ICU EEG: Encephalopathic, Periodic and Coma Patterns

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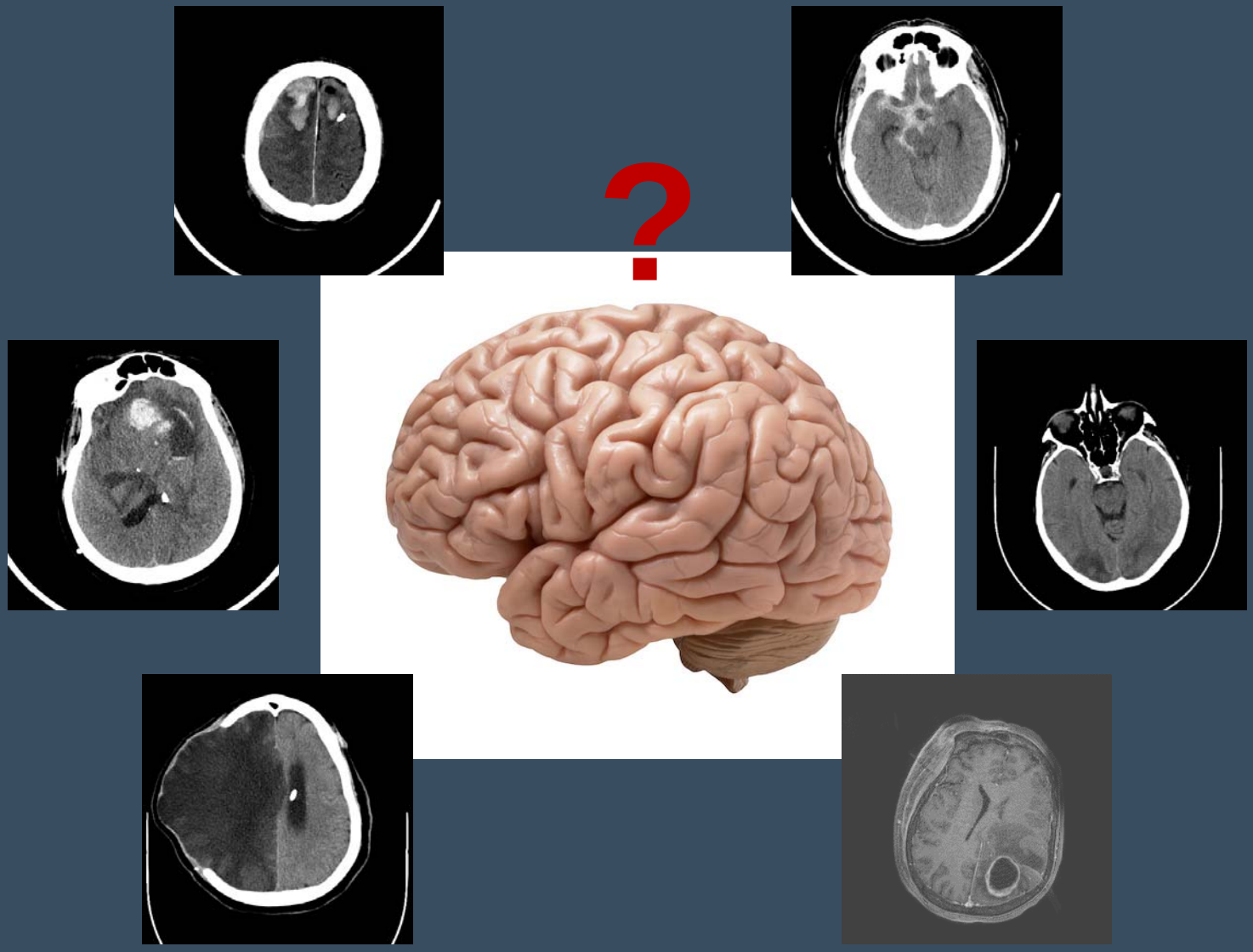
Objectives

- Recognize importance of neuromonitoring
- Recognize EEG patterns and understand prognostic significance of these patterns in the critically ill patient
- Review terminology pertaining to EEG monitoring of the critically ill



Encephalopathy

Cleveland Clinic

Encephalopathy: Clinically

- Mild (awake/lethargy)
  - Drowsiness, agitated, confused, inattentive, hallucinations
- Moderate (stupor/obtunded)
  - Depressed consciousness but arousable to vigorous stimulation, may follow simple commands/interact with environment
- Severe (coma)
  - Unresponsive to inappropriately responsive to external stimulation (may grimace/withdrawal to pain)
- Profound (coma)
  - Unresponsive to external stimulation

Encephalopathy: EEG

- Purpose of EEG:
  - Assess depth of coma and severity of cortical dysfunction
  - Determine etiology/depth of depressed LOC (medication, seizure, etc)
  - Assess for changes over time (worsening/improving encephalopathy, ischemia)
    - Need to be aware of changes in background, reactivity, state changes, sleep architecture, etc
  - Prognostication
  - Compliments neuroimaging to exclude other causes (catatonia, psychogenic coma)

- EEG Characteristics:
  - Slow activity (rhythmic delta activity)
  - Periodic patterns (periodic discharges)
  - Coma/stupor patterns including medication effect
  - Suppression
  - Reactivity

Handbook of ICU EEG Monitoring, 2013

Slow Activity

	Background Slow	Intermittent Slow	Continuous Slow
Frequency	Theta	Theta and/or delta	Theta and/or delta
Distribution	As in normal background rhythm	Variable	Variable
Waveform	Rhythmical	Irregular/rhythmical	Irregular
Quantity	Continuous	Intermittent	Continuous (≥90% of record)
Reactivity	Highly responsive	Highly responsive	Nonresponsive

Mild Diffuse Encephalopathy

- Background slow
  - Frequency of background rhythm is lower than the normal value
    - 1y: < 5Hz
    - 4y: < 6Hz
    - 5y: <7Hz
    - 8y: <8Hz
      - Diffuse theta activity, occasional delta activity
  - Interpretation:
    - Cortical or subcortical mechanisms involved in the generation of the background rhythm are disturbed
    - Nonspecific marker of diffuse dysfunction but may be related to cerebral perfusion or metabolic/toxic etiologies

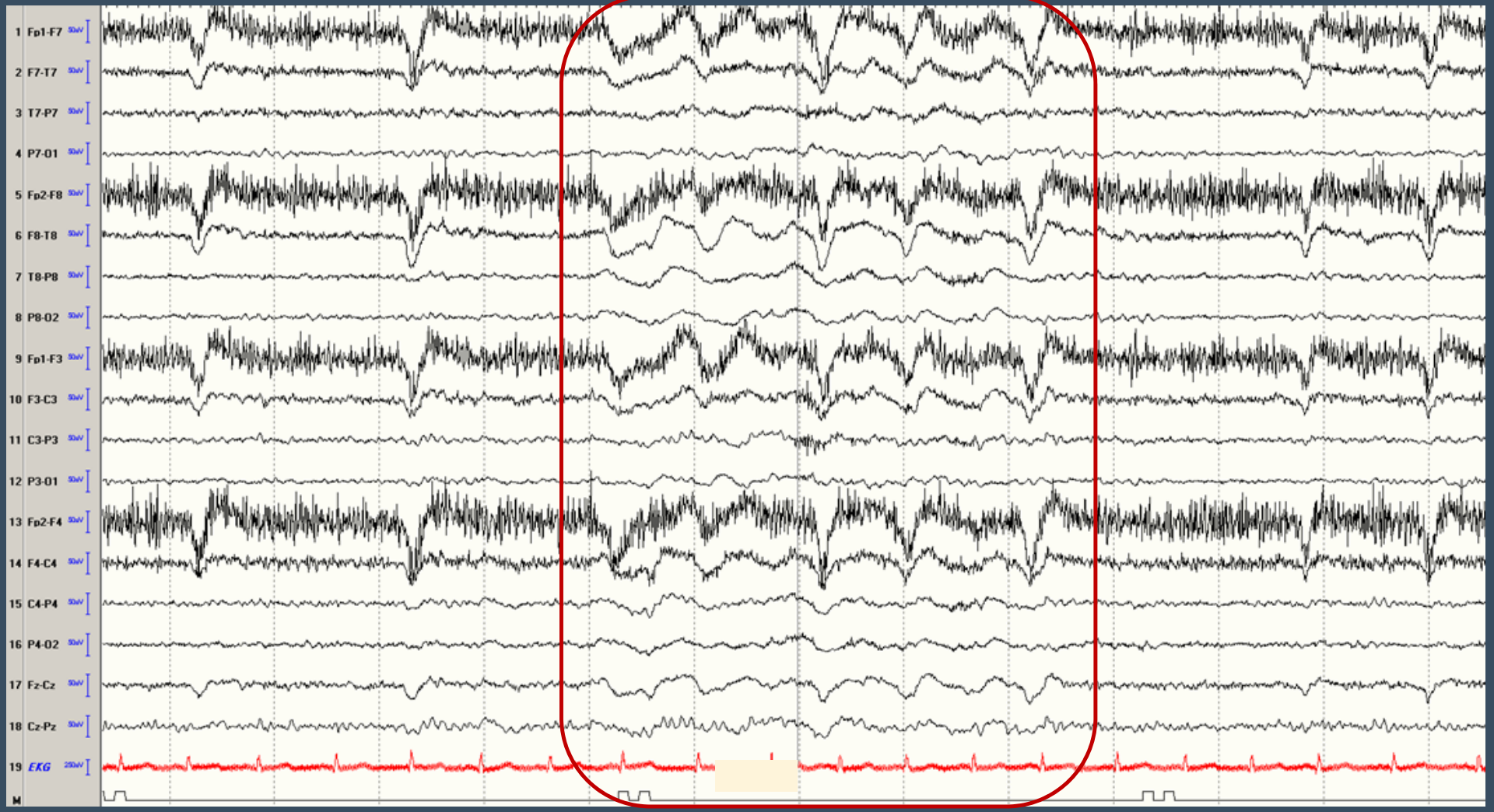
Dementia


1 Fp1-F7
2 F7-T7
3 T7-P7
4 P7-O1
5 Fp2-F8
6 F8-T8
7 T8-P8
8 P8-O2
9 Fp1-F3
10 F3-C3
11 C3-P3
12 P3-O1
13 Fp2-F4
14 F4-C4
15 C4-P4
16 P4-O2
17 Fz-Cz
18 Cz-Pz
20 EKG1-EKG2
M

Mild Diffuse Encephalopathy

- Intermittent Slow (Rhythmic Delta Activity)
  - Not caused by drowsiness
  - Can be generalized (may be frontal or occipital predominant), regional, or lateralized
- Interpretation:
  - Marker for nonspecific functional dysfunction, especially if generalized

Meningoencephalitis



Moderate Diffuse Encephalopathy

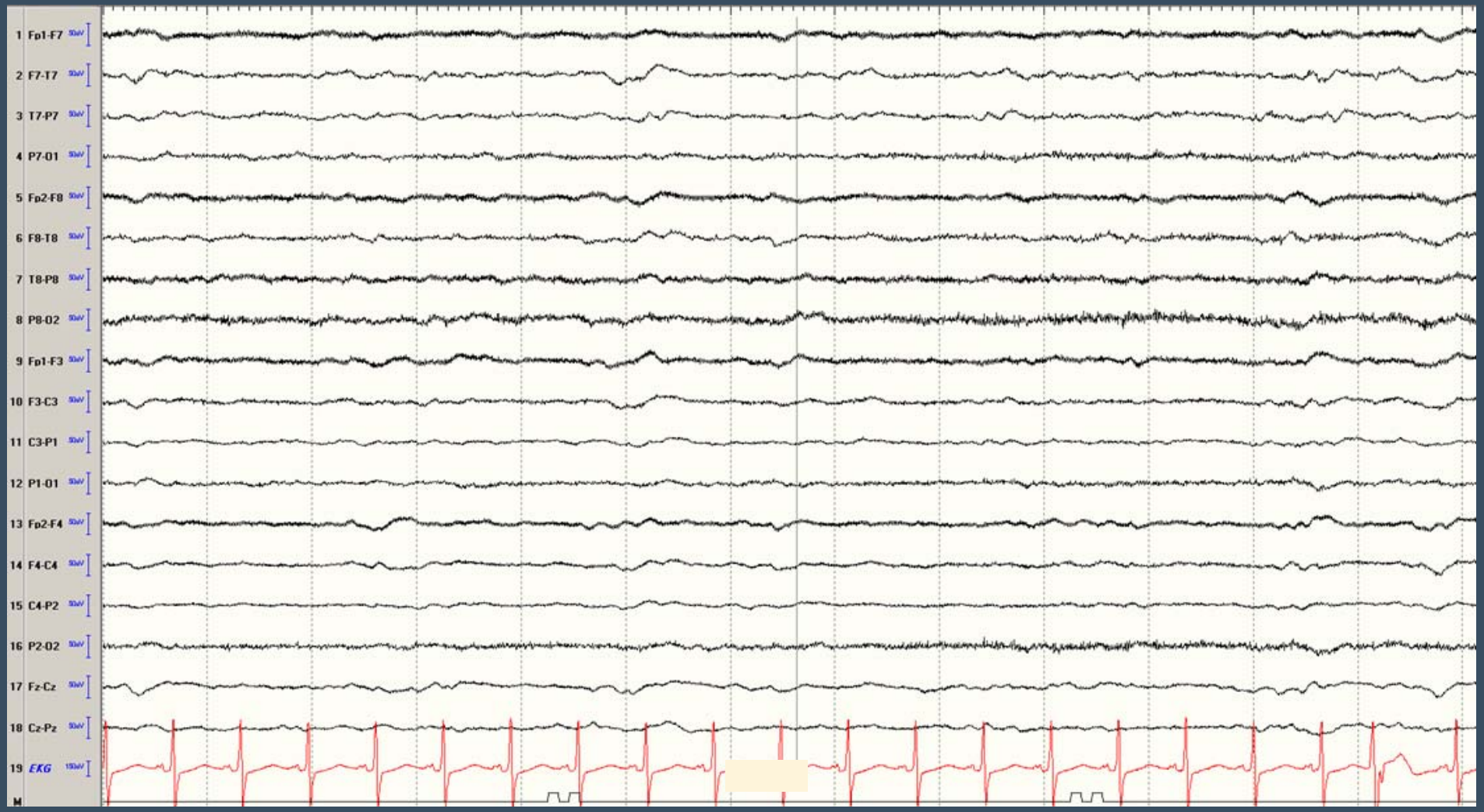
- Continuous Slow (Rhythmic Delta Activity)
  - Sleep structures may still be present
  - Posterior dominant rhythm may still be present
  - State changes and reactivity present

Pontine ischemic stroke

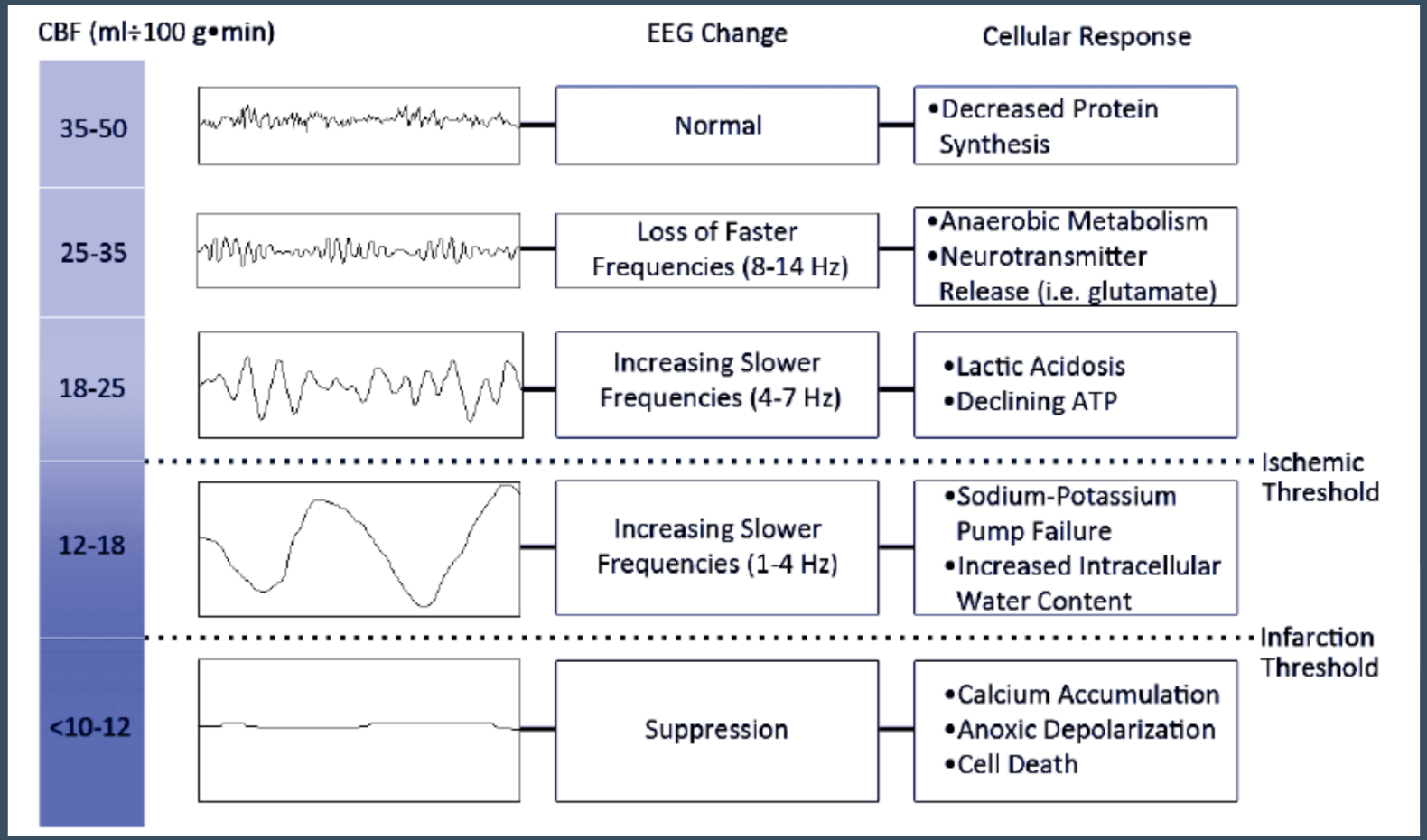
Severe Diffuse Encephalopathy

- Continuous Slow (Rhythmic Delta Activity)
  - Typically not responsive to external stimulation
  - Exceeds the amount considered physiologically normal for the patient's age
  - No posterior dominant rhythm
  - No sleep structures, state changes
  - May be admixed with faster frequencies, variable periods of diffuse attenuation
- Interpretation:
  - Severe disturbance of interneuronal connections or of the biochemical environment of cortical neurons

