

Invasive EEG evaluation

Indications and Methods

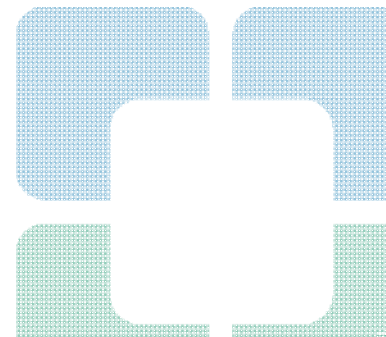
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Neurological Institute
Cleveland Clinic
2020



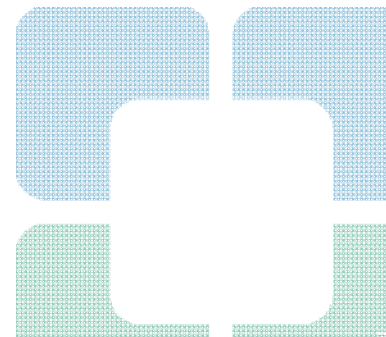
Outline

- Rationale for the use of invasive evaluation techniques
- Indications of invasive evaluations in epilepsy surgery
- Methods
 - Acute intraoperative ECOG
 - Subdural and Depth electrodes
 - Stereoelectroencephalography SEEG
- Limitations and complications
- Conclusions



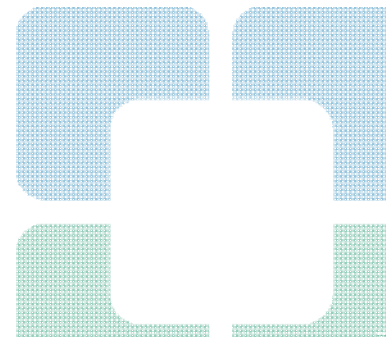
Rationale for the use of invasive evaluation

- Noninvasive testing at times fails to provide adequate information to plan surgery, where the central question is about identification and localization of the “epileptogenic zone” (EZ) and its relation with cortical and subcortical eloquent cortex.
- And it is reasonable to believe that further information will likely lead to surgical resection.



Indications of invasive evaluation in Epilepsy Surgery

- MRI-negative cases
- Electroclinical and MRI data discordance
- Overlap with eloquent cortex
 - Localize motor, sensory and language function



MRI-negative

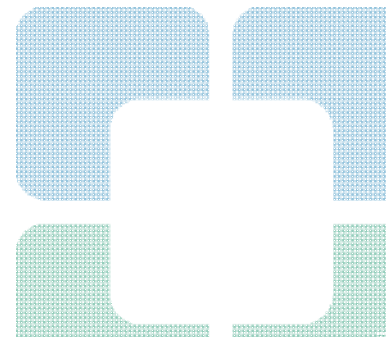
Illustrative case

- Adult, right handed
- Aura: mixture of “weird feelings”: (fuzzy feeling in her head, strange feeling in the stomach, floating sensation), it will progress to visual hallucinations such as “everything becomes black or blue color”.

Aura followed by repetitive chewing/swallowing.

During the seizure patient has naming problem, word finding difficulty, unable to repeat sentence fluently while maintaining awareness (following verbal command).

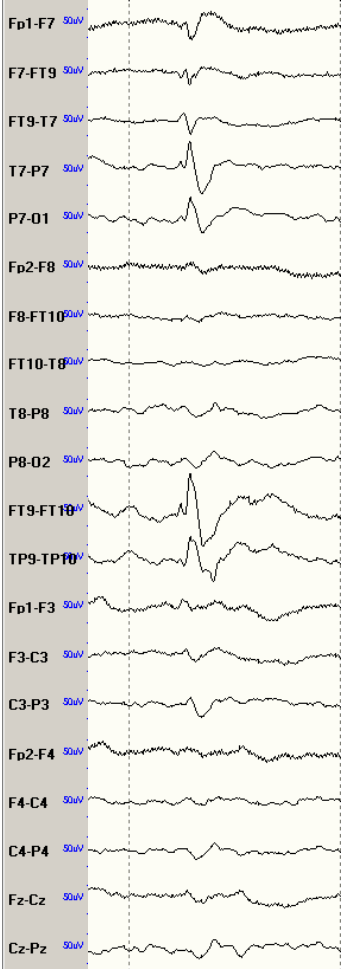
Postictally, can not get words out while knowing what she wanted to say.



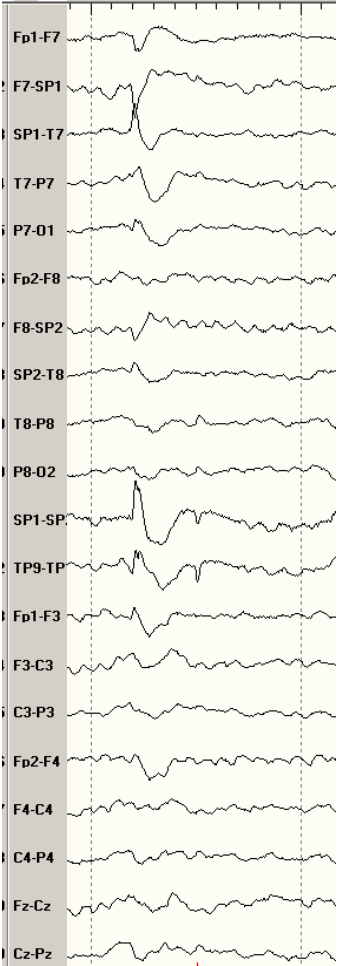
MRI-negative

Illustrative case

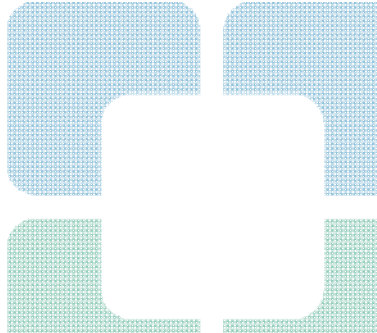
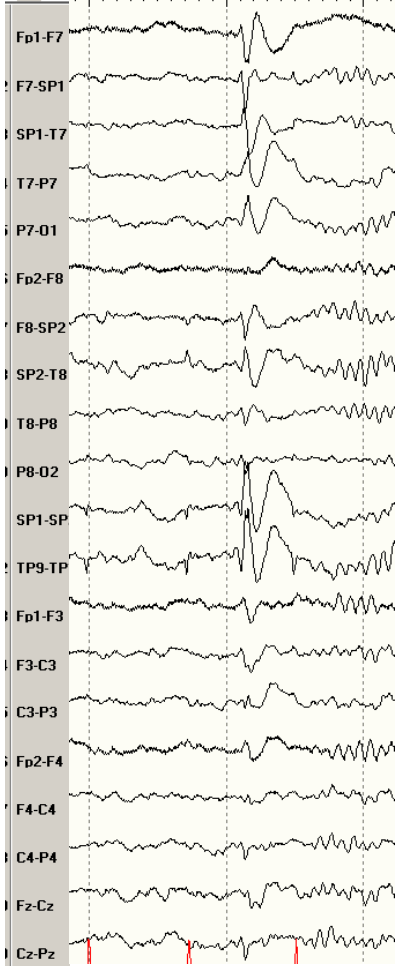
T7/T9/TP7



Sp1/T9/FT9/F9

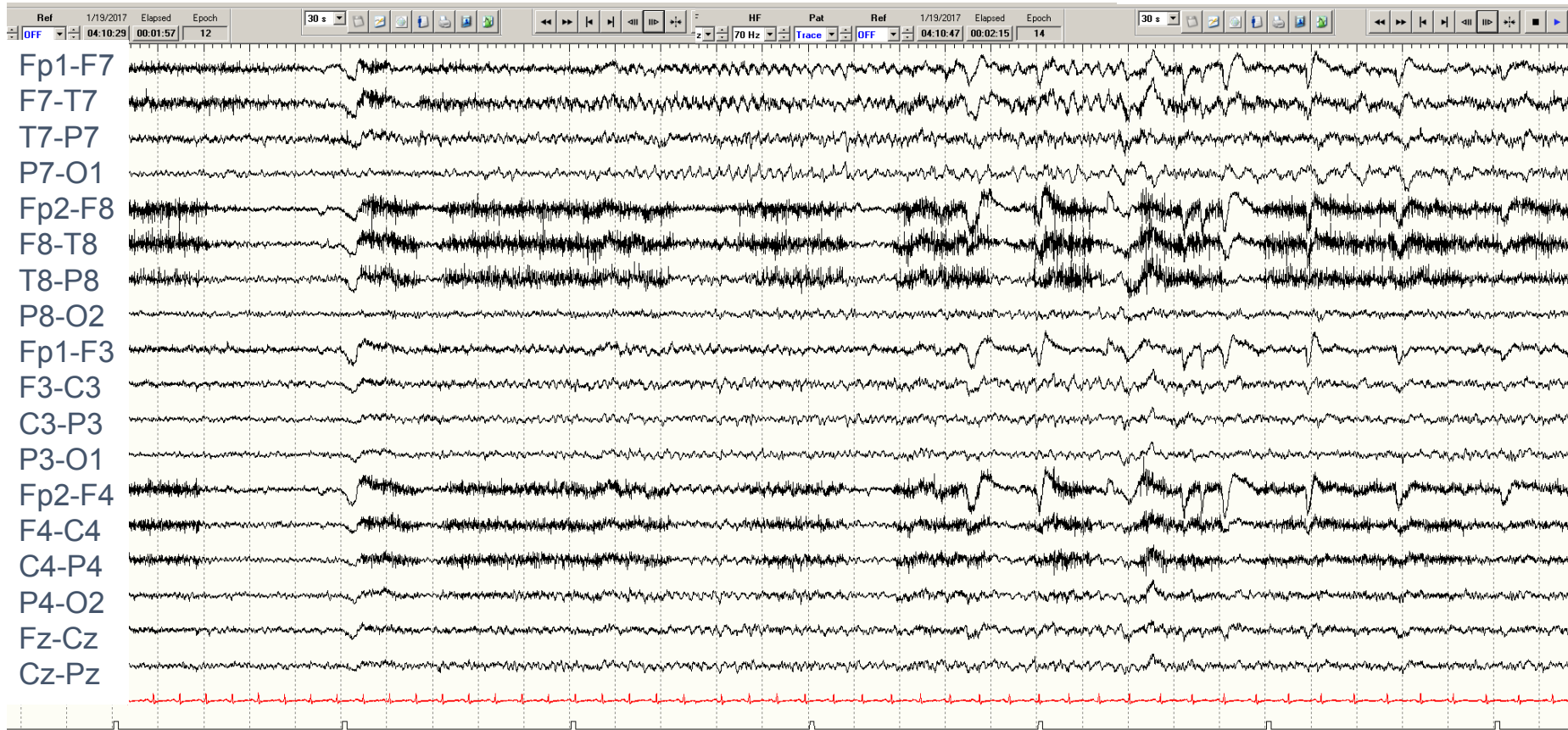


Initial frontal negativity f/by SP1

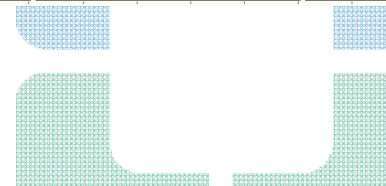


MRI-negative

Illustrative case

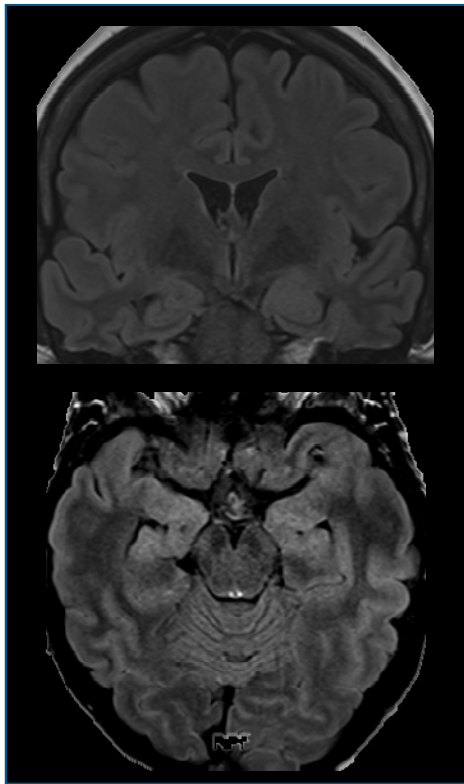


EEG seizure: Regional bilateral posterior? -> Left frontotemporal
Patient complained of visual aura (color)

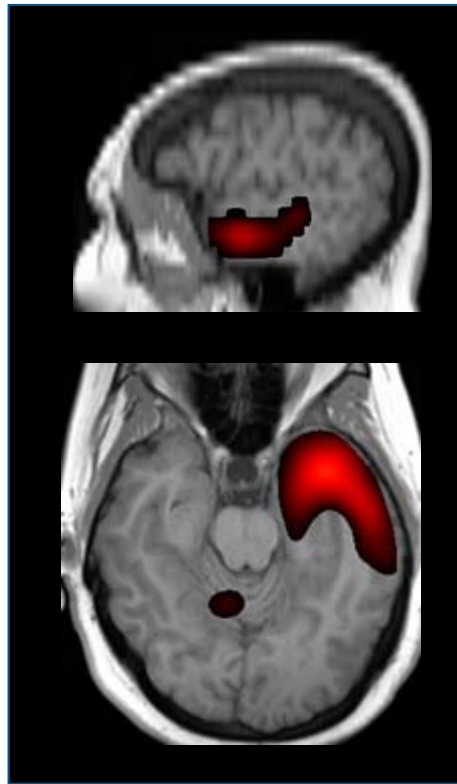


MRI-negative

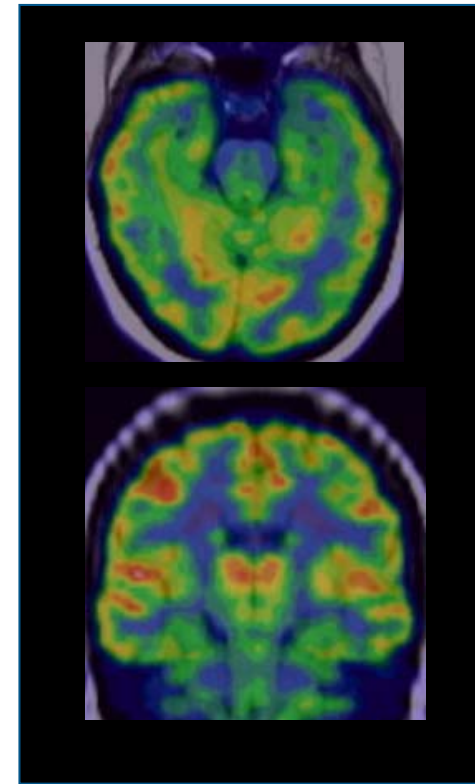
illustrative case



3T MRI: unremarkable

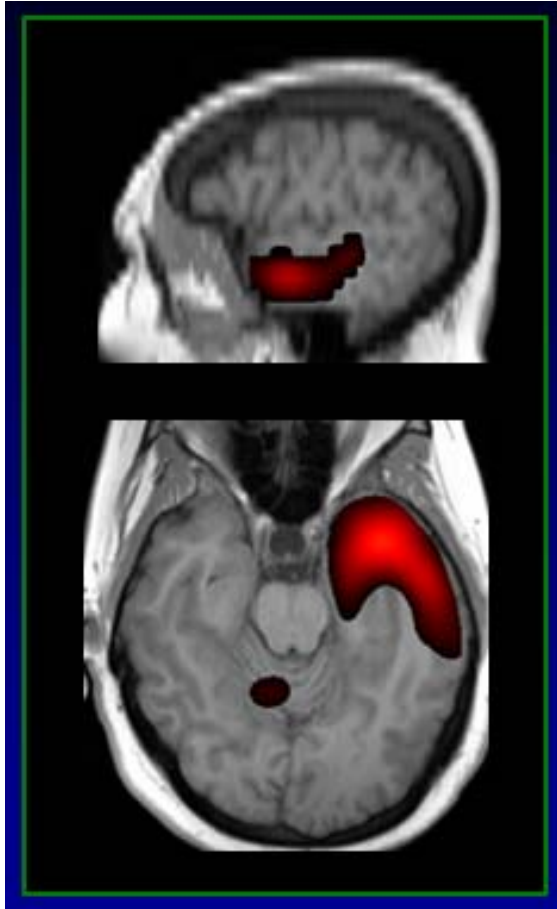


- Left mid superior temporal
- Left Posterior basal temporal
- Right basal occipital region
- Bilateral inferior mesial occipital



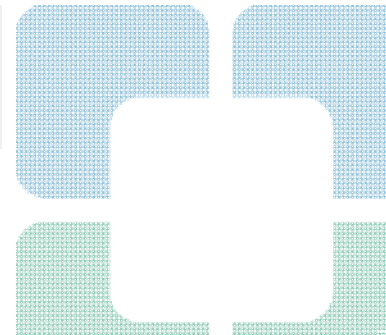
- Left anterior Temporal
- Left Posterior Basal Temporal
- Left Temporo-Frontal operculum
- Lateral Frontal

MRI-negative

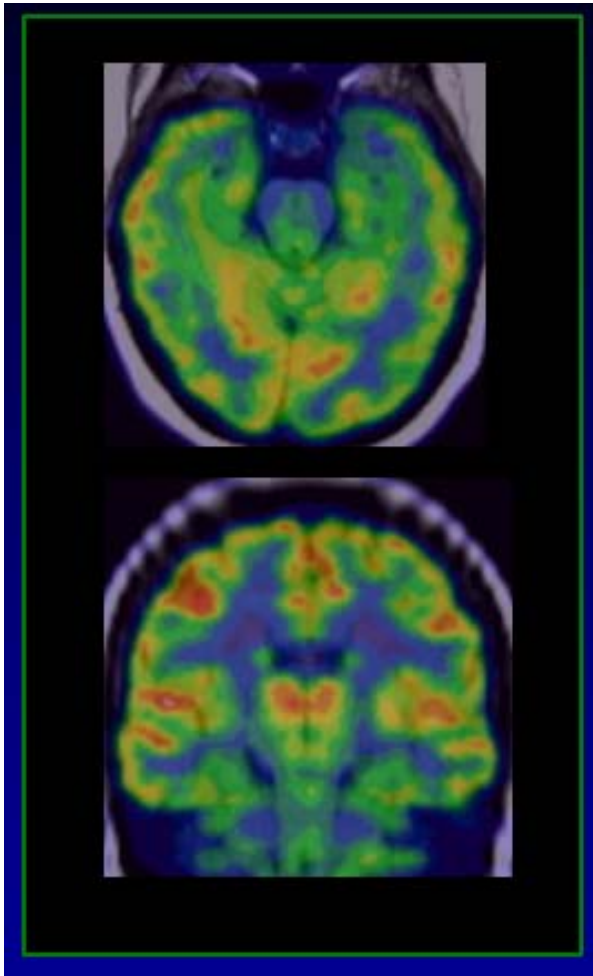


SISCOM has moderate sensitivity in localizing the epileptogenic zone and can provide complimentary information when MRI is negative.

