Neonatal & Pediatric EEG

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Neonatal EEG: Background

• Neurological examination in neonate: limitation for prediction of neurological outcome

• Objective methods of measuring the functional integrity of the immature cortex and its connection, the impact of known neurological insult, and detection of neonatal seizure

• Neuronal maturation depending on conceptual age should be considered for correct interpretation
Neonatal EEG: Technical Aspects

- Modification of international 10-20 system
- Vertex regions
  - Positive vertex sharp transients
  - Negative vertex sharp transients
  - Seizures confined to vertex area
Neonatal EEG: Artifact

- The most troublesome for correct interpretation
- **Environmental artifacts**: NICU enablers
- Seizure–mimicking paroxysmal events
- Physiological movements
FIG. 6.3. Sucking artifact in an infant 46 weeks of conceptional age with a history of hypoxic ischemic encephalopathy (HIE) and seizures. Sucking artifact (arrow) is clearly evident over both temporal regions, the left more than the right.

FIG. 6.4. Hiccup artifact in an infant 41 weeks of conceptional age with meningitis. Typical hiccup artifacts (arrow) are present, which impart a "periodic" appearance to the record. Note the prominent movement artifact contaminating the electrocardiogram and respiratory channels, which confirms its extracebral origin.

FIG. 6.5. Eye movements artifact in an infant 40 weeks of conceptional age with Kleine-Levin syndrome and seizures. Eye movements artifact (arrow) is present throughout the electroencephalographic background.

FIG. 6.6. Electrocardiogram (ECG) artifact in an infant 40 weeks of conceptional age with Kleine-Levin syndrome and seizures. ECG artifact is present throughout the electroencephalographic background. Note the positive T3 and negative T4 dipole of the QRS complex.
HFV artifact

Electrode artifact

Seizure-mimicking event artifact

Patting artifact

Electrode artifact
Visual Analysis: Conceptual Age

- Key point of interpretation
- Determination factor of EEG maturity
- Neurological development rate: intrauterine = extrauterine
Earliest vestiges of EEG activity: 8 weeks of GA

Brief periods of electric activity (bursts)
Periods of quiescence interrupting bursts (interburst period: IBP)

Interburst interval (IBI): decreases with CNS maturity and increased influence of the deep gray structures modulating cortical function

Continuous (steady amplitude) Vs Discontinuous (burst + IBP)
Background Continuity (II)

- IBI

Semiquantative measurement: selected 10 minute-sample
Mean, median, longest IBI
Conceptual age: prime determinant

Median IBI
  - GA 24 weeks: 10 seconds
  - Term: 2–4 seconds
Correlates with survival rate, medical condition
• **Amplitude & waveform composition**

• **No universal agreement about amount of asymmetry**

• **Practical guideline – 2:1 ratio**
## Excessive Discontinuity for Conceptual Age

- **Longest acceptable single IBI** for conceptual age

<table>
<thead>
<tr>
<th>Weeks</th>
<th>IBI (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30 weeks</td>
<td>30–35s</td>
</tr>
<tr>
<td>31–33 weeks</td>
<td>20s</td>
</tr>
<tr>
<td>34–36 weeks</td>
<td>10s</td>
</tr>
<tr>
<td>37–40 weeks</td>
<td>6s</td>
</tr>
</tbody>
</table>
FIG. 6.20. Asymmetry secondary to scalp edema in an infant 41 weeks of conceptional age with tetralogy of Fallot and seizures. The infant’s head was turned to the right, and marked right scalp edema was present. The amplitude is decreased on the right side, but the background composition is similar to that of the left. The asymmetry disappeared after the scalp edema resolved.
**Background Interhemispheric Synchrony (I)**

- Temporal electrographic feature

- **Asynchrony**: time gap more than 1.5–2 seconds

- **Under 30 weeks of GA**: hypersynchrony: unknown physiology

- **31–32 weeks of GA**: 70% of synchrony

- **33–34 weeks of GA**: 80% of synchrony

- **35–36 weeks of GA**: 85% of synchrony

- **After 37 weeks**: 100% of synchrony
Background

Interhemispheric Synchrony (II)

