PEDIATRIC CONTINUOUS EEG MONITORING (CEEG)

Michigan Society of Electroneurodiagnostic Technologists

9.27.13
Daniel Arndt, MD
Director, Pediatric Epilepsy
Beaumont Children’s Hospital & Health System
LEARNING OBJECTIVES

1. History of cEEG
2. What’s what of common cEEG terminology
3. Update current practice of cEEG
   - NICU – Neonatal Intensive Care Unit
   - PICU – Pediatric Intensive Care Unit
4. Epidemiology – Subclinical Seizures / S.E.
5. Impact – Electrographic Seizures / S.E.
6. ACNS Guidelines & Critical Care EEG Terminology
   - Pediatric / Adult
   - Neonatal
CONTINUOUS EEG VIDEO MONITORING (CEEG)

- Monitoring brain’s electrical activity
  - Video correlation w/ clinical signs (reported sx’s)

- Indications:
  - Cerebral function monitoring (i.e. CEA, Anesthesia)
  - Event identification
  - Detect subclinical Sz AND CLINICAL Sz
  - EMU/Presurgical, ICU

- Where:
  - PICU, NICU, Floors
CEEG DEVELOPMENT OVER THE YEARS........

# of cEEG monitoring studies by year

1978: 1st video EEG

QEEG for CEA, Anesthesia, Brain Trauma

DeGeorgio ’92, Jordan ‘93, 94-04, 01-05

PubMed Search 9.25.13
WHAT'S WHAT – COMMON CEEG TERMINOLOGY

- Electroclinical Seizure = Clinical + EEG
- Clinical Seizure = Clinical +/- EEG
- Subclinical Seizure = Subtle Clinical or EEG-only
- Nonconvulsive Seizure = Subclinical Seizure
  - *Or = Subtle Clinical Seizure
- Electrographic Seizure = EEG +/- Clinical Signs
  - *Or = Subtle Clinical or Nonconvulsive Seizure
- Electrographic-Only Seizure = EEG only
DEMAND FOR CEEG MONITORING

CLINICAL

AEDs

SUBCLINICAL

NCSz/SE

EEG-Only

LPDs, LPDs+, Periodic, Rhythmic

BIRDs

Interictal – Ictal continuum
DEMAND FOR CEEG MONITORING (CONT.)

- Nonconvulsive seizures/NCSE occur commonly
- NCSz/NCSE potentially:
  - Worsen Acute Brain Injury
  - Increased Risk for Future Neurocognitive Morbidity
  - Increased Risk of Development of Epilepsy
- NCSE → ↑ Morbidity/Mortality
SUPPLY RESOURCES FOR CEEG

- ↑↑ Utilization of cEEG in PICU/NICU over past 5yrs
- Resource Development & EEG reimbursement Δs
- Institutional Guidelines – Standardize Monitoring
- ACNS Guidelines: Neonatal, Pediatric, & Adult
- Research Consortia:
  - Pediatric Critical Care EEG Group (PCCEG)
  - Critical Care EEG Monitoring Research Consortium (CCEMRC)
CURRENT PRACTICE - OVERVIEW

- Sz are common in critically ill patients
- cEEG is required to diagnose Sz
- Most Sz are identified in 1-2 days monitoring
- cEEG findings change management
- Electrographic Sz probably worsen outcome
- Lack studies that identifying/managing Electrographic Sz improves outcome
- cEEG is increasingly being utilized
- Guidelines & position statements en vogue
SZ/CEEG - NEONATAL ICU (NICU)

- Sz in 1.5 - 5.5/1000 Neonates
  - 4% <30wks & 1.5% >30wks
  - Scher ’93, Scher ’93

- Clinical data do not predict Sz
  - Murray ’06

- If you have 1 Sz......usually many
  - S.E. diagnosed ~1/3

- Unique Patients/Brains & Unique EEG
  - Seizure incidence higher than any other time in life
  - Sheth 99
Unique Sz Semiology
- Accurate recognition of Clinical Sz is challenging\textsuperscript{Scher 02}
- Experience clinicians frequently fail to recog Clin Sz
  - Staff ID 9\% of 526 Clinical Sz\textsuperscript{Murray 08}
  - 78\% of 177 PBE (-EEG)\textsuperscript{Murray 08}
  - Video Review: 50\% accuracy (Poor interater agreement)\textsuperscript{Malone 09}
- Sz frequently Subclinical\textsuperscript{Connell 89, Hellstrom-Westas 85, Nash 11, Scher 03, Clancy 06}
Continuous EEG monitoring of neonatal seizures: diagnostic and prognostic considerations.

