- ** Thanks you to
  - Dr. Lawrence J. Hirsch, M.D
  - Susan T. Herman, M.D.
  - Jed A. Hartings, Ph.D.
  - Thomas P. Bleck MD
  - Denis Azzopardi

Why do we need ICU-EEG ?

Residual electrographic SE after control of visible SE in VACSP 265

- 130 overt GCSE patients in whom EEG monitoring was begun within 30 minutes of start of treatment
- 26/130 (20%) remained in electrographic SE after motor movements had stopped (twitchless electrical activity)

Faught *Epilepsia* 1998

Persistent nonconvulsive SE after the control of convulsive SE

- 52% had no after-SE ictal discharges
  - EEG showed generalized slowing, attenuation, PLEDS, focal slowing, and/or burst suppression
- The remaining 48% demonstrated persistent electrographic seizures
  - over 14% manifested NCSE, predominantly CPSE

DeLorenzo *et al* **Epilepsia** 1998;39:833-40

Unsuspected NCSE

- 8% of a consecutive series of patients referred for EEG because of coma had NCSE

Towne *et al* **Neurology** 2000;54:340-5

Continuous EEG Monitoring in the Intensive Care Unit: An Overview

Lawrence J. Hirsch

Abstract: Due to technological advances, it is now feasible to record continuous digital EEG (CEEG), with or without video, in critically ill patients and review recordings remotely. Nonconvulsive seizures (NCSzs) are more common than previously recognized and are associated with worse outcome. The majority of seizures in ICU patients are nonconvulsive and will be missed without CEEG. Factors associated with an increased risk for NCSzs include coma, prior clinical seizures, CNS infection, brain tumor, recent neurosurgery, and periodic epileptiform discharges. In addition to detecting seizures, CEEG is also useful for characterizing paroxysmal spells such as posturing or autonomic changes, detecting ischemia, assessing level of sedation, following long-term EEG trends, and prognosticating. Most NCSzs will be detected in the first 24 hours of CEEG in noncomatose patients, but longer recording periods may be required in comatose patients or in those with periodic epileptiform discharges. EEG patterns in encephalopathic or comatose patients are often equivocal. How aggressively to treat NCSzs and equivocal EEG patterns in these patients is unclear and requires further research. Real-time detection of ischemia at a reversible stage is technologically feasible with CEEG and should be developed into a practical form for prevention of in-hospital infarction in the near future.

Key Words: Continuous EEG monitoring, Critically ill, Intensive care unit, Nonconvulsive seizures, Seizure detection, Ischemia detection.

(*J Clin Neurophysiol* 2004;21: 332–340)

memory storage capabilities, and the ability to review studies remotely via computer networking.

The most common reason for performing CEEG (Table 1) is *to detect nonconvulsive seizures* (NCSzs) or nonconvulsive status epilepticus (NCSE) (Fig. 1C). Although previously thought to be uncommon, NCSzs and NCSE are being recognized more frequently. In fact, it is fair to say that anyone who works with critically ill neurologic patients and does not see NCSzs and NCSE on a regular basis is missing the diagnosis.

Continuous EEG monitoring is quite helpful for *characterizing spells* in intensive care unit (ICU) patients. It is not unusual for comatose or stuporous patients to have sudden posturing, rigidity, tremors, chewing, agitation, or sudden changes in pulse or blood pressure without an obvious explanation. All of these could be seizures, though they are usually not. We have seen patients with paroxysmal spells of whole-body rigidity and tremors/jerking diagnosed as generalized convulsions by the neurologists at the bedside, but which proved to have no EEG correlate (an example of what I refer to as ICU pseudoseizures). EEG recording of a spell such as this would obviously affect diagnosis and management.