A: 37 weeks, HIE pt
B: 46 weeks, Nonketotic hyperglycinemia
C: 27 weeks with hypersynchrony
Ontogeny Overview (I)

- Development of fetal brain: functional abilities
  - Anatomic appearance
  - Synaptic connectivity
  - Time dependent genetic expression of neurotransmitter receptor subunits

- Predictable pattern of neonatal EEG characteristics in parallel with anatomical and functional changes
### Ontogeny Overview (II)

<table>
<thead>
<tr>
<th>CA (wk)</th>
<th>Awake</th>
<th>Quiet sleep</th>
<th>Active sleep</th>
<th>Awake</th>
<th>Quiet sleep</th>
<th>Active sleep</th>
<th>EEG Difference Between Arousal and Sleep</th>
<th>Appearance and Disappearance of Specific Wave Form and Pattern</th>
<th>Reactivity to Stim.</th>
</tr>
</thead>
<tbody>
<tr>
<td>27–28</td>
<td>-</td>
<td>D</td>
<td>D</td>
<td>-</td>
<td>+++</td>
<td>+++</td>
<td>No</td>
<td>1. Temporal theta bursts</td>
<td>NR</td>
</tr>
<tr>
<td>29–30</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td>2. Beta–delta complexes in central region 3. Occipital very slow activity</td>
<td>NR</td>
</tr>
<tr>
<td>31–33</td>
<td>D</td>
<td>D</td>
<td>C</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>No</td>
<td>1. Beta–delta complexes in TO region 2. Rhythmic 1.5Hz activity in frontal leads in transitional sleep 3. Temporal alpha bursts replace 4–5 Hz bursts</td>
<td>NR</td>
</tr>
<tr>
<td>38–40</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>++++</td>
<td>+++</td>
<td>+++</td>
<td>Yes</td>
<td>1. Occipital beta–delta complexes decrease and disappear by 39wk 2. Trace alternant pattern (NREM sleep)</td>
<td>R</td>
</tr>
</tbody>
</table>
Ontogeny Overview (III)

Average duration of discontinuous periods in NREM sleep in the EEG of the premature infant

Appearance and disappearance of developmental EEG landmarks from prematurity to 3 months postterm
Ontogeny: GA 24 – 29 Weeks

- Discontinuous pattern
- Brief periods of moderate-amplitude cerebral electrical activity
  - Delta brush
  - Monorhythmic occipital delta activity
  - Bursts of rhythmic occipital and temporal theta activity
- IBP: < 25 μV
- Average IBI: 6–12 seconds
- Hypersynchrony of bursts period
- Little agreement between the clinical and electrographic expressions of the biobehavioral state
GA 26 weeks with

Centro-temporal theta activities
Hypersynchrony
Occipital monomorphic delta activities
**Ontogeny: GA 30 –32 Weeks**

- Differentiation from wakefulness or REM sleep & NREM sleep
- **Bursts period**
  - Dominant synchronized
  - Monorhythmic occipital delta activity with delta brush: migrate more from occipital to temporal area
- IBP: $<$ 25 $\mu$V
- Average IBI: 5–8 seconds
- **Trace discontinua**
- Marginal reactivity to stimuli
GA 34 weeks with rhythmic occipital theta
GA 33 weeks with

Trace discontinua

Delta brush
Ontogeny: GA 33 – 34 Weeks

- More clearly distinguish from wakefulness & quiet sleep
- Trace discontinua
- Monorhythmic occipital delta is fading
- Rhythmic theta at temporal area is increasing

- Average IBI: 5–8 seconds
- Less synchronized than earlier age (70–80%)
GA 34 weeks with centrotemporal theta
### Ontogeny: GA 35 – 36 Weeks

- **Definite and reproducible reactivity to external stimuli**

- **Wakefulness & REM sleep**
  - Continuous pattern
  - Low-to-medium amplitude, mixed frequency activity *(activité moyenne = average activity)*

