ENCEPHALOPATHIC PATTERNS AND ICU EEG

Kevin Haas, MD, PhD

OVERVIEW

- Spectrum of EEG Patterns in Encephalopathy
- Rhythmic and Periodic Discharges
- EEG Patterns in Cardiac Arrest
- EEG Patterns in Coma
- EEG in Brain Death

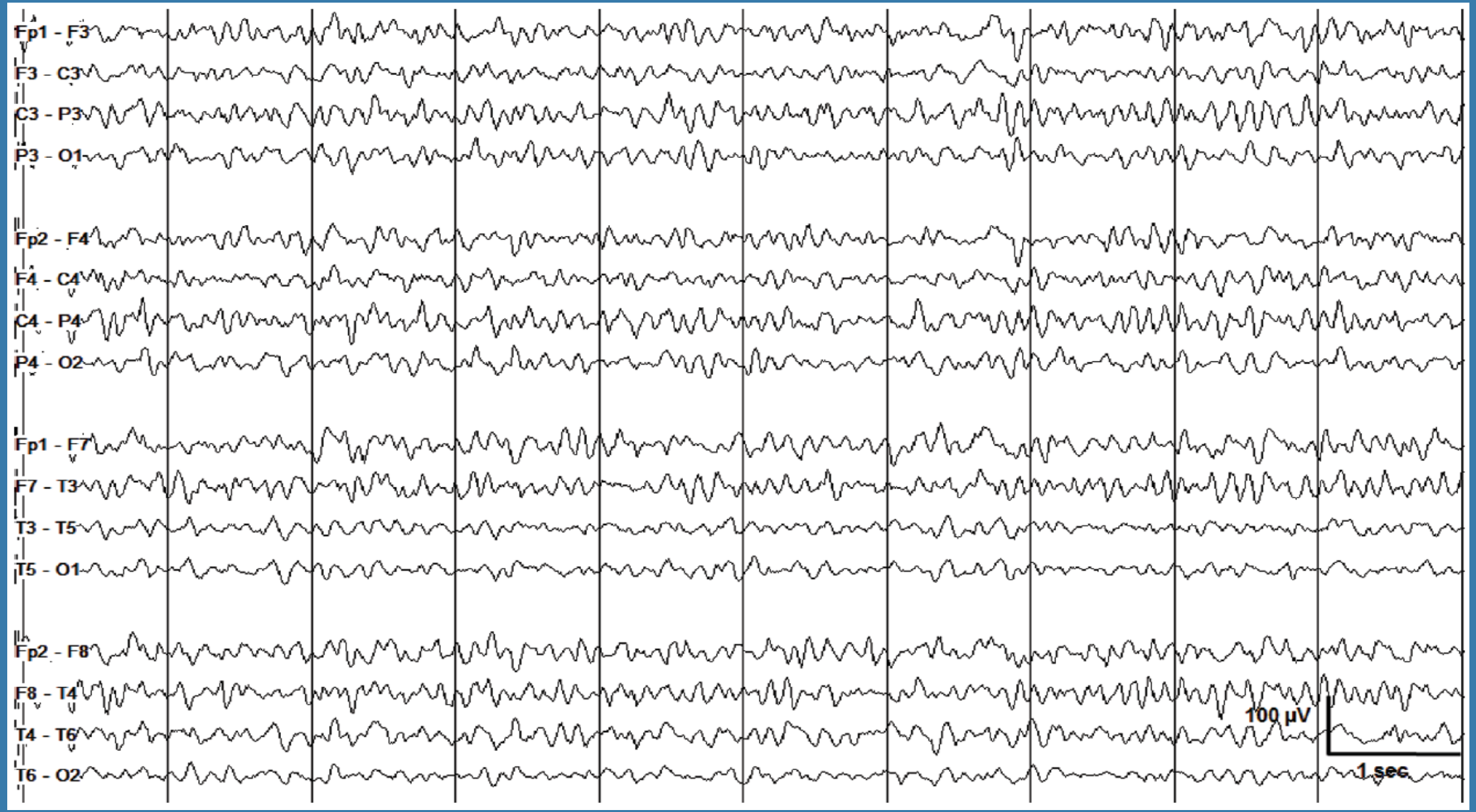
EEG BACKGROUND ACTIVITY

- While often non-specific for etiology, EEG background activity provides a real-time window for monitoring changes in critically ill patients
- ACNS has developed a standardized terminology for describing background features
- Ongoing efforts are underway for developing a more standardized system for grading the severity of encephalopathy

Dhakar et al., J Clin Neurophys, 2022

EEG IN MILD ENCEPHALOPATHY

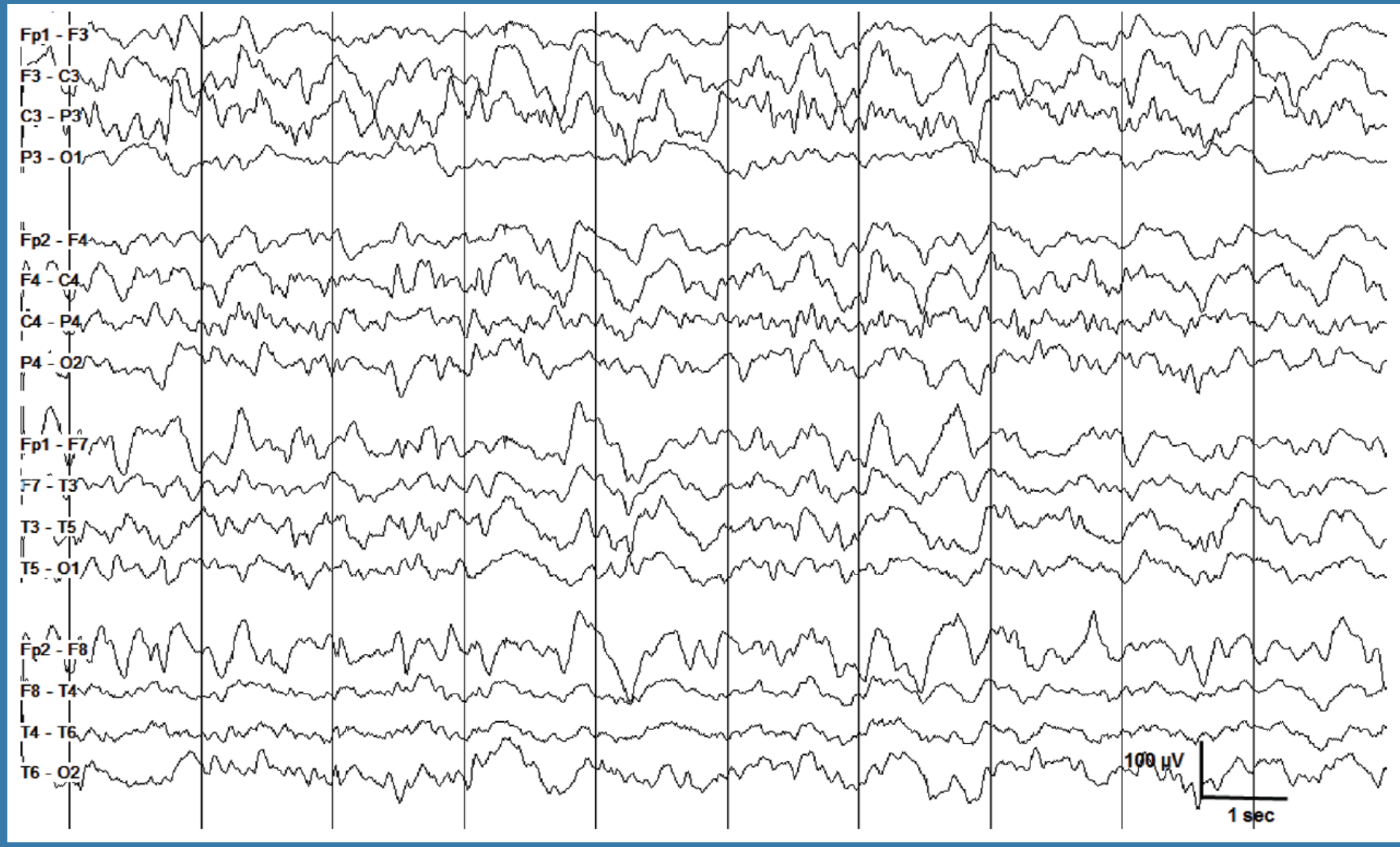
- Continuous background with generally desynchronized normal amplitude intermixed faster and slower frequencies
- Slowing of posterior dominant rhythm (≥ 7 Hz)
- Prominent theta or any delta during wakefulness



Desynchronized alpha and theta activity with intermixed delta activity as seen in mild encephalopathy

