MAYO CLINIC

High density EEG

Role in epilepsy surgery evaluation, with case demonstrations

Anteneh M. Feyissa, MD, MSc.
Assistant Professor of Neurology
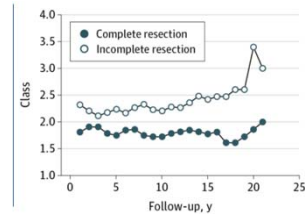Mayo Clinic
Jacksonville

Prelude

- The epileptogenic zone cannot be localized by a single method

Rosenow and Lüders, 2001. Brain 124:1683-1700.

Disclosures

- None

MRI-Negative Epilepsy

- Without potentially epileptogenic lesion regardless of final histopathology

Radhakrishnan et al., 1998. Neurology 51:465-471.
Kim et al., 2017. JAMA Neurol 63:24-331.
Shi et al., 2017. Epilepsy Res 133:103-108.

Objectives

- Recognize the value of hdEEG in epilepsy surgery evaluation
- Describe visual hdEEG analysis using illustrative cases
- Describe EEG source imaging using illustrative cases

Implications beyond outcome

- No anatomical structure to guide surgical resection
- Location & extent of implantation not readily apparent
- Risk of complications by 40% for every 20 additional electrodes

Affordable and accessible means to localize the epileptogenic zone

Courtesy of Dr. So

Hamer et al., 2002. Neurology 58:97-103.

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Localizing the epileptogenic zone

- Advanced MRI
- SISCOM/SPM
- PET MRI
- MEG/MSI
- MR spectroscopy
- EEG-fMRI
- DTI/DSI (Connectomes)

Work flow
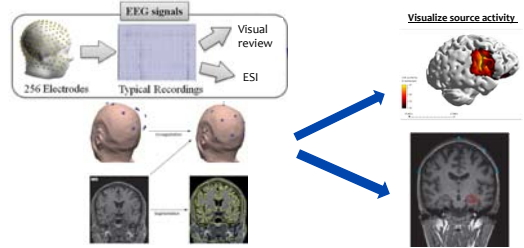
Pros & Cos

- **Advantages**
  - **Non-invasive**
  - **Non-lesional to lesional (PET MRI)**
  - **Prognostication (PET/SISCOM)**
  - **Detection of mild MTS (MRS)**

	FDG PET	SISCOM/SPM	MEG/MSI*
Concordance with icEEG, nonlesional	19%-69%	64-82%	20-100%
Prediction of Engel class I outcome	75-88%*	55%-70%	38-86%
Cost (interpretation)	>$1500*	> $3,600	>$2000
Availability	Ubiquitous	Limited	Limited

How about adding more electrodes?

How many electrodes?

- Max 2–3 cm of IE distance =less distortion of potential distributions
- Higher numbers of electrodes =smaller dipole-localization errors
- Precision of source localization is nonlinear, plateau at 100
- Consider placing more electrodes over the region of interest

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High density EEG (hdEEG)

- As many as 256 channels (1-2cm)
- Improves spatial sampling by reducing distance btn. electrodes
- Computer-assisted EEG source analysis methods (ESI)


Visual analysis

- Commonly used in routine clinical practice
- Simple unlike mathematically complex and non-intuitive-ESI
- Does not require additional software
- Not a precise tool for the identification of epileptogenic zone
- Limited insight into the extent of the involved cortical network
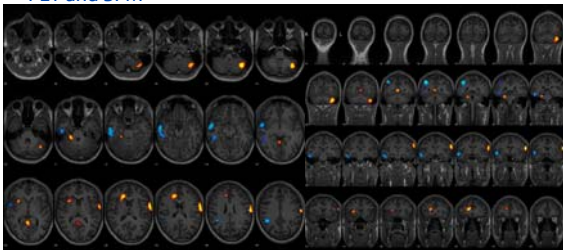

Case 1

- 21 yo RH M with refractory stereotyped sleep-related seizures
  - Grunts and might hold his laughter like a "child in a church"
  - Body turning and some unusual mouth movements
  - Symmetric bilateral arm and leg extension and stiffening
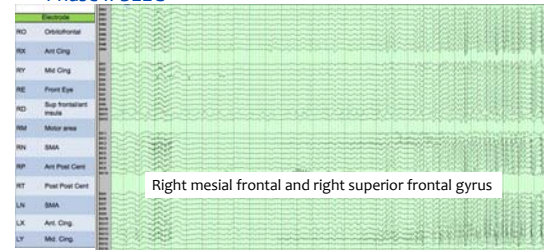- 10-20 EEG: non-lateralizing (midline)
- MRI-ve

