Technical Aspects of ICU EEG: Hardware, Software, Staffing

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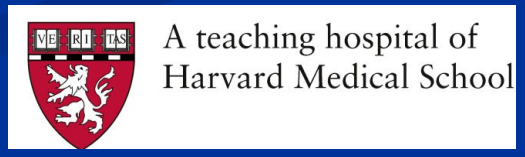
Boston, MA



Disclosures

- None relevant to this presentation
- Scientific Advisory Board
  - Eisai Inc.
  - Biotie, Inc.
- Research
  - UCB Pharma
  - Acorda Therapeutics
  - Epilepsy Therapy Development Project
  - Sage Pharmaceuticals
  - NeuroPace, Inc.
  - Pfizer

Continuous EEG in ICU

- Critically ill patients with altered mental status
- EEG recorded continuously for hours to days
- Raw EEG
- Video
- Quantitative graphical displays
- Review
  - Frequent monitoring and interpretation essential for clinical decision-making (optimal = real-time)
  - Frequent communication with ICU staff
    - Diagnosis, treatment, response to treatment

CEEG Monitoring: Advantages

- Sensitive to changes in neurologic functioning from variety of causes
  - Structural
  - Metabolic / physiologic
- Good spatial resolution
  - Monitor many brain areas simultaneously
- Excellent temporal resolution
  - 2-4 msec
- Bedside use

CEEG Monitoring: Disadvantages

- Not specific for etiology of abnormality
  - Susceptible to drug effects
- Technically difficult to implement
  - Requires skilled technologists & interpreters 24 hrs / day
  - Large amounts of data to review
- Susceptible to artifacts (eye movements, EKG, EMG, patient movement, 60Hz interference, electrical equipment)
- May interfere with other testing (neuroimaging)

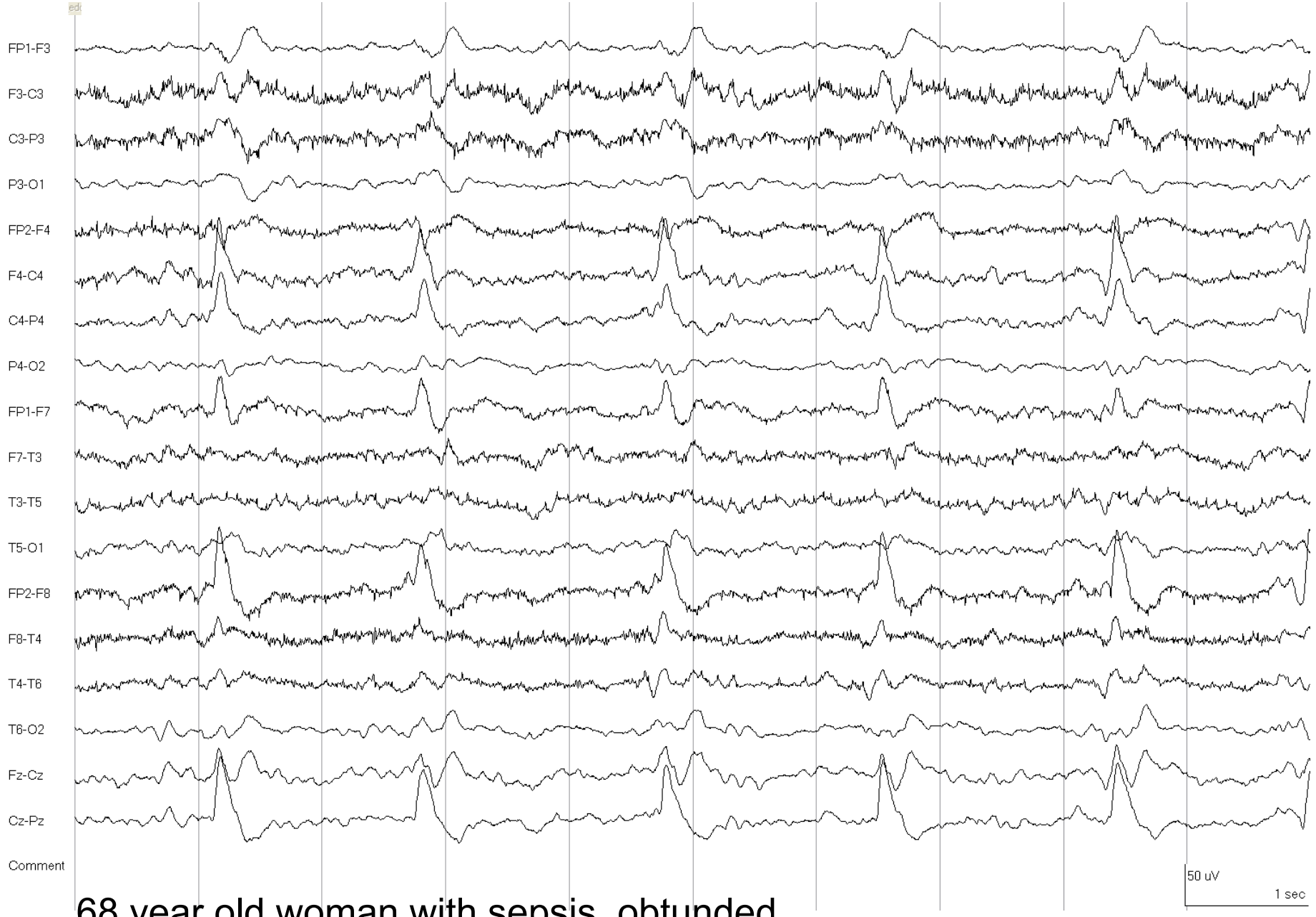
ICU EEG Use

- ICU CEEG is expensive and labor intensive
- Marked increase in use
  - Nationwide Inpatient Sample, 2005-2009, mechanically ventilated patients receiving cEEG
  - Increased by 263% over 4 years, mean 33% annually
  - Hospitals nearly doubled from 135 to 244
- Substantial variability in clinical practice, even in established centers
  - Availability of staff
  - Availability of equipment
  - Lack of high-quality evidence

Ney JP, van der Goes DN, Nuwer MR, Nelson L, Eccher MA. Continuous and routine EEG in intensive care: Utilization and outcomes, United States 2005-2009. Neurology 2013;81:2002-8