EEG IN MILD-MODERATE ENCEPHALOPATHY

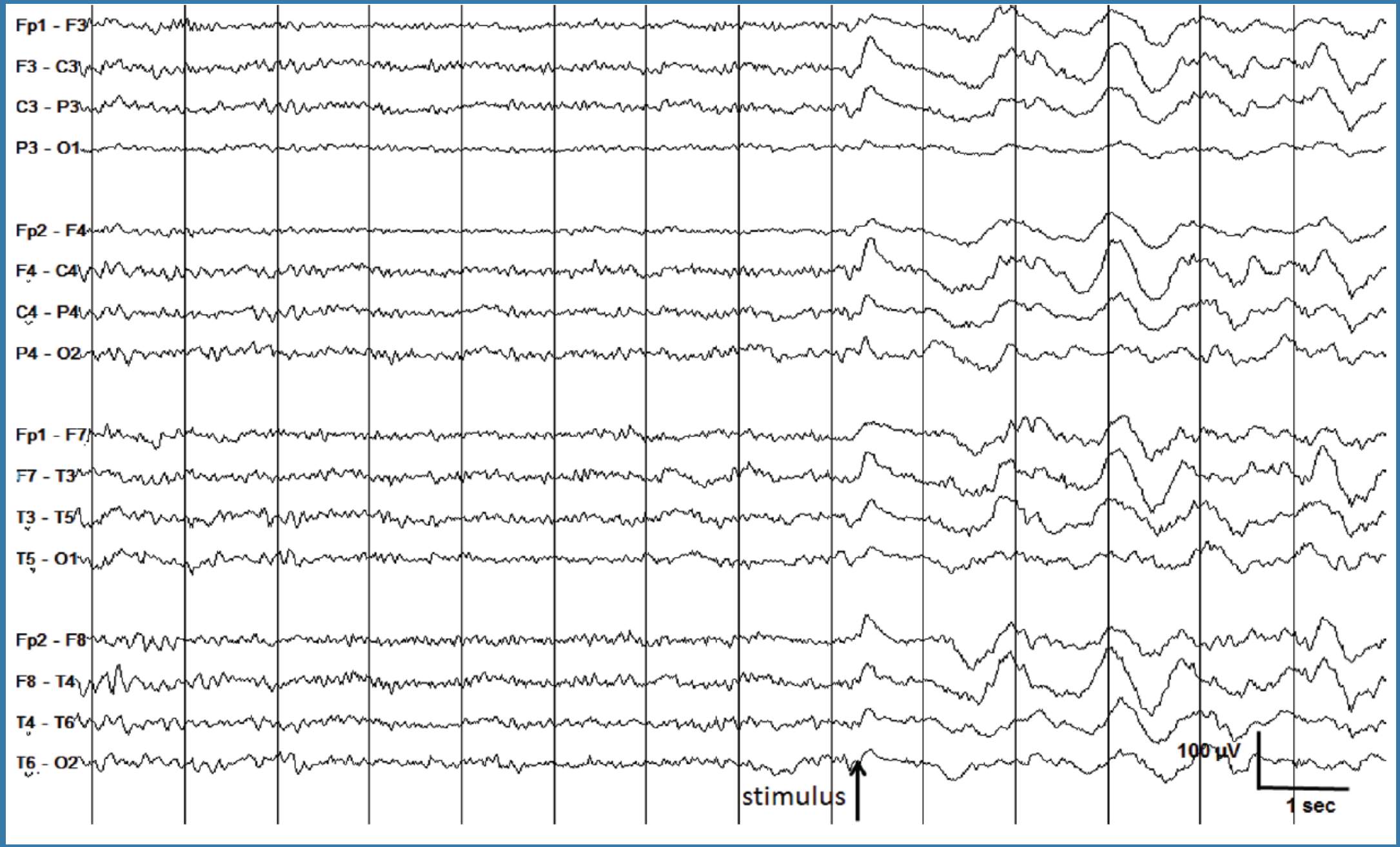
- Continuous background with mixed theta and delta frequencies predominating
- Posterior dominant rhythm present, but < 7 Hz
- Loss of normal faster activity (temporal theta/alpha, frontal beta)
- Reactive background
- Stage II sleep activity present



Generalized high-amplitude delta activity with intermixed alpha and theta activity as seen in mild to moderate encephalopathy

EEG REACTIVITY

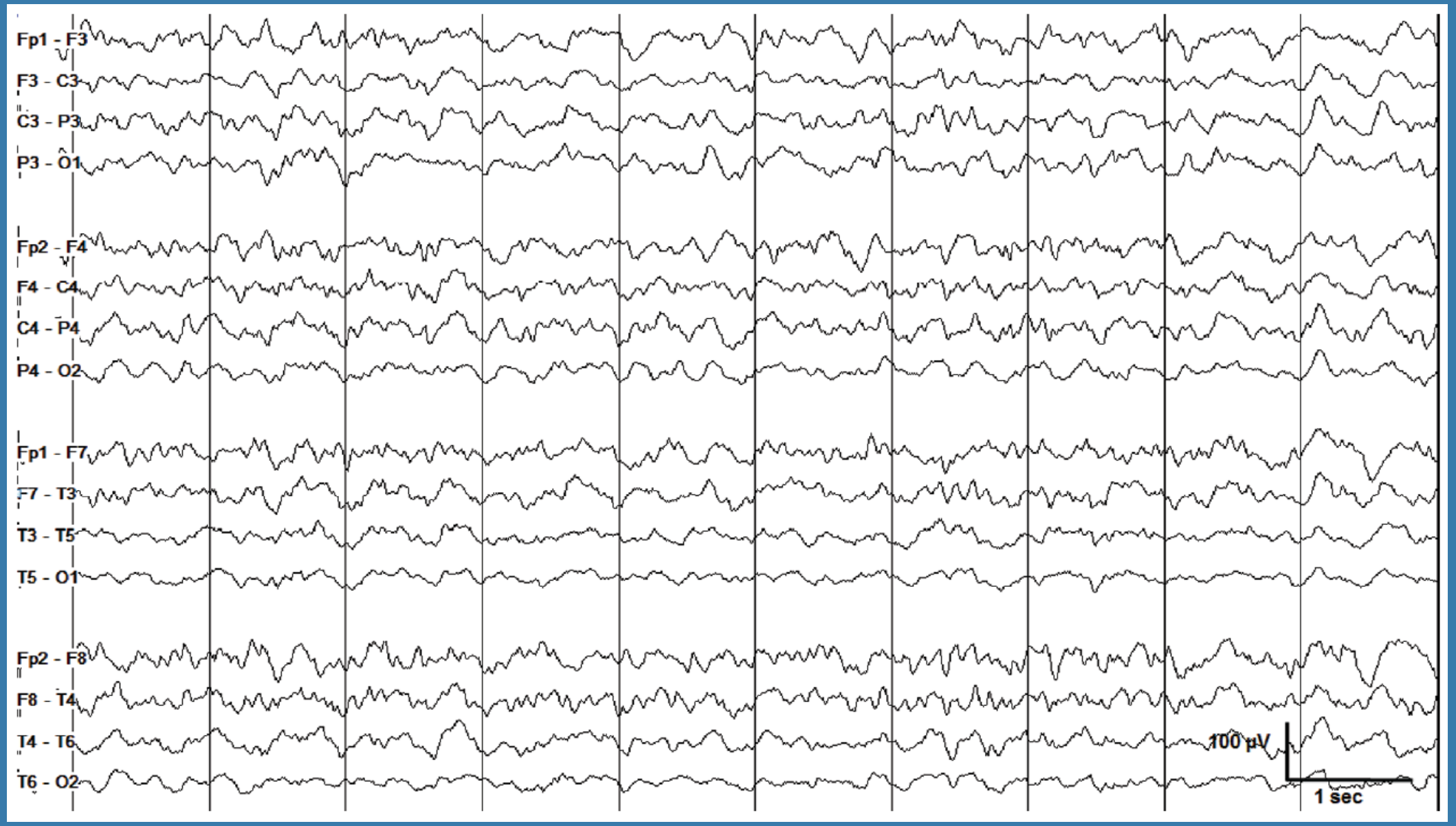
- Requires an intact reticular activating system and lemnisical thalamocortical connectivity
- Should be tested in continuous EEG at least once every 24 hours
- Graded stimuli given (start with auditory stimuli), if no response is elicited then progress to somatosensory then to noxious stimuli
- Any clear correlated change in cerebral activity on EEG in response to stimulation should be accepted
- Presence of activity is a positive prognostic sign and a marker of less severe encephalopathy



EEG reactivity to somatosensory stimulation

EEG IN MODERATE ENCEPHALOPATHY

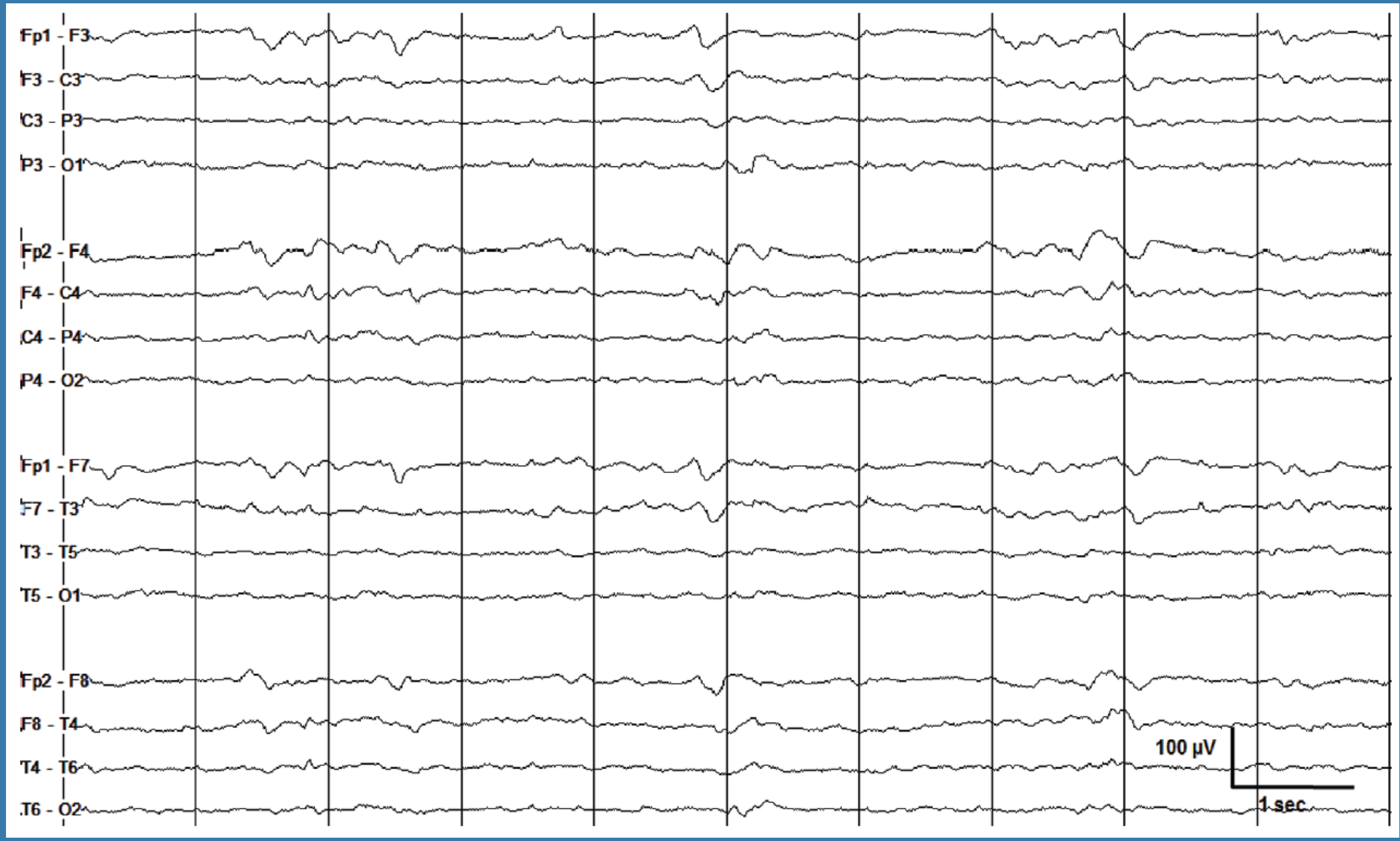
- Continuous or nearly continuous background
- 3-6 Hz delta and theta activity predominates
- Absent PDR
- Reactive background
- State changes present



