Invasive EEG evaluation
Indications and Selection of techniques

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Outline
• Goals and techniques of presurgical evaluation
• Rationale for the use of invasive evaluation techniques
• Indications of invasive evaluations in epilepsy surgery
• Technical considerations
• Principles, indications and selection techniques
  - Subdural and Depth electrodes
  - Stereoelectroencephalography SEEG
• Extraoperative cortical stimulation
• Seizure Outcome, limitations and complications
• Conclusions
Introduction

- The main indications for an invasive evaluation in focal pharmacoresistant epilepsy are when non-invasively obtained data is insufficient to recommend a safe therapeutic procedure.
- It is reasonable to believe that further information will likely lead to surgical resection.

Presurgical Evaluation
Goals and Technics

- Establish the diagnosis of pharmacoresistant epilepsy
- Mapping of the anatomo-electro-clinical network leading to the identification of the epileptogenic zone and its extent
- Assessment of the functional status of the epileptic regions

Presurgical Evaluation
Formulation of a Testable Hypothesis

- Taking into context:
  - Clinical history, semiology, neurological examination
  - Various noninvasive tests
    - Scalp VEEG, MRI, Functional imaging (PET, Ictal SPECT), MEG, Neuropsychology, Wada test, fMRI
  - Discussion in a multi-disciplinary patient management conference
**Video EEG**

Semiology / Clinical Signs

- Clinical signs which, taken individually, have a **unequivocal localizing value** are rare:
  - Simple lateralized visual hallucinations
  - Contralateral pericalcarin discharge
  - Auditory illusions and hallucinations
  - Superior temporal gyrus / Heschl’s gyrus
  - Déjà vu and vivid “memories”
  - Mesial and lateral aspects of Temporal lobe, Amygdala, Ant Hipp, Sup Temporal gyrus

**Presurgical Evaluation**

Identification of a lesion on MRI (+)

- What?
- Where?
- How many?

**Cortical-Subcortical projections**

- Ascending epigastric sensation
- Insular cortex
- Mesial Frontal cortex

- Focal Cortical Dysesthesia
- Cavernous Angioma
- Hippocampal Sclerosis
- Congenital Tumor
Transmantle Malformation of Cortical Development

Transmantal MCD

Presurgical Evaluation

no identification of a lesion on MRI (-)

- A non lesional epilepsy is most often defined based on the lack of definite MRI abnormalities using the state of the art MRI sequences and highest magnet strength available

- Epileptologist and expert neuroradiology analysis

- The rates among surgically treated patients range from 3% to 21% and results of epilepsy surgery are also usually considered to be less satisfactory
Invasive Evaluation
Indications

• The anatomical location of the MRI-identified lesion is not concordant with the electro-clinical hypothesis.

Invasive Evaluation
Indications

• There are two or more anatomical lesions with the location of at least one of them being discordant with the electro-clinical hypothesis.

• Both lesions are located within the same functional network and it is unclear if one (or both) of them is (are) epileptic.

Invasive Evaluation
Indications

• The generated anatomo-electro-clinical hypothesis (MRI-negative or MRI-identifiable lesion) involves a potentially highly eloquent cortex.

• The identification of the epileptogenic zone, mapping of its extent, and/or its relationship with potentially eloquent cortex are not typically resolved in these cases.
**Invasive Evaluation**

**Indications**

- The MRI does not show a cortical lesion in a location that is concordant with the electro-clinical/functional hypothesis generated by non-invasive data (MRI negative)

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**Subdural and Depth Electrodes**

**Principles and Indications**

- Extra-operative mapping with the subdural method has the main advantage of allowing an optimal coverage of the subdural space adjacent cortex with adequate and continuous superficial functional mapping capabilities
3D reconstruction of subdural and depth electrodes

Intraoperative photograph showing the left hemisphere covered by subdural and depth electrodes

Types of Subdural Interictal Discharges

- Isolated spikes
  - Amplitude >200 µV, frequency >7 Hz, irregular firing
- Repetitive spikes
  - Burst duration > 0.5s, amplitude >200 µV, frequency ± 7-10 Hz, regular firing
- Runs of slow repetitive spikes
  - Burst duration > 0.5s, amplitude >200 µV, frequency < 7-10 Hz, regular firing

Boonyapisit. et al. Epilepsia 2003

Repetitive Spikes, Left Inferior Frontal

Boonyapisit. et al. Epilepsia 2003
EEG Seizure, Onset

With Clinical Signs – 4 recorded

EEG Seizure (SB35-39 and depths)

EEG Seizure, +15 sec
Subdural and Depth Electrodes

Outcomes

- The best resective surgical outcomes following SDG implantation are achieved in patients with clear cortical lesions (in particular tumors).

- Those patients with clear cortical surface lesion(s), in particular those patients where the main indication for the invasive evaluation is electro-functional eloquent cortex mapping in the setting of a superficial cortical lesion.

