Neonatal Electroencephalography: Normal and Abnormal

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Learning Objectives

• Understand the clinical utility of neonatal electroencephalography
• Recognize normal developmental features of neonatal EEG
• Recognize abnormal features of neonatal EEG and their clinical implications
• Recognize electrographic seizure discharges
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The Electroencephalogram of the Premature Infant and Full-Term Newborn

Normal and Abnormal Development of Waking and Sleeping Patterns

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EEG in Assessment of the Neonate

• General considerations
  – Role of EEG relative to other testing modalities
  – Technical considerations
  – Issues in interpretation

• Features of the normal and abnormal neonatal EEG

• Application to specific clinical problems
Neonatal EEG Best Utilized as a Correlative Study

- Infant’s medical history
- Recording strategies based upon history and physical findings
- Clinical observation and stimulation during recording
- Relationship of EEG findings to other laboratory findings
- Consultation between neonatologist and neurophysiologist
Application of Neonatal EEG in Consideration of Clinical Questions

- Determination of conceptional age
- Assessment of diffuse brain injury
  - Assessment of presence of brain death
- Assessment of focal brain injury
- Determination of timing of brain injury
- Determination of prognosis
- Diagnosis of neonatal seizures
Technical Considerations

- Electrode application
- EEG channel selection
- Polygraphic channels
  - Respirations
  - Electrocardiogram
  - Electro-oculogram
  - Electromyogram
Recording Strategies

• Montage selection
  – Single montage
  – Inclusion of Cz and other midline regions

• Recording duration

• Recording protocol
  – Wake/sleep cycles
  – Suspected abnormal clinical events
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

• Cautions
  – No intercurrent CNS injuries
  – Recently challenged by computer-based analysis
Trends in Appearance of Neonatal EEG Parallel Brain Development

- Continuity
- Synchrony
- Waveforms
- Wake/sleep cycles
Continuity

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

27-28 wks CA
Continuity

- Continuity first appears in wakefulness
- Residual discontinuity in sleep, even at term

40 weeks CA
Developmental Trends of Discontinuity
Synchrony

- Initial period of “hypersynchrony”
- Associated with discontinuity

27-28 wks CA
Synchrony

• Initial period of synchrony
  – “hypersynchrony”
• Followed by asynchrony
• Then gradual return to synchrony on the two sides
  – Degree of synchrony increases with conceptional age
Synchrony
Discontinuity and Asynchrony

29-30 weeks CA
Synchrony

40 weeks CA
Specific Waveforms

• Emergence and disappearance of specific waveforms
  – Specific character and location
  – Orderly progress

• “Grapho-elements”

• Markers of conceptional age
  – Beta-delta complexes: “brushes”
  – Temporal bursts: theta and alpha
  – Frontal sharp waves: “encoches frontales”
Grapho-elements

- Tracé Alternant
- Frontal Sharp Wave Transients
- Temporal Alpha Bursts
- Occipital Dominant Alpha Rhythm
- Temporal Theta Bursts
- Vertex Transients
- Beta Delta Complexes
- Sleep Spindles

Conceptional Age (weeks)
Beta-delta Complexes

• Hallmark of prematurity
  – Slow-wave with superimposed fast frequency activity
• Initially central
• Eventually posterior
• Onset: 29 weeks C.A.
• Disappearance: 38 weeks
Beta-delta Complexes

• First appearance
  – Infrequent
  – Central regions

• Later appearance
  – Persistent
  – Temporal-occipital

• Typically asynchronous and asymmetrical in voltage

29-30 weeks CA
Temporal Theta Bursts

30-32 weeks CA
Temporal Alpha Bursts

32-33 weeks CA
Frontal Sharp Transients

• Synchronous, symmetrical
• Onset: 34-35 weeks C.A.
• Persist through term

36 weeks CA
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.
Normal Features Waves

• There are some waveforms that are considered normal but not specifically considered age-dependent grapho-elements
  – Bifrontal delta in near-term and term infants
Bifrontal Delta

38 – 40 weeks CA
Waveforms of Uncertain Diagnostic Significance

• Midline sharp waves
• Rhythmic theta and alpha activity
Midline Central Theta

40 weeks CA
Age-dependent EEG Abnormalities
Suggesting Diffuse vs. Focal Injury

• EEG abnormalities are dependent upon the range of possible activity at a given epoch of age
  – 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.
Age-dependent Patterns of Diffuse Brain Injury

- Prolonged interburst duration 27-28 wks C.A.
- Depressed voltage 27-28 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.
Dyschronism

- Determination of conceptional age depends upon the presence or absence of certain 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
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
    - Intrauterine cerebral insult
Internal Dyschronism
Depressed and Undifferentiated Background

