ORIGINAL RESEARCH

Utilization of Quantitative EEG Trends for Critical Care Continuous EEG Monitoring: A Survey of Neurophysiologists

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Purpose: Quantitative EEG (QEEG) can be used to assist with review of large amounts of data generated by critical care continuous EEG monitoring. This study aimed to identify current practices regarding the use of QEEG in critical care continuous EEG monitoring of critical care patients.

Methods: An online survey was sent to 796 members of the American Clinical Neurophysiology Society (ACNS), instructing only neurophysiologists to participate.

Results: The survey was completed by 75 neurophysiologists that use QEEG in their practice. Survey respondents reported that neurophysiologists and neurophysiology fellows are most likely to serve as QEEG readers (97% and 52%, respectively). However, 21% of respondents reported nonneurophysiologists are also involved with QEEG interpretation. The majority of nonneurophysiologist QEEG data review is aimed to alert neurophysiologists to periods of concern, but 22% reported that nonneurophysiologists use QEEG to directly guide clinical care. Quantitative EEG was used most frequently for seizure detection (92%) and burst suppression monitoring (59%). A smaller number of respondents use QEEG for monitoring the depth of sedation (29%), ischemia detection (28%), vasospasm detection (28%) and prognosis after cardiac arrest (21%). About half of the respondents do not review every page of the raw critical care continuous EEG record when using QEEG. Respondents prefer a panel of QEEG trends displayed as hemispheric data, when applicable. There is substantial variability regarding QEEG trend preferences for seizure detection and ischemia detection.

Conclusions: QEEG is being used by neurophysiologists and nonneurophysiologists for applications beyond seizure detection, but practice patterns vary widely. There is a need for standardization of QEEG methods and practices.

Key Words: Quantitative EEG, QEEG, Critical care continuous EEG monitoring, Nonconvulsive seizures, Nonconvulsive status epilepticus, QEEG trending, Ischemia detection.

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Nonconvulsive seizures (NCS) are seen in 8% to 48% of patients in medical or neuroscience intensive care units (ICUs) (Claassen et al., 2004b; Herman et al., 2015; Jordan, 1995; Oddo et al., 2009; Pandian et al., 2004; Privitera et al., 1994; Swisher et al., 2015a; Towne et al., 2000). Primarily due to the increase in awareness of NCS, utilization of critical care continuous EEG (CCEEG) monitoring continues to grow. Between 2005 and 2009, the number of ICU CCEEGs performed increased by an average of 33% per year (Ney et al., 2013). Quantitative EEG (QEEG) is a tool that can aid in the interpretation of a large volume of data generated by CCEEG monitoring. Quantitative EEG refers to any computational method that uses mathematical and analytical algorithms to transform and compress raw EEG signals, usually into a graphical representation.

Various applications of QEEG in critically ill patients include NCS detection, ischemia detection, vasospasm/delayed cerebral ischemia (DCI) detection, prognosis after cardiac arrest, monitoring depth of sedation, and monitoring depth of therapeutic burst suppression. Although commercial EEG software often includes QEEG tools, the evidence for its diagnostic accuracy is sparse, resulting in various levels of utilization among neurophysiologists. In a 2014 survey, 52% of neurophysiologists incorporated QEEG for CCEEG monitoring (Gavvala et al., 2014).

The 2015 American Clinical Neurophysiology Society consensus statement on CCEEG in critically ill adults and children states that CCEEG is suggested as an adjunct tool for identification of cerebral ischemia and that QEEG analysis should be included as part of ischemia monitoring (Herman et al., 2015). However, this consensus statement did not describe the practical implementation of QEEG.

To identify current practices regarding the use of QEEG for CCEEG monitoring, we surveyed adult and pediatric neurophysiologists. In the absence of well-designed prospective trials, we hypothesize that the results will identify a wide variability of QEEG practice patterns and identify points of uncertainty in the community. This information may serve as a basis for development of QEEG educational initiatives, future guidelines for the CCEEG community, and identify barriers to implementation of QEEG-based multicenter trials.