J Connell, R Oozeer, L de Vries, L M Dubowitz and V Dubowitz

doi:10.1136/adc.64.4_Spec_No.452

- Connell article – data
- 4 or 8 channel EEG – 275 Consecutive NICU adm
  - 25% critically ill
  - ¾ preterm infants
- 20% Sz
  - 42% Sz infants = Electrographic-only
    - 40% of E-only Sz infants were medically paralyzed
  - Additional 36% Sz infants = Electrographic onset preceded Clin Sz
    - Thus, 78% E-only portions of Sz (Would be similar to Clancy ‘06 #)
- 55% of Sz infants expired
  - No diff +/- Clinical Sz (Few had Clinical only Sz)
Nonparalyzed infants: Only 20% ESz provoke Clin Signs

- >42% seen in Connell ’89 – Better EEG

Electroclinical uncoupling – Phenobarbital – 50%

Slide adapted Abend ’13, PHB Data: Scher ’03, Connell ’89
CURRENT NICU CEEG INDICATIONS

- **HIE & THERAPEUTIC HYPOTHERMIA**
  - Nash ’11
    - N=41, 34% Sz → 10% S.E., 43% Subclinical
  - Wusthoff ’11
    - N=26, 65% Sz → 23% S.E., 47% Subclinical

- **Cardiac Surgery**
  - Peri-operative Subclinical Sz 6-20% Chock 06, Clancy 05, Helmers 97, Gaynor 05, Schmitt 05

- **ECMO**
  - Subclinical Sz 11-30% Campbell 91, Hahn 93, Horan 07
CURRENT NICU CEEG UTILIZATION

- **Glass ‘12:**
  - International Survey
  - Monitor “at risk” newborns: EEG 24%, aEEG 24%, Both 19%
    - None 34%
  - Seizure Diagnosis: Clinical 8%, EEG 58%, aEEG or EEG 38%
  - EEG Duration: <60min 31%, 24hrs 17%, Sz-free 24hrs 49%

- **Boylan ‘10:**
  - EEG Monitoring Access = 90% (EEG 27%, aEEG 22%, Both 51%)
  - Confident or Very Confident interpreting = 28%

- **aEEG (Amplitude integrated EEG):**
  - Sensitivity (single channel w/out raw EEG single channel for confirmation): <50%
    - Rennie 04, Shellhaas 07
  - Addition of 2nd aEEG channel w/ ability to review raw EEG improves sensitivity to 76%, specificity 78%
    - Shah 08
  - But Sz detection remains difficult with this tool
  - It has been shown to reduce total seizure duration in neonates

Van Rooij 10
Shellhaas ‘11:

- Idealized Goals – NOT Mandated Standard of Care
- **Indications:**
  - Differential Diagnosis – Abnormal Paroxysmal Events
  - Detection of Electrographic Sz in High Risk Populations
  - Monitoring Burst Suppression
  - Judge severity of encephalopathy
- **Procedures for monitoring**
- **Duration of monitoring:** 24hrs – Routine EEG little value
- **Training of caretakers**
- **EEG interpretation & reporting**
  - 1st hour reported asap & >2x in 24hrs
- **Data Retention & Storage**
- **Digital trending & analyses**
TABLE 1. Examples of Sudden, Stereotyped Clinical Events That May Raise the Suspicion for Neonatal Seizures

- Focal clonic or tonic movements
- Intermittent forced, conjugate, horizontal gaze deviation
- Myoclonus
- Generalized tonic posturing
- “Brainstem release phenomena” such as oral–motor stereotypes, reciprocal swimming movements of the upper extremities or bicycling movements of the legs
- Autonomic paroxysms such as unexplained apnea, pallor, flushing, tearing, and cyclic periods of tachycardia or elevated blood pressures

TABLE 2. Examples of High-Risk Clinical Scenarios Which May Lead to Consideration of Long-Term Neonatal EEG Monitoring

Examples of Clinical Scenarios Conferring High Risk of Neonatal Seizures

- Clinical syndrome of acute neonatal encephalopathy
  - Neonatal depression from suspected perinatal asphyxia (chronic or acute)
  - After cardiopulmonary resuscitation
- Cardiac or pulmonary risks for acute brain injury and clinical encephalopathy
- Significant respiratory conditions such as severe persistent pulmonary hypertension
- Need for ECMO
- Congenital heart defects requiring early surgery using cardiopulmonary bypass
- CNS infection
  - Laboratory confirmed meningoencephalitis
  - Suspected CNS infection, such as clinical evidence in setting of maternal chorioamnionitis, funisitis, group B streptococcus or HSV colonization
- CNS trauma
  - Intracranial subarachnoid, subdural, or intraventricular bleeding
  - Clinical encephalopathy and suspicion for CNS injury, for example, maternal trauma, traumatic delivery, prolonged second stage of labor, or suspected nonaccidental trauma
  - Inborn errors of metabolism (suspected or confirmed)
  - Perinatal stroke (suspected or confirmed)
- Sinovenous thrombosis (suspected or confirmed)
- Premature infants with additional risk factors
  - Acute high-grade intraventricular hemorrhages
  - Very low birth weight with clinical concern for encephalopathy
- Genetic/syndromic disease involving CNS
- Cerebral dysgenesis on neuroimaging
- Dysmorphic features or multiple anomalies with microcephaly
- PICU cEEG Experience more ~ Adult Experience than that of neonates
  - 2-4yo – Significant myelination
  - Still quite different than adults:
    - Incidence
    - Treatment
    - Significance/Outcome
1st Paper - CEEG PICU

