Intraoperative Brain Mapping with Electrocorticography and Local Field Potentials

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Disclosures

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Brain Mapping Signals

Single unit activity

Field potentials

ECoG/EEG signals

Hemodynamic signals

As neurosurgeons, our best and most unique opportunity to advance this field is in the ORs.

Increasing resolution

Decreasing risk

Subdural
Epidural
Extracranial
NIRS
fMRI
Clinical Neurosurgical Brain Mapping
Traditional Uses of Intraoperative Recordings

Somatosensory Evoked Potentials

Seizure Monitoring

Single Unit Activity
Neurosurgery: Rare and unique opportunity to study the awake functioning human brain
ECoG during DBS Surgery?
Opportunities to integrate invasive human signals with non-invasive imaging
Functional Validation of DTI

1. Basic Science Application
2. Clinical Application
Cortical-Subcortical Structural-Functional Relationships

Validation of connectivity-based thalamic segmentation with direct electrophysiologic recordings from human sensory thalamus

W. Jeffrey Elias, Zhong A. Zheng, Paul Demer, Mark Quigg, Nadia Porfirio

Neuroimage
Connectivity-Based Thalamic Segmentation

Thalamic segmentation based on distinct patterns of probabilistic connectivity with unique cortical areas.

Validation of connectivity-based thalamic segmentation for DBS targeting

Region of Maximal Thalamic Connectivity With Premotor Cortex

DBS Electrode Overlay

Multi-institutional evaluation of deep brain stimulation targeting using probabilistic connectivity-based thalamic segmentation

Nader Pouratian, M.D., Ph.D., Ji Zhe Zeng, B.S., S. Jay Amin, A. Rani, M.D., Ph.D., Eric Breiner, B.S., W. Jeff Elias, M.D., and Antonio A. E. DeSalvo, M.D., Ph.D.
Electrophysiological Mapping Using Local Field Potentials (LFPs)

Local Field Potentials: Measures integrated population level electrophysiological activity, rather than spiking of individual neurons.

These can be measured using the same electrode that is used for permanent implantation and are generally easier to obtain than single unit activity.

Analysis and interpretation of signals is more easily automated.
Electrocorticography (ECoG)

Courtesy of
Jeff Ojemann, MD
University of Washington
Decoding flexion of individual fingers using electrocorticographic signals in humans.
P300 speller

1. **HEL**

   A B C D E F
   G H I J K L
   M N O P Q R
   S T U V W X
   Y Z 0 1 2 3
   4 5 6 7 8 9

2. **Signal Classifier**

3. "L"
Improvements

- Electrocorticography (ECoG)
- Natural Language Processing (NLP)
ECoG “P300” Speller

1. HEL

   A B C D E F
   G H I J K L
   M N O P Q R
   S T U V W X
   Y Z 0 1 2 3
   4 5 6 7 8 9

2. Image of brain with electrodes

3. Signal Classifier

   Language Model

“L”
Subjects
Intracranial p300 – time and spectral domain
Intracranial p300 – accuracy

<table>
<thead>
<tr>
<th>Subject</th>
<th>SR (selections/min)</th>
<th>Accuracy (%)</th>
<th>Bit Rate (bits/min)</th>
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<tbody>
<tr>
<td></td>
<td>Standard</td>
<td>NLP + Spec</td>
<td>Standard</td>
</tr>
<tr>
<td>1</td>
<td>11.32</td>
<td>10.41</td>
<td>82.77</td>
</tr>
<tr>
<td>2</td>
<td>8.73</td>
<td>8.64</td>
<td>59.03</td>
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<tr>
<td>AVG</td>
<td>10.02</td>
<td>9.52</td>
<td>70.9</td>
</tr>
</tbody>
</table>

AVG 10.02 9.52 70.9 86.06 29.64 38.26

```
Subject | Standard | NLP + Spec | Standard | NLP + Spec | Standard | NLP + Spec |
--------|----------|------------|----------|------------|----------|------------|
1       | 9.23     | 10.51      | 86.22    | 94.4       | 35.86    | 48.05      |
2       | 7.5      | 8.78       | 73.54    | 87.46      | 22.34    | 34.95      |
3       | 9.23     | 9.68       | 79.17    | 93.84      | 31.05    | 43.76      |
4       | 5.45     | 7.54       | 74.76    | 81.56      | 16.69    | 26.67      |
5       | 5.45     | 6.79       | 54.83    | 66.05      | 10.14    | 16.99      |
6       | 4.29     | 6.86       | 72.58    | 76.84      | 12.5     | 21.95      |
AVG     | 6.86     | 8.36       | 73.52    | 83.36      | 21.43    | 32.06      |
```
Results – Single flash accuracy
Conclusion

