MR Electrical Impedance Tomography of Acetylcholine Induced Neural Activity

Grace N. Chrzanowski[1,2], S.C. Grant[1,2]

[1]Dept. of Chemical & Biomedical Engineering, FAMU-FSU College of Engineering
[2]The National High Magnetic Field Laboratory, The Florida State University

Introduction:

Magnetic Resonance Electrical Impedance Tomography (MREIT) is a method for mapping electrical conductivity. MREIT is utilized to map the changes in magnetic flux density due to external current injection. MREIT has been employed on cells to identify activation by depolarization of the plasma membrane. **This study seeks to expand the application of MREIT and test the hypothesis that MREIT can detect the activity of specific neurons inside the ganglion resulting from neurotransmitter action.** Utilizing neurotransmitters and low amplitude current injections should allow the mapping of specific and selective neuron activation by MREIT.

Overview:

A single abdomen ganglion was obtained via dissection and scanned using MREIT pre- and post- perfusion of a 1 mg/mL concentration of acetylcholine (ACh) at a rate of 0.1 mL/min. The two scans provide basal and stimulated levels of neural activation, respectively. One day after perfusion, a *dead* MREIT scan also was acquired. Phase differencing images were constructed with appropriate ROI calculations of mean and standard deviations of the ganglion in the pre-perfusion, post-perfusion and *dead* scans to determine activation levels.

MREIT Theory:

NMR magnetization for positive (+) & negative (-) current injections of equal magnitude during acquisition:

$$\mathcal{M}_j^{\pm}(x,y,z) = M(x,y,z)e^{i\delta(x,y,z)}e^{\pm i\gamma B_{z,j}(x,y,z)T_c}$$

The ratio of the M^+_j & M^-_j yields the induced phase difference:

$$\Phi(x,y,z) = \arg\left(\frac{\mathcal{M}^+(x,y,z)}{\mathcal{M}^-(x,y,z)}\right)$$

Specimen and Preparation

- *Aplysia californica* used due to simple nervous system (~1000 neurons) and large ganglion (~2 mm)
- The excised abdominal ganglion was equilibrated in ASW with 1 mg/mL of a chelated gadolinium.
- The ganglion then was placed into a custom built acrylic chamber with a diameter of 4 mm containing four recessed hydrogel pads used for current injection.

MREIT Chamber:

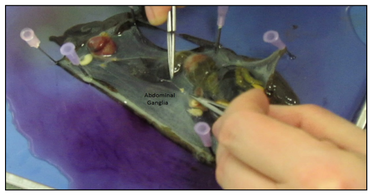


Fig. 1: abdominal ganglia in situ before removal.

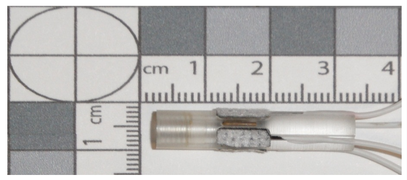
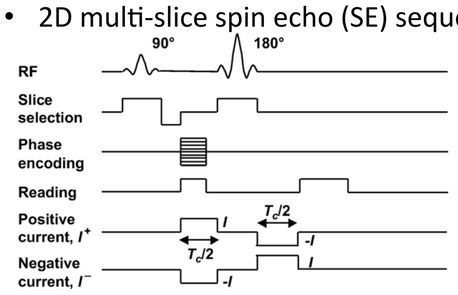


Fig. 2: MREIT chamber for excised ganglion

- **Chamber specifics**
  - Transparent acrylic
  - Central chamber: ⌀=4 mm
  - 4 offset ports (2x4 mm) arranged at polar locations around central chamber
  - Paired ports are in either horizontal or vertical orientations for current injection
  - Carbon fiber leads affixed to hydrogel pads to minimize magnetic perturbations and provide electrical interface
  - Isolated ganglion remains viable for several hours

MR & MREIT Methods:

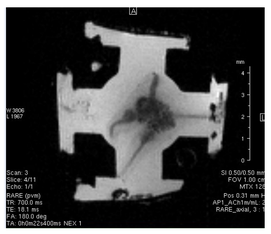
- ^{1}H imaging performed at 11.75 T with 10-mm birdcage coil
- 2D multi-slice spin echo (SE) sequences with:



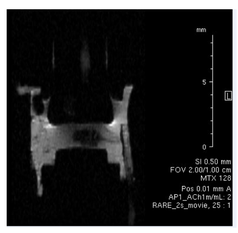
TE/TR = 14/330 ms
11 slices
Sl thickness = 500 µm
in-plane resolution = 70x70 µm

- Synchronized with acquisition, a 100-µA sinusoidal current was injected for 3 ms per lobe (T_c=6 ms) across paired horizontal or vertical ports with both (+) and (-) magnitudes

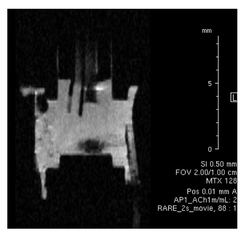
- **Excitatory conditions with 100-µA current injections**
  - Pre-perfusion scan: ASW-Gd => basal neural activity
  - Post-perfusion scan: ACh-ASW-Gd => neurostimulation
  - Dead: ACh-ASW-Gd => 24 h later



Magnitude Image



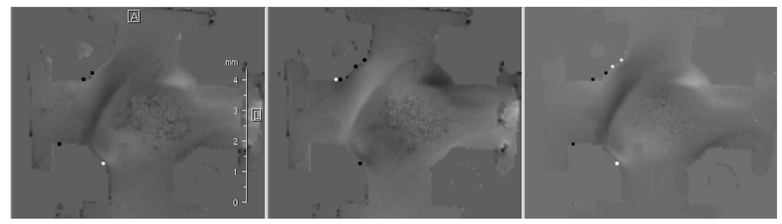
Pre-Perfusion



Post-Perfusion

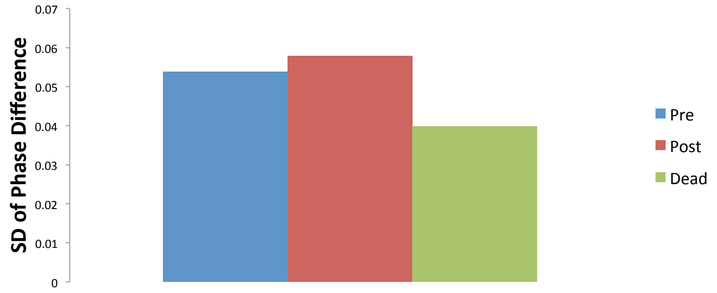
Results:

- Plots were generated of the standard deviation of the phase difference for the various trial conditions.
- Example ganglion data is shown below for 100mA Current Injection:



Positive injection Phase Image | **Negative injection Phase Image** | **Phase Difference**

Variation in Phase Difference Images for Aplysia Ganglion 1



Conclusions & Ongoing Work:

- Perfusion of ACh shows overall increase in activation via phase difference MREIT, but more trials need to be performed with to make a definite conclusion
- ASW perfusion (not shown) displayed reductions in phase difference when the same MREIT protocol was applied
- Attempting to improve protocol to gain statistical significance and increase resolution to detect single neuron activity
- Other concentrations and neurotransmitters, such as serotonin, dopamine and glutamate, will be tested
- Neurotransmitter antagonists will be perfused in concert with neurotransmitter to demonstrate reduced activation to confirm findings

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