Frequency and Predictors of Nonconvulsive Seizures During Continuous Electroencephalographic Monitoring in Critically Ill Children

Nathalie Jette, MD, MSc; Jan Claassen, MD; Ronald G. Emerson, MD; Lawrence J. Hirsch, MD

- 44% Sz (75% EEG-only)
- 23% S.E. (89% NCSE)
Prior single-studies – varying incidences of ESz:

7 - 48% Abend 11, Hosain 05, Jette 06, Abend 07, Alehan 01, Tay 06, Saengpattrachai 06, Shahwan 10, Abend 09, Williams 11, Greiner 12, Kirkham 12

Variability:
- Small sample size
- Case mix variability across institutions
- Interinstitution variabilities in cEEG indications
- Range of studies performed over a decade – cEEG/Crit Care evolved
PCCEG Epidemiologic Study

- Retrospective
- 11 sites
- 550 subjects
- PICU (1mo-21yrs)
- Clinically indicated cEEG

<table>
<thead>
<tr>
<th>Site</th>
<th>PCEEG Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston</td>
<td>Tobias Loddenkemper</td>
</tr>
<tr>
<td></td>
<td>Ivan Sanchez Fernandez</td>
</tr>
<tr>
<td>Chicago</td>
<td>Joshua Goldstein</td>
</tr>
<tr>
<td>DC</td>
<td>Jessica Carpenter</td>
</tr>
<tr>
<td>Denver</td>
<td>Kevin Chapman</td>
</tr>
<tr>
<td>Duke</td>
<td>William Gallentine</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Christopher Giza</td>
</tr>
<tr>
<td></td>
<td>Jason Lerner</td>
</tr>
<tr>
<td></td>
<td>Joyce Matsumoto</td>
</tr>
<tr>
<td>Miami</td>
<td>Ann Hyslop</td>
</tr>
<tr>
<td>Michigan</td>
<td>Daniel Arndt</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>Nick Abend</td>
</tr>
<tr>
<td></td>
<td>Dennis Dlugos</td>
</tr>
<tr>
<td>Phoenix</td>
<td>Korwyn Williams</td>
</tr>
<tr>
<td>San Francisco</td>
<td>Kendall Nash</td>
</tr>
<tr>
<td>Toronto</td>
<td>Cecil Hahn</td>
</tr>
<tr>
<td></td>
<td>Eric Payne</td>
</tr>
</tbody>
</table>
Electrographic seizures in pediatric ICU patients
Cohort study of risk factors and mortality

Nicholas S. Abend, MD
Daniel H. Arndt, MD
Jessica L. Carpenter, MD
Kevin E. Chapman, MD
Karen M. Cornett, MT
William B. Gallentine, DO
Christopher C. Giza, MD
Joshua L. Goldstein, MD
Cecil D. Hahn, MD, MPH
Jason T. Lerner, MD
Tobias Loddenkemper, MD
Joyce H. Matsumoto, MD
Kristin McBain, MS
Kendall B. Nash, MD
Eric Payne, MD
Sarah M. Sánchez, BA
Iván Sánchez Fernández, MD
Justine Shults, PhD
Korwyn Williams, MD, PhD
Amy Yang, BS
Dennis J. Dlugos, MD

ABSTRACT

Objectives: We aimed to determine the incidence of electrographic seizures in children in the pediatric intensive care unit who underwent EEG monitoring, risk factors for electrographic seizures, and whether electrographic seizures were associated with increased odds of mortality.

Methods: Eleven sites in North America retrospectively reviewed a total of 550 consecutive children in pediatric intensive care units who underwent EEG monitoring. We collected data on demographics, diagnoses, clinical seizures, mental status at EEG onset, EEG background, interictal epileptiform discharges, electrographic seizures, intensive care unit length of stay, and in-hospital mortality.

Results: Electrographic seizures occurred in 162 of 550 subjects (30%), of which 61 subjects (38%) had electrographic status epilepticus. Electrographic seizures were exclusively subclinical in 59 of 162 subjects (36%). A multivariable logistic regression model showed that independent risk factors for electrographic seizures included younger age, clinical seizures prior to EEG monitoring, an abnormal initial EEG background, interictal epileptiform discharges, and a diagnosis of epilepsy. Subjects with electrographic status epilepticus had greater odds of in-hospital death, even after adjusting for EEG background and neurologic diagnosis category.

Conclusions: Electrographic seizures are common among children in the pediatric intensive care unit, particularly those with specific risk factors. Electrographic status epilepticus occurs in more than one-third of children with electrographic seizures and is associated with higher in-hospital mortality. Neurology® 2013;81:383–391

GLOSSARY

CEEG = continuous EEG; CI = confidence interval; IQR = interquartile range; OR = odds ratio; PICU = pediatric intensive care unit.