Subdural and Depth Electrodes
Relationship to Pathology

- Most intrinsically epileptogenic lesions where ECoG is likely to show reliable pathological patterns:
  - Focal cortical dysplasia
  - Glioneuronal tumors

Ferrier. et al. Epilepsia 2006

Pathology and IEEG patterns

- Paroxysmal Fast and repetitive spikes
  - More common in FCD type 2


Predictors for Seizure Recurrence

- Ictal onset at edge of plate 14%
- Diffuse ictal onset 29%
- > 1 ictal onset zones 35%
- Morphology of ictal onset not significant

Kalamangalam. JCNNP et al. 2009
Kim DW. et al. Epilepsia 2010
### Predictors for Seizure Recurrence

**Extent of Resection**

- Ictal and interictal activity completely resected – 80%
- Incomplete ictal resection 26%
- Incomplete interictal resection 42%

Widdes-Walsh et al. Neurology, 2007
Kim DW. et al. Epilepsia, 2010

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### Subdural and Depth Electrodes

**Stimulation Parameters**

- Duration = 5-7 seconds
- Frequency: 50 Hz
- Duration: 0.3 msec
- Amplitude: 1-15 mA

Nair DR, et al. Clinic Neurophysiol. 2008

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### Subdural grids and depths

**Limitations and complications**

- Most patients who are implanted with SDE tolerate the procedure well
- The main limitations of SDG include surgical morbidity risks, and the spatial/cortical sampling limitations
- Meta-analysis (n=2542 patients / 5 deaths)
  - Infections: 1.8%-3%
  - Intracranial hemorrhage: 4%
  - Acute Focal Neurological deficits 4.6%

Arya R et al, Epilepsia 2013
SEEG Studies the Epileptic Network

Stereotactic placement of depth electrodes in medically intractable epilepsy

SEEG Indications

- The possibility of a deep-seated or difficult to cover location of the EZ in areas such as the opercular areas, cingulate gyrus, posterior orbitofrontal areas, insula, and depths of sulci.
- The need for extensive bi-hemispheric explorations (in particular in focal epilepsies arising from the interhemispheric or deep insular regions).
- Presurgical evaluation suggestive of a functional network involvement (e.g., limbic system, parietal-frontal system, parietal-temporal system, etc.) in the setting of normal MRI.
Post –Op MRI and Pathology

SEEG

Limitations and Complications

• In neocortical epilepsy and particularly when generator is located over the convexity depth electrodes may suffer from poor sampling
• SEEG is not well adapted to map functional areas during neurostimulation
• Meta-analysis (n=2624 patients / 5 deaths)
  • The overall complication rate 1.3%
  • Infections: 0.8%
  • Intracranial hemorrhage 1%

Mullin J. et al, Epilepsia 2016

Complications

• Disoriented patients may pull on electrodes and cables
  - system for easy detachment of connectors
• Light microscopic examination of cortical sites of cortical stimulation showed no changes attributed to electrical stimulation

Gordon et al. 1990
Cortical Mapping

Subdural and Depth Electrodes
Stimulation Parameters

Nair DR, et al. Clinic Neurophysiol. 2008

SEEG
Stimulation Parameters

Cortical Mapping
Mapping somatic sensorimotor cortex

- **Primary motor cortex:**
  - Contralateral muscle tonic or clonic movements

- **Primary somatosensory cortex:**
  - Contralateral paraesthesia:
    - most frequently tingling, numbness, burning
    - less frequently painful sensations
  - Premotor cortex:
    - Arrest of ongoing motor activity (fine distal movements) with or without contralateral or ipsilateral decreased or increased motor tone
    - Head and eye turning in the direction contralateral to stimulation (adverse rotation)

- **Supplementary motor area:**
  - Aversive eye movements
  - Variety of movements and dystonic postures
  - Arrest or slowing of voluntary movements and speech
  - Sensations

- **Second sensory area**
  - Similar responses to those describe in primary sensory area
  - Pain

Cortical Mapping
Mapping language

- Arrest of ongoing speech and disturbance in speech understanding
  - Tasks: (clinically relevant for each individual case)
    - spontaneous speech
    - reading
    - word repetition
    - object description
    - comprehension
  - Basal temporal language area
    - expressive, receptive and repetition deficits
    - anomia
Cortical Mapping
Mapping visual cortex

- Phosphenes (flickering lights, dancing lights, stars, colors, shades, gray spots)
- Elementary visual shapes (lines, whirling circles) seen in the contralateral visual field
- Resections should also spare visual pathways, such as optic radiations and other connections that can be identified by electrical stimulation

Conclusions

- The areas of the brain where electrodes will be implanted should be selected, based on a very careful analysis of all the data collected during the noninvasive presurgical investigations
- Clear hypothesis and clear questions will lead to a good implantation strategy with the most appropriate techniques
- Only a good implantation will lead to a good surgical outcome

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