Cardiac arrest

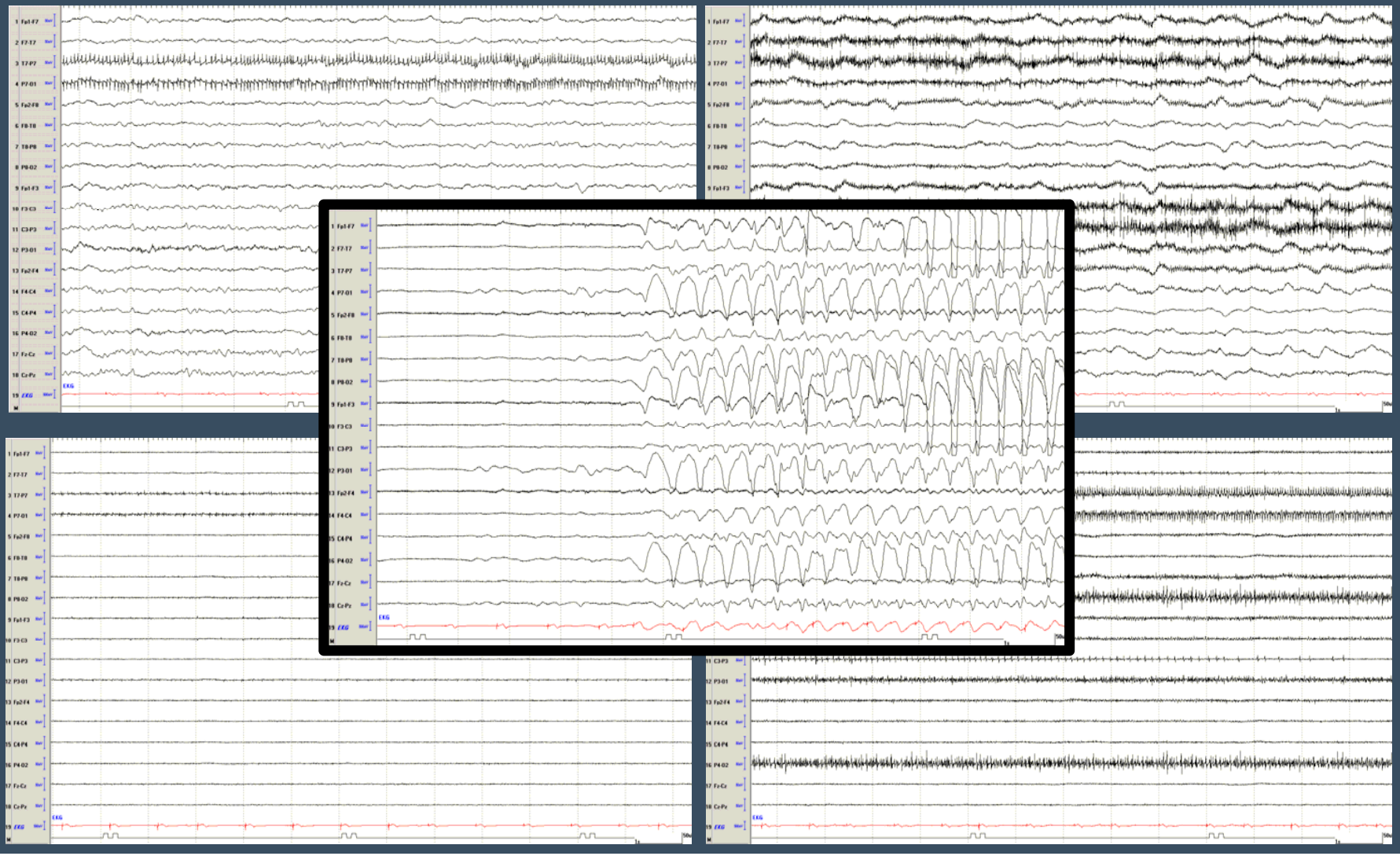


EEG Changes with Cerebral Blood Flow



Foreman and Claassen, 2012

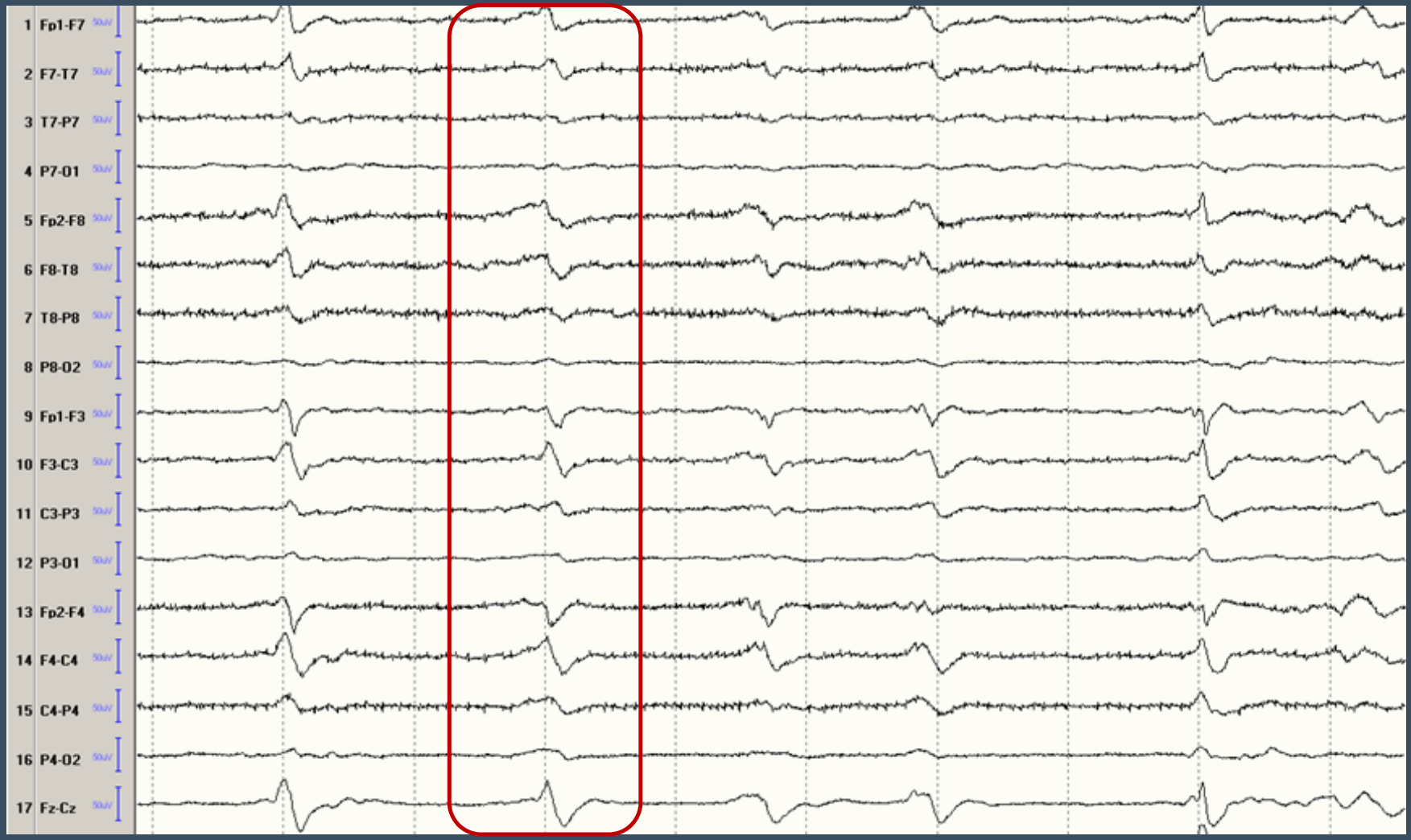
AMS and worsening cardiac function



Generalized Periodic Discharges (GPDs)

- Stereotypical waveforms with a periodic rate
  - Generalized periodic discharge +/- triphasic morphology
  - Frontocentral predominant but may also be frontotemporal midline or occipital predominant
  - Typically have a negative polarity
  - Discharge can be up to 0.5seonds long; <4 phases
  - Interdischarge interval should not vary by more than 50%
- Interpretation:
  - Indicates an acute/subacute, severe diffuse encephalopathy

Cardiac arrest



CJD


1 Fp1-F7
2 F7-T7
3 T7-P7
4 P7-O1
5 Fp2-F8
6 F8-T8
7 T8-P8
8 P8-O2
9 Fp1-F3
10 F3-C3
11 C3-P3
12 P3-O1
13 Fp2-F4
14 F4-C4
15 C4-P4
16 P4-O2
17 Fz-Cz
18 Cz-Pz
19 EKG2-EKG1
M

Triphasic Morphology

- High amplitude sharp transients followed by low amplitude negative wave
  - First negative wave generally has a lower amplitude than the negative afterwave
  - Typically generalized with the largest deflection in the frontal electrodes on bipolar montage; wave duration ~300-500msec; can increase/appear on stimulation/arousal
- Interpretation:
  - Classically seen in metabolic diffuse encephalopathies (hepatic/renal failure), toxic encephalopathies (baclofen overdose, lithium overdose),
  - Can occur in white matter diseases, atrophy, hemorrhage, stroke, anoxia, hypoglycemia, sepsis, hypercalcemia
  - Typically has a lower seizure risk

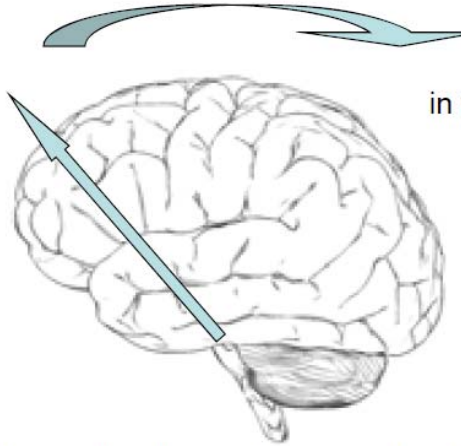
Handbook of ICU EEG Monitoring, 2013; So, 2016

Triphasic Morphology

- May appear to have a delay (or lag) on bipolar montage, which is not seen on ear reference montage

What could do this?
Oscillating dipole? Traveling wave?

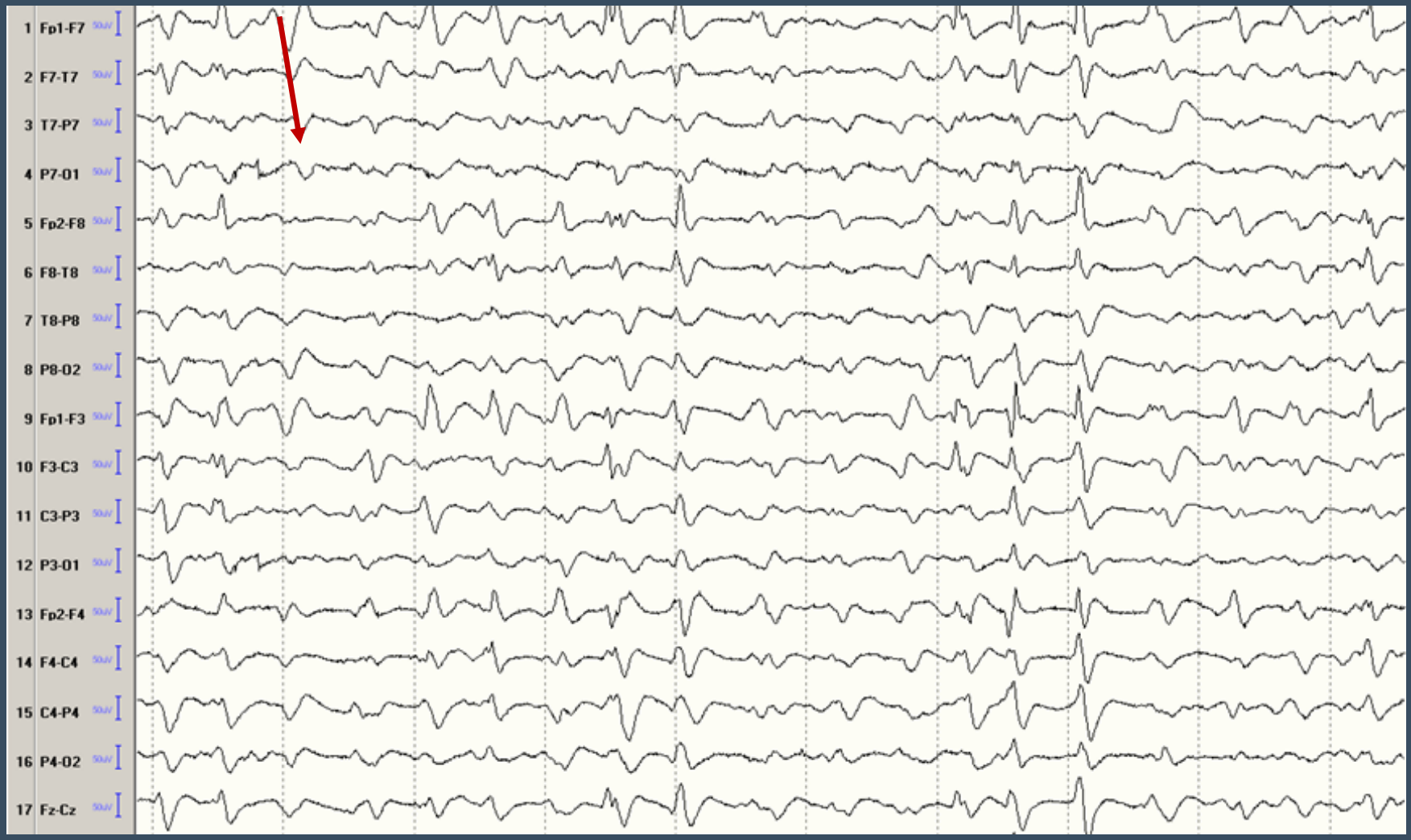
Bickford & Butt 1955 calculated a traveling wave spreading over cortex at 1.5m/s



Phase leads and lags on bipolar montage need not be a critical criterion, and often are a result of bipolar phase cancellation as differences disappear on referential display (Fisch & Klass 1988)

Handbook of ICU EEG Monitoring, 2013; So, 2016

Hepatic failure



Renal failure

- Ear Referenced

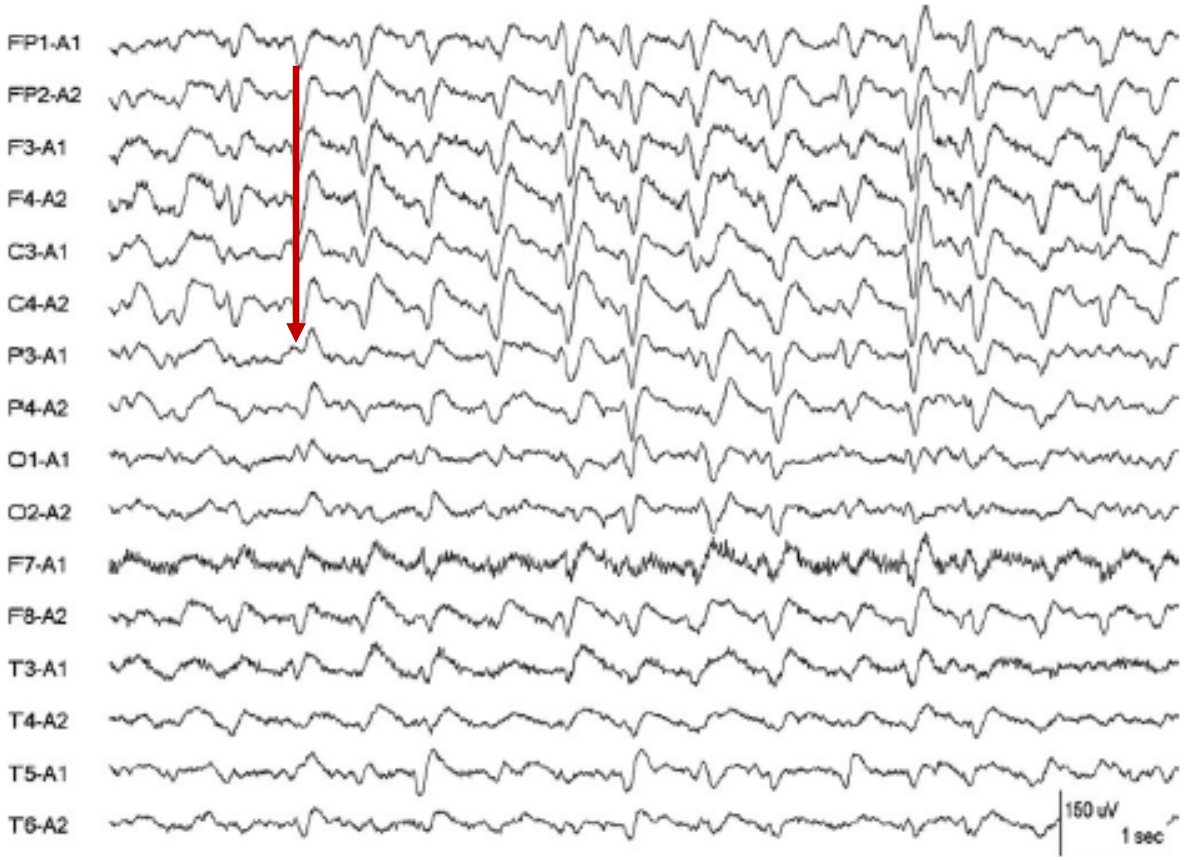


FIGURE 3. Triphasic waves in a 74-year-old man with renal failure.

