

EDITORIAL

Quantitative Continuous EEG: Bridging the Gap Between the ICU Bedside and the EEG Interpreter



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Non-convulsive seizures (NCSZs) and non-convulsive status epilepticus (NCSE) are common in critically ill patients and are associated with neurophysiologic disturbances, mortality, and worsened recovery [1–7]. Continuous electroencephalography (cEEG) is required to detect NCSZs, but at most centers, tracings can only be intermittently reviewed by neurophysiologists a few times per day, primarily during day-time hours [8]. Multi-disciplinary professionals who are at the bedside caring for critically ill patients usually do not have specific proficiency in EEG interpretation, while neurophysiologists infrequently have critical care expertise and commonly interpret cEEG tracings remotely rather than at the bedside. Although a growing number of neurointensivists have at least some EEG training, additional strategies are needed to better integrate cEEG information into patient care and to bridge the gap between bedside providers and neurophysiologists, thereby ensuring that appropriate treatment is delivered in a timely fashion.

Quantitative cEEG consists of visually simplified, time-compressed displays summarizing various elements of electrographic data (frequencies, amplitude, power, and rhythmicity), allowing interpreters to see, in effect, “the forest” rather than “the trees” [9]. Interpreters can screen large amounts of data much more efficiently than by reviewing the entire raw cEEG tracing [10, 11]. For example, in the 8 h of quantitative cEEG data shown in Fig. 1, there is little change between 12:00 and 18:00, such that less time can be spent reviewing the raw EEG obtained during these hours.

Electrographic seizures are characterized by the onset of rhythmic epileptiform discharges that usually evolve in frequency, morphology, and location [4, 12]. In many cases, these transient changes can be observed without difficulty using quantitative displays. In Fig. 1, reviewers’ attention would be immediately drawn to the abrupt and brief alterations in EEG frequencies and power beginning at about 18:00. Each of the subsequent “events” in the panel coincides with an electrographic seizure (these are magnified in Fig. 2 by shortening the epoch to 4 h).

The previous literature has assessed the diagnostic accuracy of quantitative EEG displays in comparison with the gold standard of raw cEEG interpreted by board-certified neurophysiologists (Table 1) [10, 11, 13–22]. Color density spectral array (CDSA) and amplitude integrated EEG (aEEG) are the quantitative modalities that have been best studied, while a proprietary “rhythmicity spectrogram” has become available more recently and has not been studied as extensively (Figs. 1 and 2). For neurophysiologists, the main advantage of quantitative displays is in saving time during cEEG interpretation [10, 11]. For critical care physicians and nurses, the primary purpose is in recognizing transient alterations in the cEEG tracing that could alert them to the presence of seizures. The sensitivity of quantitative displays has been reported to be in the range of 65–90% and does not appear to differ significantly based on the expertise of the interpreter, or when CDSA and aEEG are compared. Seizures may be missed, especially if they are low in amplitude, low in frequency, focal, or have other characteristics that prevent them from standing out compared to the EEG background.

A variety of non-ictal EEG patterns (e.g., periodic discharges, artifact related to patient movement, or state changes) may be indistinguishable from seizures using quantitative cEEG displays, such that suspicious time

