Multimodal Neuromonitoring & Advances in EEG for Seizure Detection

"in the ICU"

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1

Multimodal neuromonitoring
in the ICU

2

Monitoring in the ICU

- Monitoring in the ICU aims to
  - 1) Early detect potential harmful derangements
  - 2) Predict prognosis
  - 3) Guide management in real time
    - The goal of optimizing conditions to maximize the potential for recovery

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3

Patients in ICU <-- > Acute brain injury (ABI)

- Primary injury
  - Trauma, infection, stroke, etc.
- Secondary injury
  - A cascade of maladaptive
    - Edema, seizures, spreading cortical depolarization, metabolic failure, neuro-inflammation
- A diverse and heterogenous range of pathologic processes that can lead to irreversible neurologic insult (subsequent cellular death)

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4

Neuromonitoring

- Acute brain injury (ABI): complex cerebral pathology
- A single neuromonitoring device
  - Insufficient in a comprehensive scope
- Multimodal monitoring (MMM)
  - Bundling several devices
  - Each device has its specific strengths and limitations

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5

Neuromonitoring

- Multimodal neuromonitoring
  - Bundling several neurologic devices
  - Non-invasive and/or invasive
- Complementary neuromonitoring techniques
  - To enhance the predictive value of the physiologic outputs
  - To manage and allow for individualized patient management decision
  - To characterize cerebral autoregulation capacity with the goal of optimizing cerebral perfusion

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6

Common clinical neuromonitoring techniques

- Neurological examination
- Neuroimaging
- Intracranial pressure
- Brain tissue oxygenation
- Transcranial doppler
- Near-infrared spectroscopy
- Electroencephalography

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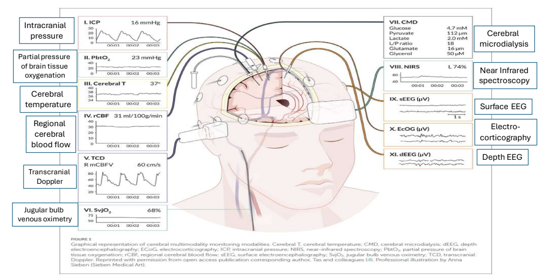
7



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8

Multimodal neuromonitoring

Cerebral autoregulation evaluation

- Most of techniques "except" quantitative electroencephalography (qEEG) and cerebral microdialysis

Seizure detection

- EEG
- qEEG

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9

Modality	Description	Primary signal output	Relevant thresholds	Cerebral autoregulation indices	Signals correlated	Thresholds
Intracranial pressure monitoring	Invasive insertion into cranium. Most commonly in the ventricular or parenchymal space.	ICP CPP	≤20 or 22 mmHg (34) 60–70 mmHg (34)	PRx	ICP and MAP	>0.2 Mortality (13) >0.05 Unfavorable Outcome (13)
Brain tissue oxygenation	Invasive probe measuring oxygen tension in brain parenchyma. Reflects the balance between cerebral oxygen delivery, diffusion and demand.	$PbtO_2$	>15–20 mmHg (35)	ORx	$PbtO_2$ and CPP	>0.3–0.4 Unfavorable Outcome (14)

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10

Modality	Description	Primary signal output	Relevant thresholds	Cerebral autoregulation indices	Signals correlated	Thresholds
Transcranial doppler	Non-invasive low frequency ultrasound capable of detecting proximal cerebral vessel blood flow	CBFV PSV EDV MFV PI	MCA MFV >160–200 cm/s suggests vasospasm in SAH (36, 37) MFV < 40 cm/s or EDV <20–25 cm/s associated with worse outcome in TBI (38, 39) PI>1.3–1.5 associated with worse outcome in TBI (40, 41)	Sx Sx_a Mx Mx_a	PSV and CPP PSV and MAP MFV and CPP MFV and MAP	>−0.2 Mortality (25) >−0.15 Unfavorable Outcome >0.05 Mortality (25) >−0.1 Unfavorable Outcome >0.3 Mortality (25) >0.3 Unfavorable Outcome >0.3 Unfavorable Outcome (25)
Near infrared spectroscopy	Non-invasive near infrared light source sensitive to oxygenation status of hemoglobin with ability to describe cerebral oxygenation and blood flow	rSO_2 TOI	Absolute values <50–60% (42) or decline in baseline by >13% concerning for ischemia (43)	COx TOI THx	rSO_2 and MAP TOI and MAP HbT and MAP	Limited clinical evidence to support clear thresholds In general (+) values have been considered consistent with impaired autoregulation