- **NREM sleep: discontinuous**
  - Discontinuous pattern but trace alternant
  - IBP: > 25 μV
  - Average IBI: 4–6 seconds
  - Synchrony: 85%
  - Abundant delta brushes
GA 36 weeks with activite moyenne on REM sleep
Ontogeny: GA 37 – 40 Weeks

- Quiet sleep

  **Trace alternant pattern** → continuous slow wave sleep (CSWS)
  IBI: 2–4 seconds
  All bursts: synchronous

  **CSWS**: moderate-to-high amplitude uninterrupted delta activities
  **Delta brushes**: abundant in quiet sleep
  Early expression of **frequency–amplitude gradient**
GA 38 weeks with Trace alternant
Ontogeny: GA 41 – 44 Weeks

- Activite moyenne at wakefulness and active sleep period
- Delta brushes gradually disappear by 44 weeks
- CSWS: increase
- Trace alternant: decrease (disappear till 44 weeks)
- IBI: 2–4 seconds, >50 µV
**Ontogeny: GA 45 – 46 weeks**

- **Sleep spindles** in CSWS: symmetric but not synchronized
- Full synchronization of sleep spindles: up to 2 yrs of age
### Ontogenic Maturation: Case

<table>
<thead>
<tr>
<th>Case Details</th>
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<tbody>
<tr>
<td>GA 27+3 wk with 870 gm</td>
</tr>
<tr>
<td>AS: 2 / 4 / 4</td>
</tr>
<tr>
<td>RDS (+)</td>
</tr>
<tr>
<td>Ventilator dependency (+)</td>
</tr>
<tr>
<td>Brain MRI (GA 36 wk): c/w PVL</td>
</tr>
</tbody>
</table>
GA 28wk

Synchrony btw hemisphere
Trace discontinua
Monothythmic theta on left CT area
GA 32wk

Trace discontinua (more than 30 seconds)

Monothymic theta on left or right T area
Burst–Suppression Pattern

- The most extreme degree of discontinuity
- Prolonged IBI (sometimes longer than 30 minutes or more) with very low voltage (<5 μV)
- Brief (1–10 seconds) bursts of paroxysmal higher voltage theta, delta, and other frequencies
- Differentiation among biobehavioral states: lost
- No reactivity to noxious stimuli
- Commonly seen in encephalopathies
- Unfavorable prognostic implication
GA 42 weeks with Tonic spasms

Brain MRI: lissencephaly

Flaccid posture
**Sharp EEG Transient (SET): Frontal SET (I)**

- **Encoches frontales:** physiological SET
- **High amplitude (＞150 μV), broad, biphasic (negative–positive) transient at frontal regions**
- **Generally symmetrical, bilateral, synchronously**
- **First appear at around 34 weeks (sometimes asynchronous)**
  - Sometimes intermixed with slow 2–4 Hz waves (anterior dysrhythmia)
- **Begin to disappear at 4 weeks after birth**
- **Rare during active sleep and arousal state**
Pathological frontal sharp transients

- Excessive amount of frontal slowing
- During active sleep / wakefulness
- Resolving of HIE, meningitis, or metabolic encephalopathies

Atypical morphology (e.g.: true spike)
Markedly asymmetrical
GA 41 weeks with asynchronous but physiologic frontal sharp transients
GA 40 weeks with
Pathological frontal sharp transients
Suppressed background activity
No clinical seizure
**SET: Temporal and Central Negative SET**

- Can be seen in any region, most frequently in centro–temporal area
- Best seen during low voltage, continuous portion (wakefulness / active sleep)
- Few data available before age of 33 –34 weeks
- **Abnormal negative sharp waves**: controversial

**Nonspecific EEG finding**: various pathological condition, without clear relationship to clinical or electrical seizure

Counterpart to sharp waves in adult EEG in case of **uremia, hypoxia, drug withdrawal without presence of seizure**

Some evidence of epileptiform discharges
GA 40 weeks with physiological central sharp transients
**SET: Positive at Rolandic, Vertex, and Temporal**

