Neonatal Electroencephalography: Maturational Changes of the Preterm Brain

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Learning Objectives

• Recognize normal age-dependent developmental features of neonatal EEG
• Recognize abnormal age-dependent features of neonatal EEG and their clinical implications
• Understand the clinical utility of neonatal electroencephalography

ACNS Guidelines and Neonatal EEG

• Guideline 5: Minimal Technical Standards for Pediatric Electroencephalography
  – August 2016
• Guideline 13: Continuous EEG Monitoring in Neonates
  – January 2012
• Guideline 16: Standardized EEG Terminology and Categorization for the Description of Continuous EEG Monitoring in Neonates
  – December 2012
  [http://www.acns.org/practice/guidelines]

Basis for Interpretation

• The normal neonatal EEG undergoes rapid and predictable changes as a consequence of brain growth and development.
• Abnormalities may be characterized by altered developmental characteristics as well as specific patterns or wave-forms.
• Patterns that are normal at one development stage may be abnormal at another.

Challenges in Interpretation

• The significance of some features of the neonatal EEG have not been determined.
• Certain abnormal EEG findings in the period immediately following brain injury may be transient.
  – Their significance is related to change over time
  – Underscores the need for serial recordings
Neonatal EEG and Brain Development

- Basic assumption
  - Brain development proceeds at the same rate whether the infant is in the nursery or in utero
- Caution
  - No intercurrent CNS injuries

An Accelerated Anatomic View of Brain Development

http://medstat.med.utah.edu

Neonatal Electroencephalography Marker of Rapid Brain Growth

27-28 weeks CA

30-32 weeks CA

36 weeks CA

60 weeks CA
Trends in Appearance of Neonatal EEG
Parallel Brain Development:
Orderly Approach to Visual Analysis

• Continuity
• Synchrony
• Waveforms
• Wake/sleep cycles

Continuity

• There is a gradual change from a discontinuous pattern to a continuous pattern

Developmental Trends of Discontinuity

Synchrony

• Initial period of synchrony
  - "Hypersynchrony"
  - May be variable
• Followed by asynchrony
• Then gradual return to synchrony on the two sides
  - Degree of synchrony increases with conceptional age

Synchrony

• Initial period of “hypersynchrony”
• Associated with discontinuity
Synchrony

Specific Waveforms

- Emergence and disappearance of specific waveforms
  - Specific character and location
  - Orderly progression
- “Grapho-elements”
- Markers of conceptional age
  - Beta-delta complexes: “brushes”
  - Temporal bursts: theta and alpha frequencies
  - Frontal sharp waves: “encoches frontales”

Beta-delta Complexes

- Hallmark of prematurity
  - Slow-wave with superimposed fast activity
- Initially central
- Eventually posterior
- Onset: 29 weeks C.A.
- Disappearance: 38 weeks
Temporal Theta Bursts

Temporal Alpha Bursts

Frontal Sharp Transients

Synchronous, symmetrical; Onset at 34–35 weeks C.A.; Persist through term

Development of Reactivity and Wake/Sleep Cycles

• Changes in EEG activity in response to stimuli emerge at about 33–34 weeks C.A.
  – State-dependent
• Clear EEG differences between wakefulness and sleep emerge at about 36–37 weeks C.A.

Sleep

• Classification
  – Active
  – Quiet
  – Transitional
  – Indeterminate
• Wake-Sleep Cycling
  – Pattern of alterations of behavioral states

<table>
<thead>
<tr>
<th></th>
<th>Preterm</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Behavioral: eyes closed, intermittent REM, limb and body movements</td>
<td>Behavioral: eyes closed, intermittent REM, irregular respiration, small and large body movements</td>
</tr>
<tr>
<td></td>
<td>EEG: Discontinuous, increasing continuity with increasing CA</td>
<td>EEG: Indistinguishable from normal wakefulness</td>
</tr>
<tr>
<td>Quiet</td>
<td>Behavioral: eyes closed, absent REM, limited body movements</td>
<td>Behavioral: eyes closed, absent REM, limited body movements</td>
</tr>
<tr>
<td></td>
<td>EEG: Discontinuous, increasing continuity with increasing CA</td>
<td>EEG: Alternates between higher and lower voltage slow activity during alternation; revert to post-term</td>
</tr>
</tbody>
</table>

