Chosing Phase 2 Electrodes

ACNS Course ECoG/Invasive EEG
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Disclosures

No COI related to the content of this talk.
Outline

- Introduction
- Intra-operative Electrocorticography
- Extra-operative Invasive EEG Monitoring
  - Subdural Electrodes
  - Depth Electrodes
- Summary
Epilepsy Surgery

Eloquent Cortex
Preoperative
Anatomy
Handedness
Neuropsychology
fMRI
Tractography
MEG

Wada
TMS

Intraoperative
Anatomy
SSEP
ECS
Awake Mapping

Lesion
MRI
FDG PET

Ictal Onset Zone
Semiology
Scalp Video EEG
Ictal SPECT
Extra-operative ECoG
Stereo-EEG

Irritative Zone
EEG
MEG
Intra-operative ECoG
Intraoperative Electrocorticography

Lesional Epilepsy; Nonlesional TLE

- **Pros:**
  - Low risk, possible benefit
  - Patient unable to tolerate implantation
  - Some centers: any resection which did not require implantation

- **Cons:**
  - Significance of interictal abnormalities
  - Anesthesia effect, time constraints, “blind” placement
  - Over-resection, spike chasing
  - Actual impact on already planned resection strategy
The value of intraoperative electrocorticography in surgical decision making for temporal lobe epilepsy with normal MRI

*Neal Luther, †Elayna Rubens, ‡Nitin Sethi, ‡Padmaja Kandula, †Douglas R. Labar, ‡Cynthia Harden, †Kenneth Perrine, §§Paul J. Christos, *J. Bryan Iorgulescu, *Guido Lancman, ‡Neil S. Schaul, ‡Dmitriy V. Kolesnik, #Shahin Nouri, #Andrew Dawson, **Apostolos J. Tsiouris, and *†Theodore H. Schwartz

**Failure-Free Survival by Group**

Failure-free survival as defined as postoperative seizure in patients with “M” onsets (blue line) versus those with “L” or “ML” onsets (red line).

*Epilepsia © ILAE*
Extraoperative Invasive EEG

Phase 2 Evaluation

- General characteristics
  - Subdural electrodes
  - Depth electrodes
- Specific situations
  - Temporal Lobe Epilepsy
  - Extratemporal Lobe Epilepsy
General Characteristics

Subdural Electrodes

Historical Aspects
- Ajmone-Marsan and Van Buren: Subdural strips in TLE 1958
- Goldring: Epidural electrodes 1978
- Lüders, Wyler/Ojemann: Subdural electrodes 80ies

Principles
- Craniotomy, sometimes combined with additional burr-holes
- Usually uni- or bilobar exploration; can include interhemispheric grids with electrodes to both side
Fig. 3. The figure shows a standard $8 \times 8$ subdural grid fashioned from platinum-iridium electrodes measuring 3.97 mm in diameter and with a center-to-center interelectrode distance of 1 cm (custom-made at the Cleveland Clinic, Cleveland, OH). Note the small cross-section, high-density connectors, with attached tails for pulling through the stab incision. Also pictured is a quarter for size comparison.
General Characteristics
Subdural Electrodes

Advantages

- **Interictal Epileptiform Activity**
  Prolonged sampling, no anesthesia effect

- **Ictal Recording**
  7-14 days

- **Cortical Mapping**
  Systematic
  Reproducible
  Awake, no anesthesia
  Two dimensional map of eloquent cortex prior to resection

- **Decision Making**
  Able to weigh risk/benefits with patient
  But: craniotomy has already been performed!
Disadvantages

- *Complications (5-25%)*
  - CSF leak, meningitis, wound infection, hemorrhage/hematoma, transient neurologic deficits, cerebral edema, death

- *Craniotomy*

- *Removal without resection: > 20%*

- *Placement can be unpredictable*
  - Subtemporal/mesial temporal: blind
  - Interhemispheric: bridging veins
  - Incomplete separation: frontal lobes, cingulate gyrus
  - Post-op reconstruction