Several single-center studies have reported electrographic seizures in 10%–40% of children who
Electrographic Sz – 30% (162/550)

- Electrographic S.E. – 38%
  - Sz >30min – 46%
  - Recurrent Sz >50% of 1hr Epoch – 56%

Sz w/ Clinical correlate?:
- All – Only 27%
- Some – 34%
- None – 36%

Sz risk factors: (multivariate analysis)
- Younger Age
- Clinical Sz prior to cEEG
- Abnormal initial EEG background
- IEDs
- Epilepsy Diagnosis

NCSz risk factors: (reported elsewhere)
- Younger Age
- Convulsive SE
- Acute Seizures
- Structural Brain Injury & TBI
- EEG: Lack of Reactivity
- Abnormal initial EEG background
- Discont
<table>
<thead>
<tr>
<th>Table 1</th>
<th>Electrographic seizure characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrographic seizure characteristic</td>
<td>n (%)</td>
</tr>
<tr>
<td>Typical seizure duration (n = 158)</td>
<td></td>
</tr>
<tr>
<td>10–59 s</td>
<td>60 (38)</td>
</tr>
<tr>
<td>1–5 min</td>
<td>63 (40)</td>
</tr>
<tr>
<td>6–30 min</td>
<td>25 (16)</td>
</tr>
<tr>
<td>&gt;30 min</td>
<td>10 (6)</td>
</tr>
<tr>
<td>Clinical correlate (n = 162)</td>
<td></td>
</tr>
<tr>
<td>All (100%)</td>
<td>43 (27)</td>
</tr>
<tr>
<td>Most (50%–99%)</td>
<td>22 (14)</td>
</tr>
<tr>
<td>Some (1%–49%)</td>
<td>33 (20)</td>
</tr>
<tr>
<td>None (0%)</td>
<td>59 (35)</td>
</tr>
<tr>
<td>Unknown</td>
<td>5 (3)</td>
</tr>
<tr>
<td>Seizure onset localization (n = 162)</td>
<td></td>
</tr>
<tr>
<td>Focal</td>
<td>86 (53)</td>
</tr>
<tr>
<td>Multifocal</td>
<td>30 (19)</td>
</tr>
<tr>
<td>Generalized</td>
<td>39 (24)</td>
</tr>
<tr>
<td>Unknown</td>
<td>7 (4)</td>
</tr>
<tr>
<td>Seizure maximal spread localization (n = 162)</td>
<td></td>
</tr>
<tr>
<td>Focal-unilateral</td>
<td>80 (49)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>76 (47)</td>
</tr>
<tr>
<td>Unknown</td>
<td>6 (4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Electrographic seizure occurrence by diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnosis (n)*</td>
<td>Electrographic seizures present, %</td>
</tr>
<tr>
<td>Sepsis (19)</td>
<td>58</td>
</tr>
<tr>
<td>Epilepsy (159)</td>
<td>48</td>
</tr>
<tr>
<td>Brain malformation (24)</td>
<td>38</td>
</tr>
<tr>
<td>CNS inflammation or autoimmune disorder (24)</td>
<td>33</td>
</tr>
<tr>
<td>Stroke (33)</td>
<td>30</td>
</tr>
<tr>
<td>Traumatic brain injury (61)</td>
<td>30</td>
</tr>
<tr>
<td>Metabolic (59)</td>
<td>29</td>
</tr>
<tr>
<td>CNS infection (28)</td>
<td>29</td>
</tr>
<tr>
<td>Unknown (14)</td>
<td>21</td>
</tr>
<tr>
<td>Tumor/oncologic (21)</td>
<td>19</td>
</tr>
<tr>
<td>Hypoxic-ischemic encephalopathy (73)</td>
<td>18</td>
</tr>
<tr>
<td>Pharmacologic sedation—no known neurologic problem (15)</td>
<td>13</td>
</tr>
<tr>
<td>Toxin (8)</td>
<td>13</td>
</tr>
<tr>
<td>Paralytic administration (26)</td>
<td>8</td>
</tr>
</tbody>
</table>

*a Subjects could have more than one diagnosis.*
<table>
<thead>
<tr>
<th>Diagnosis (N)</th>
<th>Seizure(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sepsis (19)</td>
<td>58%</td>
</tr>
<tr>
<td>Epilepsy (159)</td>
<td>48%</td>
</tr>
<tr>
<td>Brain Malformation (24)</td>
<td>38%</td>
</tr>
<tr>
<td>Central Nervous System Inflammation or Autoimmune Disorder (24)</td>
<td>33%</td>
</tr>
<tr>
<td>Stroke (33)</td>
<td>30%</td>
</tr>
<tr>
<td>Traumatic Brain Injury (61)</td>
<td>30%</td>
</tr>
<tr>
<td>Metabolic (59)</td>
<td>29%</td>
</tr>
<tr>
<td>Central Nervous System Infection (28)</td>
<td>29%</td>
</tr>
<tr>
<td>Unknown (14)</td>
<td>21%</td>
</tr>
<tr>
<td>Tumor/oncologic (21)</td>
<td>19%</td>
</tr>
<tr>
<td>Hypoxic-Ischemic Encephalopathy (73)</td>
<td>18%</td>
</tr>
<tr>
<td>Pharmacologic sedation – no known neurologic problem (15)</td>
<td>13%</td>
</tr>
<tr>
<td>Toxin (8)</td>
<td>13%</td>
</tr>
<tr>
<td>Paralytic Administration (26)</td>
<td>8%</td>
</tr>
</tbody>
</table>
CURRENT PICU INDICATIONS