Ictal EEG
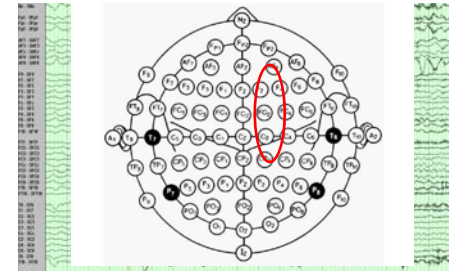
PET and SPM

Phase II-SEEG

Right mesial frontal and right superior frontal gyrus

Seizures abated with lifestyle changes and add on CBZ
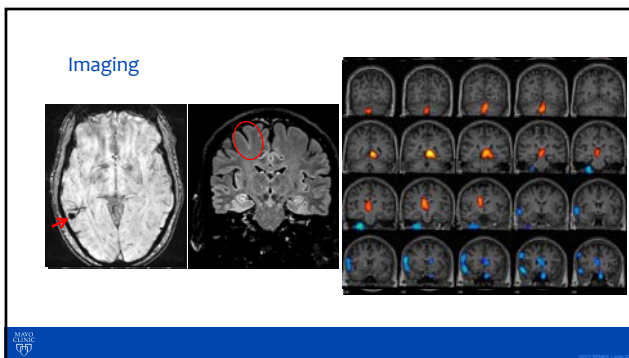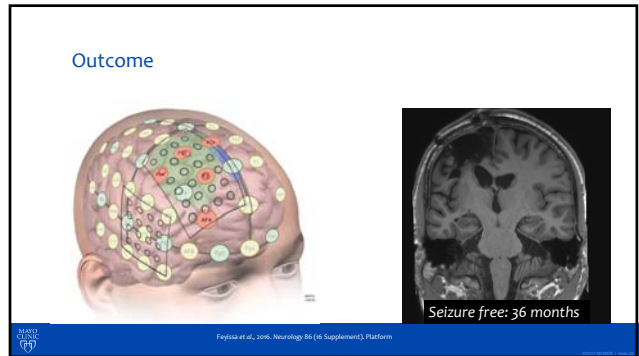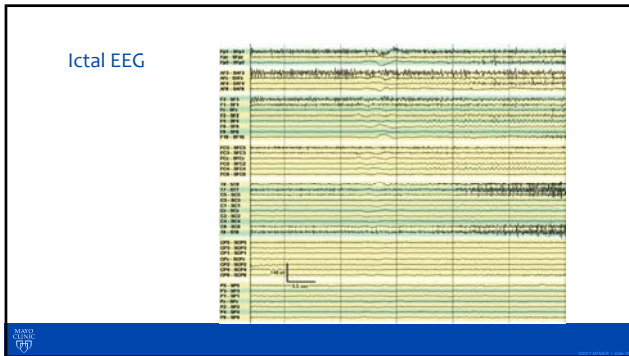
Interictal EEG

Case 2

- A 34 years old right handed man with drug resistant focal epilepsy
  - An aura consisting of an out-of-body kind of experience + deja vu
  - Staring blankly, loss of awareness, unresponsiveness,
  - Suddenly laughter, and lastly hypermotor behavior
  - With GTCs

Ictal EEG

Outcome
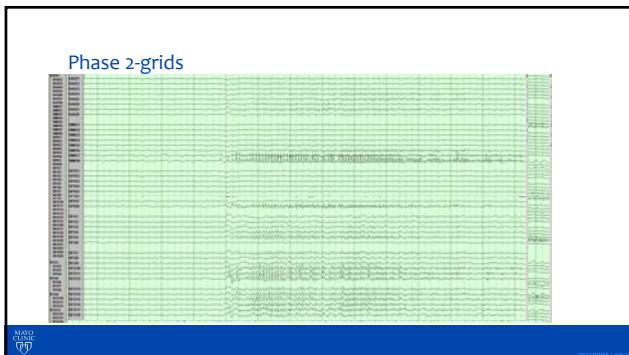

Seizure free: 36 months

Imaging

hdEEG in FLE

- The 10-20 system in FLE
  - short seizure duration
  - fast cortical spread
  - motion and muscle artifact
  - suboptimal spatial distribution
  - false lateralization from MF

Nonlocalizing, pseudodiffuse, or wo correlate

Phase 2-grids

Visual hdEEG in suspected midline FLE

	Lobar concordance with iEEG*	Lateralization concordance with iEEG**
hdEEG (10-10 sys)	12/14	14/14
Conventional EEG	3/14	9/14
SISCOM/SPM	2/12	3/12

hdEEG vs SISCOM, p <0.01 and vs conventional EEG, p<0.01.
**hdEEG vs SISCOM, p <0.01 and vs conventional EEG, p=0.04.
hdEEG: dense array; iEEG: intracranial recording; SISCOM: subtraction ictal SPECT co-registered to MRI.