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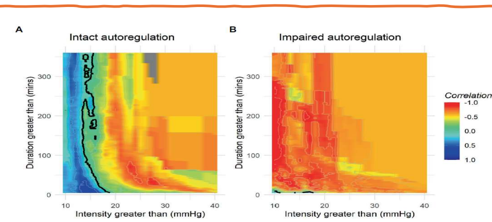
11



Population based ICP intensity map stratified by autoregulatory status

- Red areas = ICP density with poor outcomes
- Blue areas = ICP density with good outcomes

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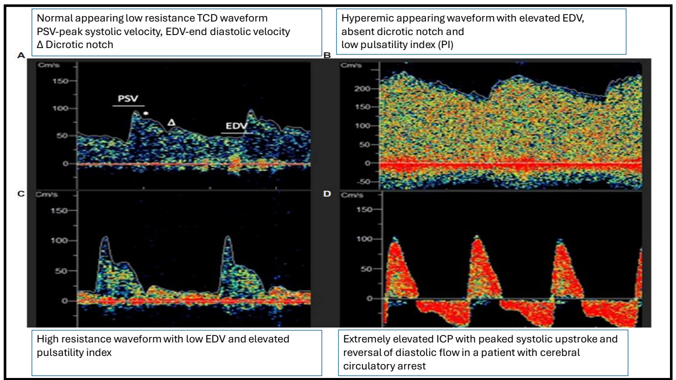
12



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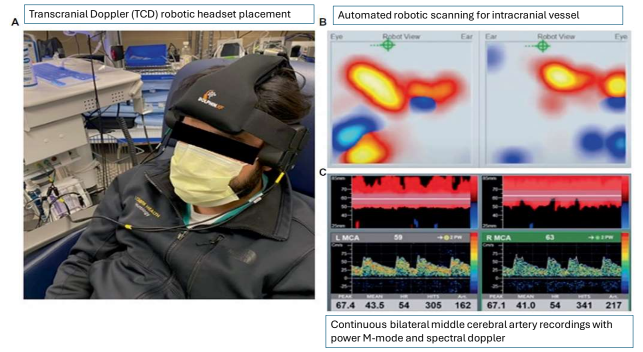

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14

Common neurocritical monitoring tools

Physiologic events	Tools	Advantage	Disadvantage
Global neurological status	- Glasgow coma scale - Full Outline of Unresponsiveness - Nociception coma scale-revised - Intensive care delirium screening checklist	- Mostly commonly used manually - No need of expensive instruments	- Too late to prompt preventive strategies for potential secondary brain injury

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15

Common neurocritical monitoring tools

Physiologic events	Tools	Advantage	Disadvantage
Cerebral oxygenation	PET scan	Gold standard	Usually unavailable in ICU
	Jugular bulb venous oximetry (SjvO2)	Measure the global brain oxygenation	Invasive with complications
	Intraparenchymal oxygen sensors	Measure the regional brain oxygenation	- Invasive with complications - Variation by probe location
	Near-infrared spectroscopy (NIRS)	Noninvasive	- Limited by depth of light penetration interference from other sources - Uniform distribution of infrared light in CSF

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16

Common neurocritical monitoring tools

Physiologic events	Tools	Advantage	Disadvantage
Cerebral blood flow	Thermal diffusion flowmetry	Gold standard measure regional CBF	- Sensitivity to ambient light and temperature
	Laser Doppler flowmetry		- Sensitivity to positioning
	CT, MRI, PET scan	Noninvasive	- Usually unavailable in ICU - Failure in continuous monitoring
	TCD	- Noninvasive - Available in ICU	- Limited by operator variability - Usually failure in continuous monitoring

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17

Common neurocritical monitoring tools.

Physiologic events	Tools	Advantage	Disadvantage
Cerebral pressure	Intracranial ICP sensors	Gold standard	Invasive with complications
	TCD	Noninvasive	-Less accurate
	Optic nerve sheath diameter (ONSD)	Noninvasive	Less accurate
	Tympanic membrane displacement (TMD)	Noninvasive	- Less accurate - Large standard error and inter-subject variability

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18

Common neurocritical monitoring tools.