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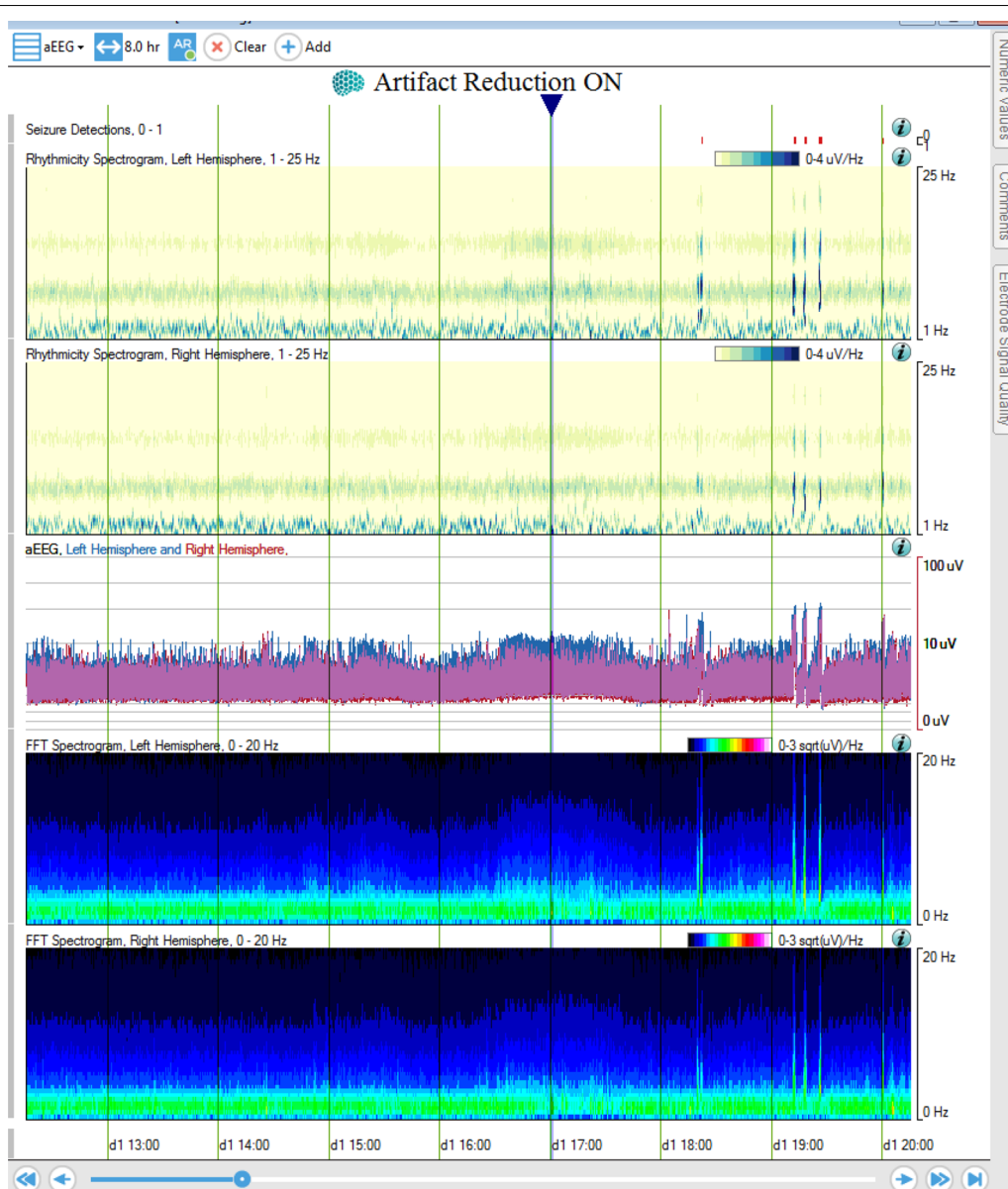


Fig. 1 Eight-hour quantitative EEG panel (rhythmicity spectrogram, aEEG, and CDSA) from 33-year-old patient with viral encephalitis complicated by non-convulsive status epilepticus. Beginning at 18:00, there are multiple events with rhythmicity and increased EEG amplitude and frequency. Raw EEG confirmed that these were electrographic seizures

periods should always be assessed using the raw cEEG tracing before prompting changes in management (Fig. 3). In several studies, false positives are common, especially among non-experts, who also generally do not have the advantage of being able to correlate the quantitative tracing with the corresponding raw cEEG. For example, a recent study found as many as 7–8 false positive “seizures” per 24 h when quantitative displays were reviewed by pediatric intensive care unit (ICU) fellows [19]. Another study reported a specificity of only 38%

when tracings were interpreted by ICU nurses [22]. Inappropriate treatment of false positives could potentially cause complications and increased ICU length of stay. Conversely, if ICU professionals call a neurophysiologist for each false positive, it may become overly burdensome and non-sustainable. Thus, even if quantitative displays are used, it is helpful for ICU physicians and nurses to develop at least some proficiency in EEG interpretation, especially to rule out seizures when quantitative cEEG changes are obviously due to artifact. The previous