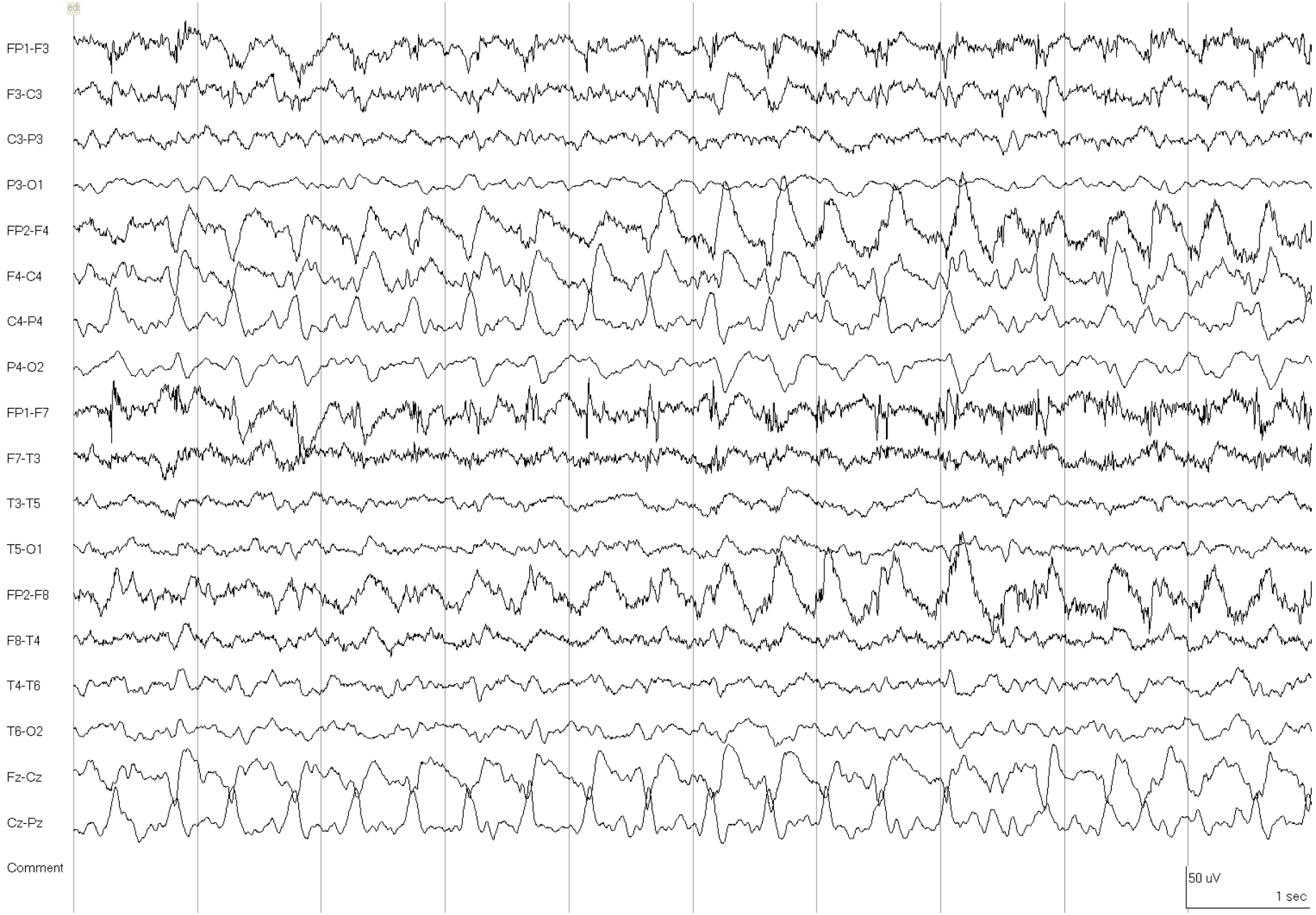
Area	Responses	2009 Mixed	2013 Peds	2014 Adult
EEG availability	All times 24/7, in house	63%	28%	26%
	All times 24/7, on call		51%	60%
	Limited additional hours	25%	21%	11%
	Only standard weekday hours	12%		3%
Remote reading	Possible for all/most records	35%	68%	53%
	Possible for some records	43%	23%	42%
	Not possible	22%	9%	5%
QEEG	Yes	34%	39%	52%
CEEG pts/mo	<1	17%	Median	
	1-5	41%	US	12%
	6-20 (11-20 2013)	29%	10	30%
	>20 (21-40 2013)	13%	Canada	30%
	>40	N/A	3	28%

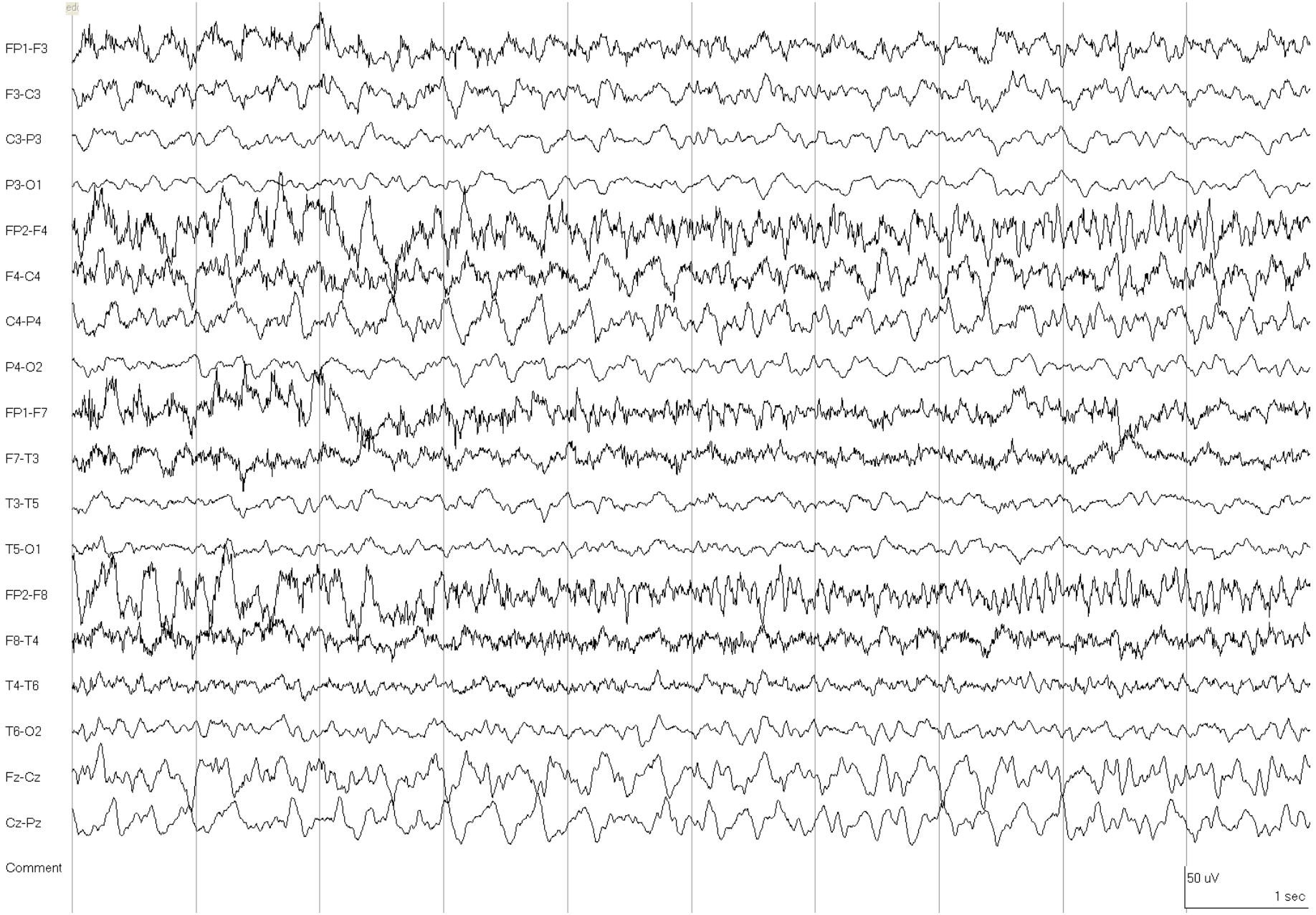
Abend NS et al. Neurocritical Care 2010;12:382-389; n=330, adult and peds
Sanchez et al. J Clin Neurophysiol 2013;30:156-160; n = 58, peds US/Canada
Gavvala J et al. Epilepsia 2014;55:1864-1871; n=151; adult, EEG and neuroICU



68 year old woman with sepsis, obtunded


FP1-F3
F3-C3
C3-P3
P3-O1
FP2-F4
F4-C4
C4-P4
P4-O2
FP1-F7
F7-T3
T3-T5
T5-O1
FP2-F8
F8-T4
T4-T6
T6-O2
Fz-Cz
Cz-Pz
Comment
50 uV
1 sec


FP1-F3
F3-C3
C3-P3
P3-O1
FP2-F4
F4-C4
C4-P4
P4-O2
FP1-F7
F7-T3
T3-T5
T5-O1
FP2-F8
F8-T4
T4-T6
T6-O2
Fz-Cz
Cz-Pz
Comment
50 uV
1 sec


FP1-F3
F3-C3
C3-P3
P3-O1
FP2-F4
F4-C4
C4-P4
P4-O2
FP1-F7
F7-T3
T3-T5
T5-O1
FP2-F8
F8-T4
T4-T6
T6-O2
Fz-Cz
Cz-Pz
Comment
50 uV
1 sec

CEEG: Other Aspects

	NCC	ESICM
CEEG vs. intermittent		2, C
Technologists		
Interpreting physicians	Special training; I, C	
Recording equipment / techniques		
Electrodes		
Standard montage		2, C
Video recommended		
Remote review		
Review EEG (technologist)		
Review EEG (physician)		
Written reports		
Communication with ICU team		
QEEG		