Physiologic events	Tools	Advantage	Disadvantage
Cerebral autoregulation	Intraparenchymal oxygen sensor and ICP monitoring	Gold standard	Invasive
	Near-infrared spectroscopy (NIRS)	Noninvasive	Less accurate
	TCD	Noninvasive	Less accurate
Cerebral metabolism	Microdialysis	Measure common brain metabolites - markers of tissue injury, energy failure, cellular stress	- Timing consuming - Low temporal resolution - Volume limitation - Placement matters

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19

Common neurocritical monitoring tools

Physiologic events	Tools	Advantage	Disadvantage
Cerebral electrical activity (real time)	EEG	- Primary aim: detect epileptiform discharges - Secondary aim: measure brain electrical activity for predict clinical outcome or prognosis	- High expense - Need for technicians to place EEG leads - Need experts to interpret the recordings - Variability of result between expert readers

Continuous and simultaneous EEG and ICP recordings showed a strong relationship, which could lead to the development of a medical device to measure ICP in a noninvasive way.

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20

Advances in EEG for seizure detection in the ICU

21

The prevalence of seizure in the ICU

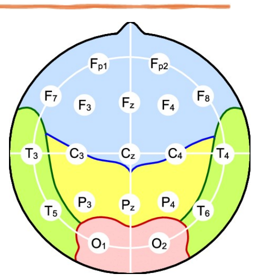
- Among patients with altered mental status (ASM)
  - 15%-30%
    - Up to 90% -- no/or subtle clinical signs
  - 87%-93% of seizure captured within 48-hour and increased frequency of seizures

Claassen J, et al. Neurology. 2004., Friedman D, et al. Anesth Analg. 2009., Towne AR, et al. Neurology. 2000., Newey CR, et al. J Clin Neurophysiol. 2018.

22

Technical aspects of EEG monitoring in the ICU

- Electrode, collodion
- The contact impedance 1-10 KΩ (typical 5-10)
- Even – right, odd – left
- Fp, F, C, P, O, T, Z, representing anatomica area of the brain
- One-channel for ECG ± EMG, EOG, respiratory sensors
- Bipolar montage, referential, average
- Net polarity: negative → upward deflection, positive → downward deflection
- Frequency: delta (1-3Hz), theta (4-7Hz), alpha (8-12Hz), beta (13-30Hz), gamma (30-100Hz)



23

Type of EEG in the ICU

- Ideal EEG
  - The standard 21-electrode montage from the international 10-20 system
- Optional EEG
  - Fewer electrode placement
- Surface EEG
- Intracortical depth electrodes
- Intermittent or routine EEG (rEEG) – 20-60 minutes
- Short-term video EEG (STEEG) - 1-8 hours
- Continuous EEG (cEEG) – 12-24 hour or longer

Claassen J, et al. Neurology. 2004., Friedman D, et al. Anesth Analg. 2009., Towne AR, et al. Neurology. 2000., Newey CR, et al. J Clin Neurophysiol. 2018.

24

Continuous electroencephalogram (cEEG)

- A widespread practice in neuro-ICU
- The American Clinical Neurophysiology Society (ACNS) recommends for detecting of secondary injury in critically ill patients with altered mental status
  - To detect nonconvulsive seizures and status epilepticus and to monitor response to treatment
  - To detect secondary ischemia
  - To detect pharmacological sedation
  - To provide prognostication after cardiac arrest
- Problem: resource consuming

Herman ST, et al. J Clin Neurophysiol. 2015

25

Indication for EEG monitoring in ICU: Critical care and neurophysiology societies guidelines

- Seizure detection
  1. Patients with convulsive status epilepticus (CSE) without return to baseline
  2. Comatose patients with or without brain injury and without clear explanation of their mental status
  3. Unresponsive hypoxic-ischemic brain injury (HIBI) patients, during hypothermia, and within 24 hour of rewarming
- Other indications
  1. Delayed cerebral ischemia in SAH patients
  2. Prognostication after coma esp. in patients with hypoxic ischemic brain injury (HIBI)
  3. Monitoring of continuous sedation

Claassen J, et al. Intensive Care Med. (2013)., Le Roux P, et al. Intensive Care Med. (2014)., Herman ST, et al. J Clin Neurophysiol. (2015).