Kaplan and Rossetti, 2016

Lateralized Periodic Discharges (LPDs)

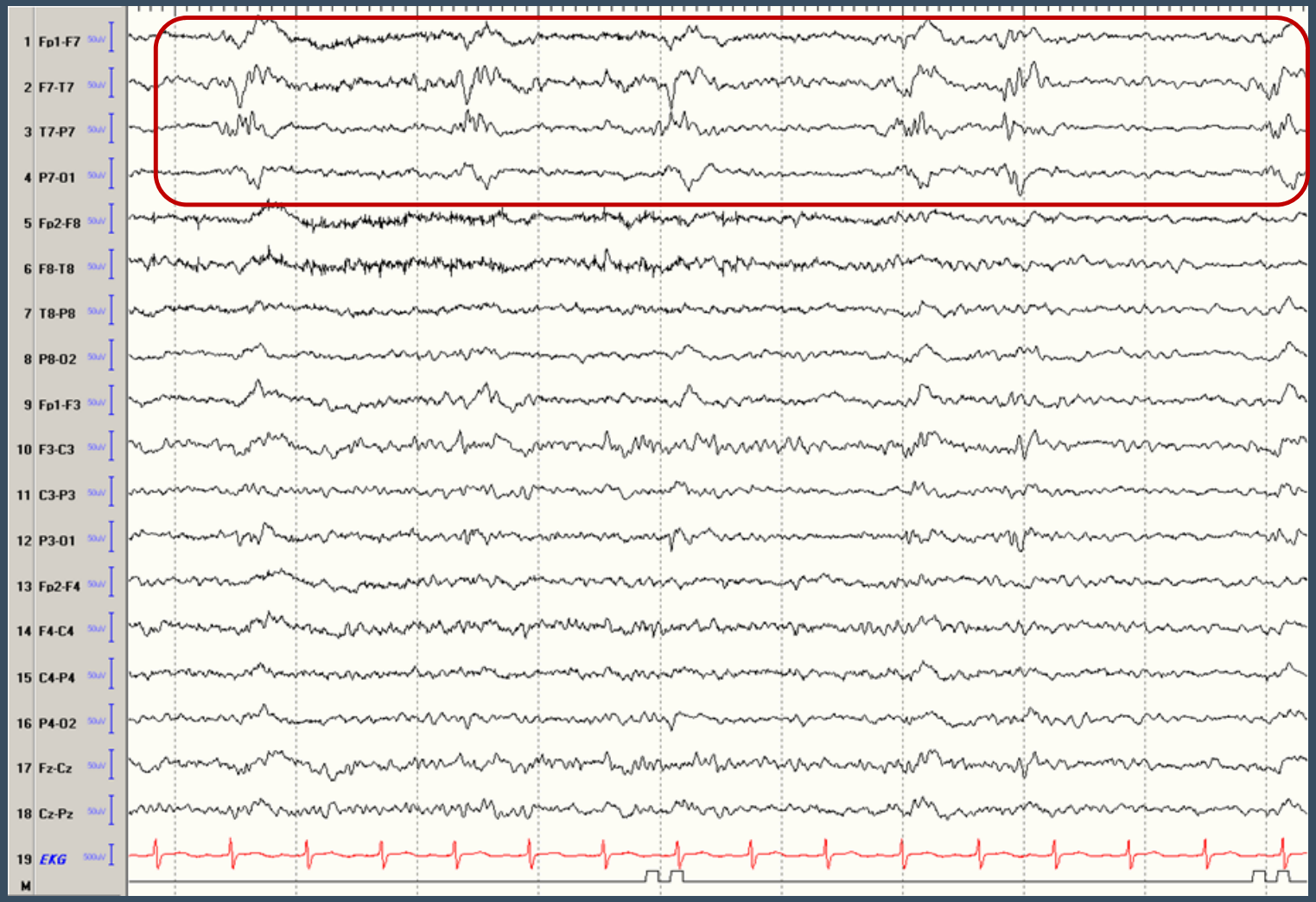
- Sharp transients (SWs or spikes) that occur in a periodic fashion either regionally or lateralized
  - Main component is negative
- Interpretation:
  - Acute/subacute: severe, regionally destructive lesion (such as ischemic, tumor, encephalitis, hemorrhage, abscess, PRES), TBI
  - Chronic: tumor, remote stroke, or TBI

Lesion on imaging	Cortical	Subcortical	Both
Orta	23%	12%	65%
Kalamangalam	70%	23%	

- Focal deficits: 60-80%
- Altered LOC: 10-35%
- High risk for seizures: 50-90% (40-70% for NCSz)
- Can precede or develop after seizure
- Mortality 25-40%

Orta 2009; Kalamangalm 2007; So, 2016

Autoimmune encephalitis



Bilateral Periodic Discharges

- Lateralized periodic discharges from two hemispheres, independent from one another
- Interpretation:
  - Seen in multifocal, bihemispheric, or diffuse cerebral insults and encephalopathies (strokes, anoxia, toxic, metabolic, infection, tumor)
  - May have an increased mortality risk compared to LPDs (61% vs 29%) and more likely to be comatose (72% vs 24%)

De la Paz and Brenner, 1981

Cardiac arrest

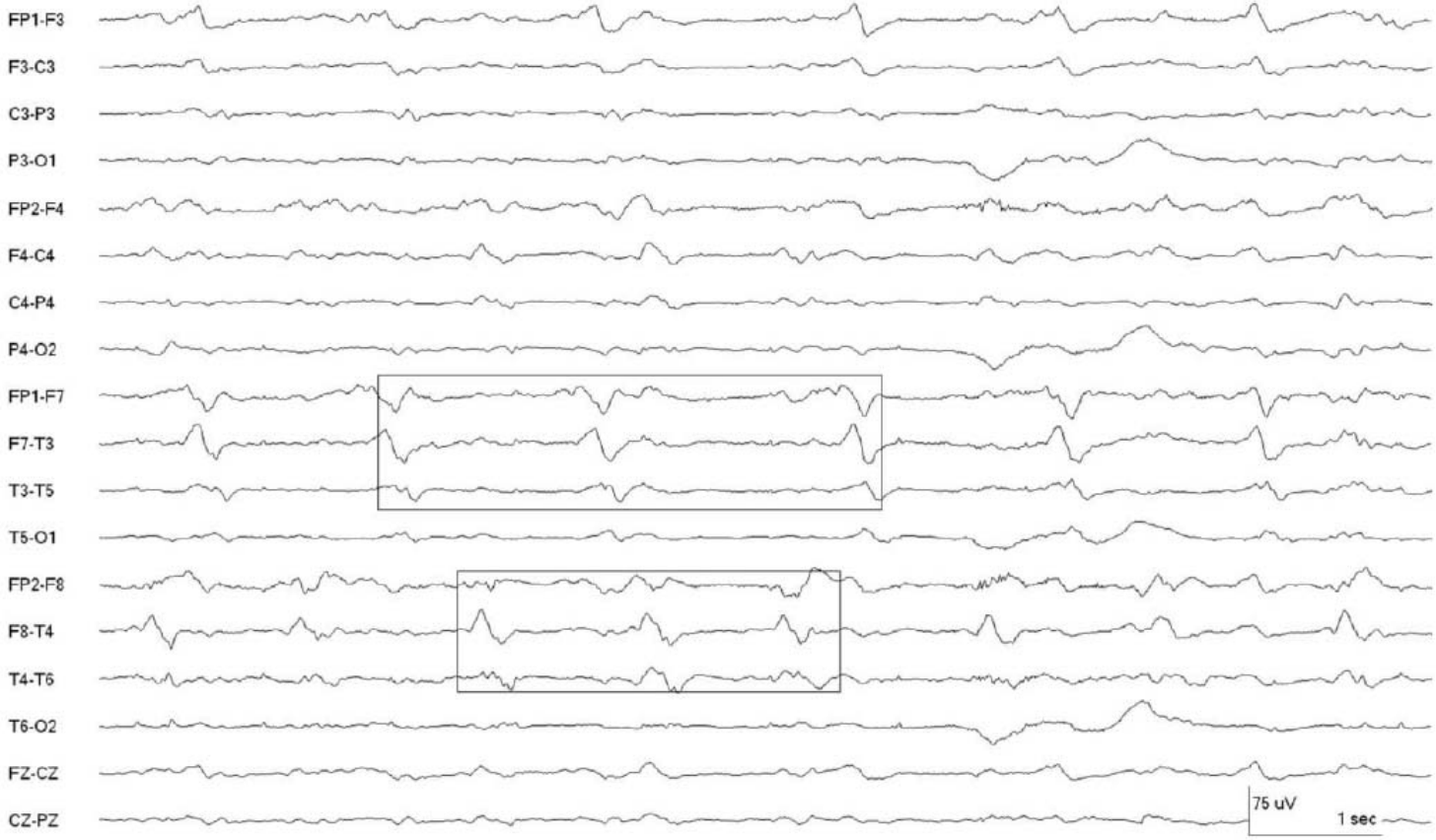


Figure 4.11 BIPLEDs. The EEG in this 75-year-old comatose woman shows BIPLEDs (three discharges on each side are boxed). The patient had a cardiac arrest the day before.

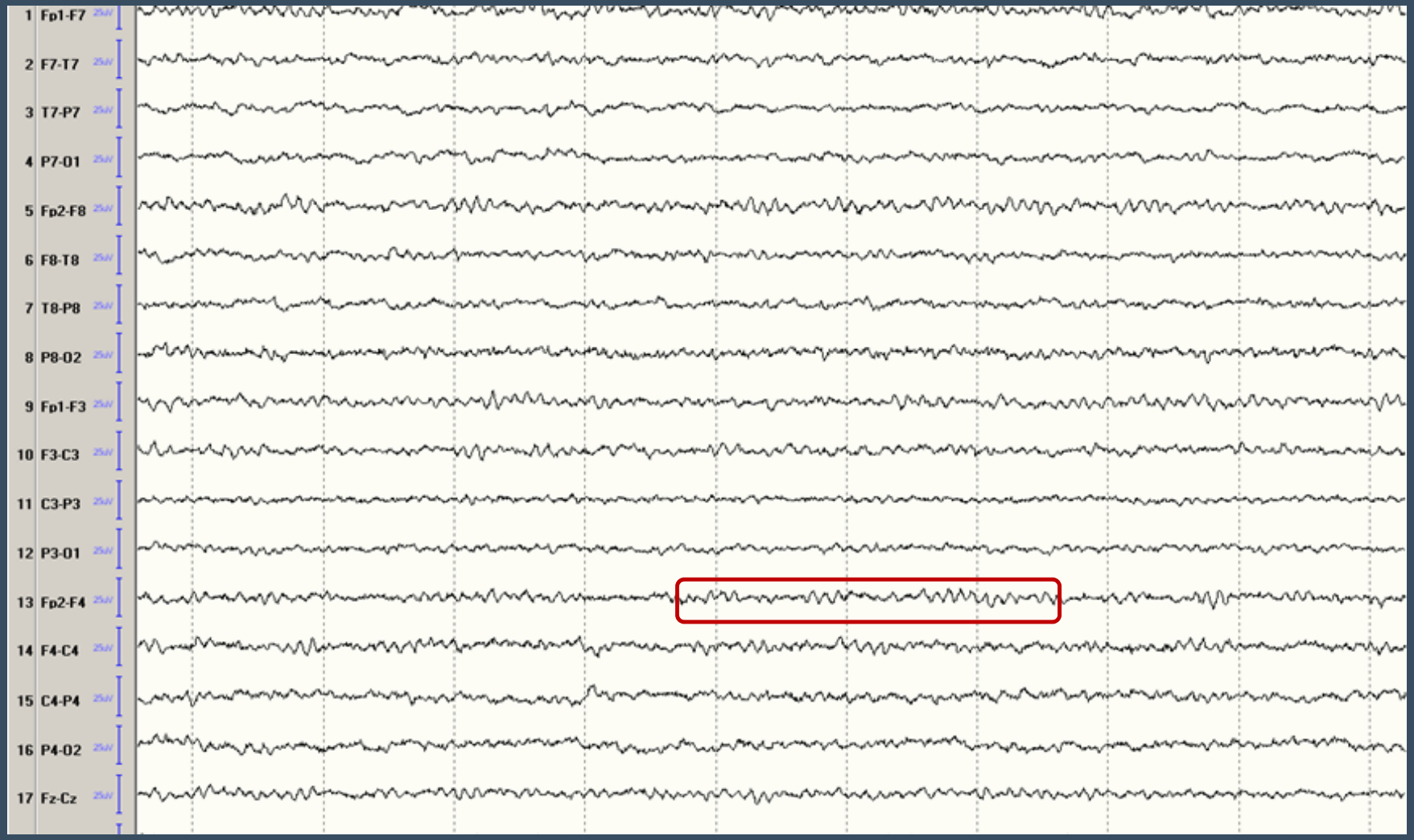
ACNS proposal name: BIPDs.

Hirsch and Brenner, 2010

Alpha Coma/Stupor

- Diffuse, invariant alpha activity (8-12Hz) in a comatose/stuporous patient
- Interpretation:
  - May indicate lesions of the brainstem at the pontomesencephalic level
  - Also seen in anoxic brain injury and drug-induced

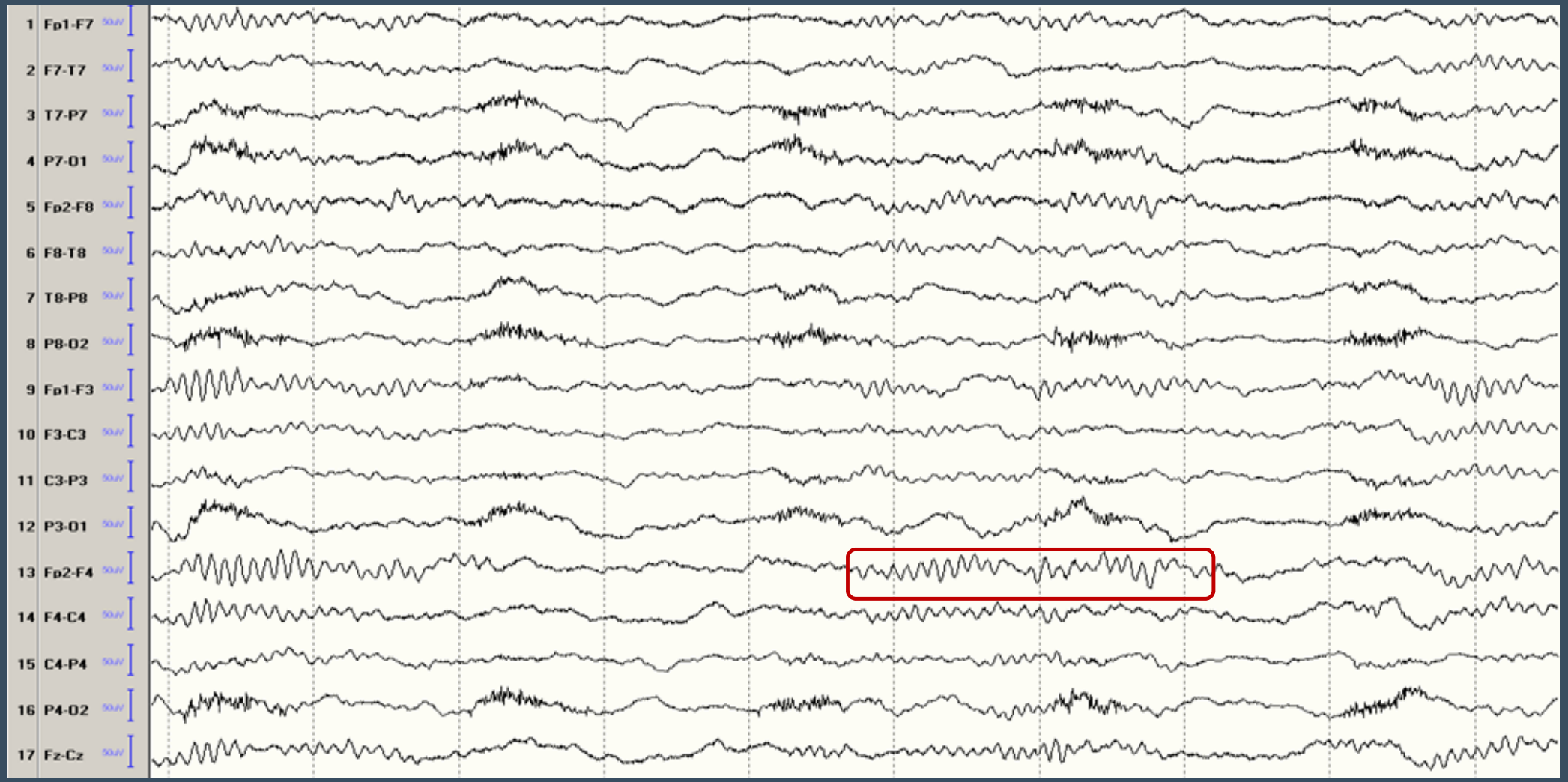
Cardiac arrest



Spindle Coma/Stupor

- EEG showing spindle (11-14Hz) in the comatose/stuporous patient
- Interpretation:
  - Typically seen in patients with lesions in the brainstem that does not impair normal sleep-generating mechanisms (i.e., caudal to the thalamus)
  - Medication effect

