Update on trends in Invasive Monitoring for Epilepsy

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Invasive Monitoring

• Indications: Refractory epilepsy thought to be focal onset without clear localization and definition of epileptogenic zone on noninvasive evaluation
• Need for definition of epileptogenic zone
Subdural grids
Pt with subdural grid electrodes, bone flap stored in bone bank during invasive monitoring stay- up to 7 days. Pt will return to OR for grid removal, replacement of bone flap and possible brain cortical resection.
Stereoeencephalography (SEEG) Origins

- Talairach and Bancaud

History

• Techniques developed by Talairach and Bancaud in 1950 and 60’s
• 1973: Stereotaxic Approach to Epilepsy: Methodology of Anatomo-Functional Stereotaxic Investigations
• Electrodes placed with stereotaxic techniques into brain parenchyma to record seizure onset and spread
• “We feel that the conditions of surface corticographic investigation do not enable one to follow the spread of the after discharge with sufficient accuracy or even to determine its point of origin with certainty.”
Stereotactic investigations in frontal lobe epilepsies.

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Author information

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Abstract

The aim of a Stereo-EEG investigation is to verify and prove that the hypothesis, done on the basis of the preliminary investigations (clinical, EEG, neuroradiological), are correct. This task is particularly hard in frontal lobe epilepsies, because of anatomical and physiopathological reasons. Among 277 consecutive patients, 86 were explored for a probable frontal epilepsy. The stereotactically introduced electrodes. 1) simultaneously record the electrical activity on both, mesial and lateral cortical areas, and, 2) in 3/4 of cases also investigate extra-frontal, mainly temporal, areas. Two small, non-surgical haematomas were provoked in one patient. The spatial trajectory of the discharges, evaluated with this methodology, permits of limiting the surgical removal in many cases.
Methods of SEEG

- Traditional: Talairach frame, angiography, all electrodes placed orthogonal to sagittal plane, exploration of functional connectivity
Figure 1. This 35-year-old, right-handed woman was suffering from drug-resistant, partial seizures associated with right hippocampal sclerosis. (A) Clinically, seizures were initiated by auditory illusions (1) followed by consciousness impairment (2), version of the head and eyes towards the left, left tonic-clonic brachio-facial motor signs with sialorhea (3), bilateral clonic jerks (4), and rapid recovery with a post-ictal motor deficit of the left arm. This sequence of symptoms strongly suggested the initial involvement of Heschl's gyrus with spreading of the discharge to the suprasylvian opercular cortex and primary motor cortex. (B) The SEEG study was designed according to this hypothesis and also to understand whether mesio-temporal lobe structures could be initially involved without any initial accompaniment. Intracerebral recordings of spontaneous seizures confirmed that seizures arose from the posterior part of the first temporal gyrus (T1), quickly involved, almost simultaneously, the anterior part of T1 and the suprasylvian pre- and post-central operculum (Op), and then spread over the second temporal gyrus (T2) from its posterior to its anterior part, while the temporal pole and the hippocampus were tardily and only slightly involved.
Methods-

- Modifications: CTA or MRI contrast alone without angiography, variable angle trajectories (Milan, CCF)
- 3D Grid (Case)
- Frameless (London)
- Combined SEEG and subdural strips (CCF)
Stereoelectroencephalography: Surgical Methodology, Safety, and Stereotactic Application Accuracy in 500 Procedures

BACKGROUND: Stereoelectroencephalography (SEEG) methodology, originally developed by Talairach and Bancaud, is progressively gaining popularity for the presurgical invasive evaluation of drug-resistant epilepsies.

OBJECTIVE: To describe recent SEEG methodological implementations carried out in our center, to evaluate safety, and to analyze in vivo application accuracy in a consecutive series of 500 procedures with a total of 6496 implanted electrodes.

METHODS: Four hundred nineteen procedures were performed with the traditional 2-step surgical workflow, which was modified for the subsequent 81 procedures. The new workflow entailed acquisition of brain 3-dimensional angiography and magnetic resonance imaging in frameless and markerless conditions, advanced multimodal planning, and robot-assisted implantation. Quantitative analysis for in vivo entry point and target point localization error was performed on a sub-data set of 118 procedures (1567 electrodes).

RESULTS: The methodology allowed successful implantation in all cases. Major complication rate was 12 of 500 (2.4%), including 1 death for indirect morbidity. Median entry point localization error was 1.43 mm (interquartile range, 0.91–2.21 mm) with the traditional workflow and 0.78 mm (interquartile range, 0.49–1.08 mm) with the new one ($P < 2.2 \times 10^{-16}$). Median target point localization errors were 2.69 mm (interquartile range, 1.89–3.67 mm) and 1.77 mm (interquartile range, 1.25–2.51 mm; $P < 2.2 \times 10^{-16}$), respectively.