Chen T. et al; The role of SISCOM in preoperative evaluation for patients with epilepsy surgery. Seizure, 2016 (41):43-50



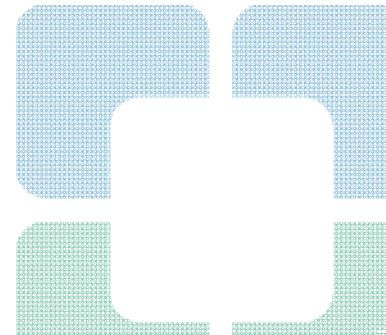
MRI-negative



- Surgical outcomes of MRI-, PET+ TLE patients are similar to those of MTS patients.
- HM on PET is a good predictor for surgical outcome in patients with normal MRI
- More than 2/3 of MRI-, PET+ patients with TLE are seizure-free.

Capraz IY et al, Seizure 2015

Lo-Pinto-Khoury C et al, Epilepsia 2012



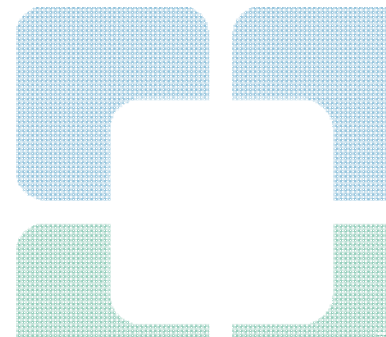
Key points

- The lack of abnormalities on brain MRI is not per se an indication of intracranial evaluation.
- Other clinical neurophysiologic and neuroimaging modalities can provide evidence of localization-related epilepsy, including clinical semiology combined with video-EEG, (PET), and (SPECT).
- However, when brain MRI is negative and other modalities are discordant, intracranial evaluations, most often SEEG, are required.



Indications of invasive evaluation in Epilepsy Surgery

- MRI-negative cases
- Electroclinical and MRI data discordance
- Overlap with eloquent cortex
 - Localize motor, sensory and language function



Electroclinical and MRI data discordance

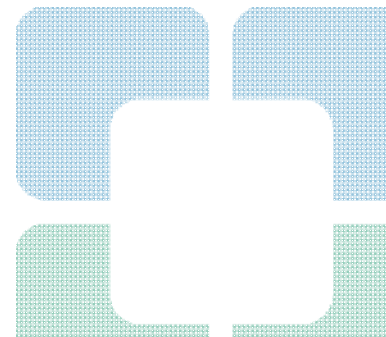
- Seizure history:
 - First seizure: 3 years old prolonged GTC (Left Todd's paresis)
 - Seizure-free till 15 years of
 - Frequency: 1 every 6 weeks
- Recorded (single seizure type):

Aura: unique smell (burnt chocolate)

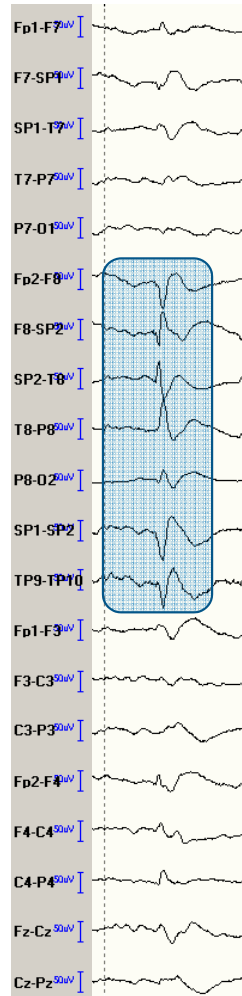
Preserved awareness → ictal speech ("It's going to be OK") → chewing/swallowing → grabbing, rubbing hands → rocking movements → unresponsiveness → LEFT turning → GTC

All seizures with autonomic features

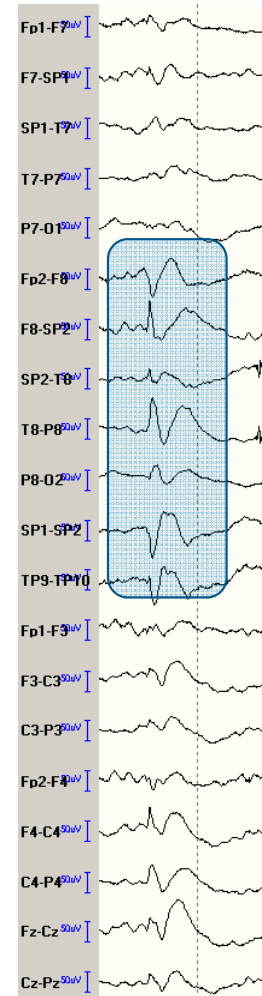
Duration: 30 seconds to 5 min
- Historical: Prolonged seizures



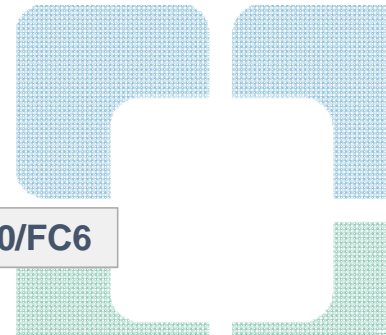
SW right antero-mesial and fronto-temporal



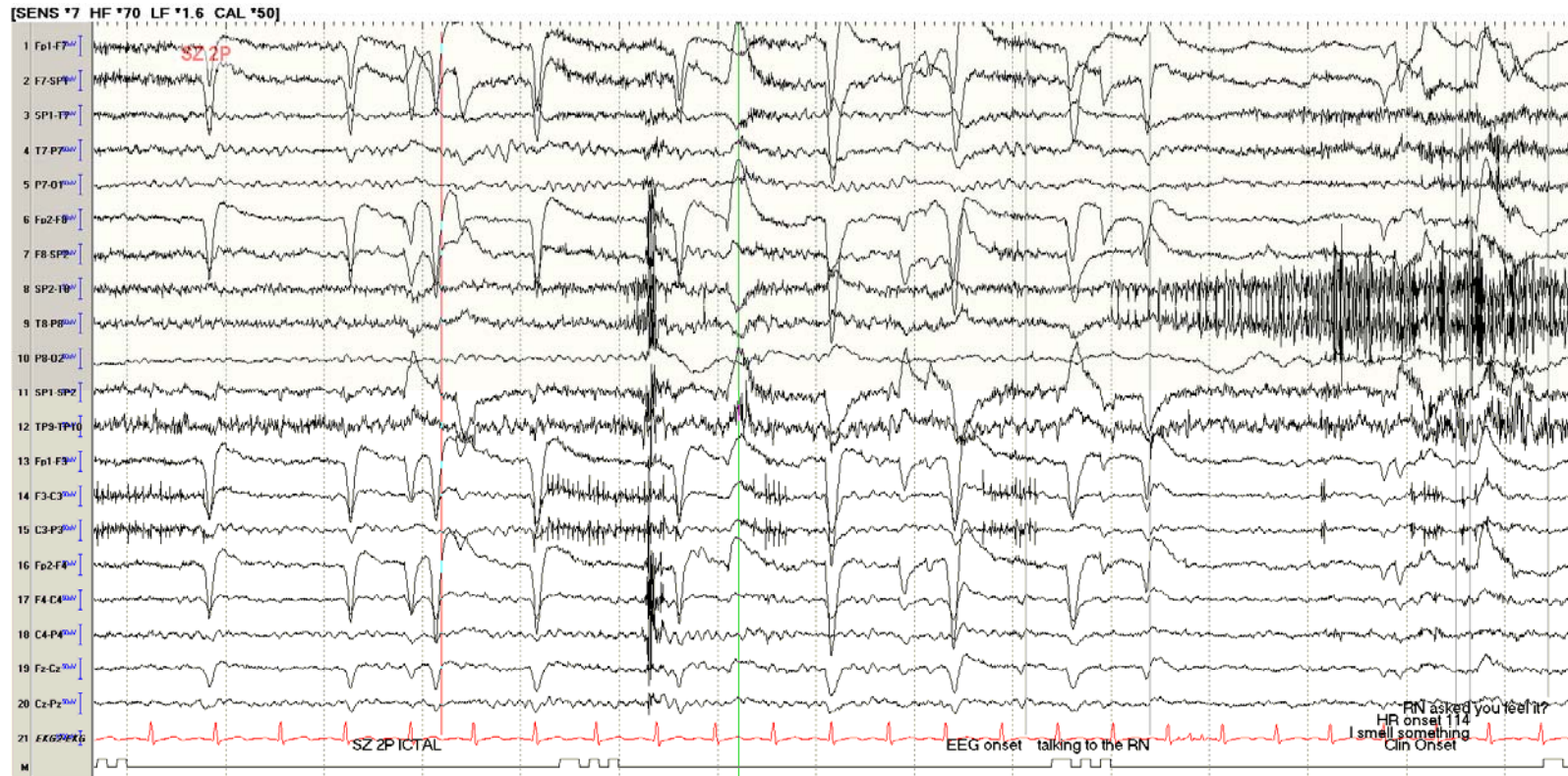
Sp2/FT10/F10/T10→FT8/F8/T8



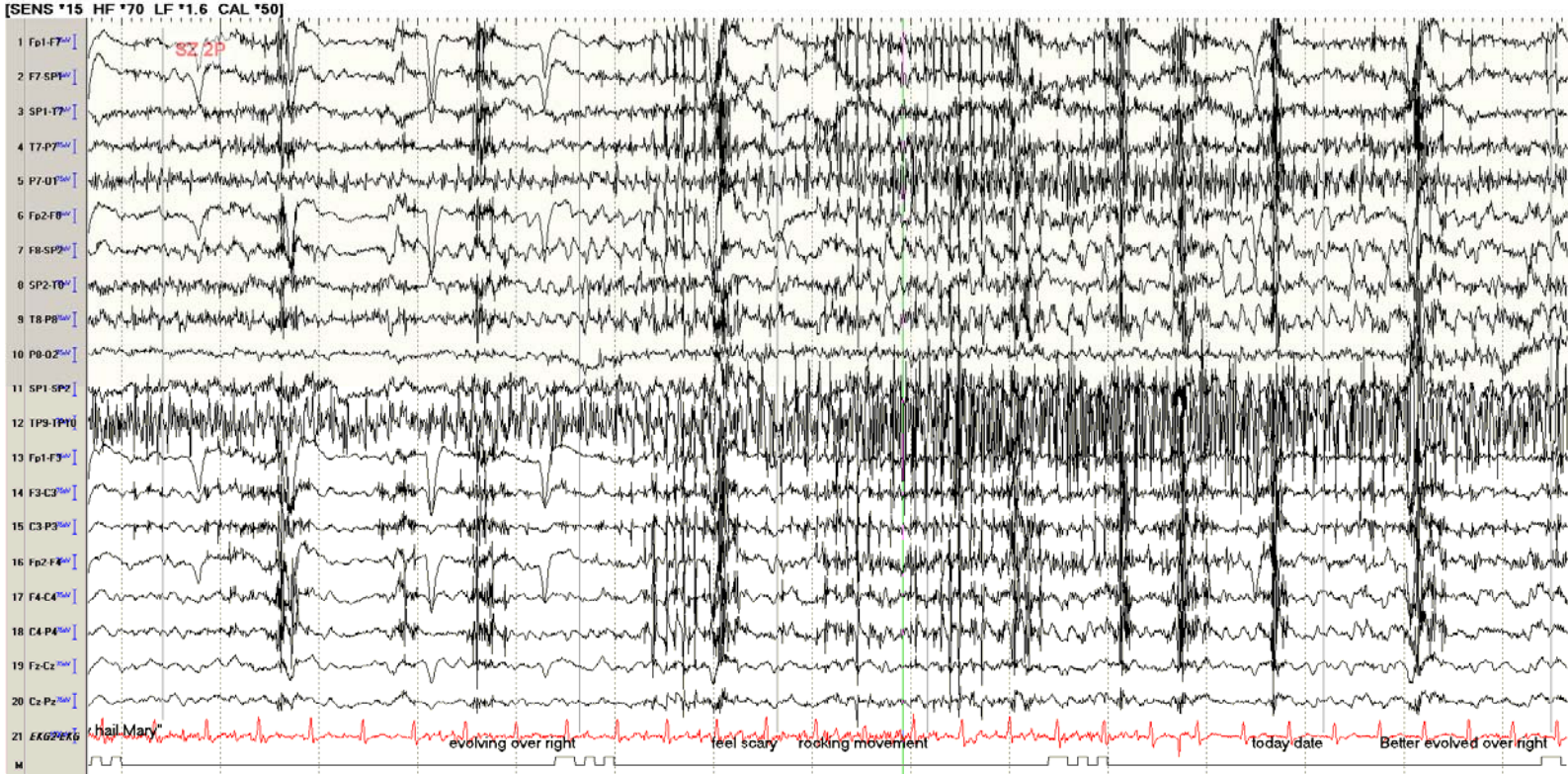
FT8/F8/FT10>AF8>F10/FC6



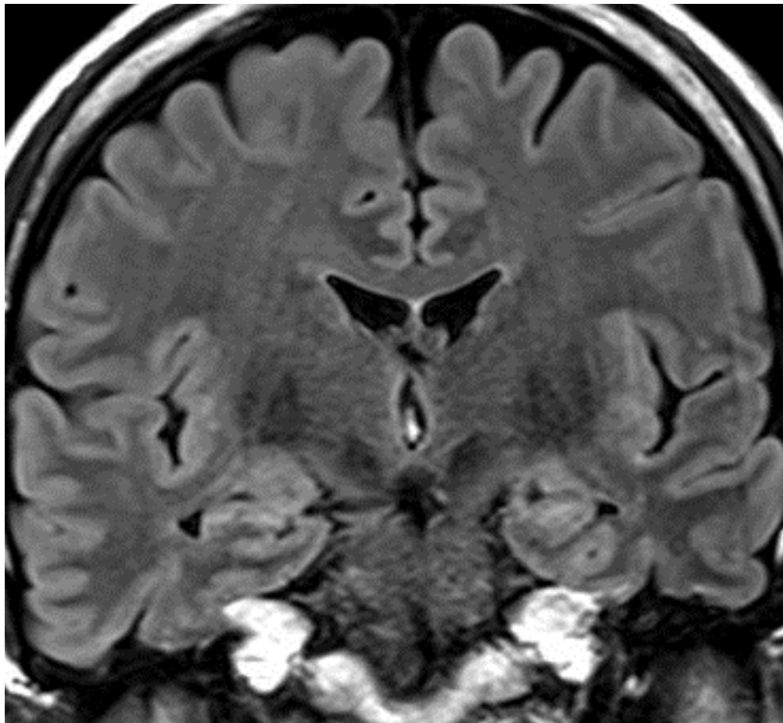
Electroclinical and MRI data discordance



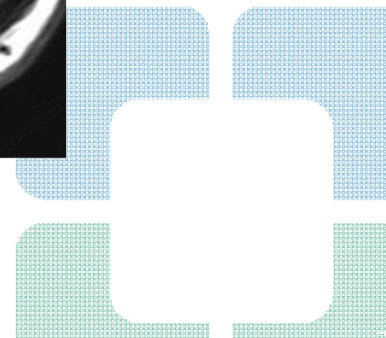
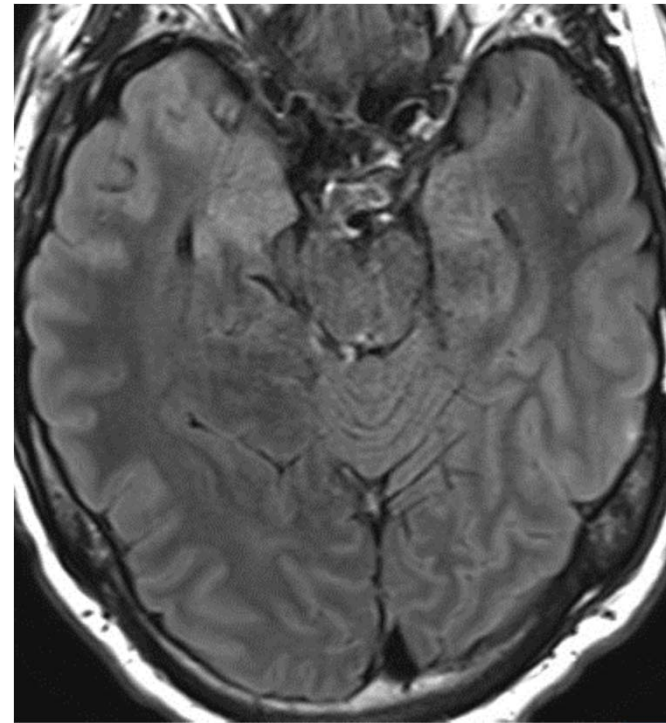
Electroclinical and MRI data discordance



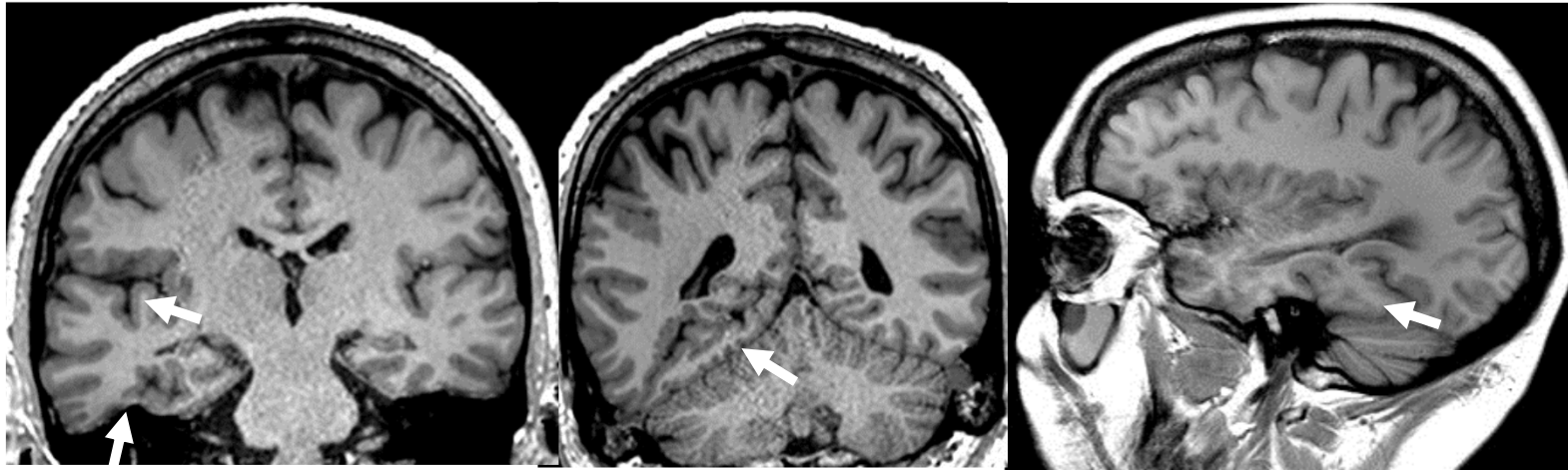
Electroclinical and MRI data discordance



