Using Intracranial Video EEG for Localization

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Disclosures

- Research Support: Eisai Inc., Monteris Medical, Neuropace, UCB Phamaceuticals
- Consulting: Basilea Inc., Blackthorn Therapeutics, Livanova Inc., Monteris Medical, UCB Pharmaceuticals
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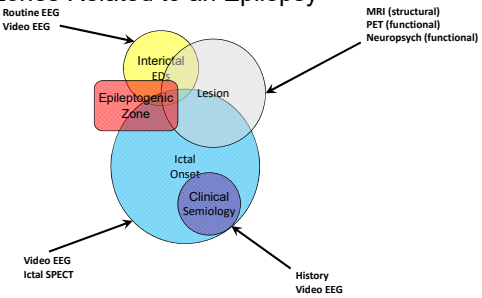
Objectives

- Discuss indications for intracranial EEG monitoring
- Review technical aspects of iEEG: electrode types and placement, recording parameters, logistics of data review
- Review and through examples discuss interpretation of iEEG: interictal and ictal findings

Brain Zones Related to an Epilepsy



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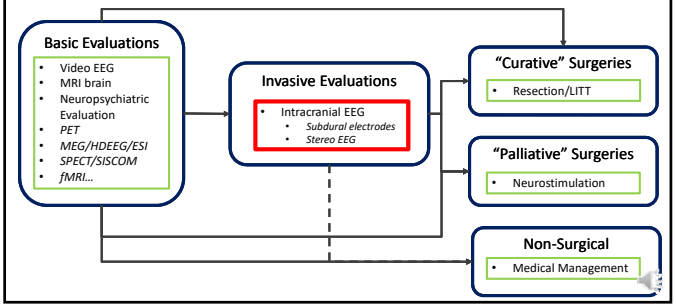
Evaluation for Epilepsy Surgery



The Perfect Surgical Candidate

- Lesional
- Scalp EEG
  - Well-localized pattern
  - EEG onset before or close to clinical onset
  - Location consistent with seizure semiology
  - Location consistent with lesion
- Not near eloquent cortex
  - Language, motor, primary visual, etc.
- Low risk of multifocal disease – e.g., unilateral MTS, tumor, vascular malformations

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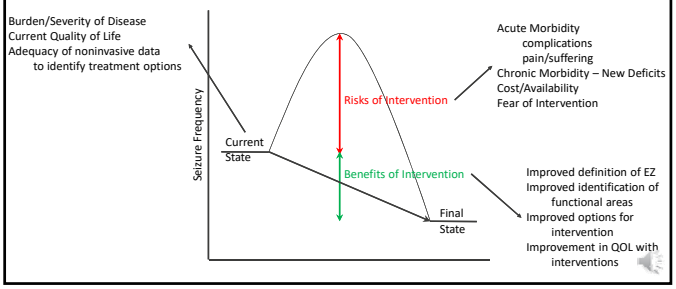
Red Flags from Non-invasive Testing

- Non-lesional
- Discordant data
  - Scalp EEG non-lateralizing/non-localizing
  - EEG onset after clinical onset
  - Scalp EEG localizes away from known lesion
  - EEG/imaging does not match clinical semiology
    - Versive eye/head deviation
    - Focal dystonic posturing
    - Focal clonic movements
    - Focal sensory symptoms
- Etiology of seizures
  - Post-infectious
  - Post-traumatic
  - Tuberous sclerosis/cortical dysplasia

Indications for IEEG

- Define epileptogenic zone
  - Noninvasive data inconclusive or divergent
- Mapping of eloquent cortex
  - Noninvasive data suggests close proximity
- Indication for not doing IEEG
  - Likelihood of desirable outcome(s) too low to justify risks/costs
  - Low likelihood of altering the likely intervention/treatment

Risk Benefit Analysis for IEEG



Considerations for IEEG

- Must be hypothesis driven!!!
  - Main candidate for epileptogenic zone
  - Alternative candidate(s) for EZ
  - Functional areas to identify and include/exclude

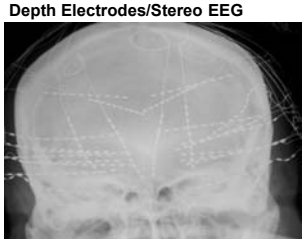
Anatomo-Electro-Clinical Hypothesis

- Hypothesis based on:
  - Clinical history
  - Seizure semiology
  - Preoperative imaging
  - Video EEG/supportive data