Generalized mixture of theta and delta activity with some faster activity as seen in moderate encephalopathy

EEG IN MODERATE TO SEVERE ENCEPHALOPATHY

- Periods of attenuation or suppression
- Delta frequencies predominate
- Absent PDR
- Unreactive background
- Some state changes present



Low amplitude delta slowing intermixed with theta activity with periods of background attenuation consistent with mod-severe encephalopathy

EEG IN SEVERE ENCEPHALOPATHY

- Discontinuous background, often burst suppression
- Absent PDR
- Unreactive background
- State changes absent

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American Clinical Neurophysiology Society's Standardized Critical Care EEG Terminology: 2012 version

L. J. Hirsch, S M LaRoche, N Gaspard, E. Gerard, A. Svoronos, S T Hennan, R. Mani, H. Arif, N Jette, Y. Minazad, J. F. Kerrigan, P. Vespa, S Hantus, J. Claassen, G. B. Young, E. So, P. W Kaplan, M. R. Nuwer, N. B. Fountain, and F. W Drislane

J Clin. Neurophys, 2012, 2021

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American Clinical Neurophysiology Society's Standardized Critical Care EEG Terminology: 2021 Version

Lawrence J. Hirsch[*], Michael W.K. Fong[†], Markus Leitinger[‡], Suzette M. LaRoche[§], Sandor Beniczky[‖], Nicholas S. Abend[¶], Jong Woo Lee[#], Courtney J. Wusthoff[**], Cecil D. Hahn[††], M. Brandon Westover[‡‡], Elizabeth E. Gerard[§§], Susan T. Herman[‖‖], Hiba Arif Haider[§], Gamaleldin Osman[¶¶], Andres Rodriguez-Ruiz[§], Carolina B. Maciel[##], Emily J. Gilmore[*], Andres Fernandez[***], Eric S. Rosenthal[†††], Jan Claassen[‡‡‡], Aatif M. Husain[§§§], Ji Yeoun Yoo[‖‖‖], Elson L. So[¶¶¶], Peter W. Kaplan[###], Marc R. Nuwer[****], Michel van Putten[††††], Raoul Sutter[‡‡‡‡], Frank W. Drislane[§§§§], Eugen Trinka[‡], Nicolas Gaspard[‖‖‖‖]

J Clin. Neurophys, 2012, 2021

IMPORTANCE OF STANDARDIZED TERMINOLOGY FOR DESCRIBING EEG PATTERNS

- Leads to greater consistency in reporting and reduces unintended conclusions drawn from reports
- Facilitates communication between physicians
- Allows for study of the importance of indeterminate EEG patterns (ictal-interictal continuum)

PERIODIC VS. RHYTHMIC

- Periodic: discharges with a defined separation or interval in between which should vary by less than 50% between successive discharges

- Rhythmic: contiguous waveforms that occur without other intervening activity

- Six consecutive cycles are needed to apply these terms.