All cases with diffuse hdEEG ictal onset also had diffuse iEEG onset!

Consider placing more electrodes over the region of interest!

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EEG source imaging (ESI)

- Co-registration of the electric source estimations with MRI
- Signal processing techniques to estimate current sources
- Insight into the extent of the involved cortical network
- Identify the electric sources underlying epileptogenic activity

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Inverse solution

- The problem of identifying the source of a given surface field potential

- Equivalent current dipole (ECD) vs distributed source models

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Inverse solution

- The problem of identifying the source of a given surface field potential
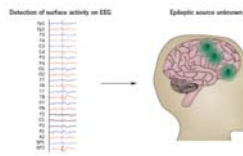
- Equivalent current dipole (ECD) vs distributed source models
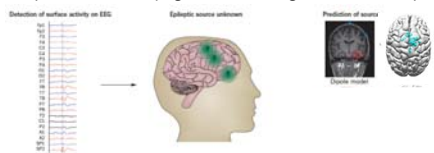

Utility of ESI in epilepsy

- Identification of the irritative zone (spikes and/or sharp waves)
- Identification of the ictal onset zone (EEG seizure onset)
- Identification of seizure networks (seizure propagation)

Inverse solution

- The problem of identifying the source of a given surface field potential

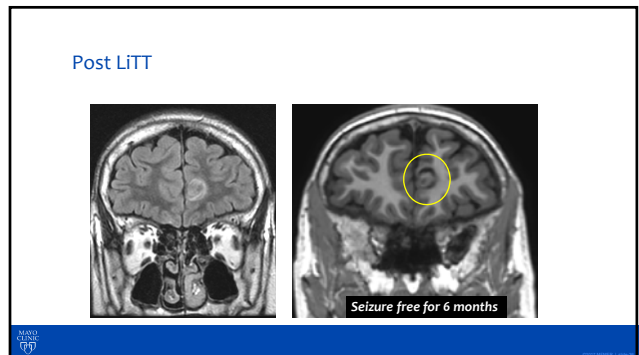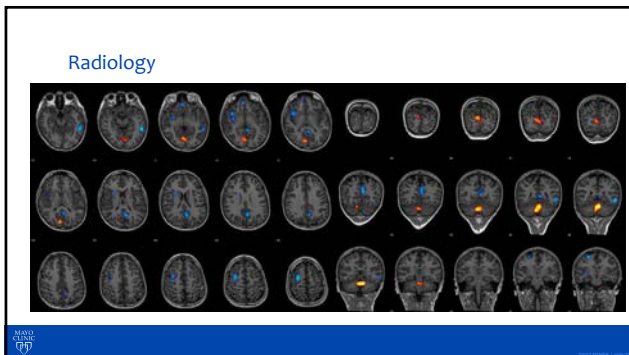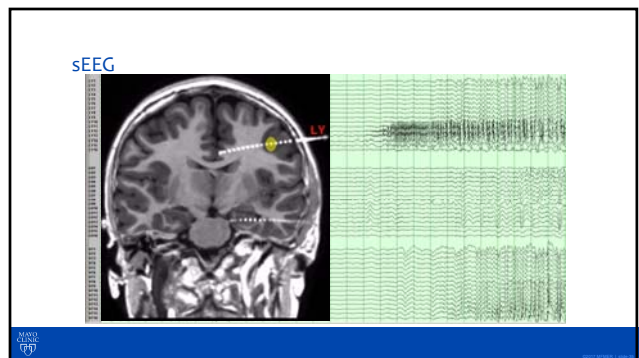- Equivalent current dipole (ECD) vs distributed source models

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Case 3

- A 13 yo RH boy with medically intractable focal epilepsy
  - Confused followed by generalized convulsive activity with UI
  - Nocturnal events of starring off, nonspecific vocalization with UI
  - 2-3/week
- MRI –ve (initial read)

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ESI-sLORETA

Courtesy of B. Brinkmann *unpublished* 2018

sEEG

	Electrode	
LF	Left Mesial Frontal FCD- anterior	
LN	Left Mesial Frontal FCD- posterior	
LX	Anterior Cingulate	
LY	Mid Cingulate/ Posterior Frontal	
LZ	Posterior Temporal	
LC	Hippocampal Tail	
LB	Hippocampal Head	
LO	Orbitofrontal	
VT	Visualise Track	