In patients that require sedation or paralysis for medical management, CEEG can help *assess the level of sedation* and *identify clinically silent neurologic events*. Although anesthe-

The ACNS Subcommittee on Research Terminology for Continuous EEG Monitoring: Proposed Standardized Terminology for Rhythmic and Periodic EEG Patterns Encountered in Critically Ill Patients

Lawrence J. Hirsch, Richard P. Brenner,† Frank W. Drislane,‡ Elson So,§ Peter W. Kaplan,‖ Kenneth G. Jordan,¶ Susan T. Herman,# Suzette M. LaRoche,** Bryan Young,†† Thomas P. Bleck,‡‡ Mark L. Scheuer,† and Ronald G. Emerson**

Journal of Clinical Neurophysiology • Volume 22, Number 2, April 2005

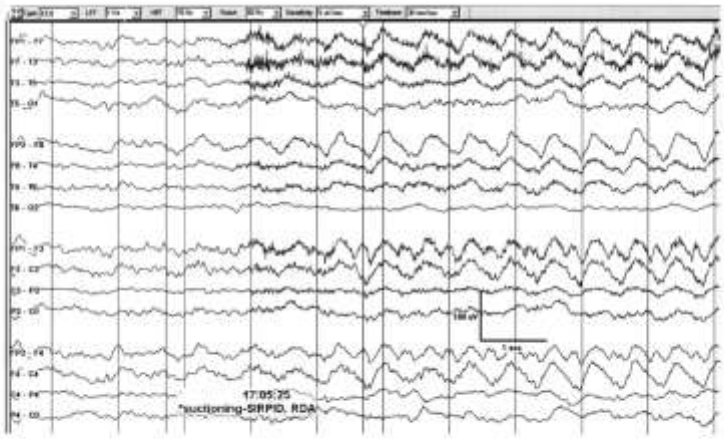


FIGURE 1. SI-GRDA: Stimulus-induced generalized rhythmic delta activity. In this case, the pattern was elicited by suctioning the patient.

TABLE 1. Examples of Corresponding New Terms for Older Terms

Old Term	New Term*
Triphasic waves, most of record	Continuous 2/sec GPDs (with triphasic morphology can be added)
PLEDs	LPDs
BIPLEDs	BIPDs
GPEDs/PEDs	GPDs
FIRDA	Occasional brief 2/sec GRDA (if 1–10% of record); frontally predominant can be added
PLEDS+	LPDs+
SIRPIDs w/focal evolving RDA	SI-Evolving LRDA
Lateralized seizure, delta frequency	Evolving LRDA
Semirhythmic delta	Quasi-RDA

*Some could have alternative new terms depending on the exact pattern.
SIRPIDs, stimulus-induced rhythmic, periodic, or ictal discharges.

Continuous EEG in ICU

- EEG recorded continuosly for hours to days
- Raw EEG
- Quantitative graphical displays

- Nonconvulsive seizure (NCS) and nonconvulsive status epilepticus (NCSE)

Continuous EEG in ICU

- EEG recorded continuosly for hours to days
- Raw EEG
- Quantitative graphical displays
  - Which quantitative displays
  - How many trends
- Video
- Emerging VS Standard Techniques

Electrodes

- Disk: Plastic silver-chloride or metal
  - Imaging compatibility
  - Infection control
- Needle
  - Appropriate for some emergency situations
  - Not appropriate for long-term recordings
- Subdermal wire electrodes
- Apply with collodion, EC2 paste
- Maintenance every 24 hrs
- Intracranial electrodes
  - Mini-depths, ? Subdural strips

Electrode Location and Number

- International 10-20 system
- Minimum of 8 electrodes
- 16 or more electrodes optimal

- Inadequate spatial sampling
- Inability to distinguish artifact from cerebral activity

Limited Montages

		subhairline (1)	Hairline(2)
N		70 patients	120
Methods		Commercial limited EEG	Reformatted from standard 10-20 digital
Channels		4	6
Duration		24 hour	2-3 min samples
Seizures	Sensitivity	68%	72%
	Specificity	98%	92%
PLEDs	Sensitivity	39%	54%
	Specificity	92%	97%

1.Young GB et al. neurocrit Care 2009

2. Kolls BJ. Husain AM. Epilepsia 2007

Video / Audio

- Strongly recommended
  - Correlate clinical with EEG features
  - Avoid misinterpretation of artifacts
- Optimal recoding requires both fixed wide-angle cameras and high resolution color cameras with remote zoom and pan-tilt functions
  - Portability
  - Cost
  - Amount of data generated / network bandwidth

Review

- Frequent enough to influence clinical management
- At least twice daily
  - May occasionally require continuous or frequent review until patient stabilized
- Written reports daily
  - Interim verbal reports to clinical team as needed
- Remote review should be available

- Optimal
  - Continuous review of raw EEG, quantitative EEG and video
  - trained personnal

