Update on trends in Invasive Monitoring for Epilepsy

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Neurosurgical Society of Alabama
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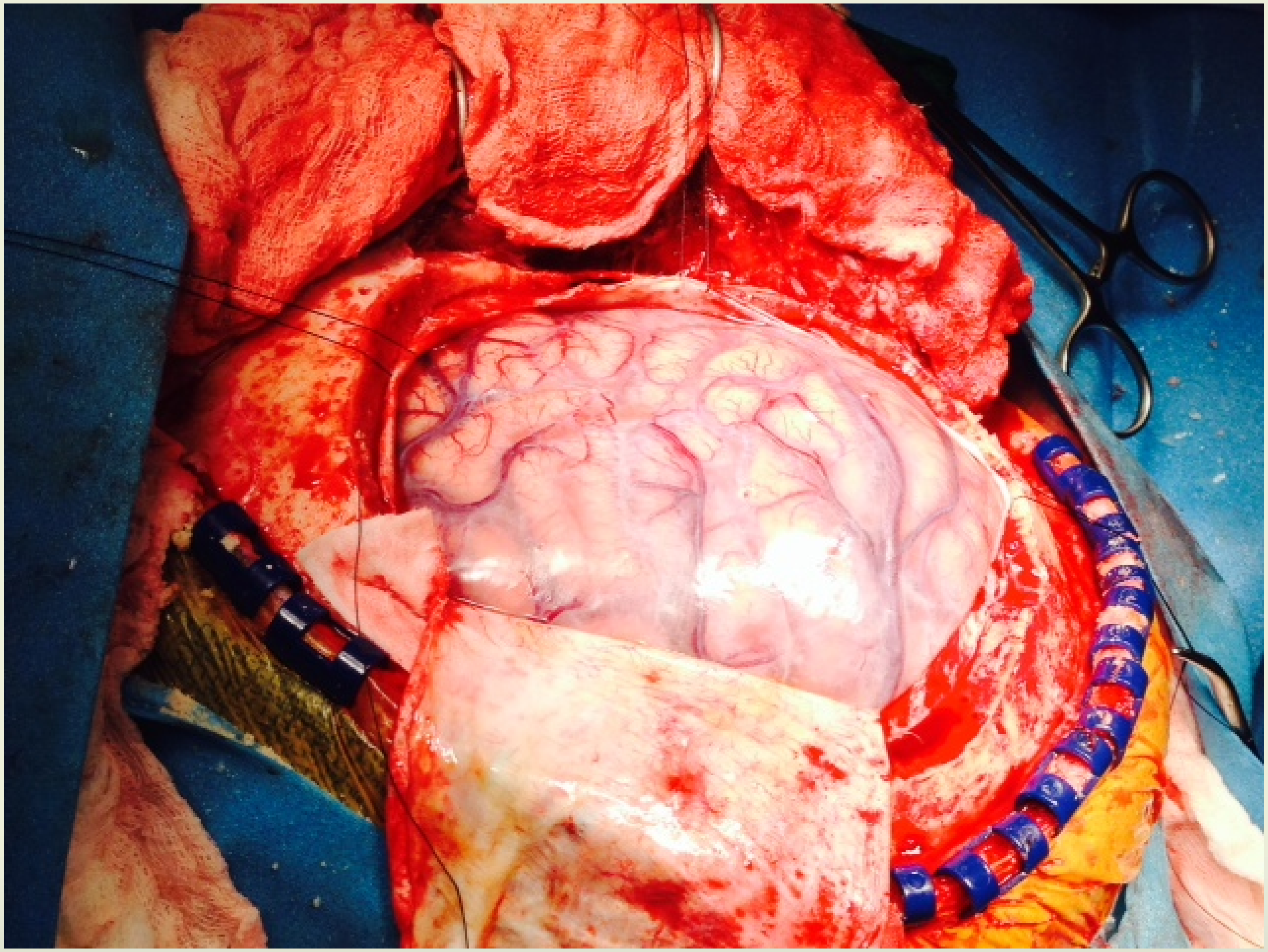
Invasive Monitoring