26

ONLINE REVIEW ARTICLE

How and Whom to Monitor for Seizures in an ICU: A Systematic Review and Meta-Analysis

Limotai, Chusak MD[1–3]; Ingsathit, Atiporn MD, PhD[1]; Thadanipon, Kunlawat MD[1]; McEvoy, Mark PhD[4]; Attia, John MD, PhD[4]; Thakkinstian, Ammarin PhD[1]

Author Information

Critical Care Medicine 47(4):p e366-e373, April 2019. | *DOI:* 10.1097/CCM.0000000000003641

Continuous EEG (cEEG) vs. intermittent routine EEG (rEEG)

A total of 78 (16,707 patients) and eight studies (4,894 patients)

cEEG was superior to rEEG in detecting non-convulsive seizures (NCS) and non-convulsive status epilepticus (NCSE)

Pooled odds ratios from studies with independent data was 1.57 (95% CI, 1.00–2.47)

	NCS	NCSE	Either NCS or NCSE
rEEG	3.1%	6.2%	6.3%
cEEG	17.9%	9.1%	15.6%
• Post CSE	33.5%	20.2%	32.9%
• CNS infection	23.9%	18.1%	23.9%
• Post cardiac arrest	20%	17.3%	22.6%

Limotai C, et al. Crit Care Med. (2019)

27

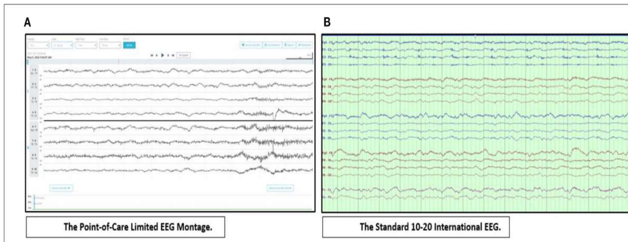


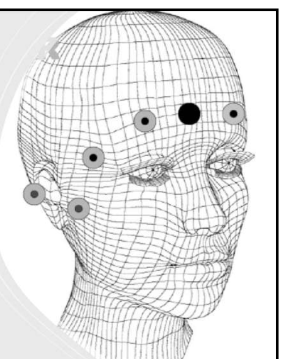
FIGURE 1 | Point-of-care EEG. Suspected seizures in a 62-year-old man with decreased level of consciousness ruled out within 10 min with the use of a point-of-care limited EEG montage. The findings were later confirmed with the standard cEEG. **(A)** displays diffuse, irregular, attenuated mixed frequency delta-theta activity in the point-of-care limited EEG montage. Display: 10 s, Scale: ±50 μV, High Pass: 1 Hz, Low Pass: 70 Hz, Notch: 60 Hz. **(B)** displays diffuse, irregular, attenuated mixed frequency delta-theta activity in the standard International 10–20 EEG. Bipolar montage, LFF: 1 Hz, HFF: 70 Hz, Notch: 60 Hz, Sensitivity: 7 μV/mm, Timebase: 30 mm/s.

Sharma S et al. Frontier in Neurology 2022

28

The sub-hairline electrode montage

Clinical trials in critically ill patient



A prospective study (n = 170)

- Comparing the full-montage 10–20 placement of electrodes to the sub-hairline electrode montage
- 8% of patients had seizures
  - Sensitivity of the sub-hairline montage = 54%, specificity = 100%

A prospective study (n = 70)

- Simultaneously connected with a full 10–20 system and the four-channel sub-hairline montage
- A sensitivity of 68% and specificity of 98% for seizure detection for both focal and generalized seizures

Tanner AE, et al. J Clin Neurophysiol 2014., Young GB, et al. Neurocrit Care 2009.

29

Rapid response EEG system

- 8 channels from a bipolar array of 10 electrodes
- A portable EEG recorder and a disposable electrode headband
- The data is acquired as digital samples at a rate of 250 Hz, with a frequency response of 0.5-100 Hz
- During recordings, the rapid response EEG recorder automatically measures electrode impedances at regular intervals
- A user "without prior training in EEG set up"

Kamousi B, et al. Clinical Neurophysiology Practice 2019

30

Rapid response EEG system channels	Corresponding conventional EEG channels	Rapid response EEG system channels	Corresponding conventional EEG channels
1–2	Fp1-F7	6–7	Fp2-F8
2–3	F7-T3	7–8	F8-T4
3–4	T3-T5	8–9	T4-T6
4–5	T5-01	9–10	T6-02

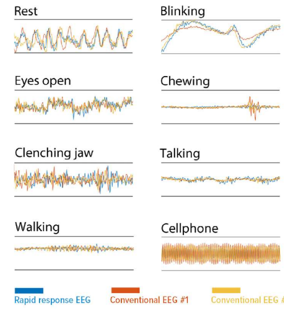
The tested rapid response EEG system's electrode pairs simultaneously with 2 conventional EEGs
One healthy subject

Kamousi B, et al. Clinical Neurophysiology Practice 2019

31

Comparison of epochs of interest

- The EEG waveforms captured by:
  - Rapid response EEG (blue traces)
  - Conventional EEG #1 (orange traces)
  - Conventional EEG #2 (yellow traces)



Kamousi B, et al. Clinical Neurophysiology Practice 2019

32

22 critically ill patients (non-simultaneously: rapid system vs. conventional EEGs)

Table 4
Concordance of clinical information obtained with the rapid response EEG and conventional EEG.