40 weeks CA
Suppression-Burst Background

40 weeks CA
Suppression-burst Patterns

- Hypoxic-ischemic encephalopathy
- In-born errors of metabolism
Suppression-burst Patterns
Suppression-burst Patterns
Age-dependent Patterns of Focal Brain Injury

- Voltage depression over one hemisphere 27-28 wks C.A.
- 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.
Voltage Depression Over One Hemisphere

40 weeks CA – subarachnoid hemorrhage
Central Positive Sharp Waves

• Postive rolandic sharp waves
• Initially associated with intraventricular hemorrhage
• Now more clearly associated with sequelae
  – Periventricular leukomalacia
Central Positive Sharp Waves

29-30 weeks CA
Central Positive Sharp Waves

36 weeks CA - IVH
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
Temporal Sharp Waves
Temporal Sharp Waves
Temporal Sharp Waves
Temporal Sharp Waves
Temporal Sharp Waves
Temporal Sharp Waves
Multifocal Sharp Waves
Focal or diffuse brain injury?
Multifocal Sharp Waves

32 weeks CA
Clinical Utility of Neonatal EEG

• 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?
  – When did the CNS injury occur?
  – What is the prognosis?
  – Has the infant experienced a seizure?
What is the Infant’s Conceptional Age?

• When dates are uncertain or there are conflicting data
  – Head ultrasound
  – Dates by history
  – Physical examination

• Neonatal EEG can be utilized to determine conceptional age based upon age-dependent features
  – Within 2 weeks
Has the Infant Suffered a Diffuse CNS Injury?

• Features that indicate diffuse dysfunction
  – Undifferentiated
  – Depressed and undifferentiated
  – Suppression-burst
  – Isoelectric

• Features that suggest diffuse dysfunction
  – Internal dyschcronism
  – Multifocal sharp waves
  – Lack of wake-sleep cycling
Has the Infant Suffered a Diffuse CNS Injury?

• Generalized abnormalities may indicate the degree of diffuse disturbance
• EEG abnormalities, typically, are not representative of a specific neuropathologic process
Has the Infant Suffered a Diffuse CNS Injury?

- The EEG is typically not utilized in the neonate in the determination of brain death
- Brain death in this age group is a clinical diagnosis
- The time course in the determination of brain death may be longer than in older patients
- EEG data will be more clinically pertinent in relation to prognosis
Has the Infant Suffered a Diffuse CNS Injury?

- Understanding the timing of the EEG in relationship to injury may be as important as in the interpretation of the findings.

40 weeks CA – day 1 of life
Has the Infant Suffered a Diffuse CNS Injury?

• Understanding the timing of the EEG in relationship to injury may be as important as in the interpretation of the findings.

4 days later
Is There Evidence of Focal CNS Injury?

• Persistent focal abnormalities suggest focal structural lesions
  – Sharp waves
  – Voltage asymmetry
  – Focal slow

• Differentiate normal from abnormal transients
Are Focal Abnormalities Specific To an Underlying Etiology?

• Attempts have been made to correlate focal findings with etiology
  – Positive central (rolandic) sharp waves
    • Initially: intraventricular hemorrhage
    • Now: periventricular leukomalacia
  – Periodic laterized epileptiform discharges (PLEDs)
    • Initially: herpes simplex encephalitis
    • Now: seizure discharges of the depressed brain
When Did the Injury Occur?

- Most controversial aspect of neonatal EEG interpretation
- Finding of delayed maturation suggests that the injury occurred \textit{in utero}
  - Dyschronism
What is the Prognosis?

- The greater the EEG abnormality, the more grave the prognosis
- Although the initial EEG may be very abnormal the accuracy of prognosis is based upon the evolution of the abnormality
  - Degree and rate of resolution
- A normal initial EEG reliably suggests a good prognosis
  - Within first 24 hours
EEG Features Thought to Have Prognostic Significance

• Developmental assessment
• Character of the background activity
• Focal features
Prognostic Value of Abnormal or Absent Developmental Features

- Possible association with neurological impairment ("at-risk")
  - Dyschronism
  - Absence of expected grapho-elements
  - Delayed maturation in serial recordings
Prognostic Value of EEG Background Activity

• Association with significant neurological impairment or death
  – Electrocerebral inactivity
  – Suppression-burst
  – Depressed and undifferentiated
  – Prolonged interburst intervals (pre-term)

• Association with possible neurological impairment
  – Depressed or undifferentiated
  – Non-reactive
  – Aberrant sleep architecture
Prognostic Value of Focal EEG Features

- Association with significant neurological impairment or death
  - Positive rolandic sharp waves (>2/min)
  - Persistent voltage asymmetry