- ACNS Guidelines – PICU: Pending

- Follow Neurocritical Care Society Guidelines for S.E.:
  - Recent clinical Sz or S.E. w/out RTB >10min
  - Coma, including post-cardiac arrest
  - Epileptiform activity or Periodic discharges initial 30m
  - Intracranial hemorrhage including TBI, SAH, ICH
  - Suspected NCSz/NCSE in pts w/ AMS

- Post-cardiac arrest - Hypothermia
- Traumatic Brain injury
- ECMO
- Cardiac Surgery
EXAMPLE – SPECIFIC PATIENT TYPE
CEEG – ACUTE BRAIN INJURY

1st Report – Adult Neuro ICU: Jordan ’93 & ’95
- Varied BI
- Sz o NICU Course: 35%
  - 75% EEG-only Sz (~25%)

Similar reports – Adult Neuro-ICU:
- EEG-only Sz: 11% Litt 94 - 55% Claassen 04

2 TBI-specific reports early:
- Vespa ‘99 - Prospective
- Ronne-Engstrom ‘06 - Retrospective
Increased incidence and impact of nonconvulsive and convulsive seizures after traumatic brain injury as detected by continuous electroencephalographic monitoring

Paul M. Vespa, M.D., Marc R. Nuwer, M.D., Ph.D., Valeriy Nenov, Ph.D., Elisabeth Ronne-Engstrom, M.D., Ph.D., David A. Hovda, Ph.D., Marvin Bergsneider, M.D., Daniel F. Kelly, M.D., Neil A. Martin, M.D., and Donald P. Becker, M.D.

Division of Neurosurgery and Department of Neurology, University of California at Los Angeles School of Medicine, Los Angeles, California, and Department of Neurosurgery, Uppsala University, Uppsala, Sweden

- Prospective
- cEEG mod-sev TBI (GCS 3-12) – 94pts
  - Standardized care protocols: ICP, CPP, Ventilation, PHT (10-20) ER + >7d
- EPTS: 22%
  - EEG-only = 52%
  - EPTSz ≥48hrs: 2/21
    - Clinical Literature: 56-100% PTSz ≤24hrs
- Non-Sz Group: 10% Epileptiform d/c’s
Continuous EEG monitoring in patients with traumatic brain injury reveals a high incidence of epileptiform activity


- Retrospective
- cEEG >24hrs, Standardized care protocols: ICP, CPP, Ventilation
- EPTS: 33%
  - “Significant %” EEG-only
- Non-Sz Group: 16% epileptiform d/c’s
Animals:

- Prince et al. ’09: (Lit Review)
  - Electrographic only (no clinical signs) focal Sz in TBI simulated Rats
  - Depth electrodes & video EEG

- Pitkanen et al.
OTHER POTENTIAL DX BENEFIT?

- Preepileptic signatures? Damaged brain - Image Neg TBI?
  - Ronne-Engstrom ’06: Focal high frequency d/c’s + slow wave
    - 66% (12/18) FHFDs → Epileptiform activity
    - 44% (8/18) had Sz

1. Vespa ’02:
   - Impaired α variability - Px value - GCS 3-8

2. Vespa ’97 & Claassen:
   - α/Δ ratio - Impending vasospasm - SAH
Nonconvulsive electrographic seizures after traumatic brain injury result in a delayed, prolonged increase in intracranial pressure and metabolic crisis.

Results:
- **+EPTSz group:** Overall ↑ ICP & Lactate
  - ↑ >100hrs

Conclusions:
1. **PTSz NOT just benign epiphenomena!**
   - Direct evidence: ↑ ICP, ∆ IC Hemodynamics, & potentiate metab stress
2. **PTSz Therapeutic target for TBI patients**
3. Consider cEEG in TBI pts w/ ICP refractory to conventional measures
   - ↑ICP >96hrs post-injury
   - Detecting & Rx Sz (E/C) may improve ICP control
Nonconvulsive seizures after traumatic brain injury are associated with hippocampal atrophy


Neurology 2010;75;792-798

Figure 2

Long-term brain atrophy in hippocampal regions are shown for the seizure and nonseizure groups

<table>
<thead>
<tr>
<th>Percentage atrophy</th>
<th>Seizure ipsilateral</th>
<th>Seizure right</th>
<th>Seizure left</th>
<th>Seizure contralateral</th>
<th>Nonseizure right</th>
<th>Nonseizure left</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.35</td>
<td>0.30</td>
<td>0.25</td>
<td>0.20</td>
<td>0.10</td>
<td>0.05</td>
</tr>
</tbody>
</table>

