Stereoelectroencephalography in Presurgical Evaluation of Focal Epilepsy

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Why Stereoencephalography?

- The only technique that provides direct access to electrophysiological recordings in the seizure onset zone, when located in deep brain structures.
- Allows determination of the depth of epileptogenic areas.
- Requires insertion of depth electrodes (7-14).
- Electrode placement is achieved through stereotactic techniques.
Stereotaxy

- Uses a 3D coordinate system to locate brain structures
- Requires a stereotactic positioning device
- Multi-modal imaging (CT, MRI, Angiography etc) that allows visualization of patient anatomy and co-registration with the stereotactic frame
Electroencephalographic depth recordings

- High specificity / spatial resolution
- High frequencies well evidenced
- Stable, no EMG artifacts
Spatial scale of scalp, cortical and depth recordings

- Scalp EEG requires a $\sim 7\text{cm}^2$ patch having synchronous activity
- ECoG and SEEG require $\sim 10\text{mm}^2$ of cortex
- Microwires, a sphere having $R \sim 150\mu\text{m}$

After Worrell et al, Progress in Neurobiology, 2012
Goals of SEEG investigation

- Confirming that brain regions suspected of being involved in seizure onset and propagation show the expected ictal pattern.

- Delineating the border of the epileptogenic zone as precisely as possible, to perform the minimum cortical resection.

- Assessing whether the complete removal of the epileptogenic zone will be possible or not by performing stimulation mapping of the eloquent areas.

- Evaluating the precise relationships between an anatomical lesion (when present) and the epileptogenic zone.

After Kahane et al, 2004
Implantation patterns

- Follow a certain hypothesis, based on the anatomical evidence (if any), ictal semiology and scalp EEG.

A - Amygdala; B - Anterior Hippocampus; C - Posterior Hippocampus; E - Entorhinal Cortex; U - Superior Temporal Gyrus; D - Retrosplenial cortex; I - Temporal Pole; O - Orbitofrontal; F - Fusiform gyrus; R - Rolandic Operculum; W - Wernicke;
Stereotactic planning

Preoperative MRI with contrast
- Patient anatomy, vasculature
Stereotactic planning

Angiography
- Virtual angiography from contrast-enhanced MRI through 3D Frangi vesselness filtering
Safe electrode placement

- Frangi scales: $\sigma = [0.85, 1.35]
- 3D smoothing: $\sigma = 2.00$

Safety index: 0.83
Safe electrode placement

Distance from target (mm)

Normalized MRA level

Safety index: 0.90

Traj 5:

Frangi scales \( \sigma = [0.85, 1.35] \)

3D smoothing \( \sigma = 2.00 \)
Stereotactic frame - Leksell

Lat = 111.0
A-P = 50.5
Vert = 106.5
Ring = 59.8
Arc = 176.9
Stereotactic devices

- StarFix technology, FHC Inc
- No adjustable components
- Waypoint Navigator, FHC Inc
Stereotactic devices

- StarFix, personalized fixture
Personalized Stereotactic Frame

- Advantages:
  - Simplicity - no adjustable parts, thus minimizing risk of human error
  - Reduces OR time with a factor of two
  - Two-step procedure (anchor implant, actual surgery) spaced one to two weeks
  - Surgical planning can be performed in the generous interval between the two steps. It does not have to be performed the day of the surgery
  - Frame coordinates match anatomical coordinates (centered on MCP and aligned with mid-plane), making targeting more consistent across patients.
Electrode Implantation

- Percutaneous Hole Drilling
- Dura Electrocoagulation
- Anchor placement
- Stylet insertion
- Electrode Insertion
Postoperative CT

- Verification of electrode position, hemorrhages
- B01-B03 – Hippocampus
- B04-B05 – Parahippocampal gyrus
- B06-B08 – WM
- B11-B12 – Middle Temporal Gyrus (T2)
SEEG Recordings and Stimulation

- 1-3 weeks video EEG monitoring
  - Continuous recording using wireless amplifier
  - Several ictal events captured

- Various stimulation protocols for:
  - Eliciting responses characteristic to inter-ictal or ictal patterns
  - Functional mapping of eloquent cortex, to delineate the area that can be resected with minimal deficit
Typical SEEG Signals

- **R7-R8 Broca’s area**
  - speech arrest on stimulation ($f=50$ Hz, $I=2$ mA)
Typical SEEG Signals

- O2-O3 Orbitofrontal Cortex
  - Low amplitude Delta
Typical SEEG Signals

- P10-P1 - Parietal
Typical SEEG Signals

- U4-U5 Infrasylvian Operculum
Typical SEEG Signals

- F5-F6 Fusiform Gyrus
Typical SEEG Signals

- D1-D2 Retrosplenial Cortex
Typical SEEG Signals

- **D1-D2 Retrospenlial Cortex**
  - Propagation from Amygdala
Typical SEEG Signals

- O1-O2 Supra-Calcarine
Typical SEEG Signals

- F2-F3 Fusiform Gyrus
  - inter-ictal spikes
Seizure onset on SEEG
Time-frequency map
Seizure propagation
Electrical Stimulation

- Stimulation protocols:
  - 1 Hz, 3 ms biphasic pulses, 1-5 mA, 40 s
  - 50 Hz, 1 ms biphasic pulses, 1-3 mA, 5 s

Amigdala - seizure reproduction
Electrical Stimulation

- A1-2 (Amygdala), 50 Hz, 1 ms biphasic pulses, 1-3 mA, 5 s – seizure reproduction
10. Tailored resections

Temporal lobe pole resection
Conclusions

- Despite its complexity, SEEG method can provide invaluable information regarding:
  - 3-D localization of the seizure onset zone in deep brain structures
  - propagation paths of the ictal discharges
  - functional mapping of eloquent cortex for delineating the resection
Acknowledgments

- SEEG Team:
  - Ioana Mindruta, Jean Ciurea, Alin Rasina, Bogdan Balanescu

- Stereotactic mT Platform design:
  - Ron Franklin

- Funding:
  - UEFISCDI PN-II-ID-PCE-2011-3-0240

- Institutions
  - Bucharest University, Physics Dept, Biomedical Engineering
  - University Emergency Hospital, Bucharest
  - Bagdasar-Arseni Emergency Hospital