Technical Aspects of ICU EEG: Hardware, Software, Staffing

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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

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

Abend NS et al. Neurocritical Care 2010;12:382-389; n=330, adult and peds
Gavvala J et al. Epilepsia 2014;55:1864-1871; n=151; adult, EEG and neuroICU
68 year old woman with sepsis, obtunded
### CEEG: Other Aspects

<table>
<thead>
<tr>
<th></th>
<th>NCC</th>
<th>ESICM</th>
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<tbody>
<tr>
<td>CEEG vs. intermittent</td>
<td></td>
<td>2, C</td>
</tr>
<tr>
<td>Technologists</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpreting physicians</td>
<td>Special training; I, C</td>
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<tr>
<td>Recording equipment / techniques</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrodes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard montage</td>
<td></td>
<td>2, C</td>
</tr>
<tr>
<td>Video recommended</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remote review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review EEG (technologist)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review EEG (physician)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Written reports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication with ICU team</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QEEG</td>
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# ACNS Guidelines

## Long Term EEG Monitoring in Neonates

<table>
<thead>
<tr>
<th>Guideline</th>
<th>ACNS</th>
<th>Date</th>
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</thead>
<tbody>
<tr>
<td>Guideline on Continuous EEG Monitoring in Neonates</td>
<td>13</td>
<td>1/16/12</td>
</tr>
<tr>
<td>Standardized EEG Terminology and Categorization for the Description of Continuous EEG Monitoring in Neonates</td>
<td>16</td>
<td>12/10/12</td>
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</table>

## Continuous EEG Monitoring in Critical Care

<table>
<thead>
<tr>
<th>Guideline</th>
<th>ACNS</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardized Critical Care EEG Terminology</td>
<td>14</td>
<td>8/31/12</td>
</tr>
<tr>
<td>Pocket version</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learn to use the 2012 Standardized Critical Care EEG Terminology with the Critical Care EEG Monitoring Research Consortium's Training Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guidelines for Continuous EEG Monitoring in the Intensive Care Unit</td>
<td></td>
<td>pending</td>
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</table>
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  
| 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 artifact from cerebral activity
- Poor quality of uninterpretable study if any of few electrodes are dislodged or artifactual
# Limited Montages

<table>
<thead>
<tr>
<th></th>
<th>Subhairline (1)</th>
<th>Hairline (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>70</td>
<td>120</td>
</tr>
<tr>
<td>Methods</td>
<td>Commercial limited EEG</td>
<td>Reformatted from standard 10-20 digital</td>
</tr>
<tr>
<td>Channels</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Duration</td>
<td>24 hours</td>
<td>2-3 min samples</td>
</tr>
<tr>
<td>Seizures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>68%</td>
<td>72%</td>
</tr>
<tr>
<td>Specificity</td>
<td>98%</td>
<td>92%</td>
</tr>
<tr>
<td>PLEDs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>39%</td>
<td>54%</td>
</tr>
<tr>
<td>Specificity</td>
<td>92%</td>
<td>97%</td>
</tr>
</tbody>
</table>

1. Young GB et al. Neurocrit Care 2009
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
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
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
Acknowledgments

- 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
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