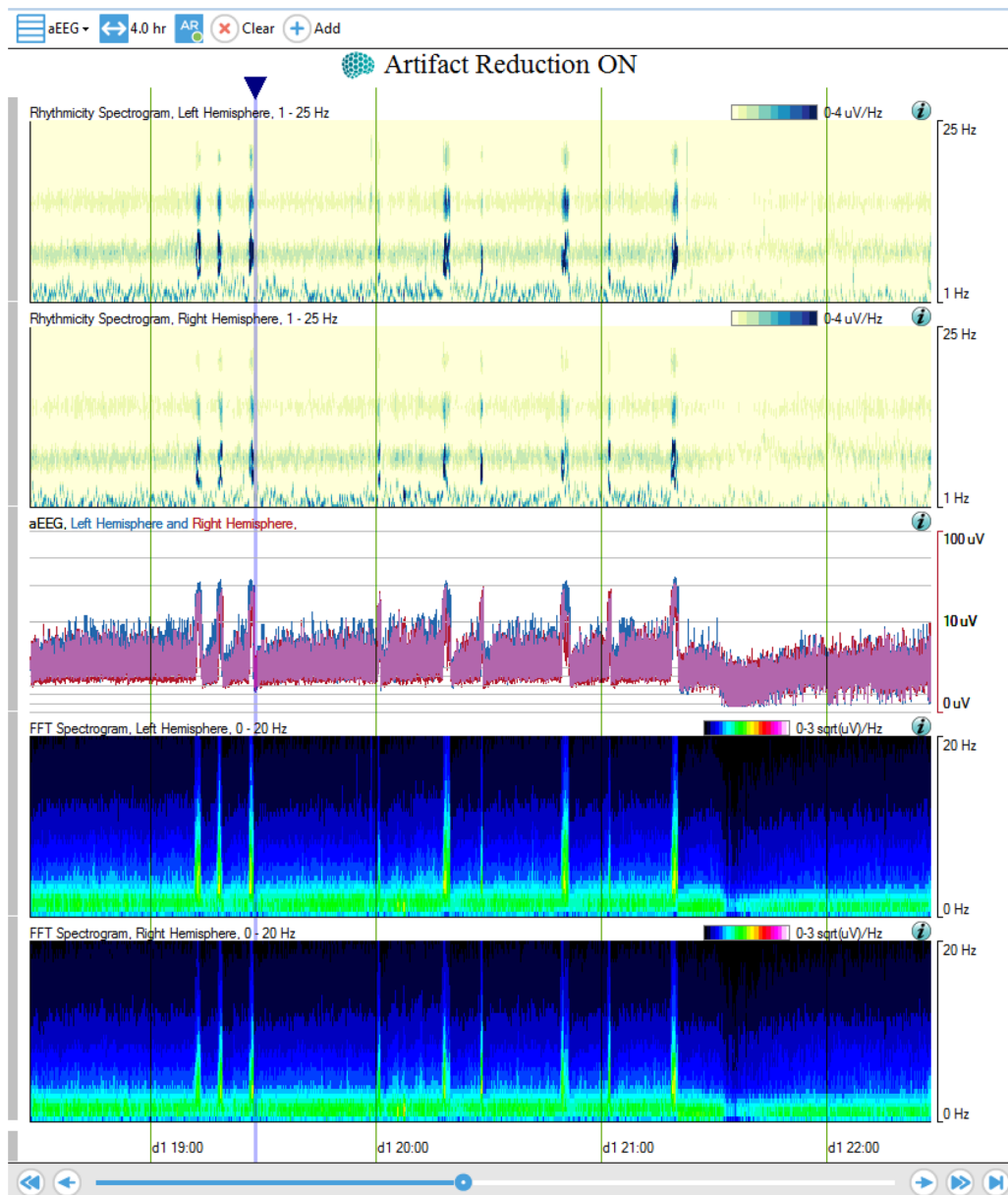


Fig. 2 Four-hour quantitative EEG panel of same patients as Fig. 1 (right), showing changes attributable to multiple NCSZs. After each seizure, the patient received a bolus dose of a sedative followed by an increment in the infusion rate. NCSZs were abolished shortly after 21:00 with a combination of propofol (50 $\mu\text{g}/\text{kg}/\text{min}$) and ketamine (3 $\text{mg}/\text{kg}/\text{h}$) infusions

literature has shown the feasibility of training neurocritical care nurses to recognize electrographic seizures on raw EEG, but further research is needed to demonstrate generalizability [23].