Approaches to Invasive Monitoring

Subdural Electrodes

Depth Electrodes/Stereo EEG



SDE vs SEEG

Subdural Electrodes

- Advantages
  - Cover large contiguous cortical areas
  - Mapping of eloquent cortex
- Disadvantages
  - Poor coverage of deep structures and structures on mesial/inferior aspects
  - Usually more uncomfortable for patient
  - Surgery often performed at time of explantation – limited time for decision making

Depth Electrodes/SEEG

- Advantages
  - Access to deeper structures
  - Allows for sampling over larger areas (e.g., bilateral, multiple lobes)
  - Allows for longer implantations
  - Craniotomy not needed
- Disadvantages
  - Limited coverage of contiguous areas
  - Limited electrodes in contact with gray matter
  - Greater requirement for understanding of networks/semiology
  - Limited ability to map

Additional Stereo-EEG Limitations

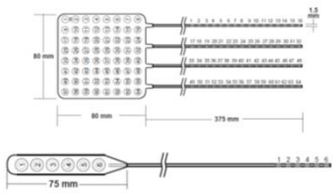
- "Blind" procedure: limited control of intracerebral bleeding
- Significant time required for placement of larger numbers of electrodes in OR
- Age limitation – thickness of skull

SEEG vs SDE Complications (Meta-Analysis)

	SEEG	SDE
Overall Complication Rate	1.3% (0.9-1.7%)	
Hemorrhage	1.0% (0.6-1.4%)	4.0% (3.2-4.8%)
Infection	0.8% (0.3-1.2%)	2.3% (1.5-3.1%)
Permanent Neurological Deficits	0.6% (0.2-1.0%)	0.5% (0.2-0.8%)
Transient Neurological Deficits	0.6% (0.1-1.1%)	4.6% (3.2-6.0%)

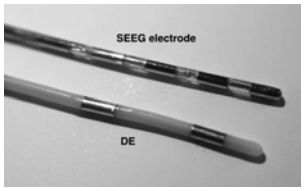
Mullin JP et al. (2016), *Epilepsia* 57: 386
Arya R et al. (2013), Epilepsia 54:828-39

Subdural Electrodes



- Grids/Strips in various configurations/shapes
- Electrode spacing: typically 1.0 cm (can be 0.5 or other)
- Electrode size: 4.0mm disk but 2.3mm exposed area
- Material:
  - Platinum/platinum-iridium alloy for implantation
  - Stainless steel offered for acute use

SEEG Electrodes



Electrodes
- Depths with closely spaced contacts
  - Typically 2-8 mm spacing
  - Contact size: 1.32-2.50 mm
  - Diameter: 0.86-1.26 mm
- Options:
  - Constant spacing – more traditional
  - Variable spacing with constant number of contacts

- Material:
  - Platinum/platinum-iridium alloy for implantation

Recording Logistics

- Location of electrodes:
  - Critical to know which electrode is which at the surface (especially for SDE)
  - Epileptologists/technologists should be in OR!!
- Reconstruction:
  - Preoperative MRI
  - Postimplantation CT/skull x-rays or MRI
  - Can use
    - Physical model
    - Commercial Software: Curry, BrainLab, etc.
    - Free Software
    - Others

Recording Logistics

- Reference/Ground Electrodes:
  - Two scalp electrodes
  - Inactive implanted contacts
  - Implanted ground
    - Strip facing away from brain under skull (for SDE)
    - Depth under scalp
- Recording Parameters
  - Sampling rates: minimum 400Hz, often much higher
  - Generates much higher volume of data – may reduce performance of software depending on networks/computers

Reviewing Data – Practical Issues

- Screen size/resolution/orientation
- Filter settings: 1 – 100 Hz or 1 Hz high pass only
- Montage:
  - Referential
  - Bipolar
- # of channels
  - Exclude channels that are not in areas of interest – e.g., white matter or external to surface of brain
  - For screening:
    - Referential: every other channel
    - Bipolar: no chains:
      - 1-2, 3-4, 5-6, 7-8 instead of 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8

Reviewing Data – Practical Issues

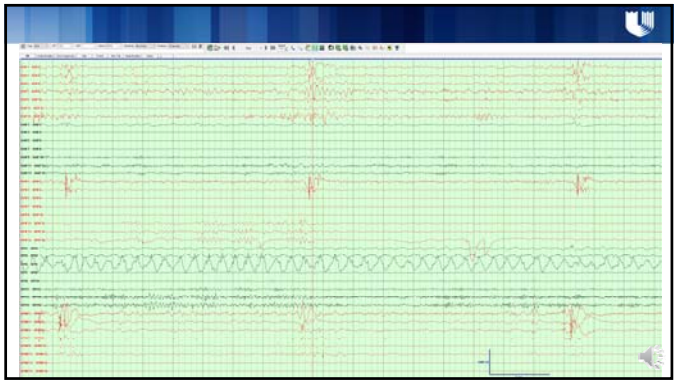
- Review all data:
  - Higher likelihood of subclinical/electrographic seizures
  - More onerous and often slower
- Concern for atypical discharges or events related to irritation of implantation