Propofol


1 Fp1-F7
2 F7-T7
3 T7-P7
4 P7-O1
5 Fp2-F8
6 F8-T8
7 T8-P8
8 P8-O2
9 Fp1-F3
10 F3-C3
11 C3-P3
12 P3-O1
13 Fp2-F4
14 F4-C4
15 C4-P4
16 P4-O2
17 Fz-Cz

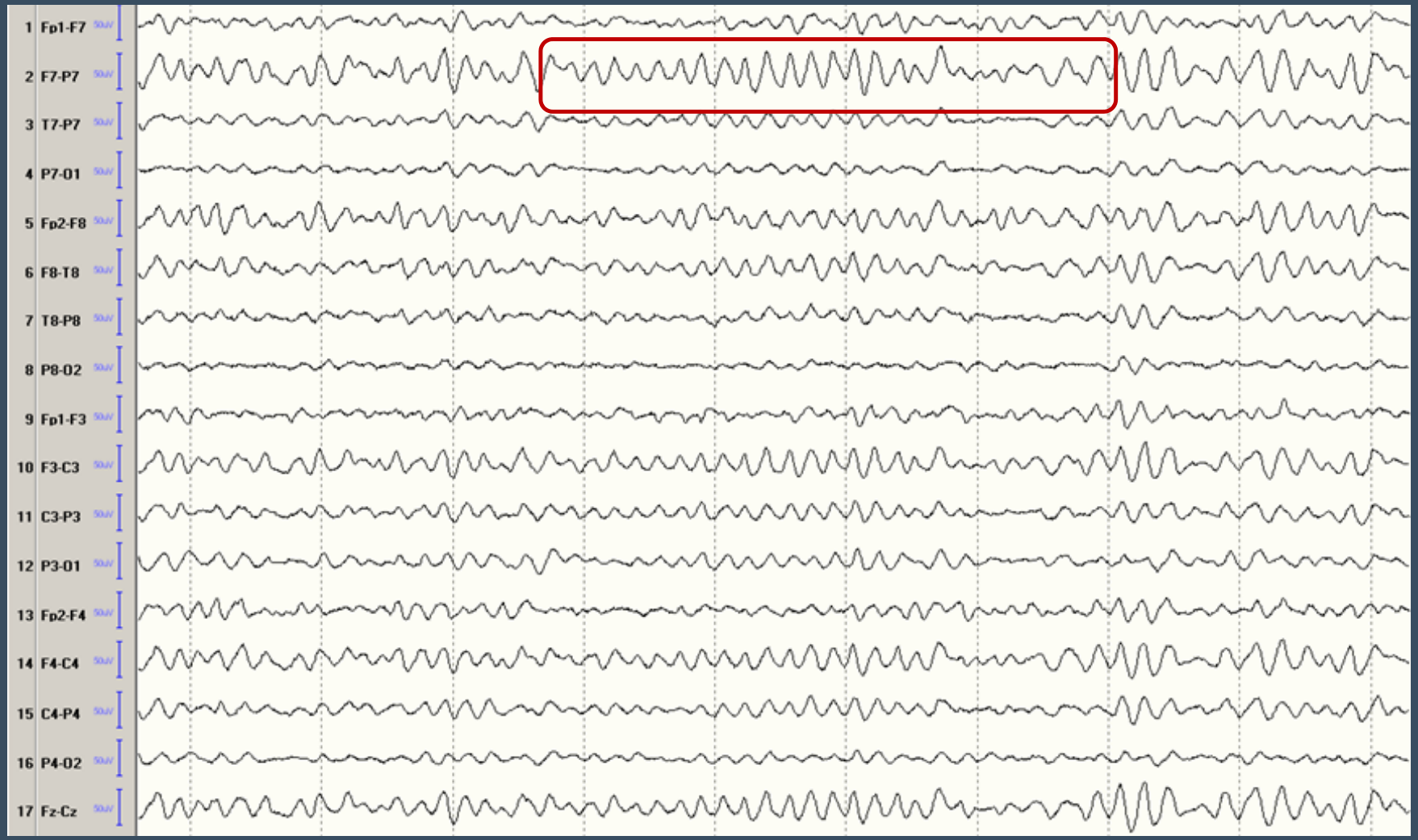
Beta Coma/Stupor

- EEG showing predominance of beta activity with amplitudes higher than 30 microvolts in the comatose/stuporous patient
- Interpretation:
  - Typically indicates drug intoxication

Theta Coma/Stupor

- EEG shows predominance of theta waves
- Interpretation:
  - Typically seen in severe diffuse encephalopathy

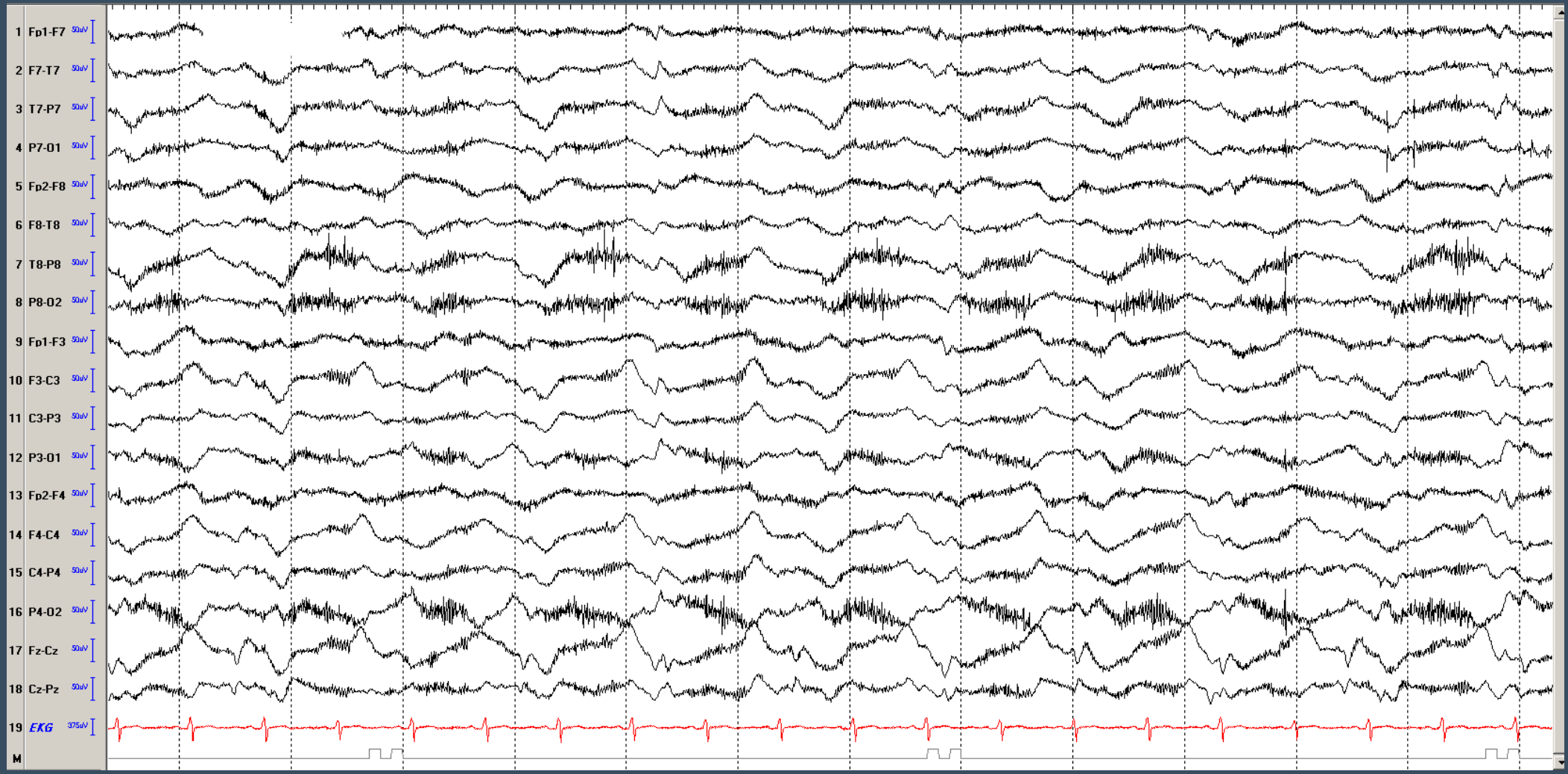
Cardiac arrest



Delta Coma/Stupor

- EEG shows predominance of delta waves
- Interpretation:
  - Typically seen in severe diffuse encephalopathy

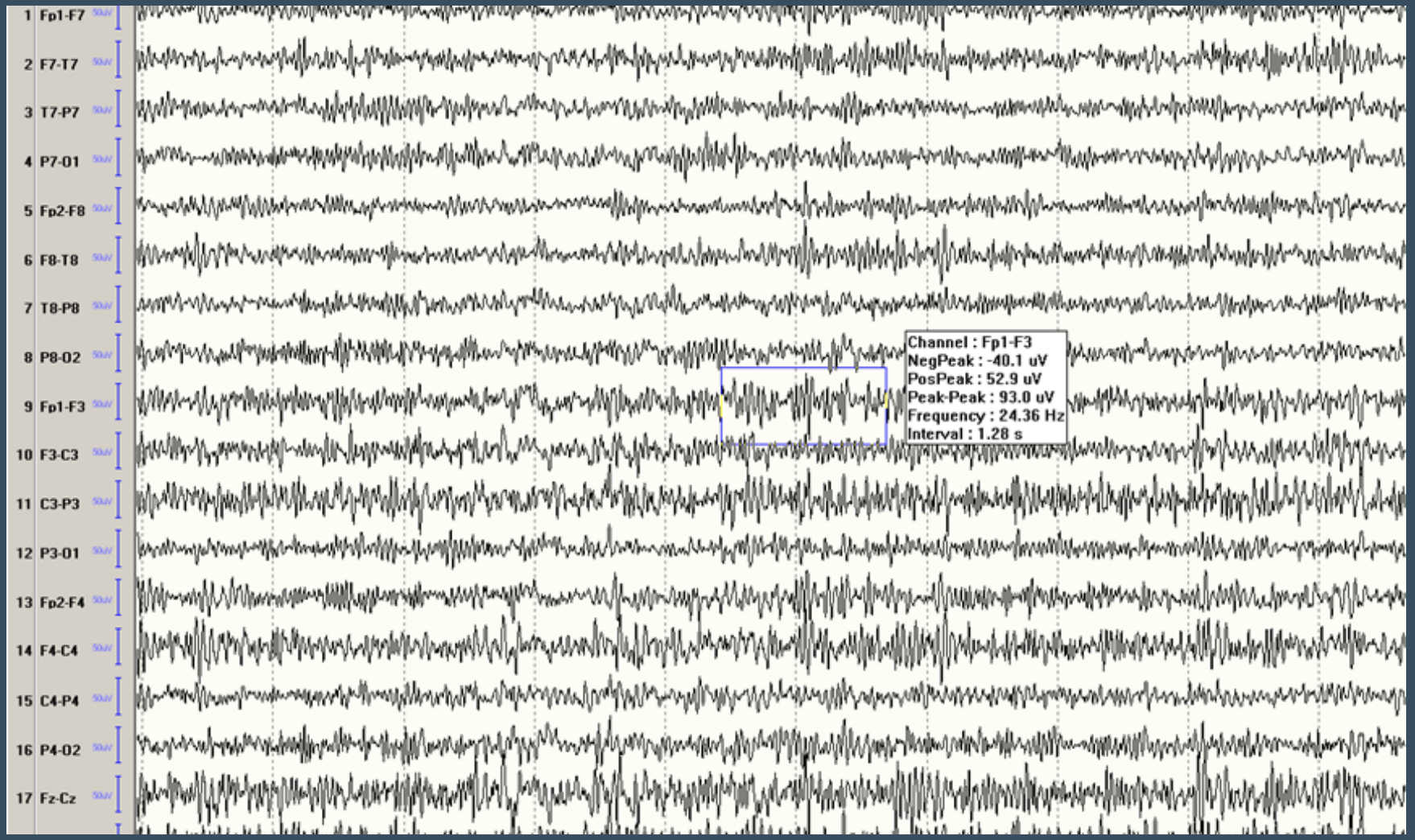
NMDA encephalitis



Excessive Fast

- At least 50% of the recording is dominated by beta activity of an amplitude of at least 50 microvolts
  - Refers to generalized EEG finding
- Interpretation:
  - Frequent finding with sedative medications such as benzodiazepines and barbiturates

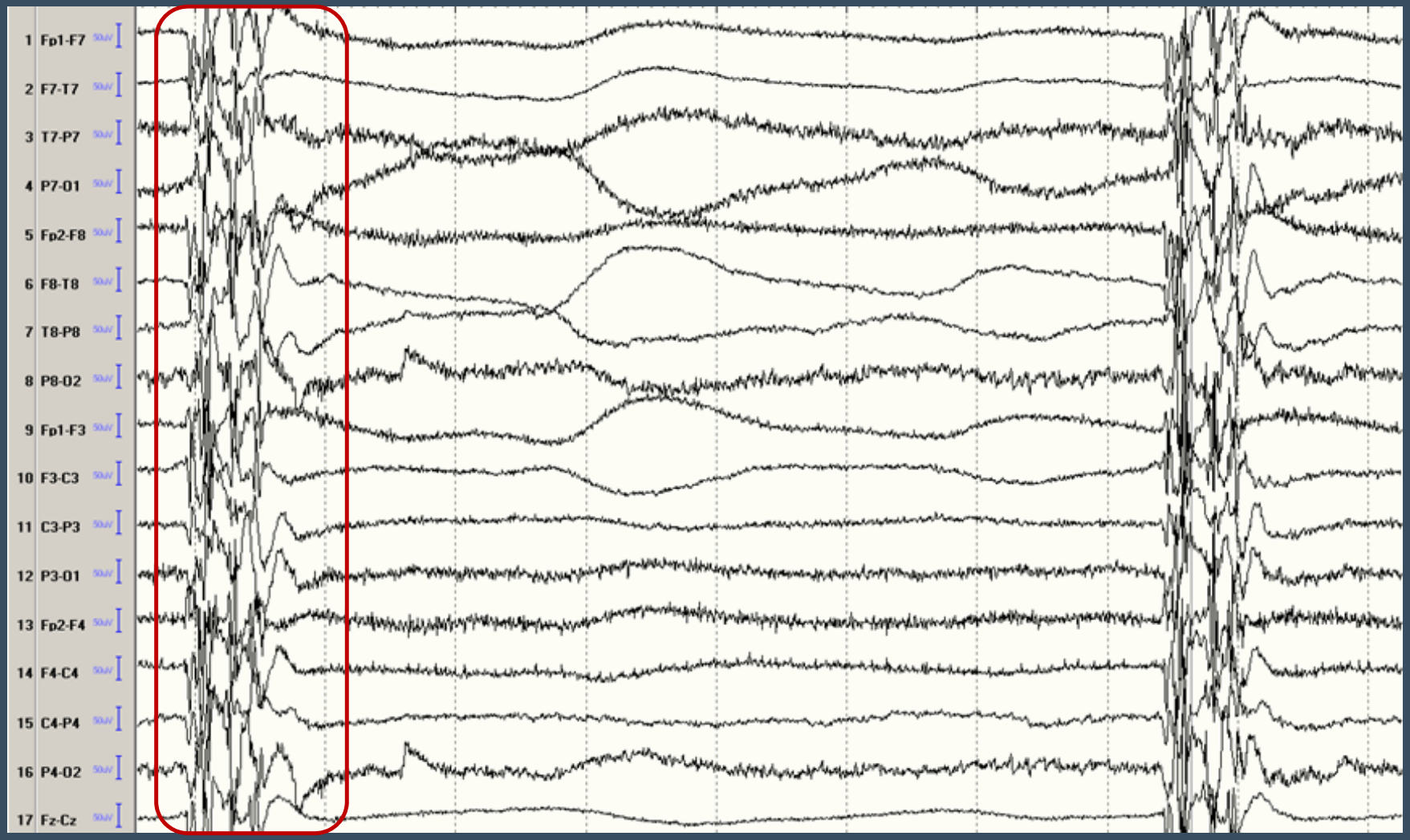
Benzodiazepine



Burst Suppression

- Burst of high amplitude complexes followed by background suppression (<10 microvolts)
- Interpretation:
  - Seen in comatose patients with severe toxic or anoxic encephalopathies
  - Profound, diffuse encephalopathy