	Time* (mins)	Rapid response EEG Finding	Conventional EEG Finding
1	21	Focal seizure in the right occipital region (7 min 23 s into recording)	Moderate diffuse slowing. Generalized rhythmic delta activity with frontal intermittent rhythmic delta activity.
2	43	Focal right hemispheric seizure (12 min 04 s into recording)	Moderate to severe diffuse slowing. Patient was loaded with Keppra 1000 mg prior to conventional EEG.
3	134	Diffuse slowing	Diffuse slowing
4	47	Diffuse slowing, missing data from electrode 8 (on bandage)	Diffuse slowing
5	8	Diffuse slowing	Diffuse slowing
6	7	Diffuse slowing	Diffuse slowing with left frontal epileptiform discharges and 4 electrographic left frontal seizures
7	21	Excessive beta, otherwise mildly slow	Normal awake and asleep EEG
8	74	Slow bilaterally but with excessive movement artifact especially in the posterior channels	Moderate to severe slowing with bifrontal sharply contoured transients
9	81	Diffuse slowing	Diffuse slowing
10	115	Diffuse slowing	Diffuse slowing with Generalized Periodic Discharges
11	44	Generalized periodic discharges on suppressed background with excessive muscle artifact	Myoclonic status epilepticus with intervening burst suppression
12	2	Diffuse slowing	Diffuse slowing
13	90	Diffuse slowing	Diffuse slowing
14	25	Diffuse slowing	Diffuse slowing with additional right fronto-parietal slowing and suppression
15	92	Diffuse slowing	Diffuse slowing
16	25	Diffuse slowing with GPDs	Diffuse slowing with episodes of generalized rhythmic slowing (GRDA), and rare runs of non-specific generalized periodic discharges (GPDs)
17	76	Diffuse slowing	Intermittent epileptiform discharges over the left and right frontal regions, less frequently over the bitemporal regions, and sometimes in the form of lateralized periodic discharges, mild to moderate diffuse slowing with additional intermittent focal slowing over the right
18	70	Diffuse slowing with GPDs	Diffuse slowing, including rhythmic slow patterns with additional intermittent rhythmic slowing and nonspecific periodic discharges over the left frontal region
19	76	Right > left slow and stimulus induced rhythmic activity	Diffuse slowing with stimulus induced rhythmic waveforms upon noxious stimulation
20	115	Diffuse slowing with sharply contoured waveforms (L > R)	Diffuse slowing with brief periods of discontinuities and non-specific blunted generalized discharges, occasionally in runs (Generalized Periodic Discharges)
21	33	Diffuse slowing	Diffuse slowing
22	117	Diffuse slowing	Occasional runs of Generalized Periodic Discharges (GPDs) upon stimulation with diffuse slowing

* Time = duration of rapid response EEG recording.

Conclusion:
The tested rapid response EEG system provides EEG data that is equivalent in quality to the recordings made using conventional EEG systems despite the fact that the rapid response system can be applied within few minutes and with no reliance on specialized technologists.

Kamousi B, et al. Clinical Neurophysiology Practice 2019

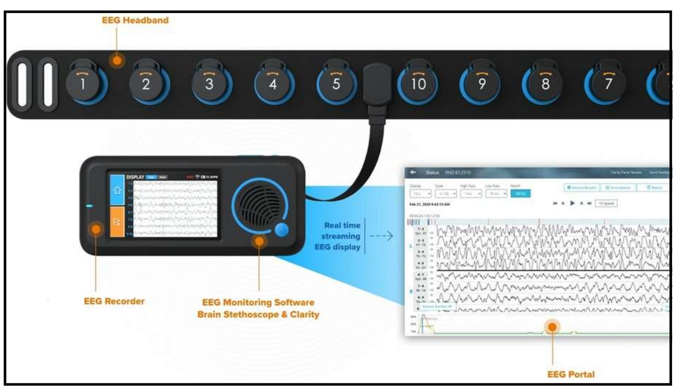
33

Rapid system for detecting status epilepticus

- A small prospective study
- 10 patients: rapid response EEG
- 20 patients: 18-electrodes EEG montage
- Time to diagnosis of status epilepticus — Rapid response: 23.8 minutes; 18-channel: 126.5 minutes

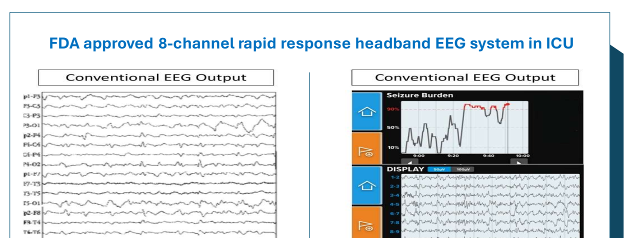
LaMonte MP. Et al. Epilepsia Open 2021.