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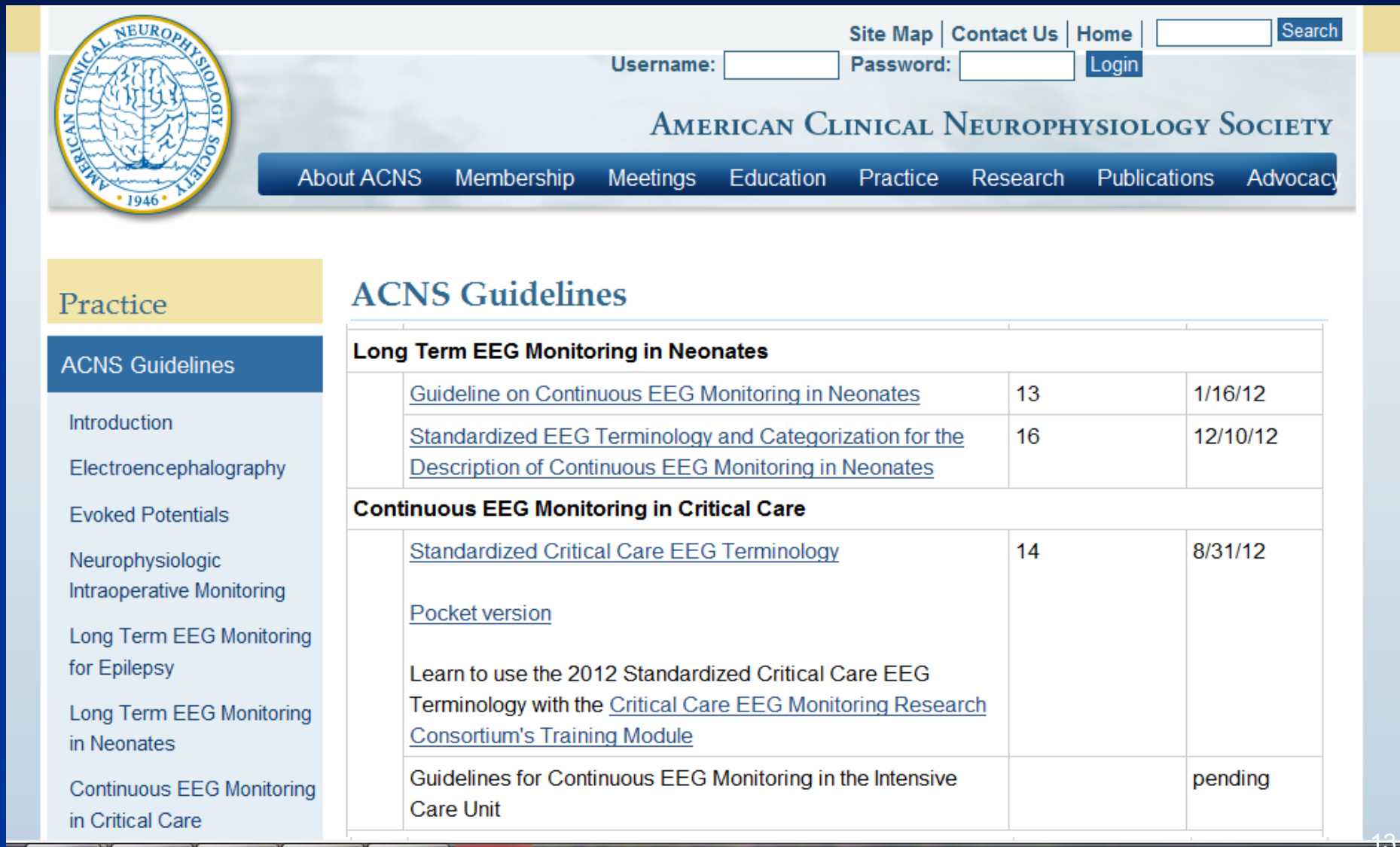
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Continuous EEG Monitoring in Critical Care
ACNS Guidelines
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Guideline on Continuous EEG Monitoring in Neonates 13 1/16/12
Standardized EEG Terminology and Categorization for the Description of Continuous EEG Monitoring in Neonates 16 12/10/12
Continuous EEG Monitoring in Critical Care
Standardized Critical Care EEG Terminology 14 8/31/12
Pocket version
Learn to use the 2012 Standardized Critical Care EEG Terminology with the Critical Care EEG Monitoring Research Consortium's Training Module
Guidelines for Continuous EEG Monitoring in the Intensive Care Unit pending

Objectives for Guideline

- Standardize technical aspects of ICU CEEG monitoring
  - Hardware / Software
  - Recording techniques
- Provide guidance for required personnel and resources
- Facilitate multicenter studies using similar techniques
- Strike appropriate balance between current and ideal states
  - Recognize limitations of evolving technology
  - Set goals for optimal techniques
- Identify areas requiring further development and research

ACNS Technical Guidelines Continuous EEG in ICU

Staffing and Training	• Physicians • Technologists • Nurses
Technical Aspects of CEEG	• Electrode type and number • Equipment / Video • Quantitative EEG
Patient Selection and Duration	• Protocols • Daily maintenance
CEEG Review	• Real-time vs. intermittent review
Reports	• Communication with ICU team • Written reports
Data Storage	• Networking

Qualifications of CEEG Personnel

- Physician: Clinical electroencephalographer
  - Board Certification
    - American Board of Psychiatry & Neurology Clinical Neurophysiology
    - American Board of Clinical Neurophysiology
  - Fellowship training in clinical neurophysiology
- Specialized training
  - CEEG equipment: recording, safety, troubleshooting
  - Effects of acute brain injuries and drugs on EEG activity, ICU artifacts
  - Use, yield and limitations of quantitative EEG

Qualifications of CEEG Personnel

- EEG Technologist
  - ABRET Registered EEG Technologist (R. EEG T.)
- Specialized CEEG Technologist
  - ASET National Competency Skill Standards for ICU/cEEG Monitoring
  - Registration in CLTM by ABRET
  - Special training
    - CEEG use, routine maintenance, troubleshooting
    - Ictal and interictal electrographic patterns and artifacts commonly encountered in the ICU

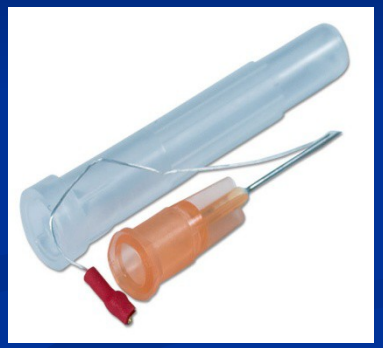
ASET = American Society of Neurodiagnostic Technologists
ABRET = American Board of Registration of Electroencephalographic and Evoked Potential Technologists

Qualifications of CEEG Personnel

- ICU nurse
  - No specific training on EEG required
  - Depends on level of involvement in EEG
    - Electrode placement
    - Electrode removal
    - Use of bedside QEEG trends
- Monitoring technologist
  - R. EEG. T
  - PCT: what training is needed?
  - Video, raw EEG vs. QEEG trends

Electrodes

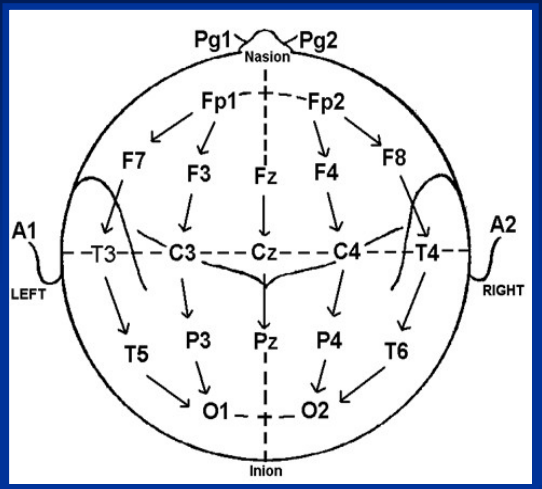
- Disk: Plastic silver-chloride / metal
  - Imaging compatibility (CT & MRI)
  - Infection control
- Needle
  - Emergency situations
  - Not appropriate for long-term recordings
- Subdermal wire electrodes
- Caps / template systems
- Apply with collodion, EC2 paste
- Maintenance every 24 hrs



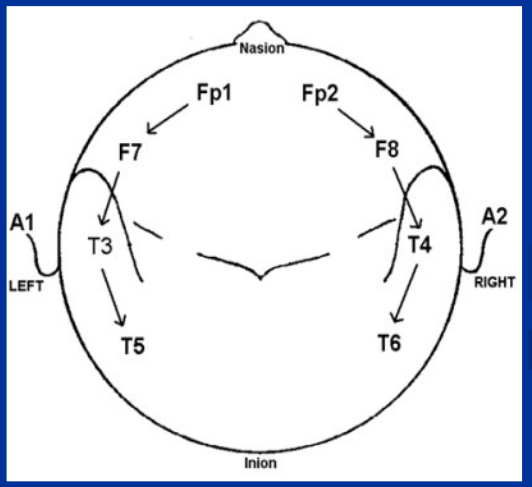
Images courtesy of John Ives, Kathleen Principe, Ken Jordan

