Guidelines for Neonatal and Pediatric EEG Monitoring

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Disclosures

- **No conflicts of interest?**
  - I am a neurologist.
    - I read EEGs for a living.
  - I am not a neonatologist.
    - I rarely read amplitude-integrated EEGs.

- I am grateful to NICHD, Child Neurology Foundation, and Janette Ferrantino Award for funding my research.

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Goals/Objectives

- Identify indications for EEG monitoring among high-risk neonates [and children].
- Discuss relative strengths and weaknesses of conventional EEG monitoring versus amplitude-integrated EEG (aEEG).
- Review preferred methods for neonatal [and pediatric] ICU EEG monitoring.

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Caveats…

- There is no evidence that EEG monitoring, seizure detection, or treatment of seizures, impacts long-term outcome.

– Consensus: Dx & Rx of seizures is important.

– Any EEG recording is better than none.
  - Delayed seizure detection is better than no recognition.

– Transport (solely) for conventional EEG monitoring may be detrimental to some patients.
  - Not currently a standard of care.

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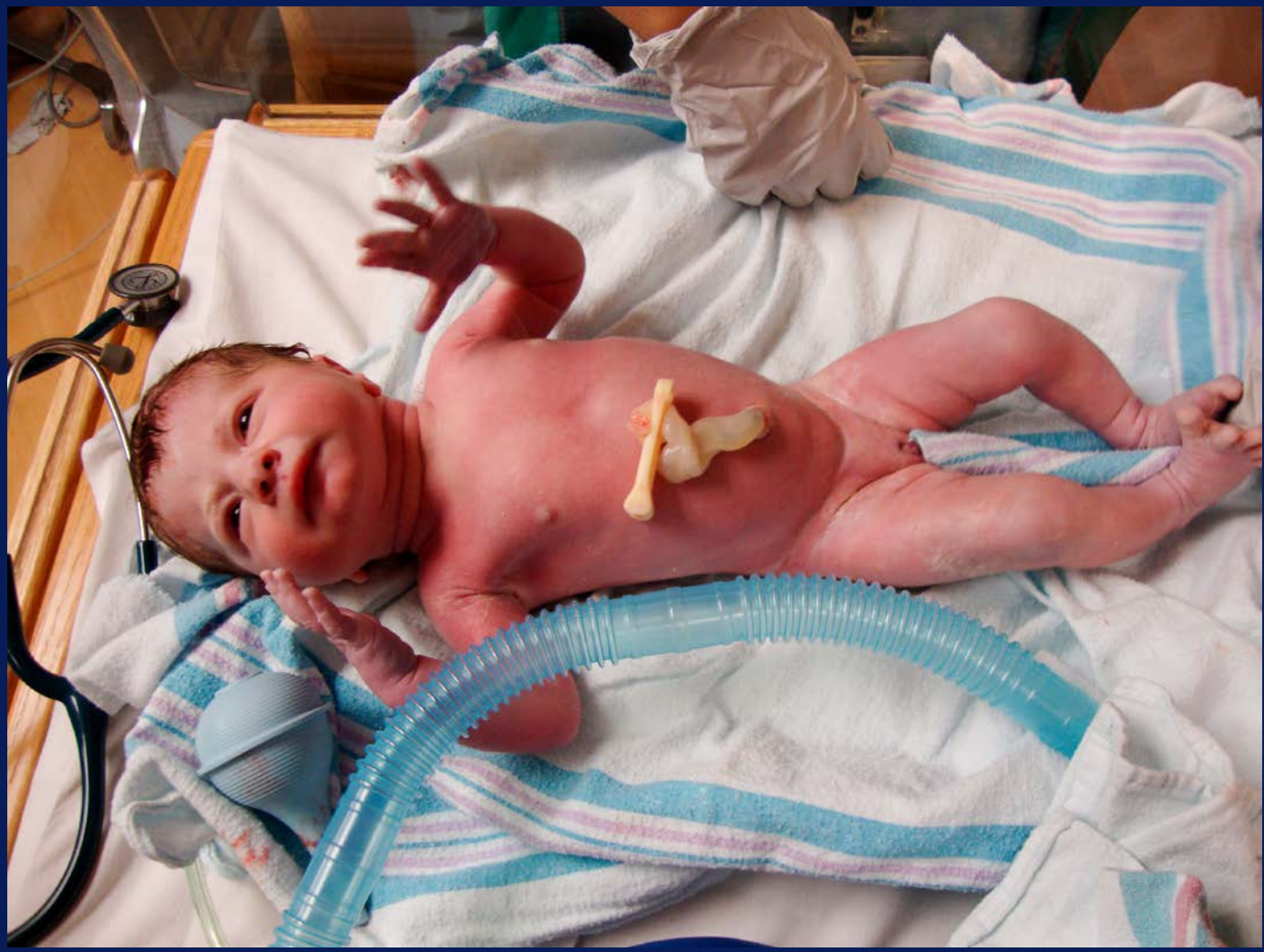
Neonatal ICU Monitoring



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Shellhaas, et al. ACNS Guideline. J Clin Neurophysiol. 2011 28(6):611-617.

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Indications for EEG monitoring

1. **High risk for seizures**
2. **Differential diagnosis of paroxysmal events**
3. **Monitoring during/after anticonvulsant wean**
4. Monitoring pharmacologically-induced burst suppression

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Indications: Seizure Detection

- **Sick babies often have unusual movements.**
  - Most of these are not seizures.
- **>50% of all neonatal seizures are subclinical.**
  - Only detectable with EEG monitoring
- **Electroclinical dissociation / uncoupling:**
  - With treatment, clinical signs may vanish while subclinical electrographic seizures continue.

Clancy, et al. Epilepsia. 1988; 29:256-261.
Scher, et al. Pediatrics. 1993;91:128-134.
Scher, et al. Pediatric Neurol. 2003;28:277-280.

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Seizures and Prognosis

- Babies with neonatal seizures are at high risk for death or neurologic morbidity.
  - Mortality: 25-40% (may be higher in preterm)
  - Developmental delay: 67% @ 2-3 yrs
  - Cerebral palsy: 63% @ 2-3 yrs
  - Post-neonatal epilepsy: 17-56%

McBride, Neurology 2000;55:506-514.
Mizrahi, Epilepsia 2001;42(S7):102.
Legido, Pediatrics 1991; 88:583-596.
Scher, Pediatr Neurol 1989; 5:17-24
Scher, Pediatrics 1993; 91:128-134.

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Clinical vs. electrographic seizures

- **Video-EEG monitoring of high-risk infants.**
  - 9% of electrographic seizures (48/526) had clinical signs recognized and documented by NICU staff.
  - 27% of seizures which did have clinical signs (48/179) were recognized and recorded.
  - 73% of "seizures" documented by NICU staff had no electrographic correlate (129/177).

Murray, et al. Arch Dis Child Fetal Neonatal Ed. 2008;93:F187-F191.

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The literature…read the fine print

- Many studies talk about "seizures" but don't tell us if they are clinical or electrographic (aEEG or cEEG).
  - Older studies usually mean *clinical* seizures…less applicable now that we know most seizures are subclinical.