- May appear in the **sick neonate (pathological)**
- Duration less than 400 – 500 milliseconds
- Brief runs with moderate to high voltage (50 – 250 μV)
- Sometimes combined with beta activity

- Not indicative of “lowered seizure threshold”
- **EEG markers of parenchymal brain injury**, esp in deep cerebral white matter (PVL, IVH, hydrocephalus, meningitis, IEM, HIE)
GA 38 weeks with HIE

Positive vertex sharp transients without clinical seizure
Neonatal Seizure: EEG, Interictal

- No reliable interictal EEG marker of potential epileptogenesis
- Focal sharp waves: normal development feature Vs interictal epileptiform discharges – controversial

- Evaluation of the background activity: indirect indicator of degree and severity of CNS dysfunction

- Serial EEG: essential for characterizing evolution of brain injury and predicting prognosis
Neonatal Seizure: EEG, Interictal

- Continuous or periodic EEG abnormal pattern with specific diagnostic or etiologic significance

  Burst-suppression pattern: Early myoclonic epilepsies
  Theta pointue alternant pattern: benign neonatal convulsion

  Quasi-periodic focal or multifocal pattern: neonatal HSV encephalitis
### Neonatal Seizure: EEG, Ictal

<table>
<thead>
<tr>
<th><strong>Focal or localized ictal onset</strong></th>
<th>Complex in nature, characterized by focal electrographic activity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most common</td>
<td>Centro-temporal &gt; occipital &gt; midline &gt; frontal: frontal area develops later than do posterior head region</td>
</tr>
<tr>
<td>Discrete ictal onset (simultaneously but independently)</td>
<td>Frequency, voltage, morphology</td>
</tr>
<tr>
<td>Electrical seizure activity of the depressed brain: severe encephalopathy</td>
<td>* Decoupling of the clinical from the electrical seizure</td>
</tr>
</tbody>
</table>
Full term with trace discontinua

One month later
GA 39 weeks with severe asphyxia

Fetal distress (+)
AS: 1 / 1
Ventilator dependency

Clinical seizure (-)
Electro-clinical dissociation (+)

Expire at 3rd day of life
Characteristics of Pediatric EEG

- Age-specific maturation pattern
- Non-epileptic physiological activities
- High amplitude, low frequency

<table>
<thead>
<tr>
<th>State</th>
<th>Group</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awake</td>
<td>infant</td>
<td>4–5 Hz</td>
</tr>
<tr>
<td></td>
<td>Children</td>
<td>5–8 Hz</td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td>8–10 Hz</td>
</tr>
<tr>
<td>Sleep</td>
<td>light</td>
<td>5–6 Hz</td>
</tr>
<tr>
<td></td>
<td>Deep</td>
<td>2–3 Hz</td>
</tr>
</tbody>
</table>
Normal Waking EEG

- Posterior dominant rhythm
- Low voltage fast activity
- Rolandic mu rhythm
- Posterior slow rhythm of youth
**Posterior Dominant Rhythm**

<table>
<thead>
<tr>
<th>Ontogenesis</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mo</td>
<td>4 Hz</td>
</tr>
<tr>
<td>12 mo</td>
<td>6 Hz</td>
</tr>
<tr>
<td>24 mo</td>
<td>6–7 Hz</td>
</tr>
<tr>
<td>36 mo</td>
<td>7–8 Hz</td>
</tr>
<tr>
<td>8 yr</td>
<td>full developed</td>
</tr>
</tbody>
</table>

- **Awaking with eye closed**
- **Pediatric age**: occipital area (95%), higher voltage than adult

- **Voltage difference**: > 50%
- **Frequency difference**: 1–1.5 Hz between hemispheres
12yr/F Normal PDR with frequent ventricular ectopic beat
6yr/F Poorly regulated & low voltage, left TO DNET
3yr/M right TO slowing, right TO Pachygyria
4yr/M Asymmetrical PDR, left PT neuroepithelial cyst
Low Voltage Fast Activity