Seizure Detection Algorithms

- Epilepsy monitoring
  - Sensitivity .33-.93
  - False positive rates: .11-3.1 per hour
  - Compared to human: sensitivity 92%. FP 0.1/h
- Utility in ICU has not been evaluated
  - Seizure patterns verydifferent from those in epilepsy patients
  - Frequent incorrect notifications problematic when reviewed by inexpert staff
  - May need to record entire duration of event rather than just start of seizure

ScheuerML, J ClinNeurophysiol2004;21: 353–378

Trends

- Quantitative graphical displays of EEG
  - Fast Fourier transformation of EEG data
  - Color spectrograms
  - Hidden line compressed spectral arrays
  - Displays of total power in certain bands to broader EEG power
  - Envelope trend
  - Amplitude-integrated EEG

Trends

- No studies on sensitivity specificity for seizure detection in ICU
- Nearly limitless combinations of trend type, electrodes / brain regions, and time displays
  - Difficult to standardize
- Use of quantitative trends is encouraged
  - May detect gradual or subtle changes that are not visible with review of raw EEG
- Can not used alone for seizure or ischemia detection
  - Adjunct to review of raw EEG

Interrater Reliability

- Interrater reliability for seizures in ICU population (1)
  - 90 10s epochs from 23 comatose patients
  - 9 readers kappa
    - Experienced 0.5
- Research terminology (2)
  - 5 readers; 58 EEG samples from 11 SAH patients
  - Moderate agreement for main terms; others slight to fair
  - Agreement lower with longer EEG segments (20 min)

1. Ronner HE et al. Seizure 2009;18:257-263.
2. Gerber PA et al. J Clin Neurophysiol 2008;25:241-249

Diagnostic Accuracy

- How test compares to “gold standard ” reference test
- No other diagnostic test comparison of CEEG results
  - Compare to shorter EEGs

Recurrent or continuous (>30 min) ictal discharges, frequencies >=3Hz	Continuous ictal discharges, frequencies < 3Hz
Repetitive or rhythmic spikes, sharp waves, rhythmic waveforms, frequency 3-20Hz	Repetitive or rhythmic spikes, sharp waves, rhythmic waveforms
Duration > 10 sec	Gradual evolution in voltage, frequency, and/or field
Paroxysmal change from baseline	Significant improvement in clinical state or EEG after IV AED
Evolution in amplitude, frequency, and/or field	+ / - Postictal slowing or attenuation
+ / - Postictal slowing or attenuation	

Young GB et al. Neurology 1996;47:83-89

Diagnostic Impact

- Heterogeneous patient populations
  - Adults
  - Children
  - Neonates
  - Neuro ICU vs. general ICU
- Retrospective studies
  - Few centers with non-generaizable patient groups
  - No predetemined inclusion / exclusion criteria
  - Selection bias
    - Across and even within centers

Indications for CEEG

- Detection of subclinical seizures
  - Fluctuating mental status
  - Unexplained alteration of mental status
  - Acute supratentorial brain injury with altered mental status
  - After convalsive status epilepticus
- Characterization of spells
  - Episodic posturing, other paroxysmal movements
  - Subtle twitching, nystagmus, eye deviation, chewing
  - paroxysmal autonmic spells including tachycardia
- Monitoring treatment efficacy in NCSE and refractory SE

Therapeutic Impact

- No prospective studies or pertinent
  - Seizure cortical
  - Impact on EEG features
  - Outcome
  - Adverse effects
- High mortality rates even with aggressive therapy
- Increased mortality in elderly with NCSE treated with benzodiazepines

conclusions

- Wide variability in practice of CEEG
- Optimal practices will change as technology evolves
- No evidence that treatment of detected seizures is effective or impacts outcome

- Cannot assess impact of seizures and treatment on outcome until can be rapidly and rapidly and reliably detected

CEEG:

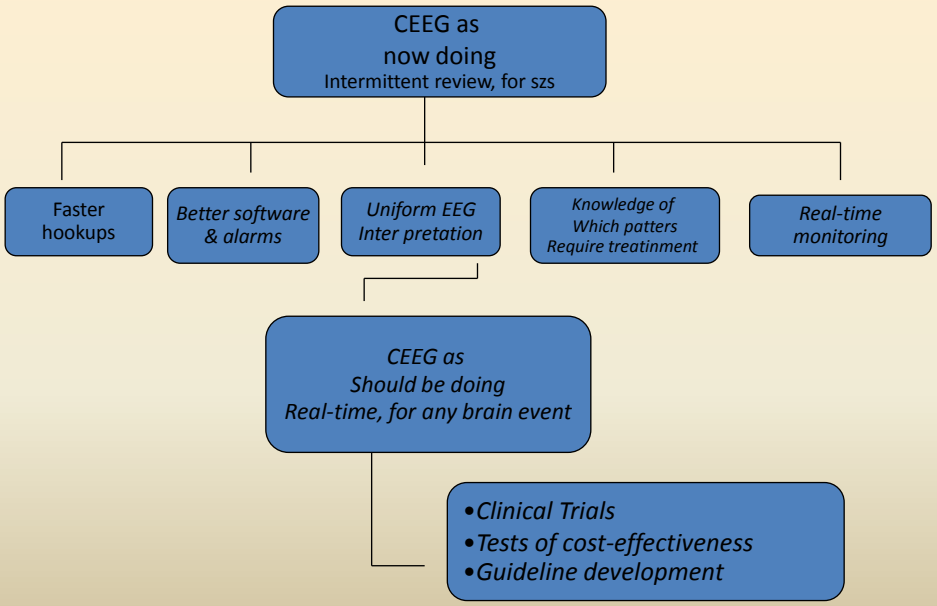
The Cutting Edge and Beyond

December 8,2009

Lawrence J. Hirsch, MD
Columbia University
New York, NY

American Epilepsy Society Annual Meeting

CEEG ROADMAP



The era of NEUROTELEMETRY is here --almost

- Seizures
- Ischemia
- Hydrocophalus
- Hemorrhalus
- Hypotension/hypoxia/Co2 retention/sepsis
- Alarms feasible though not easy
  - Artifact detection and rejection in place
  - 24 hour EEG techs in place (but not ones continuously)
  - Networking in place
  - Imaging compatible electrodes available-invisible on CT and MR (?angio)-but expensive

CEEG IN THE Medical ICU

Oddo M,et al, Care Med 2009

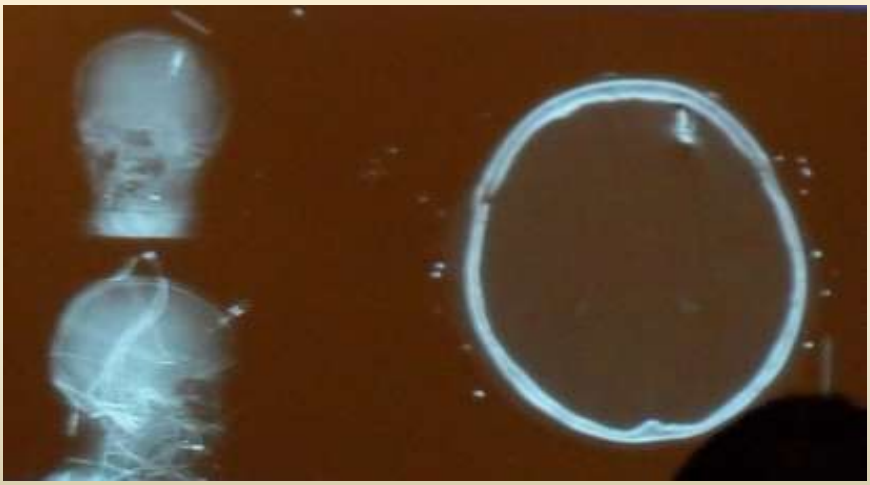
- 201 patients 2004-2007
  - Mean of 3 days of ceeg
  - 60% sepsis, 48% comatose
- 22% had seizures or PEDs
- Seizures in 21
  - 67% patents with 52% had nonconv. only
- PEDs in 34

CEEG IN THE MICU, cont'd

Oddo M, et al, Care Med 2009

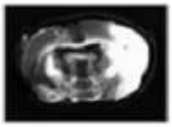
- Independent predictors of worse outcome
  - Electrographic Szs
  - PEDs
  - Each assoc'd with double the rate of poor outcome
- Sepsis subgroup: 31% had sis or PEDs
  - In multivariate analysis, presence of Sis or PEDs remained highly significant predictor of worse outcome (O.R. 10,p<o.oo1)