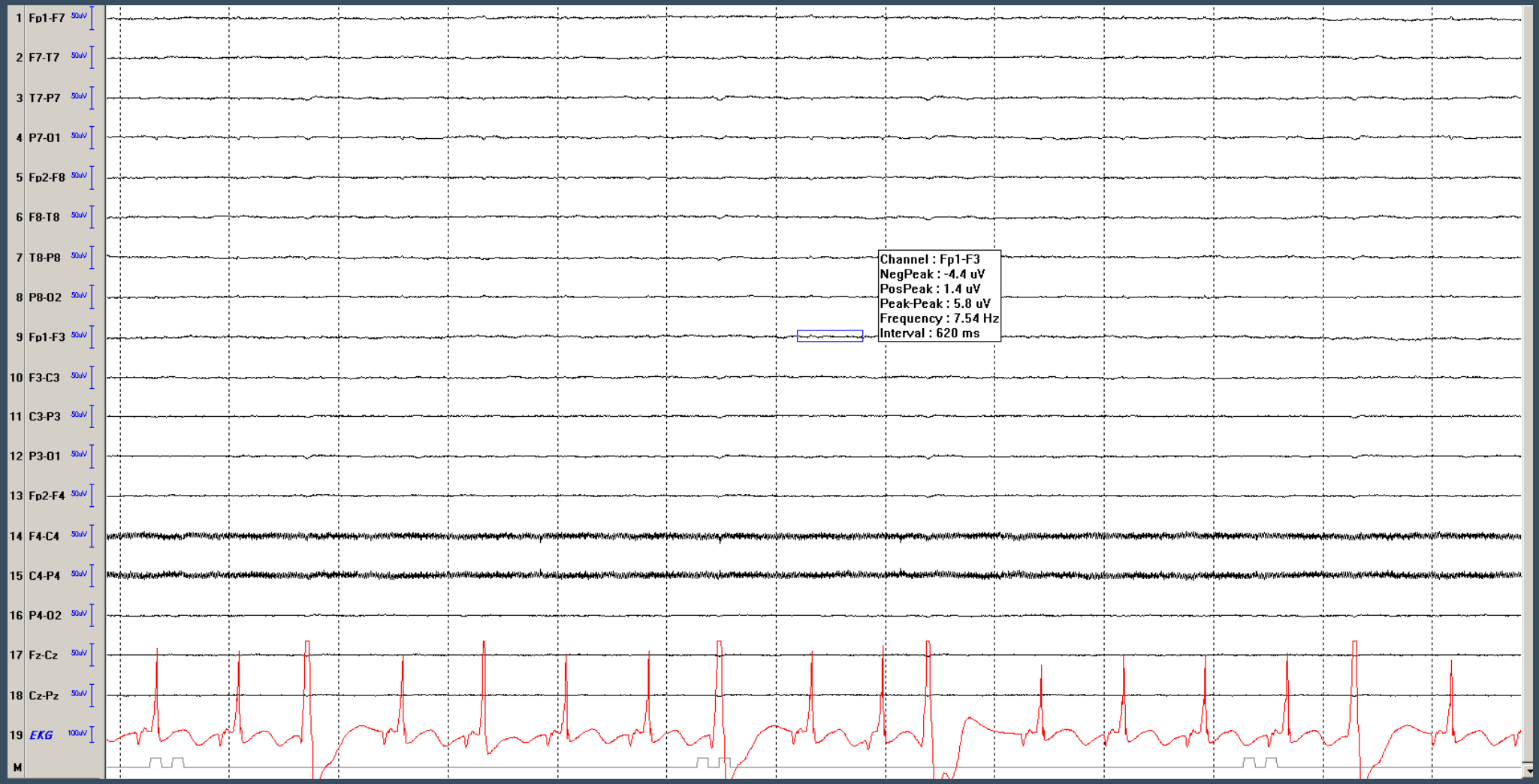
Cardiac arrest



Background Suppression

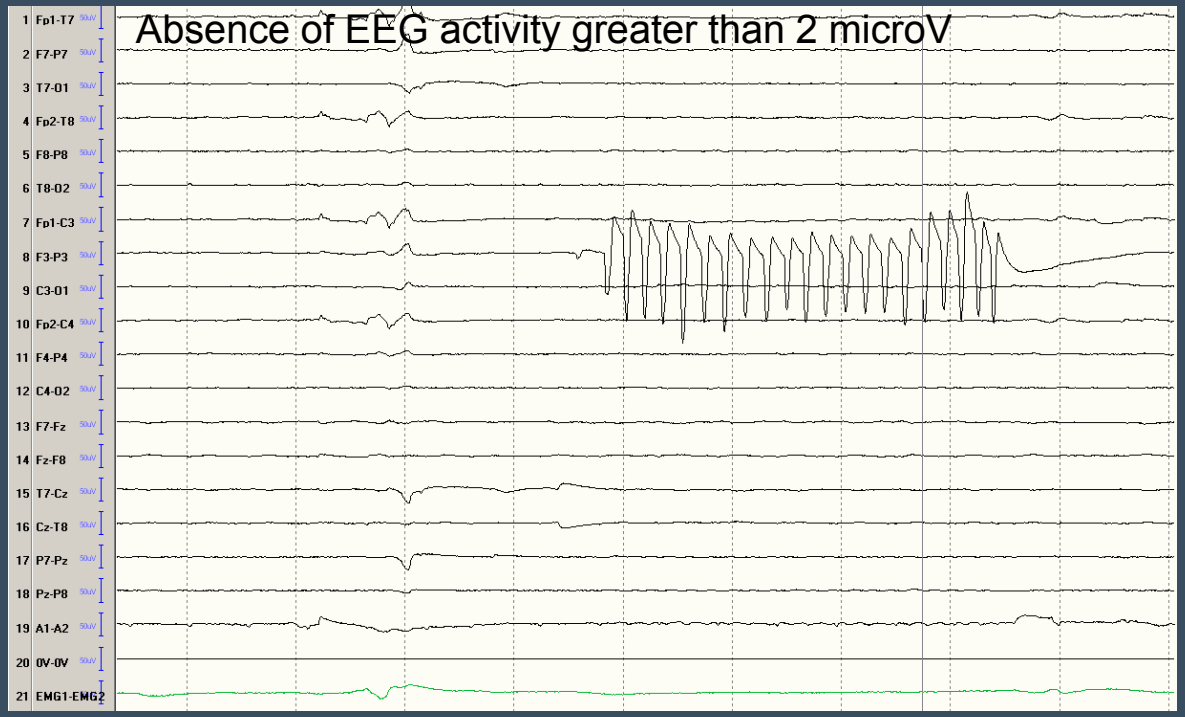
- EEG activity of less than 10 microvolts
- Interpretation:
  - Profound, diffuse encephalopathy

Right MCA stroke with malignant cerebral edema



Electrocerebral Inactivity

1. A minimum of 8 scalp electrodes should be utilized
   - A full 10-20 head set now used except in small neonates with additional extracerebral electrodes
2. Interelectrode impedances <10,000 Ohms, > 100 Ohms
   - Avoid unequal impedances (60Hz), avoid salt bridge
3. Integrity of the entire recording system should be tested
   - Touch each electrode to verify that the system from electrodes to output is connected
4. Interelectrode distances should be at least 10 cm
   - Achieved by doubling standard 10-20 distances to increase differential signal
5. Sensitivy must be increased from 7μV/mm to 2μV/mm for at least 30 mins of the recording, with the inclusion of appropriate calibrations
   - Self-limited period of ECI of up to 20 mins may occur
6. Filter settings should be appropriate for the assessment of ECS
   - LFF ≤1Hz, HFF ≥30Hz. No problem using 60Hz filter
7. Additional monitoring techniques should be employed when necessary
   - ECG essential
   - Document respiration/ventilator cycles
   - Physiological noise from patient monitored by 2 electrodes on dorsum of hand
   - Machine/environmental noise checked by a "dummy" 10,000 Ohm resistor in one channel
   - If EMG obscures record, use short-acting neuromuscular paralysis
8. There should be no reactivity to intense somatosensory, auditory, or visual stimuli
9. Recordings should be made only by a qualified technologist
10. A Repeat EEG should be performed if there is doubt about ECS
    - After interval of 6 hours or more



Stimulatory: Auditory, visual, tactile; tap on P3; sensitivity of 2uV/mm

ACNS website, accessed 10/2015

EEG of Focal Lesions

TABLE 3. Anatomic Localization and EEG Pattern

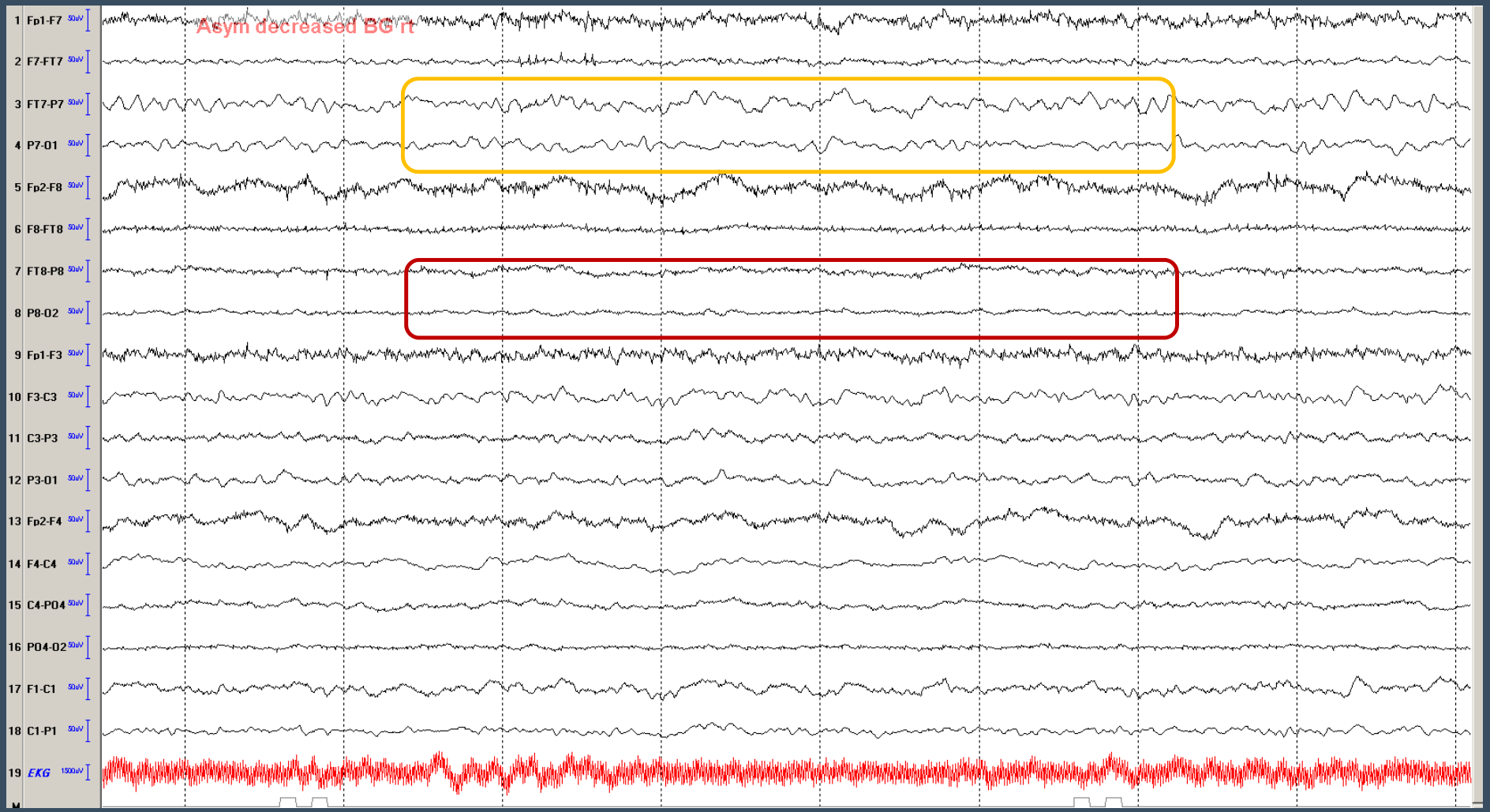
Anatomic Localization	EEG Frequency/Pattern
Cortical	Decreased α amplitude Slowing of posterior α background frequency
Subcortical/white matter	Increased polymorphic or arrhythmic δ-activity TWs Frontal intermittent δ-activity
Cortical and subcortical	Slow posterior basic rhythm (background activity) *with* slow-wave intrusion (arrhythmic δ-activity)
Brain stem	Arrhythmic δ-activity, rhythmic δ-activity Impaired arousal patterns Spindle activity

Kaplan and Rossetti 2016

Asymmetry

- Refers to amplitude differences of physiological EEG activity
- Asymmetry of frequency is classified as regional or lateralized slowing
- Classified when there is a reduction of at least 50% (or increase of at least 100%) compared to the contralateral hemisphere
- Interpretation:
  - Typically a reliable sign of regional structural lesions or in those with prior craniotomy

Right MCA ischemic stroke



Left frontal aneurysm s/p clipping

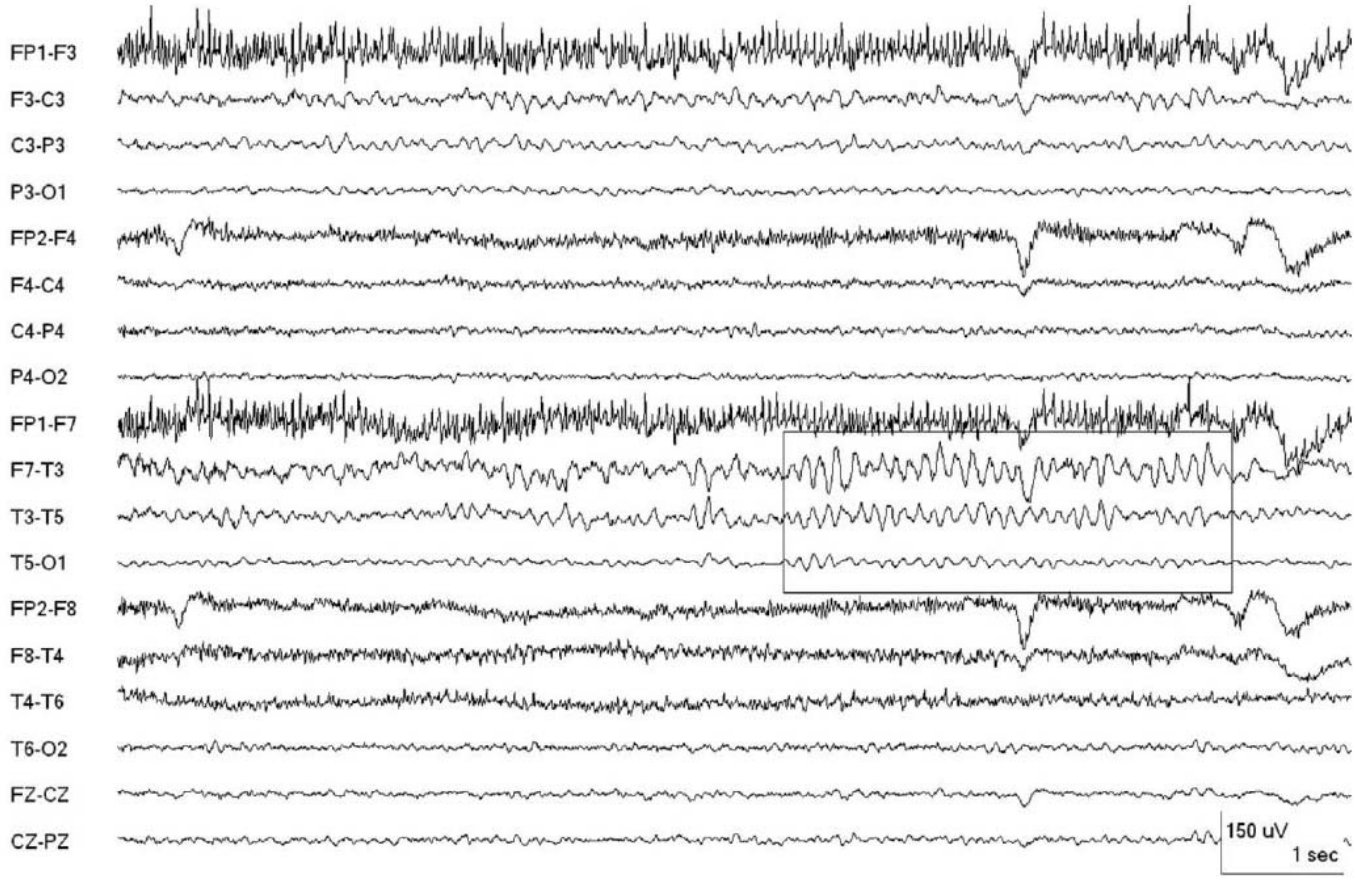


Figure 2.15 Breach rhythm. A 63-year-old woman s/p left frontal aneurysm clipping. This EEG shows higher amplitudes of faster frequencies on the left compared to the right, most prominent at T3 (left temporal; box). This is due to a skull defect on the left. In the presence of a skull defect (even a small one such as a skull fracture or burr hole), faster frequencies appear higher amplitude and often sharper, resulting in what is known as a breach rhythm or breach effect.