- Low amplitude (20 μV), mainly frontal area
- 18–25 Hz dominant
- Increased by drug, drowsy, light sleep, REM sleep
- Decreased by cortical injury, subdural effusion, deep sleep, post-ictal period
8yr/M  suppressed BGA with excessive fast activities by barbiturate
6yr/F A–P gradient (frequency–voltage gradient)
Rolandic Mu Rhythm

- Acriform central rhythm of alpha frequency (9–10 Hz)
- Most common in young adult (7% of normal children)
- Frequently asymmetrical, asynchronous
- Not attenuated by eye-opening
- Attenuated by contralateral somatosensory or motor stimuli
- Enhanced by immobility, skull defect, et al
Rolandic Mu Rhythm

13yr/M Rolandic Mu Rhythm
**Lambda Wave (λ wave)**

- **Sharply contoured occipital transients** with prominent surface–positive phase lasting 75–150 msec
- **6 mo – 10 yrs** (max: 2–3 yrs)
- **Monophasic, triangular shape**
- **Differential points from occipital spikes**
  - Only when eyes are open
  - No after–coming slow waves
  - Usually electropositive
Lambda wave

5yr/M asymmetric high voltage lambda wave
Posterior Slow Wave of Youth

- 7–10% of children
- Common at 8–14 yrs
- Single, high amplitude delta waves mixed with posterior alpha rhythm
- Blocked by eye opening
6yr/M normal waking with post. Slow rhythm of youth
### Characteristics of Pediatric Sleep EEG

- Loss of occipital alpha rhythm
- Hypnagogic hypersynchrony
- Sleep spindles
- K–complex with vertex sharp transients
- POST (positive occipital sharp transients)
## Stage I Sleep EEG

### Hypnogogic Hypersynchrony (drowsy to stage I sleep)
- Intermittent or sustained, 3–5 Hz high voltage activity
- Predominantly over frontal and central region
- Age specific: Appear at 3–5 months, most prominent at 2–5 yrs, disappear by 10 yrs

### Vertex sharp transient (Stage I–II sleep record)
- Bilaterally synchronous, central
- Onset: 2–4 mo
- 5–6 mo: almost synchronous, symmetric
- Younger age, higher voltage
Hypnagogic hypersynchrony

4yr/F hypnagogic hypersynchrony
10yr/F repetitive vertex sharp transients
Stage II Sleep EEG

- Sleep spindles (stage I–II sleep)
  - Frontal & central area
  - 2–4 sec duration
  - Appear at age of 6–8 weeks
  - Initially asynchronous
  - Synchronous by 18 months (≥2 yrs: abnormal)
  - Prolonged spindles at NREM sleep disorder, MR, autism

- K–complex (stage II sleep)
  - High voltage, diphasic or polyphasic slow waves
  - Wader distribution than vertex wave
  - Often followed by sleep spindles
3yr/M, normal sleep spindles
Stage II sleep EEG

- Positive occipital sharp transients (POST)

  Non-REM sleep (esp. stage I–II)
  Single or runs of 4–5 Hz, check mark or lambdoid shape
  Sharp surface-positive, then low negative

Onset: 5 yrs
May persist at mid-age
7yr/M, POST during stage II sleep
Activation Procedures

- **Hyperventilation**
  - Increased posterior slow wave of youth
  - Build-up pattern: <7yrs posterior dominant
  - >8yrs anterior dominant
  - Rebuild-up pattern: vascular lesion such as MMD

- **Photic stimulation**
  - Photic driving response
  - Photomyoclonic response
  - Photoparoxysmal response
  - Photosensitive epilepsy

- **Sleep**
  - activate epileptiform abnormality (spontaneous, drug induced, sleep deprivation)
| 8yr/F MMD, physiologic build-up pattern during hyperventilation |