In patients with NCSE, the electrographic characteristics of individual NCSZs are usually fairly characterized. Consequently, the quantitative EEG tracings tend to be similar from one seizure to the next. In practice, a neurophysiologist can therefore instruct bedside clinicians

regarding what specifically to look for as they monitor the patient over the subsequent hours. In this way, therapy can be rapidly titrated to achieve seizure control, even without continuous presence or availability of a neurophysiologist (Fig. 2) [24].

In this volume of neurocritical care, Kang and colleagues have contributed to the literature by performing a *prospective* study where quantitative EEG was utilized *at the bedside* by ICU nurses (rather than in a

Table 1 Studies assessing the diagnostic accuracy of quantitative continuous electroencephalography in neurocritical care patients (excluding neonates)

Study	Number tracings	Setting	Interpreters	Type of display	Sensitivity	Specificity
Stewart [13]	27	PICU	Neurophysiologists	8-h CDSA and aEEG	83% CDSA 82% aEEG	FP: 0–0.13/h CDSA FP: 0–0.19/h aEEG
Moura [10] Williamson [21]	118	Adults (ICU and non-ICU)	Neurophysiologists	2-h CDSA	87–89%	NR
Pensirikul [14]	21	PICU	Neurophysiologists	2-h CDSA	65–75%	78–92%
Topjian [15]	100	PICU (cardiac arrest)	ICU MDs ICU fellows ICU RNs	2-h CDSA	70%	68%
Dericioglu [16]	20	AICU	ICU fellows ICU RNs	1-h CDSA and aEEG	88–99%	89–95%
Swisher [17]	180	AICU	Neurophysiologists EEG technologists ICU RNs	1-h CDSA, aEEG Rhythmicity spectrograms EEG asymmetry index	80–87%	61–80%
Haider [11]	15	AICU	Neurophysiologists	6-h CDSA and aEEG Rhythmicity spectrograms Envelope trend	67%	FP: 1/h
Du Pont-Thibodeau [18]	100	PICU (cardiac arrest)	ICU MDs ICU fellows ICU RNs	2-h aEEG + CDSA tracings	77% aEEG 77% aEEG + CDSA	65% aEEG 68% aEEG + CDSA
Lalgudi Ganesan [19]	27	PICU	ICU fellows ICU RNs Neurophysiologists EEG technologists	8-h CDSA and aEEG	73–88% CDSA 67–84% aEEG	FP: 0–7.7/24 h CDSA FP: 0–4.2/24 h aEEG
Sun [20]	30	AICU	Neurophysiologists	24-h CDSA and aEEG	80% CDSA 81% aEEG	FP: 4/24 h CDSA FP: 2/24 h aEEG
Amorim [22]	49	AICU	ICU RNs Neurophysiologists	2-h CDSA	74% RN 66% neurophysiologists	38% RNs 69% neurophysiologists

aEEG amplitude integrated EEG, AICU adult intensive care unit, CDSA color density spectral array, FP false positives, MD medical doctor, PICU pediatric ICU, RN registered nurse

simulated post hoc setting). Nurses received individualized, patient-specific quantitative EEG instructions while caring for their patients, with examples provided of what CDSA, aEEG, and rhythmicity spectrogram tracings had looked like during previous seizures. With this pragmatic approach, nurses' diagnostic accuracy in the recognition of subsequent seizures was excellent, with a sensitivity of 85%, specificity of 89% (approximately one false positive every 10 h), and a high rate of interobserver agreement. As in previous studies, seizures were more consistently recognized when they were topographically more extensive and of longer duration.

Even with an excellent educational strategy, it is likely not realistic for most large and busy ICUs to educate all of their nursing staff in the competent and consistent recognition of electrographic seizures. In contrast, providing patient-specific quantitative EEG instructions at the onset of cEEG monitoring is more feasible. The main limitation of the work by Kang and colleagues is that it applies only to a subset of patients, namely those

admitted to the ICU with status epilepticus, where previous electrographic seizures have been observed. It is unlikely that this approach would be as accurate if comatose patients, in whom no previous seizures have been detected and who are less likely to develop seizures at all, undergo cEEG monitoring. Also, the average length of data collection was only 8 h. In every-day practice, the quality of EEG tracings tends to deteriorate over time due to patient movement and diaphoresis, such that the potential for false positives and false negatives due to EEG artifact also increases, especially if EEG technologists are unavailable to assist with electrode re-application. These considerations likely explain the higher specificity observed by Kang and colleagues in comparison with the previous research involving ICU nurses [18, 19, 22].