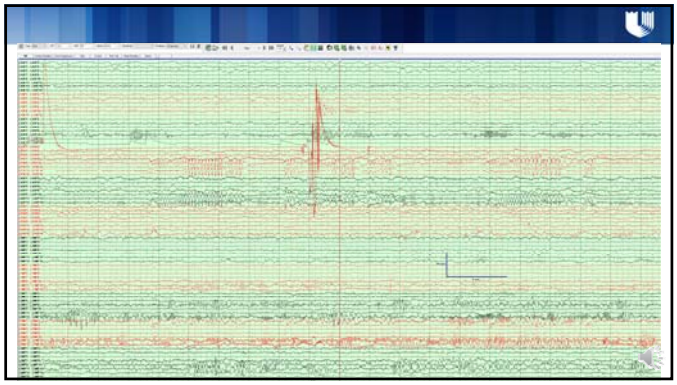
Interpretation

- Interictal background – normal activity not well defined
  - Frauscher B et al. (2018), Brain 141(4):1130-1144

Frontal	Beta activity (20-24 Hz)	Prominent beta in precentral gyrus
Occipital	Alpha peak (9.25-10.25 Hz)	
Parietal	Intermediate alpha (8.25-9.25 Hz) Beta (17-20 Hz)	
Temporal	Lower alpha (7.75-8.25 Hz) Delta (0.75-2.25 Hz)	

  - Kalamangalam GP et al. (2020), Clin. Neurophysiol. 131:665-675





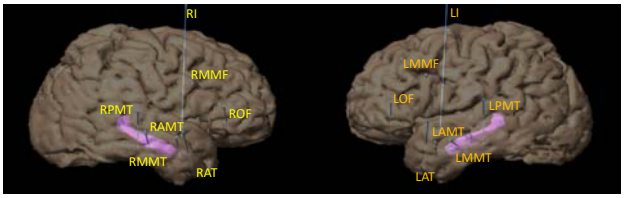
Ictal Patterns

- Like scalp EEG, many different patterns at onset (Lagarde S. et al. (2019), *Epilepsia* 60(1):85-95)
  - LVFA
  - LVFA preceded by spikes, polyspikes or slow wave/DC shift
  - } 79%
  - Sharp theta/alpha/beta waves
  - Rhythmic spikes/spike-waves
  - Other: delta brush
- May reflect types of pathology, proximity to actual epileptogenic zone (versus area of spread), brain region
- Possibly related to outcome – better for LVFA group?

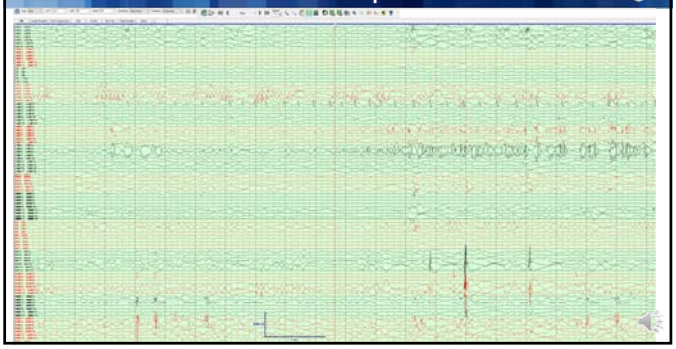
55 y/o LH M

- Onset: 55 y/o (likely earlier)
- Risk factors: none
- Seizure type/frequency:
  - Focal with impaired awareness: staring, oral automatisms; 2-3/week
- Past ASM: VPA, OXC, LEV, LTG
- Imaging: MRI normal; subtle hypometabolism R>L T
- VEEG: R>L T sharp waves; 10 seizures, 2 from R, 7 from L; 1 unclear
- Neuropsych Testing: weakness in learning (verbal and visual); verbal fluency