- 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



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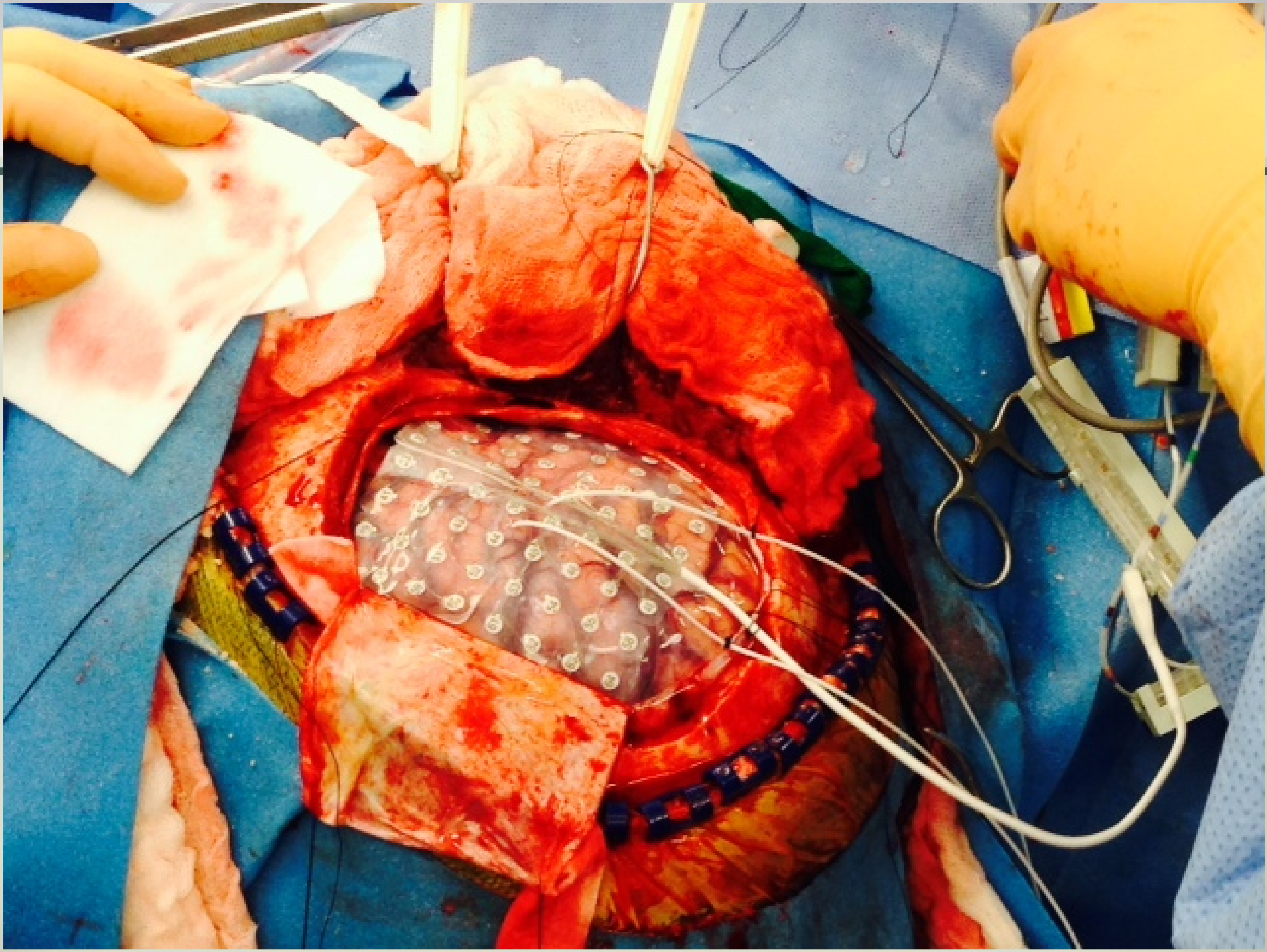

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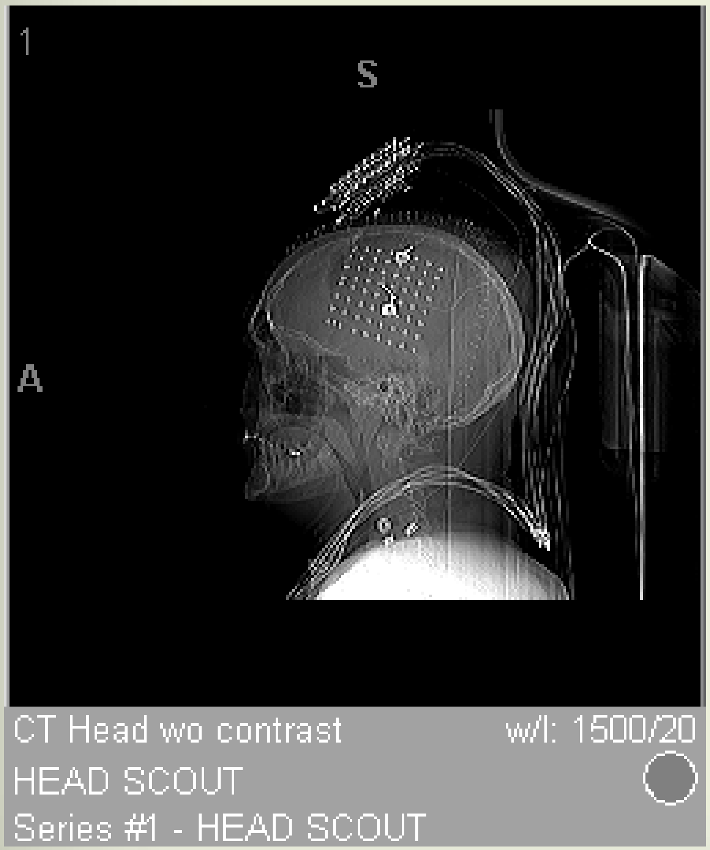
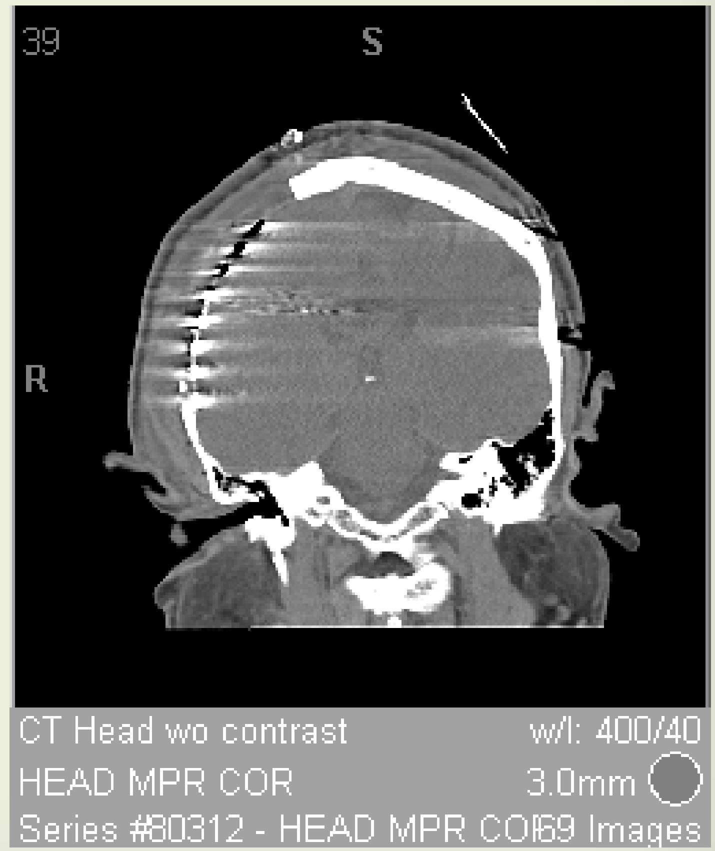
Pt with subdural grid electrodes, bone flap stored in bone bank during invasive monitoring stay- up to 7 days.
Pt will return to OR for grid removal, replacement of bone flap and possible brain cortical resection