Virtually all of the published studies to date have selection bias as an important limitation, since they generally do not involve an unfiltered, consecutive sample of patients and cEEG tracings in a "real-life" setting.

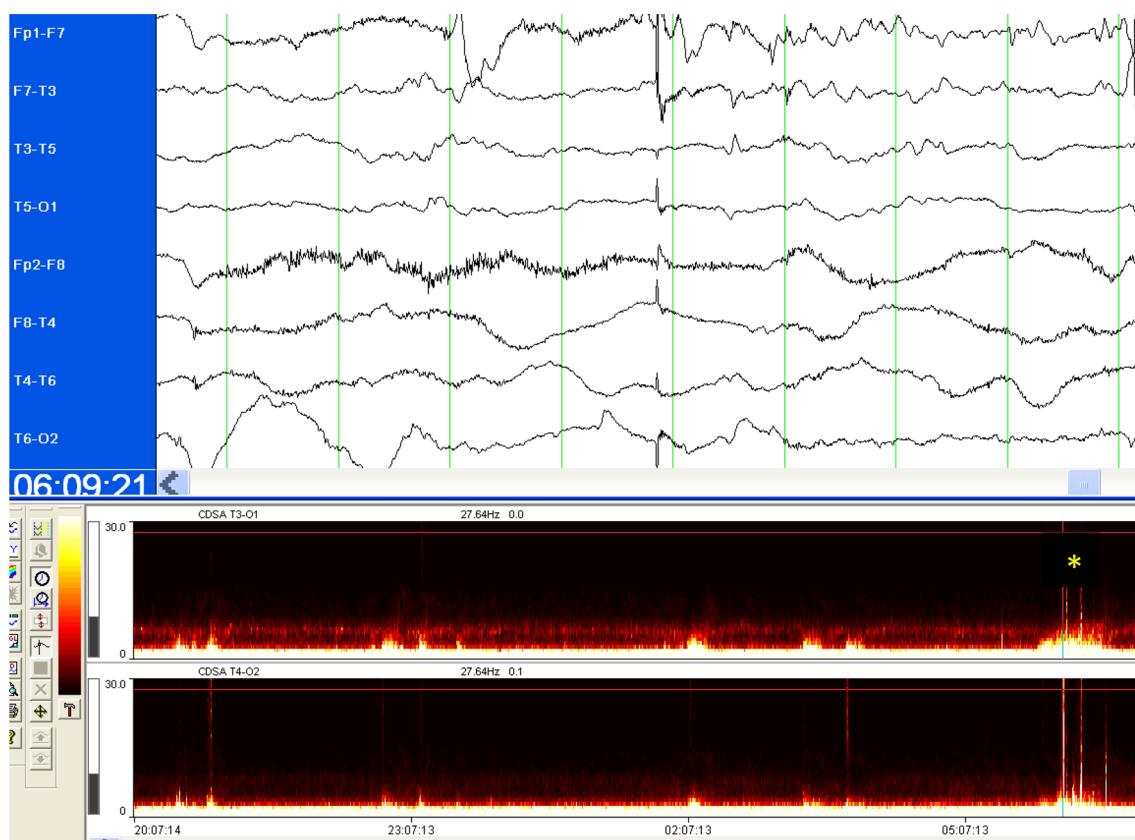


Fig. 3 Sudden change in quantitative CDSA tracing (raw EEG corresponds in time to asterisk) caused by EEG artifact while patient was being suctioned. The preceding paroxysmal alterations seen on the CDSA tracing (bottom of figure) were induced by frontal intermittent rhythmic delta activity (FIRDA; corresponding raw EEG not shown) rather than electrographic seizures

In order to advance this field further, more prospective studies of consecutive quantitative cEEG are required, including among patients not necessarily known in advance to have repeated, electrographically similar seizures. Future research should also pursue methods of improving quantitative cEEG detection of focal, low-amplitude, and relatively brief seizures.

In summary, Kang and colleagues have prospectively validated a practical approach in an important subgroup of patients. This methodology can easily be applied at any center that uses cEEG monitoring and has access to quantitative software.

Author Contributions

Dr. Kramer wrote the first draft, edited, and approved the manuscript. Dr. Kromm edited and approved the manuscript.

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Conflict of interest

The authors declare that they have no conflict of interest.

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