METHODS

This study was approved by the Duke Institutional Review Board. To identify current practices regarding the use of QEEG in critical care patients, an e-mail request to participate in the survey was sent to 796 members of the American Clinical

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TABLE 1. Survey Questions and Answers

Question	Answer Choices
1. How many years have you been in practice as a neurophysiologist? Select one.	<5, 5–10, 10–20, or >20 years
2. What type of practice are you in? Select one.	University, teaching or university affiliate, Veteran's Affairs, or private
3. Is your hospital a tertiary care center? Select one.	Yes or No
4. How large is the adult Neuroscience ICU? Select one.	None, <10 beds, 10–20 beds, or >20 beds
5. What EEG types do you routinely interpret? Select one.	Adult ICU continuous EEGs, pediatric/neonate ICU continuous EEGs, both, or none
6. On average, what is the weekly volume of ICU CCEEGs at your institution (including both adult and pediatrics)? Select one.	<5, 6–10, 11–20, 21–30, or >30
7. Does your institution have quantitative EEG (QEEG) software? Select one.	Yes or No
8. What is the use for QEEG at your institution? Select one.	Clinical care, research, or both
9. Who performs clinical QEEG interpretation at your institution? Select all that apply.	Neurophysiologists, neurophysiology fellows, EEG techs, neurocritical care attendings, neonatologists, neuro ICU fellows, neuro ICU NPs/PAs, neuro ICU nurses, neurology residents, or other
10. If non-neurophysiologists interpret QEEG, what is the goal of their interpretation? Select all that apply.	Alert neurophysiologists and/or neurophysiology fellows to periods of concern, direct QEEG interpretation to guide their clinical care, or other
11. Does your institution have a protocol in place for non-neurophysiologist review of the QEEG? Select providers that such a protocol applies to. Select all that apply.	No QEEG interpretation protocols for non-neurophysiologists, EEG techs, neurocritical care attendings, neonatologists, neuro ICU fellows, neuro ICU NPs/PAs, neuro ICU nurses, neurology residents, or other
12. How often do you review the QEEG data on average? Select one.	Never, rarely (less than once a day), once a day, 2–3 times a day, 4–10 times a day, or >10 times a day
13. On average, when using QEEG, how many times do you review the raw CCEEG record within a 24 hour period? Select one.	Once, 2–3 times, 4–5 times, 6–10 times, or >10 times
14. On average, when using QEEG, how much raw EEG do you review? Select one.	<25%, 25–50%, 51–75%, >75% but not all, or every page
15. What are the clinical uses for QEEG at your institution? Select all that apply.	Seizure detection, ischemia detection, vasospasm/DCI detection in SAH, prognosis for cardiac arrest, burst suppression monitoring, monitoring depth of sedation, or other
16. What is you preference for display of QEEG data? Select one.	Hemispheric (i.e., CDSA displayed separately for the left and right hemispheres), individual electrode pairs (i.e., individual CDSA trends for each electrode pair), or regional (i.e., separate CDSA trends for each quadrant)
17. When reading QEEGs, do you prefer to use a panel of trends or an individual trend? Select one.	Panel of trends or individual trend
18. For seizure detection, which trend(s) do you use? Select all that apply.	Automated seizure detector, rhythmicity spectrogram (R2D2), CDSA/CSA/DSA/FFT spectrogram, asymmetry index/asymmetry spectrogram, amplitude-integrated EEG (aEEG), envelope trend (ET), burst suppression ratio (BSR), relative alpha variability (RAV), total power, delta power, theta power, alpha power, beta power, alpha delta ratio (ADR), other power ratio or other
19. For ischemia/DCI detection, which trend(s) do you use? Select all that apply.	Automated seizure detector, rhythmicity spectrogram (R2D2), CDSA/CSA/DSA/FFT spectrogram, asymmetry index/asymmetry spectrogram, amplitude-integrated EEG (aEEG), envelope trend (ET), burst suppression ratio (BSR), relative alpha variability (RAV), total power, delta power, theta power, alpha power, beta power, alpha delta ratio (ADR), other power ratio or other
20. Is there a QEEG display shown at the bedside in the Neuroscience ICU? Select one.	Yes, no or sometimes
21. If so, which trends are displayed? Select all that apply.	Automated seizure detector, rhythmicity spectrogram (R2D2), CDSA/CSA/DSA/FFT spectrogram, asymmetry index/asymmetry spectrogram, amplitude-integrated EEG (aEEG), envelope trend (ET), burst suppression ratio (BSR), relative alpha variability (RAV), total power, delta power, theta power, alpha power, beta power, alpha delta ratio (ADR), other power ratio or other
22. Please identify any factors that you feel limit the utilization of QEEG at your institution. Select all that apply.	Lack of remote capabilities for QEEG software, lack of data showing the utility of QEEG for seizure detection, lack of data showing utility of QEEG for ischemia/DCI, lack of experience by neurophysiologists regarding how to read QEEG, lack of experience by non-neurophysiologists regarding how to read QEEG, volume of CCEEGs isn't high enough to necessitate the use of QEEG software to assist with CCEEG review, neurointensivists prefer more traditional methods to monitor for ischemia/DCI, concern about false-positives, concern about false-negatives, or other