- Reoperation or adjustment: Increased complication rate
Specific Situations

- Temporal Lobe Epilepsy Surgery
  - Lesional
  - Nonlesional (dominant TLE)
  - Bitemporal

- Extratemporal Lobe Epilepsy Surgery
  - Lesional (multilobar, poorly defined EZ)
  - Nonlesional
Specific Situations
Subdural Electrodes

31 y/o year old
Handedness: Left
Level of education: College graduate, he works as a Financial Analyst
Onset Age: 23 years of age

EPILEPSY CLASSIFICATION
Nonlesional Left temporal lobe epilepsy

SEIZURE CLASSIFICATION (by history)
Automotor seizure -> Generalized tonic-clonic seizure

Failed: 6 AEDs
Neuropsych: IQ 110. No memory deficit.
PET Brain Refractory Seizure Evaluation

There is a moderate degree of diffusely decreased activity in the left temporal lobe compared to the right, most marked laterally.

Wada Test 2/10/2010

Right injection:
No speech arrest; perseverated on counting.
Remembered 13/15 items 87%

Left injection:
No speech arrest; perseverated on initial stimulus, neologisms.
Remembered 7/8 items 87.5%

Impression:
Left hemisphere dominant for speech.
Bilateral memory representation.
Why Invasive?

Questions which can be addressed:

- Temporal vs. Pseudo-temporal
- Mesial vs. Neocortical
- Selective resection
Interictal
- AH 1, 2, 3, MH 1, 2, 3
  - Frequency q2-10s
- D1, D2 with AH 1, 2, 3, MH 1, 2, 3
  - Frequency q11-20s
- C1, 2 at times with C7, 8 spread to D1, D2 with AH 1, 2, 3, MH 1, 2, 3
  - Frequency q 20-30s

The brain map shows the distribution of these activities across different regions labeled A, B, AM, AH, MH, PH, and D, with specific frequencies and durations indicated.
Ictal: no clinical signs
- C2, C3 maximum
- C1, C7, C8, C9 involved
- Lasted 30-120s

AH1, AH2, MH1, MH2 maximum
- D1, AM1, C7, MH1, C1, PH1 also involved
- Lasted 74s
Specific Situations
Subdural Electrodes

- TLE – Bitemporal

  Bitemporal strips
  Through Burrholes
  Additional: OF strips

**Conclusion**: We conclude that although there are high concordance rates between subdural and depth electrodes, localization of seizure onset based on subdural strip electrodes alone may result in inaccurate focus identification with potential for possible suboptimal treatment of temporal lobe epilepsy. When subtemporal subdural electrodes provide recording from the parahippocampal region, there is accurate localization of the seizure focus. If suboptimal placement occurs lateral to the collateral sulcus, the electroencephalographer cannot make a definitive identification of the seizure focus. © 2001 Elsevier Science Ireland Ltd. All rights reserved.

Specific Situations
Subdural Electrodes

♦ XTEL – nonlesional

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N</th>
<th>Recurred n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET characteristics (P-value = 0.48)</td>
<td>37</td>
<td>20 (54)</td>
</tr>
<tr>
<td>Normal</td>
<td>9</td>
<td>6 (67)</td>
</tr>
<tr>
<td>Abnormal ipsilaterally</td>
<td>20</td>
<td>11 (55)</td>
</tr>
<tr>
<td>Abnormal bilaterally</td>
<td>8</td>
<td>3 (37)</td>
</tr>
<tr>
<td>MRI characteristics (P-value = 0.01)</td>
<td>69</td>
<td>38 (55)</td>
</tr>
<tr>
<td>Normal</td>
<td>18</td>
<td>15 (83)</td>
</tr>
<tr>
<td>Abnormal Frontal</td>
<td>51</td>
<td>23 (45)</td>
</tr>
<tr>
<td>Multilobar</td>
<td>22</td>
<td>17 (77)</td>
</tr>
</tbody>
</table>

FLE – 17% nonlesional patients Sz free

Fig. 2. The diagram schematically illustrates invasive electrodes’ field of view of the cortical electrical activity. The subdural electrode (on the left) would be able to “see” a dipole layer if oriented perpendicular to the recording electrode. In cases when the dipole layer is parallel to the superficial cortical surface (as shown on the right) a depth electrode may better record these potentials.