– ***When I say "seizure", I mean EEG seizure.***

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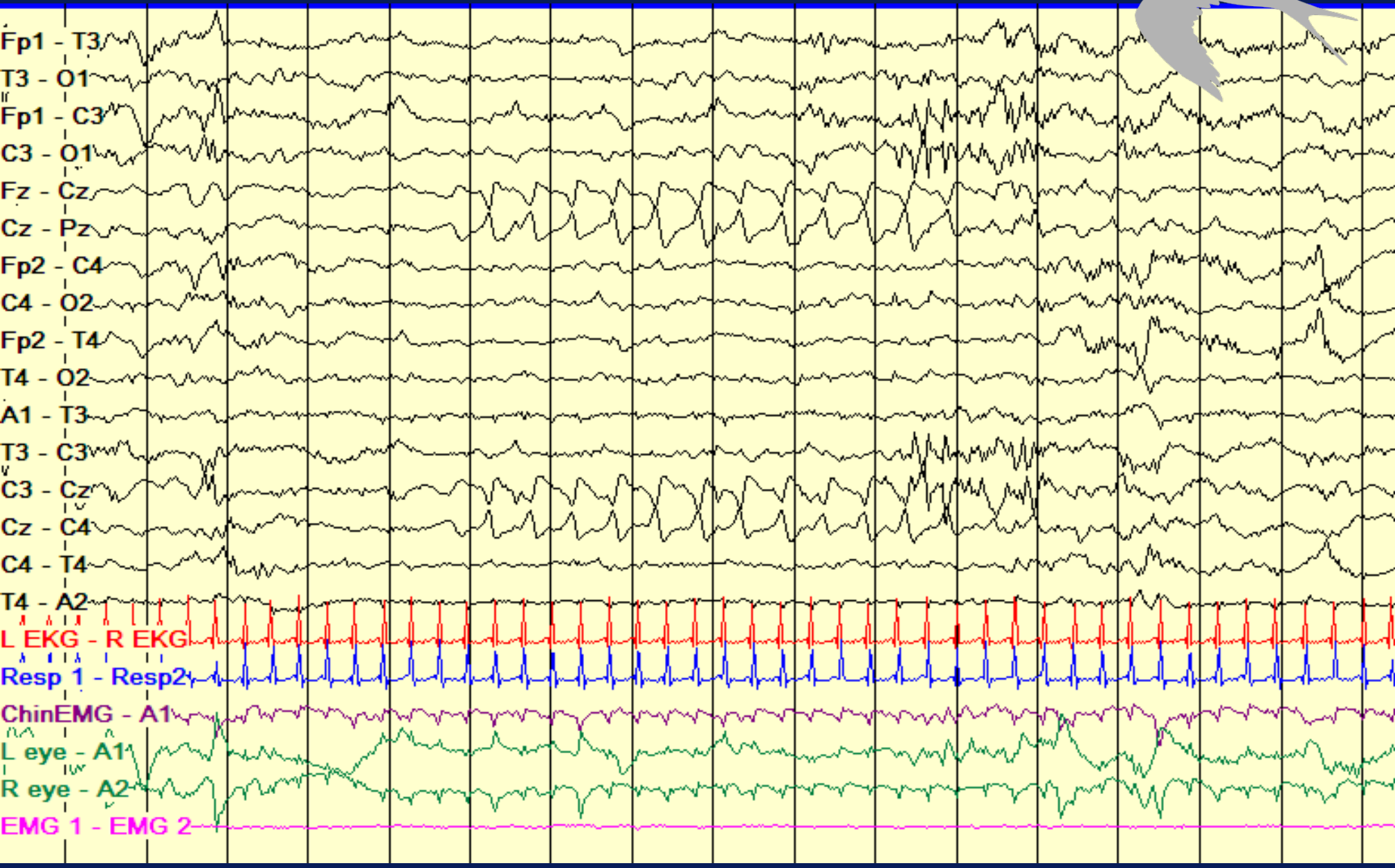
BIRDs and Seizures

- **BIRD =** Brief Intermittent Rhythmic Discharge
  - <10 seconds
  - High risk for seizures

- **Seizure** = sudden, repetitive, evolving and stereotyped ictal pattern with a clear beginning, middle, and ending, an amplitude of at least 2μV, and a minimum duration of 10 seconds

BIRD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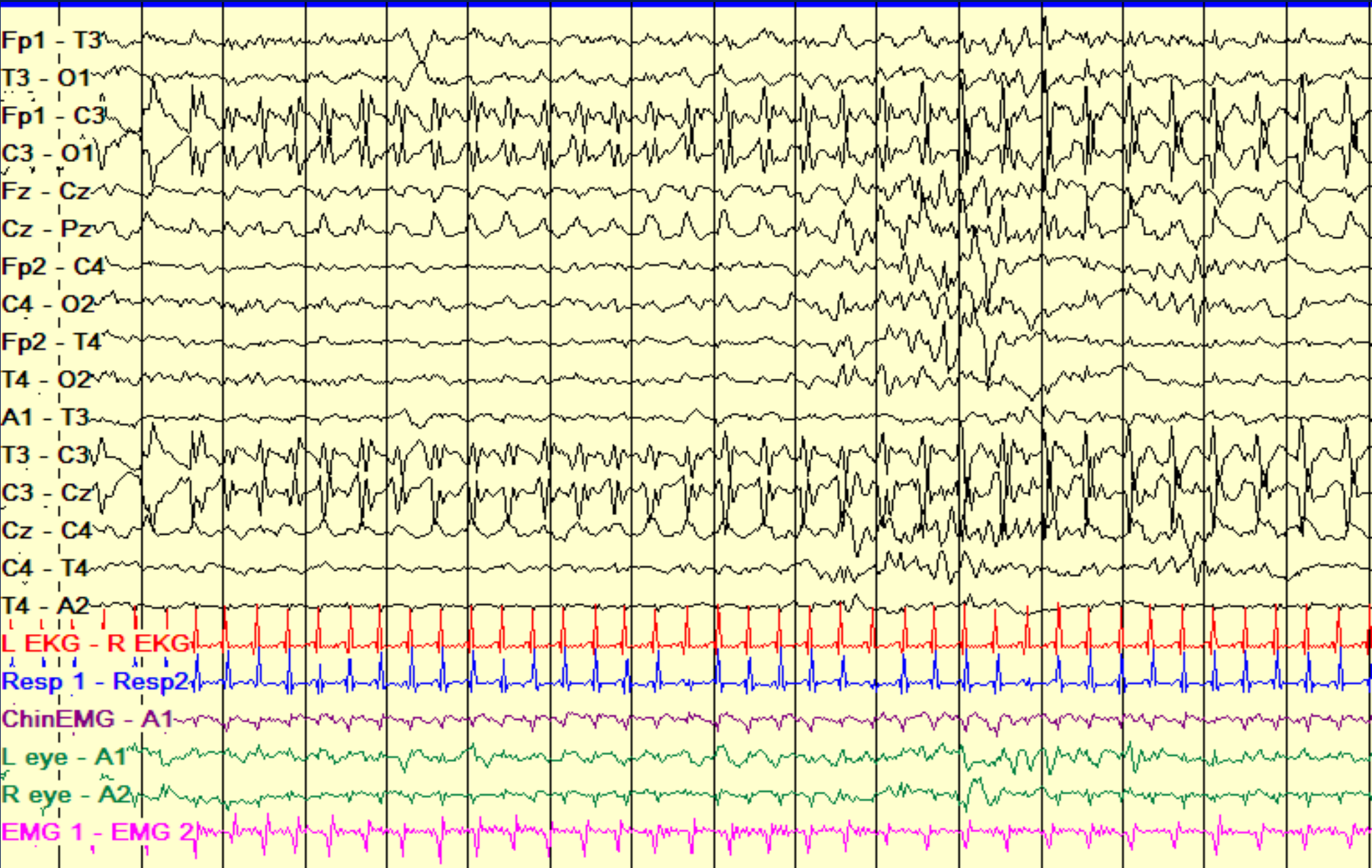
T3 - O1
Fp1 - C3
C3 - O1
Fz - Cz
Cz - Pz
Fp2 - C4
C4 - O2
Fp2 - T4
T4 - O2
A1 - T3
T3 - C3
C3 - Cz
Cz - C4
C4 - T4
T4 - A2
L EKG - R EKG
Resp 1 - Resp2
ChinEMG - A1
L eye - A1
R eye - A2
EMG 1 - EMG 2

SEIZURE


Fp1 - T3
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Fz - Cz
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Fp2 - C4
C4 - O2
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A1 - T3
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Resp 1 - Resp2
ChinEMG - A1
L eye - A1
R eye - A2
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High risk for seizures

High risk of acute brain injury	Demonstrated acute acquired brain injury	Clinically suspected seizures
Prolonged circulatory arrest	Arterial ischemic stroke	Focal clonic or tonic movements
Hypoxic-ischemic encephalopathy	Cerebral sinovenous thrombosis	Eye blinking, gaze-deviation
Infants with sustained hypoxia	Intracranial hemorrhage	Unexplained apnea
Pharmacologically-induced paralysis	Encephalitis	Myoclonus
Head trauma with altered mental status	Cerebral edema due to inborn errors of metabolism	Bicycling

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Indications: Differential diagnosis

Clinically suspected seizures
Focal clonic or tonic movements
Eye blinking, gaze-deviation
Unexplained apnea
Myoclonus
Bicycling
Unexplained altered mental status

- **Most abnormal neonatal movements have no electrographic correlate.**
- **Neonates don't have generalized tonic-clonic seizures!**
- **Heart rate changes during seizures are not consistent.**
- **Isolated changes in vital signs are <u>rarely</u> due to seizures.**

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Indications: During/after anticonvulsant drugs are weaned

- Depends on seizure etiology
  - Lissencephaly vs. HIE
- How hard were the seizures to control?
- How many meds are you giving?
- What are your goals?