- Association with possible neurological impairment
  - Positive rolandic sharp waves (<2/min)
  - Multifocal sharp waves
Practical Considerations

• Know the timing of EEG in relation to suspected injury
  – Further from the injury with an abnormal EEG the more likely it is to be persistent

• Perform serial EEGs
  – Abnormal EEGs early in the course of injury may improve, suggesting an improved prognosis
Clinical Utility of Neonatal EEG

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  – Has the infant experienced a seizure?
Has the Infant Experienced a Seizure?
Clinical Imperatives
Consequences of Neonatal Seizures

• Immediate
  – Alternations of autonomic function
    • Heart rate
    • Respirations
    • Systemic blood pressure
  – Hypermetabolic state
  – Etiology of underlying CNS dysfunction

• Long-term
  – High early death rate
  – Impairment later in life
    • Developmental delay
    • Neurological abnormalities
    • Post-neonatal epilepsy
Problems of Seizure Recognition

• Timing
  – Unpredictable in onset
  – Frequency unpredictable
  – Duration is unpredictable
    • Self-limited
    • Intractable

• Clinical Identification
  – Some features unique to neonatal period
  – Recognition may be difficult
  – Pathophysiology differs by seizure type
    • Epileptic
    • Non-epileptic
Classification of Neonatal Seizures

• Methods of Classification
  – Clinical features
    • Predominant clinical behavior
    • Components of an evolving seizure
  – Temporal relationship of clinical features to EEG seizure activity
  – Pathophysiology
Classification of Neonatal Seizures

• Clinical Features
  – Focal Clonic
  – Focal Tonic
  – Myoclonic
  – Spasms
  – Generalized Tonic
  – Motor Automatisms

• Relationship of Clinical:EEG Seizures
  – Electroclinical
    • Focal clonic
    • Focal tonic
    • Spasms
    • Myoclonic*
  – Clinical only
    • Generalized tonic
    • Motor automatisms
    • Myoclonic*
  – Electrical only
Elements of Neonatal EEG in Relation to Seizures

- Technical quality
  - Adherence to recording protocols
    - Clinical history
    - Duration
    - Observation
    - Stimulation

- EEG features
  - Background
  - Interictal waveforms
  - Electrical seizures

- Clinical aspects
  - Seizure recognition and characterization
Interictal Sharp Waves
Electrical Seizure Activity
Seizure Duration
Central Onset of Electrical Seizure Activity
Temporal Onset of Electrical Seizure Activity
Frontal Onset of Electrical Seizure Activity
Midline Central Onset of Electrical Seizure Activity
Midline Central Onset of Electrical Seizure Activity
Occipital Onset of Electrical Seizure Activity
Multifocal Electrical Seizure Activity
Multifocal Electrical Seizure Activity
Low-Voltage Electrical Seizure Activity
High-Voltage Electrical Seizure Activity
Spike Morphology of Electrical Seizure Activity
Slow Wave Morphology of Electrical Seizure Activity
Slow Wave Morphology of Electrical Seizure Activity
Complex Morphology of Electrical Seizure Activity
Complex Morphology of Electrical Seizure Activity
Complex Morphology of Electrical Seizure Activity
Complex Morphology of Multifocal Electrical Seizure Activity
Migration of Electrical Seizure Activity
Electrical Seizure Activity Not Associated with Clinical Seizures

• Seizure discharges of the depressed
• Alpha seizure discharges
• Seizure discharges in infants paralyzed for respiratory care
Seizure Discharges of the Depressed Brain
Alpha Seizure Discharges
Alpha Seizure Discharges
Ictal Features of Epileptic Spasms
Sources of Artifacts that May Mimic Electrical Seizures

• Environmental interference
  – Electrical interference due to mechanical devices
• Alterations of electrode impedance
• Movement-induced artifacts
• Endogenous non-cerebral potentials
Environmental Interference: Mechanical Device – IV Pump
Environmental Interference: Mechanical Device – ECMO
Alterations of Electrode Impedence
Induced by Movement: Mechanical Ventilation
Induced by Movement: Spontaneous Tremors
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Induced by Movement:
Patting
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Endogenous Non-cerebral Potentials: EKG
Endogenous Non-cerebral Potentials: Sucking
Endogenous Non-cerebral Potentials: Jaw Tremor
Endogenous Non-cerebral Potentials: Eye Movements
Endogenous Non-cerebral Potentials: EMG
Endogenous Non-cerebral Potentials: EMG with Arousal
Practical Considerations in the Interpretation of Neonatal EEG

• Consider conceptional age
  – Parameters of the normal and abnormal EEG are conceptional age dependent

• Consider the EEG in relation to the clinical problem
  – Try to address the clinical issues
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