Increased signal in the right hippocampus

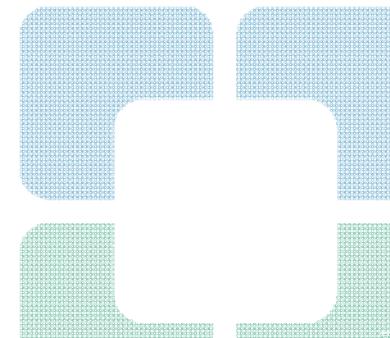


Electroclinical and MRI data discordance

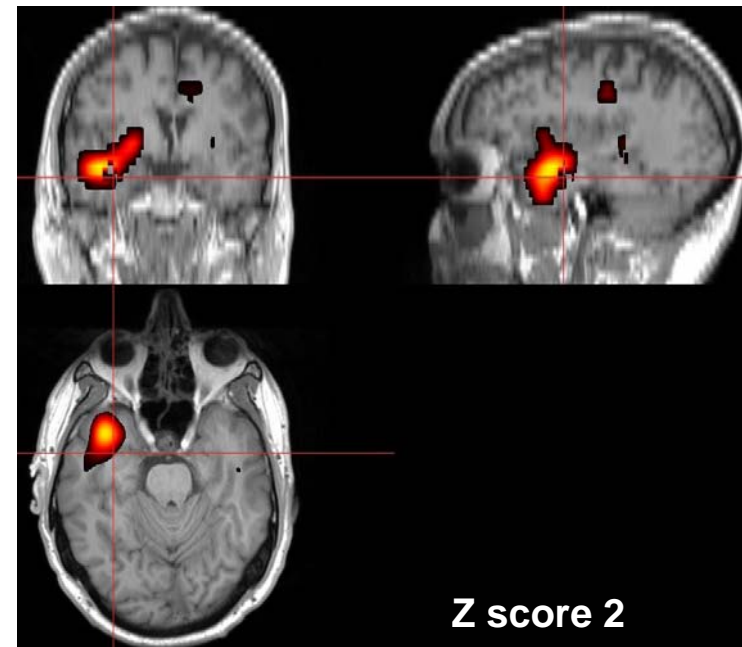
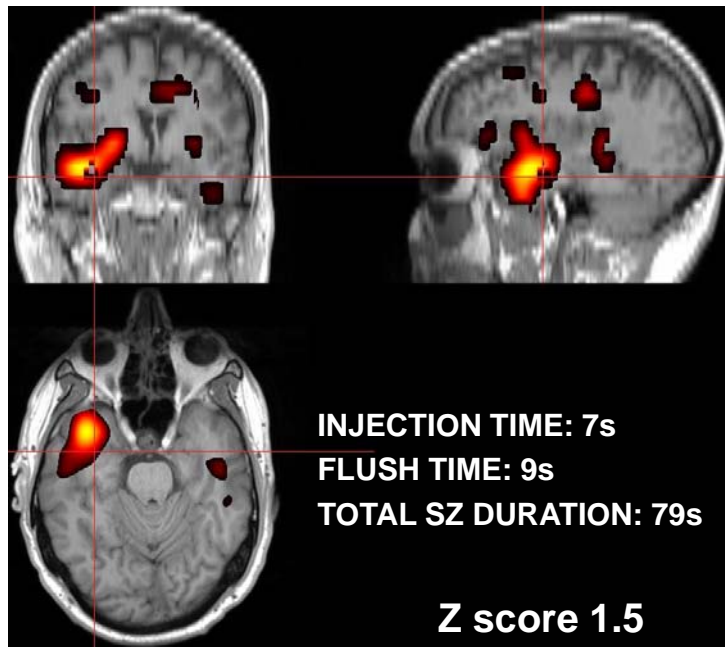


Right hemispheric polymicrogyria with multiple clefts involving:

- Right parietal and temporal opercular areas
- Right dorsal insular cortex
- Right temporal/occipital region (with amygdala/hippocampal dysmorphism) and the most of the fusiform gyrus.

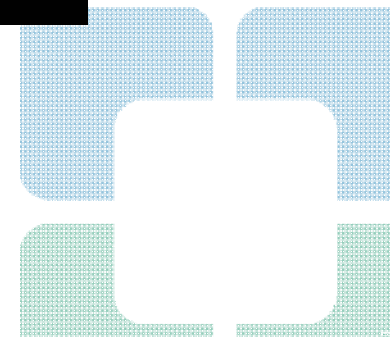


Electroclinical and MRI data discordance

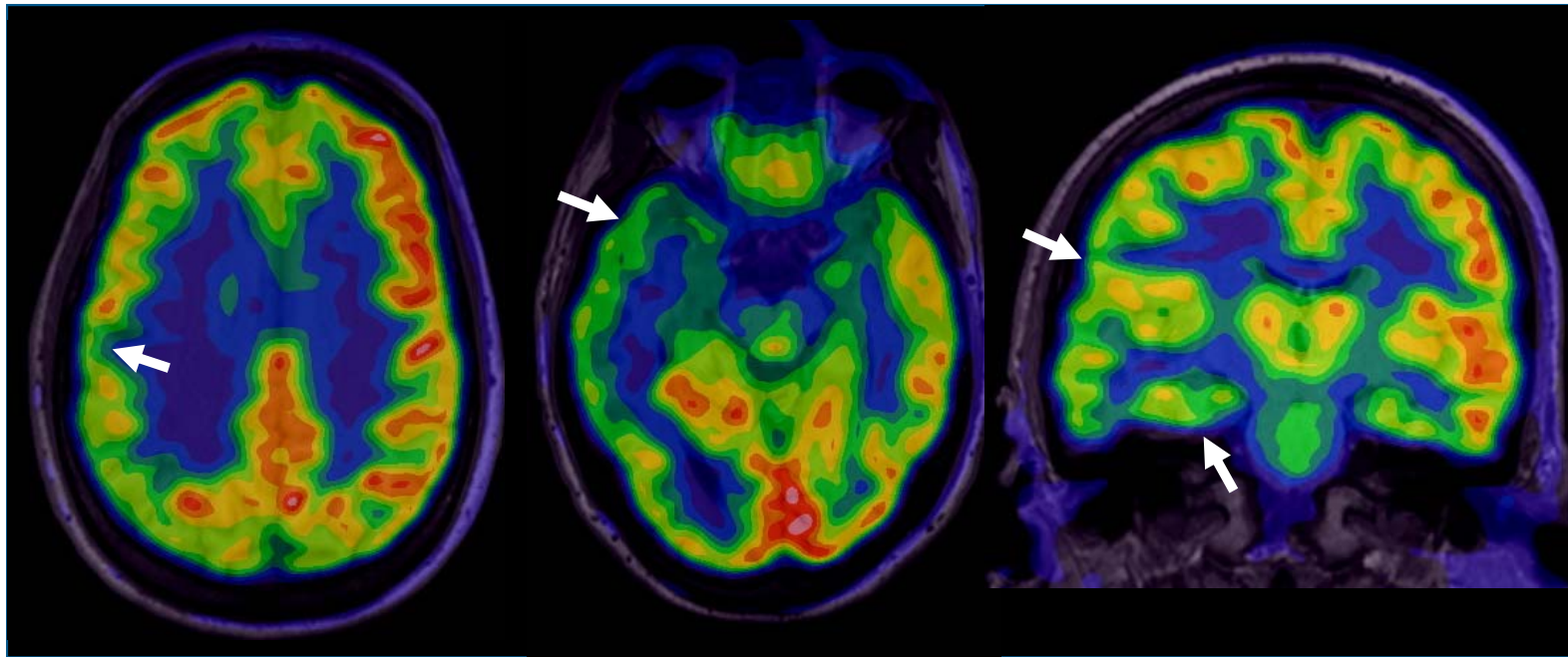


Sz 2P: Olfactory aura → Autonomic Sz → Automotor sz → Hypermotor sz

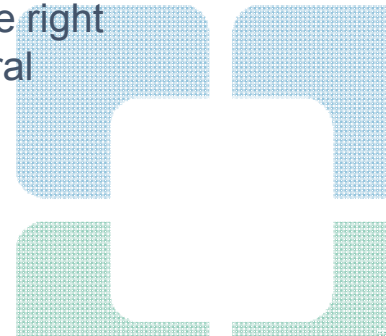
Right anterior Temporal region
Right Ventral Insular region



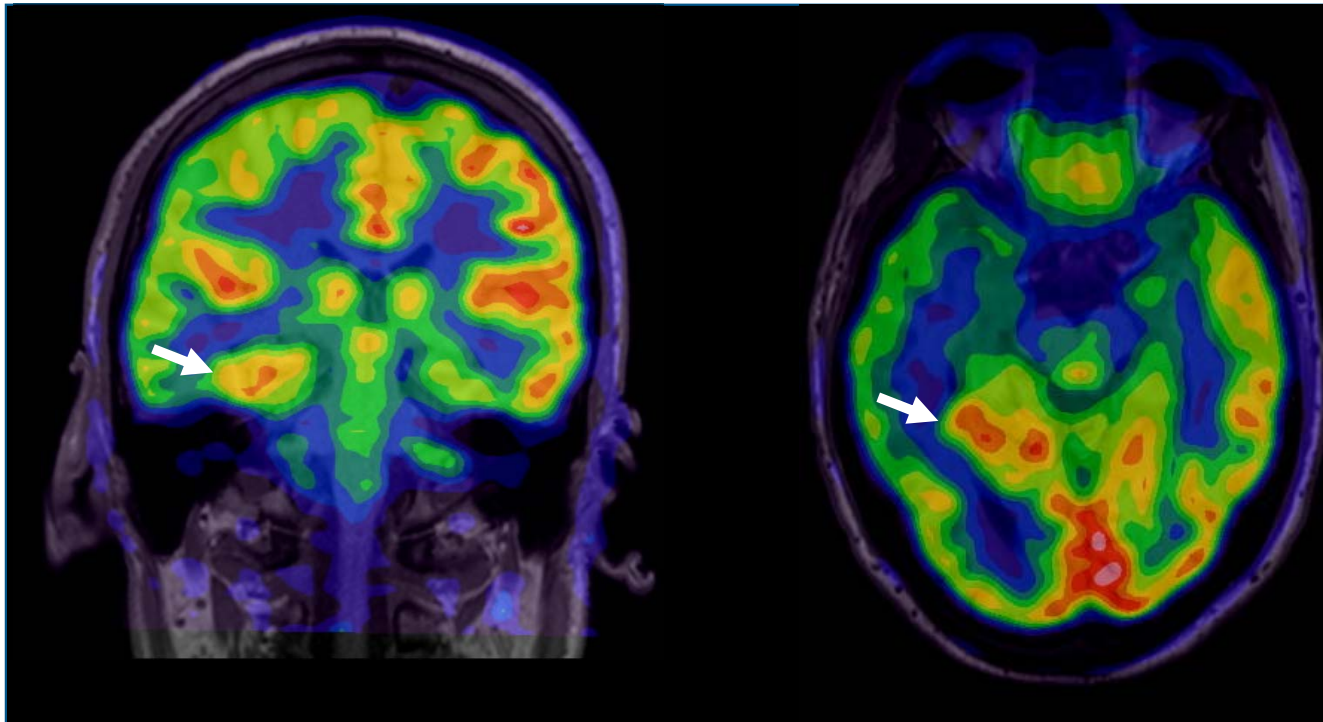
Electroclinical and MRI data discordance



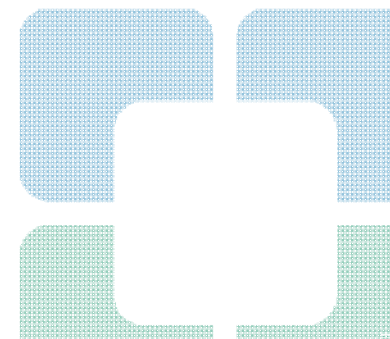
Diffuse cortical hypometabolism involving right hemisphere, more pronounced in the right peri-opercular region, right anterior temporal, right mid to posterior basal temporal



Electroclinical and MRI data discordance



Hypermetabolism involving the mesial basal temporo-occipital PMG

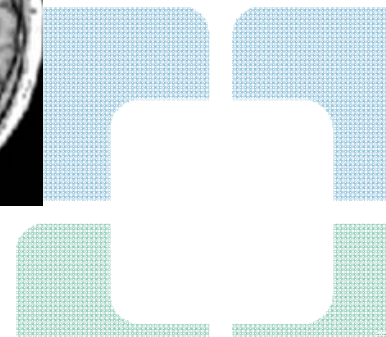
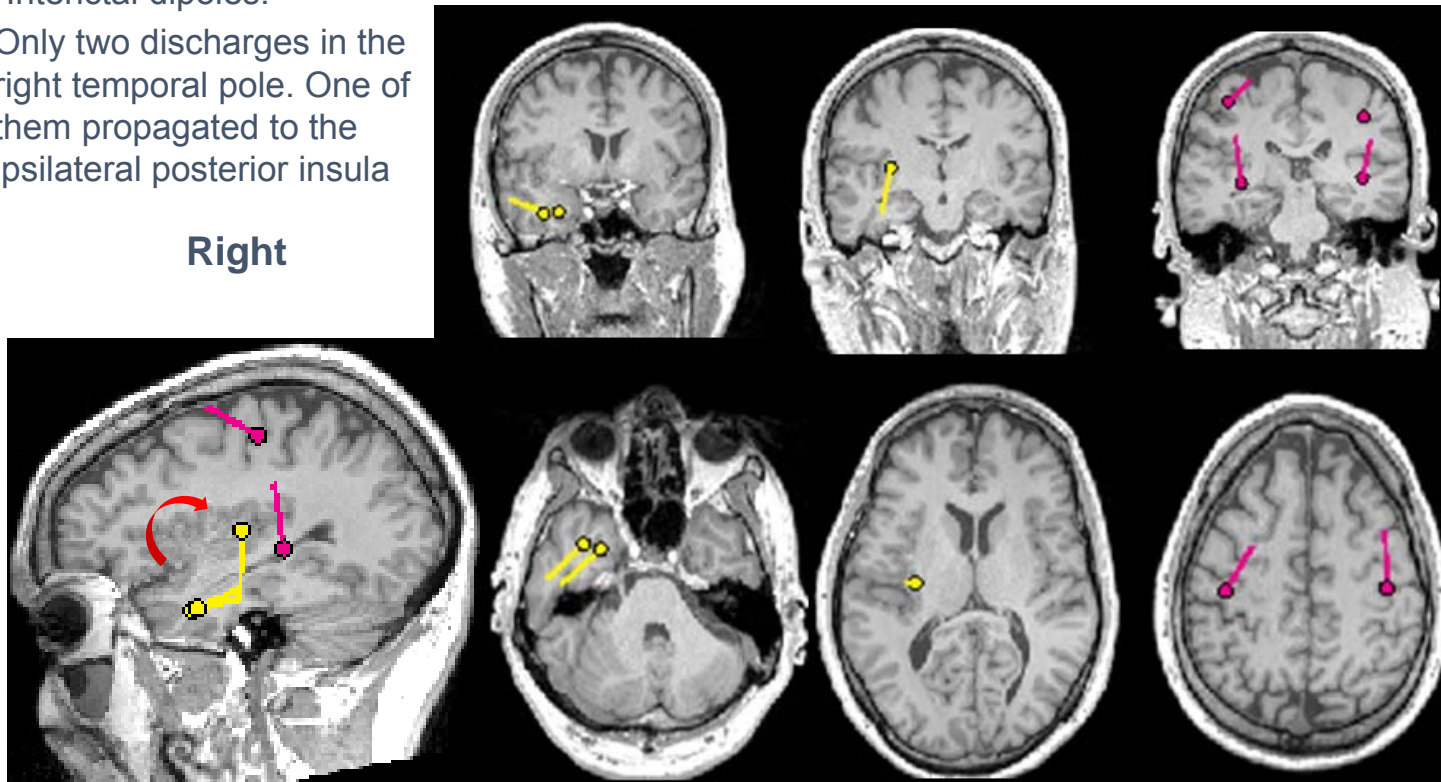


Electroclinical and MRI data discordance

- Interictal dipoles:

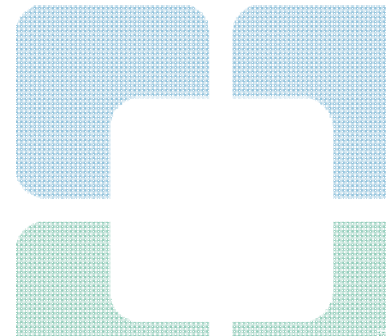
Only two discharges in the right temporal pole. One of them propagated to the ipsilateral posterior insula

Right



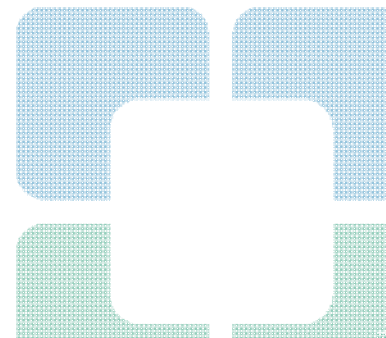
Key Points

- Two or more anatomical lesions, and the location of at least one is discordant with the electroclinical hypothesis, or both lesions are located within the same functional network and it is unclear if one (or both) of them is (are) epileptic.
- Cases of deeply seated brain lesions (PVNH and BOS FCD).