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Indications: Burst suppression

- Refractory status-epilepticus:
  - Titrate medication to optimize burst/interburst ratios.
- Severe metabolic encephalopathy:
  - e.g. Discontinuity improves as hyperammonemia is corrected

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Indications: Prognosis

- **Evaluating EEG background:**
  - Evolution of background patterns in neonatal encephalopathies

- **<u>Serial</u> routine EEGs may be sufficient.**
  - Sufficient duration to capture both wakefulness and sleep, if such state changes exist

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Background Classification

- **<u>Mildly abnormal</u>:**
  - Mild excess discontinuity
  - Mild simplification of mixture of frequencies
  - Mild focal abnormalities (like excess sharp transients or focal voltage attenuation)

- **Prognosis is good!**

  - Remember context... Ex: Babies with Down syndrome can often have normal neonatal EEG but can be expected to have abnormal developmental outcome.

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Background Classification

- **<u>Moderately Abnormal</u>**
  - Moderately excessive discontinuity
  - Moderately excessive asynchrony
  - Poverty of expected background rhythms
  - Definite focal abnormalities
  - Persistent low voltage (<25μV)

- **Some do well, others do poorly.**

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Background Classification

- **<u>Markedly abnormal</u>:**
  - Markedly excessive discontinuity (can have some preservation of age-appropriate background patterns)
  - Burst suppression
  - Gross interhemispheric asynchrony
  - Extreme low voltage (<5μV)
  - Depressed and undifferentiated
  - Isoelectric

- **Prognosis is poor.**

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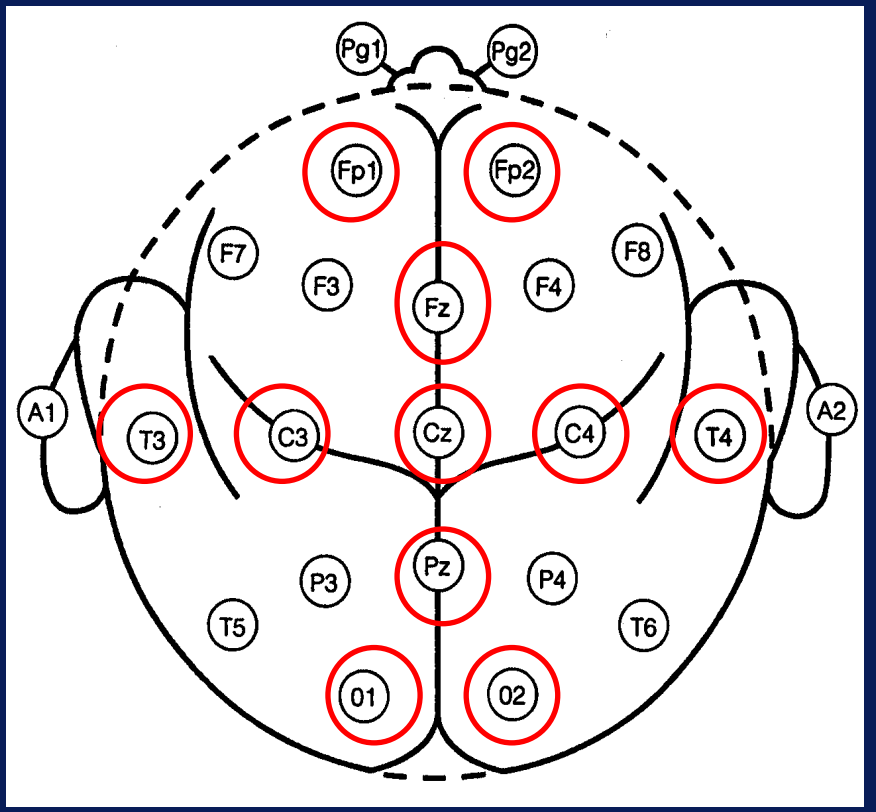
Neonatal EEG: Technical Aspects

- **International 10-20 system**
  - Modified for neonates*
  - Minimum 9 scalp electrodes
- **EKG**
- **Respiratory channel**
- **Eye leads**
- **EMG lead**



*Not all laboratories utilize the Pz electrode. Alternate terminology designates "FP" electrodes as "AF", and $T_{3/4}$ as $T_{7/8}$.

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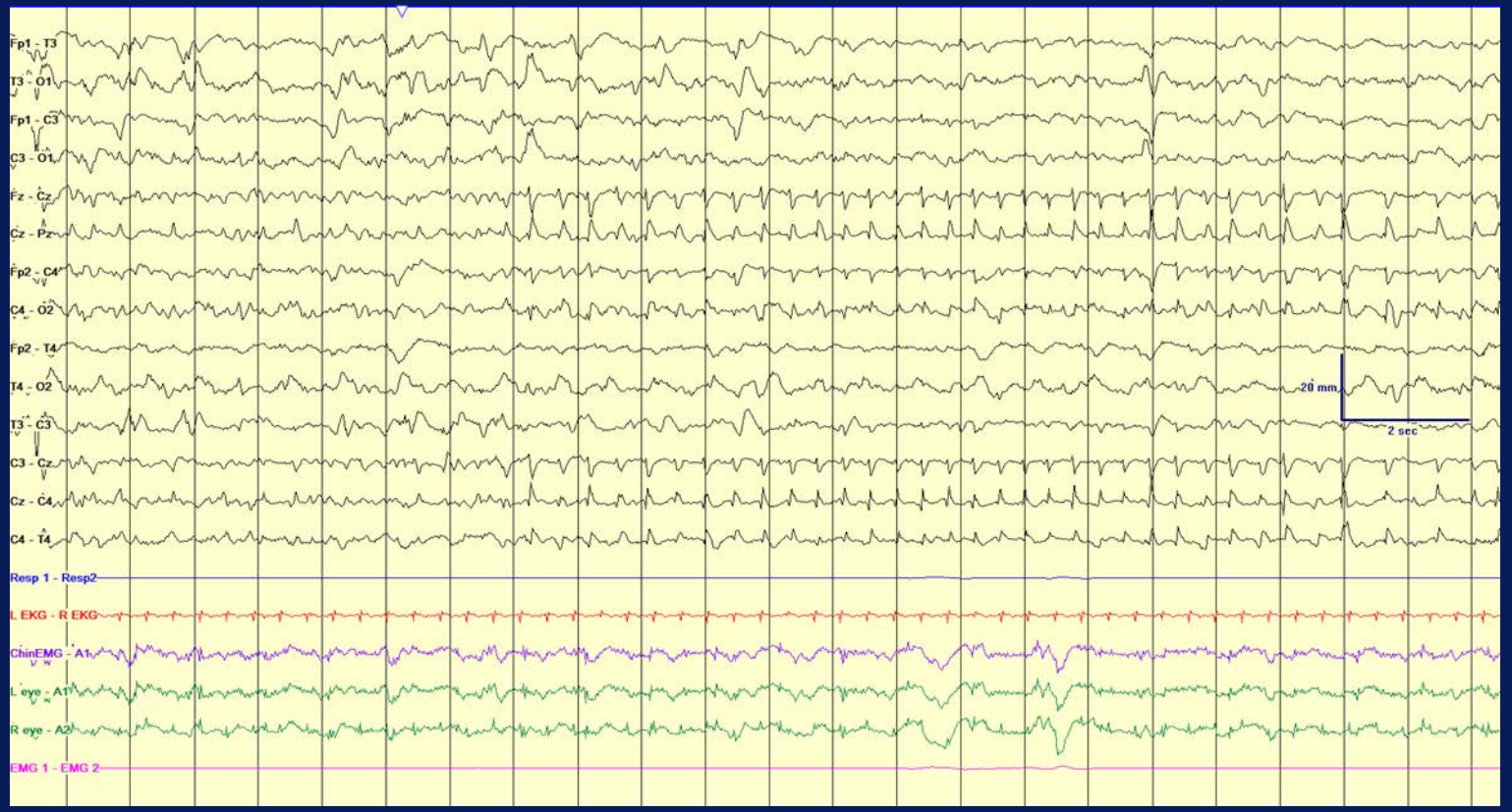
Technical Aspects: Neonatal Montages