General Characteristics

Depths Electrodes

- Combined
  - Anchor bolts, e.g. occipitotemporal electrode
  - Burr-holes, combined with strips
  - Craniotomy, in addition to grids and strips
  - Mostly temporal

- Exclusive Depth Electrode Evaluation
  - 3D exploration - “Stereo EEG”
General Characteristics

Longitudinal vs. Perpendicular

41 patients
No difference in:
Efficacy of monitoring
Complications
Seizure outcome

Advantage Perpendicular Placement:
More practical
Less change of head position
and re-draping
Shorter operative time

Stereo EEG
Talairach and Bancaud

- Irritative Zone
  - ictal spike activity
- Lesional Zone
  - Pre-Imaging
  - Slow-Wave activity on SEEG
- Epileptogenic Zone
  - Area of ictal onset and early seizure organization
  - Including area of stimulation induced habitual seizures
- Shortcomings:
  - Limited delineation of eloquent cortex
Stereo EEG

Figure 1. Imaging fusion and placement of multiple electrodes using the SEEG method. A and B show the Pre-Op imaging processing with MRI, angiography and fluoroscopic images. Electrode trajectories are then planned safely, avoiding vascular structures. C shows an intra-operative fluoroscopic image, fused with a 3-D angiogram. Note the "bull's eye" image, confirming the avascular trajectory for a specific electrode trajectory (arrow). D shows an intra-operative fluoroscopic image fused with a pre-operative MRI. Note the final position of 13 electrodes and their precise anatomical correlation.
Complication rate: 500 Patients. Major complications: 2.4% (12 pts)

<table>
<thead>
<tr>
<th>TABLE 1. Complications*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complication</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Phase 1: angiography</td>
</tr>
<tr>
<td>Epidural hematoma (frame positioning)*</td>
</tr>
<tr>
<td>ICA dissection*</td>
</tr>
<tr>
<td>Iodine contrast medium allergic reaction</td>
</tr>
<tr>
<td>Phase 2: implantation</td>
</tr>
<tr>
<td>Subdural hematoma*</td>
</tr>
<tr>
<td>Intraparenchymal hematoma (2 permanent hemiplegias, 1 mild astereognosia) b,c</td>
</tr>
<tr>
<td>Minor intracranial bleeding</td>
</tr>
<tr>
<td>Encephalitis (1 probably aseptic)*</td>
</tr>
<tr>
<td>Death (severe hyponatremia and massive brain edema)</td>
</tr>
<tr>
<td>Phase 3: video-EEG monitoring</td>
</tr>
<tr>
<td>Retained broken electrode*</td>
</tr>
<tr>
<td>Psychotic attack</td>
</tr>
<tr>
<td>Severe status epilepticus*</td>
</tr>
<tr>
<td>Phase 4: electrode removal</td>
</tr>
<tr>
<td>Acute obstructive hydrocephalus (clot in aqueduct)*</td>
</tr>
<tr>
<td>Minor intracranial bleeding*</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*EEG, stereoelectroencephalography. Complications were considered major:
*when requiring surgical treatment.
*when resulting in a permanent neurological deficit.
*or for their potential severity.
*events that occurred in the same patient.