34



35

FDA approved 8-channel rapid response headband EEG system in ICU



	Conventional	Ceribell
Frequency		
Sampling rate (range)	200–1,000 Hz	250 Hz
Frequency response (range)	0.01–500 Hz	0.5–100 Hz
Channels	32	8
Number of electrodes	21	10

36

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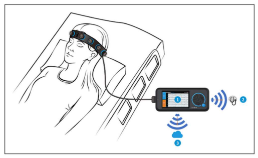
Evaluating the Clinical Impact of Rapid Response Electroencephalography: The DECIDE Multicenter Prospective Observational Clinical Study

Paul M. Vespa, MD[1], DaiWai M. Olson, RN, PhD[2], Sayona John, MD[3], Kyle S. Hobbs, MD[4], Kapil Gururangan, MD[5], Kun Nie, PhD[6], Masoom J. Desai, MD[7], Matthew Markert, MD, PhD[8], Josef Parvizi, MD, PhD[8], Thomas P. Bleck, MD[7], Lawrence J. Hirsch, MD[9], M. Brandon Westover, MD, PhD[10]

- A recent larger prospective multicenter non-randomized observational study
- 5 centers in the US
- 164 critically ill patients: evaluated for NCSE
- Rapid response EEG compared to clinical diagnosis

DECIDE trial

- The sensitivity improved from 77.8% to 100%
- The specificity improved from 63.9% to 89%
- Time to EEG placement was a median of
  - 5 minutes rapid response system
  - 239 minutes with conventional EEG
- The rapid response = economically feasible



Vespa PM, et al. Crit Care Med. (2020)

37

Quantitative EEG (qEEG) in the ICU

- The real-time visual analysis
- Computational analysis of the EEG signal in a simplified display
- For reviewing large amounts of data → reducing the time to detect electrographic seizures
- Problems
  - No 24-hour availability of an experienced electroencephalographer for real time interpretation of the data
  - The data takes significant time and effort
  - Subtle changes to trends on war EEG may be easily missed

ScheuerML, et al. J Clin Neurophysiol. (2004)., Swisher CB, et al. J Clin Neurophysiol. (2016)

38

Quantitative EEG (qEEG) in the ICU

- A collection of sinusoidal waves with key properties utilized by the mathematical algorithms to produce different qEEG panels or trends
- The color spectrogram power scale is measured in decibels (dB) with cooler colors representing lower power and warmer colors representing higher power
- *** seizures are most easily recognized on a spectrogram by a "flame" appearing pattern due to the abrupt increase in power across a range of frequencies that stands out from the backgrounds

Westover MCNJJMB. Atlas of Intensive Care Quantitative EEG. (2020).

39

Common qEEG panels or trends

- Compressed spectral array (CSA)
- Density spectral array (DSA)
- Asymmetry relative spectrogram
- Fast Fourier transform (FFT) spectrogram
- Rhythmicity spectrogram
- The amplitude EEG (aEEG)
- Seizure detector panel

Goenka A, et al. Seizure. (2018)

40

Common qEEG panels or trends

- The compressed spectral array (CSA) generates a 3-dimensional display by plotting successive epochs as a function of time
- The density spectral array (DSA) depicts EEG spectral power amplitude as a grey-scale or color density function rather than vertical deflections as seen in the CSA
- The asymmetry relative spectrogram, displays power differences between homologous electrodes at discrete frequencies and illustrates power asymmetry across the 2 hemispheres
- It is a line graph that displays an average of the absolute values over a specified frequency range or relative asymmetry data as a function of time

Goenka A, et al. Seizure. (2018)

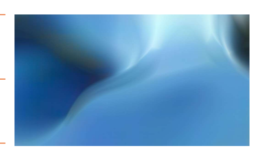
41

Common qEEG panels or trends

The fast fourier transform (FFT) spectrogram displays color coded power of EEG at different frequencies using a FFT analysis of the amplitude of waveforms as a function of time