CONCLUSION: SEEG is a safe and accurate procedure for the invasive assessment of the epileptogenic zone. Traditional Talairach methodology, implemented by multimodal planning and robot-assisted surgery, allows direct electrical recording from superficial and deep-seated brain structures, providing essential information in the most complex cases of drug-resistant epilepsy.

KEY WORDS: Complications, Epilepsy surgery, In vivo application accuracy, Intraoperative imaging, Invasive EEG, Stereoelectroencephalography, Stereotaxy
Stereotactic placement of depth electrodes in medically intractable epilepsy

Technical note

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Pt with SEEG electrodes in place secured by anchor bolts, no bone removal. Electrodes remain for length of monitoring, can be longer than one week.
32 yo RH WF with stereotyped events for 6 years. Described as head turning, extremity waving, fencer posturing- multiple events/day, also type with whole body tensing during sleep

On LTG, LEV, LCM. Has had up to 100 events/day prior to LCM
MRI- NL
VEEG- no epileptiform activity
SPECT- not helpful
PET- NL
Neuropsych- broad cognitive dysfunction, nonlocalizing
Hypothesis: frontal, plan extensive bifrontal coverage
Grids versus SEEG

**Pros** - spatial resolution
- Mapping of contiguous structures
- Direct visualization of vessels during placement
- Surgeon/Epileptologist familiarity

**Cons** - lack of deep structure/depth of sulci recordings
- Maximally invasive
- Higher complication profile

**Pros** - Able to record deep
- Can eval multiple lobes
- Minimally invasive
- Lower complication rate
- Potential therapeutic options (lesioning)

**Cons** - limited spatial resolution around electrode
- Mapping limited spatially
- Lack of surgeon/epileptologist familiarity
Complications

• SEEG-
  – Cardinale/Milan paper: 500 cases, 6496 electrodes, major complications 2.4%, infection < 1%, hemorrhage 2.6%
  – CCF/100pts: 3%, risk per electrode 0.2%, no infection, 1 asymptomatic SDH, 2 ICH (1 had deficit, weak foot resolved in 2 wks)
### TABLE 2. Morbidity: Literature Review