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Stereoencecphalography (SEEG) Origins

- Talairach and Bancaud

- Bancaud, 1959 Bancaud J. Apport de l'exploration fonctionnelle par voie stéréotaxique à la chirurgie de l'épilepsie. Neurochirurgie 1959; 5: 55-112.
- Bancaud and Dell, 1959 Bancaud J, Dell MB. Techniques et méthodes de l'exploration fonctionnelle stéréotaxique des structures encéphaliques chez l'homme (cortex, sous-cortex, noyaux gris centraux). Rev Neurol 1959; 101: 220-1.
- Bancaud et al 1965 Bancaud J, Talairach J, Bonis A, et al. La stéréoencéphalographie dans l'épilepsie. Informations neuro-physio-pathologiques apportées par l'investigation fonctionnelle stéréotaxique. Paris: Masson, 1965; (321 pp.).
- Bancaud et al 1973 Bancaud J, Talairach J, Geier S, et al. EEG et SEEG dans les tumeurs cérébrales et l'épilepsie. Paris: Edifor, 1973; (351 pp.).

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."

- Acta Neurochir Suppl (Wien). 1989;46:9-12.
- **Stereotactic investigations in frontal lobe epilepsies.**
- Munari C[1], Giallonardo AT, Brunet P, Broglin D, Bancaud J.
- **Author information**
- [1]INSERM U 97, Paris, France.
- **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

The Bancaud and Talairach view on the epileptogenic zone: a working hypothesis

Philippe Kahane[1,5], Elisabeth Landré[2], Lorella Minotti[1], Stafano Francione[3], Philippe Ryvlin[4,5]

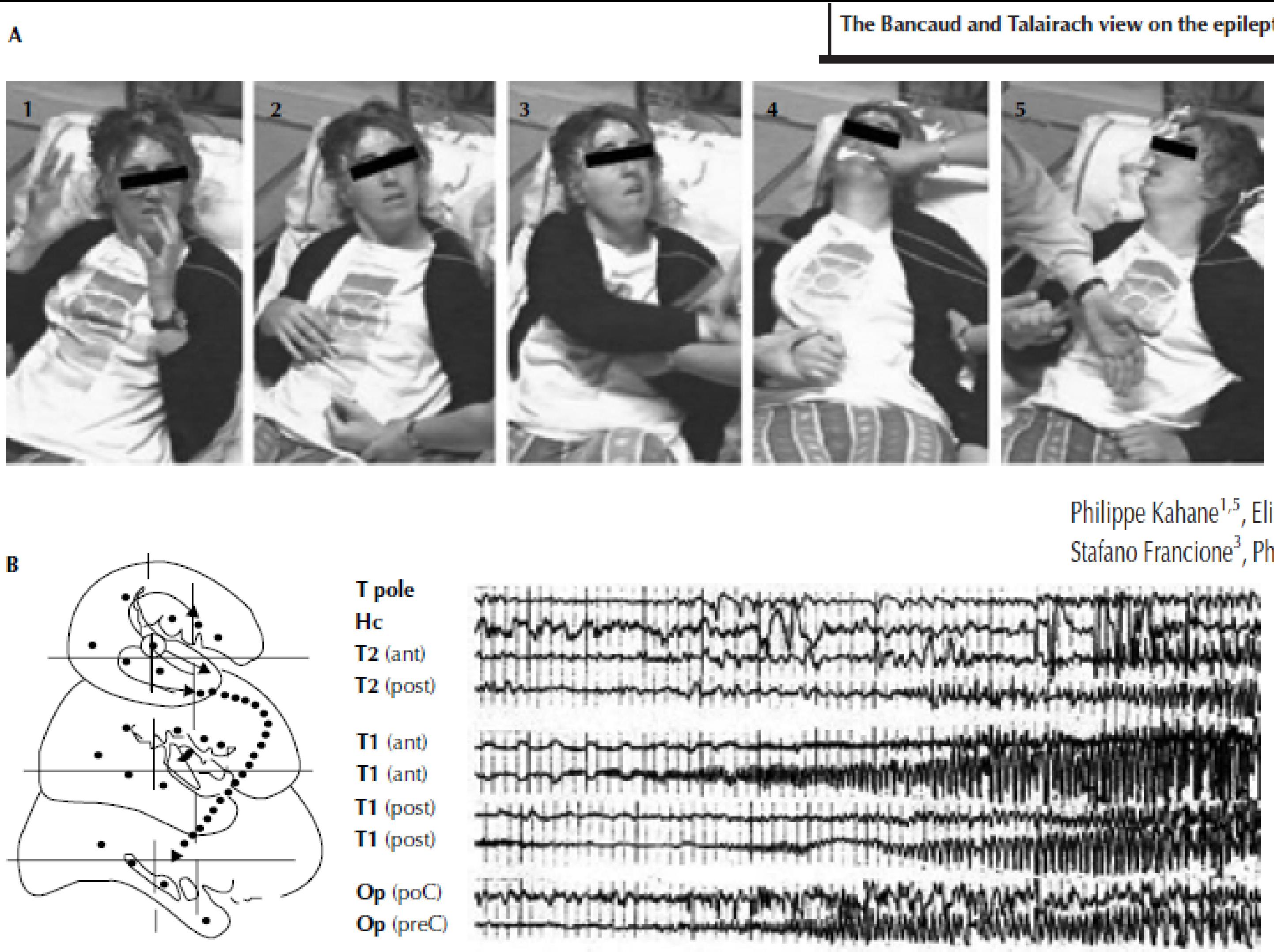

Figure 1. This 35-year-old, right-handed woman was suffering from drug-resistant, partial seizures associated with right hippocampal sclerosis. (**A**) Clinically, seizures were initiated by auditory illusions (1) followed by consciousness impairment (2), version of the head and eyes towards the left, 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. Intracrebral 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