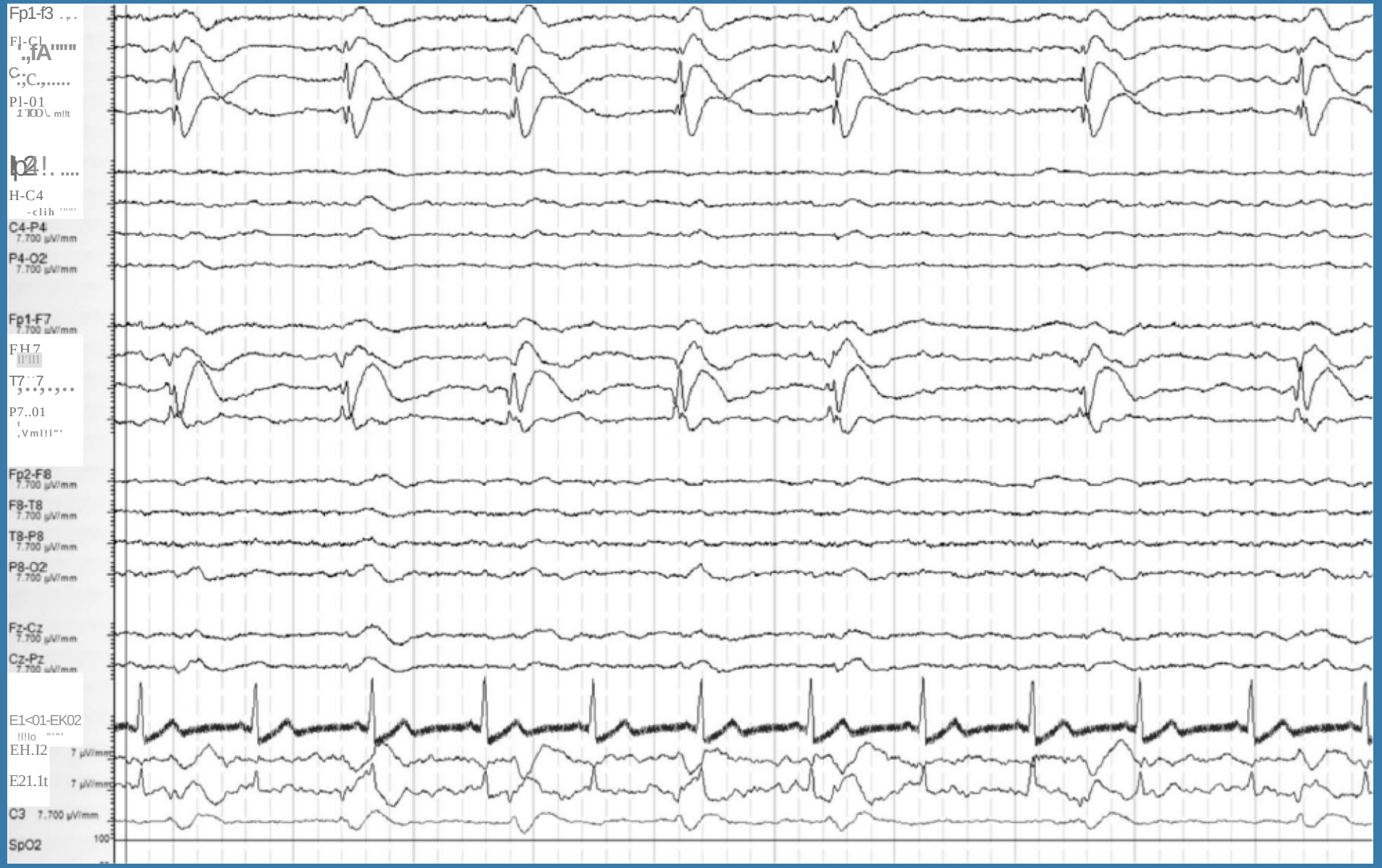
ACNS CRITICAL CARE EEG TERMINOLOGY

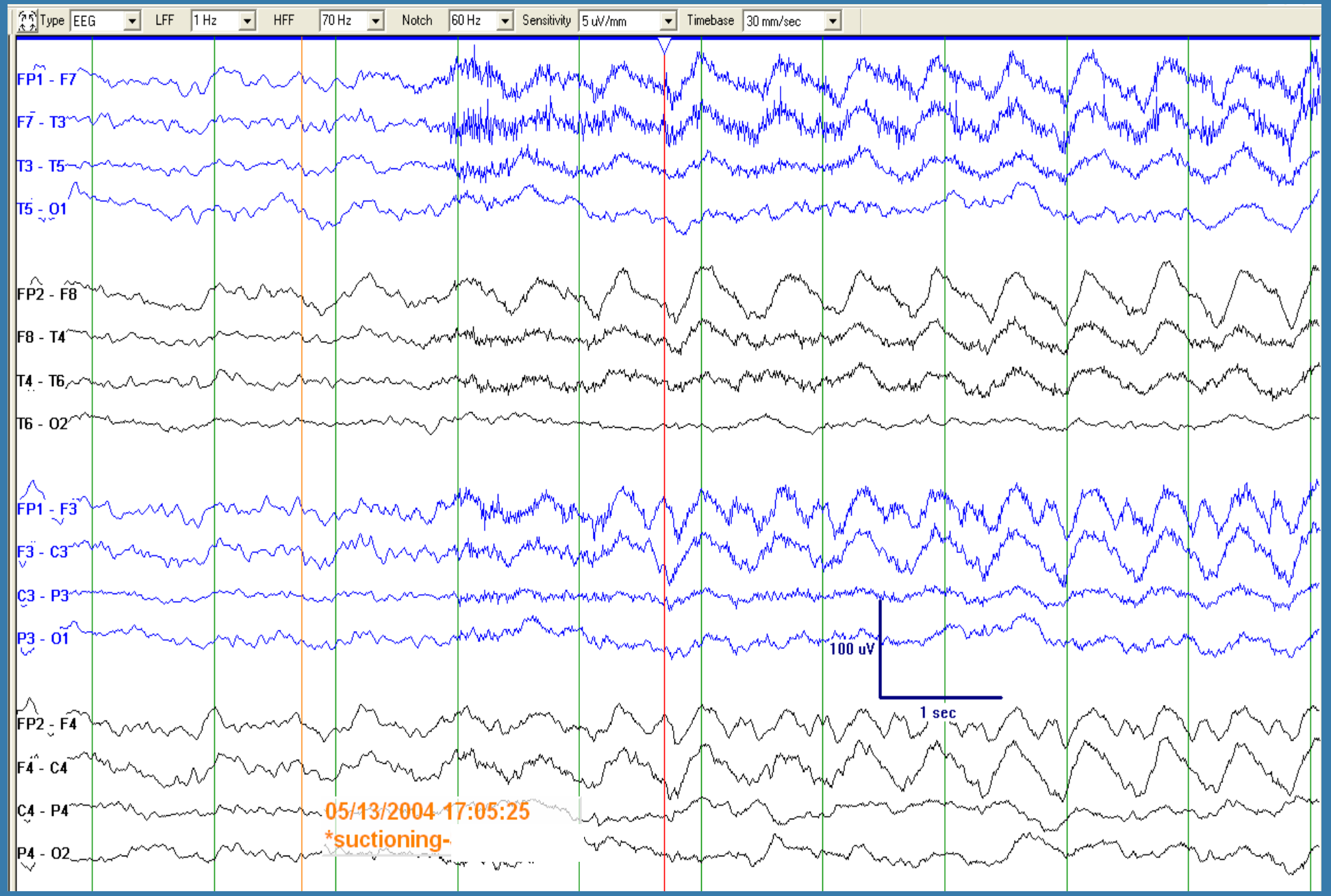
Main Term #1
Generalized G
Lateralized L
Bilateral Independent BI
Multifocal M

Main Term #2	Plus Modifier	
Periodic Discharges PD s	+ F	Superimposed **FAST** activity use with PDs or RDA only
	+ R	Superimposed **RHYTHMIC** activity use with PDs only
	+ FR	Use for PDs if both subtypes apply
Rhythmic RDA	+ F	Superimposed **FAST** activity use with PDs or RDA only
	+ S	Superimposed **SHARP** waves or Spikes use with RDA only
	+ FS	Use for RDA if both subtypes apply
Spike-wave SW		

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

www.acns.org/practice/guidelines


Fp1-f3
C4-P4
P4-O2
Fp1-F7
Fp2-F8
F8-T8
T8-P8
P8-O2
Fz-Cz
Cz-Pz
C3
SpO2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HFF 70 Hz
Notch 60 Hz
Sensitivity 5 uV/mm
Timebase 30 mm/sec
FP1 - F7
F7 - T3
T3 - T5
T5 - O1
FP2 - F8
F8 - T4
T4 - T6
T6 - O2
FP1 - F3
F3 - C3
C3 - P3
P3 - O1
FP2 - F4
F4 - C4
C4 - P4
P4 - O2
100 uV
1 sec
05/13/2004 17:05:25
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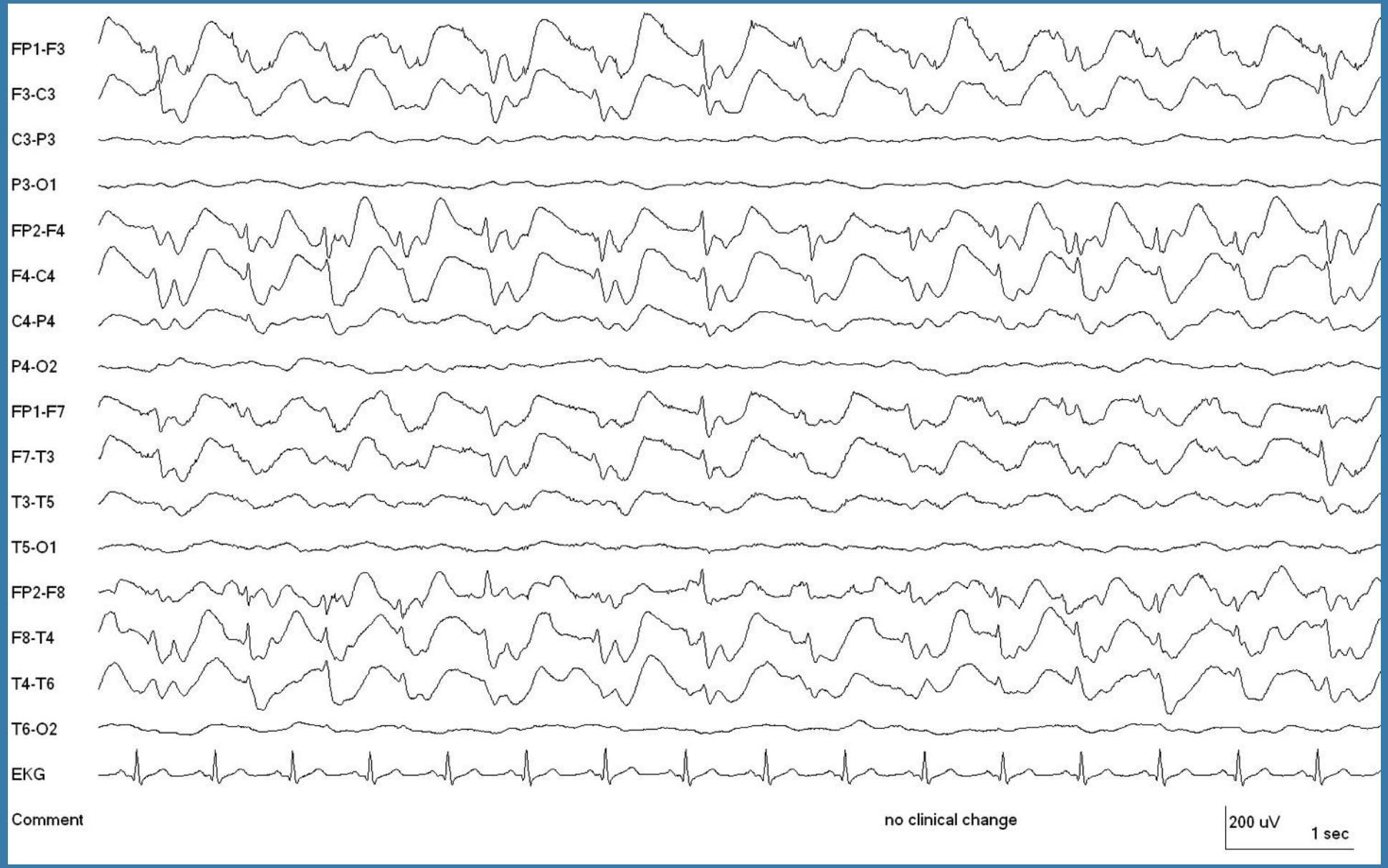
Type EEG
LFF 1 Hz
HFF 50 Hz
Notch 60 Hz
Sensitivity 10 uV/mm
Timebase 30 mm/sec
FP1 - F3
F3 - C3
C3 - P3
P3 - O1
FP2 - F4
F4 - C4
C4 - P4
P4 - O2
FP1 - F7
F7 - T3
T3 - T5
T5 - O1
FP2 - F8
F8 - T4
T4 - T6
T6 - O2
200 uV
1 sec


Type EEG
LFF 1 Hz
HFF 70 Hz
Notch 60 Hz
Sensitivity 7 uV/mm
Timebase 30 mm/sec
Fp1 - F3
F3 - C3
C3 - P3
P3 - O1
Fp2 - F4
F4 - C4
C4 - P4
P4 - O2
Fp1 - F7
F7 - T3
T3 - T5
T5 - O1
Fp2 - F8
F8 - T4
T4 - T6
T6 - O2
Fz - Cz
Cz - Pz
EKG1 - EKG2
140 uV
1 sec


FP1-F3
F3-C3
C3-P3
P3-O1
FP2-F4
F4-C4
C4-P4
P4-O2
FP1-F7
F7-T7
T7-P7
P7-O1
FP2-F8
F8-T8
T8-P8
P8-O2
FZ-CZ
CZ-PZ
PZ-OZ
EKG1-EKG2
150uV
1 sec


FP1-F3
F3-C3
C3-P3
P3-O1
FP2-F4
F4-C4
C4-P4
P4-O2
FP1-F7
F7-T3
T3-T5
T5-O1
FP2-F8
F8-T4
T4-T6
T6-O2
EKG
Comment
no clinical change
200 uV
1 sec


Type EEG
LFF 1 Hz
HFF 70 Hz
Notch 60 Hz
Sensitivity 7 uV/mm
Timebase 30 mm/sec
F3 - C3
C3 - P3
P3 - O1
F4 - C4
C4 - P4
P4 - O2
F7 - T3
T3 - T5
T5 - O1
F8 - T4
T4 - T6
T6 - O2
140 uV
1 sec

American Clinical Neurophysiology Society's Standardized Critical Care EEG Terminology: 2021 Version