* p < 0.001
** p = 0.02

Mod-Sev TBI w/ cEEG
N=140

+ acute & chronic MRI
N=29

6/29 had Sz & were compared w/ 10 controls w/o Sz

Slide courtesy of Chris Giza, MD
43% Sz rate
  ➢ RF: Younger age, AHT

16% Subclinical Sz (6.9% only Subclinical Sz)
  ➢ RF: Younger age, AHT, & Intraaxial bleed

18.4% S.E.
  ➢ RF: Younger age, AHT, & Intraaxial bleed

13.8% Subclinical S.E.
  ➢ RF: Younger age, AHT, & Intraxial bleed

Subclinical Sz:
  ➢ Lower Hospital D/c KOSCHI score

S.E. & Subclinical S.E.
  ➢ Increased Hospital LOS
  ➢ Lower Hospital D/c KOSCHI score
Acute Symptomatic Sz after brain injury ARE NOT BENIGN
- Vulnerable State

HOWEVER, No clinical class I/II trials:
- Sz provoked injury affects outcome
- Absolutely Chg Mgmt for these Sz

HOWEVER, Substantial evidence mounting
- Acutely injured brains
- EEG-only Sz
CURRENT PICU CEEG UTILIZATION

- Sanchez et al. – PCCEEG ‘13:
  - Surveyed 61 institutions - Retrospective
  - 47/50 US centers & 11/11 Canadian
  - 31 questions (5-10 min)
  - Significant increase (~30%) over 1 year period
  - US – median 10 pts/month
  - Technologists: Available 24/7 87% (often call-back)
    - Screen EEG: 50%
  - Most institutions utilize EEG screening by physicians & Techs 2-3x/day
  - 60% have formal qualifications to interpret EEG
  - 31% have clinical pathways addressing cEEG use

<table>
<thead>
<tr>
<th>cEEG Indication</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event Characterization (movement, Δvital signs)</td>
<td>100%</td>
</tr>
<tr>
<td>Altered Mental Status</td>
<td></td>
</tr>
<tr>
<td>After seizure or status epilepticus</td>
<td>96%</td>
</tr>
<tr>
<td>With acute primary neurologic disorder</td>
<td>89%</td>
</tr>
<tr>
<td>Unknown etiology</td>
<td>89%</td>
</tr>
<tr>
<td>Specific Conditions</td>
<td></td>
</tr>
<tr>
<td>Resuscitation from cardiac arrest</td>
<td>68%</td>
</tr>
<tr>
<td>Traumatic Brain Injury</td>
<td>60%</td>
</tr>
<tr>
<td>ECMO</td>
<td>36%</td>
</tr>
</tbody>
</table>
Electroencephalography monitoring in critically ill children: Current practice and implications for future study design


*Departments of Neurology and Pediatrics, The Children’s Hospital of Philadelphia and the Perelman School of Medicine at the University of Pennsylvania, Philadelphia, Pennsylvania, U.S.A.; Departments of Pediatrics and Neurology, Oakland University William Beaumont School of Medicine, Royal Oak, Michigan, U.S.A.; Department of Neurology, Children’s National Medical Center, Washington, District of Columbia, U.S.A.; Division of Neurology, Children’s Hospital Colorado and University of Colorado School of Medicine, Aurora, Colorado, U.S.A.; Division of Neurology, Duke Children’s Hospital and Duke University School of Medicine, Durham, North Carolina, U.S.A.; Division of Neurology, Department of Pediatrics Mattel Children’s Hospital and UCLA Brain Injury Research Center, Department of Neurosurgery, David Geffen School of Medicine at UCLA, Los Angeles, California, U.S.A.; Division of Neurology, Children’s Memorial Hospital and Northwestern University Feinberg School of Medicine, Chicago, Illinois, U.S.A.; Division of Neurology, The Hospital for Sick Children and University of Toronto, Toronto, Ontario, Canada; Division of Epilepsy and Clinical Neurophysiology, Department of Neurology, Boston Children’s Hospital and Harvard Medical School, Boston, Massachusetts, U.S.A.; Department of Biostatistics and Epidemiology, Center for Clinical Epidemiology and Biostatistics, Perelman School of Medicine at the University of Pennsylvania, Pennsylvania, Philadelphia, U.S.A.; and Department of Pediatrics, University of Arizona College of Medicine and Barrow’s Neurological Institute at Phoenix Children’s Hospital, Phoenix, Arizona, U.S.A.

SUMMARY

Purpose: Survey data indicate that continuous electroencephalography (EEG) (CEEG) monitoring is used with increasing frequency to identify electrographic seizures in critically ill children, but studies of current CEEG practice have not been conducted. We aimed to describe the clinical utilization of CEEG in critically ill children at tertiary care hospitals with a particular focus on essential criteria for designing feasible prospective multicenter studies evaluating the impact of electrographic seizures on outcome.

Methods: Eleven North American centers retrospectively enrolled 550 consecutive critically ill children who underwent CEEG. We collected data regarding subject characteristics, CEEG indications, and CEEG findings.