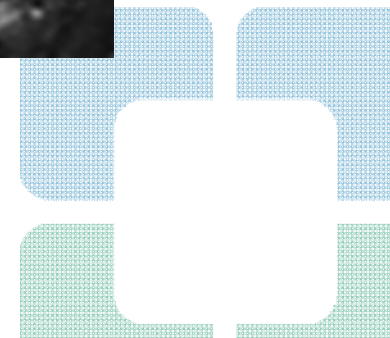
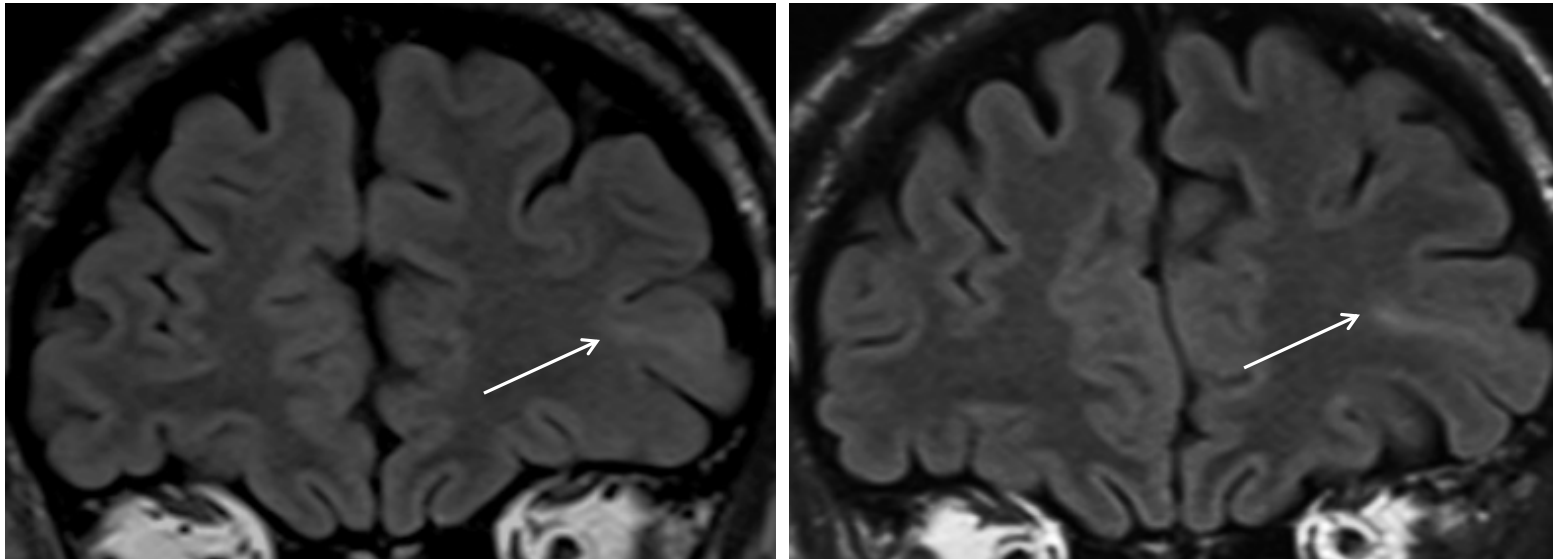


Indications of invasive evaluation in Epilepsy Surgery

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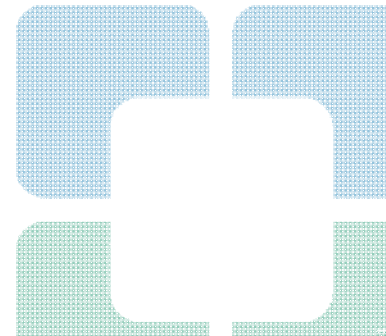


Transmantle Malformation of Cortical Development



Overlap with eloquent cortex

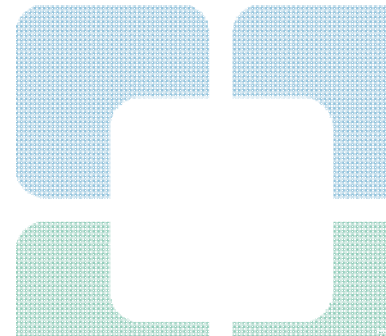
- The generated hypothesis (MRI +/-) involves potentially highly eloquent cortex.
- The identification of the EZ, mapping of its extent, and its relationship with potentially eloquent cortex are not typically resolved in these cases.



Overlap with eloquent cortex

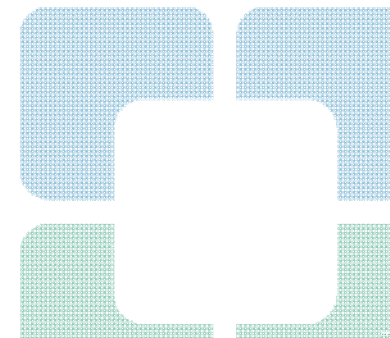
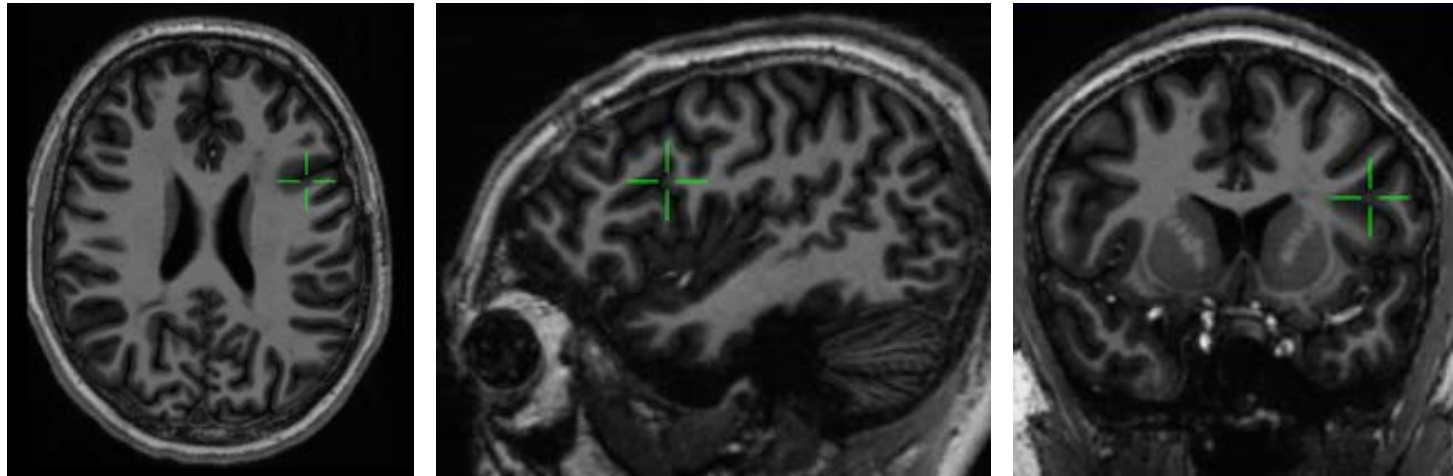
Illustrative case

- Never alerts about the seizure
 - “tingling sensation” inside the head
 - “difficulties to talk”
- Seizure semiology:
 - Axial stiffening with prominent tonic bilateral facial grimace
 - Upper body mild flexion, proximal stiffening of the arms and right arm dystonic posturing
 - Then moves semi-purposefully at the onset of tonic phase, have axial and hand stereotypies
 - Toward the end of the seizure may start follow the commands, but does not respond verbally



Overlap with eloquent cortex

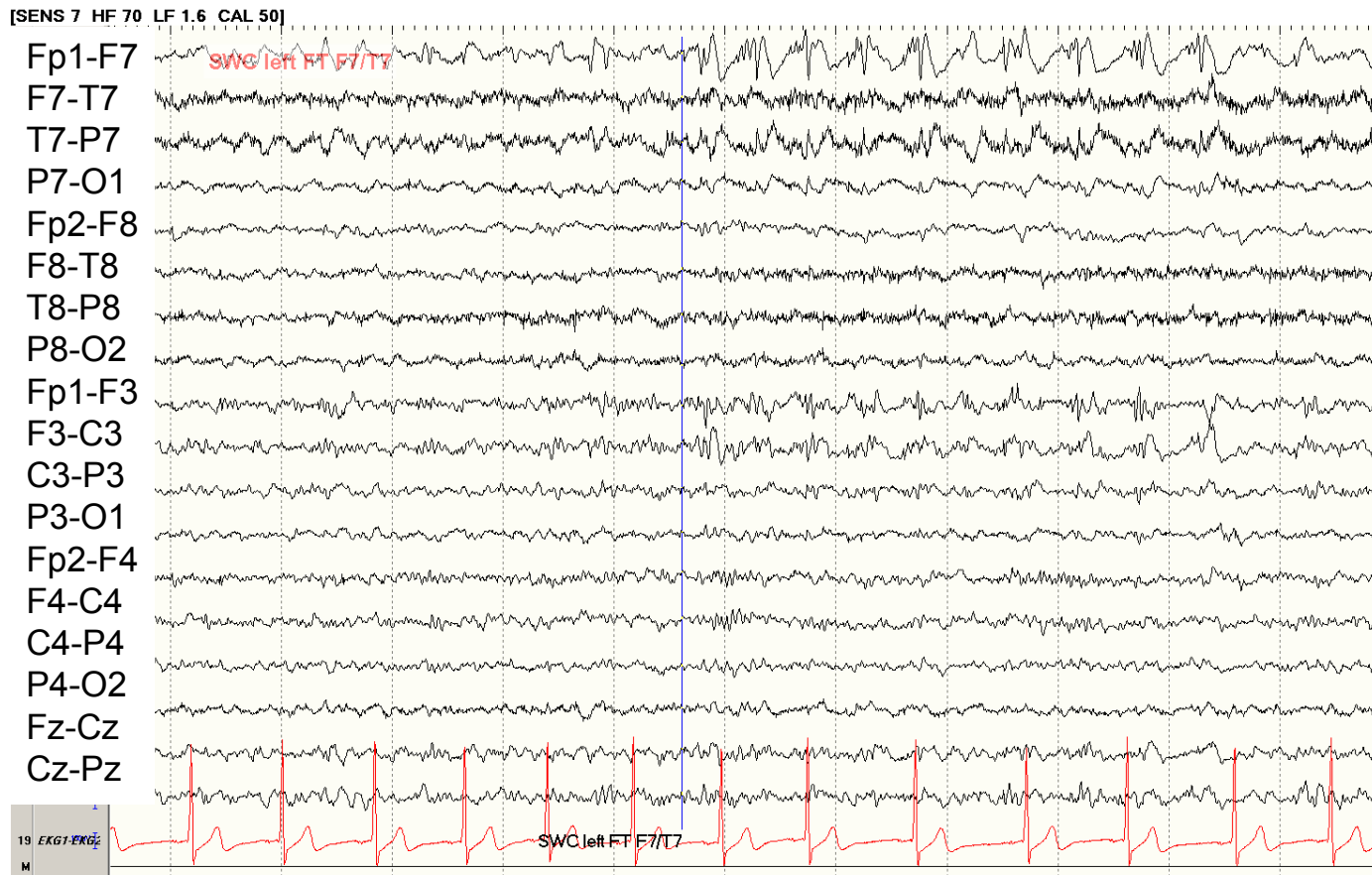
Illustrative case



Overlap with eloquent cortex

Illustrative case

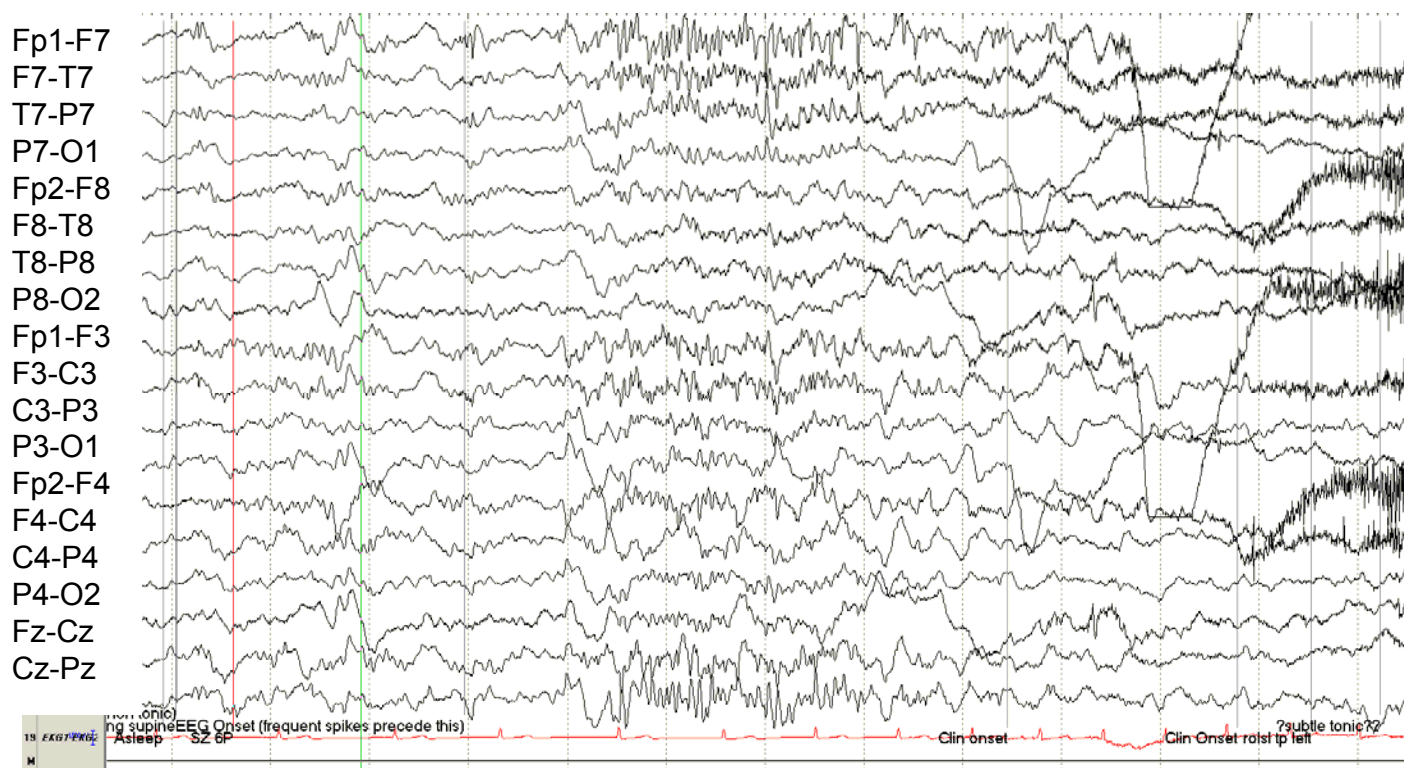
Interictal EEG



Overlap with eloquent cortex

Illustrative case

Ictal EEG

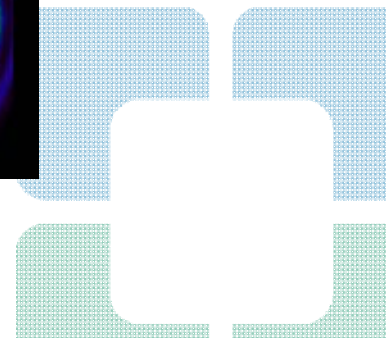
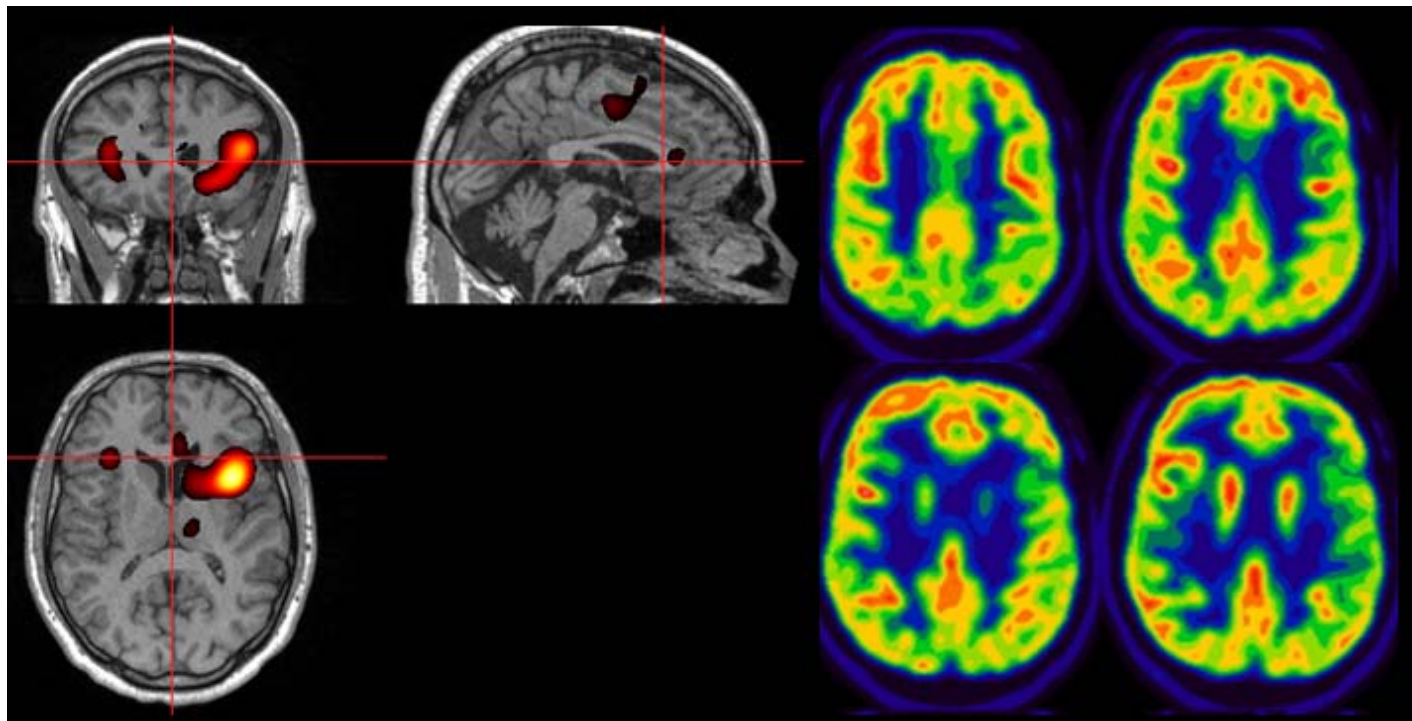


Overlap with eloquent cortex

Illustrative case

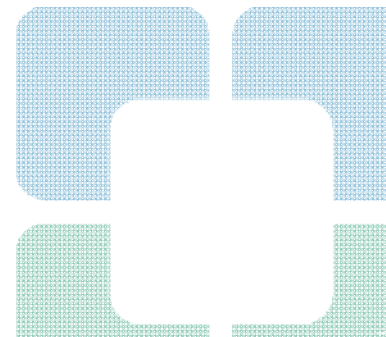
SPECT

PET

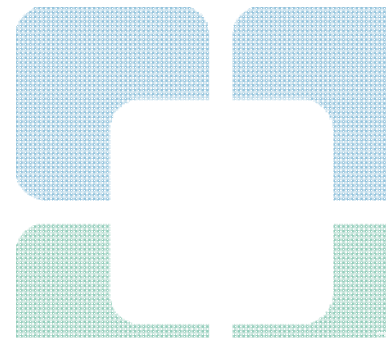


Key points

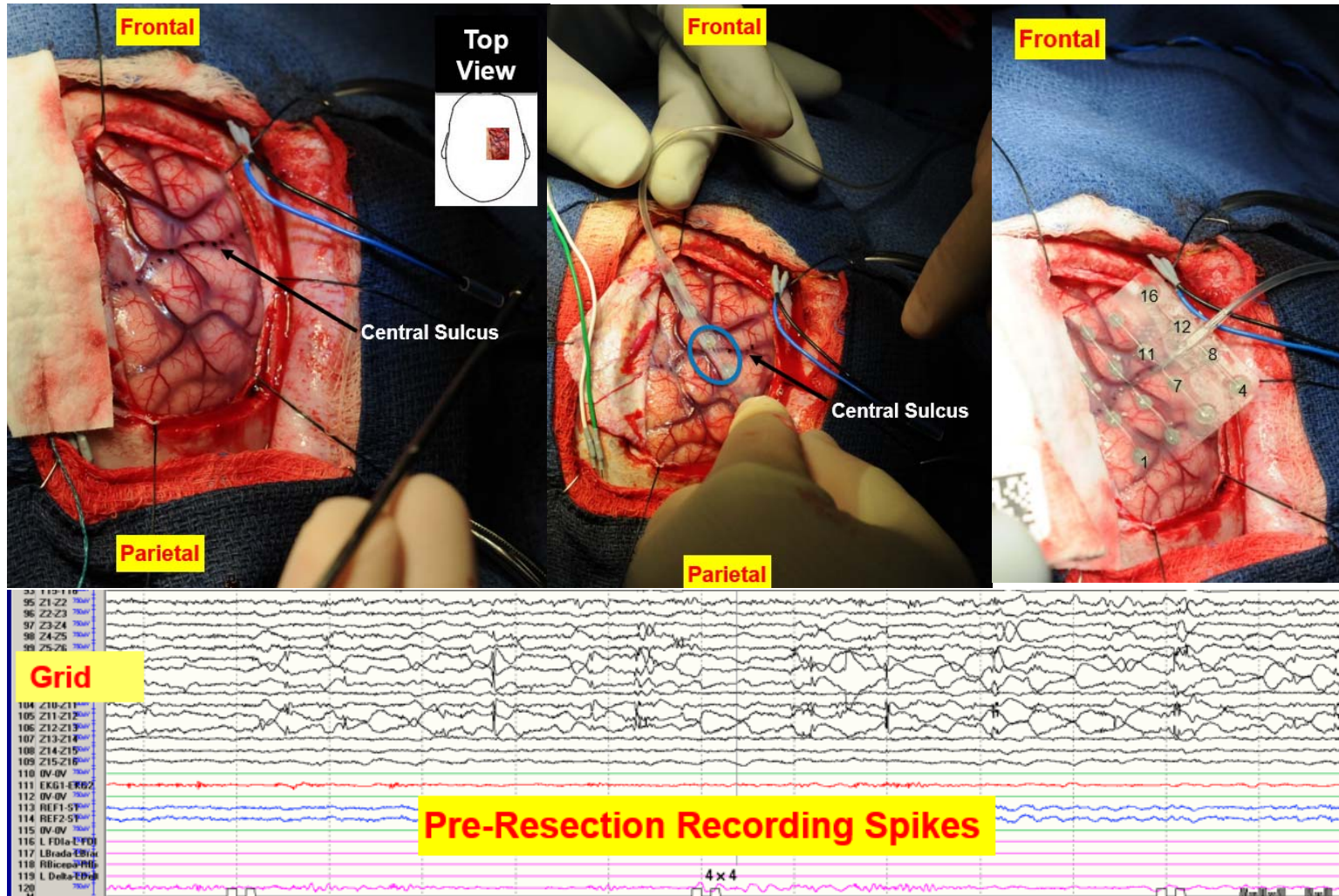
- In this situation, the management approach is individualized according to the patient's condition.
- IntraOp-Electrocorticography (EcoG).
- SDG/depth electrodes, given their superior ability for mapping eloquent function.