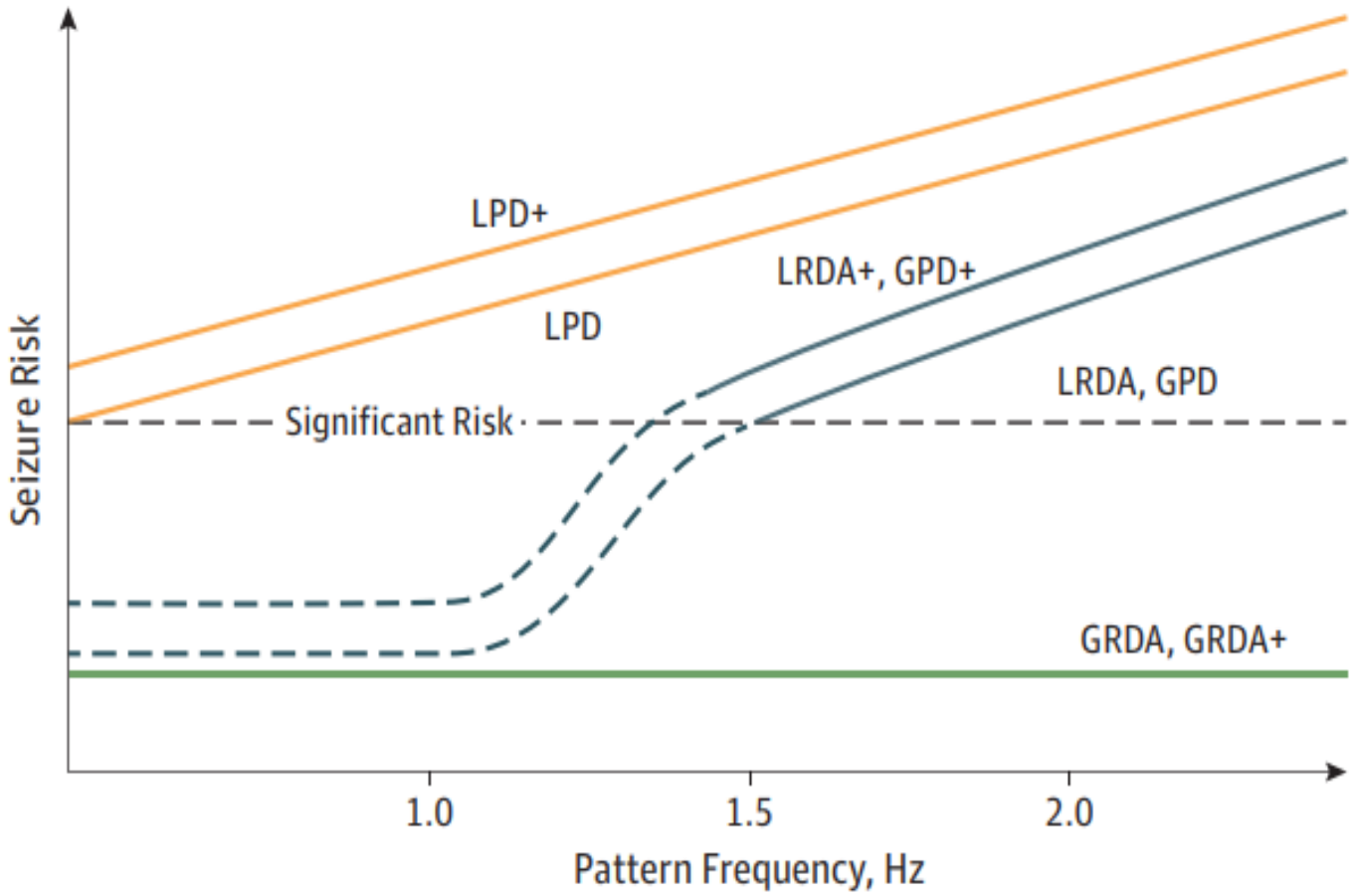
New main term: Unilateral independent

ICTAL-INTERICTAL CONTINUUM

- Periodic or rhythmic patterns that do not meet criteria for a definite electographic seizure (frequency too slow or lack evolution)

- Significance of these patterns is not fully known, but they represent possible seizure patterns

Figure. Model of Pattern Characteristics and Seizure Risk



Rodriguez Ruiz et al., JAMA Neurology, 2017

GPDS WITH TRIPHASIC MORPHOLOGY

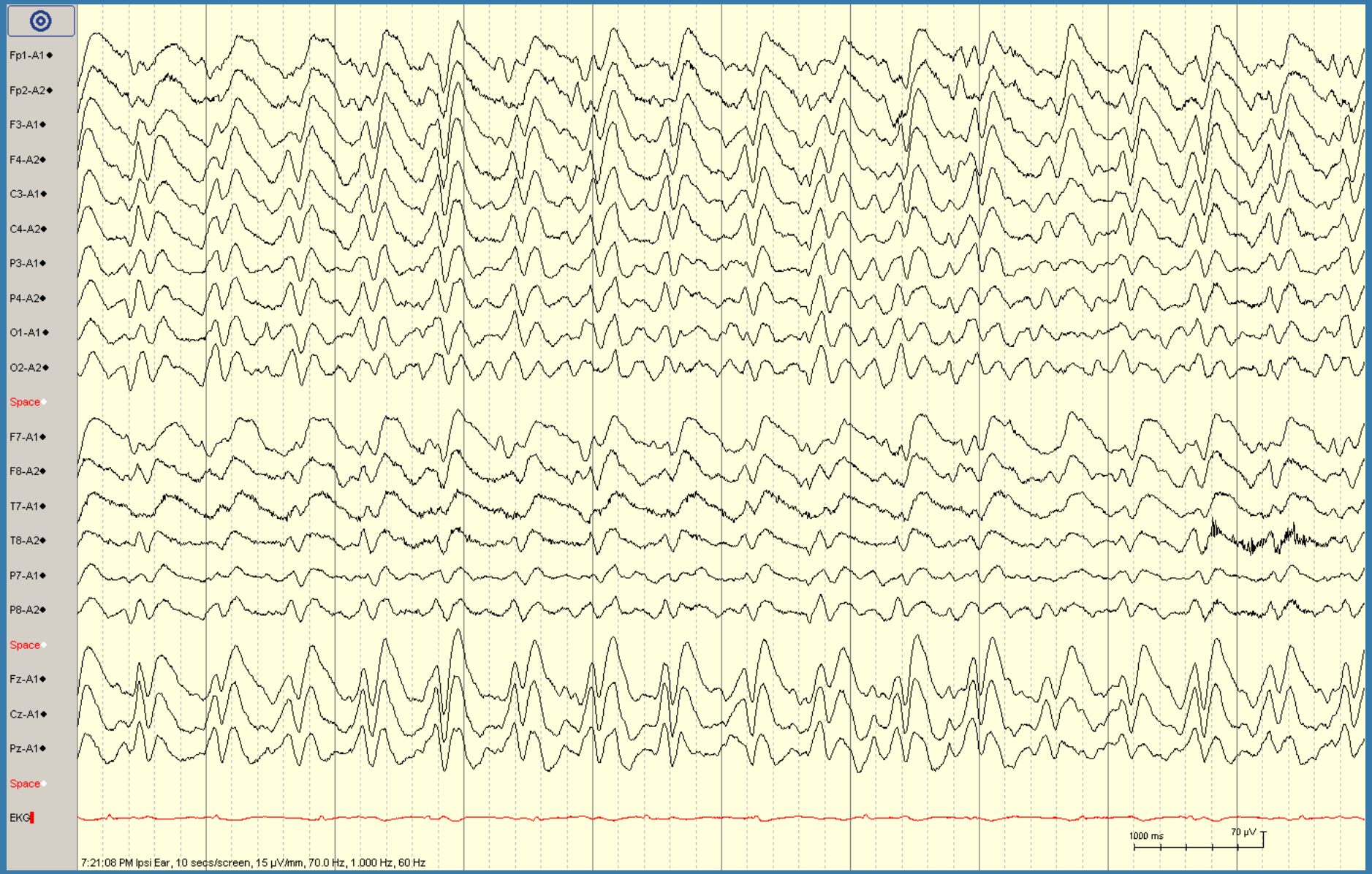
- Formerly called Triphasic Waves (TPW)
- Three phases (negative-positive-negative)
  - N1 smallest – sometimes absent, P1 largest
  - Usually 100 to 300 µV, occurring ~1-2/sec
  - Usually frontally predominant
  - Can have anterior-posterior lag (~200 msec)
- Typically associated with toxic or metabolic encephalopathy (hepatic, renal, etc.)
- Can attenuate with treatment, even when not ictal

PERIODIC DISCHARGE ASSOCIATIONS

	LPDs	GPDs	Long interval GPDs
Interval duration	0.5-4 sec	0.5-4 sec	4-30 sec
Seizure association	Common	Rare*	Rare
Etiology	Varied (vascular, CNS infection, anoxia)	Metabolic; anoxia; toxic (cefepime, lithium, iphosphamide, etc); CJD; NCSE	SSPE; toxic; anoxia

adapted from Brenner and Schaul, 1990

GPDs (with triphasic morphology) in CJD



Long interval GPDs in SSPE

CEFEPIME

- Widely used 4th generation cephalosporin
- Studies show it is a competitive inhibitor at the GABA-A receptor suggesting that mechanism may be a decrease of central inhibition
- Patients with renal failure are at higher risk for central neurotoxicity
- GPD w/triphasic wave pattern. Usually resolves with cefepime discontinuation

GPDs in Cefepime Toxicity

IPHOSPHAMIDE

- Alkylating chemotherapy agent used in treatment of sarcomas, lymphoma, gynecological, and testicular cancers
- Mechanism of CNS toxicity not known
- EEG pattern has spectrum from generalized slowing/GRDA -> GPDs w/triphasic morphology -> GPDs on burst attenuation background
- Orofacial myoclonus has been reported

GPDs in Iphosphamide Toxicity

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EEG IN CARDIAC ARREST

- The EEG reader is often asked to prognosticate, but any approach to prognostication after cardiac arrest should be multimodal including parameters from clinical examination, electrophysiology, biomarkers, and imaging
- A self-fulfilling prophecy is dangerous (we may withdraw care based on perception of poor prognosis, leading to poor prognosis)