Electrode Location and Number

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



- Inadequate spatial sampling
- Inability to distinguish artfiact from cerebral activity
- Poor quality of uninterpretable study if any of few electrodes are dislodged or artifactual



Limited Montages

		Subhairline (1)	Hairline (2)
N		70	120
Methods		Commercial limited EEG	Reformatted from standard 10-20 digital
Channels		4	6
Duration		24 hours	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;48:959-965

EEG Machines / Video / Audio

- Fixed vs. portable units
  - Small footprint
  - Wall-mounted
  - Flexibility
- Video strongly recommended
  - Correlate clinical behavior with EEG features
  - Avoid misinterpretation of artifacts
  - IP addressable cameras, can pan/tilt/zoom via network

Polygraphic Data Acquisition

- Recognition of artifacts
  - Electrocardiogram (EKG)
  - Electrooculogram (EOG)
  - Electromyogram (EMG)
- Correlation with other physiologic parameters / data
  - Blood pressure
  - Respiratory effort
  - Oxygen saturation
  - Intracranial pressure
  - Brain tissue oxygenation
  - Cerebral microdialysis
  - Information from IV pumps, respirator

Information Technology Needs

- Speed of data review depends of network speed
- Remote review
  - In-hospital
    - Fast enough to review video
  - Out-of-hospital (balance cost and speed)
    - Desktop sharing
    - Terminal server applications
    - Virtual application servers
- Storage
- Security
- Information technology support staff

ICU CEEG Team: Staffing

- Dependent on local resources
- Hook-ups
  - EEG technologists
    - In-house vs. on-call
    - Expanded lab hours at minimum (evening, weekends)
    - 24 / 7 is goal
  - Limited EEG arrays by ICU nurses, residents, others
    - For emergency reads only

ICU CEEG Team: Staffing

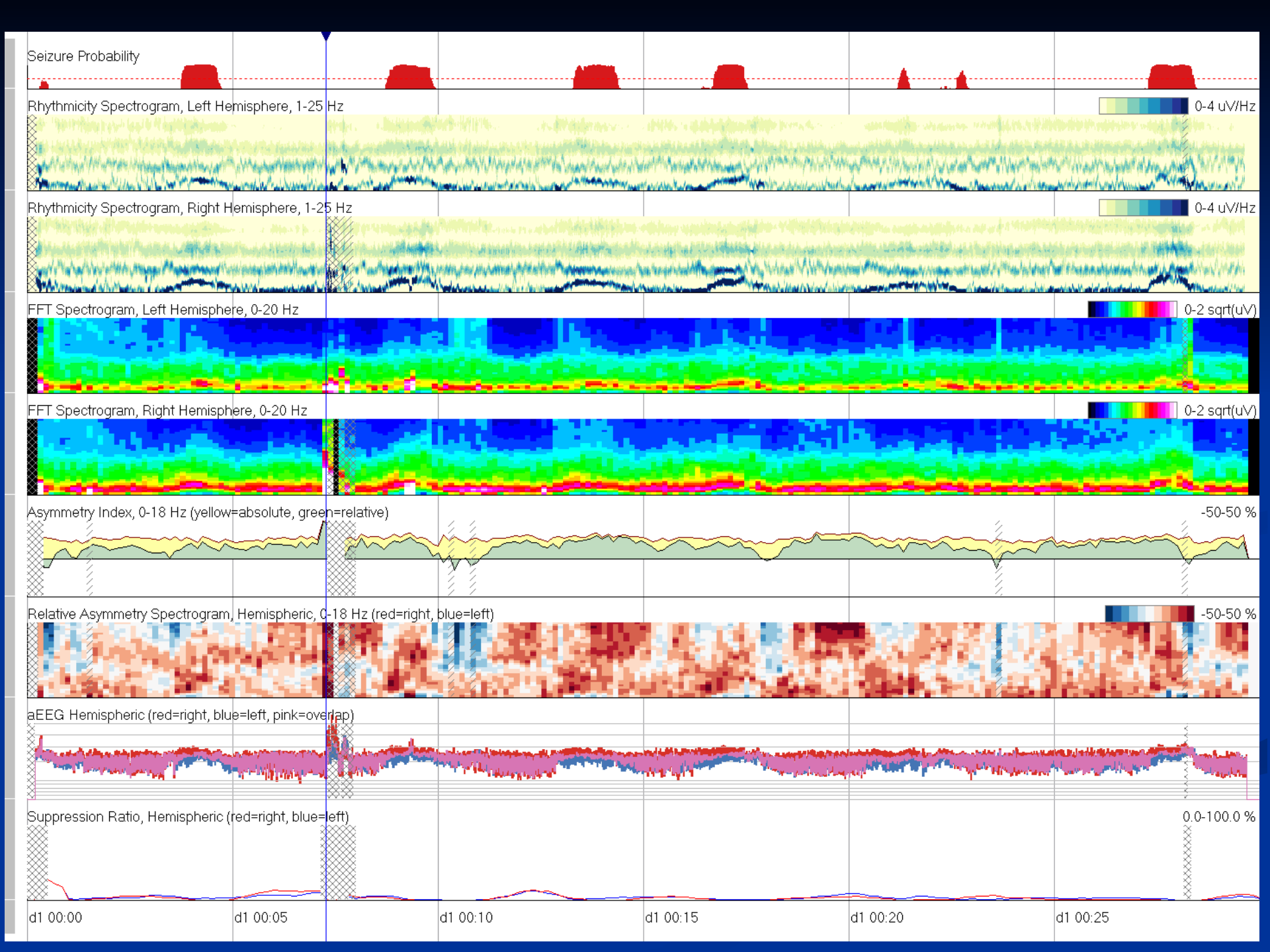
- Screening for EEG changes
  - Who?
    - ICU nurses or patient care technicians
    - Neurology residents
    - Clinical neurophysiology fellows
    - Advanced EEG technologists
  - Continuous or intermittent?
  - Raw EEG or trends?
- Interpretation / clinical recommendations
  - Attending staff: 24 hour availability