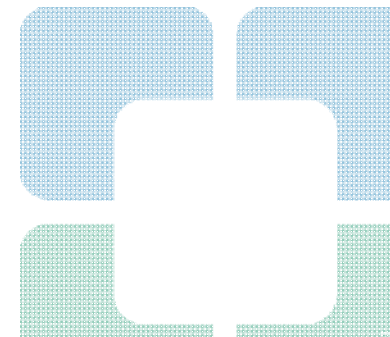
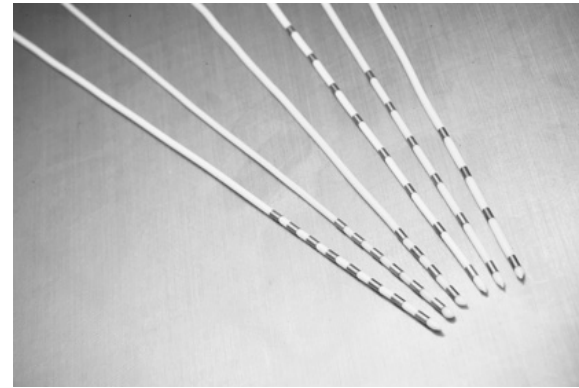
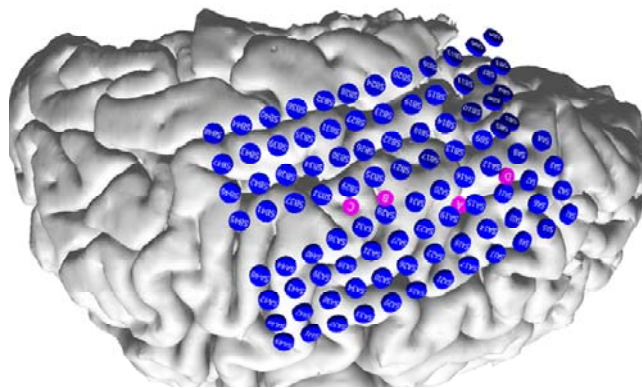
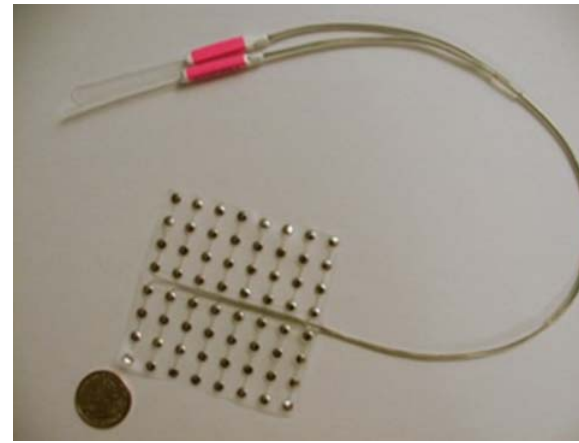
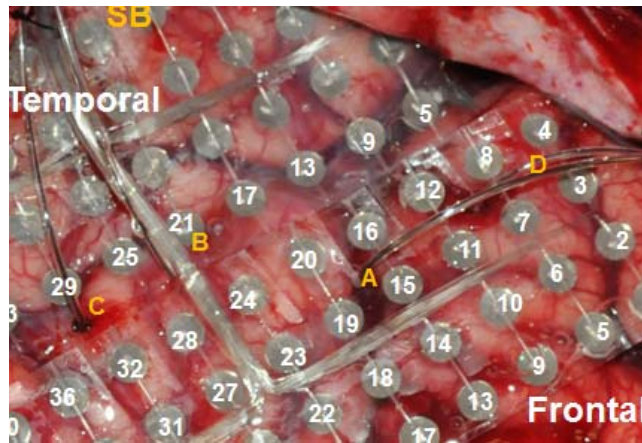
Intracranial Evaluations Methods



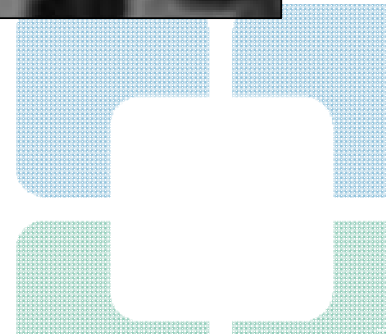
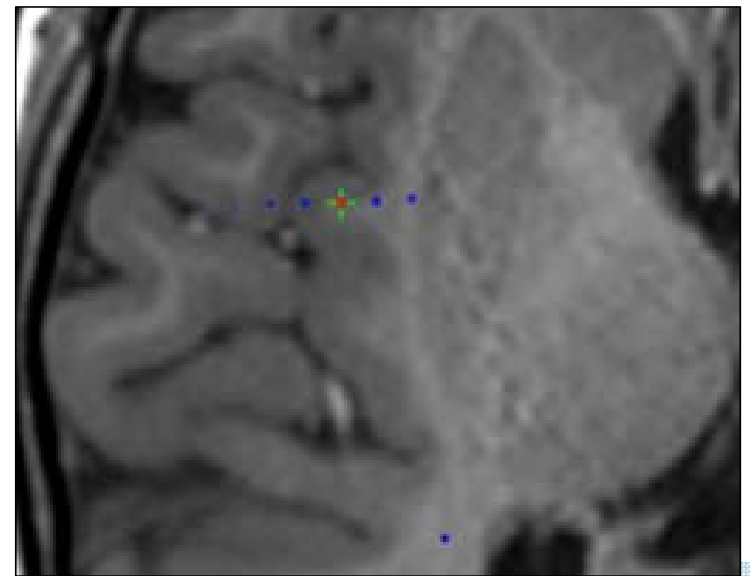
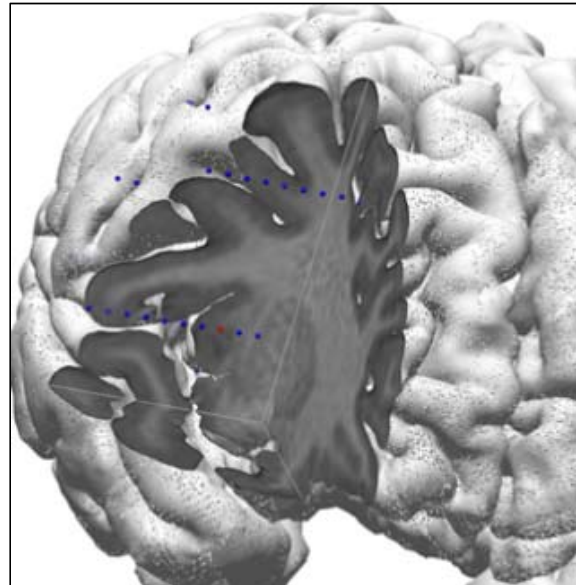
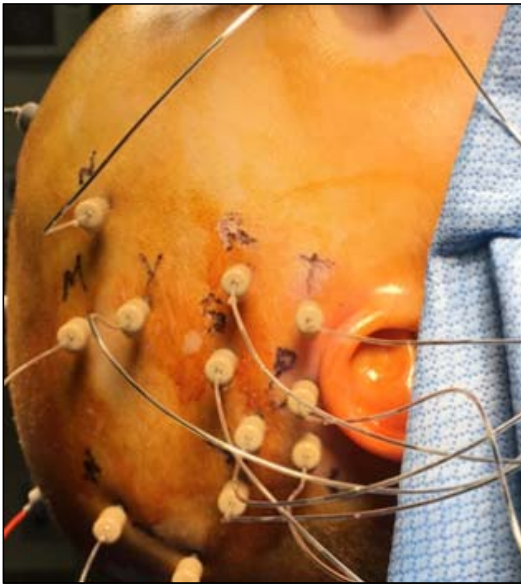
Acute intraoperative ECOG



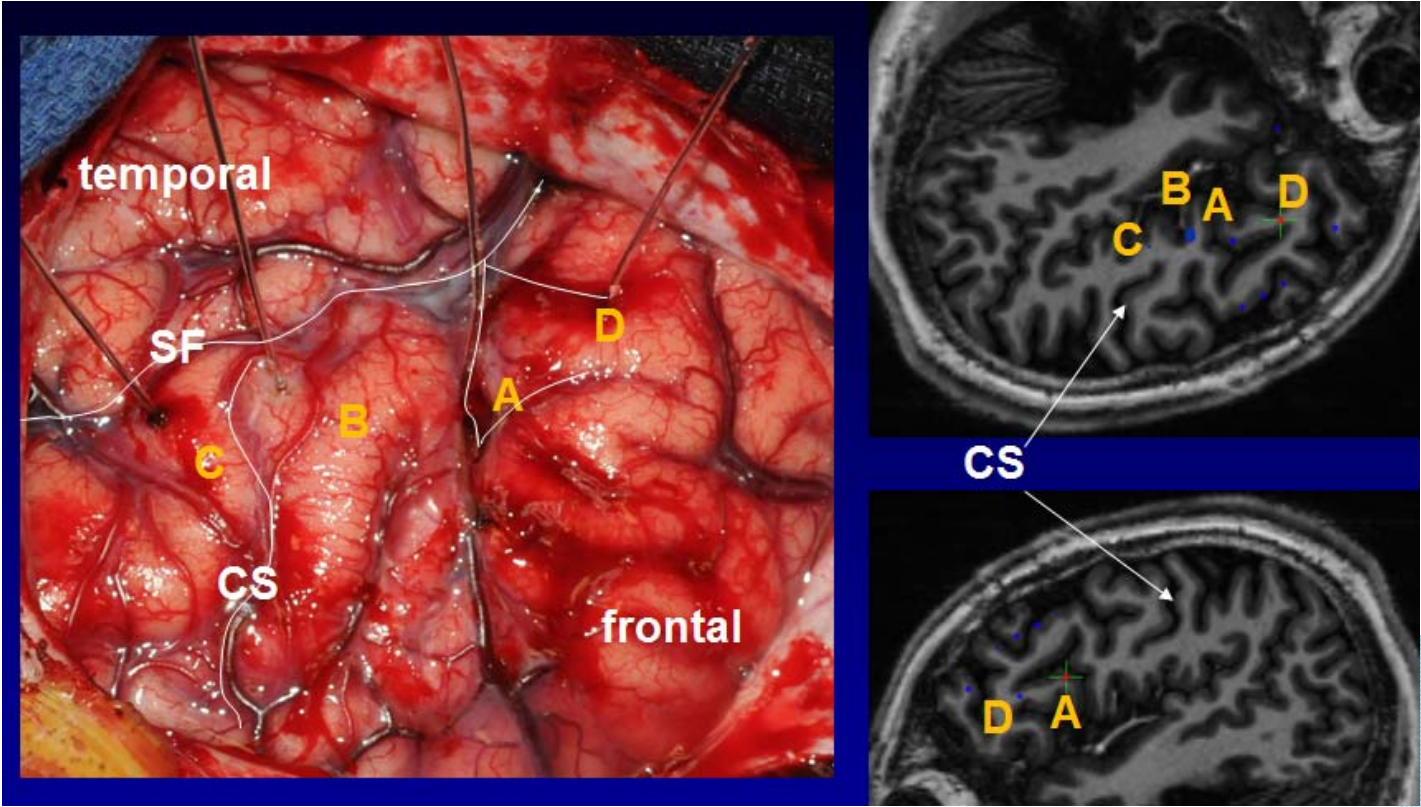
Subdural Grid and Depth electrodes



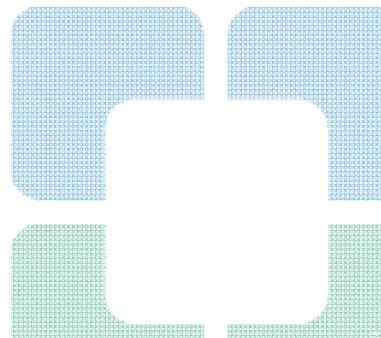
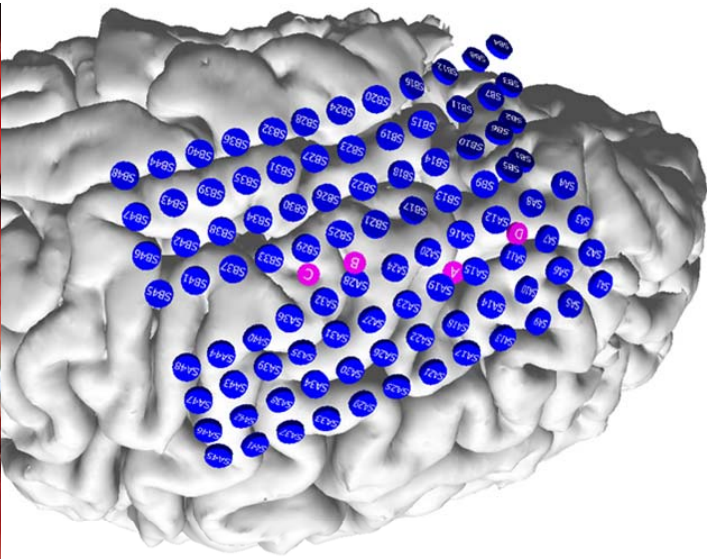
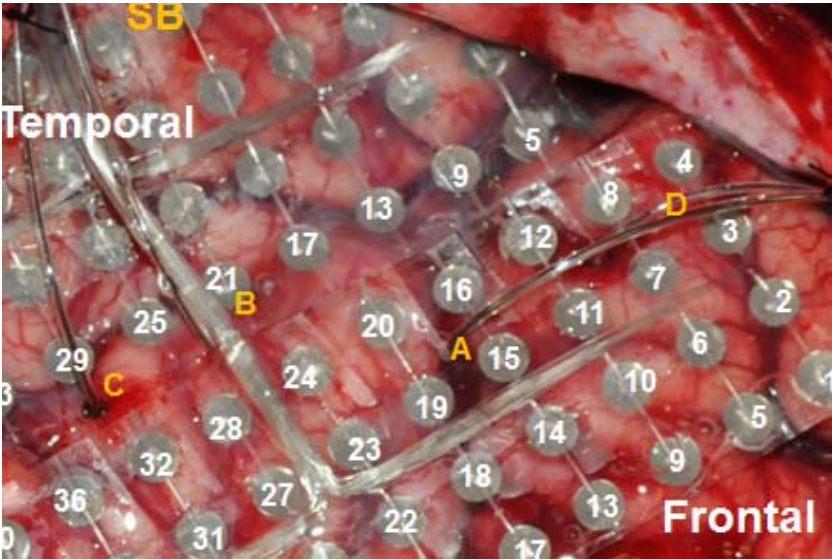
Stereoelectroencephalography -SEEG-