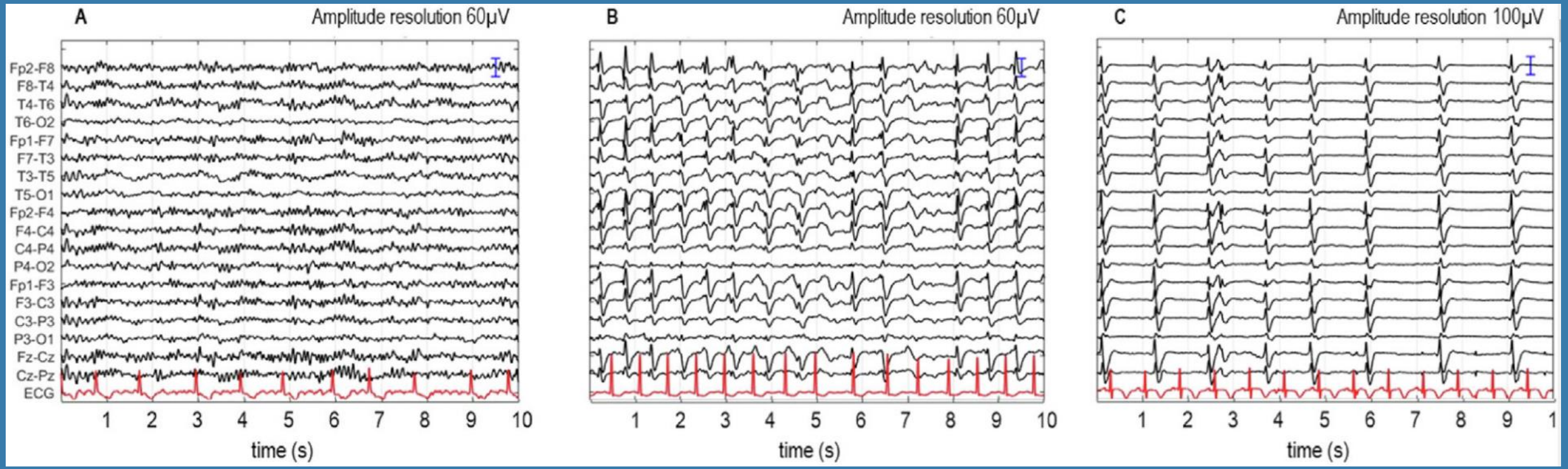
De Georgia and Raad, Continuum, 2012

EEG POST CARDIAC ARREST

- cEEG monitoring has become standard to detect and treat NCS
- Sedation, paralytics, and hypothermia all affect EEG background
- Significance of EEG background pattern is highly dependent on the time window after arrest

EEG PATTERNS POST CARDIAC ARREST

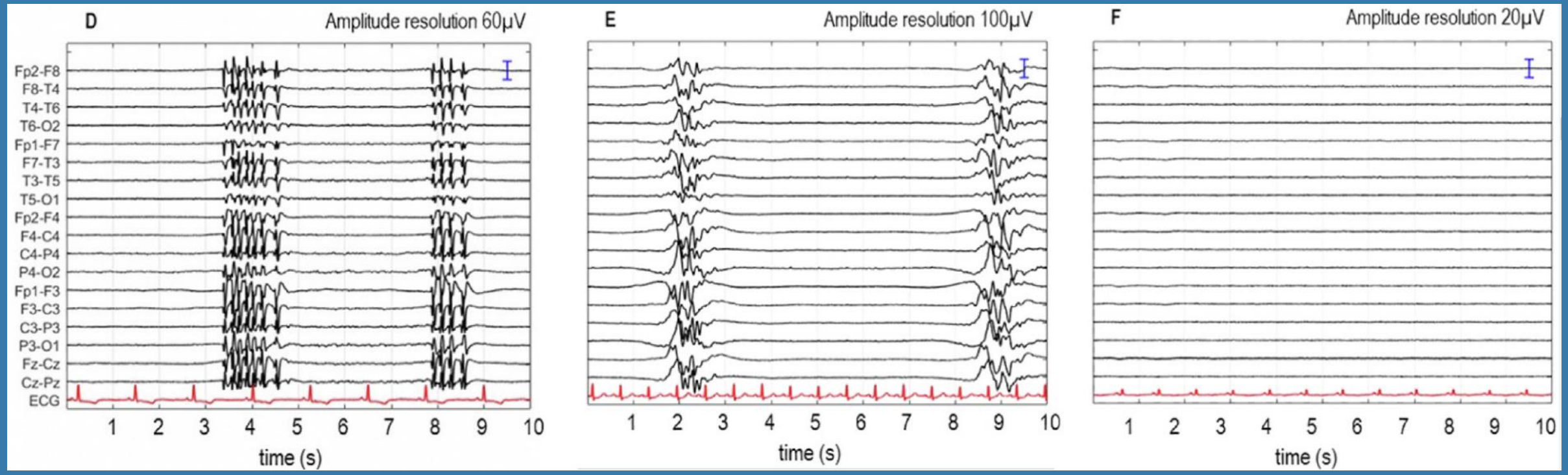
- Continuous background (pattern A) indicates a high probability of good recovery if seen within 12-24 hours after cardiac arrest
- GPDs (pattern B) no predictive value and based on a large recent trial, no benefit was seen to intensive treatment with ASMs, but more reliable predictor of poor outcome if seen on a flat background (pattern C)



Hoedemaekers et al, Resusitation, 2023; Ruijter et al., NEJM 2022

EEG PATTERNS POST CARDIAC ARREST

- Burst suppression with epileptiform bursts, burst suppression with identical bursts (patterns D, E) are predictors of poor outcome irrespective of timing
- Generalized suppressed EEG (pattern F) is a predictor of poor outcome if persists after rewarming



Hoedemaekers et al, Resusitation, 2023

POST-ANOXIC MYOCLONUS

- Post-anoxic myoclonus

  Repeated motor manifestations in a comatose patient beginning within 24 hours or anoxic injury and may be accompanied EEG findings of generalized polyspikes, spikes or sharp waves that are time-locked with clinical myoclonus.

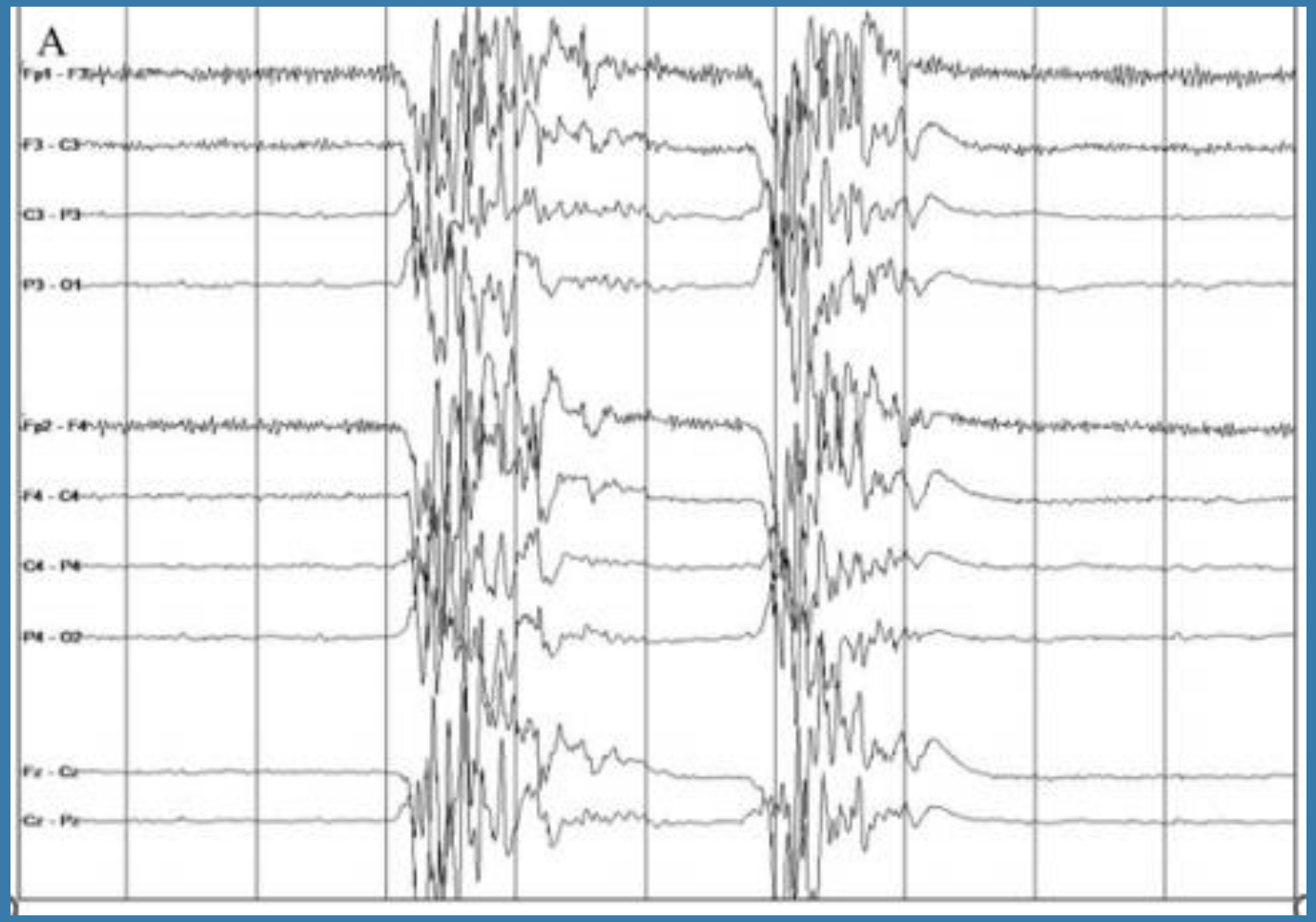
- Lance-Adams syndrome

  Action myoclonus after awakening from anoxic injury

EEG PATTERNS IN POST-ANOXIC MYOCLONUS

- Prospective study of comatose patients treated after cardiac arrest: 16% had early myoclonus