The rhythmicity spectrogram displays a 3-dimensional representation of the power characteristics for the EEG

A density spectral array of frequencies as a function of time



Goenka A, et al. Seizure. (2018)

42

Common qEEG panels or trends

- A graphical depiction of the amplitude of primary rhythmic EEG components present in four frequency bands: 1-4, 4-9, 9-16, 16-25 Hz
- Amplitude (aEEG) spectrogram displays amplitude characteristics of the EEGs as a function of time
- The seizure detector trend displays the combination of multiple inputs as a seizure probability, dichotomized into a value of zero or one

Goenka A, et al. Seizure. (2018)

43

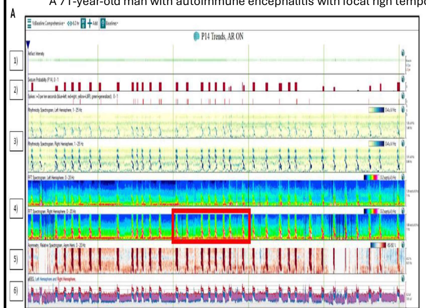
Common qEEG panels or trends

- Compressed spectral array (CSA)
- Density spectral array (DSA)
- Asymmetry relative spectrogram
- Fast Fourier transform (FFT) spectrogram
- Rhythmicity spectrogram
- The amplitude EEG (aEEG)
- Seizure detector panel

Goenka A, et al. Seizure. (2018)

44

A 71-year-old man with autoimmune encephalitis with focal righ temporal electro-clinical status epilepticus



1) The artifact intensity panel

2) The seizure probability panel (0-1)

3) The left and right rhythmicity spectrogram pane; displays the power characteristics for each frequency band (1-4, 4-9, 9-16 and 16-25 Hz) as a function of time

4) The left and right FFT (fast Fourier transform) spectrogram panel displays the color-coded power of different EEG frequency band

5) The relative asymmetry spectrogram panel (left in blue and right in red) displays power differences between homologous electrodes at discrete frequencies and illustrates power asymmetry across the 2 hemispheres

6) The left (in blue) and right (in red) hemisphere amplitude EEG (aEEG) panel displays amplitude characteristics of the EEG as a function of time

qEEG in 6 hours

45

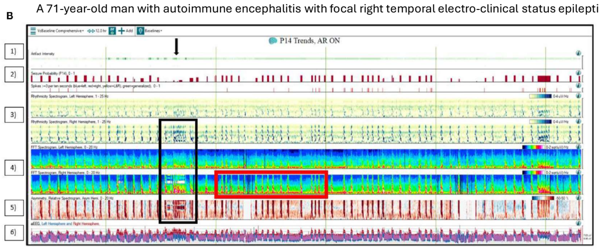
Common qEEG panels or trends

- Compressed spectral array (CSA)
- Density spectral array (DSA)
- Asymmetry relative spectrogram
- Fast Fourier transform (FFT) spectrogram
- Rhythmicity spectrogram
- The amplitude EEG (aEEG)
- Seizure detector panel

Goenka A, et al. Seizure. (2018)

46

A 71-year-old man with autoimmune encephalitis with focal right temporal electro-clinical status epilepticus



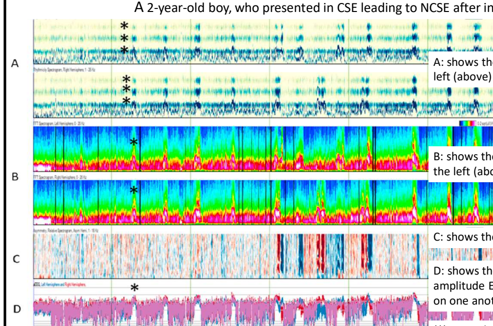
qEEG in 12 hours

1. Black arrow: artifacts, detected by the artifact intensity panel
3. Black box: The relative asymmetry spectrogram: increase peak asymmetry on the right
4. Red box: Peaks in the right FFT (flame) spectrogram panel indicating discrete right temporal seizures
5. Asymmetry Several peak in red
6. Higher amplitude on the right hemisphere

47

Quantitative EEG display (left/right hemispheric montage): The display is condensed to review a 2-hour period.

A 2-year-old boy, who presented in CSE leading to NCSE after intubation



A: shows the rhythmicity spectrogram for the left (above) and right hemisphere (below).

B: shows the CSA/FFT spectrogram for the left (above) and right hemisphere (below)

C: shows the asymmetry spectrogram

D: shows the left and right hemisphere amplitude EEG (aEEG) superimposed on one another

(*) examples of seizure activity.