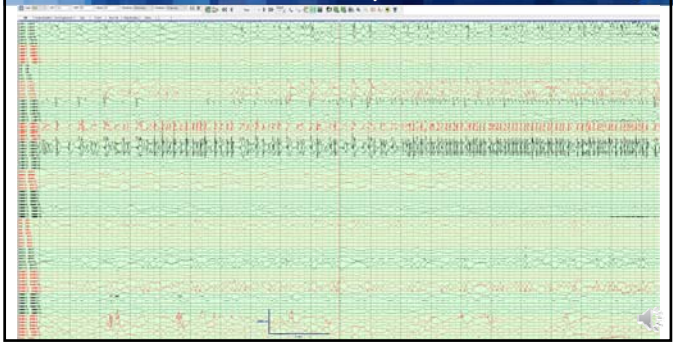
Bilateral Temporal Exploration



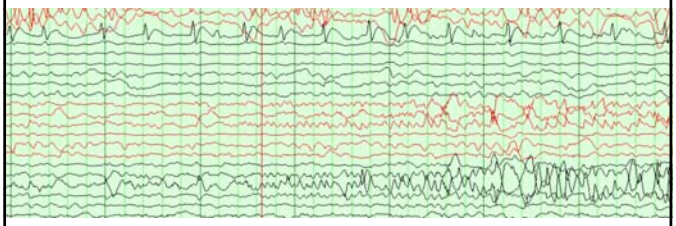
Bilateral mesial temporal onset



Bilateral mesial temporal onset



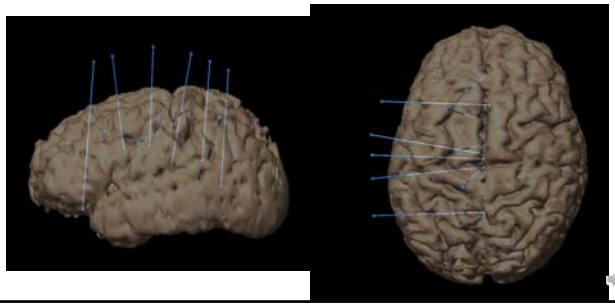
Bilateral mesial temporal onset



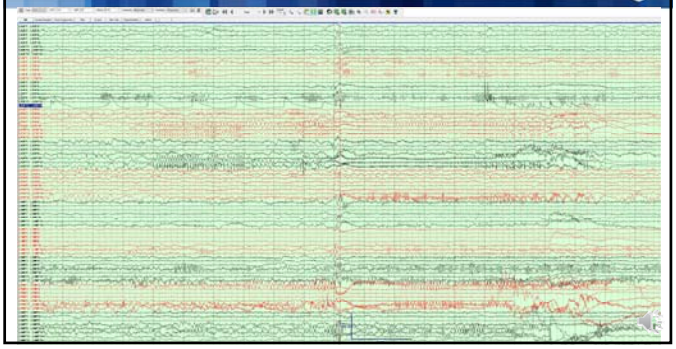
28 y/o RH F

- Onset: 7 y/o
- Risk factors: family history
- Seizure types/frequency
  - Focal Aware: bicycle motion of R leg → torso/arm; 1/week
  - Focal to Generalized: rare
- Past AEDs: LEV, LTG, OXC, LAC, PMP, CLB
- Current AEDs: LAC 200mg BOD; CLB 10mg BID
- MRI brain: normal
- VEEG: ictal pattern in central leads only, possibly L>R