Intracortical EEG (mini-depth recordings) in acute brain injury
Wazai A, Claassen J. Comnolly S. Mayer SA et al. Ann Neurol 2009



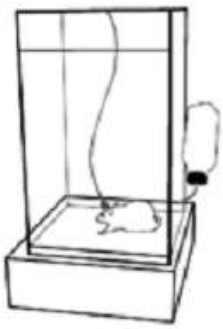
MCAo model of non-convulsive seizures

Animals subjected to permanent or temporary Middle Cerebral Artery Occlusion



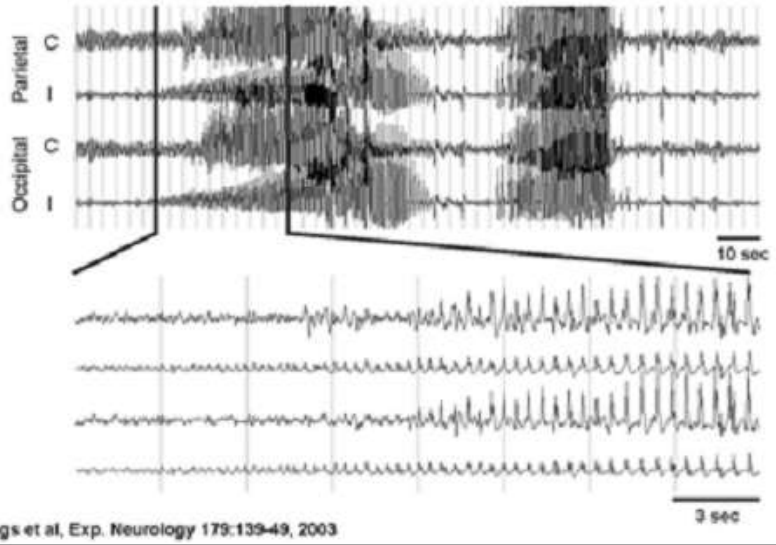
Referential EEG recordings from 10 epidural skull screw electrodes

Continuous recordings obtained prior to and 24 h following MCAo in freely behaving animals



Hartings et al, Exp. Neurology 179:139-49, 2003

Seizures are Generalized, Episodic, and Non-Convulsive



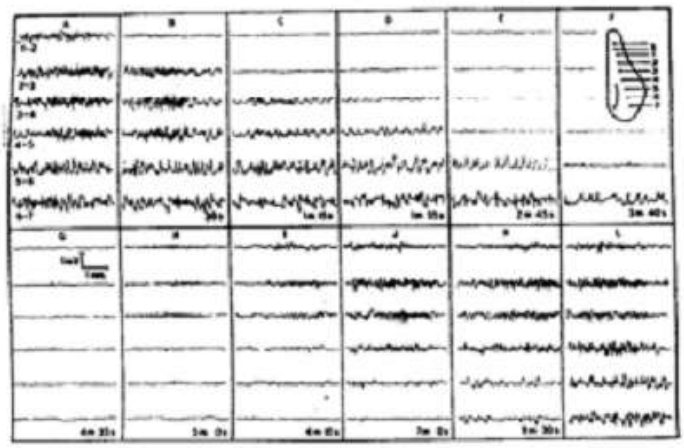
Hartings et al, Exp. Neurology 179:139-49, 2003

Spreading depression in rabbit cortex (Leao, 1944)