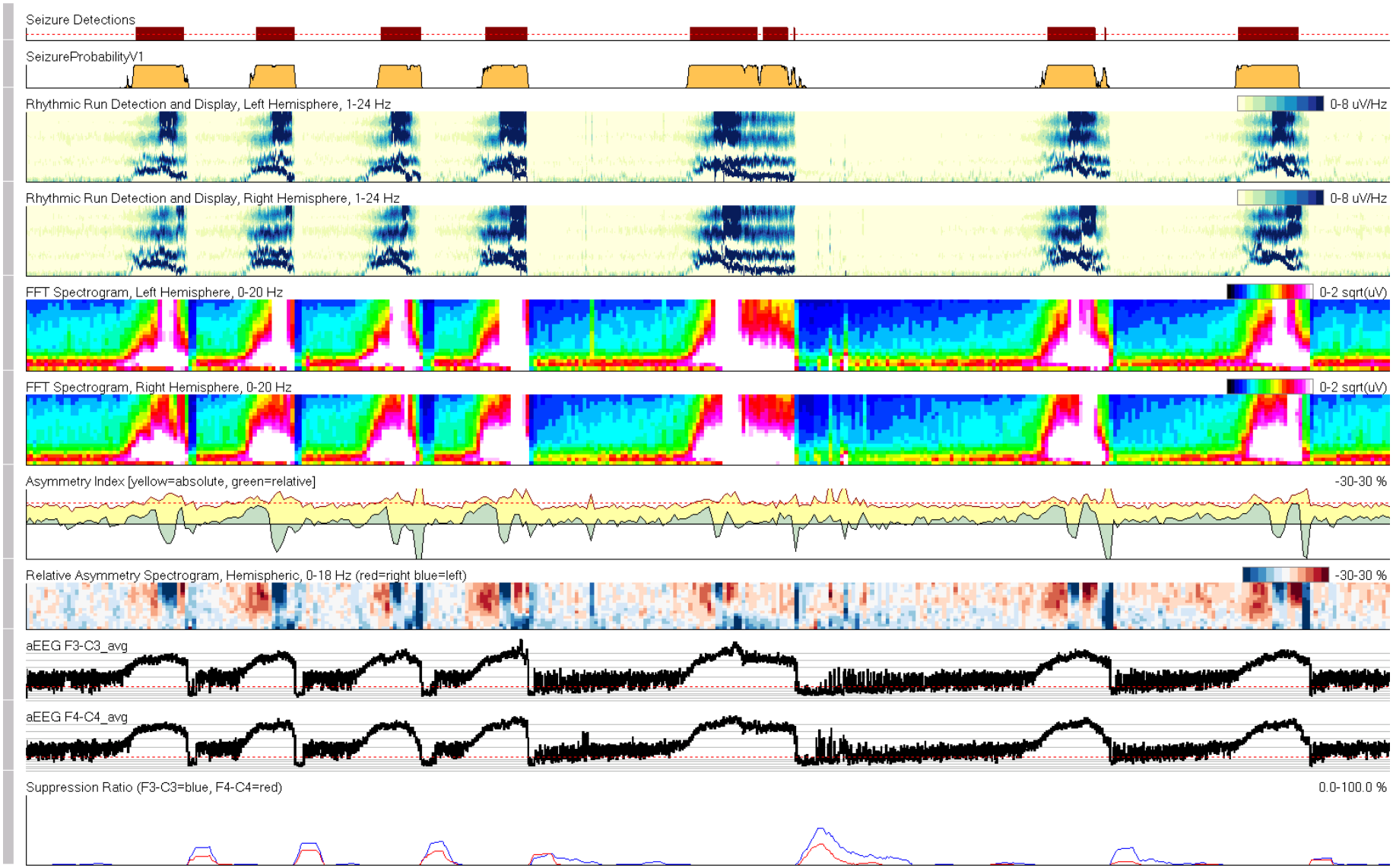
Quantitative EEG

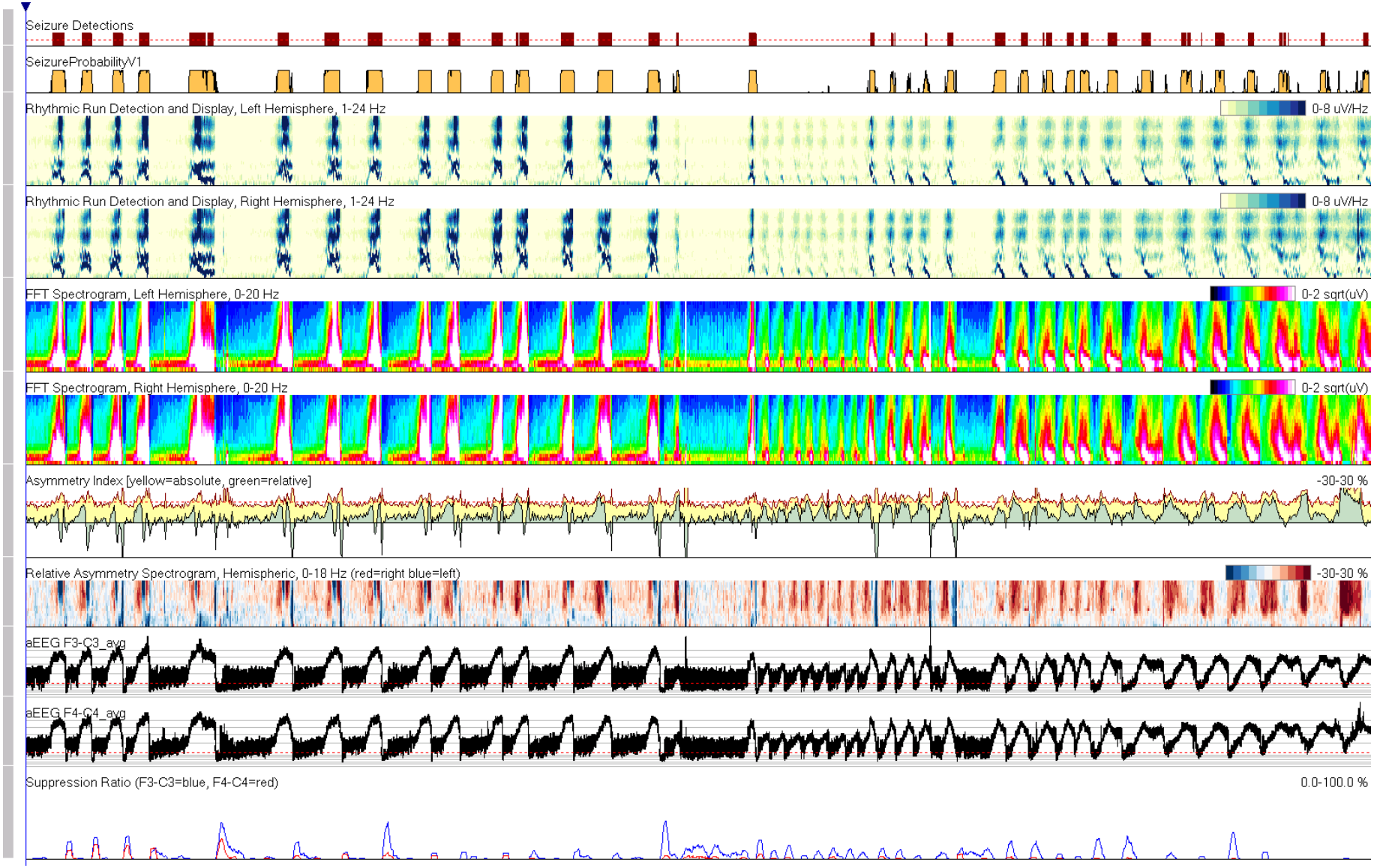
- Data reduction
  - 8640 10-second pages in 24 hour EEG study
    - 5 sec/pg review = 28 min
    - 1 sec/pg review = 2 hrs 24 min
  - Indicate segments of EEG that may contain events of interest
  - Increase speed of review
- Decrease complexity
  - Allow bedside caregivers to use EEG
- Visualize trends that may be difficult to see in raw EEG
- Allow quantitative comparison of EEGs

Quantitative EEG Trends

- No studies on sensitivity and 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 be used alone for seizure or ischemia detection
  - Adjunct to review of raw EEG

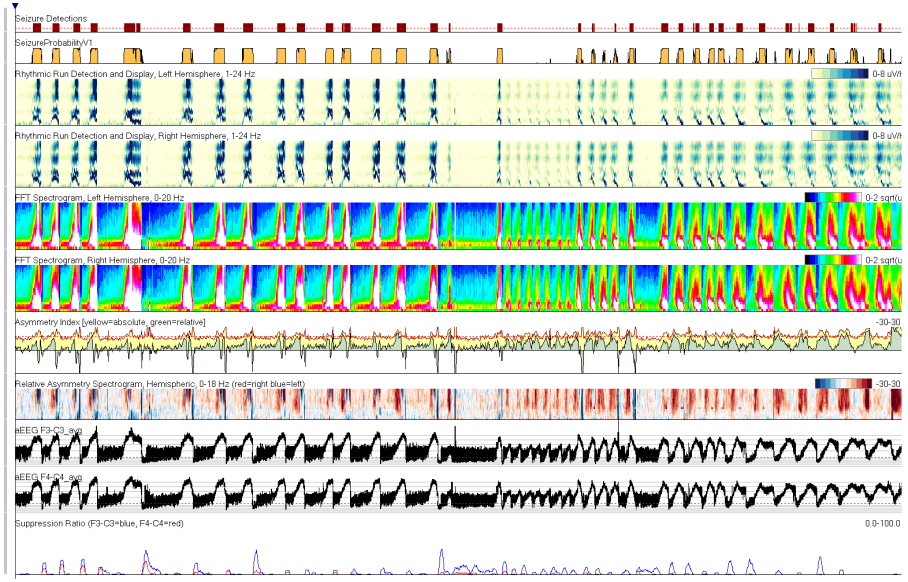

Seizure Probability
Rhythmicity Spectrogram, Left Hemisphere, 1-25 Hz
0-4 uV/Hz
Rhythmicity Spectrogram, Right Hemisphere, 1-25 Hz
0-4 uV/Hz
FFT Spectrogram, Left Hemisphere, 0-20 Hz
0-2 sqrt(uV)
FFT Spectrogram, Right Hemisphere, 0-20 Hz
0-2 sqrt(uV)
Asymmetry Index, 0-18 Hz (yellow=absolute, green=relative)
-50-50 %
Relative Asymmetry Spectrogram, Hemispheric, 0-18 Hz (red=right, blue=left)
-50-50 %
aEEG Hemispheric (red=right, blue=left, pink=overlap)
Suppression Ratio, Hemispheric (red=right, blue=left)
0.0-100.0 %
d1 00:00
d1 00:05
d1 00:10
d1 00:15
d1 00:20
d1 00:25