- ECoG can increase “P300” speller bitrate
- Primarily drive by visually evoked potentials
- Electrode location is critical and can dramatically affect accuracy
Opportunities during Deep Brain Stimulation Surgery
Deep Brain Stimulation: Limitations

Because we don’t really understand the physiology and the pathophysiology of the diseases or our interventions…

We’re throwing the kitchen sink at potentially very eloquent problems

Limitations:
(1) Open-loop system
(2) Preoperative targeting based on anatomy rather than function
(3) Precise but not specific
(4) Relatively simple stimulation patterns

We are considering methods to identify “pathologic” electrophysiological activity and to understand how therapy alters these patterns so that we can design closed loop systems.

We are developing preoperative functional brain mapping algorithms to target DBS electrode implantation.
Electrophysiological Mapping Using Local Field Potentials (LFPs)

Raw LFP recordings and Power analyses

Optimal Position for Stimulation can be derived from analysis of Beta power

Figure 2. Subthalamic beta and HFOs in the off and on motor states have different characteristics
Data acquisition
Results – GPi 200-300 Hz peak extraction
Results – GPi 200-300 Hz peak extraction
Results – Intra-subject

- CAR
- Movement
- Power (dB)
- Time (sec.)

- BIP
- Movement

S1

S2

S5
Cross Frequency Coupling

Cross-frequency coupling is evident in two forms:

1. **phase synchrony**, during which a consistent number of higher-frequency cycles occur within single cycles of a lower frequency rhythm

2. **phase amplitude coupling** during which the phase of a lower-frequency rhythm modulates the amplitude of a higher-frequency oscillation
Fig. 1. High gamma (80 to 150 Hz) power is modulated by theta (4 to 8 Hz) phase.
Movement-Related GPi CFC Changes
Simultaneous DBS LFP-Electrocorticography
PD Movement-Related ECoG Signal Changes
DBS Stimulation-Related ECoG Signal Changes

Starr Lab
UCSF Neurosurgery
PNAS 2013
DBS Movement-Related ECoG Signal Changes

Starr Lab
UCSF Neurosurgery
PNAS 2013
Cortical Potentials: Effect of Microlesion?

Pallido-cortical coherence during rest and movement

Difference in activity vs rest pallido-cortical coherence
Conclusions

- Invasive recordings in PD and non-PD patients provide unique insight into the pathophysiology of disease

- High-frequency bands may have signals of significance

- Cortex appears to be gated by BG-thalamic circuits AND are hypothesized to be aberrant in PD

- Future directions – more recordings…
Defining “Normal” Cortical-Subcortical Relationships

**Anatomic Methods**
- Diffusion Tractography

**Functional Methods**
- Analysis of Coherence (EEG)
- (rsfMRI)
- Cross-Frequency Coupling

**Neurosurgical Implications:**
1. Understanding how interventions modulate biological systems
2. Targeting Functional Interventions

R T Canolty et al. Science 2006;313:1626-1628
Cortical Physiology: Time-dependent Variability
Cortical Physiology: Time-dependent Variability

Time-dependent cortical CFC depends on phase-encoding power

$p < .001$
Cortical CFC: What does it depend on?
Thalamocortical CFC is also time-dependent.

TC CFC highly correlated with cortical CFC.

Intracortical CFC dynamics depend on thalamocortical coherence.
What are the thalamo-cortical relationships?
Thalamocortical Causal Relationship
Conclusion & Future Directions

• Integrating measures of structural and functional connectivity can help elucidate mechanisms of distributed control and coordination throughout the brain.

• Thalamus theorized to play a central role: Evidence of time-dependent PAC/CFC between thalamus and cortex that is spatially specific and structurally constrained.

• ECoG can identify acute effects of microlesion of cortical dynamics.

• Unique electrophysiological signatures can be assessed using measures of LFP.

• Ample opportunities to study cortical-subcortical dynamics through neurosurgical practice.
Primary motor cortex single units encode direction, not muscle groups

Schwartz, J Physiol 2007
Georgeopolous J Neurosci 1982
Green = cursor path
Blue = hand trajectory
Red = neural trajectory
Human trials – directional modulation
Braingate – Nature 2006
Donoghue lab - Brown University
Acknowledgements

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