48

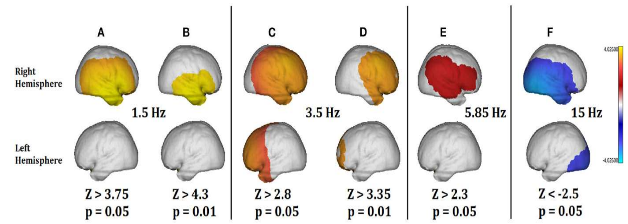


FIGURE 4 | Summary of the qEEGt analysis of the 71 years old patient. The more significant results are shown for bands Delta, Theta, and Gamma at two thresholds ($p = 0.05$ and $p = 0.01$). **(A)** ($p = 0.05$) and **(B)** ($p = 0.01$) show a pathological excess of Delta activity in the right hemisphere. **(C)** ($p = 0.05$) and **(D)** ($p = 0.01$) show the excess of pathological activity in the right hemisphere and frontal part of the left hemisphere. **(D)** Shows that the most pathological areas in Theta coincide with the exact location of the surrounding area of the lesion. **(E)** Shows that no pathological activity was significant at 5.85 Hz for $p = 0.01$. **(F)** Shows a pathological decrease of activity in the Beta band, related to the location of the lesion and the edema area. No significant differences were found in the Alpha band. The implications of these results are discussed in the text.

Jorge Bosch-Bayard, et al. Frontiers in Neuroinformatics 2020

49

Accuracy of qEEG in critically ill patients

A cohort of 562 seizures from 58 pediatric and adult patients

- Sensitivity for seizure detection ranges 43-72%
  - Highest sensitivity by seizure detection trend, 402/562, 72%
- Sensitivity for detecting focal seizure
  - Highest by the asymmetry spectrogram (94%)
- Most sensitive for detecting secondarily generalized seizures
  - The FFT spectrogram (158/187, 84%)
- Most sensitive for generalized onset seizures
  - The seizure detection trend 197/250, 75%

Goenka A, et al. Seizure. (2018)

50

Accuracy of qEEG in critically ill patients: A retrospective study 118 adult patients

qEEG Vs. gold standard (raw cEEG)	Sensitivity
• Seizure detection	87.3%
• Periodic epileptiform discharges	100%
• Rhythmic delta activity	97.1%
• Focal slowing	98.7%
• Generalized slowing	100%

Data from	Mean duration to review 24 hours (minutes) ± SD
• Compressed spectral array (CSA)-guided review	8 ± 4
• Raw cEEG	38 ± 17

Moura LM, et al. Neurology. (2014)

51

An ICU qEEG survey in 2016

75 neurophysiologists from the American Clinical Neurophysiology Society (ACNS)

Utilized qEEG for
- Seizure detection (92%)
- Prognosis for cardiac arrest (21.3%)

The most frequently used qEEG trends or panels for seizure detection
- Rhythmicity spectrogram (61%)
- Automated seizure detector (55%)

Swisher CB, et al. J Clin Neurophysiol 2016.

52

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Continuous EEG in ICU: Not a Luxury After All

Continuous vs Routine Electroencephalogram in Critically Ill Adults With Altered Consciousness and No Recent Seizure: A Multicenter Randomized Clinical Trial

Rossetti AO, Schindler K, Sutter R, Rüegg S, Zubler F, Novy J, Oddo M, Warpelin-Decrausaz L, Alvarez V. *JAMA Neurol.* 2020;77(10):1-8. doi:10.1001/jamaneurol.2020.2264

- CERTA study (multicenter RCT in Switzerland)
- 364 patients using e30–48-hour total) or 2 eRRGs ither the cEEG ((20 minutes each)
- This pragmatic trial shows that in critically ill adults with impaired consciousness and no recent seizure, **"cEEG leads to increased seizure detection and modification of antiseizure treatment"** but is **"not related to improved outcome compared with repeated rEEG"**

53

Conclusion

- The EEG is an essential apparatus in critical care that provides a relatively inexpensive tool for clinicians to monitor cerebral activity in real time.
- Although the awareness of subtle electro-clinical and electrographic non-convulsive seizures has increased in critical care, cEEG continues to be underutilized.
- With the rise in cEEG monitoring, the burden falls to the electroencephalographer and the institution to provide this necessary instrument to critically ill patient.
- The introduction of "qEEG" and "other future machines" learning applications, we may find more efficient and less taxing means of acquiring this necessary electrocerebral data.

54