- Combined double- and single-distance electrodes



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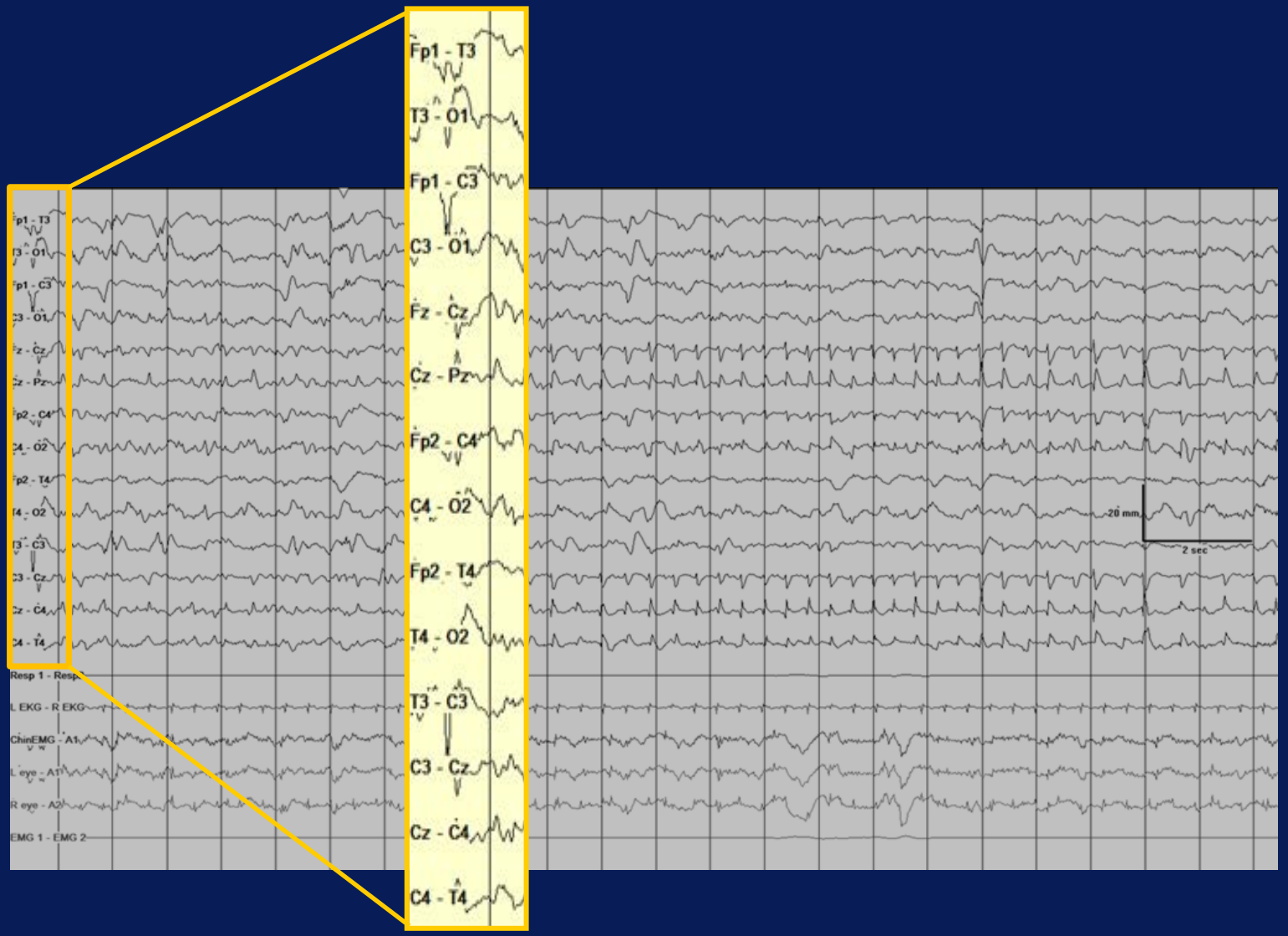
Technical Aspects:
Neonatal Montages



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Technical Aspects: Event marker

- **<u>Event button</u> to be pressed for:**
  - clinical episodes
  - relevant medication administration
  - events that could cause cerebral injury
  - Need the <u>bedside observer</u> to **PTFB!!!!**
  - **When you push the button SAY OUT LOUD why you are doing so.**
    - **"Look! His left pinky finger twitched."**
    - **"I'm giving the phenobarb bolus now."**

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Technical Aspects:
Bedside log

- **<u>Bedside log</u> to document the time and description of event(s).**
  - –Or direct annotation on video EEG record
    - Type into computer

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Duration of Recording: SCREENING for Seizures

- **<u>A routine EEG is inadequate to screen for neonatal seizures.</u>**
  - Normal EEG background does not preclude seizures.

- **Scenarios for routine EEG exams:**
  1. The baby is having seizures → need EEG monitoring
  2. We didn't capture an event → need EEG monitoring
  3. EEG background looks terrible → need EEG monitoring
  4. Background looks ok but baby doesn't → need EEG monitoring
  5. See the pattern?

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Duration of Recording: SCREENING for Seizures

- ***Recommend* a minimum of 24 hours.**
  - Skip the routine EEG.
  - If no seizures and EEG background is stable, stop after 24 hours of monitoring.
  - Mean time to seizures:
    - Neonatal cardiac surgery: 21 hrs (range 10-36 hrs)
    - HIE with hypothermia: 9.5 hrs (range 5.5-98 hrs).
    - Heterogeneous high-risk neonates: Always ≤22 hrs.

Clancy et al, Epilepsia. 2005;46:84-90.
Laroia et al, Epilepsia. 1998;39:545-51.
Wusthoff et al, J Child Neuro. 2011;26:724-728.

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Duration of Recording: CONFIRMED Seizures

- ***Recommend* conventional EEG monitoring until 24-hrs seizure-free.**
  - Unless, in consultation with a neurologist, the decision is made to stop sooner.
  - Almost no data…

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Duration of Recording: Differential Diagnosis of Events

- **R*ecommend* continuing EEG monitoring until multiple typical events are recorded.**
  - If 3-4 typical events are captured, and are not seizures, and the EEG background remains normal or stable, then monitoring may be discontinued.

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EEG Interpretation & Reporting

- **Interpretation by technologists / nurses:**
  - Tech to remain at bedside for 1st 1-hr epoch
  - Tech and nurses to periodically assess EEG quality
- **Interpretation by clinical neurophysiologist:**
  - First hour of EEG should be interpreted ASAP.
  - EEG should be reviewed at least twice per 24-hour epoch.
- **Reporting results:**
  - At least daily
  - Verbal and written communication are required.
  - *This recommendation applies to both conventional AND reduced montage EEG.*

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What about aEEG?

