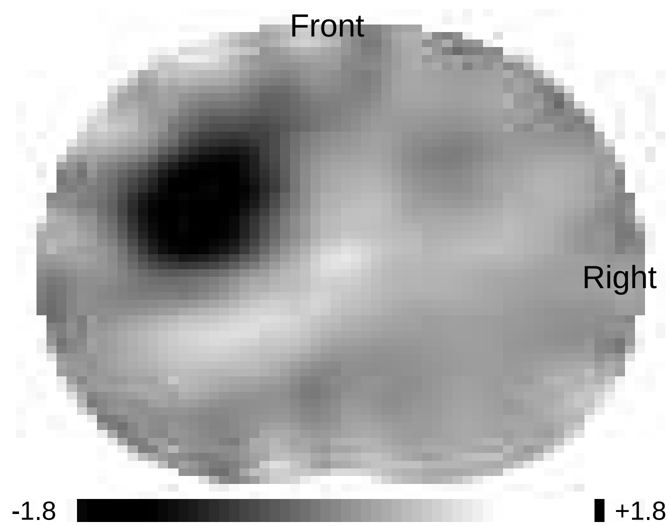

Figure 1: Abdominal Section of the log Conductivity Change due to ingestion of 355 ml Coca-Cola.

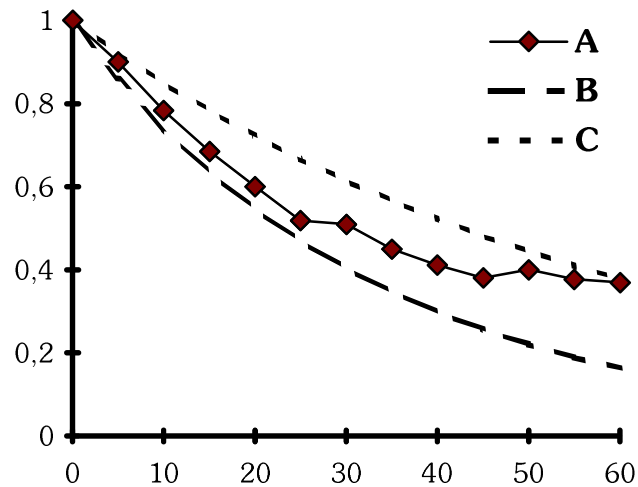

Figure 2: Relative conductivity change vs. minutes after ingestion
A: Normalised conductivity change
B: Maximum typical gastric motility
C: Miminum typical gastric motility

References

[1] R. Guardo, C. Boulay, B. Murray, M. Bertrand, "An experimental study in electrical impedance tomography using backprojection reconstruction", *IEEE Trans. Biomed. Eng.*, pp. 617 - 627, July 1991.

[2] B. Brown, D. Barber, N. Harris, A. Seagar, "Applied Potential Tomography: Possible Clinical Applications", *Clin. Phys. Physiol. Meas.*, Vol. 6, pp. 109-121, 1985.

[3] A. Adler, R. Guardo, "An iterative reconstruction technique for Electrical Impedance Tomography", *Proc. Can. Med. Biol. Eng. Society,* pp. 264 - 265, Ottawa, May 12-15, 1993

[4] R. Taillefer, K. McKusick, "Clinical Applications of Nuclear Medicine in Gastroenterology", *Digestive Diseases*, pp. 237-251, Vol. 5, 1987.