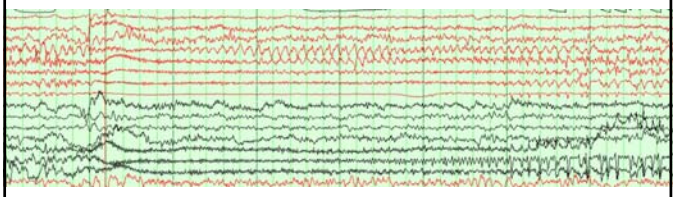
Implantation



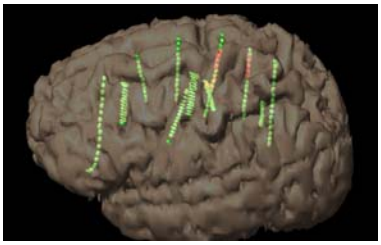
Fronto-Parietal Onset



Fronto-Parietal Onset

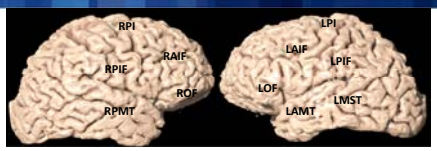


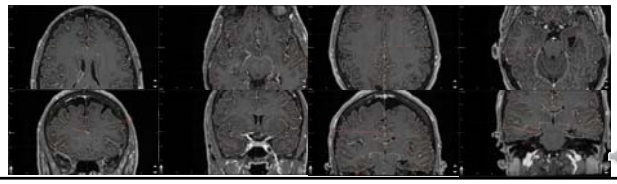
Outcome

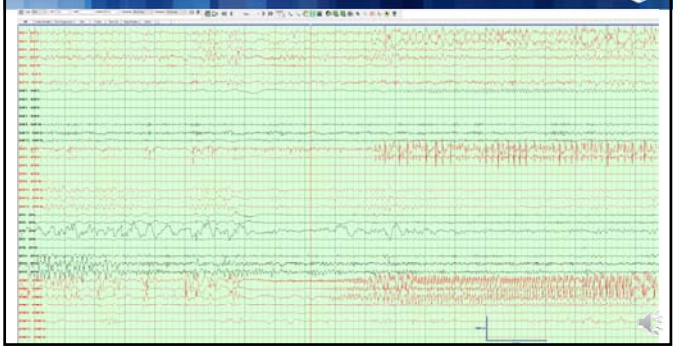


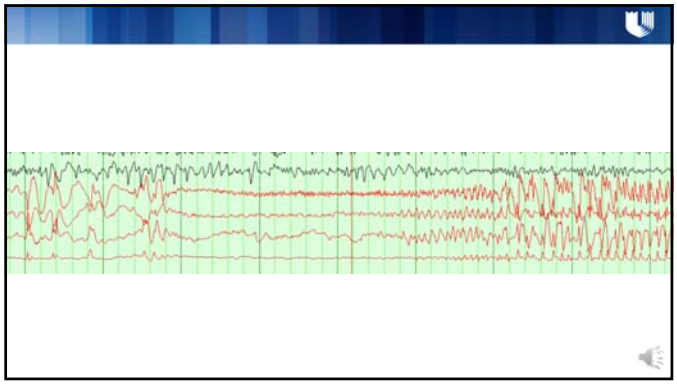
35 y/o RH M

- Onset: 23 y/o
- Risk factors: moderate TBI, few months prior
- Seizure types/frequency:
  - Focal with impaired awareness: change in stance, eyes dilate, drooling, B hand automatisms, currently 2/week
- Seizure free x14 months after L mesial T ablation, but then returned, same semiology
- Imaging: initially non-lesional; now s/p L mesial T LITT with residual amygdala
- ASMs: currently Cenobamate, CBD, LAC, LEV, PMP (many others in past)
- Previous IEEG with B temporal subdural strips: B spikes; 11 clinical seizures from L; 33 electrographic seizures from L
- VEEG: B T interictal discharges, 5 seizures with R onset, 2 poorly localized



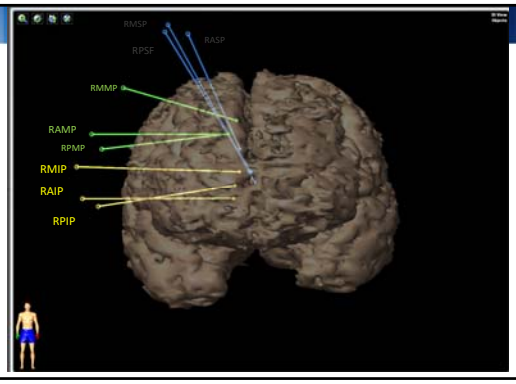


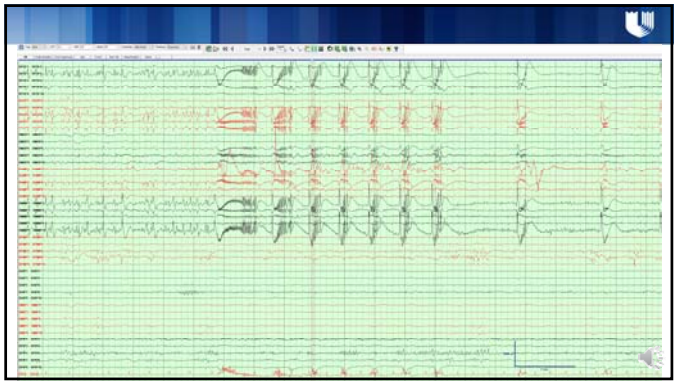




33 y/o RH M

- Onset: 20 y/o
- Risk factors: mild TBI
- Seizure types:
  - Stabbing pain in L abdomen, jerking of L leg, may progress to convulsion
- Seizures: 3-4/day
- Meds: LEV 1500mg BID; LAC 200mg BID
- Failed Meds: CLB, EZG, LAC, LTG, LEV, PHT, VPA → ZON, OXC, PGB
- MRI brain: normal
- VNS: inadequate response





Summary

- IEEG is a powerful tool to aid in precise definition of the epileptogenic zone and identification of functional areas
- IEEG must be hypothesis driven and well-planned
  - Risks are low but definite
  - Complication and bad outcomes will happen!
- IEEG interpretations requires expertise and time