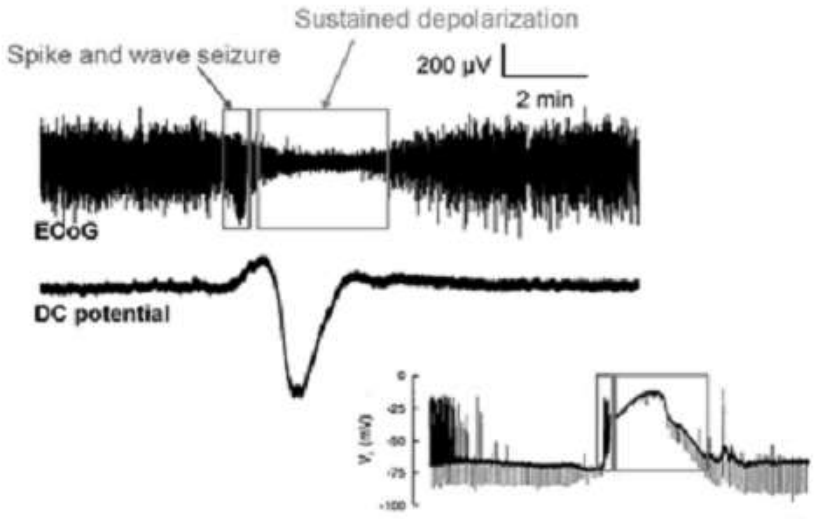
SPREADING DEPRESSION OF ACTIVITY IN THE CEREBRAL CORTEX*

ARISTIDES A. P. LEÃO
Department of Physiology, Harvard Medical School, Boston, Massachusetts

(Received for publication August 14, 1944)

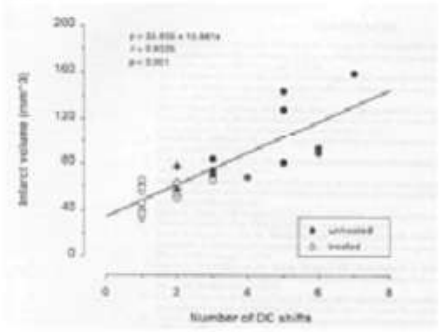


What is Spreading Depression?



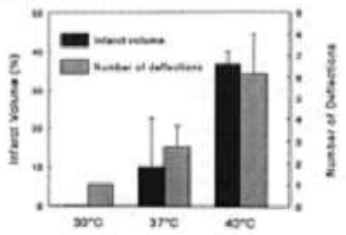
Treatments which inhibit PIDs are also neuroprotective

MK-801



Mies et al., Neuroreport 4:709, 1993

Hypothermia



Chen et al., JCBFM 13:389, 1993

Co-Operative Study on Brain Injury Depolarizations

COSBID

The Group/Aims
Background
Centers/Training
Useful Links
Newsletters
Downloads
Equipment
Address Book
Discussion Forum
Impressum

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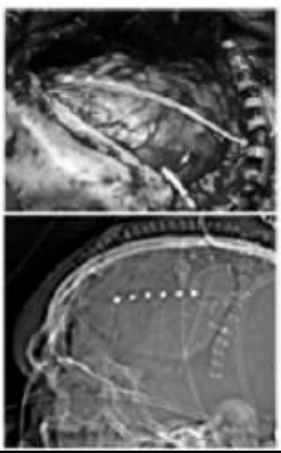
CO OPERATIVE STUDY ON BRAIN INJURY DEPOLARISATIONS

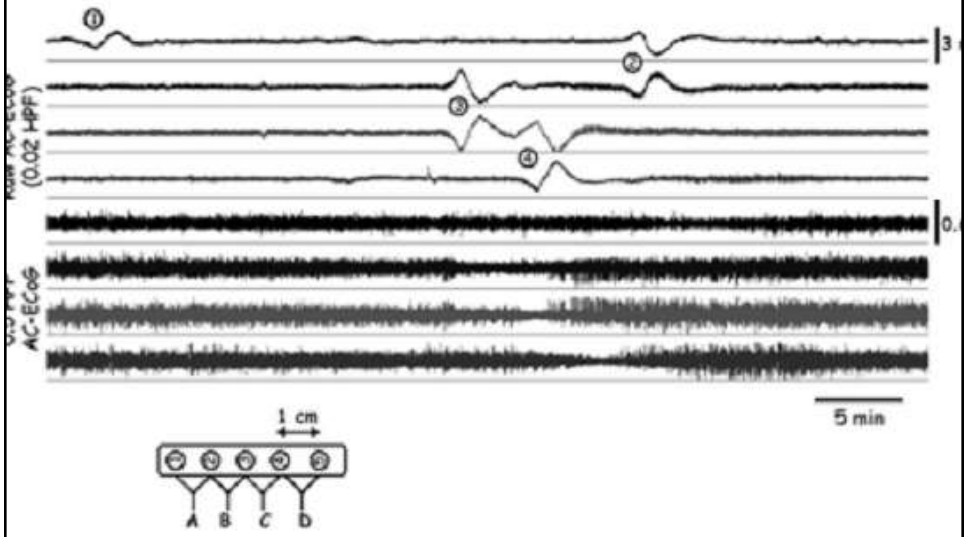
(TRAUMATIC AND ISCHAEMIC INJURY TO THE HUMAN BRAIN)