Subdural Grid and Depth electrodes



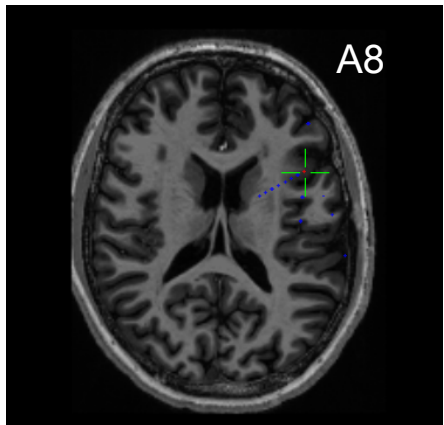
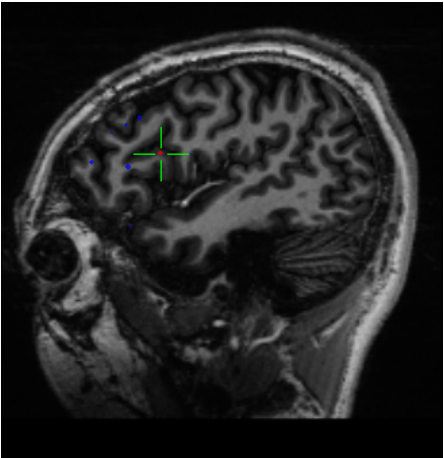
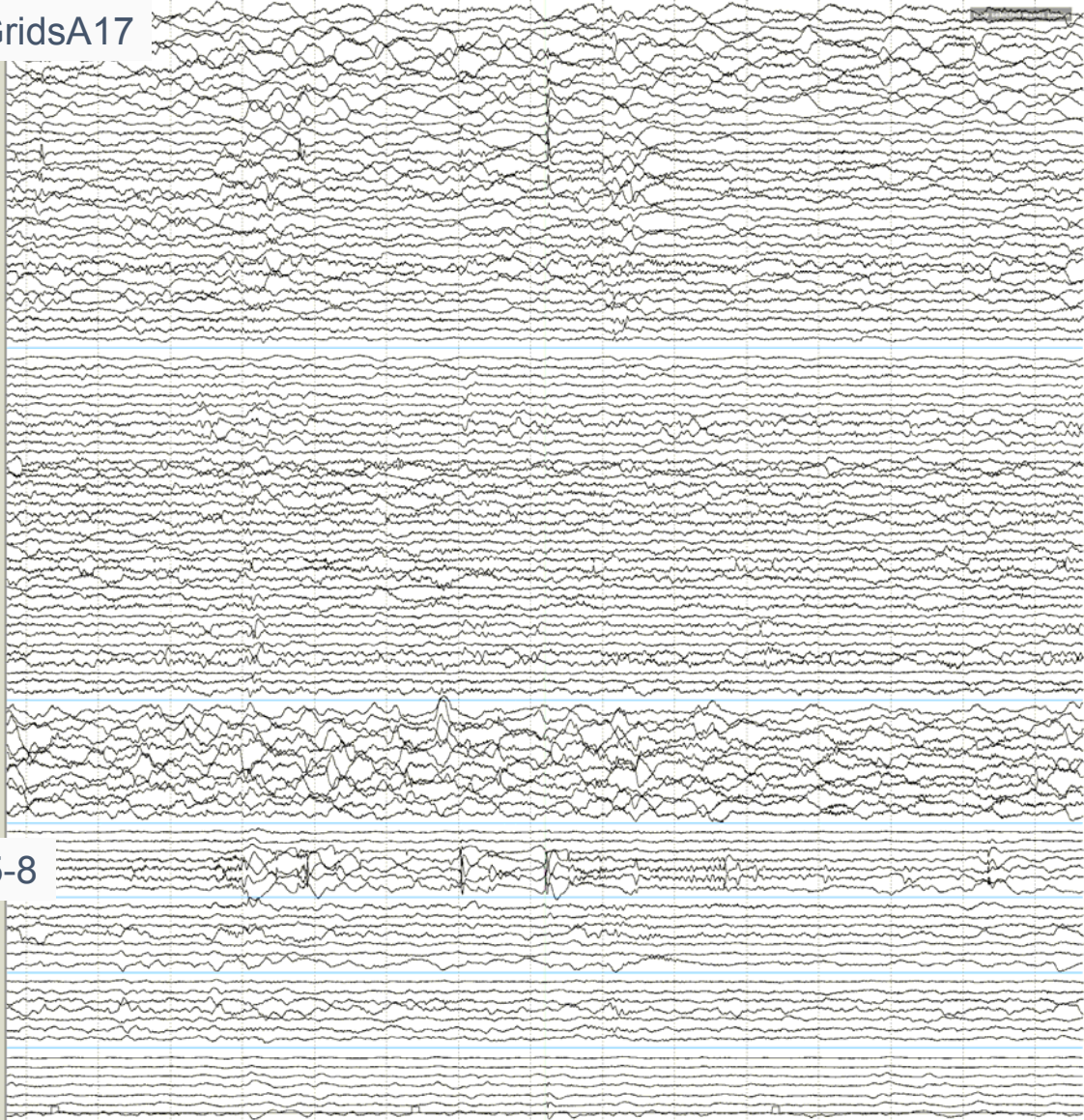
Subdural Grid and Depth electrodes



[SENS: 7.5 MP: 300 LP: 0.53 CAL: 50]

GridsA17

- 1
- 2
- 3
- 4
- 5
- 6
- 7 SA18-SA19
- 8 SA18-SA11
- 9 SA11-SA12
- 10 SA13-SA14
- 11 SA14-SA15
- 12 SA15-SA16
- 13 SA17-SA18
- 14 SA18-SA11
- 15 SA15-SA16
- 16 SA21-SA22
- 17 SA22-SA23
- 18 SA23-SA24
- 19 SA25-SA26
- 20 SA26-SA27
- 21 SA27-SA28
- 22 SA28-SA29
- 23 SA30-SA31
- 24 SA31-SA32
- 25 SA33-SA34
- 26 SA34-SA35
- 27 SA35-SA36
- 28 SA37-SA38
- 29 SA38-SA39
- 30 SA39-SA40
- 31 SA41-SA42
- 32 SA42-SA43
- 33 SA43-SA44
- 34 SA45-SA46
- 35 SA46-SA47
- 36 SA47-SA48
- 37 OV-OV
- 38 SB1-SB2
- 39 SB2-SB3
- 40 SB3-SB4
- 41 SB5-SB6
- 42 SB6-SB7
- 43 SB7-SB8
- 44 SB8-SB9
- 45 SB10-SB11
- 46 SB11-SB12
- 47 SB13-SB14
- 48 SB14-SB15
- 49 SB15-SB16
- 50 SB16-SB17
- 51 SB17-SB18
- 52 SB18-SB19
- 53 SB19-SB20
- 54 SB21-SB22
- 55 SB22-SB23
- 56 SB23-SB24
- 57 SB25-SB26
- 58 SB26-SB27
- 59 SB27-SB28
- 60 SB29-SB30
- 61 SB30-SB31
- 62 SB31-SB32
- 63 SB33-SB34
- 64 SB34-SB35
- 65 SB35-SB36
- 66 SB37-SB38
- 67 SB38-SB39
- 68 SB39-SB40
- 69 SB41-SB42
- 70 SB43-SB44
- 71 SB45-SB46
- 72 SB46-SB47
- 73 SB47-SB48
- 74 SB47-SB48
- 75 OV-OV
- 76 SC1-SC2
- 77 SC2-SC3
- 78 SC3-SC4
- 79 SC5-SC6
- 80 SC6-SC7
- 81 SC7-SC8
- 82 SC9-SC10
- 83 SC10-SC11
- 84 SC11-SC12
- 85 SC13-SC14
- 86 SC14-SC15
- 87 SC15-SC16
- 88 OV-OV
- 89 A1-A2

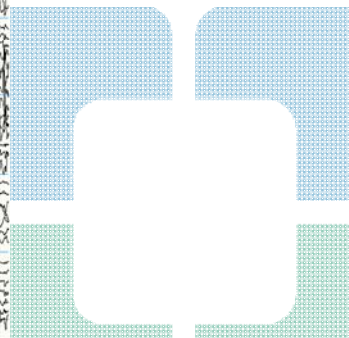
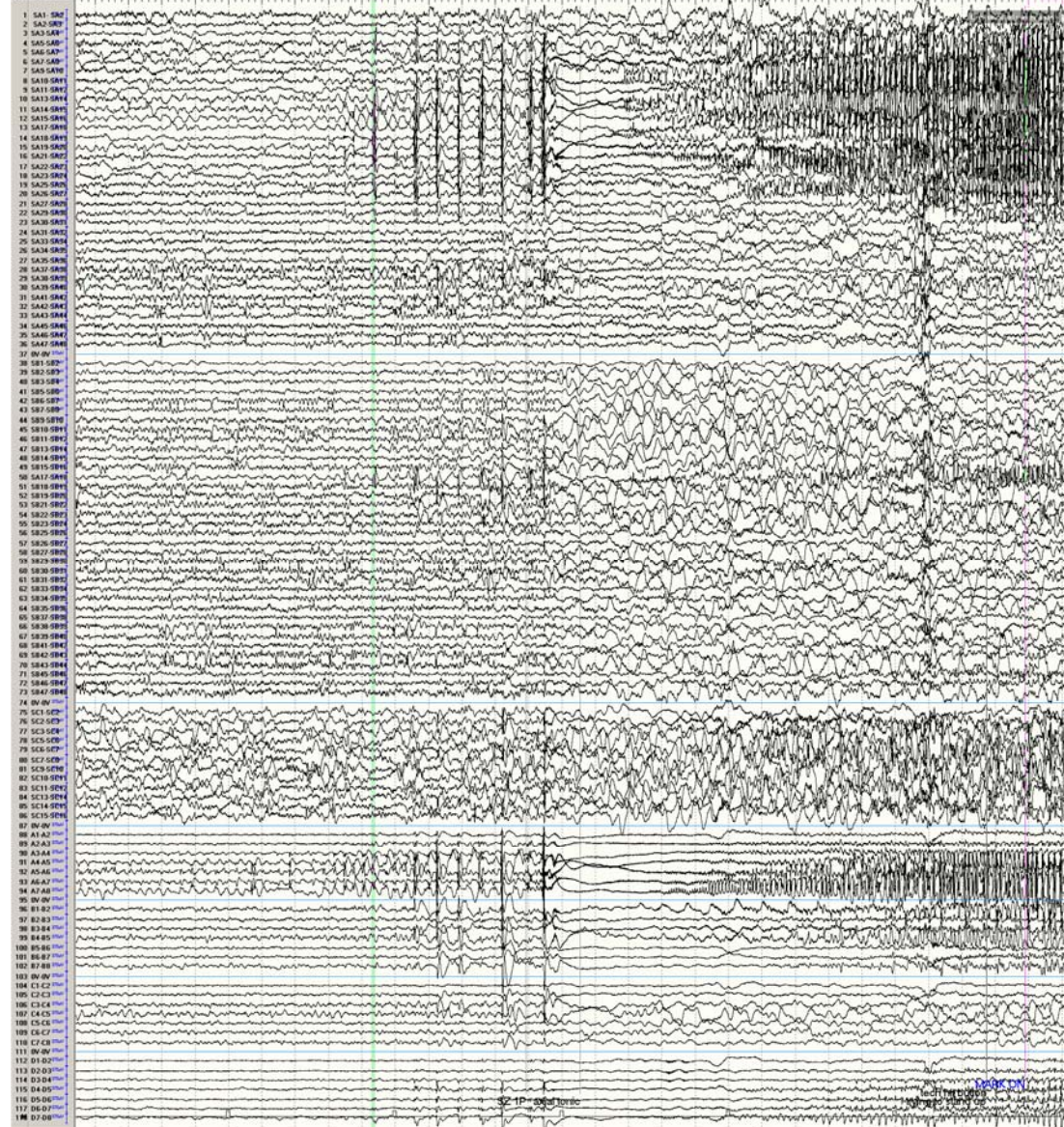


A8

A5-8

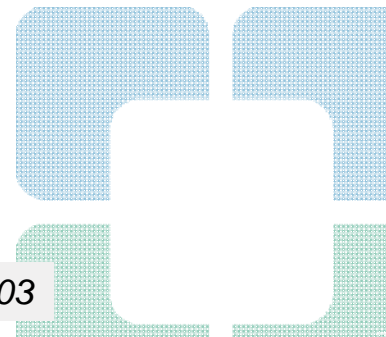
- 97 B1-B2
- 98 B2-B3
- 99 B3-B4
- 100 B4-B5
- 101 B5-B6
- 102 B6-B7
- 103 B7-B8
- 104 OV-OV
- 105 C1-C2
- 106 C2-C3
- 107 C3-C4
- 108 C4-C5
- 109 C5-C6
- 110 C6-C7
- 111 C7-C8
- 112 OV-OV
- 113 D1-D2
- 114 D2-D3
- 115 D3-D4
- 116 D4-D5
- 117 D5-D6
- 118 D6-D7
- 119 D7-D8

[SENS *75 HF *300 LF *0.53 CAL *50]



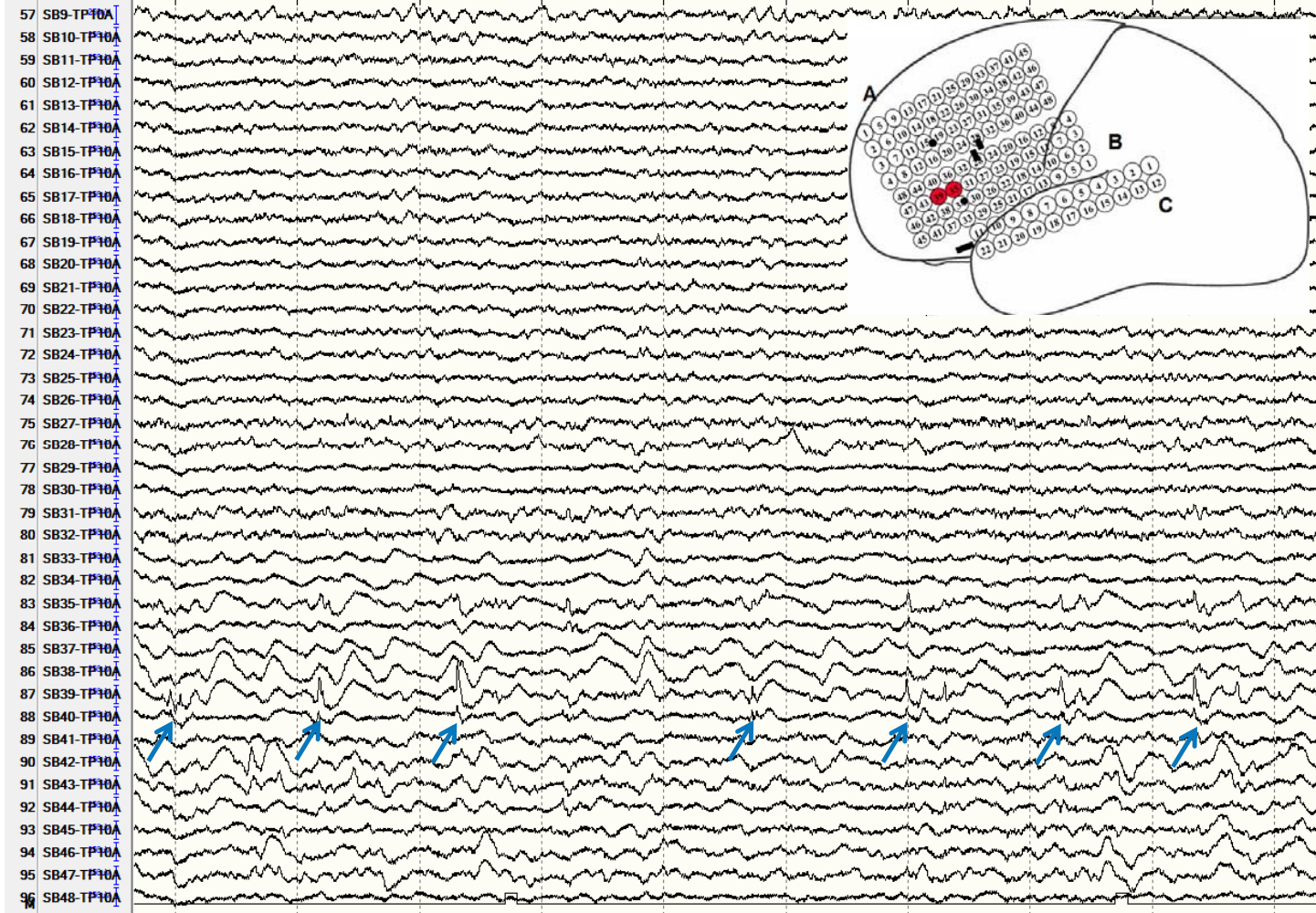
Types of Subdural Interictal Discharges

- Isolated spikes
 - Amplitude $>200 \mu\text{V}$, frequency $>7 \text{ Hz}$, irregular firing
- Repetitive spikes
 - Burst duration $> 0.5\text{s}$, amplitude $>200 \mu\text{V}$, frequency $\pm 7\text{-}10 \text{ Hz}$, regular firing
- Runs of slow repetitive spikes
 - Burst duration $> 0.5\text{s}$, amplitude $>200 \mu\text{V}$, frequency $< 7\text{-}10 \text{ Hz}$, regular firing



Repetitive Spikes, Left Inferior Frontal

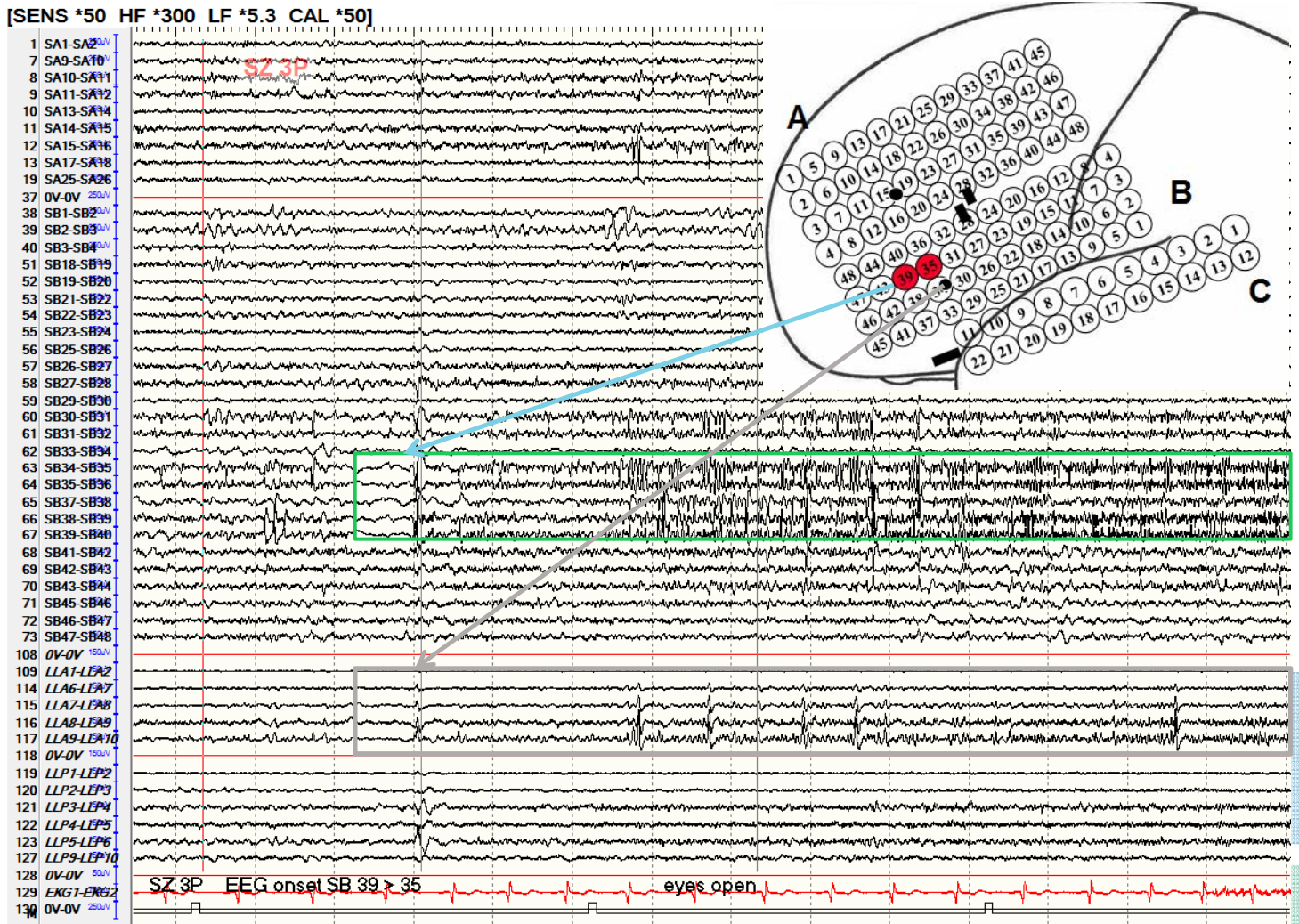
[SENS *50 HF *120 LF *1.6 CAL *50]