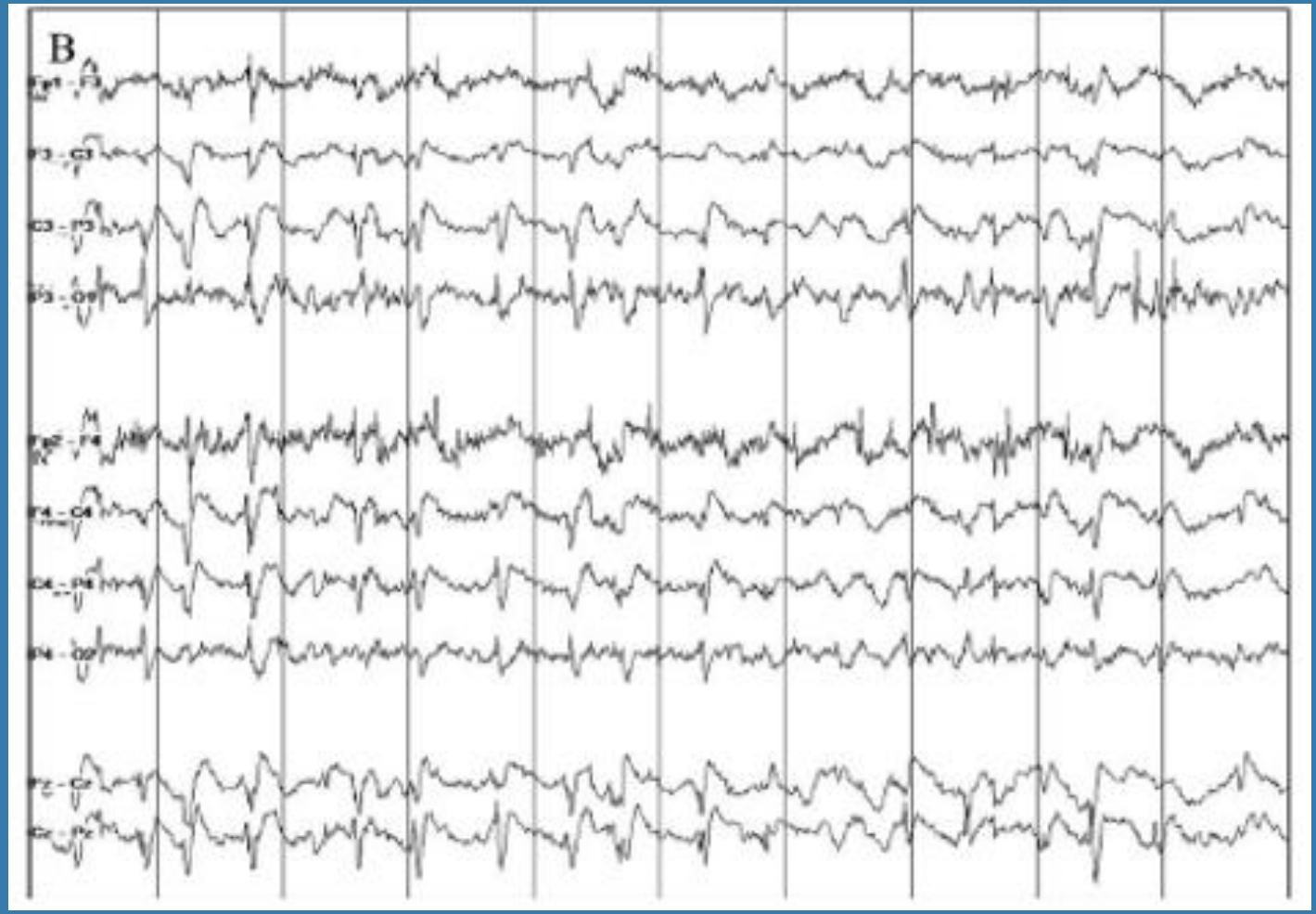
- Majority of these patients had burst suppression background with generalized polyspikes and none survived with favorable neurological outcome



Elmer et al., Annal Neurol. 2016

EEG PATTERNS IN POST-ANOXIC MYOCLONUS

- Small proportion of patients had continuous low-amplitude EEG background with narrow polyspikes
- Half of these cases survived with good neurological outcome
- Proposed that this pattern may evolve into Lance-Adams syndrome



Elmer et al., Annal Neurol. 2016

LANCE-ADAMS SYNDROME

- Myoclonic jerks (epileptic or non-epileptic) in a non-comatose cardiac arrest patient (often stimulus/action induced)
- Patients awaken and have a GOOD prognosis
- Treatment of non-epileptic myoclonus is still anticonvulsants

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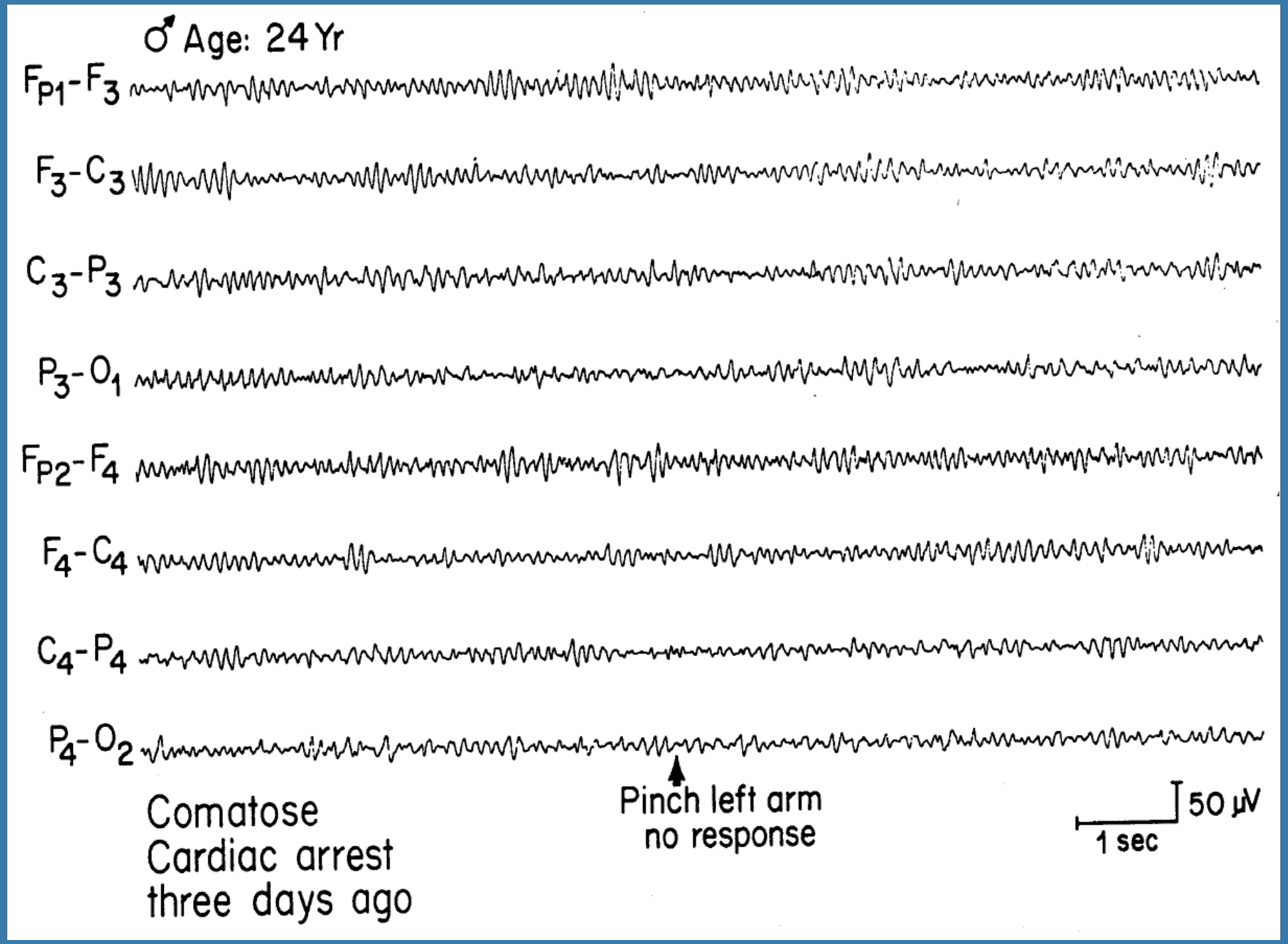
EEG CAN BE NORMAL IN COMA

- May suggest brainstem process (e.g., locked-in syndrome) or psychogenic coma
- EEG evaluates cortical function and thalamocortical synchrony/integrity not brainstem function
- Conversely, a flat EEG may occur with intact brainstem (cortical injury, drugs, etc.)