General Characteristics

Stereo EEG

Advantages

- **Interictal Epileptiform Activity**
  Prolonged sampling, no anesthesia effect

- **Ictal Recording**
  Prolonged recordings, average 7-14 days
  3D aspect of Epileptogenic Zone

- **Electrode placement**
  Reduced Morbidity and Complications (3-5%)
  Drill holes with minimal cosmetic sequelae
  Electrode placement is more predictable
  Further electrodes can be added
  Bilateral or hemispheric exploration more straightforward

- **Decision Making**
  Able to weigh risk/benefits with patient
  Resection can be delayed
  Higher percentage of patients who may not undergo resection
General Approach and Differences

Stereo EEG

Disadvantages

- *Limited contiguous coverage*
- *Mapping*
  No systematic delineation of eloquent area
  Resection may have to be combined with awake craniotomy and/or intraoperative cortical mapping
- “Blind” procedure. Limited control of intracerebral bleeding.
Specific Situations

- Temporal Lobe Epilepsy Surgery
  - Lesional
  - Nonlesional (particularly dominant TLE)
  - Bitemporal

- Extratemporal Lobe Epilepsy Surgery
  - Lesional (multilobar, poorly defined EZ, unable to confirm epileptogenicity of a deeper lesion)
  - Nonlesional
Semiologic and Electrophysiologic Correlations in Temporal Lobe Seizure Subtypes

*Louis Maillard, Jean-Pierre Vignal, Martine Gavaret, Maxime Guye, Arnaud Biraben, Aileen McGonigal, Patrick Chauvel, and Fabrice Bartolomei
Temporal Exploration

Comparison: Stereo EEG – Subdural

- **SEEG:**
  - Precise electrode placement, regardless if lateral or mesial
  - Insular exploration or other deeper lesions

- **SDG:**
  - EZ proximity to language cortex – better mapping
### Table 2. Statistical association between each predictor variable and seizure freedom

<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups</th>
<th>Patients (n)</th>
<th>Seizure free patients (n)</th>
<th>p-Value</th>
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<tr>
<td>Gender</td>
<td>Female</td>
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<td>15</td>
<td>0.697</td>
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<tr>
<td></td>
<td>Male</td>
<td>30</td>
<td>18</td>
<td></td>
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<tr>
<td>DOB</td>
<td>Adults</td>
<td>46</td>
<td>31</td>
<td>0.052</td>
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<tr>
<td></td>
<td>Children</td>
<td>7</td>
<td>2</td>
<td></td>
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<tr>
<td>Side of implantation</td>
<td>Bilateral</td>
<td>16</td>
<td>7</td>
<td>0.077</td>
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<tr>
<td></td>
<td>Left</td>
<td>14</td>
<td>8</td>
<td></td>
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<tr>
<td></td>
<td>Right</td>
<td>23</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Side of resection</td>
<td>Left</td>
<td>23</td>
<td>12</td>
<td>0.185</td>
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<tr>
<td></td>
<td>Right</td>
<td>30</td>
<td>21</td>
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<tr>
<td>Pathology</td>
<td>Normal</td>
<td>7</td>
<td>1</td>
<td>0.005*</td>
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<tr>
<td></td>
<td>Abnormal</td>
<td>46</td>
<td>32</td>
<td></td>
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<tr>
<td>MRI</td>
<td>Normal</td>
<td>28</td>
<td>16</td>
<td>0.205</td>
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<tr>
<td></td>
<td>Abnormal unilateral</td>
<td>22</td>
<td>14</td>
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<tr>
<td></td>
<td>Abnormal bilateral</td>
<td>3</td>
<td>3</td>
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<tr>
<td>Type of resection</td>
<td>Temporal</td>
<td>13</td>
<td>9</td>
<td>0.717</td>
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<tr>
<td></td>
<td>Extratemporal unilobar</td>
<td>27</td>
<td>17</td>
<td></td>
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<tr>
<td></td>
<td>Extratemporal multilobar</td>
<td>13</td>
<td>7</td>
<td></td>
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<tr>
<td>Previous operations</td>
<td>No</td>
<td>38</td>
<td>24</td>
<td>0.831</td>
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<tr>
<td></td>
<td>Yes</td>
<td>15</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

*Statistically significant.
Implant Date: July 14, 2014
22 year old
Handedness: right handed
Level of education: In College, pre med

Onset Age: 20 years old

EPILEPSY CLASSIFICATION
Right temporoparietal lobe epilepsy

SEIZURE CLASSIFICATION
Epigastric aura -> Psychic aura -> Dialeptic Seizure; Postical headache and nausea