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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

- From:

Stereotactic placement of depth electrodes in medically intractable epilepsy

Technical note

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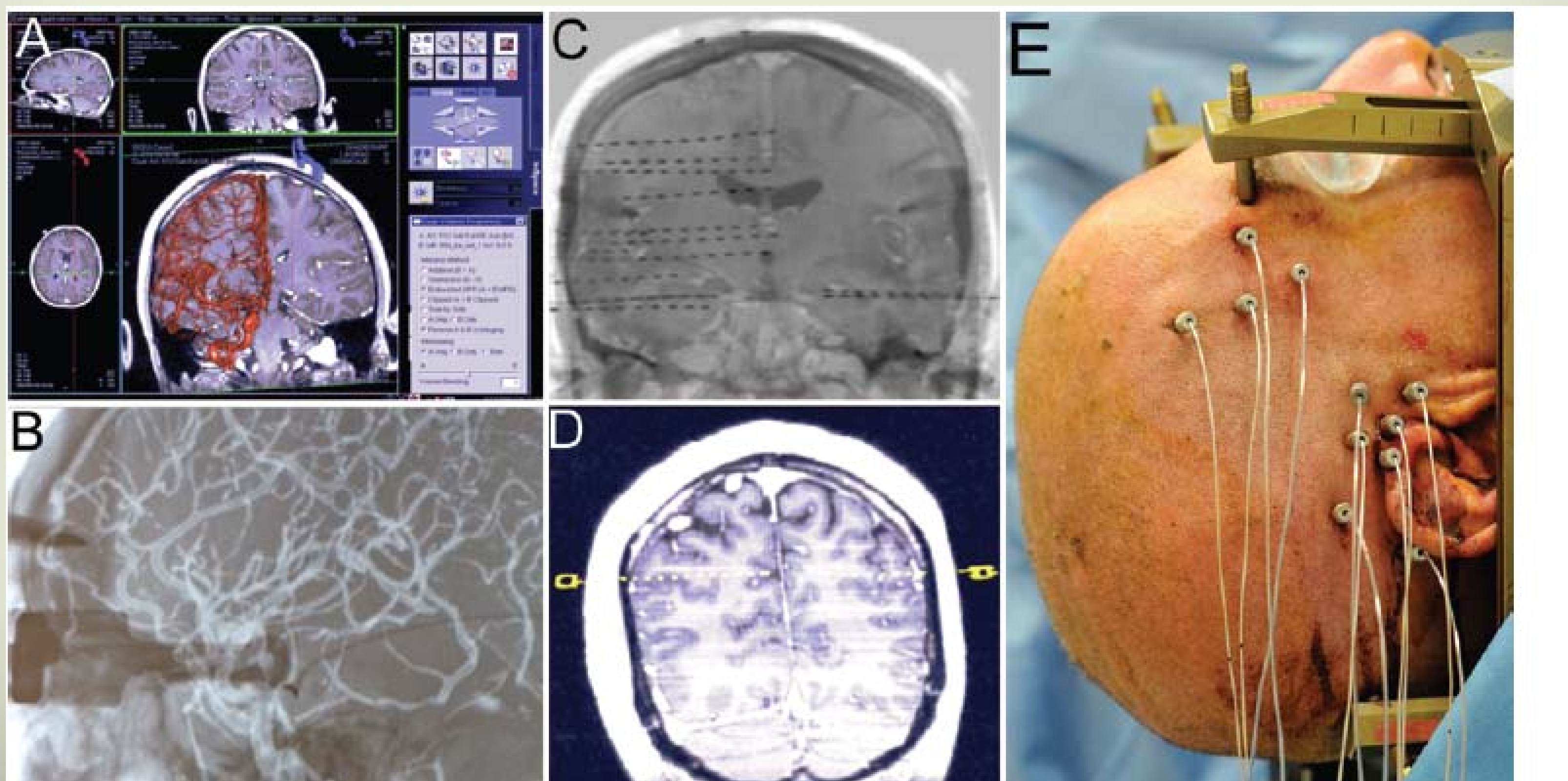
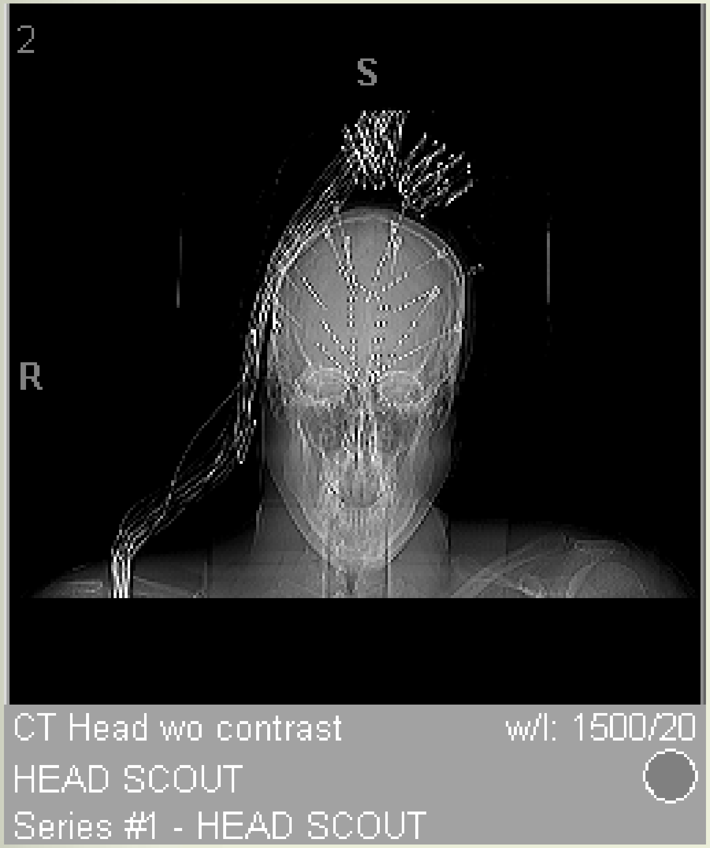
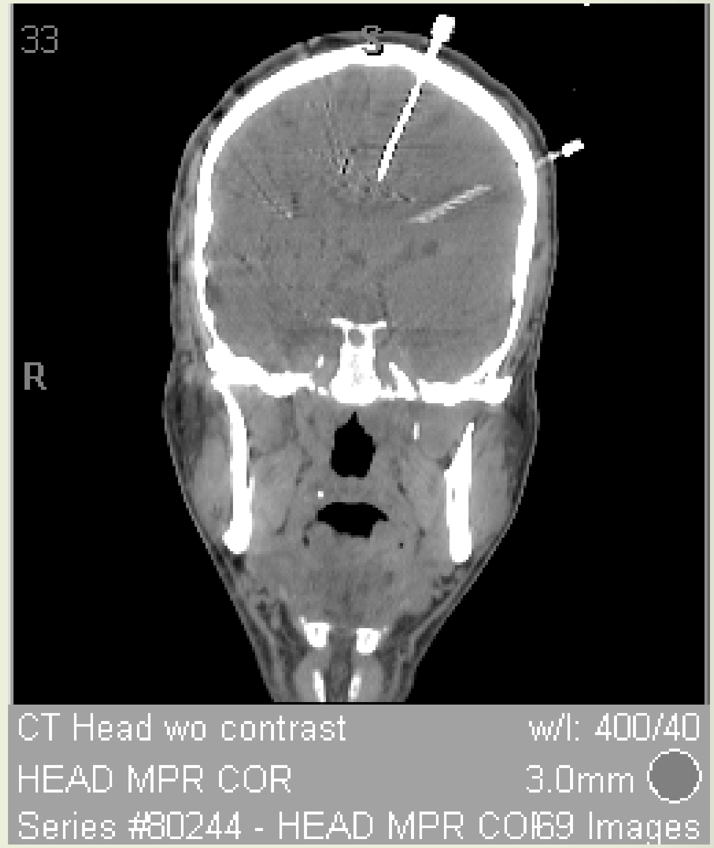
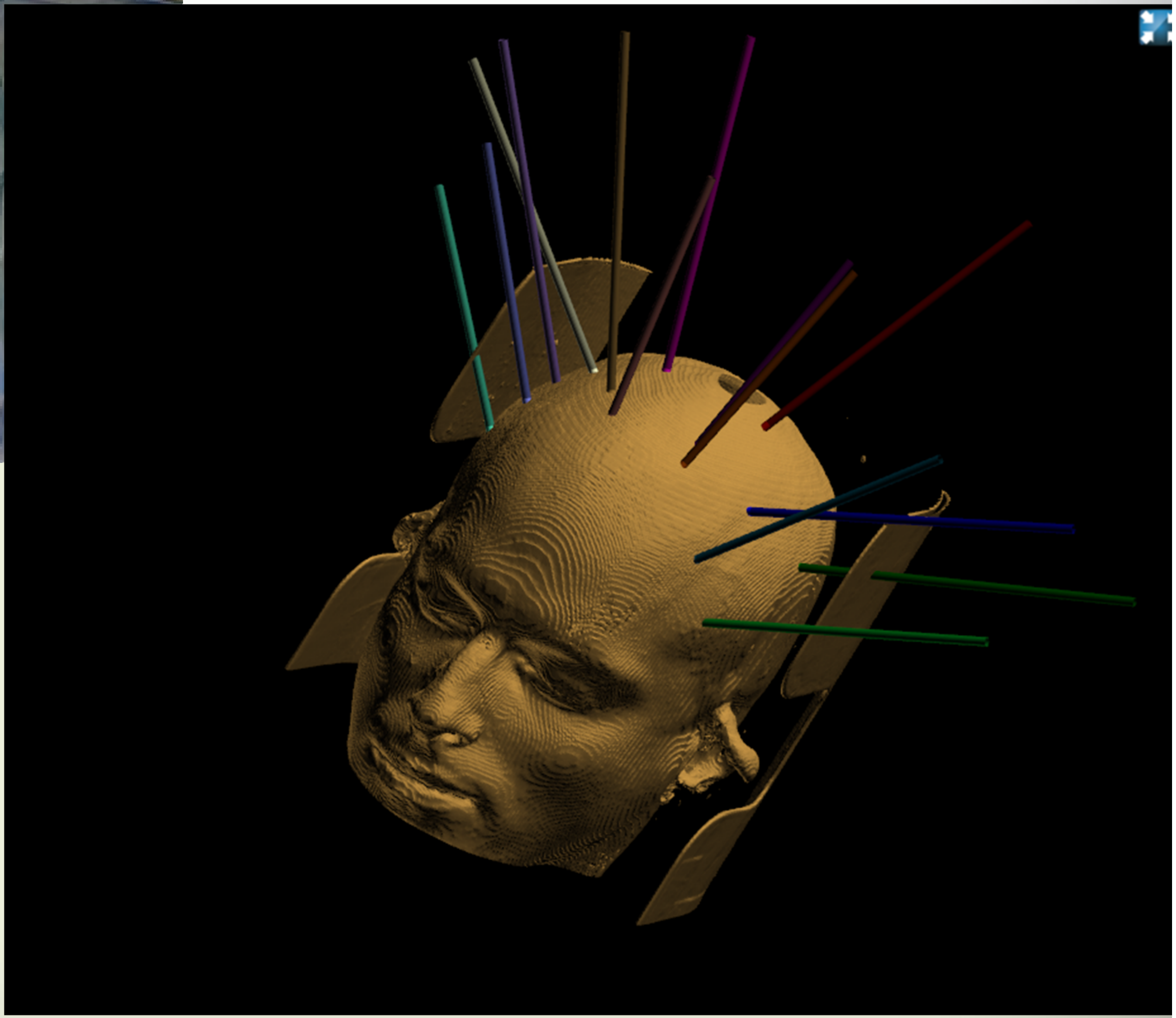