Hirsch and Brenner, 2010

Reactivity

- Types:
  - Increase of background frequencies
  - Brief diffuse attenuation
  - Decreased background frequencies (“paradoxical reactivity”)
  - Stimulus-induced rhythmic periodic, or ictal discharges (SIRPIDS)
    - Related to dysregulated afferent input into hyperexcitable cortex

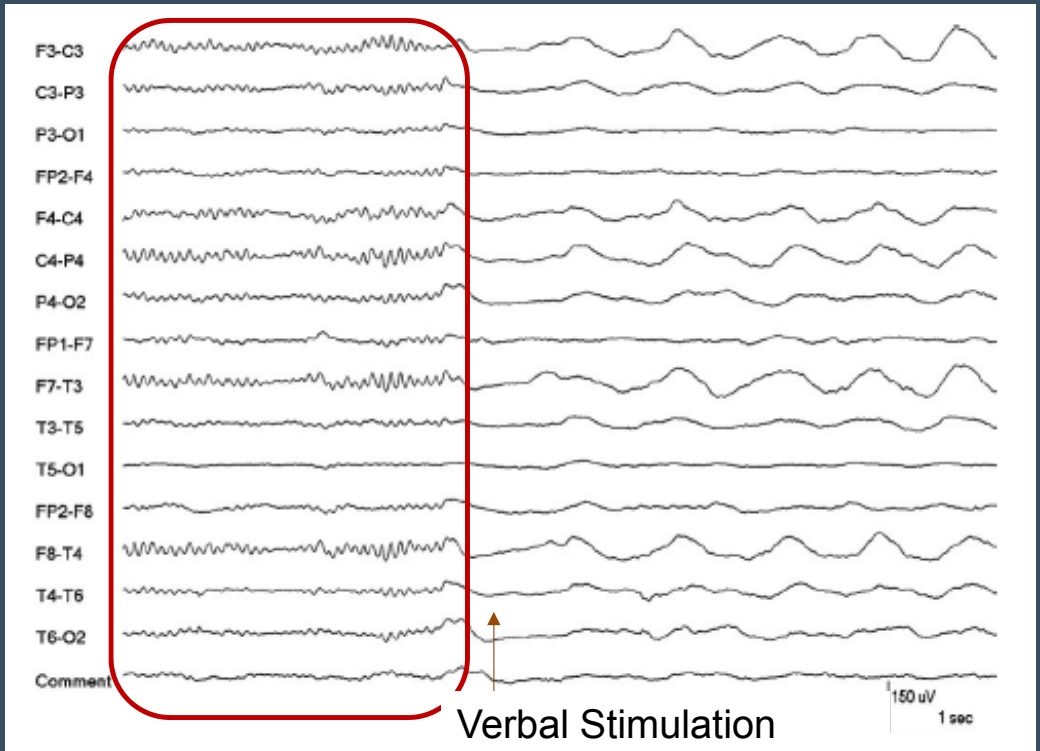
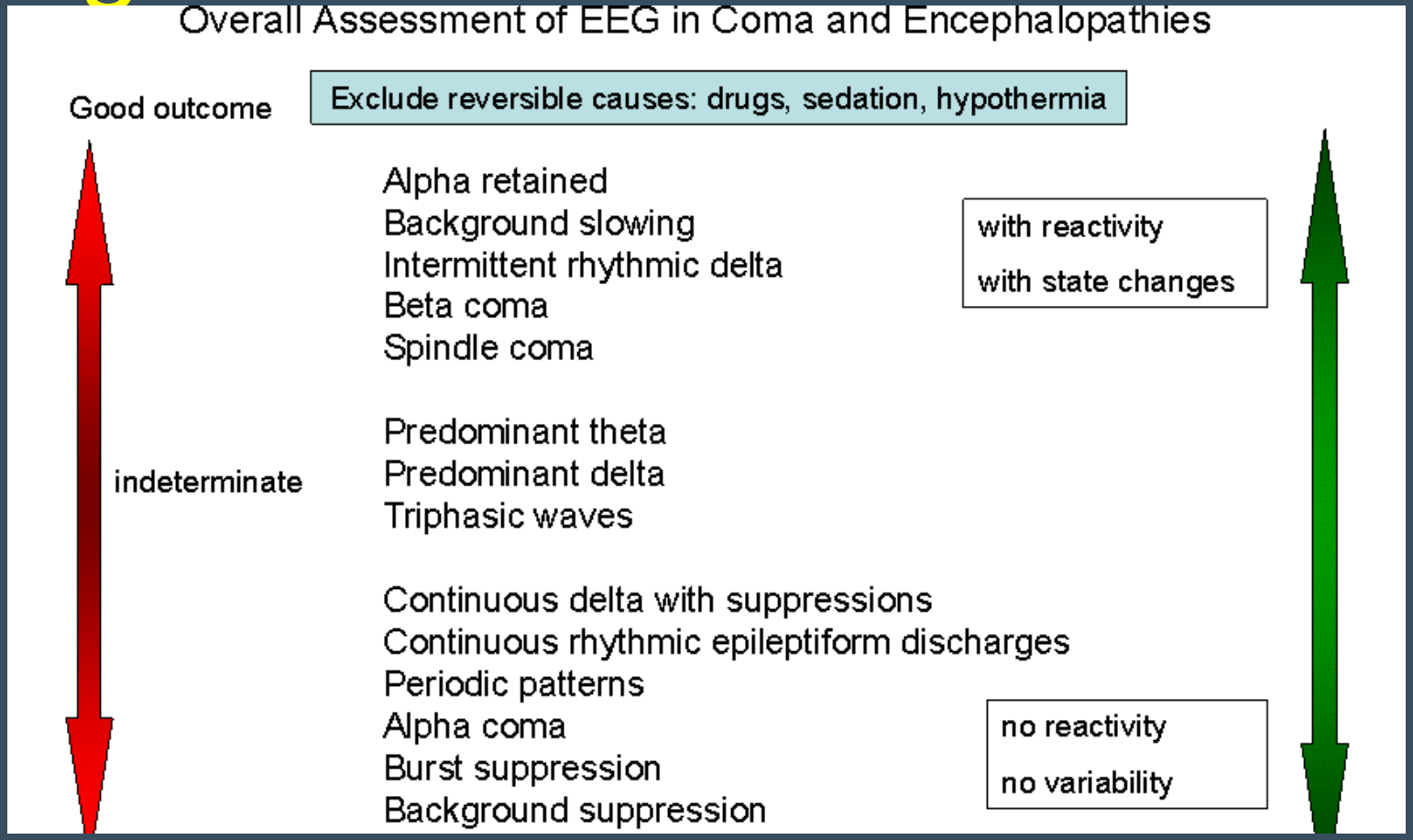


FIGURE 2. Reactivity in a 19-year-old woman with an intraventricular hemorrhage. There is attenuation of faster frequencies and bursts of delta activity when the patient is called.

Kaplan and Rossetti 2016

Prognosis



Bricolo, 1978; Jaitly 1997; DeLorenzo 1998; Lawn 2000; Vespa 2003; Claassen et al., 2006; Claassen et al., 2007; Claassen EEG surface and depth ppt, accessed 10/2015; Tjepmkema-Cloostermans et al., 2015; Rossetti et al., 2010 ; Azabou et al, 2018

Association with Seizures

- Stimulus Induced Rhythmic, Periodic, or Ictal Discharges (SIRPIDS)
  - 33 patients (22%) found to have SIRPIDs
    - 24 of the patients had acute brain injury
  - 17/33 had seizures
- Brief Potentially Ictal Rhythmic Discharges (B(I)RDs)
  - ~2% of ICU-EEGs (typically 1-3 seconds)
  - High prevalence of EEG seizures (75%) and occur before EEG seizures in 93%
- Lateralized periodic discharges
  - 40% of patients who had seizures also had LPDs; only 11% of patients without seizures had LPDs
  - Overlying fast frequencies have an OR of 5.16 for seizures/status epilepticus
    - Time to first seizure 40.5 +/- 12.5 hours
  - Hazard ratio of development of epilepsy among patients without electrographic seizures with LPDs was 7.7 (2.9-20.7) and was 11.4 (4-31.4) if associated with electrographic seizures
- Generalized periodic discharges
  - Associated with nonconvulsive seizures (27%) and nonconvulsive status epilepticus (22%)

Hirsch et al., 2004; Yoo et al, 2014; Foreman et al 2012; Newey et al 2017; Claassen et al, 2004; Punia et al 2018

ACNS Critical Care EEG Terminology

Cleveland Clinic

Primary Objectives

- Develop standardized terminology for scientific investigation related to rhythmic and periodic EEG patterns (i.e., patterns of uncertain significance) seen in encephalopathic patients
  - Excludes patterns that most define as seizures
- Allow collaborative, multicenter studies
- Allow comparison of results between centers

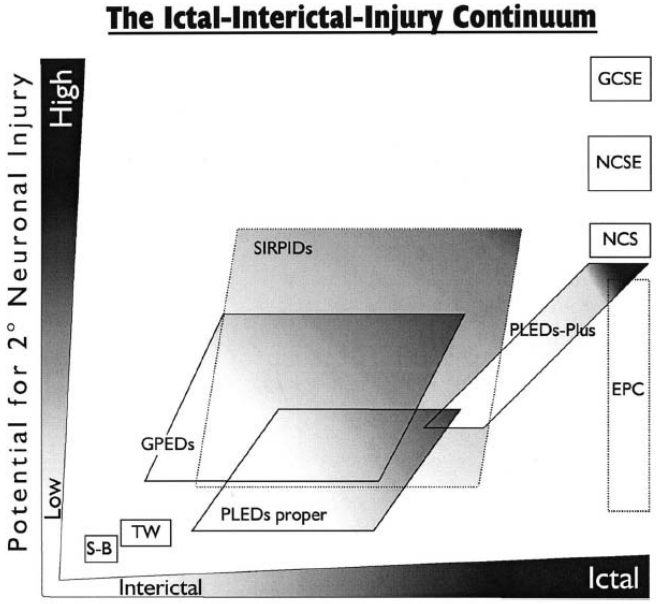


FIGURE 5. This plot demonstrates various clinicoelectrographic diagnoses depicted on the ictal-interictal continuum. The potential for secondary (2°) neuronal injury, shown on the *y*-axis, should be a more important indicator of whether treatment should be aggressive. This figure represents our current understanding of electroclinical entities along two distinct dimensions. The placement of each entity on the graph is approximate and conceptual, with further study required to improve precision and accuracy. Note that if clinical correlate is present with any of the patterns, it would be considered ictal by definition, though this does not necessarily suggest an appreciable increase in the likelihood of neuronal injury. EPC, epilepsia partialis continua; GCSE, generalized convulsive status epilepticus: GPEDs, generalized periodic epileptiform discharges; NCS, nonconvulsive seizures; NCSE, nonconvulsive status epilepticus; PLEDs, periodic lateralized epileptiform discharges; S-B, suppression-burst; SIRPIDs, stimulus-induced rhythmic, periodic, or ictal discharges; TW, triphasic waves.

Hirsch et al, 2013; Chong and Hirsch, 2005; Handbook of ICU EEG Monitoring, 2013

ACNS Terminology

Describe with main term #1 followed by #2, with modifiers added as appropriate

Term #1 (location)	Term #2 (patterns)	Plus modifiers (add only if present with pattern and not in background)	
Generalized (G)	Periodic discharges (PD)	+F	Superimposed fast activity; use with PDs or RDA only
		+R	Supermiposed rhythmic activity use with PDs only
Lateralized (L)		+FR	Use for PDs if both subtypes apply
	Rhythmic delta activity (RDA)	+F	Superimposed fast activity; use with PDs or RDA only
Bilateral independent (BI)		+S	Supermiposed sharp activity; use with PDs only
		+FS	Use for RDA if both subtypes apply
Multifocal (Mf)	Spike wave (SW)	No + modifiers	

Additional Modifiers									
Prevalence (% of record)	rare less than 1%		Occasional 1-9%		Frequent 10-49%		Abundant 50-89%		Continuous ≥ 90%
Duration	Very brief <10 s		Brief 10-59 s		Intermediate 1-4.9min		Long 5-59min		Very long ≥ 1 hour
Frequency (cycles/s)	<0.5	0.5	1	1.5	2	2.5	3	3.5	≥4
Sharpness	Blunt		Sharply contoured, ≥ 200msec		Sharp, 70-200msec		Spiky, < 70 msec		
Polarity	Positive		Negative		Diple, horizontal/tangential		Unclear		
Absolute amplitude	Very low, <20microV		Low, 20-49microV		Medium, 50-199microV		high, > 200microV		
Stimulus induced	Stimulus induced (SI-)		Spontaneous (Sp-)		Unknown				

Includes any rhythmic or periodic pattern that continues for at least six cycles (e.g., 1 per second for 6 seconds, or 3 per second for 2 seconds)

For G: specify frontally, midline, or occipitally predominant
For L, BI, Mf: specify lobes involved

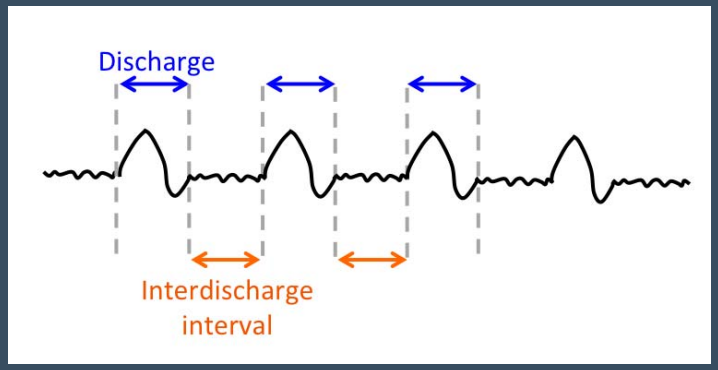
Inter-rater agreement (kappa, 95% CI):

- **Term #1: 89.3 (89.1-89.6)**
- **Term #2: 80.3 (79.4-81.2)**
- **Any plus modifier: 19.2 (17.5-20.9)**
  - **+F 65.5 (64.4-66.7)**
  - **+R 67.4 (66.5-68.3)**
  - **+S 81.8 (81.2-82.5)**
- **Triphasic morphology: 58.2 (56.1-60.2)**

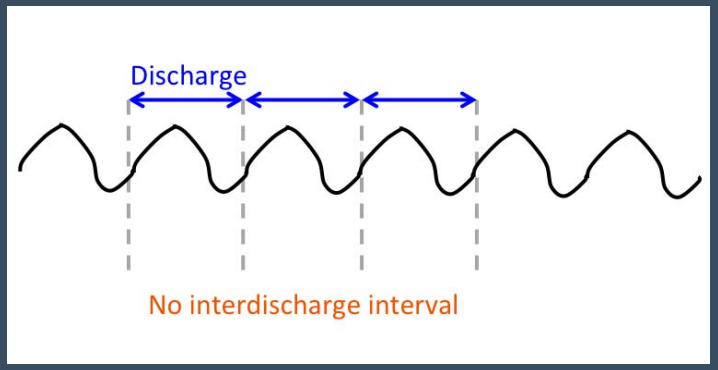
Hirsch et al, 2013; Gaspard et al, 2014; Foreman et al, 2015; Handbook of ICU EEG Monitoring, 2013

Main term #2

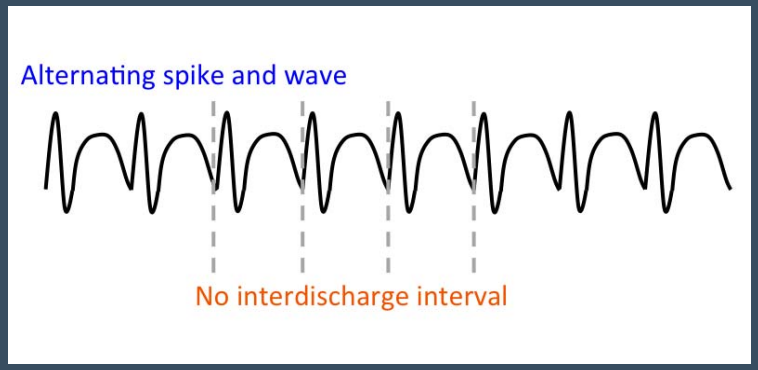
Periodic discharge



Rhythmic delta activity



Spike-wave



ACNS ICU-EEG Terminology slide deck, 2012; Handbook of ICU EEG Monitoring, 2013

Terminology

Old Term	New Term
Triphasic waves, most of record	Continuous GPDs at 2Hz with triphasic morphology
PLEDs	LPDs
BiPLEDs	BiPDs
GPEDs/PEDs	GPDs
FIRDA	Occasional brief 2Hz GRDA, frontally predominant
PLEDs+	LPDs+
SIRPIDs with evolving RDA	SI-evolving LRDA
Lateralized seizure, delta frequency	Evolving LRDA
Semi-rhythmic delta	Quasi-RDA

EEG Patterns in Coma:

- RDA – GRDA, FIRDA
- GPDs +/- triphasic morphology
- Low voltage, slow, nonreactive pattern
- Specific patterns (beta, spindle, alpha, theta coma)
- Burst suppressoin

ACNS ICU-EEG Terminology slide deck, 2012; Handbook of ICU EEG Monitoring, 2013

Conclusion

- CEEG is a neuromonitoring tool for critically ill patients.
- Many EEG patterns emerge in the critically ill patient and may have prognostic implications.
- Standardizing terminology is important for better understanding of these rhythmic and periodic patterns.

Every life deserves world class care.

Supplemental Slides

Cleveland Clinic

ACNS Terminology

Training Slides

Main Terms for *Rhythmic and Periodic patterns*

- Describe with main term # 1 followed by #2, with modifiers added as appropriate.