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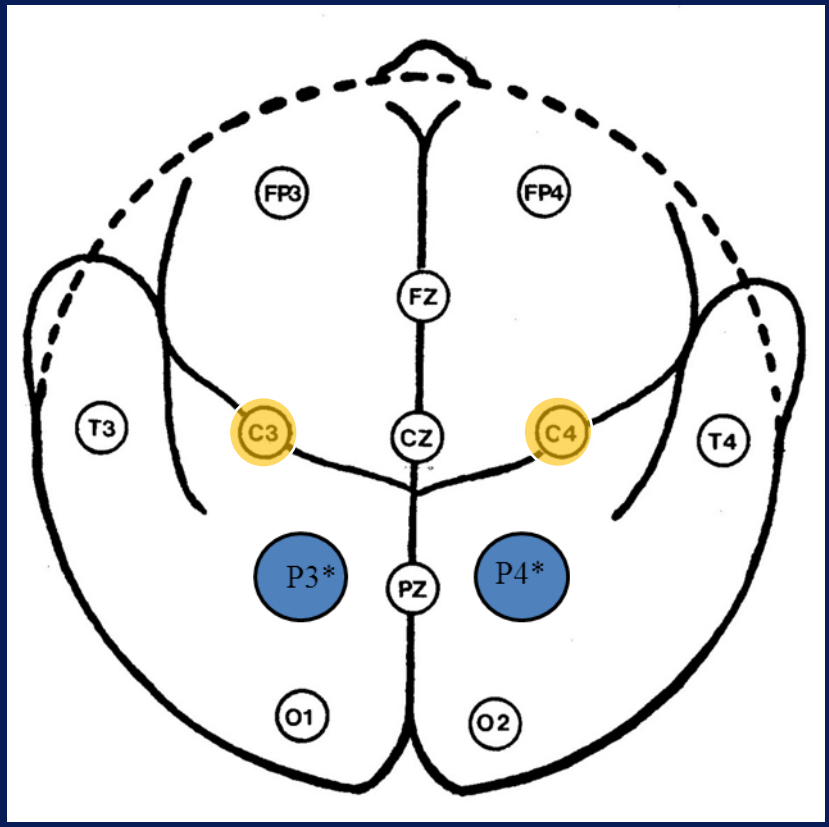
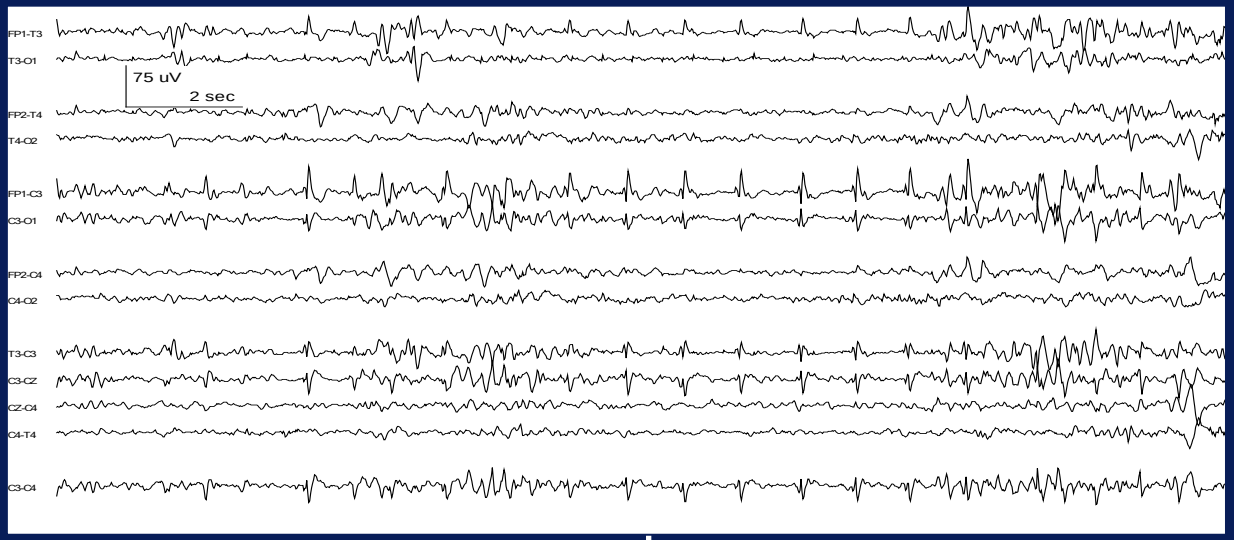
Amplitude-Integrated EEG (aEEG)

- Single channel from biparietal electrodes.
  - over watershed zone
  - many now use 2 aEEG channels plus "raw" EEG
- Leads applied by nurse or neonatologist.
- Interpreted by neonatologists.
- Short- or long-term monitoring.
- Easy to visually track trends.



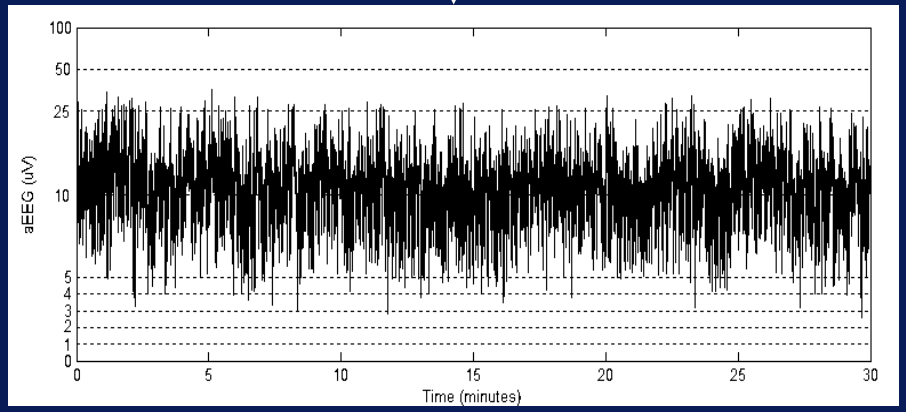
Standard neonatal EEG



Single channel raw EEG

Filter <2Hz and >15Hz, rectify, smooth, amplitude-integrate

Amplitude Integrated EEG (aEEG)



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aEEG monitoring: HIE

- **Predicting outcome after HIE:**
  - Early aEEG background
  - Sleep-wake cycling
- **Hypothermia modifies aEEG background:**
  - Normalize by 48 hours → good outcome
    - 24 hours for normothermia
  - Lack of sleep-wake cycling = poor prognosis

al Naqeeb. Pediatrics 1999;103:1263-71.
Shalak. Pediatrics 2003;111:351-7.
Toet. Arch Dis Child Fetal Neonatal Ed 1999;81:19-23.
Thoresen. Pediatrics. 2010:126;e131-e139.

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aEEG monitoring: preterm infants

- **Outcome Prediction**
  - Excessive discontinuity (lower margin amplitude)
  - Lack of sleep-wake cycling
    - predicts adverse outcome for Grade III-IV IVH.
    - < 29 weeks: excess discontinuity and absence of sleep-wake → poor short term prognosis.

- **Abrupt changes in aEEG background can correlate with new pathology.**

Bowen. Pediatric Research. 2010; 67(5):538-44.
Hellström-Westas. Neuropediatrics. 2001; 32(6):319-24.
Niemarkt . Neonatology. 2010; 97(2):175-82.
Olischar. Childs Nerv Syst. 2001; 20(1):41-5.