Methods

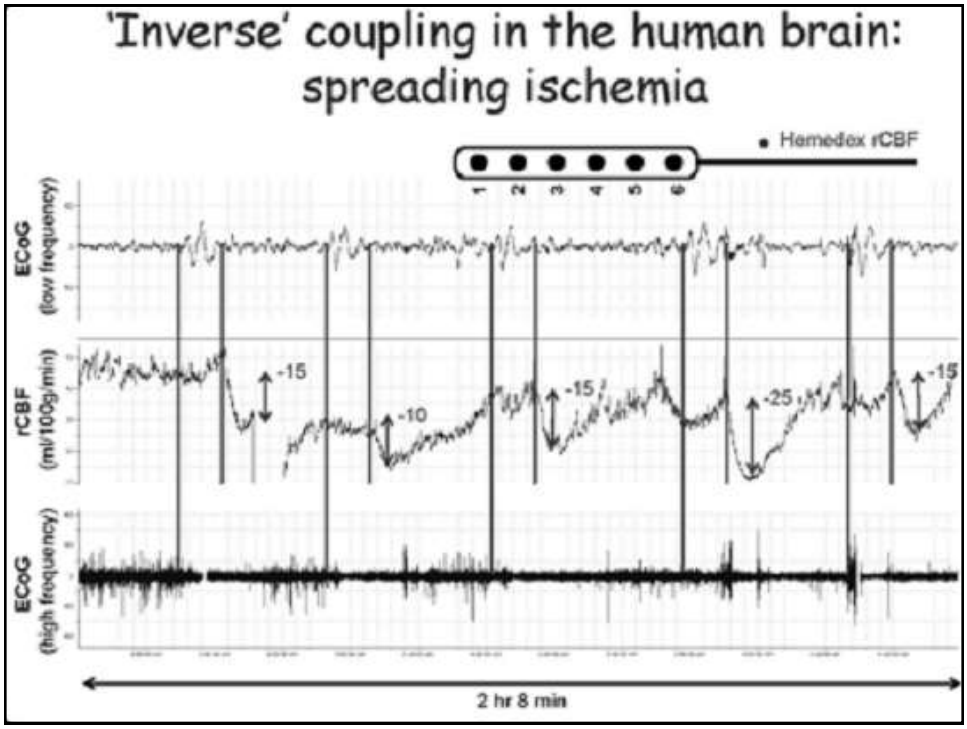
- Subdural electrode strip placed on peri-lesion cortex during neurosurgery
- Continuous electrocorticography (ECoG) during neurointensive care