ESI-sLORETA

Courtesy of B. Brinkmann *unpublished* 2018

sEEG

Radiology

Post LiTT

Seizure free for 6 months
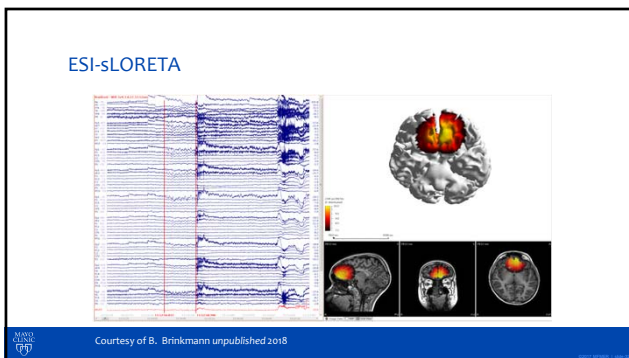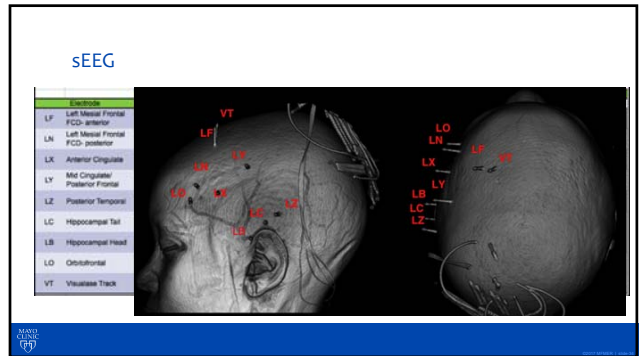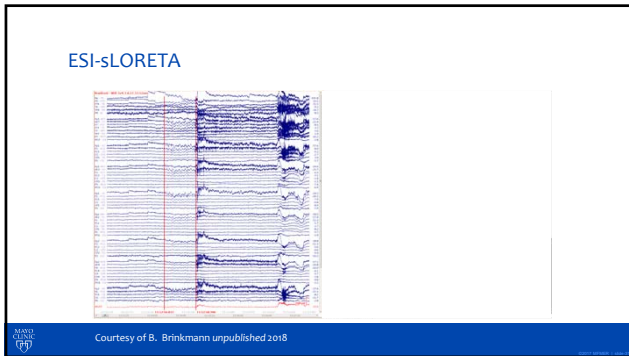
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Case 4

- A 70 yo RM with lesional drug resistant epilepsy
  - Aura of indescribable "funny feeling"
  - Then speech arrest
  - Posturing on the left and post-ictal paresis on the left
  - 1-2/month; GTC X2
- MRI negative but later fMRI revealed suspicious Rt. SMA FCD

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fMRI...
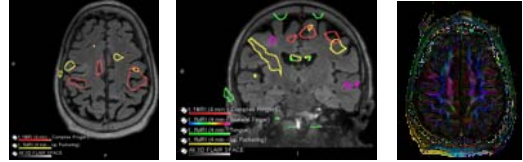
- Concern for eloquent cortex seizure onset zone
- Patient offered RNS vs Chronic subthreshold cortical stimulation
- Patient still considering his options

Interictal

Courtesy of B. Brinkmann *unpublished* 2018

What do we know?

	# of patients	concordance with iEEG or outcome
Interictal ESI		
Brodbeck et al., 2010	10	80%¥
Wang et al., 2011	7	100%
Brodbeck et al., 2011	152	84%,88%*
Mégevand et al., 2014	32	80%
Ictal ESI		
Holmes et al., 2010	10	80%
Beniczky et al., 2016	22	73%
Nemtsas et al., 2017	14	93%
Visual Inspection		
Feyissa et al., 2017	14	86%, 100%

*Why hasn't it become a standard of care?*

Need user-friendly and easy-to-use ESI software

Brodbeck et al., 2010. Epilepsia 51:583-591.
Holmes et al., 2010. Neurosurgery 66:354-362.
Wang et al., 2011. Clin Neurophysiol 122:1098-1105.
Brodbeck et al., 2011. Brain 134:2887-2897.
Mégevand et al., 2014. J Neurol Neurosurg Psychiatry 85:38-43.
Beniczky et al., 2016. Seizure 43: 1-5
Nemtsas et al., 2017. Epilepsia 58:1027-1036.
Feyissa et al., 2017. Epilepsy Res 129:157-161.

Radiology
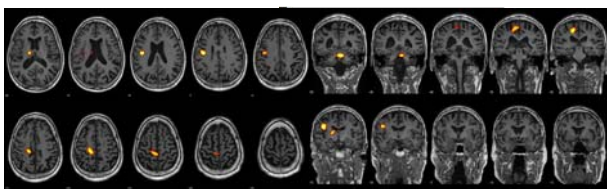
Last word

- hdEEG improves identification of potential candidates for iEEG & surgery
- Early integration may help identify cases with a low yield iEEG
- Consider placing more electrodes over the region of interest
- ESI is a promising tool and deserves a role in epilepsy surgery evaluation

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