EEG CLASSIFICATION
- Interictal: Normal
- Ictal: EEG seizure, regional right temporal (ambulatory EEG)

ETIOLOGY (suspected):
Two right periventricular nodular heterotopia

ASSOCIATED CONDITIONS:
Sister with right parietal polymicrogyria
Migraine Headache
<table>
<thead>
<tr>
<th>Elec</th>
<th>Site</th>
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</thead>
<tbody>
<tr>
<td>P</td>
<td>Ant Parietal</td>
</tr>
<tr>
<td>U</td>
<td>ST, post</td>
</tr>
<tr>
<td>D</td>
<td>Post HC/Lesion 2</td>
</tr>
<tr>
<td>C</td>
<td>Mid HC/Lesion 1</td>
</tr>
<tr>
<td>B</td>
<td>Ant HC</td>
</tr>
<tr>
<td>E</td>
<td>Inf tem, ant</td>
</tr>
<tr>
<td>F</td>
<td>Inf tem, post</td>
</tr>
</tbody>
</table>

~ 70 Contacts
LEGEND
B: Anterior Hippocampus
C: Lesion 1/Mid Hippocampus
D: Lesion 2/Posterior Hippocampus
E: Basal Temporal, Anterior
F: Basal Temporal, Posterior
P: Anterior Parietal
U: Superior Temporal, Posterior

Initial Map

P depth (P1-10)
D depth (D1-10)
E depth (E1-8)
B depth (B1-10)
F depth (F1-10)
C depth (C1-8)
U depth (U1-8)
LEGEND
B: Anterior Hippocampus
C: Lesion 1/Mid Hippocampus
D: Lesion 2/Posterior Hippocampus
E: Basal Temporal, Anterior
F: Basal Temporal, Posterior
P: Anterior Parietal
U: Superior Temporal, Posterior

Most medial depth electrode is 1
Anterior Lesion Relation to Depth
Posterior Lesion Relation to Depth
Initial Placement
Interictal prior to D replacement

Of note, rhythmic slowing was also seen intermittent at following contacts:
- F2-4, C1-3, E1-3, B1-4

Most frequent spikes, B1-3, C1-2
Most common field B1-3, C1-2 Spike (B4-6, C3-4, E1-3, F1-4)
Extent of field of B1-3, C1-2 spk (B7-8, U1-3, E4-6, and briefly afterward P1-2)
After seizures, C2-3, F3-4 PLED like discharges
Seizure 1P P, F; E; U depths
Brief Seizures
Brief Seizures
Brief Seizures
Clinical seizure with Cortical Stimulation
Ictal: Typical Seizure 1P

- Onset C3
- 1.5 seconds later: C4, E3-4, F4-5
- 4 seconds after onset: C1-2, C5-6, B1-4, E1-2, F1-3
**LEGEND**

- **B**: Anterior Hippocampus
- **C**: Lesion 1/Mid Hippocampus
- **D**: Posterior Lesion
- **E**: Basal Temporal, Anterior
- **F**: Basal Temporal, Posterior
- **P**: Anterior Parietal
- **U**: Superior Temporal, Posterior

**Anatomical Landmarks**

- **U depth (U1-8)**
- **E depth (E1-8)**
- **C depth (C1-8)**
- **B depth (B1-10)**
- **D depth (D1-10)**
- **F depth (F1-10)**
- **P depth (P1-10)**
Posterior Lesion Relation to Depth
Posterior Lesion Relation to Depth
Ictal: Typical Seizure 2P

Onset C2-4, E3-5, F4-5
2 seconds later: C1
6 seconds after onset: D1, B1-4, F2-3, E1-2
10 seconds later: D2, C5
Scheduled for Surgery during Spring Break
Summary

- 20-30% of surgical epilepsy patients require an invasive evaluation.
- Subdural grids, depth evaluations and a combination of grids and depths all have distinct advantages.
- With advancements of stereotactic surgical techniques, more and more epilepsy centers will be able to offer individualized approaches to optimize outcome.