<table>
<thead>
<tr>
<th>Fp1-F3</th>
<th>F3-C3</th>
<th>C3-P3</th>
<th>P3-O1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fp2-F4</td>
<td>F4-C4</td>
<td>C4-P4</td>
<td>P4-O2</td>
</tr>
<tr>
<td>Fp1-F7</td>
<td>F7-T3</td>
<td>T3-T5</td>
<td>T5-O1</td>
</tr>
<tr>
<td>Fp2-F8</td>
<td>F8-T4</td>
<td>T4-T6</td>
<td>T6-O2</td>
</tr>
<tr>
<td>Fz-Cz</td>
<td>Cz-Pz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Same patient, rebuild-up pattern after hyperventilation
7 yr/F, 3 Hz spike and wave with absence seizure during hyperventilation
7yr/M BRE, activated spikes in sleep
<table>
<thead>
<tr>
<th></th>
<th>Infancy</th>
<th>Early childhood</th>
<th>Pre-school</th>
<th>Older children</th>
<th>Adolescent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fast activity</strong></td>
<td>Very moderate</td>
<td>Mostly moderate</td>
<td>Mostly moderate</td>
<td>Mostly moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Hyperventilation</strong></td>
<td>Not feasible</td>
<td>Mostly not feasible</td>
<td>Often marked delta response</td>
<td>Often marked delta response</td>
<td>Delta response become less impressive</td>
</tr>
<tr>
<td><strong>Photic stimulation</strong></td>
<td>Photic driving to low flash rate after 6 month of age</td>
<td>Good photic driving to low flash rate</td>
<td>Good photic driving to low flash rate</td>
<td>Good photic driving to medium flash rate</td>
<td>Good photic driving to medium flash rate</td>
</tr>
<tr>
<td><strong>Drowsiness</strong></td>
<td>Rhythmic theta around 6 month of age</td>
<td>Marked hypnogogic hypersynchrony</td>
<td>Less prominent hypnogogic hypersynchrony</td>
<td>Gradual alpha drop-out</td>
<td>Gradual alpha drop-out</td>
</tr>
<tr>
<td><strong>Spindles</strong></td>
<td>Appear after 2 month of age</td>
<td>Symmetrical with vertex maximum</td>
<td>Typical vertex maximum</td>
<td>Typical vertex maximum</td>
<td>Typical vertex maximum</td>
</tr>
<tr>
<td><strong>Vertex ST</strong></td>
<td>Appear after 5 months of age, large, blunt</td>
<td>Large, more pointed</td>
<td>Large with more sharp component</td>
<td>Large with more sharp component</td>
<td>Not quite as large / sharp component</td>
</tr>
<tr>
<td><strong>POST</strong></td>
<td>None</td>
<td>Poorly defined</td>
<td>Poorly defined</td>
<td>Gradually evolved</td>
<td>Often very well developed</td>
</tr>
<tr>
<td><strong>14 &amp; 6 Hz positive spikes</strong></td>
<td>None</td>
<td>Rare</td>
<td>Not common</td>
<td>Fairly common</td>
<td>Fairly common</td>
</tr>
<tr>
<td><strong>Spikes or sharp waves</strong></td>
<td>Essential as abnormal condition</td>
<td>Spikes on seizure free children, mainly occipital</td>
<td>Spikes on seizure free children, mainly occipital or rolandic</td>
<td>Spikes on seizure free children, mainly rolandic</td>
<td>Rolandic spikes disappear</td>
</tr>
<tr>
<td><strong>Continuity</strong></td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td><strong>Interhemispheric Synchrony</strong></td>
<td>Always synchronous</td>
<td>Always synchronous</td>
<td>Always synchronous</td>
<td>Always synchronous</td>
<td>Always synchronous</td>
</tr>
<tr>
<td><strong>Posterior rhythm</strong></td>
<td>3-4 month: 4 Hz</td>
<td>5-8 Hz</td>
<td>6-9 Hz</td>
<td>10 Hz</td>
<td>10 Hz</td>
</tr>
<tr>
<td></td>
<td>12 months: 6 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3yr/F corpus callosal agenesis, asynchronous sleep spindles
3yr/M HSV encephalitis with hemorrhagic transformation
3yr/F Diffuse irregular delta slowings, Angelmann syndrome
11yr/M, LCS, interictal waking record
8yr/F Atypical absence, preceded by irregular delta & prominent post-ictal slowings on the left F area.