Key Findings: CEEG indications were encephalopathy with possible seizures in 67% of subjects, event characterization in 38% of subjects, and management of refractory status epilepticus in 11% of subjects. CEEG was initiated outside routine work hours in 47% of subjects. CEEG duration was <12 h in 16%, 12-24 h in 34%, and >24 h in 48%. Substantial variability existed among sites in CEEG indications and neurologic diagnoses, yet within each acute neurologic diagnosis category a similar proportion of subjects at each site had electrographic seizures. Electrographic seizure characteristics including distribution and duration varied across sites and neurologic diagnoses.

Significance: These data provide a systematic assessment of recent CEEG use in critically ill children and indicate variability in practice. The results suggest that multicenter studies are feasible if CEEG monitoring pathways can be standardized. However, the data also indicate that electrographic seizure variability must be considered when designing studies that address the impact of electrographic seizures on outcome.

KEY WORDS: EEG monitoring, Seizure, Status epilepticus, Pediatric, Nonconvulsive seizure.
HOW LONG DO WE MONITOR PATIENTS??

Most patients will have Sz 1-2 days monitoring

ACNS Neonate Guidelines:
- High Risk Neonates – Conventional EEG x 24hrs
- If Sz detected – EEG monitoring >24hrs Sz-free
HOW LONG DO WE MONITOR PATIENTS?? (CONT.)

- **Abend ‘10: Survey – cEEG Duration if No Sz**
  - 24hrs if:
    - **Comatose:** 47%
    - **Obtunded/Lethargic:** 48%
    - **Periodic EDs:** 40%

- **Specific Patients:**
  - **NICU Cooling/Hypothermia/HIE:** 4 days (3 cool, 1 warm)
    - Maximum seizure burden 22hrs
    - Sz occur any day
    - S.E. tends to occur days 1-2
  - **Neurocritical Care Society Guideline:** 48hrs if comatose
Little data

Mostly Sz impacts/does not impact outcome

Few electrographic Sz occurrence papers show it impacts outcome
Van Rooj ‘10:
- 33 HIE Neonates
- aEEG = ↓ Sz Burden
Outcome predictors

- Interictal EEG (serial) Clancy/Legido 87, Holmes 93, Monod 72, Watanabe 99, Mariani 08

Sz predictors – High Risk Neonates (i.e. HIE)

- Significantly AbNL Background EEG + Sz = 81%
- NL Background EEG + Sz = 4% Laroja 98
CEEG IMPROVES CLINICAL DECISION MAKING
ADULT/PEDS DATA

Jordan ’93 & ’95:
- 1st report in NeuroICU:
  - TBI, Stroke, Coma, etc.
  - Decisions: (1) Start/∆ AED
    (2) Get neuroimaging: CT/MRI
    (3) Adjust CPP or MAP
- cEEG decisive in 51% pts
- Significant contribution in additional 31%
  - cEEG detected subclinical pathophysiology that could be treated in 82%

Vespa ‘99b: Goal directed Sz Rx improved outcome (All Neuro-ICU)
- NO additional cost (↓Hosp cost), ↓LOS, ↑GOS, Guides care >90%

Abend ‘11: cEEG led to Mgmt Chgs in 60%
- AED Chg = 47%
- Paroxysmal Event Not Sz = 21%
- Urgent Neuroimaging = 3%

Kilbride ‘09: cEEG led to AED Px Chg in 52%
EVIDENCE MOUNTING THAT ESZ ARE NOT GOOD

**ADULT:**

1. **Vespa ‘99a:** Sz did NOT affect outcome: (1) LOS (2) 1 mo GOS (TBI specific)
   - 1 month GOS? ≤36% improvement in 6-12 month GOS
   - BUT, +PTSE = death (vs isolated Sz → no Δ mortality rate)
   - AND f/u 315 pts: 27% had PTSz → Factor ↑ mortality

2. **Vespa ’07:** EEG-only Sz ↑ICP & metabolic stress → ↑Morbidity
3. **Hirsch ’08:** “EEG-only Sz can hurt you”
4. **Vespa ‘10:** Focal MRI ipsilateral Hippocampal Atrophy with EEG-only Sz

**NEONATAL:** Kwon 11, Glass 09, Gluckman 05, Van Rooj 07, Glass 11, McBride 00, Painter 12

**PEDIATRIC:** Arndt 13, Greiner 12, Schreiber 12, Gwer 12, Kirkham 12, Topjian 12

*Still waiting for evidence that treating ESz improves outcome*
Cited prior evidence NCSz are harmful:

- NCSz or Periodic d/c's → Independ predictors worse outcome in multiple populations
- Epilepsy (w/out TBI) + Prolonged NCSz → Permanent neurologic injury, albeit rarely
- NSE (neuronal injury) ↑ p NCSE (even w/out brain injury)
- Pericontusional elect d/c's → 2º brain injury
- Preclinical rat MCA occlusion stroke → NCSz → ↑ infarct & mortality
- Preclinical rat pilocarpine-induced NCSE → Long-term motor & behav deficits
- Hemorrhagic stroke + NCSz → ↑ ML shift (28% incidence)