♂ Age: 24 Yr
F_{P1}-F_3
F_3-C_3
C_3-P_3
P_3-O_1
F_{P2}-F_4
F_4-C_4
C_4-P_4
P_4-O_2
Comatose
Cardiac arrest
three days ago
Pinch left arm
no response
50 μV
1 sec

ALPHA COMA

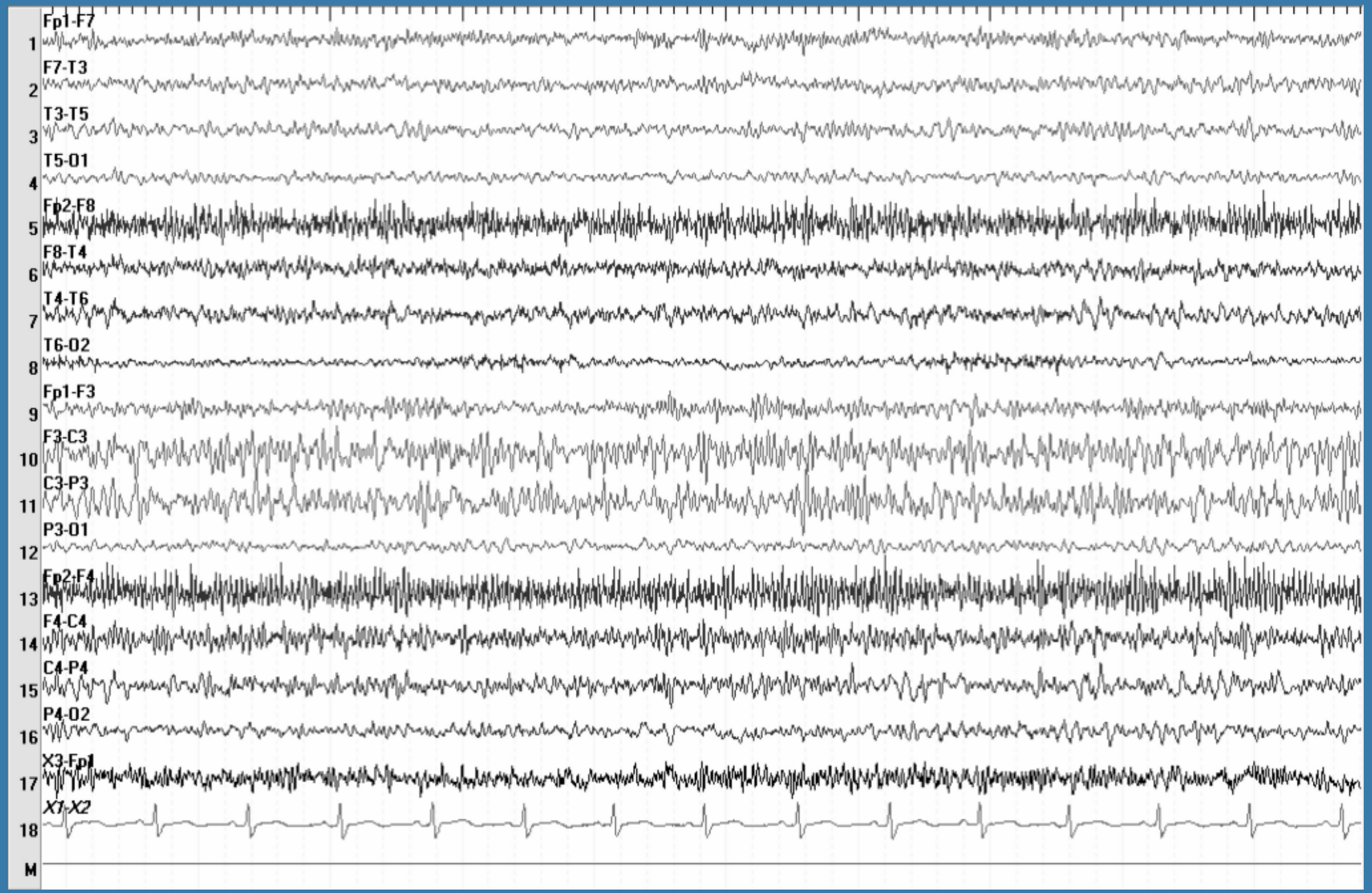
- Would be more appropriate to say “widespread alpha activity in coma”
  - “resulting from acute diffuse brain anoxia”
  - “resulting from toxic-metabolic causes”

- Lack of EEG reactivity and etiology are most important, rather than the “diagnosis” of alpha coma

Ebersole and Pedley, 2003

BETA AND SPINDLE COMA

- Coma with EEG pattern of widespread beta or spindle activity is often drug-induced, but similar to alpha coma may also be seen in metabolic, post-traumatic, or post-anoxic encephalopathy
- Spindle coma pattern is seen frequently in ICU patients in anesthetic-induce coma
- Prognosis varies depending on the etiology



Husain et al., J Clin Neurophys, 2006

Husain et al., J Clin Neurophys, 2006

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BRAIN DEATH VS. ECI/ECS

- Brain Death
  - Clinical diagnosis – requires examination
  - Diagnosis can be supported by functional studies (TCD, angiogram, EEG) but not necessarily by structural studies (CT, MRI)

- Electrocerebral Inactivity/Silence (ECI/ECS)
  - "absence over all regions of the head of identifiable electrical activity of cerebral origin, whether spontaneous or induced by physiological stimuli and pharmacological agents"
  - suggests the absence of recordable cortical activity
  - MAY be "cortical death" but is NOT "brain death"

ECI – ACNS GUIDELINES

- Interelectrode distances ≥ 10 cm
  - Typical 10-20 system – distances are 6-6.5 cm – so double distance would work

- Sensitivity must be increased from 7 µV/mm to at least 2 µV/mm for at least 30 minutes of the recording, with inclusion of appropriate calibrations

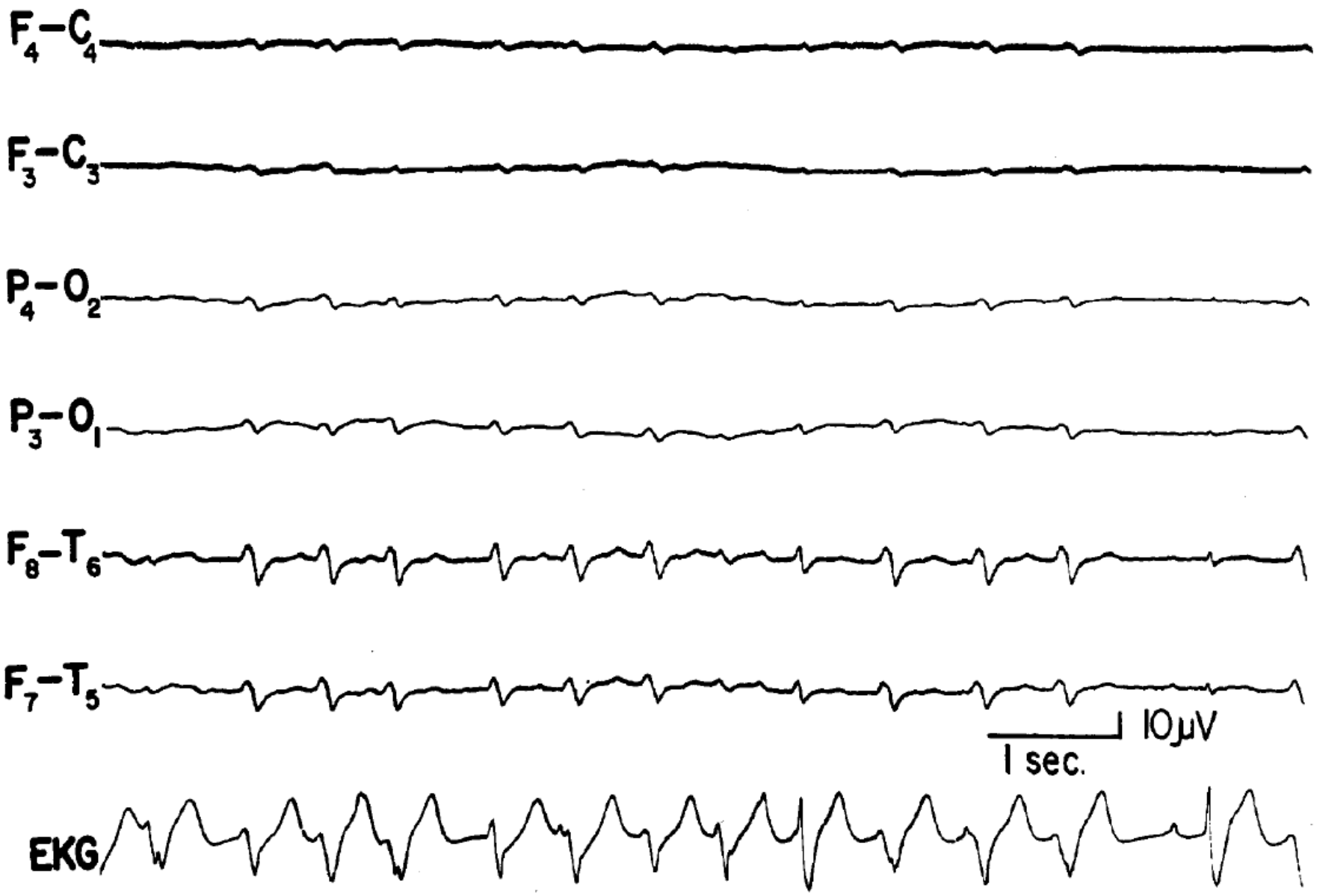
www.acns.org/practice/guidelines

ECI – ACNS GUIDELINES

- Filter settings should be appropriate for assessment of ECS
  - HFF no less than 30 Hz
  - LFF no more than 1 Hz
  - 60 Hz notch is okay

- Additional monitoring techniques should be employed when necessary
  - EKG artifact is common – MUST HAVE EKG
  - Respiration should be marked or monitored
  - Give paralytics if needed to eliminate EMG artifact
  - If artifact cannot be sufficiently eliminated, and there is still question of true cerebral activity, ECS cannot be diagnosed

ARTIFACT ASSOCIATED WITH CARDIAC ARRHYTHMIA



ECS – ACNS GUIDELINES

- There should be no EEG reactivity to intense somatosensory, auditory, or visual stimuli
- Recording should only be made by a qualified technologist
- A repeat EEG should be performed if there is doubt

CAUTIONS

- Up to 20% of clinically brain dead patients can demonstrate cerebral activity on EEG
- EEG should not be used as the only confirmatory test for brain death
- Be aware of artifact
- Be aware of all confounding factors (medications, hypothermia, cardiovascular shock, electrolyte disturbance, etc.)
- Be careful with low voltage EEGs, can still be normal
- Criteria are slightly modified for children, especially those under 2 months of age (multiple physiological measures should be included, including eye movements, EMG, respiratory, and EKG)