Main term #1	Main term #2
(G) Generalized	(PDs) Periodic Discharges
(L) Lateralized	(RDA) Rhythmic Delta Activity
(BI) Bilateral Independent	(SW) (Poly)Spike-&-Wave/Sharp-and-Wave
(Mf) Multifocal	

Main Term #1: Optional additional informations

- For G: Specify
  - *frontally predominant* (= amplitude anterior derivations >50% that in posterior derivations on ipsilateral ear, average, or noncephalic referential recording)
  - *occipitally predominant*
  - *midline predominant* (= amplitude in midline derivations that is at least 50% greater than in parasagittal derivations on an average or non-cephalic referential recording)
  - *generalized, not otherwise specified*

- For L: specify
  - *lobe(s) most involved* or *hemispheric*
  - *unilateral* vs *bilateral asymmetric*

- For BI and Mf: specify
  - *lobe(s) most involved* or *hemispheric*
  - *bilateral symmetric* vs *bilateral asymmetric*

Main Term #1: Optional additional informations

- For the purpose of this nomenclature, the term “generalized” refers to any bilateral, bisynchronous and symmetric pattern, even if it has a restricted field [e.g. bifrontal])”
- Bifrontal or bioccipital patterns are termed ‘generalized, with frontal predominance’ or ‘generalized, with occipital predominance’

- Patterns that are regional or focal would be called “lateralized”

- Patterns seen bilaterally but clearly more prominent on one side would be called “Lateralized, bilateral asymmetric” (NOT generalized)

Main Term #2

- PD: Periodic Discharges
- RDA: Rhythmic Delta Activity
- SW: Spike-and-Wave, Sharp-and-Wave or Polyspike-and-Wave

Main Term #2: Definitions

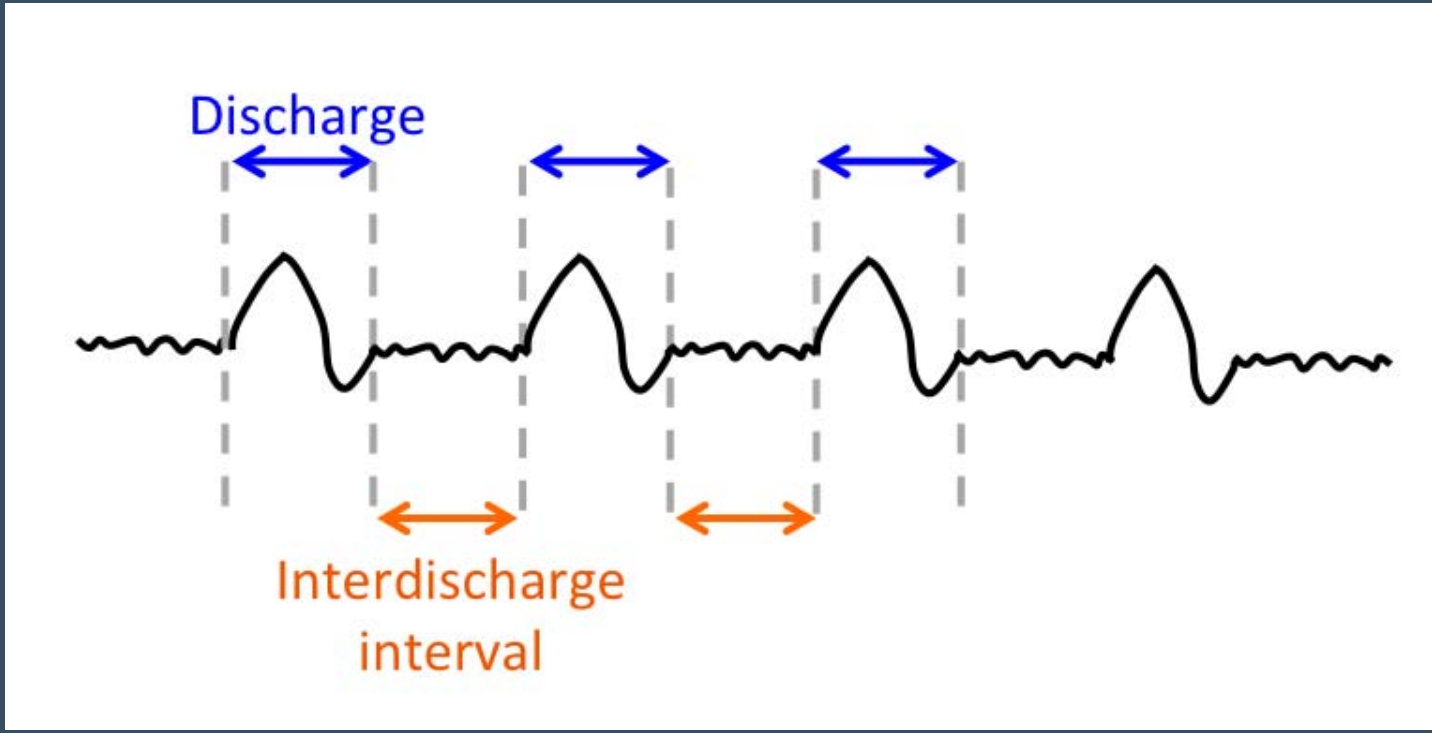
•***Periodic discharges***= repeating waveforms/discharges with (relatively) uniform morphology at nearly regular intervals. Applies *only* to **single discharges** (must have ≤3 phases [i.e. ≤2 baseline crossings] or any discharge lasting ≤0.5 sec regardless of number of phases) and *not* to **bursts** (discharges lasting >0.5 sec and having ≥4 phases [i.e. ≥3 baseline crossings]). "Nearly regular intervals" = cycle length (period) varying by <50% from one cycle to the next in most (>50%) cycle pairs.

•***Rhythmic*** = repetition of a waveform with relatively uniform morphology and duration and without an interval between consecutive waveforms. Duration of one cycle (the period) should vary by <50% from the duration of the subsequent cycle for the majority (>50%) of cycle pairs to qualify as a rhythmic pattern.

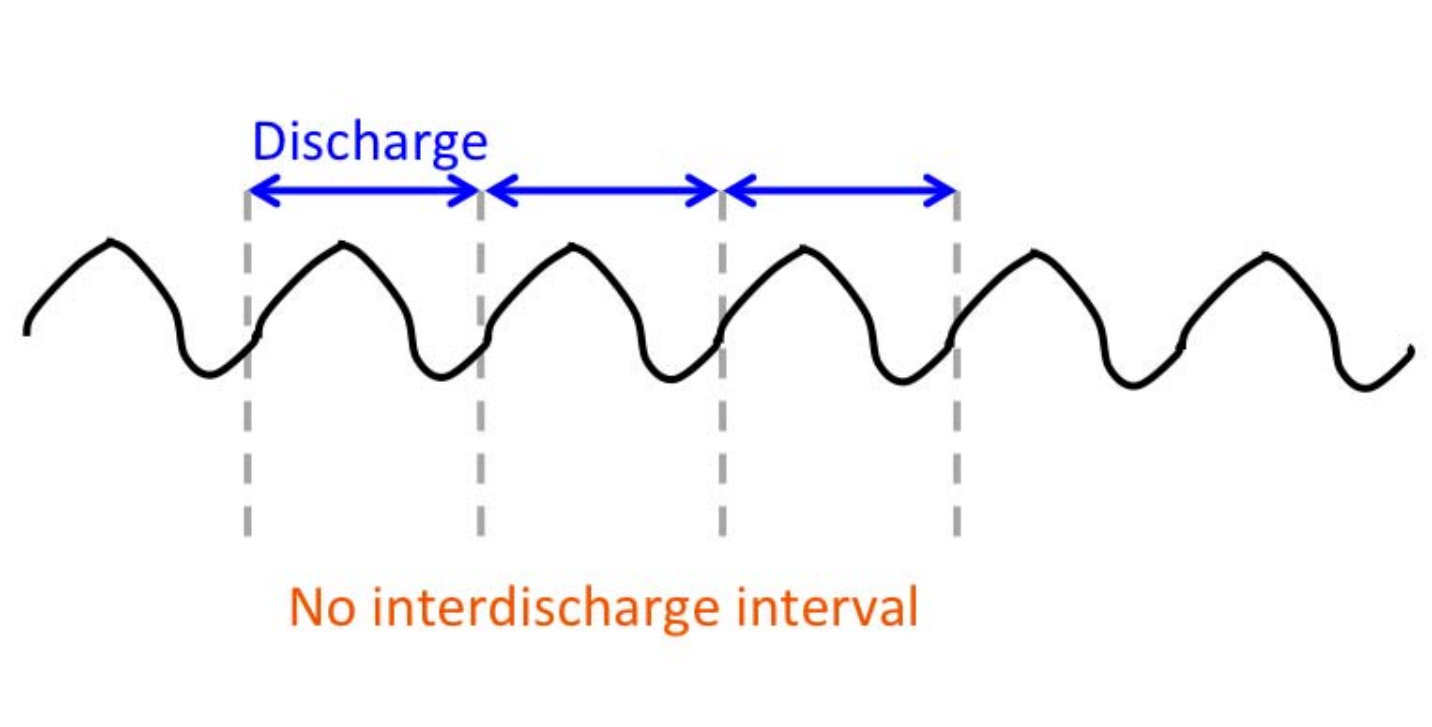
•***Spike-and-wave*** = spike, polyspike or sharp wave consistently followed by a slow wave in a regularly repeating pattern (spike-wave-spike-wave-spike-wave), with a consistent relationship between the spike (or sharp wave) component and the slow wave.

-*This terminology does not signify whether or not these patterns are ictal/related to seizures.*

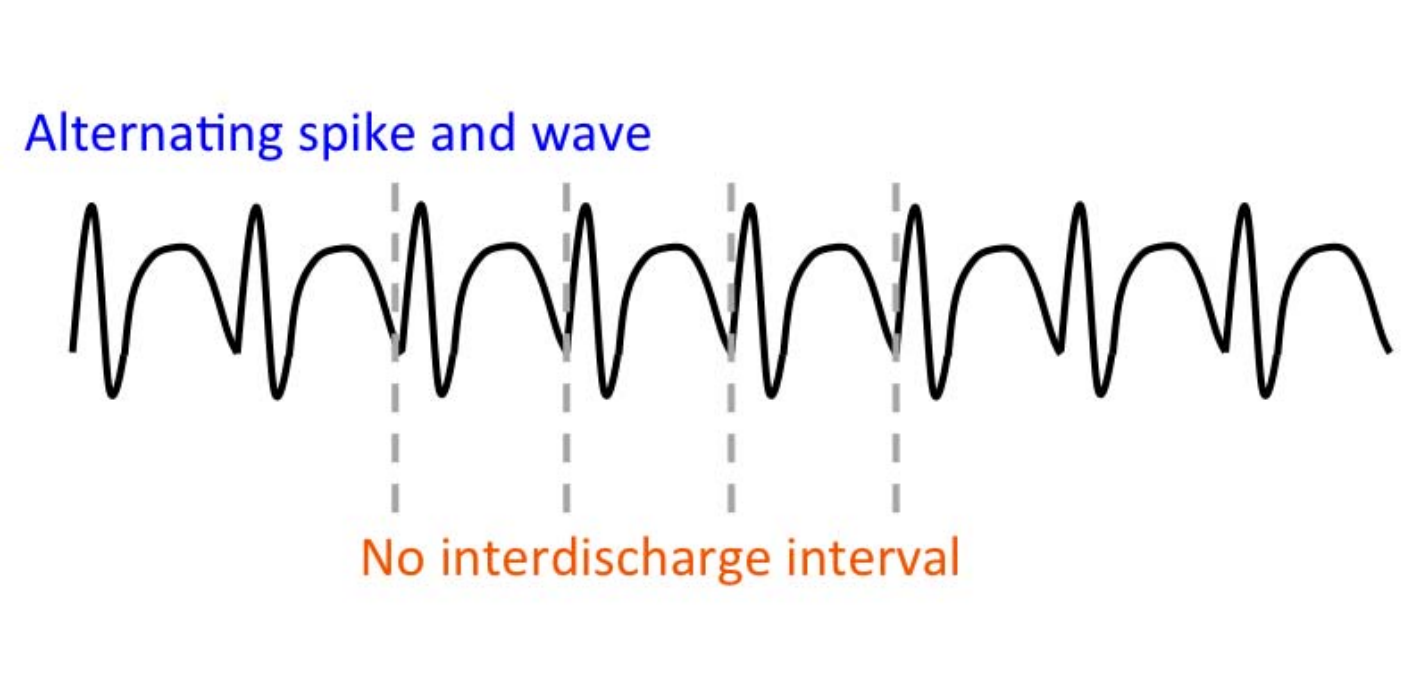
Main term 2: Periodic



Main term 2: Rhythmic



Main term 2: Spike-and-Wave



Main terms #1,2 cont'd….

- NOTE 1: A pattern can qualify as rhythmic, periodic or spike-and-wave as long as it continues for *at least 6 cycles* (e.g. 1/s for 6 seconds, or 3/s for 2 seconds).

- NOTE 2: If a pattern qualifies as both GPDs and RDA, it should be coded as GPDs+R rather than RDA+ (see slide 53 for description of "+" suffixes).

Modifiers: Prevalence

- Specify:

  Approximate percent of record/epoch, using the following divisions, or consistently use the suggested equivalent clinical terms:

  - ≥90% "Continuous"
  - 50-89% "Abundant"
  - 10-49% "Frequent"
  - 1-9% of "Occasional"
  - <1% of "Rare"

Modifiers, cont'd: Duration

- Specify for each pattern the typical duration of pattern (if not continuous) using the following divisions or suggested equivalent clinical terms.
  - ≥1 hour "Very long"
  - 5-59 min "Long"
  - 1-4.9 min "Intermediate"
  - 10-59 sec "Brief"
  - <10 sec "Very brief"

- Record total duration (over whole record or 24 hours ("daily pattern duration"; see slide 74) and longest continuous duration.

Modifiers, cont'd: Frequency

Specify for each pattern:

Rate (typical & range) to the nearest 0.5/s division
:

<0.5/s, 0.5/s, 1/s, 1.5/s, 2/s, 2.5/s, 3/s, 3.5/s, or ≥4/s.

e.g., 1/s (typical) and 0.5-2/s (range)

Modifiers, cont'd: Phases

- Number of baseline crossings of the typical discharge (in longitudinal bipolar and in the channel in which it is most readily appreciated).
- Applies to PDs and the entire spike-and-wave or sharp-and-wave complex of SW (includes the slow wave).
- Categorize as 1, 2, 3 or >3.

- Applies to PDs and SW, not to RDA.

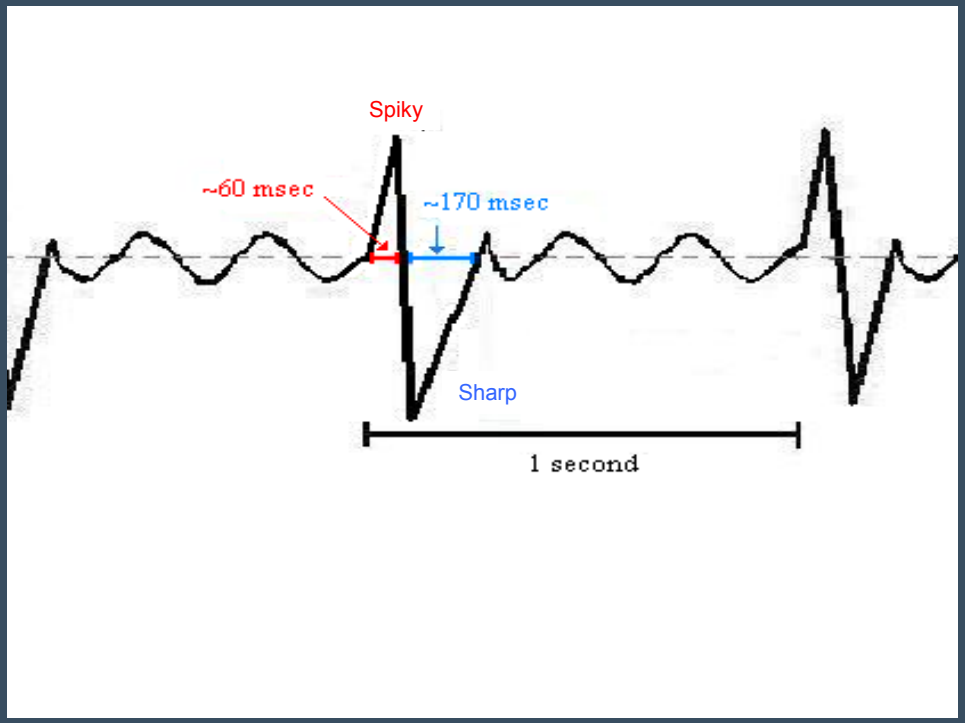
Modifiers, cont'd: Sharpness

- Specify for predominant phase (phase with greatest amplitude) and sharpest phase (if different).
- Applies only to PDs and SW, not RDA.
- If SW, specify for the spike/sharp wave only. For both phases, describe the *typical* discharge.

Categorize as one of the following:

- Spiky (duration of phase [measured at EEG baseline] <70 ms)
- Sharp (duration of phase component 70-200 ms)
- Sharply contoured (having a sharp inflection at its peak or trough, or a steep upslope or downslope (such as saw-tooth morphology), but the duration of the wave at the baseline is >200ms and thus does not qualify as sharp or spiky)
- Blunt

Sharpness



Predominant phase (greatest amplitude): sharp (70-200 ms)

Sharpest phase: spiky (<70 ms)

Modifiers, cont'd: Amplitude

- Absolute amplitude:
  - Typical amplitude measured in standard longitudinal bipolar 10-20 recording in the channel where the pattern is most apparent.
    - For PDs, this refers to the highest amplitude component.
    - For SW, this refers to the spike/sharp wave.
  - Measure peak to trough (i.e. positive to negative peak; not peak to baseline).
  - Specify for RDA as well.