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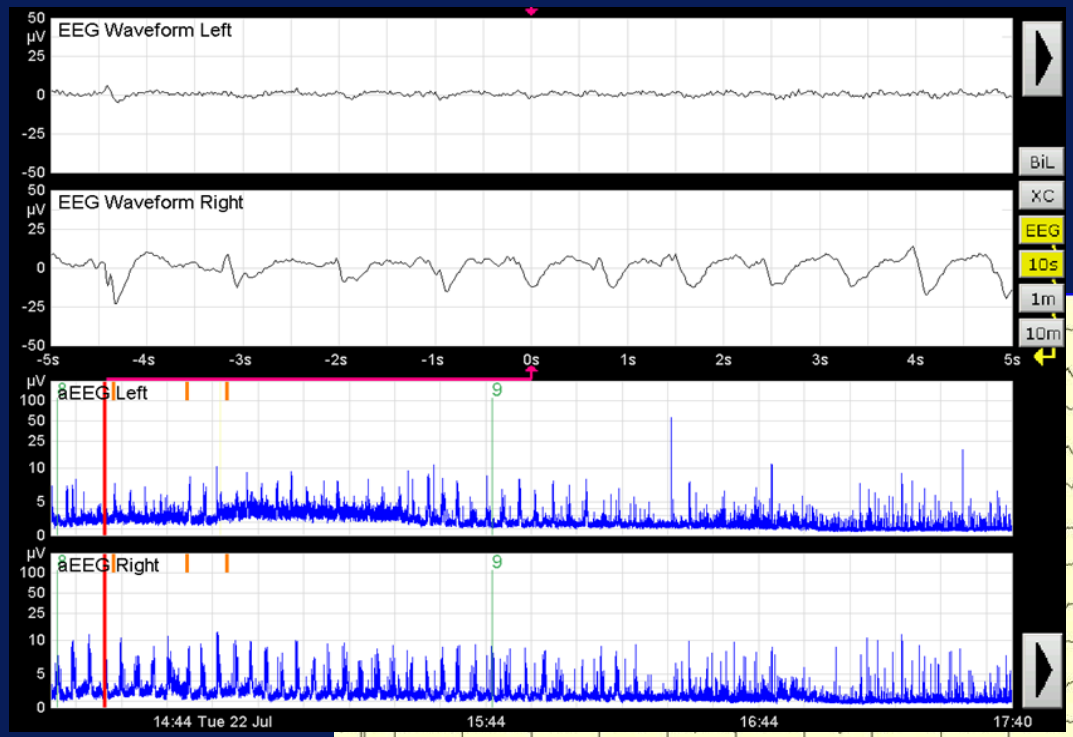
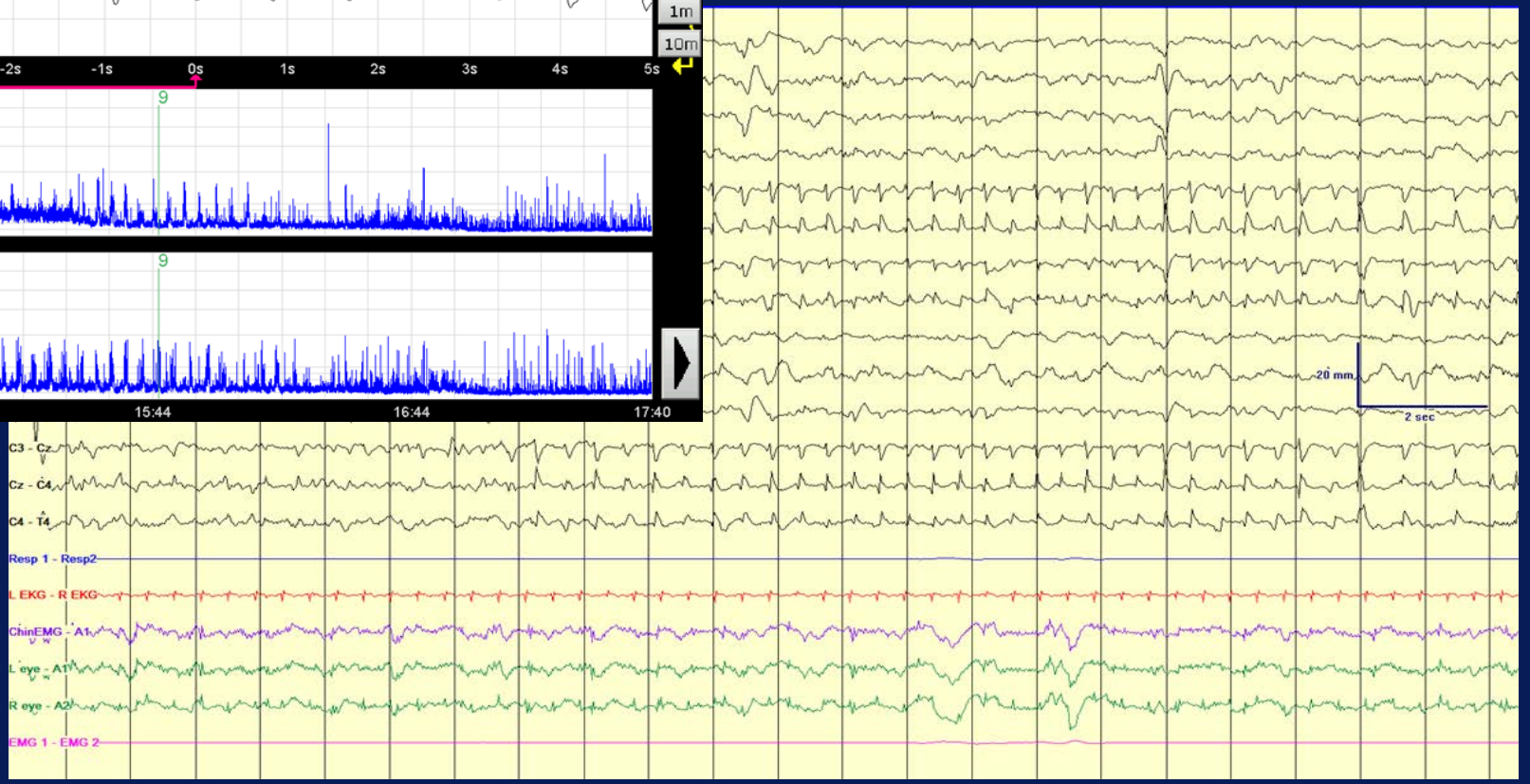
What about aEEG for seizures?





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The literature…read the fine print

- Distinguish between "seizure positive" aEEG or EEG records and individual seizure detection.
  - 8 of 10 *patients* correctly identified as having seizures versus 8 of 10 *individual seizures* correctly detected.

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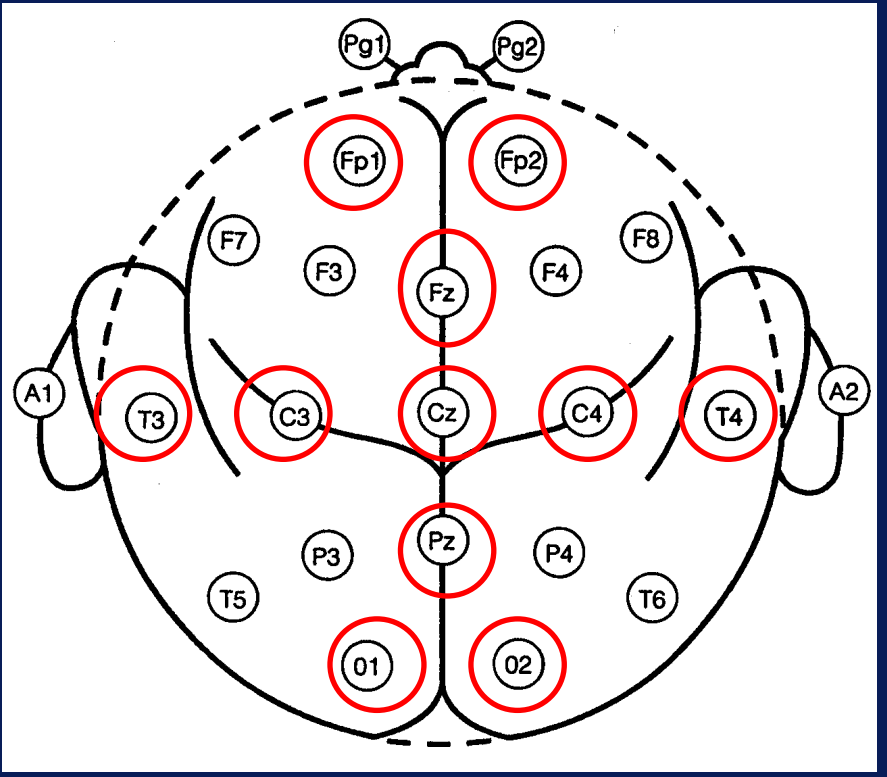
EEG: the Gold Standard