<table>
<thead>
<tr>
<th>Reference (Period)</th>
<th>Institution</th>
<th>Population</th>
<th>Procedures</th>
<th>Electrodes</th>
<th>Major Complications</th>
<th>Minor Complications</th>
<th>Total, n (%)</th>
<th>Deaths, n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munari et al. 1987</td>
<td>Hospital Saint Anne, Paris, France</td>
<td>Children, adults</td>
<td>300</td>
<td>SEEG</td>
<td>1 (0.3)</td>
<td>2 (0.7)</td>
<td>3 (1)</td>
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<td>Munari et al. 1994</td>
<td>Neuroscience Department CHRU, Grenoble, France</td>
<td>Children, adults</td>
<td>70</td>
<td>SEEG</td>
<td>1 (1.4)</td>
<td>1 (1.4)</td>
<td>2 (2.8)</td>
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<td>Adelson 1990-1992</td>
<td>Harvard Medical School Children’s Hospital, Boston, MA</td>
<td>Children</td>
<td>31</td>
<td>Grids and strips</td>
<td>1 (3.2)</td>
<td>4 (12.9)</td>
<td>5 (16.1)</td>
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<td>Swartz et al. 1996</td>
<td>California Comprehensive Epilepsy Program, Los Angeles, CA</td>
<td>?</td>
<td>58</td>
<td>Grids and strips</td>
<td>0</td>
<td>20 (34.5)</td>
<td>20 (34.5)</td>
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<tr>
<td>Behrens et al. 1997</td>
<td>University of Bonn, Bonn, Germany</td>
<td>Children, adults</td>
<td>279</td>
<td>Grids and strips (DE)</td>
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<td>Wiggins et al. 1999</td>
<td>Henry Ford Hospital, Detroit, MI</td>
<td>Adults</td>
<td>38</td>
<td>Grids and strips (DE)</td>
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<td>Lee et al. 2000</td>
<td>Asan Medical Center, Seoul, Korea</td>
<td>Adults</td>
<td>50</td>
<td>Grids</td>
<td>7 (14)</td>
<td>1 (2)</td>
<td>8 (16)</td>
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<td>Bruce and Bizz, 2000</td>
<td>Dallas Hospital, Dallas, TX</td>
<td>Children</td>
<td>85</td>
<td>Grids and strips (DE)</td>
<td>3 (3.5)</td>
<td>2 (2.4)</td>
<td>5 (5.9)</td>
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<tr>
<td>Guenon et al. 2001</td>
<td>Hospital P. Wertheimer, Lyon, France</td>
<td>?</td>
<td>100</td>
<td>SEEG</td>
<td>3 (3)</td>
<td>2 (2)</td>
<td>5 (5)</td>
<td></td>
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<td>Rydenhag and Sånder 2001</td>
<td>All Swedish epilepsy surgery centers, Sweden</td>
<td>Children, adults</td>
<td>205</td>
<td>Grids and strips (DE/ESE/FO)</td>
<td>9 (4.4)</td>
<td>4 (2)</td>
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<tr>
<td>Hamer et al. 2002</td>
<td>Cleveland Clinic Foundation, Cleveland, OH</td>
<td>Children, adults</td>
<td>198</td>
<td>Grids</td>
<td>42 (21.2)</td>
<td>18 (9.1)</td>
<td>60 (30.3)</td>
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<td>Simon et al. 2003</td>
<td>Hospital of the University of Pennsylvania, Philadelphia, PA</td>
<td>Children</td>
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<td>22 (32.8)</td>
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<td>Onal et al. 2003</td>
<td>Hospital for Sick Children, London, ON, Canada</td>
<td>Children</td>
<td>35</td>
<td>Grids and strips (DE)</td>
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<td>19 (54.3)</td>
<td>20 (57.1)</td>
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<tr>
<td>Musleh et al. 2006</td>
<td>University of Chicago Children’s Hospital, Chicago, IL</td>
<td>Children</td>
<td>34</td>
<td>Grids and strips (DE)</td>
<td>2 (5.9)</td>
<td>0</td>
<td>2 (5.9)</td>
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<tr>
<td>De Almeida et al. 2006</td>
<td>Montreal Neurological Institute, Montreal, QC, Canada</td>
<td>Adults</td>
<td>224</td>
<td>DE/CE</td>
<td>10 (4.5)</td>
<td>31 (13.8)</td>
<td>41 (18.3)</td>
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<tr>
<td>Burnett et al. 2006</td>
<td>London Health Sciences Centre, London, ON, Canada</td>
<td>Children, adults</td>
<td>116</td>
<td>Grids and strips (DE)</td>
<td>4 (3.4)</td>
<td>2 (1.7)</td>
<td>6 (5.2)</td>
<td></td>
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<tr>
<td>Fountas and Smith 2007</td>
<td>Medical College of Georgia, Augusta, GA</td>
<td>Adults</td>
<td>185</td>
<td>Grids and strips</td>
<td>6 (3.2)</td>
<td>3 (1.6)</td>
<td>9 (4.9)</td>
<td></td>
</tr>
<tr>
<td>Lee et al. 2008</td>
<td>Sanggye Paik Hospital, Seoul, Korea</td>
<td>Children, adults</td>
<td>41</td>
<td>Grids and strips</td>
<td>3 (7.3)</td>
<td>1 (2.4)</td>
<td>4 (9.8)</td>
<td></td>
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<tr>
<td>van Gompel et al. 2008</td>
<td>Mayo Clinic, Rochester, MN</td>
<td>Children, adults</td>
<td>198</td>
<td>Grids</td>
<td>12 (6.1)</td>
<td>20 (10.1)</td>
<td>32 (16.2)</td>
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<tr>
<td>Wong et al. 2009</td>
<td>Westmead Hospital and Children's Hospital, Westmead, Australia</td>
<td>Children, adults</td>
<td>71</td>
<td>Grids</td>
<td>8 (11.3)</td>
<td>10 (14.1)</td>
<td>18 (25.4)</td>
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<tr>
<td>Manohar et al. 2011</td>
<td>Cleveland Clinic Foundation, Cleveland, OH</td>
<td>Adults</td>
<td>50</td>
<td>SEEG</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

*DE, depth electrodes; CE, cortical electrodes; FO, foramen ovale electrodes; SEEG, stereoelectroencephalography. Direct morbidity for invasive recordings in epilepsy surgery: some literature evidence. Complications were reclassified (if possible) as major or minor according to the criteria reported in the main text.
Specific considerations

• Insular Epilepsy
  – Lyon experience (2004): 50pts/144 electrodes
  – No complications
  – Characterized clinical features of insular seizures based on recording and stimulation (laryngeal constriction and paresthesia, dysarthric speech, focal motor convulsive symptoms, no LOC)

• Pediatric population
  – Milan- 60pts: 2-16yo
  – Paris- 65pts:
    – 1) <5yo, 21pts- 90% to resection, 79% Engel class 1
    – 2) >5yo, 44pts-73% to resection, 59% Engel class 1
  – No complications
References

• Munyon C, et al. The 3-Dimensional Grid: A Novel Approach to Stereoelectroencephalography. Operative Nsurg 0(0), 1-7, 2015.
thoughts

- SEEG in Europe for > 50 yrs
- US for 5 yrs
- Outcomes- better than best medical therapy
- Not dramatically different with SEEG vs Grids. Can argue that some grid failures go on to good outcome after SEEG investigation
- European centers- SEEG failure- ? Go to grids
- SEEG mapping limited if not dense electrode placement (3-D grid)
- Emphasis on hypothesis generation