Pt with SEEG electrodes in place secured by anchor bolts, no bone removal.
Electrodes remain for length of monitoring, can be longer than one week.







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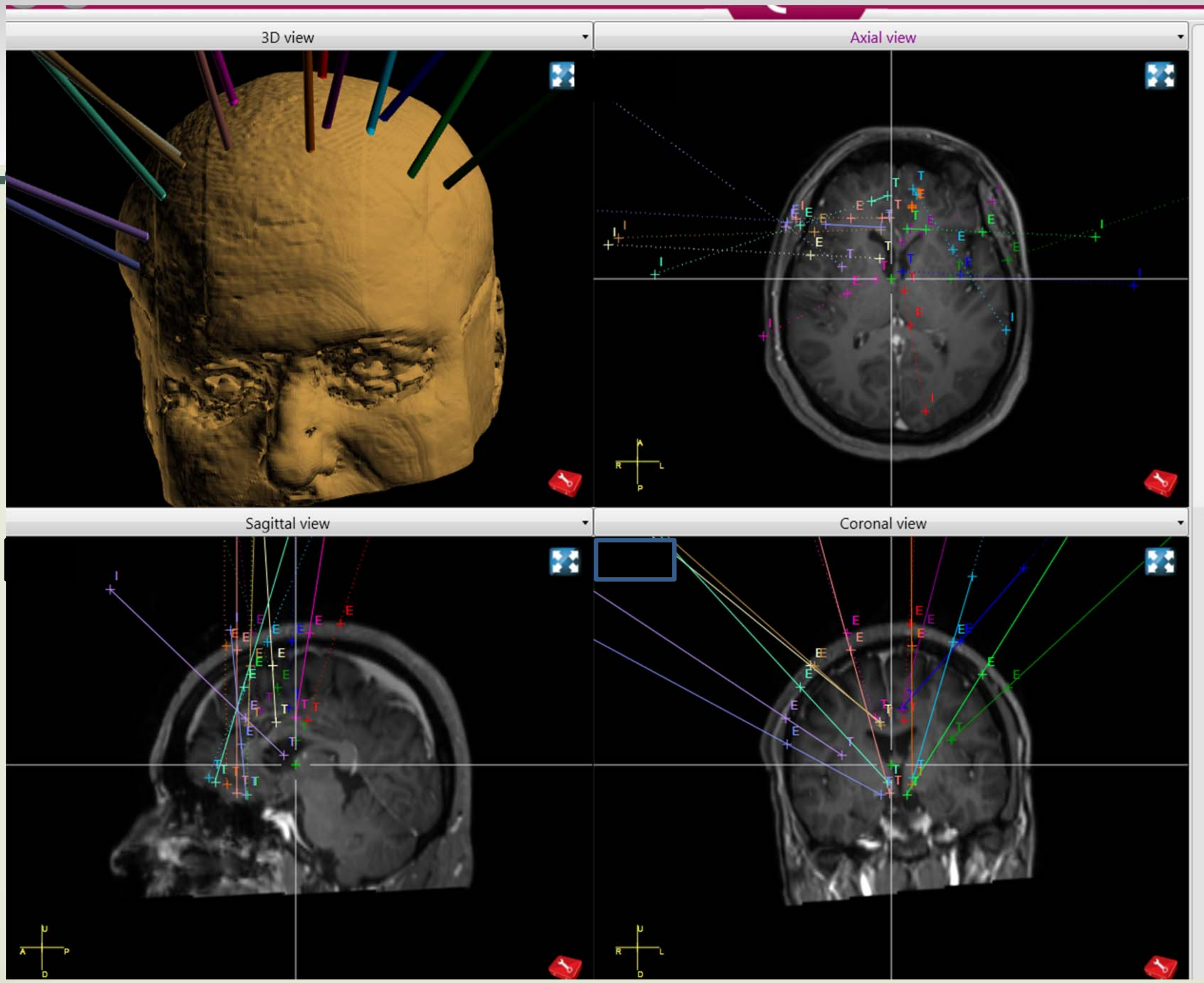