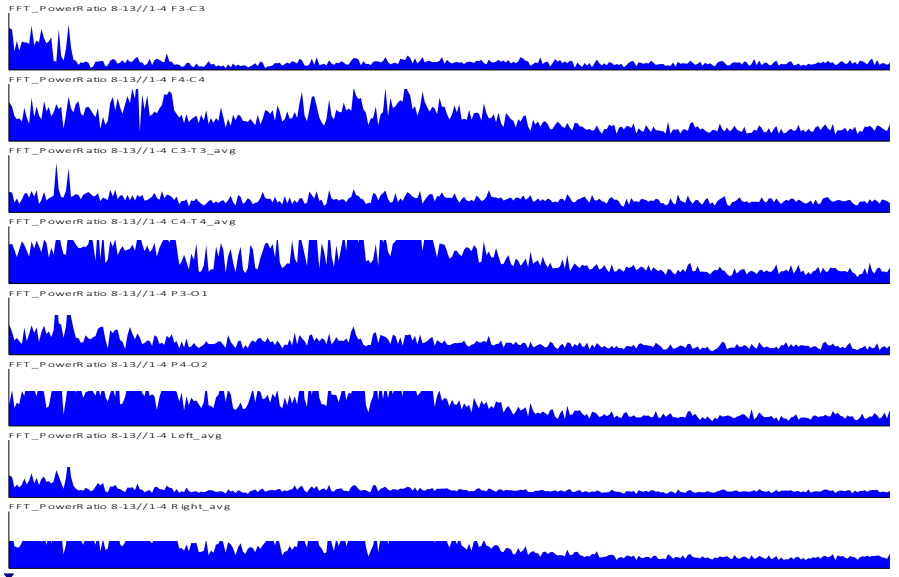

Seizure Detections
SeizureProbabilityV1
Rhythmic Run Detection and Display, Left Hemisphere, 1-24 Hz
0-8 uV/Hz
Rhythmic Run Detection and Display, Right Hemisphere, 1-24 Hz
0-8 uV/Hz
FFT Spectrogram, Left Hemisphere, 0-20 Hz
0-2 sqrt(uV)
FFT Spectrogram, Right Hemisphere, 0-20 Hz
0-2 sqrt(uV)
Asymmetry Index [yellow=absolute, green=relative]
-30-30 %
Relative Asymmetry Spectrogram, Hemispheric, 0-18 Hz (red=right blue=left)
-30-30 %
aEEG F3-C3_avg
aEEG F4-C4_avg
Suppression Ratio (F3-C3=blue, F4-C4=red)
0.0-100.0 %

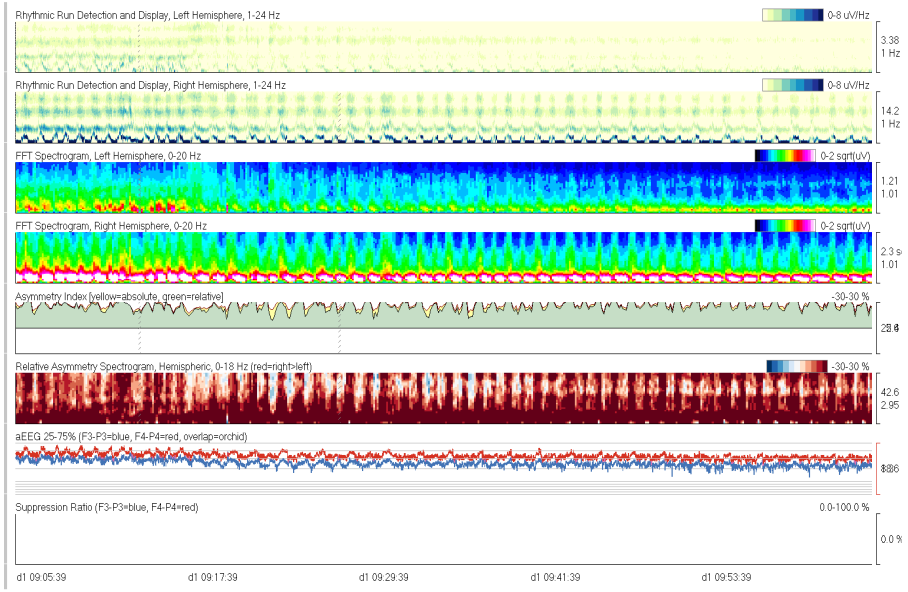

Seizure Detections
SeizureProbabilityV1
Rhythmic Run Detection and Display, Left Hemisphere, 1-24 Hz
0-8 uV/Hz
Rhythmic Run Detection and Display, Right Hemisphere, 1-24 Hz
0-8 uV/Hz
FFT Spectrogram, Left Hemisphere, 0-20 Hz
0-2 sqrt(uV)
FFT Spectrogram, Right Hemisphere, 0-20 Hz
0-2 sqrt(uV)
Asymmetry Index [yellow=absolute, green=relative]
-30-30 %
Relative Asymmetry Spectrogram, Hemispheric, 0-18 Hz (red=right blue=left)
-30-30 %
aEEG F3-C3_avg
aEEG F4-C4_avg
Suppression Ratio (F3-C3=blue, F4-C4=red)
0.0-100.0 %

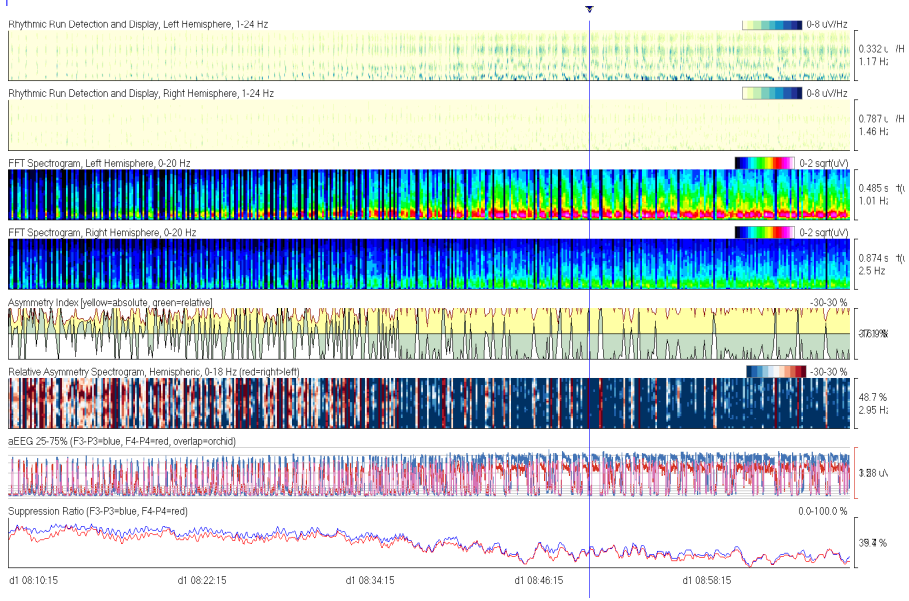
Centralized Monitoring

- Central monitoring station
  - Raw EEG
  - Video?
  - Quantitative EEG
- Staffing
  - EEG technologists
  - Monitoring technologists
- Applications for remote monitoring of multiple patients
  - Optimized for laptops, tablets, iPad