  - Categorize as:
    - <20 uV "very low"
    - 20-49 uV "low"
    - 50-199 uV "medium"
    - ≥200 uV "high"

Modifiers, cont'd: Amplitude

Relative amplitude:

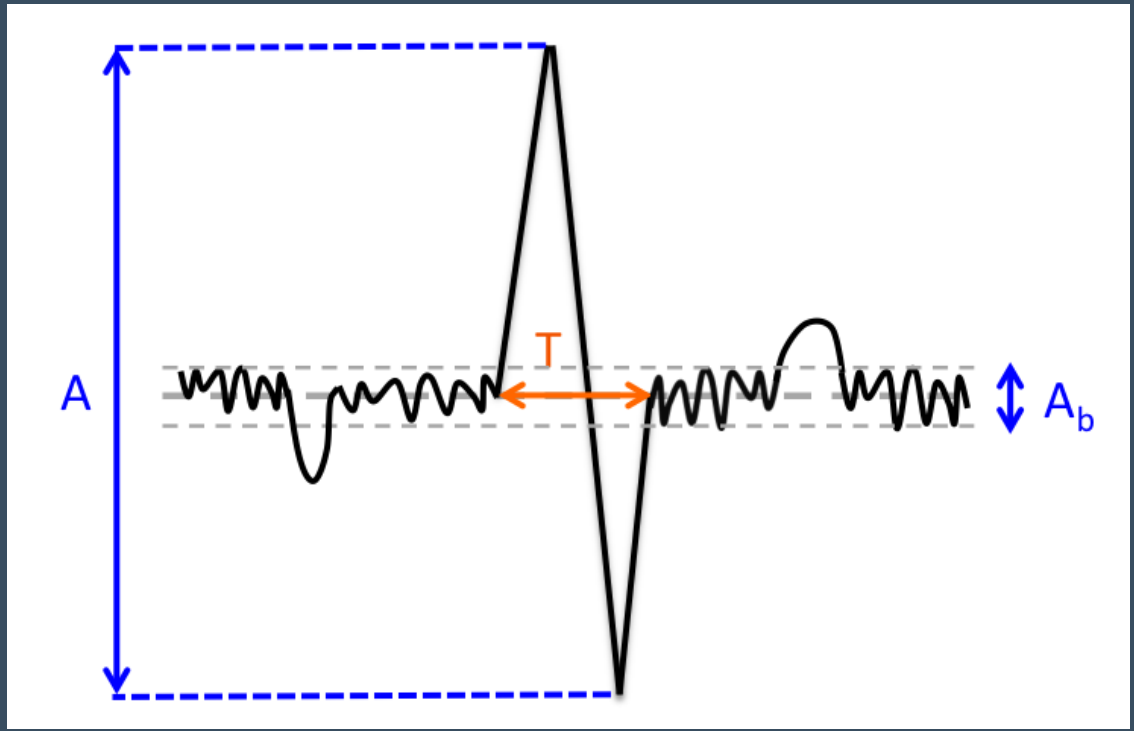
- For PDs only (require 2 amplitudes: absolute & relative).

- Typical ratio of amplitudes of:
  - highest amplitude component

  to
  - background between discharges (in same channel and montage)

- Categorize as ≤2 or >2.

Amplitude



Absolute amplitude= A ; measured from peak to through

Relative amplitude = A/A_b; A_b is amplitude of the *typical* background between discharges (i.e., does not include sporadic waves of higher amplitude; see slide 78)

Modifiers, cont'd: Polarity

Specify

- For the predominant phase (phase with the greatest amplitude) only.
- Describe the typical discharge.
- Applies only to PDs and spike/sharp component of SW, not to RDA.
- Determined in referential montage.

- Categorize as:
  - Positive
  - Negative
  - Dipole, horizontal/tangential
  - Unclear

Modifiers, cont'd: Stimulus-Induced (SI)

- Repetitively and reproducibly brought about by an alerting stimulus, with or without clinical alerting (may also occur without apparent stimulus--i.e. does not disqualify pattern as SI).

- If never clearly stimulus induced, report as spontaneous.
- If unknown, unclear or untested, report as unknown.

- Specify type of stimulus (auditory, light tactile, patient care and other non-noxious stimulations, suction, sternal rub, nostril tickle or other noxious stimulations).

Modifiers, cont'd: Evolving or Fluctuating

- Both refer to changes in one of the following
  - Frequency,
  - Location,
  - Morphology.

- If neither term applies, report as static.

Modifiers, cont'd: Evolving

At least 2 unequivocal, sequential changes in frequency, morphology or location defined as follows:

- Frequency: ≥2 consecutive increases or decreases of ≥0.5/s, (e.g. 2 → 2.5 to 3/s, or 3 → 2 to 1.5/s;
- Morphology: ≥2 consecutive changes to a novel morphology;
- Location : sequentially spreading into/out of ≥2 two different standard 10-20 electrode locations.

- To qualify as evolution in frequency or location, each change must persist ≥3 cycles (e.g. 1/s for 3 seconds, or 3/s for 1 second). Thus, the following pattern would qualify as evolving: 3/s for ≥ 1 second, then 2/s for ≥ 1.5 seconds (the first change), then 1.5/s for ≥ 2 seconds (the 2nd change).
- To qualify as evolution in morphology, each different morphology or each morphology plus its transitional forms must last at least 3 cycles. Thus the following examples would both qualify as evolving in morphology:
  - spiky 4-phase PDs for 3 cycles then sharp 2-3 phase PDs for 3 cycles then blunt diphasic PDs for 3 cycles
  - 1 blunt triphasic PD then 2 blunt biphasic PDs then 2 sharply contoured biphasic PDs then 2 sharp biphasic PDs then 3 sharp monophasic PDs.

- The pattern must not remains unchanged in frequency, morphology or location for more than 5 minutes. Thus, this pattern would not qualify as evolving: 3/s for 1 min → 2/s for 7 min → 1.5/s for 2 min

Modifiers, cont'd: Fluctuating

At least 3 changes, <1 min apart, in:

- Frequency (by ≥0.5/s),
- Morphology, or
- Location (by ≥1 standard inter-electrode distance),

BUT *not qualifying as evolving*.

- Includes patterns alternating from 1 → 1.5 → 1 → 1.5 Hz; spreading in and out of a single electrode repeatedly; or alternating between 2 morphologies repeatedly.

- *Would not* qualify as fluctuating:

  2/s for 30s → 1.5/s for 30s → 2/s for 3min → 1.5/s for 30s → 2/s for 5 min. *(Changes are too far apart, i.e. >1 minute)*.

- *Would* qualify as fluctuating:

  2/s for 10 s → 2.5/s for 30s → 2/s for 5s → 2.5/s for 5s.

Modifiers, cont'd: Evolving and fluctuating

- NOTE 1: Change in amplitude or sharpness alone would not qualify as evolving or fluctuating.

- NOTE 2: For databasing, if evolving or fluctuating, specify min, max, and typical frequency (under the frequency modifier; see slide 34). For non-generalized patterns, specify degree of spread (none, unilateral, bilateral).

Modifiers, cont'd: Plus

Additional feature which renders the patter more ictal-appearing than the same pattern without the plus:

- How to specify:
  - +F superimposed fast activity (theta or faster; for PDs or RDA)
  - +R superimposed rhythmic or quasi rhythmic delta activity (for PDs only)
  - +S "frequent" superimposed sharp waves/spikes (frequent = >1/10s but not periodic and not SW), or sharply contoured (for RDA only)
  - If both subtypes apply, PDs can have "+FR" and RDA can have "+FS".
  - Does not apply to SW.
  - If absent, database as "no plus".

Modifiers contd…

- PLUS ("+"):
  - NOTE 1: Re: Bilateral "+" vs. unilateral: If a pattern is bilateral and qualifies as plus on one side, but not on the other, the overall main term should include the plus (even though one side does not warrant a plus).
    - Example: Bilateral independent periodic discharges with fast activity superimposed in one hemisphere only (PD on one side, and PD+F on the other) would qualify for BIPDs+F. Similarly, generalized rhythmic delta activity with superimposed spikes in one hemisphere only (RDA on one side and RDA+S on the other) would qualify for GRDA+S
  - NOTE 2: Re: +F: If a pattern qualifying as RDA or PDs has superimposed continuous fast activity (theta or faster), this should be coded as +F ONLY if the fast activity is not present in the background activity when the RDA or PDs is not present. In other words, if the superimposed fast activity is part of the RDA or PD

    pattern and not simply part of the background activity.

Minor modifiers

(all except "Quasi-" are required for database studies; record presence or absence of each):

Quasi-: *Defined as*: Cycle length (period) varying by 25-50% from one cycle to the next in >50% of cycle pairs.

- *Does not qualify if the cycle length varies by >50% (in which case it is not rhythmic at all) or <25% (in which case it is rhythmic, without the "quasi-") in the majority of cycles*.
- Use only when using computer-assisted analysis. Modifies rhythmic or periodic patterns, as in *quasi-periodic* or *quasi-rhythmic.*
- (Quasi preferred over pseudo- or semi-).
- When not using computer analysis, quasi-periodic is coded as periodic, and quasi-rhythmic as rhythmic.

Onset:

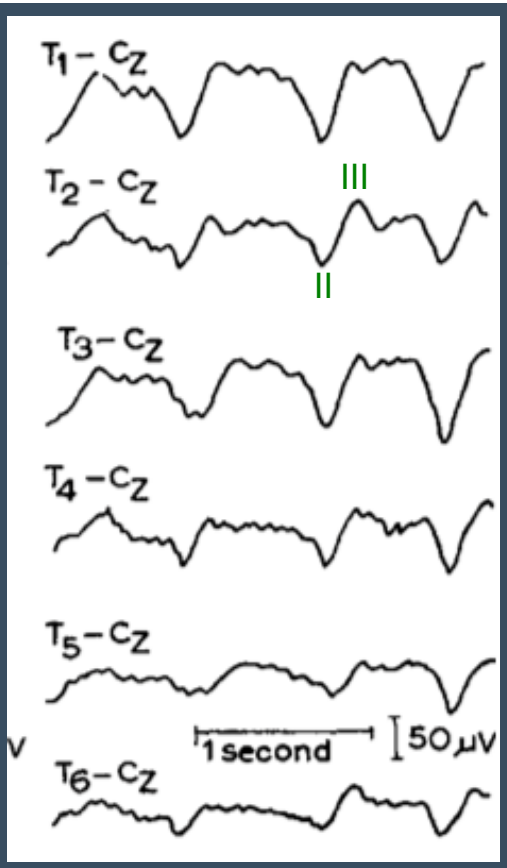
- *Sudden* (preferred over paroxysmal): Progressing from absent to well-developed in ≤3s.
- Gradual onset : Progressing from absent to well-developed in >3s.

Minor modifiers: Cont'd

(all except "Quasi-" are required for database studies; record presence or absence of each):

- ***Triphasic morphology*:** Applies to PDs and SW. Either two or three phases, with each phase longer than the previous, and the positive phase of highest amplitude. If three phases, this must be negative-positive-negative in polarity; if two phases, positive-negative. *Note that a biphasic waveform may be categorized as "triphasic" by this definition.*

- ***Anterior-posterior lag* or *posterior-anterior lag*:** Applies if a consistent measureable delay of ≥100 ms exists from the most anterior derivation to the most posterior derivation in which it is seen ; specify typical delay in msec from anterior to posterior (negative = posterior to anterior lag) in both longitudinal bipolar and in a referential montage, preferably with an ipsilateral ear reference.



Note on triphasic waves: In the typical appearance of TW, phase II is the most prominent and phases I and III are of similar amplitudes. In some cases, however, phase I may appear blunted or even be absent, resulting in TW with a biphasic morphology (phase II-III only).

Example is from SILVERMAN, D. (1962). Some observations on the EEG in hepatic coma. Electroencephalography and clinical neurophysiology, 14(1), 53–59.

Minimal time epochs to be reported/databased separately

- First ~30 minutes (equivalent to a “routine” EEG).
- Each 24 hour period.

  If significant changes occur in the record during this time period, report additional epochs separately as needed.

Moving on…

- Next slides specify how to record:
  - Sporadic epileptiform discharges
  - EEG background (e.g. slowing, posterior dominant rhythm, etc)

Sporadic (non-rhythmic and non-periodic) epileptiform discharges: Frequency

- Use the following standard time divisions or suggested equivalent clinical terms:

- ≥1 / 10s (/ typical EEG page) : ("Abundant") (average ≥1
  - ≥1/min –1/10s: ("Frequent")
  - ≥ 1/h -- 1/min ("Occasional")
  - <1/h ("Rare")

N.B. re: Prevalence/Duration/Frequency

- Note that there are 4 distinct time-related scales:

  - 1. **Prevalence** (continuous, abundant, frequent, occasional, rare): refers to percent of the entire record occupied by a pattern

  - 2. **Duration** (very long, long, intermediate, brief, very brief): refers to the typical duration of a single occurrence of the pattern, regardless of whether the pattern occurs rarely or frequently.

  - 3. **Quantification of sporadic** (aka "interictal") **epileptiform discharges** (abundant, frequent, occasional, rare)

N.B. Other terms for research use

- "Daily Pattern Duration" is defined as total duration of a pattern per 24 hours. e.g. if GPDs were present for 33% of the record for 12 hours, then 10% of the record for 12 hours, the Daily GPD Duration would be 4 hours + 1.2 hours = 5.2 hours. Daily Seizure Duration can be calculated similarly: e.g. six 30-second seizures in one day would have a Daily Seizure Duration of 3minutes.

- "Daily Pattern Index" is defined as Daily Duration X Mean Frequency (Hz). In the above example, if GPDs were at 1.5 Hz, the Daily GPD Index would be 5.2 h x 1.5 Hz = 7.8 Hz-hours.

N.B. re: Amplitudes

- Note that there are multiple ratings for amplitude:
  - 1. Absolute amplitude of a single discharge within a pattern
    - Applies to all patterns (see slide 42)
    - Categorize as:
      - <20 uV "very low"
      - 20-49 uV "low"
      - 50-199 uV "medium"
      - ≥200 uV "high"
  - 2. Relative amplitude of a single discharge to the interdischarge amplitude during a periodic pattern
    - Applies to PDs only (see slide 43)
    - Categorize as ≤2 or >2.
  - 3. Background amplitude (voltage)
    - Applies to EEG background description (see slide 79)
    - Categorize as:
      - ≥20μV "normal"
      - <20μV but ≥10μV "low"
      - <10μV "suppressed

Background EEG

- **Symmetry:**
  - Symmetric
  - Mild asymmetry (consistent asymmetry in amplitude on referential recording of <50%, or consistent asymmetry in frequency of 0.5 - 1 Hz)
  - Marked asymmetry (≥50% amplitude or >1 Hz frequency asymmetry).
- Breach effect (note presence, absence, or unclear)

When any of the following features are asymmetric, they should be described separately for each hemisphere.

- Posterior dominant "alpha" rhythm: Specify frequency (to the nearest 0.5 Hz) or absence.
- Predominant background EEG frequency: Delta, Theta, and/or ≥Alpha. If 2 or 3 frequency bands are equally prominent, record each one.
- Variability: Yes, No, or unknown/unclear/not applicable. The last choice might apply, for example, in a 30 minute awake record.
- Reactivity: Change in cerebral EEG activity to stimulation: Yes, No, or Unclear/unknown/not applicable. Appearance of muscle activity does not qualify as reactive. *If the only form of reactivity is SI-RDA, SI-PDs , SI-SW or SI-seizures, categorize as "Reactive, SIRPIDs only".*
- Voltage:
  - Normal
  - Low (most or all activity <20 μV in longitudinal bipolar with standard 10-20 electrodes, [measured from peak to trough]), or
  - Suppressed (all activity <10 μV). If discontinuous, this refers to the higher amplitude portion.

Background EEG, cont'd.

- Anterior-posterior (AP) gradient: Present, absent or reverse.
  - An AP gradient is present if at any point in the epoch, there is a clear and persistent (at least 1 continuous minute) anterior to posterior gradient of voltages and frequencies such that lower amplitude, faster frequencies are seen in anterior derivations, and higher amplitude, slower frequencies are seen in posterior derivations
  - A reverse AP gradient is defined identically but with a posterior to anterior gradient of voltages and frequencies.

- Stage II sleep transients (K-complexes and spindles):
  - Normal (K-complexes and spindles both present and normal),
  - Present (at least one) but abnormal, or
  - Absent (both absent).

Background EEG, cont'd.

- Continuity:
  - Continuous
  - Nearly Continuous: continuous, but with occasional (≤10% of the record) periods of attenuation or suppression. Describe typical duration of attenuation/suppression as above.
    - Nearly continuous with attenuation: periods of lower voltage are ≥10μV but <50% of the background voltage
    - Nearly continuous with suppression: periods of lower voltage are <10 μV
    - If suppressions/attenuations are stimulus-induced, code as "nearly continuous with SI-attenuation" or "…with SI-suppression"
  - Discontinuous: 10-49% of the record consisting of attenuation or suppression, as defined above.
  - Burst-attenuation/Burst-suppression: more than 50% of the record consisting of attenuation or suppression, as defined above, with bursts alternating with attenuation or suppression; specify the following:
    - Typical duration of bursts and interburst intervals
    - Sharpest component of a typical burst using the sharpness categories defined under modifiers
    - Presence or absence of Highly Epileptiform Bursts (HEB): Present if multiple epileptiform discharges (traditional definition) are seen within the majority (>50%) of bursts and occur at an average of 1/s or faster; record typical frequency (using categories above) and location (G, L, BI or Mf). Also present if a rhythmic, potentially ictal-appearing pattern occurs at 1/s or faster within the majority (>50%) of bursts; record frequency and location as well
  - Suppressed: entirety of the record consisting of suppression (<10 uV, as defined above).