30-32 weeks CA

32-33 weeks CA

30 to 40 weeks CA
Wake/Sleep Cycle
Awake

Wake/Sleep Cycle
NREM Sleep
Trace Alternant

Wake/Sleep Cycle
Rudimentary Sleep Spindles

Sleep Spindles

Additional Normal Waveforms

- There are some waveforms that are considered normal but not specifically considered age-dependent grapho-elements
  - Bifrontal delta in near-term and term infants
  - "Anterior Dysrhythmia"
    - Although not abnormal

Bifrontal Delta
Normal ➔ Abnormal

Age-Dependent Expectations

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Age-dependent EEG Abnormalities
Suggesting Diffuse and Focal Injury

- EEG abnormalities are dependent upon the range of possible normal activity at a given epoch of age
- 25-26 weeks C.A.
- 27-28 weeks C.A.
- 29-30 weeks C.A.
- 31-33 weeks C.A.
- 34-35 weeks C.A.
- 36-37 weeks C.A.
- 38-40 weeks C.A.
- 41-44 weeks C.A.

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Age-dependent Patterns of Diffuse Brain Injury

- Prolonged interburst duration 25-28 wks C.A.
- Depressed voltage 25-28 wks C.A.
- Dyschronism 29-30 wks C.A.
- Prolonged generalized voltage attenuation 34-35 wks C.A.
- Absence of sleep cycling 36-37 wks C.A.
- Depressed and undifferentiated background 36-37 wks C.A.
- Suppression-burst activity 36-37 wks C.A.
- Hypsarrhythmia 41-44 wks C.A.

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Dyschronism

- Determination of conceptional age depends upon the presence or absence of specific established developmental milestones characterized by specific EEG features.
- Dyschronism
  - The finding of developmental features that are inconsistent with age
    - Other EEG features
    - Infant’s actual age

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Dyschronism

- Internal
  - Mixture of developmental features present in different physiologic states
  - Precise determination of conceptional age cannot be made
  - Suggests diffuse dysfunction

- External
  - Developmental features in all wake/sleep states are immature for stated age
    - EEG-age determination correct?
    - Clinical-age determination correct?
  - Immature EEG features evidence of delayed maturation

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Internal Dyschronism
Age-dependent Patterns of Focal Brain Injury

- Voltage depression
  - 25-28 wks C.A.
  - over one hemisphere
- Central positive sharp waves
  - 29-30 wks C.A.
- Persistent focal sharp waves
  - 31-33 wks C.A.
- Electrical seizure activity
  - 34-35 wks C.A.

Central Positive Sharp Waves

- Positive rolandic sharp waves
- Initially associated with intraventricular hemorrhage
- Now more clearly associated with related abnormalities
  - Periventricular leukomalacia

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Temporal Sharp Waves

- May be present as normal activity
- No clear criteria to differentiate normal from abnormal temporal sharp waves
- Consider
  - Amplitude and duration
  - Occurrence
  - Complexity of waveform
  - Polarity
  - Changing states
Understanding the timing of the EEG in relationship to injury is important in the interpretation of the findings.
Timing of EEG and Rationale for Serial Recordings

Understanding the timing of the EEG in relationship to injury is important in the interpretation of the findings.

Clinical Utility of Neonatal EEG

Age-dependent interpretation of EEG is best utilized in the context of a clinical question:
- What is the infant’s conceptional age?
- Has the infant suffered a diffuse brain injury?
- Is there evidence of a focal brain injury?
- What is the prognosis?
- Has the infant experienced a seizure?

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Acknowledgements

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