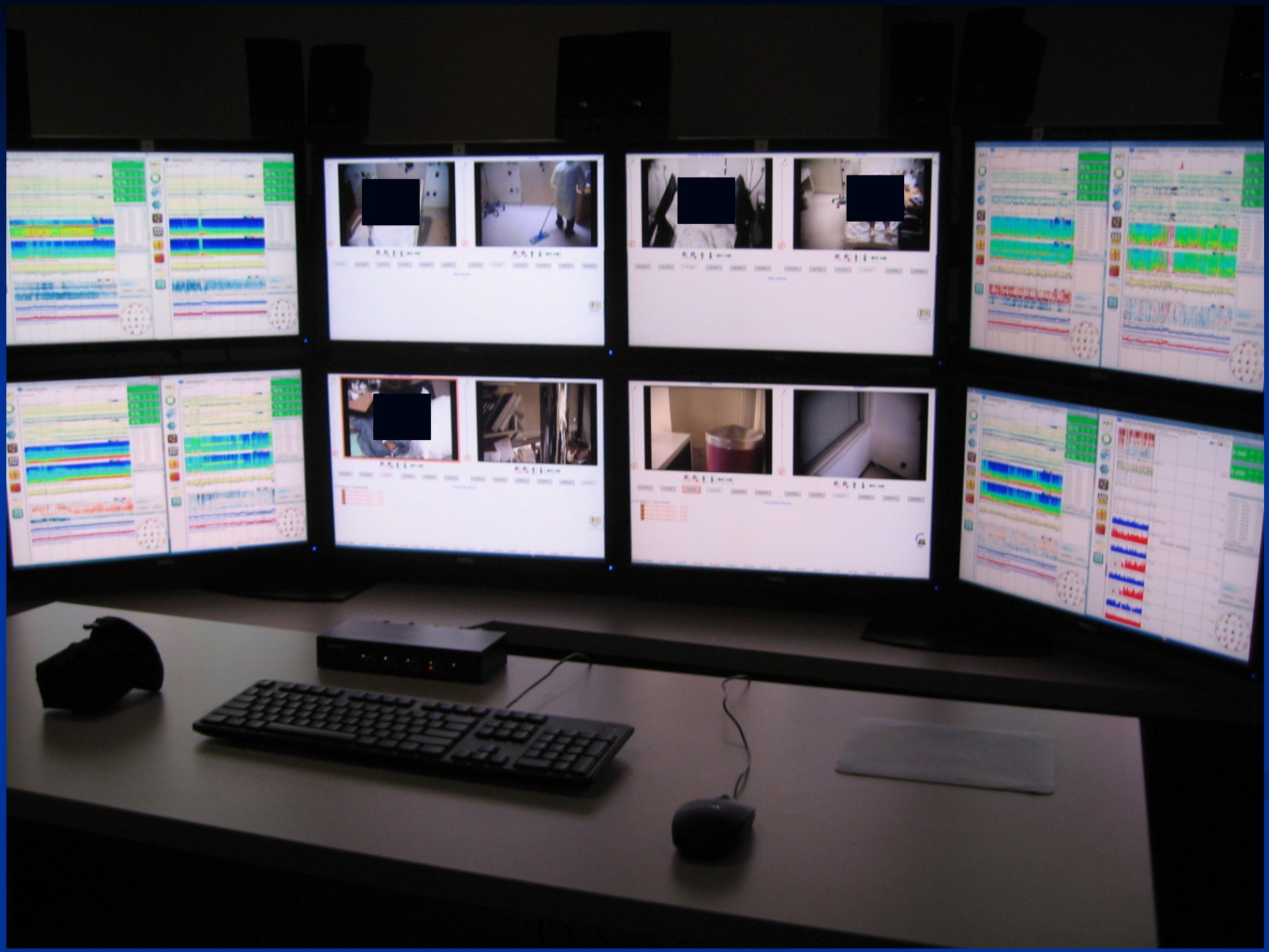

Seizure Detections
SeizureProbability(V)
Rhythmic Run Detection and Display, Left Hemisphere, 1-24 Hz
Rhythmic Run Detection and Display, Right Hemisphere, 1-24 Hz
FFT Spectrogram, Left Hemisphere, 0-20 Hz
FFT Spectrogram, Right Hemisphere, 0-20 Hz
Asymmetry Index [yellow=absolute, green=relative]
Relative Asymmetry Spectrogram, Hemispheric, 0-18 Hz (red=right blue=left)
aEEG F3-C3_avg
aEEG F4-C4_avg
Suppression Ratio (F3-C3=blue, F4-C4=red)

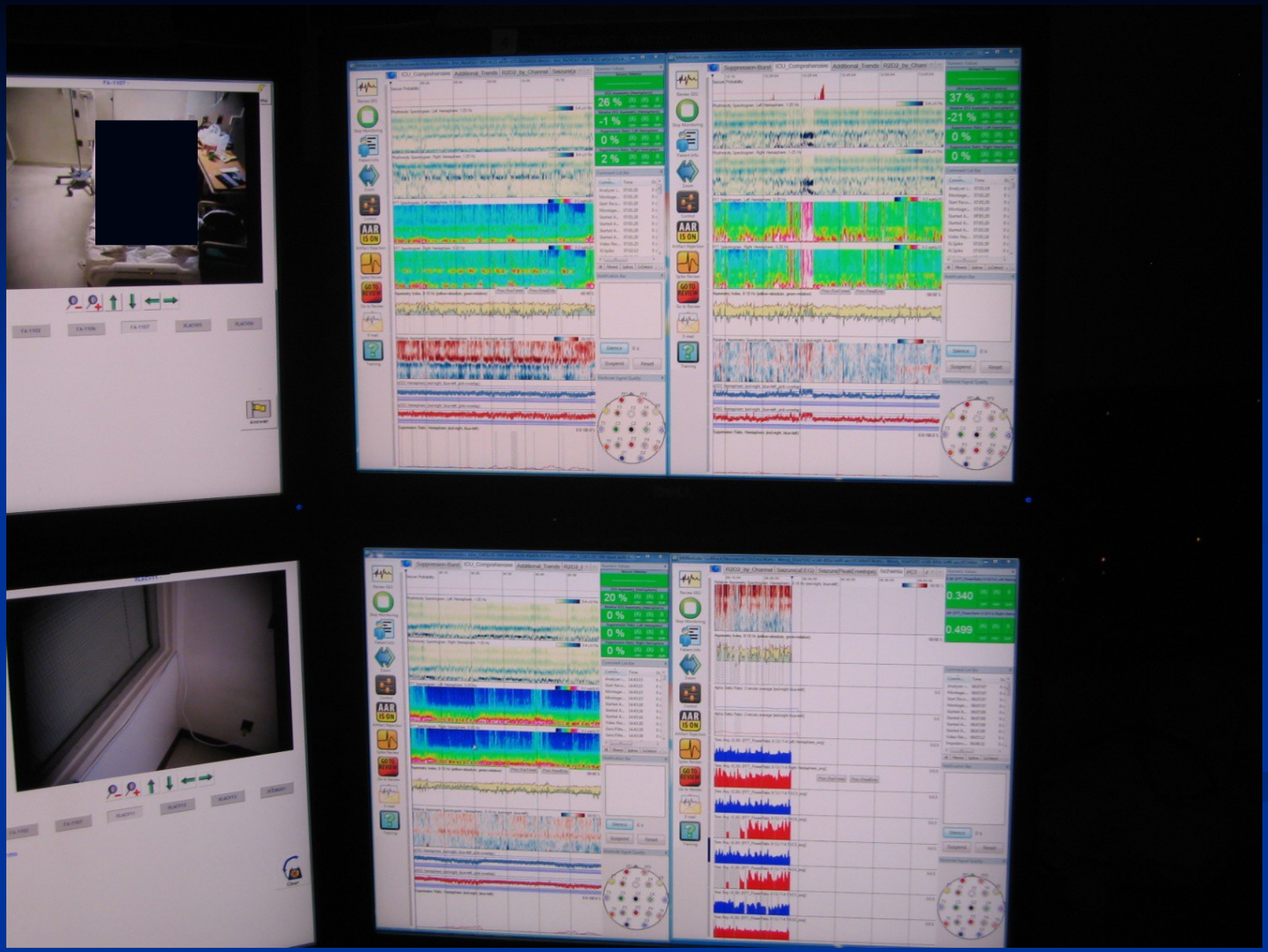

FFT_PowerRatio 8-13//1-4 F3-C3
FFT_PowerRatio 8-13//1-4 F4-C4
FFT_PowerRatio 8-13//1-4 C3-T3_avg
FFT_PowerRatio 8-13//1-4 C4-T4_avg
FFT_PowerRatio 8-13//1-4 P3-O1
FFT_PowerRatio 8-13//1-4 P4-O2
FFT_PowerRatio 8-13//1-4 Left_avg
FFT_PowerRatio 8-13//1-4 Right_avg