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

Chassoux et al. Clin Neurophysiology, 2013
Widdess-Walsh. et al. Neurology, 2007

Ictal onset patterns



Types of Ictal Patterns

Low-voltage fast activity: clearly visible rhythmic activity >13 Hz, usually 5-10 mV in initial amplitude

Low-frequency high-amplitude periodic spikes: high-voltage spiking at 0.5–2 Hz, lasting 4-5 seconds

Sharp activity at <13 Hz: low to medium-voltage sharply-contoured rhythmic activity, most commonly in the alpha-theta range

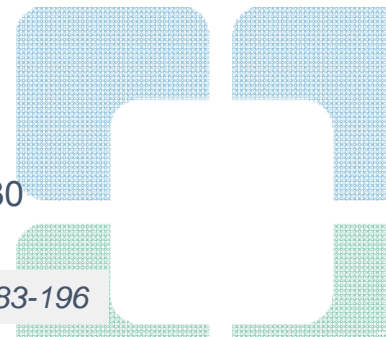
Spike-and-wave activity: medium- to high-voltage spike-and-wave complexes typically occurring at a frequency of 2–4 Hz

Burst of high-amplitude polyspikes: a single brief burst of repetitive high-voltage spikes

Burst suppression: brief bursts of medium- to high-voltage repetitive spikes alternating with brief periods of voltage attenuation

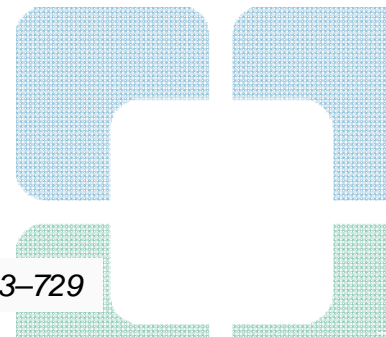
Delta brush: rhythmic delta waves at 1–2 Hz, with superimposed brief bursts of 20–30 Hz activity overriding each delta wave

Perucca P et al, Brain 2014;137; 183-196

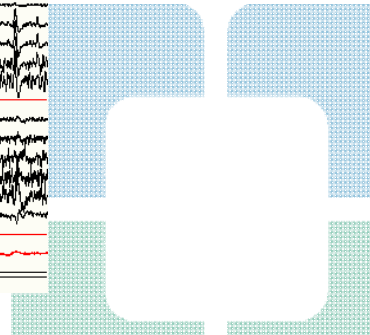
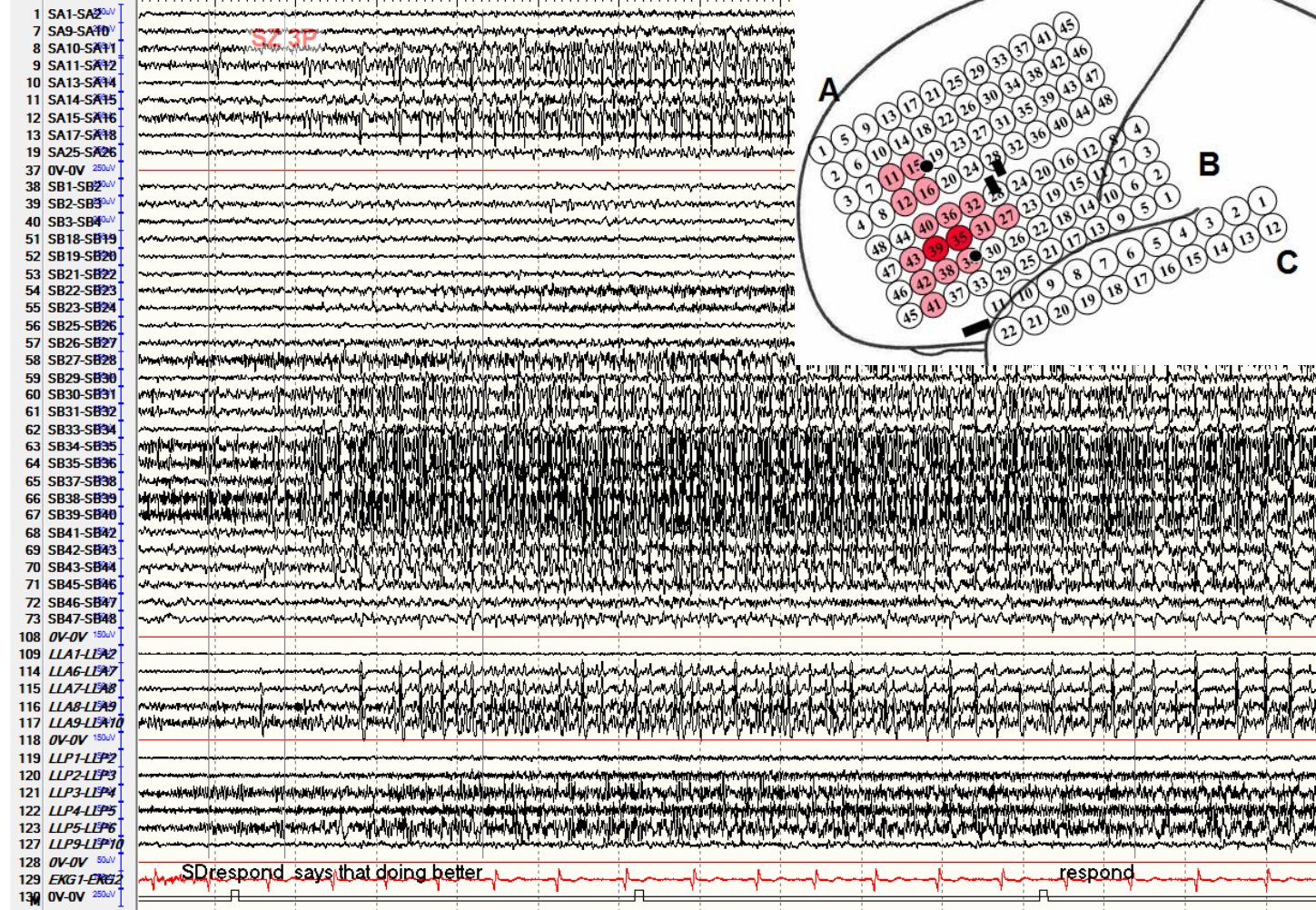


Subdural and Depth Electrodes

- Advantages
 - Optimal coverage of the subdural space adjacent cortex with adequate and continuous superficial functional mapping capabilities
- Disadvantages
 - Inability to record from deep cortical areas, as in the depth of sulci, interhemispheric regions, mesial temporal or frontal structures, and insula/opercular regions
 - Depth electrodes are not fully stereotactically implanted, their placement may not be very accurate

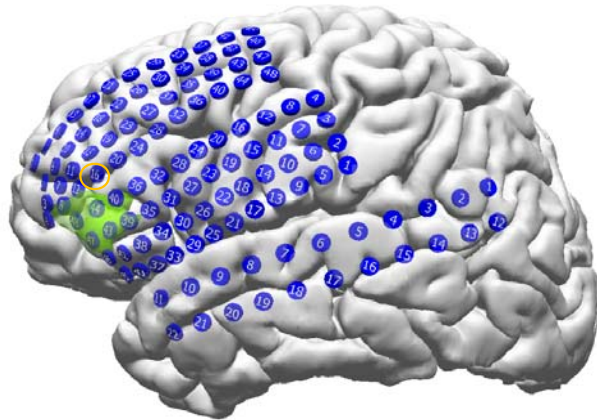


[SENS *50 HF *300 LF *5.3 CAL *50]

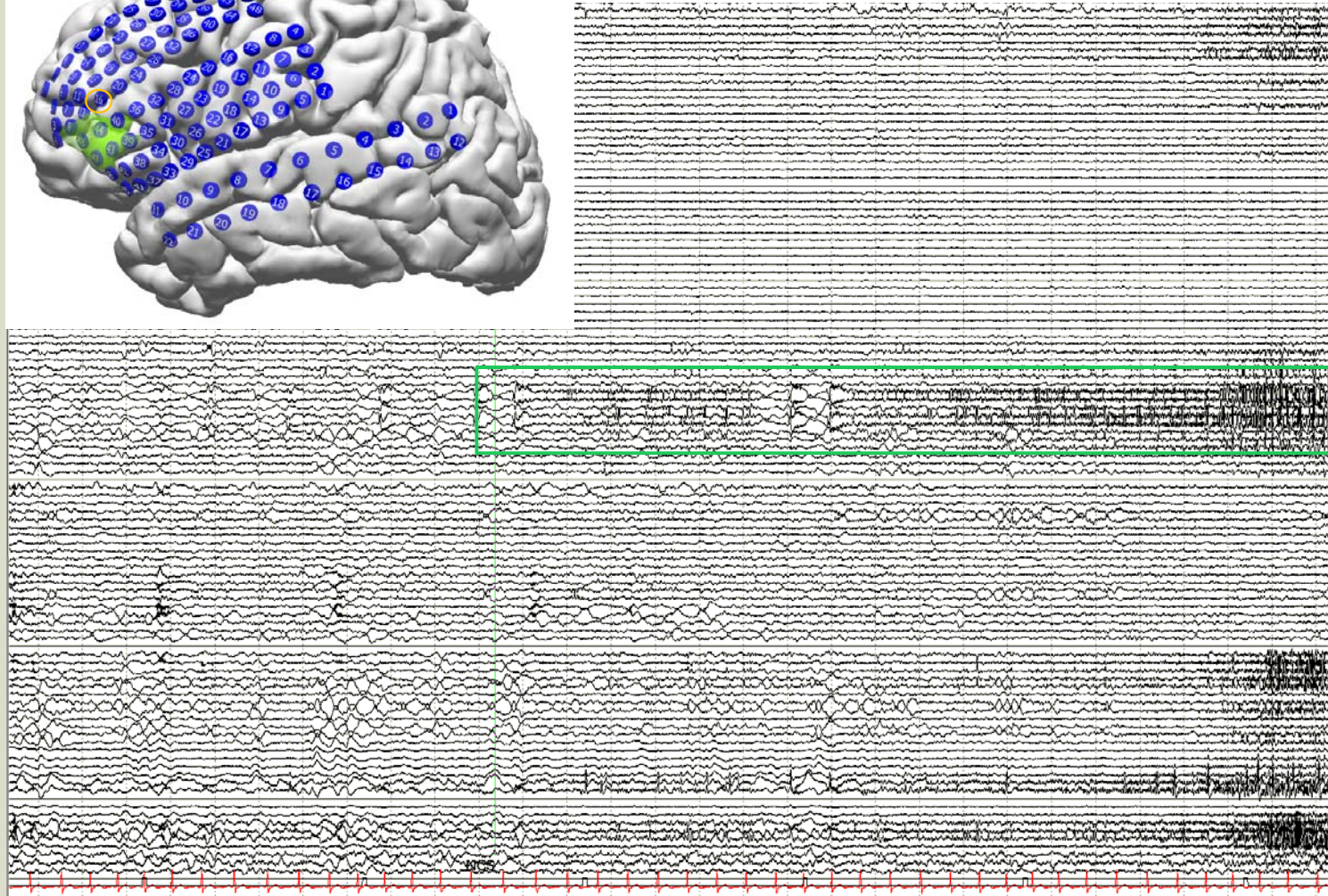


Ictal Onset Patterns

Without Clinical Signs – 1 to 2 per hr



7 SA0-SA0
8 SA10-SA10
9 SA11-SA11
10 SA13-SA13
11 SA14-SA14
12 SA15-SA15
13 SA16-SA16
14 SA17-SA17
15 SA18-SA18
16 SA21-SA21
17 SA22-SA22
18 SA23-SA23
19 SA25-SA25
20 SA26-SA26
21 SA27-SA27
22 SA28-SA28
23 SA29-SA29
24 SA31-SA31
25 SA32-SA32
26 SA33-SA33
27 SA34-SA34
28 SA35-SA35
29 SA36-SA36
30 SA37-SA37
31 SA41-SA41
32 SA42-SA42
33 SA43-SA43
34 SA44-SA44
35 SA45-SA45
36 SA46-SA46
37 SA47-SA47
38 OV-ov
39 SB1-SB1
40 SB2-SB2
41 SB3-SB3
42 SB4-SB4
43 SB5-SB5
44 SB6-SB6
45 SB7-SB7
46 SB8-SB8
47 SB9-SB9
48 SB10-SB10
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50 SB12-SB12
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68 SB30-SB30
69 SB31-SB31
70 SB32-SB32
71 SB33-SB33
72 SB34-SB34
73 SB35-SB35
74 OV-ov
75 SC1-SC1
76 SC2-SC2
77 SC3-SC3
78 SC4-SC4
79 SC5-SC5
80 SC6-SC6
81 SC7-SC7
82 SC8-SC8
83 SC9-SC9
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85 SC11-SC11
86 SC12-SC12
87 SC13-SC13
88 SC14-SC14
89 SC15-SC15
90 SC16-SC16
91 SC17-SC17
92 SC18-SC18
93 SC19-SC19
94 SC20-SC20
95 OV-ov
96 SD1-SD1
97 SD2-SD2
98 SD3-SD3
99 SD4-SD4
100 SD5-SD5
101 SD6-SD6
102 SD7-SD7
103 SD8-SD8
104 SD9-SD9
105 SD10-SD10
106 SD11-SD11
107 SD12-SD12
108 SD13-SD13
109 SD14-SD14
110 SD15-SD15
111 LA1-LA1
112 LA2-LA2
113 LA3-LA3
114 LA4-LA4
115 LA5-LA5
116 LA6-LA6
117 LA7-LA7
118 OV-ov
119 LP1-LP1
120 LP2-LP2
121 LP3-LP3
122 LP4-LP4
123 LP5-LP5
124 LP6-LP6
125 LP7-LP7
126 LP8-LP8
127 LP9-LP9
128 LP10-LP10
129 OV-ov
130 EXG1-EXG1



Predictors for Seizure Recurrence

- Ictal onset at edge of plate 14%
- Diffuse ictal onset 29%
- > 1 ictal onset zones 35%
- Morphology of ictal onset N/S

Kalamangalam. JCNP et al. 2009

Kim DW. et al. Epilepsia 2010

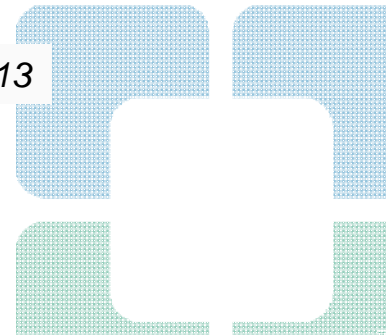
Bulacio JC, et al. Epilepsia 2012



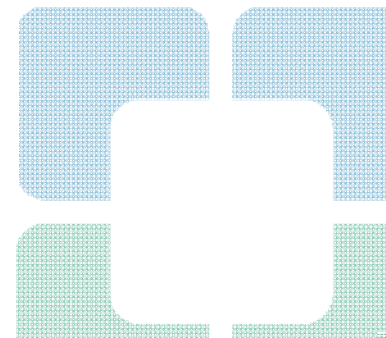
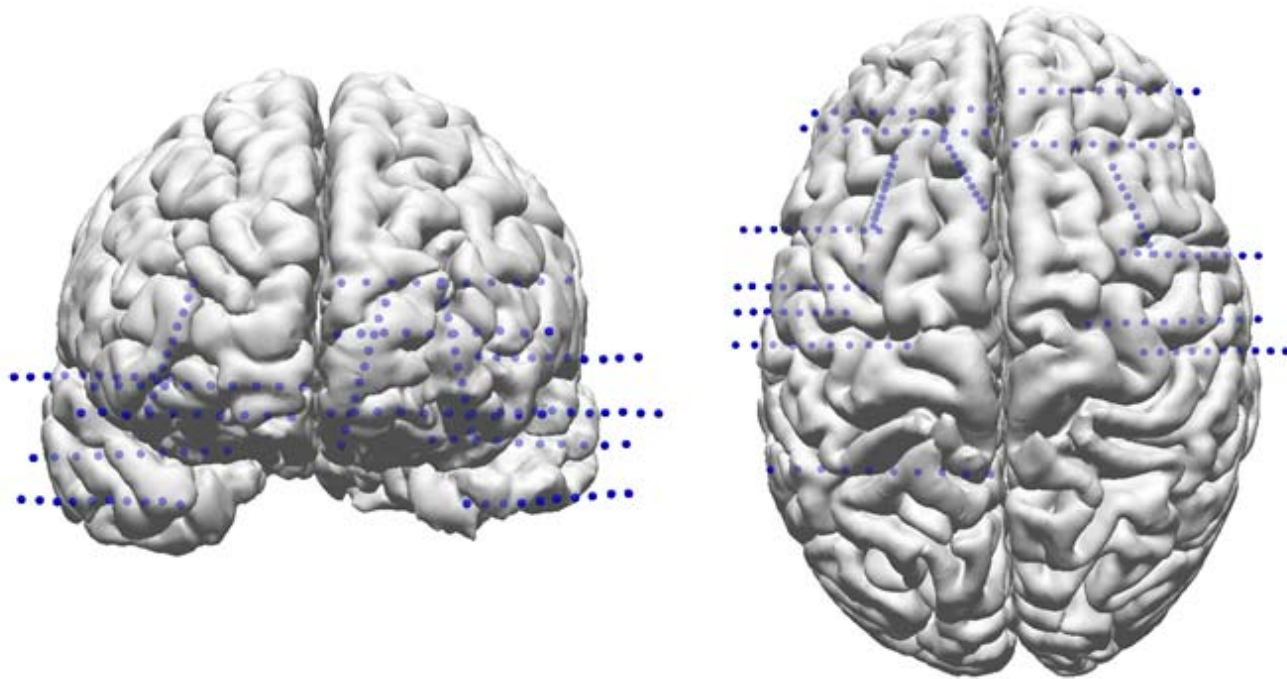
Subdural grids and depths complications

- Most patients who are implanted with SDE tolerate the procedure well
- 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