Identification of Spreading Depressions

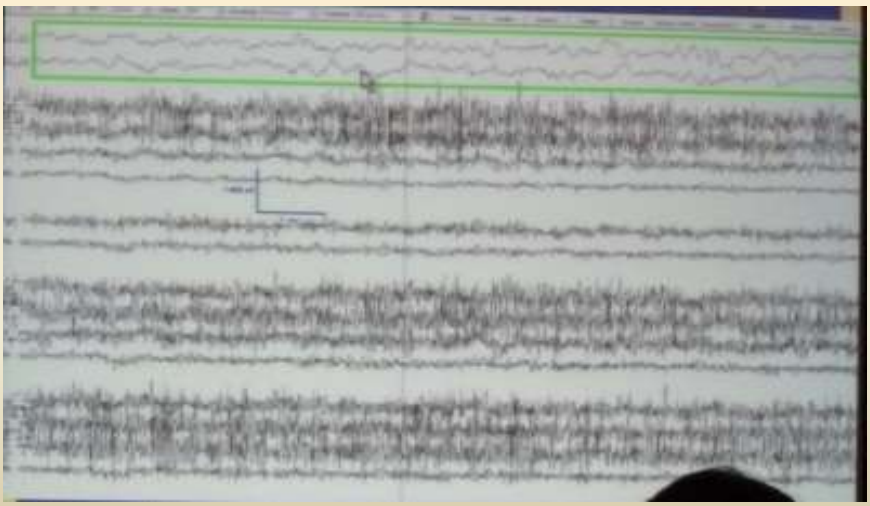


'Inverse' coupling in the human brain: spreading ischemia

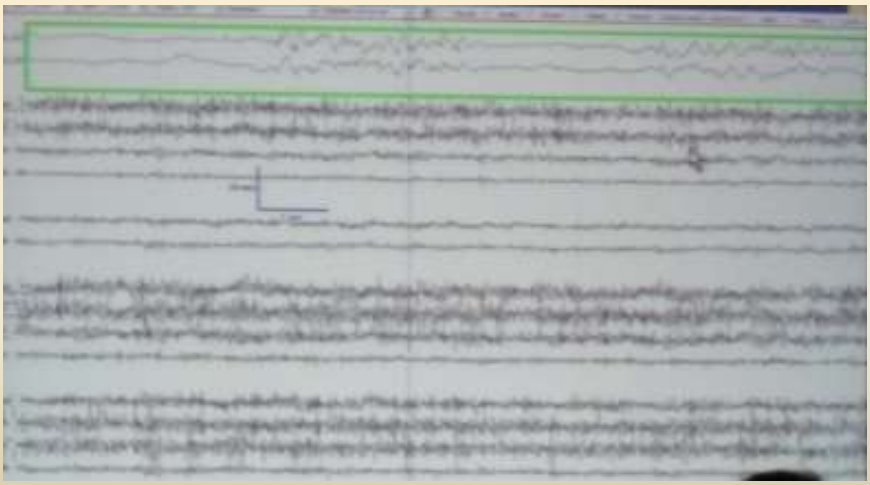


Cortical mini-depth electrode: 70 yo, SAH, R F depth

73. large R MCA infarct, hypothermia, R frontal + mini-depth

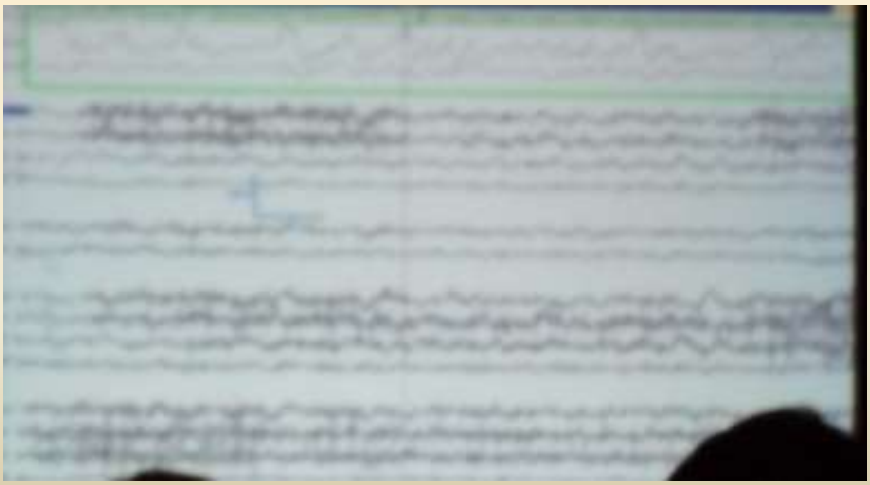


Starting 9:45 pm, discontinuity in depth



6:20 am: periodic delta waves in depth

7:25 continuous background on depth again



Summary of Findings:

Intracortical EEG (ICE) in Acute brain Injury
Waziri A. Classen J. Connolly S. et al ;Ann Neurol 2009

- 10/14 patients had seizure on the mini-depth
- 6/10 never had scalp EEG correlate, 2 showed non-ictal appearing rhythmic deite on scalp, and 2 showed scalp EEG correlate on occasion only.
- Some but not all seizure/PEDs showed corresponding microdialysis changes

If CEEG were readily available 24 hours/day for all patents, and was interpreted in real-time by an expert. Remote reader, I would order CEEG:

1. On every patient in the ICU
2. On every patient with impaired mental status in the ICU
3. On many more patients than I do now
4. On a few more patients than I do now
5. On some patients, but the same number of patients as I do now
6. Never, as I'm not convinced of the clinical utility

Conclusions, I of III

- Standard nomenclature & research consortium
- More practical electrodes, QEEG software, remote access and alarms
- Individualized, brain physiology-driven making
- Invasive EEG recordings are raising more fascinating questions
  - Theory: multimodal mini-seizures, non-synchronous
  - Metabolic effects
  - Peri-injury depolarzations