Mitchell '02: Pediatric SE paper cited similar reasons to argue for treating NCSE

NCSE: Delayed Dx & Duration - Independent predictors of worse outcome Shneker 03

- Duration:  
  - <10hrs (10% death)  
  - >20hrs (85%)  
- Delay in Dx:  
  - <30min (36% death)  
  - >24hrs (75%)  
- Etiology: Epilepsy related (3%) & Cryptogenic (18%)  
  - Acute Symp (27% death)

In contrast, Aggressive Rx often required in critically ill to stop NCSz

- Potentially harmful → Ongoing controversy → “Rx or No Rx?”
S.E.: >5min (1) continuous clinical and/or electrographic Sz activity (2) recurrent Sz activity w/out recovery (baseline) between Sz

S.E. Treatment: Should occur rapidly & continue sequentially until electrographic Sz are halted

cEEG is usually required for treatment of S.E.

cEEG should be initiated <1hr S.E. onset:
  - If ongoing Sz suspected

Duration of cEEG monitoring: 48hrs in comatose
Treatment of Recurrent Electrographic Nonconvulsive Seizures (TRENdS) Study

Aatif M. Husain

Department of Medicine (Neurology), Duke University Medical Center and Neurodiagnostic Center, Veterans Affairs Medical Center, Durham, North Carolina, U.S.A.

SUMMARY

Nonconvulsive seizures (NCS) and nonconvulsive status epilepticus (NCSE) are electrographic seizures (ESz) that are not associated with overt clinical seizure activity. NCS are distinct ESz, whereas NCSE has ongoing, continuous electrographic seizure activity. Both are common in critically ill patients admitted to hospital intensive care units (ICUs), and studies have shown that about 20% of ICU patients undergoing continuous electroencephalography (cEEG) monitoring will have NCS/NCSE. Although the treatment for convulsive SE is well established, there is no clear consensus for the treatment of NCS/NCSE. Antiepileptic drugs (AEDs), such as phenytoin (PHT) and fosphenytoin (fPHT), used in convulsive SE are also used to treat NCS/NCSE despite lack of data for their appropriateness for these conditions. Recent studies have shown that very aggressive treatment of NCSs/NCSE can lead to worse outcomes because the AEDs used can have significant adverse effects. Recently, several intravenous (IV) AEDs have become available for substitution therapy when their oral use is not possible. There are retrospective case reports and case series that suggest that these AEDs may be beneficial for treatment of NCS/NCSE. The Treatment of Recurrent Electrographic Nonconvulsive Seizures (TRENdS) Study will compare the efficacy and tolerability of fPHT and lacosamide in patients having NCS as noted by cEEG monitoring. The study is currently open to recruitment and has 13 sites in the United States. A total of 200 subjects will be randomized, 100 to each treatment arm.

KEY WORDS: Nonconvulsive seizures, Electrographic seizures, Continuous EEG monitoring, Fosphenytoin, Lacosamide.
ACNS GUIDELINES

- Critical Care EEG Terminology
  - Adult: J Clin Neurophys Volume 30, Number 1, 2013
  - Neonate: Volume 30, Number 2, 2013

- cEEG Monitoring Guidelines
  - Neonate
  - Pending: Children & Adult

*Update cEEG monitoring PICU / NICU
  J Clin Neurophys Volume 30, Number 2, 2013
ADDITIONAL ICU EEG ISSUES

- Ictal-Interictal Continuum
  - Nomenclature, Significance

- EEG background / prognosis
  - Guide for real-time Mgmt

- Quantitative EEG / Persyst / Trending
  - Efficient Sz identification
  - Identification of interval interictal background chgs
THANK YOU!
Long-term EEG monitoring in the early premature: developmental and chronobiological aspects

B. Van Sweden a, M. Koenderink a, G. Windau a, M. Van de Bor b, F. Van Bel b, J.G. Van Dijk a and A. Wauquier a

a Dept. of Clinical Neurophysiology and b Dept. of Neonatology, Leiden University Medical Center, Leiden (The Netherlands)

(Accepted for publication: 16 November 1990)

Summary Long-term cassette EEG monitoring in the neonatal intensive care unit has established prognostic criteria regarding the developmental outcome by quantifying seizure activity. The clinical significance of the organization of continuous and discontinuous EEG patterns in the early premature is still an open question. This report presents quantified EEG data from repeated 24 h records during the first week of life in premature infants (conceptional age < 32 weeks) with and without ultrasound evidence of intracerebral hemorrhage. The repartition and evolution of EEG background activity is not a reliable parameter regarding pathology. The continuity index is rather a maturational variable and its ultradian fluctuation is an early expression of the “basic rest activity cycle” (BRAC) rhythm.

Keywords: Long-term EEG monitoring; Continuous/discontinuous EEG patterns; Early prematures; Cerebral maturation; BRAC rhythm