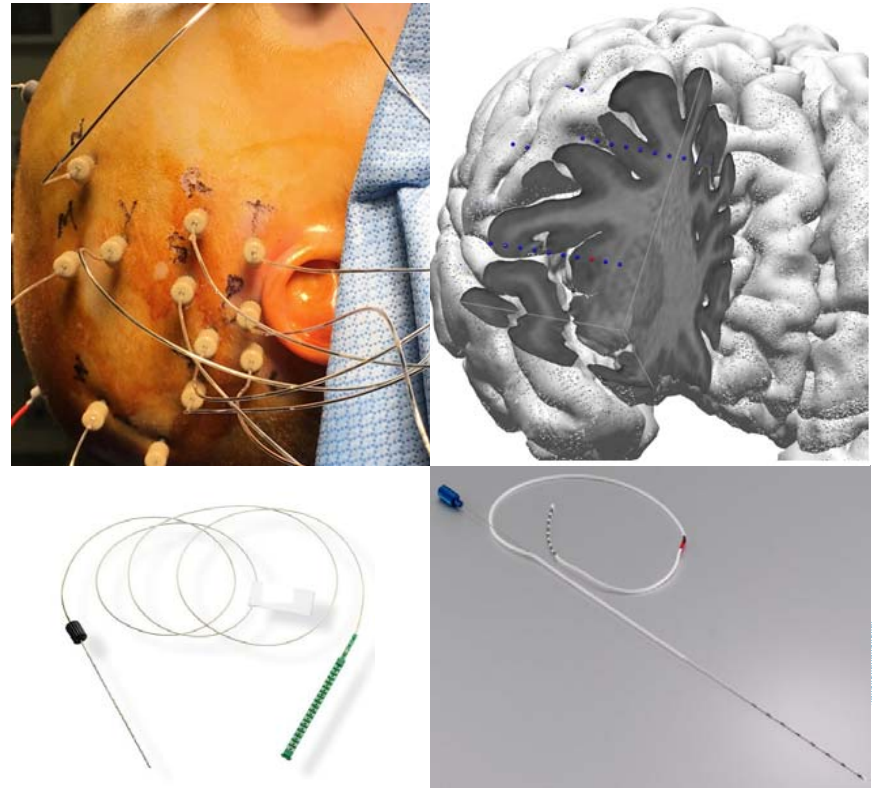


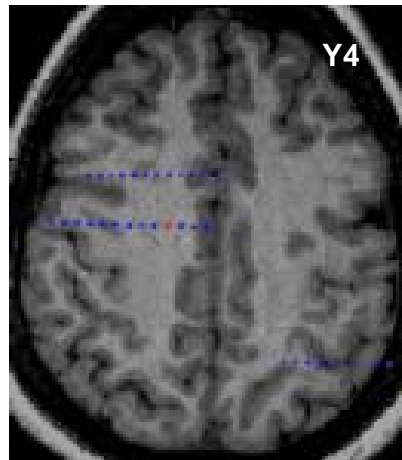
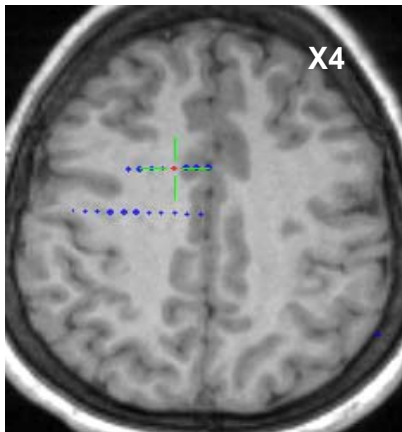
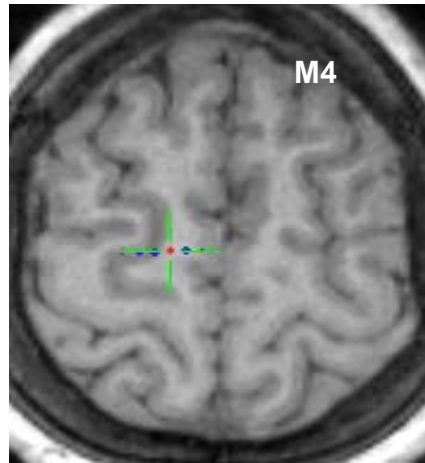
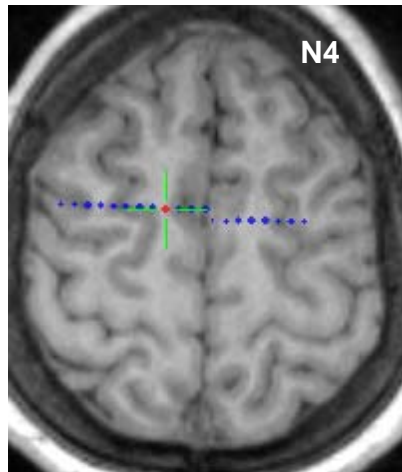
SEEG “Network”



SEEG “Network”

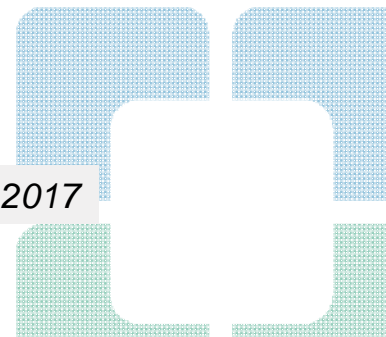
- Presurgical evaluation suggestive of a functional network involvement (e.g., limbic system, parietal-frontal system, parietal-temporal system, etc.) in the setting of normal MRI
- Bi-hemispheric explorations (in particular in focal epilepsies arising from the interhemispheric or deep insular / opercular regions)



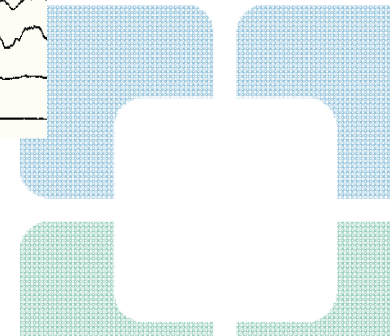
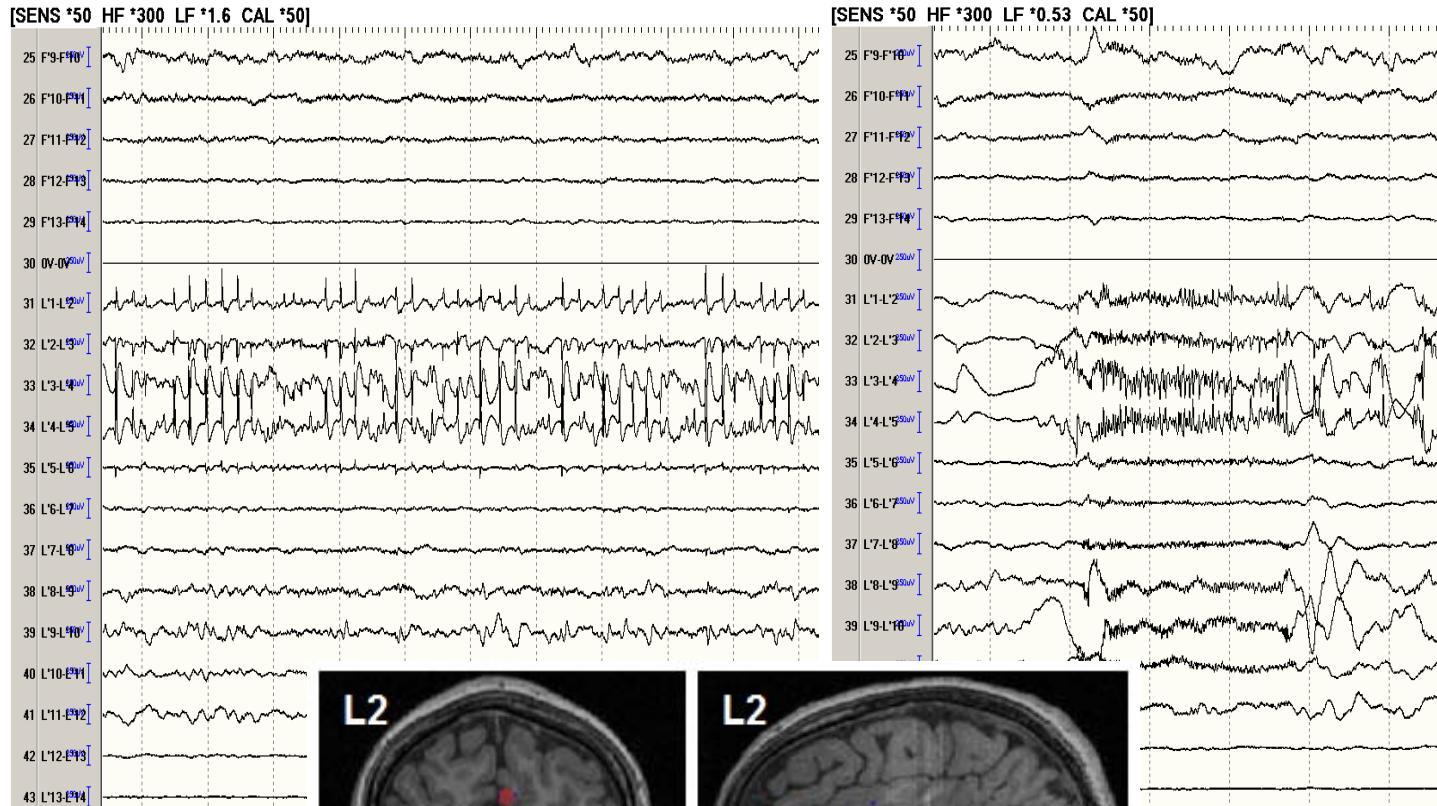


SEEG: Accurate
electrode placement

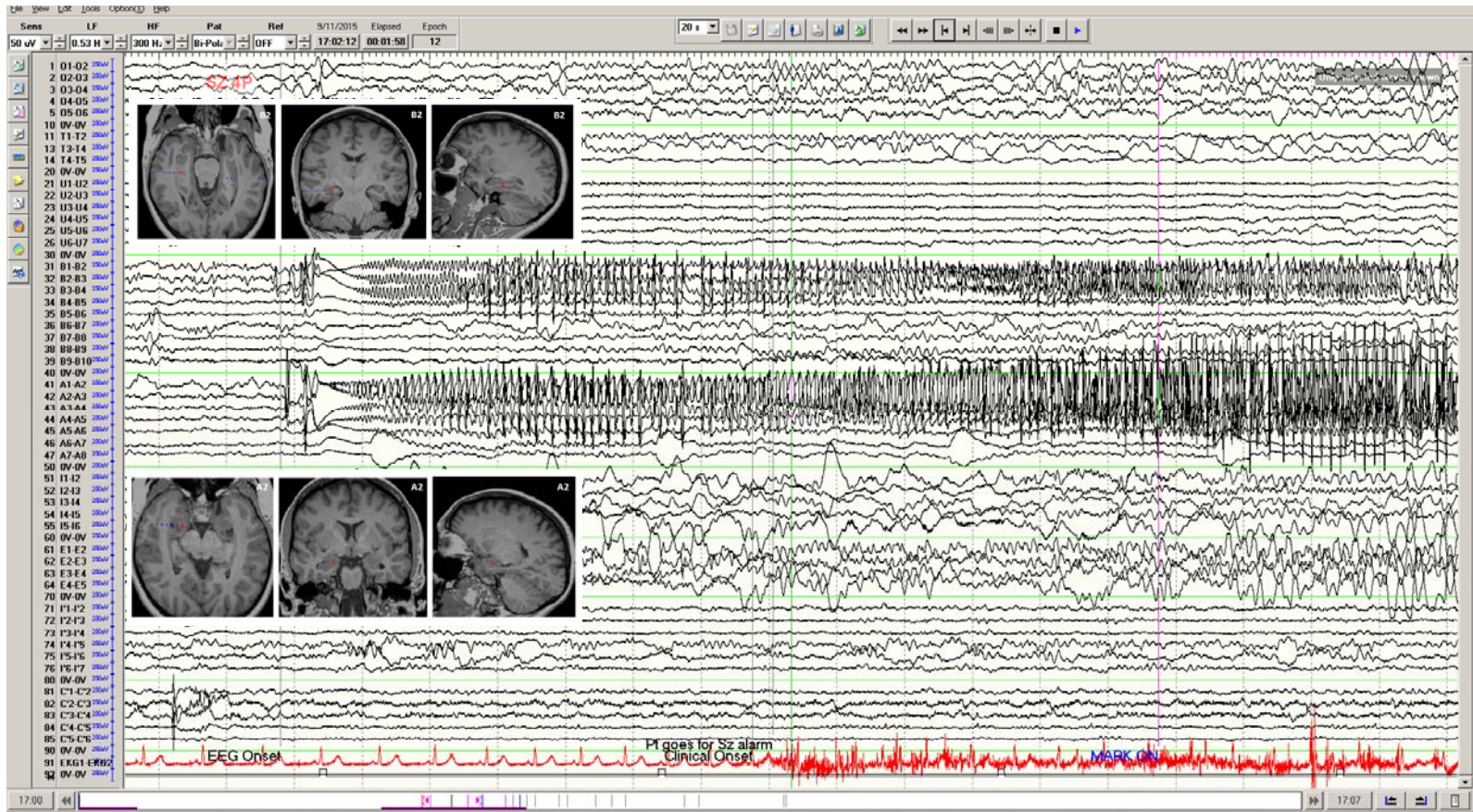
Vakharia VN et al, *Epilepsia* 2017



SEEG: Interictal Patterns

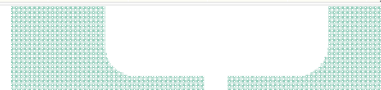
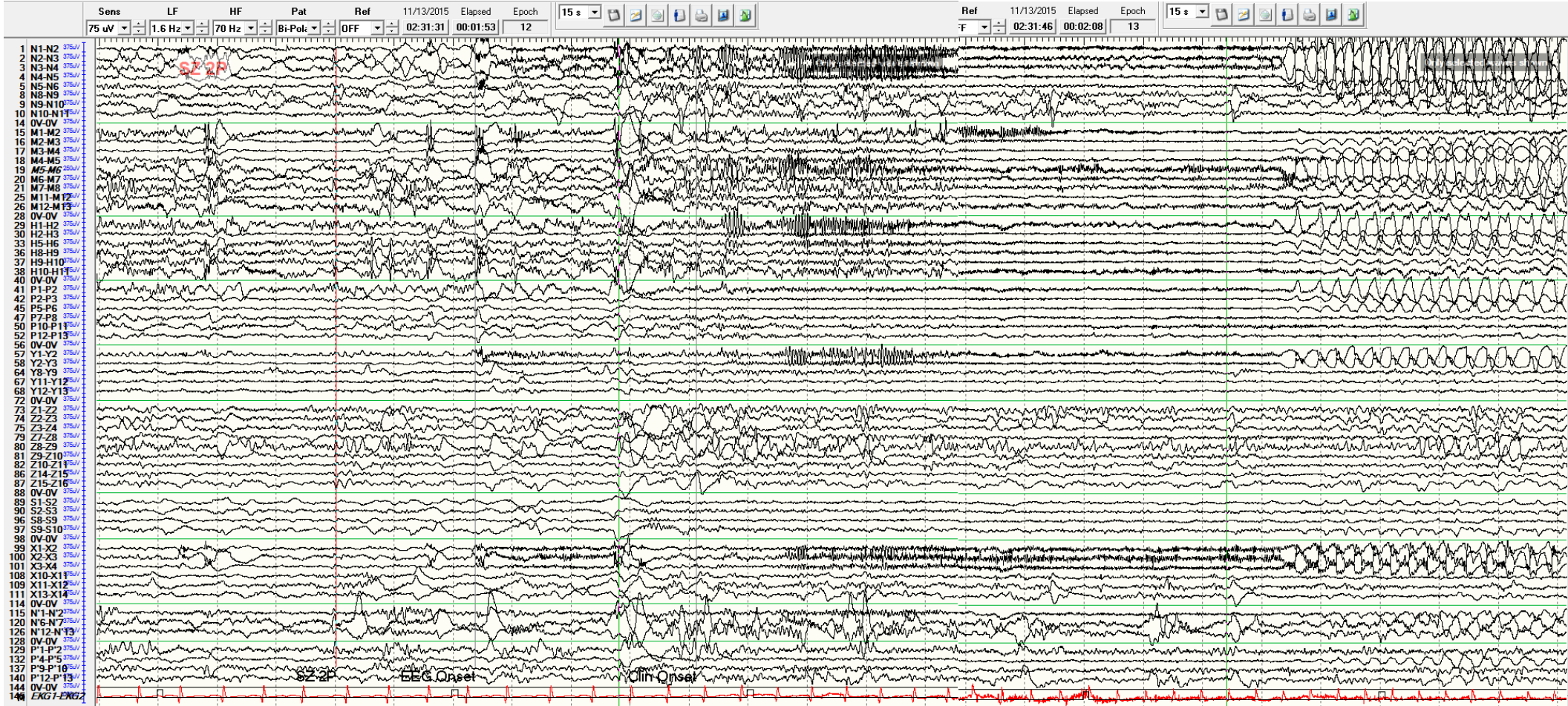


SEEG: Ictal Onset Patterns



Bulacio JC et al; J Clin Neurophysiol. 2016-503-510

SEEG: Ictal Onset Patterns

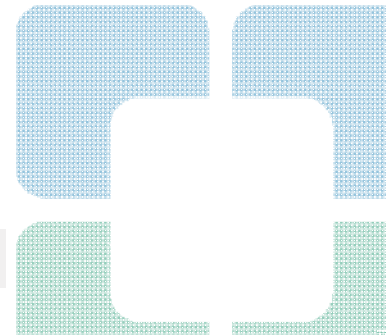


SEEG

Limitations and Complications

- In neocortical epilepsy and particularly when generator is located over the convexity depth electrodes may suffer from poor sampling
- Disoriented patients may pull on electrodes and cables
- 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



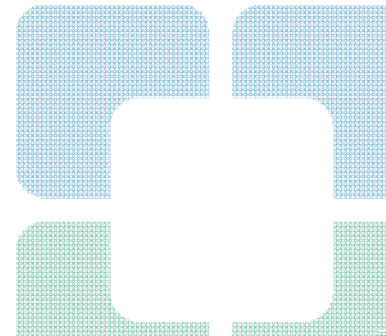
Selection criteria for different methods of Intracranial EEG

Clinical scenario	First option	Second option
<ul style="list-style-type: none"> ■ Lesional MRI: Potential epileptogenic lesion is superficially located near or in the proximity of eloquent cortex. ■ Nonlesional MRI: Hypothetical EZ located in the proximity of eloquent cortex. 	SBG	SEEG
<ul style="list-style-type: none"> ■ Lesional MRI: Potential epileptogenic lesion is located in deep cortical and subcortical areas. ■ Nonlesional MRI: hypothetical EZ is deeply located or located in noneloquent areas. 	SEEG	SBG with depths
<ul style="list-style-type: none"> ■ Need for bilateral explorations and/or reoperations 	SEEG	SBG with depths
<ul style="list-style-type: none"> ■ After SDGs failure 	SEEG	SBG with depths
<ul style="list-style-type: none"> ■ When the AEC hypothesis suggest the involvement of a more extensive, multilobar epileptic network 	SEEG	SBG with depths
<ul style="list-style-type: none"> ■ Suspected frontal lobe epilepsy in nonlesional MRI scenario 	SEEG	SEEG

Modified from Gonzalez et al, in Wyllie's Treatment of Epilepsy 2015 (Chapter 81).

Remarks

- 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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