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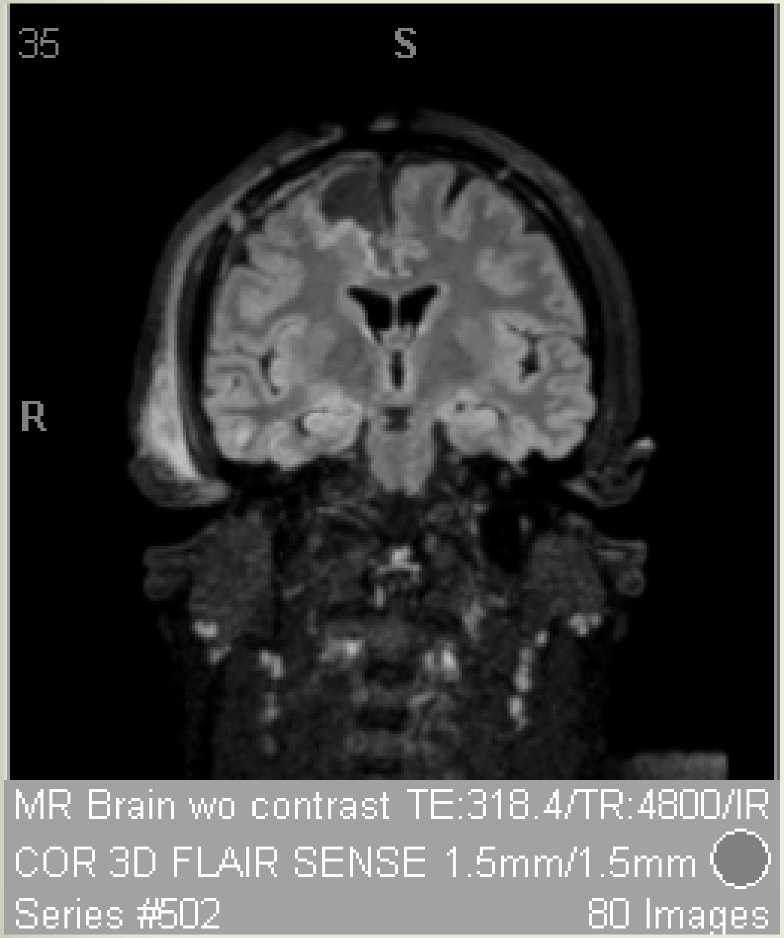
32 yo RH WF with stereotyped events for 6 years. Described as head turning, extremity waving, fencer posturing- multiple events/day, also type with whole body tensing during sleep

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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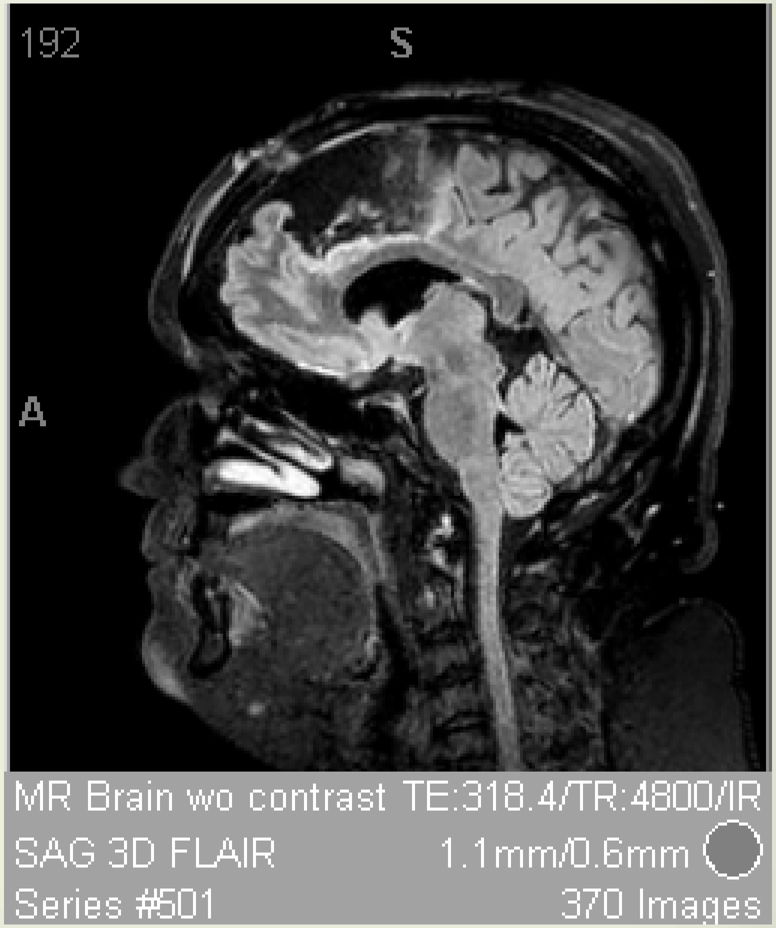
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SAG 3D FLAIR 1.1mm/0.6mm
Series #501
370 Images

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)

From: Cardinale et al. Stereoelectorencephalography: Surgical Methodology, Safety and Steretotactic Application Accuracy in 500 Procedures

TABLE 2. Morbidity: Literature Review[a]