- Conventional Neonatal EEG is the gold standard for the diagnosis and quantification of neonatal seizures and for assessment of EEG background



10-20 system, modified for neonates

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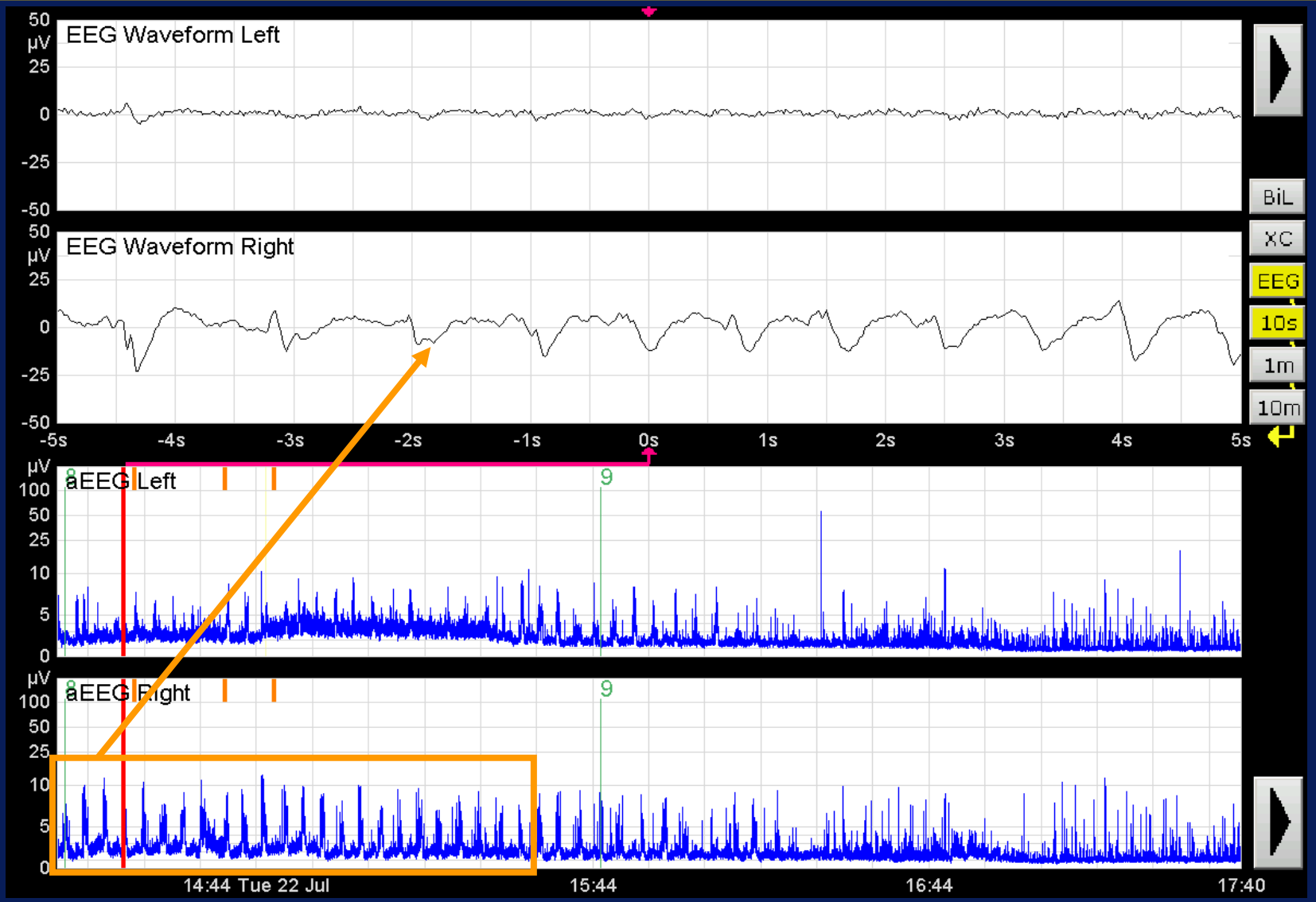
aEEG often used to screen for seizures



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Seizures on aEEG

- **125 routine EEGs with seizures (+19 without), recorded from 140 term newborns.**
- **Created single-channel aEEG traces.**
  - Interpreted by 6 neonatologists with varying expertise.

% of 125 aEEG ***records*** with seizures detected	% of 851 ***individual seizures*** detected
Mean = 40.3% ± 16.8% (range: 22-57%)	Mean = 25.5% ± 10.6% (range: 12-38%)

* No false positive records; very few false positive individual seizures.

Shellhaas, et al. Pediatrics. 2007;120:770-777.

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Seizures on aEEG

- Factors related to seizure detection by aEEG (multivariate analysis*):
  - Neonatologists' level of experience with aEEG
  - Visibility in C3→C4 raw EEG channel
  - Seizure duration
  - Peak-to-peak amplitude
  - Seizure count per hour

*P=<0.001 for all variables

Inherent features of neonatal seizures (short duration & low amplitude) make detection by aEEG very difficult.

Shellhaas, et al. Pediatrics. 2007;120:770-777.

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Adding "raw" EEG

- Simultaneously recorded single and dual channel aEEG with conventional EEG in 7 neonates with seizures.
  - Readers: two *experienced* neonatologists
  - Using both two-channel aEEG and the raw tracings, sensitivity = 76%
  - Using just aEEG, sensitivity = 27%-56%
  - 1 false-positive per 39 hours of recording

Shah, et al. Pediatrics. 2008;121:1146-1154.

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Confirming aEEG findings

- **Brief, infrequent, low amplitude seizures are hardest to detect on aEEG.**
  - If you see a seizure, you're probably right.
  - If you don't see seizures… doesn't mean they aren't there.
  - Don't declare victory based on aEEG.

- **Suspect seizures on aEEG → conventional EEG.**
  - Confirm diagnosis
  - Direct treatment

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Concurrent EEG and aEEG:
Best of both worlds?

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Summary: Neonatal EEG monitoring

- Neonatal EEG (cEEG and aEEG) background assessments can assist with estimating prognosis.
- EEG monitoring is the standard for neonatal seizure diagnosis and assessment of treatment response.
- Use aEEG when don't have EEG.
- Document!

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Pediatric ICU EEG monitoring

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Indications for EEG monitoring

1. **High risk for seizures**
2. **Differential diagnosis of paroxysmal events**
3. **Monitoring pharmacologically-induced burst suppression**

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PICU Monitoring:
High risk for seizures

- Age < 1(or 2) year(s)
- Convulsive seizure or status epilepticus
  - ± history of epilepsy
- Acute brain injury
  - Focal (stroke) or diffuse (HIE)
  - Traumatic brain injury

with altered mental status

Other high risk clinical scenarios:

- Ex: Need for pharmacologic paralysis
  + prior seizures / acute brain injury

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PICU Monitoring: High risk for seizures

- High-risk EEG features:
  - Lack of reactivity
  - Epileptiform abnormalities

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PICU Monitoring: Differential diagnosis

- Non-seizure paroxysmal events are common.
  - ~25% of unselected sample of ICU EEG monitoring studies had non-epileptic events.

    Williams. Epilepsia. 2011;52:1130-1136.

- Accurate identification matters
  - Avoid unnecessary medications (+ side effects)

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PICU Monitoring: Iatrogenic Burst Suppression

- Children requiring pharmacologically-induced burst suppression need continued EEG monitoring.
  - Evaluate for break-through seizures
  - Ensure appropriate medication titration

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PICU Monitoring: Duration

- 24 hours screening for non-convulsive (or subclinical) seizures:
  - ~95% of children with non-convulsive seizures will be detected with 24 hours of EEG.