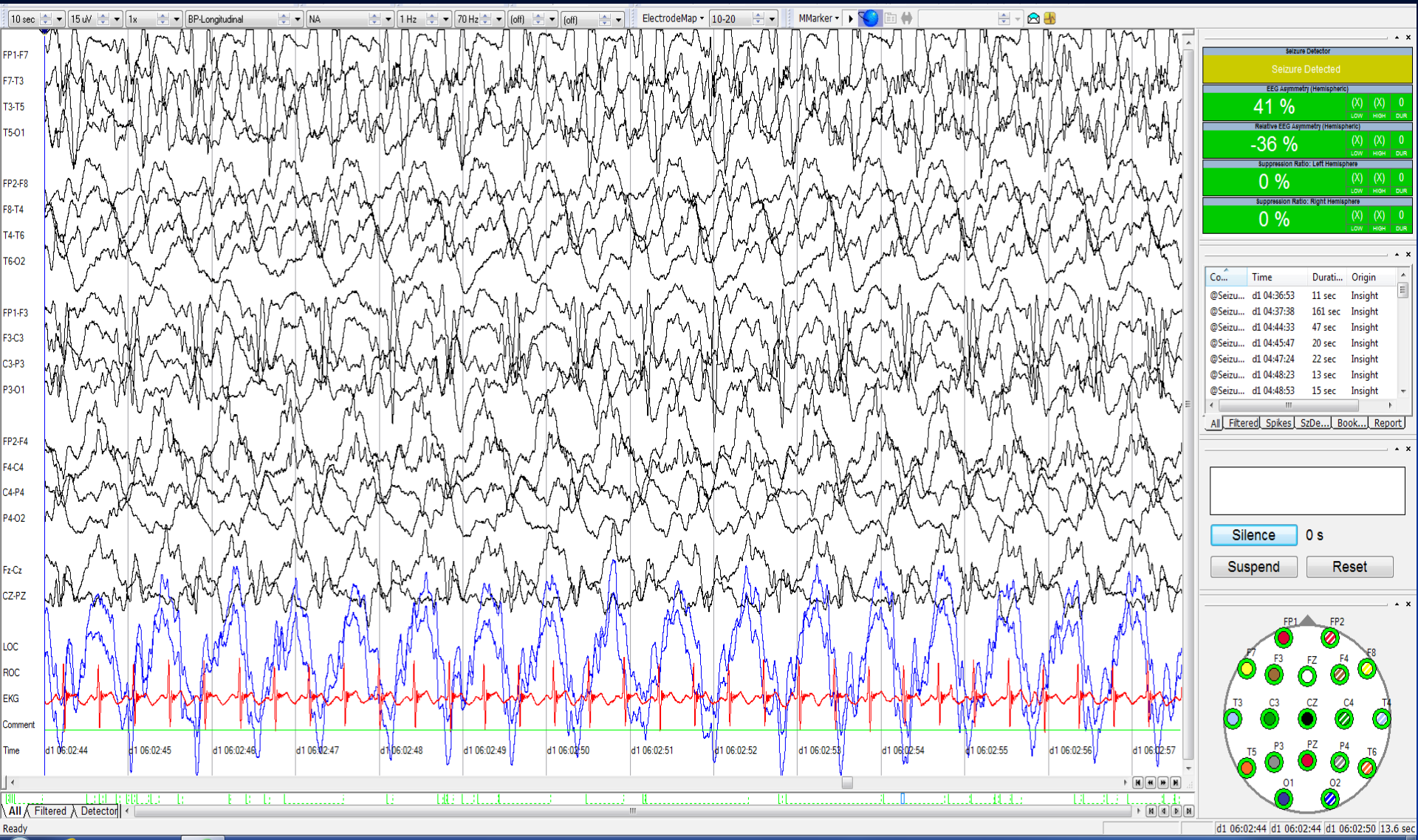

Rhythmic Run Detection and Display, Left Hemisphere, 1-24 Hz
Rhythmic Run Detection and Display, Right Hemisphere, 1-24 Hz
FFT Spectrogram, Left Hemisphere, 0-20 Hz
FFT Spectrogram, Right Hemisphere, 0-20 Hz
Asymmetry Index [yellow=absolute, green=relative]
Relative Asymmetry Spectrogram, Hemispheric, 0-18 Hz (red=right>left)
aEEG 25-75% (F3-P3=blue, F4-P4=red, overlap=orchid)
Suppression Ratio (F3-P3=blue, F4-P4=red)
d1 09:05:39
d1 09:17:39
d1 09:29:39
d1 09:41:39
d1 09:53:39


Rhythmic Run Detection and Display, Left Hemisphere, 1-24 Hz
Rhythmic Run Detection and Display, Right Hemisphere, 1-24 Hz
FFT Spectrogram, Left Hemisphere, 0-20 Hz
FFT Spectrogram, Right Hemisphere, 0-20 Hz
Asymmetry Index [yellow=absolute, green=relative]
Relative Asymmetry Spectrogram, Hemispheric, 0-18 Hz (red=right>left)
aEEG 25-75% (F3-P3=blue, F4-P4=red, overlap=orchid)
Suppression Ratio (F3-P3=blue, F4-P4=red)
d1 08:10:15
d1 08:22:15
d1 08:34:15
d1 08:46:15
d1 08:58:15


Tech Support Webex http://vitek.webex.com
Support 800-387-7518 acct. no. 22122 http://vitek.webex.com






10 sec
15 uV
1x
BP-Longitudinal
NA
1 Hz
70 Hz
(off)
(off)
ElectrodeMap
10-20
MMarker
FP1-F7
F7-T3
T3-T5
T5-O1
FP2-F8
F8-T4
T4-T6
T6-O2
FP1-F3
F3-C3
C3-P3
P3-O1
FP2-F4
F4-C4
C4-P4
P4-O2
Fz-Cz
CZ-PZ
LOC
ROC
EKG
Comment
Time
d1 06:02:44
d1 06:02:45
d1 06:02:46
d1 06:02:47
d1 06:02:48
d1 06:02:49
d1 06:02:50
d1 06:02:51
d1 06:02:52
d1 06:02:53
d1 06:02:54
d1 06:02:55
d1 06:02:56
d1 06:02:57
All
Filtered
Detector
Seizure Detector
Seizure Detected
EEG Asymmetry (Hemispheric)
41 %
Relative EEG Asymmetry (Hemispheric)
-36 %
Suppression Ratio: Left Hemisphere
0 %
Suppression Ratio: Right Hemisphere
0 %
Co...
Time
Durati...
Origin
@Seizu... d1 04:36:53 11 sec Insight
@Seizu... d1 04:37:38 161 sec Insight
@Seizu... d1 04:44:33 47 sec Insight
@Seizu... d1 04:45:47 20 sec Insight
@Seizu... d1 04:47:24 22 sec Insight
@Seizu... d1 04:48:23 13 sec Insight
@Seizu... d1 04:48:53 15 sec Insight
All
Filtered
Spikes
SzDe...
Book...
Report
Silence
0 s
Suspend
Reset
FP1
FP2
F7
F3
FZ
F4
F8
T3
C3
CZ
C4
T4
T5
P3
PZ
P4
T6
O1
O2
Ready
d1 06:02:44
d1 06:02:44
d1 06:02:50
13.6 sec

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 trends, and video by trained personnel

Communication with ICU Team

- Gather information about clinical status of patient
  - Medications, mental status, interim procedures
- Provide reports which are clinically useful for ICU team
  - Timing
  - Verbal vs. written
  - Complex interpretations may necessitate face-to-face interaction
  - ICU EEG rounds (in ICU or via remote review)
- Education for ICU attendings, fellows, nurses
- Shared research projects
- Consultations for seizure management

Conclusions

- ICU CEEG is a rapidly evolving field
- Technical aspects and staffing are major drivers of both cost and efficacy
- Frequent surveys of current practice necessary for assessment of technical advances
- Establishment and revision of guidelines

Acknowledgements

- ACNS Critical Care EEG Monitoring Committee
- ACNS CEEG in ICU Guidelines Committee
  - Susan Herman; Nicholas Abend; Suzette LaRoche; Cecil Hahn; Tammy Tsuchida; Elizabeth Gerard; Sarah Schmitt; Aatif Husain; Thomas Bleck; Peter Kaplan; Mark Quigg; Frank Drislane; Marc Nuwer; Lawrence Hirsch
- American Epilepsy Society
  - Critical Care Research EEG Monitoring Consortium Infrastructure Grant
- Epilepsy Foundation
  - Clinical Research Training Fellowship (Marjorie Bunch)
- BIDMC ICU EEG Team
  - Trudy Pang, MD, Frank Drislane, MD, Marjorie Bunch, MD, Donald Schomer, MD, Patti Morin, R.EEG Tech