Reference (Period)	Institution	Population	Procedures	Electrodes	Major Complications Subtotal, n (%)	Minor Complications Subtotal, n (%)	Total, n (%)	Deaths, n
Munari,[11] 1987 (1974-1985)	Hôpital Saint Anne, Paris, France	Children, Adults	300	SEEG	1 (0.3)	2 (0.7)	3 (1)	
Munari et al,[12] 1994 (1990-1992)	Neuroscience Department CHRU, Grenoble, France	Children, adults	70	SEEG	1 (1.4)	1 (1.4)	2 (2.8)	
Adelson 1995[13] (1990-1994)	Harvard Medical School Children's Hospital, Boston, MA	Children	31	Grids and strips	1 (3.2)	4 (12.9)	5 (16.1)	
Swartz et al,[14] 1996 (1987-1992)	California Comprehensive Epilepsy Program, Los Angeles, CA	?	58	Grids and strips	0	20 (34.5)	20 (34.5)	
Behrens et al,[15] 1997 (1987-1994)	University of Bonn, Bonn, Germany	Children, adults	279	Grids and strips (DE)	8 (2.9)	0	8 (2.9)	
Wiggins et al,[16] 1999 (1993-1997)	Henry Ford Hospital, Detroit, MI	Adults	38	Grids and strips (DE)	4 (10.5)	0	4 (10.5)	
Lee et al,[17] 2000 (1994-1998)	Asan Medical Center, Seoul, Korea	Adults	50	Grids	7 (14)	1 (2)	8 (16)	
Bruce and Bizzi,[18] 2000 (1990-1998)	Dallas Hospital, Dallas, TX	Children	85	Grids and strips (DE)	3 (3.5)	2 (2.4)	5 (5.9)	
Guenot et al,[19] 2001 (1996-2000)	Hospital P. Wertheimer, Lyon, France	?	100	SEEG	3 (3)	2 (2)	5 (5)	1
Rydenhag and Silander,[20] 2001 (1990-1995)	All Swedish epilepsy surgery centers, Sweden	Children, adults	205	Grids and strips (DE/EE/FO)	9 (4.4)	4 (2)	13 (6.3)	
Hamer et al,[21] 2002 (1980-1997)	Cleveland Clinic Foundation, Cleveland, OH	Children, adults	198	Grids	42 (21.2)	18 (9.1)	60 (30.3)	1
Simon et al,[22] 2003 (1989-2001)	Hospital of the University of Pennsylvania, Philadelphia, PA	Children	67	Grids and strips (DE)	0	22 (32.8)	22 (32.8)	
Onal et al,[23] 2003 (1996-2001)	Hospital for Sick Children, London, ON, Canada	Children	35	Grids and strips (DE)	1 (2.9)	19 (54.3)	20 (57.1)	
Musleh et al,[25] 2006 (2000-2003)	University of Chicago Children's Hospital, Chicago, IL	Children	34	Grids and strips (DE)	2 (5.9)	0	2 (5.9)	
De Almeida et al,[26] 2006 (1982-1999)	Montreal Neurological Institute, Montreal, QC, Canada	Adults	224	DE/CE	10 (4.5)	31 (13.8)	41 (18.3)	
Burneo et al,[27] 2006 (2000-2004)	London Health Sciences Centre, London, ON, Canada	Children, adults	116	Grids and strips (DE)	4 (3.4)	2 (1.7)	6 (5.2)	
Fountas and Smith,[28] 2007 (1984-2004)	Medical College of Georgia, Augusta, GA	Adults	185	Grids and strips	6 (3.2)	3 (1.6)	9 (4.9)	1
Lee et al,[29] 2008 (1997-2006)	Sanggye Paik Hospital, Seoul, Korea	Children, adults	41	Grids and strips	3 (7.3)	1 (2.4)	4 (9.8)	
van Gompel et al,[30] 2008 (1996-2004)	Mayo Clinic, Rochester, MN	Children, adults	198	Grids	12 (6.1)	20 (10.1)	32 (16.2)	
Wong et al,[31] 2009 (1988-2004)	Westmead Hospital and Children's Hospital, Westmead, Australia	Children, adults	71	Grids	8 (11.3)	10 (14.1)	18 (25.4)	2
Manohar et al,[32] 2011 (2009-2010)	Cleveland Clinic Foundation, Cleveland, OH	Adults	50	SEEG	0	0	0	

[a]DE, depth electrodes; CE, cortical electrodes; EE, epidural 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

- Kahane P, et al. The Bancaud and Talairach view on the epileptogenic zone: a working hypothesis. Epileptic Disord 8 (Suppl 2): S16-26, 2006.
- Cardinale F, et al. Stereoelectroencephalography:Surgical Methodology, Safety, and Stereotactic Application Accuracy in 500 Procedures. Neurosurgery, 72: 353-366, 2013.
- Gonzalez-Martinez J, et al. Stereoelectroencephalography in the "difficult to localize" refractory focal epilepsy: Early experience from a North American epilepsy center. Epilepsia, 54(2) 323-330, 2013.
- Nobili L, et al. Surgical treatment of drug-resistant nocturnal frontal lobe epilepsy. Brain 130, 561-573, 2007.
- Taussig D, et al. Stereo-electroencephalography (SEEG) in 65 children: an effective and safe diagnostic method for pres-surgical diagnosis, independent of age. Epileptic Disord; 16 (3): 280-95, 2014.
- Cossu M, et al. Stereo-EEG in children. Childs Nerv Syst 22: 766-778, 2006.
- Gonzales-Martinez J, et al. Stereotactic placement of depth electrodes in medically intractable epilepsy. J Neurosurg 120:639-644, 2014.
- Munyon C, et al. The 3-Dimensional Grid: A Novel Approach to Stereoelectroencephalography. Operative Nsurg 0(0), 1-7, 2015.
- Enatsu R, et al. Combining stereo-electroencephalography and subdural electrodes in the diagnosis and treatment of medically intractable epilepsy. J of Clinical NeuroScience 21: 1441-1445, 2014.
- Nowell M, et al. A Novel Method for Implementation of Frameless StereoEEG in Epilepsy Surgery. Operative Neurosurgery, 10(4), 525-534, 2014.
- Isnard J, et al. Clinical Manifestations of Insular Lobe Seizures: A Stereo-electroencephalographic Study. Epilepsia 45(9) 1079-1090, 2004.
- Arya R, et al. Adverse events related to extraoperative invasive EEG monitoring with subdural grid electrodes: A systematic review and meta-analysis. Epilepsia 54(5)828-838, 2013.

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