    Abend. Neurology. 2011.
  - 100% of those with *only* non-convulsive seizures (no clinically-apparent seizures) detected in 24 hours .

    McCoy. Epilepsia. 2011.
- Or until events of interest are recorded and determined not to be seizures.
  - And EEG background stable or normal.

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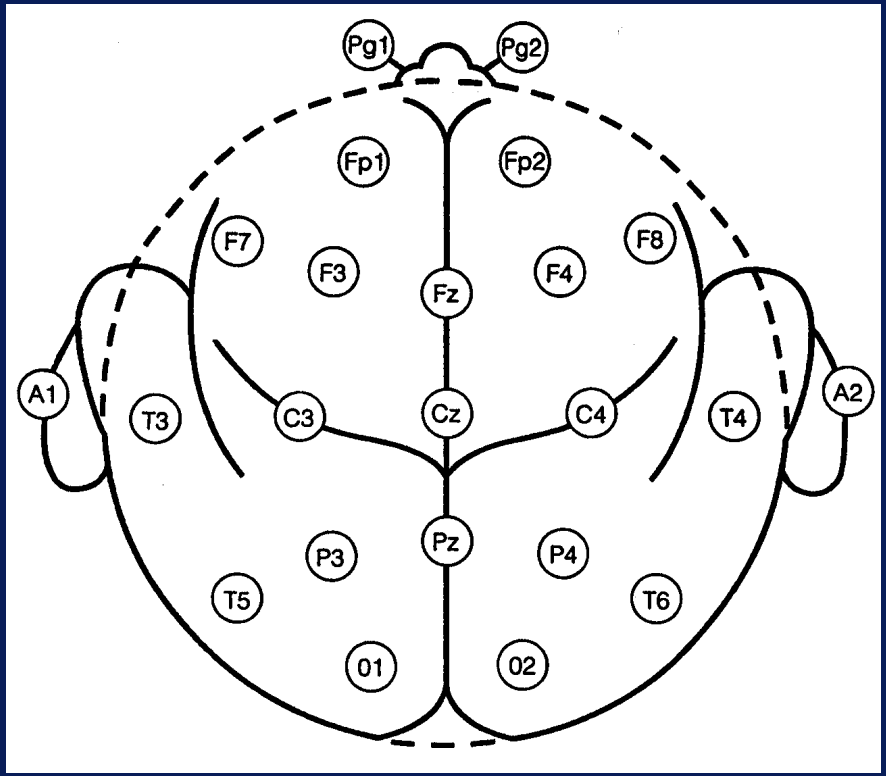
PICU Monitoring:
Technical aspects



Also EKG; others as needed.

See neonatal EEG guidelines re: review, reporting...

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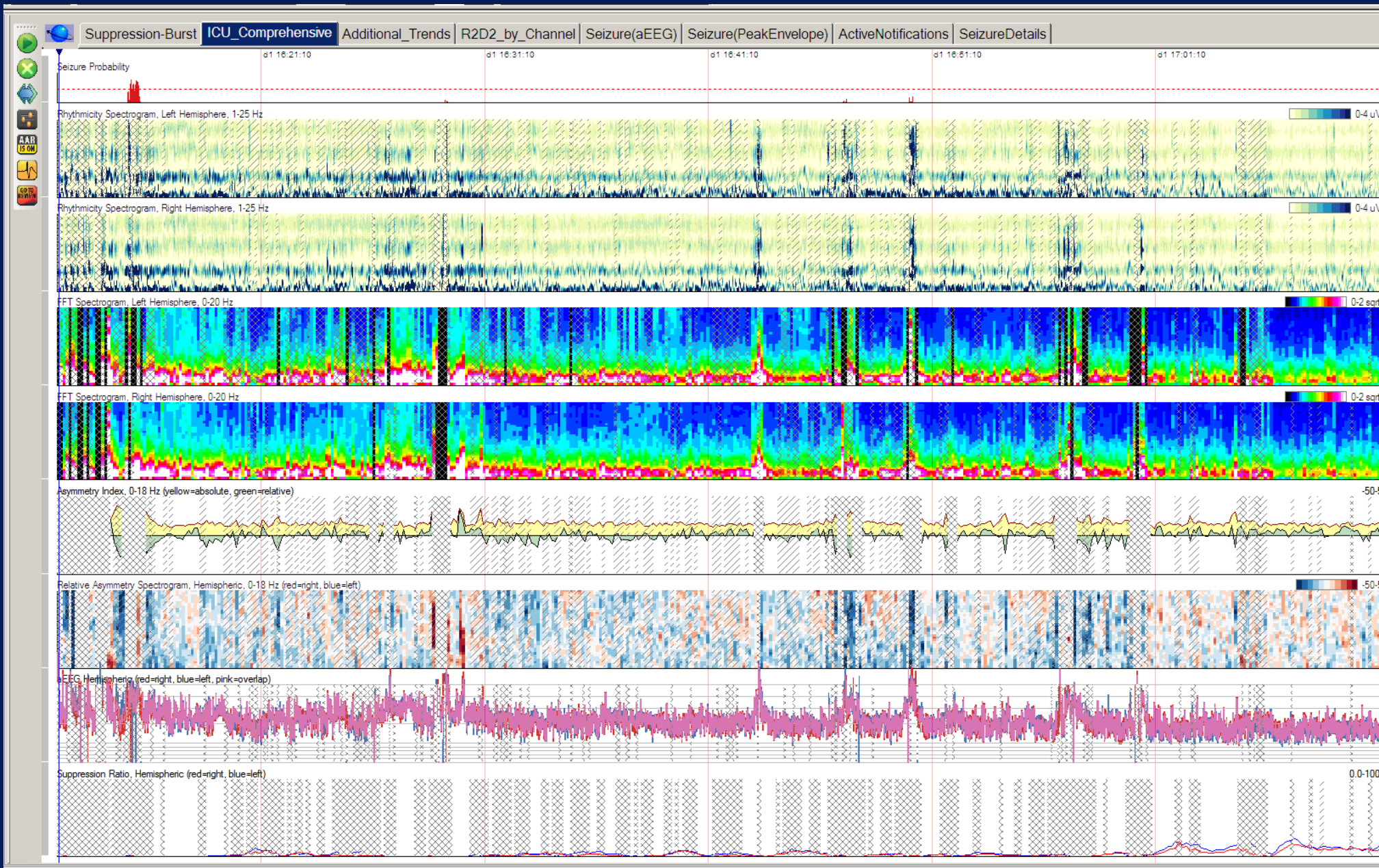
Digital Trending

- Compressed display
- Highlight epochs of concern
- Facilitate timely EEG review

- Need more study!


Suppression-Burst
ICU_Comprehensive
Additional_Trends
R2D2_by_Channel
Seizure(aEEG)
Seizure(PeakEnvelope)
ActiveNotifications
SeizureDetails
d1 16:21:10
d1 16:31:10
d1 16:41:10
d1 16:51:10
d1 17:01:10
Seizure Probability
Rhythmicity Spectrogram, Left Hemisphere, 1-25 Hz
Rhythmicity Spectrogram, Right Hemisphere, 1-25 Hz
FFT Spectrogram, Left Hemisphere, 0-20 Hz
FFT Spectrogram, Right Hemisphere, 0-20 Hz
Asymmetry Index, 0-18 Hz (yellow=absolute, green=relative)
Relative Asymmetry Spectrogram, Hemispheric, 0-18 Hz (red=right, blue=left)
aEEG Hemispheric (red=right, blue=left, pink=overlap)
Suppression Ratio, Hemispheric (red=right, blue=left)

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Conclusions

- Subclinical seizures are common among neonates and children in ICUs.
  - Can only be diagnosed with EEG.

- EEG monitoring is gold standard for seizure diagnosis and quantification.
  - Digital trending might help.
- Refer to ACNS guidelines for neonates.
- Stay tuned for ACNS pediatric & adult guidelines.