TABLE 2. Characteristics of Survey Respondents, n = 97

	n (%)
Years in practice	
<5	29 (29.9)
5–10	18 (18.6)
10–20	20 (20.6)
>20	30 (30.9)
Type of practice	
University	71 (73.2)
Teaching or university affiliate	13 (13.4)
Veteran's Affairs hospital	5 (5.2)
Private	15 (15.5)
Tertiary care hospital	
Yes	88 (90.7)
No	9 (9.3)
Size of adult neuroscience ICU	
<10 beds	7 (7.2)
10–20 beds	24 (24.7)
>20 beds	34 (35.1)
No dedicated adult neuro-ICU	32 (33)
EEG reading practice	
Adult CCEEGs	39 (40.2)
Pediatric/neonate CCEEGs	15 (15.5)
Both	35 (36.1)
Not involved in reading CCEEGs	8 (8.2)
Weekly volume of ICU CCEEGs (adult and pediatrics)	
<5	28 (28.9)
6–10	27 (27.8)
11–20	18 (18.6)
21–30	11 (11.3)
>30	13 (13.4)

CCEEG, critical care continuous EEG.

Neurophysiology Society (ACNS). The survey invitation instructed only neurophysiologists to participate in the survey because the e-mail invitation was sent to all members of the ACNS that includes nonphysicians and nonneurophysiologists. The members who chose to participate completed an anonymous online survey on Survey Monkey (www.surveymonkey.com). The survey (Table 2) consisted of 22 multiple choice questions evaluating the use of QEEG in neurocritical care patients and the respondent's experience and practice setting. The survey consisted of closed-ended questions in which answers were chosen from lists, some of which allowed multiple questions and some of which allowed only single-answer responses.

RESULTS

The survey was completed by 97 neurophysiologists (response rate of 12%). The characteristics for the survey respondents are shown in Table 1. Of the 97 respondents, 86 (88.7%) stated that they have QEEG software available at their institution. Of those, the majority use QEEG only for clinical care (n = 43, 50.0%) or for both clinical care and research (n = 32, 37.2%), leading to a total of 75 respondents who use QEEG for clinical care. The rest of the analysis was based on the responses from these 75 respondents. There were 9 respondents (10.5%) who used QEEG for research only. Two respondents (2.3%) stated that QEEG is available but not used at all at their institution.

The majority of respondents stated that neurophysiologists are involved with QEEG interpretation at their institution (n = 73, 97.3%). Nonneurophysiologists were reported to be involved with QEEG interpretation by 21% of respondents (n = 28) (Fig. 1). Two respondents stated that at their institutions, nonneurophysiologists performed QEEG interpretation in isolation (EEG techs [n = 1] and neonatologists [n = 1]) without neurophysiologists also performing any interpretation.

For the respondents who stated that nonneurophysiologists perform QEEG interpretation (n = 41), the primary goal of that interpretation was to alert neurophysiologists to periods of concern (n = 32, 78.0%). An additional 4 respondents (9.8%) stated that the goal of nonneurophysiologist interpretation was to directly guide clinical care in addition to alerting the neurophysiologists. Five respondents (12.2%) stated that the goal of nonneurophysiologist interpretation was only to directly guide clinical care. Most respondents (80.0%) stated that there was no protocol in place for nonneurophysiologist QEEG review (n = 60). Seven respondents (9.3%) stated that there was such a protocol for EEG technicians.

The most common answer regarding the frequency of QEEG data review was 2 to 3 times a day (56.0%, n = 42) (Fig. 2). When respondents do use QEEG, the frequency of raw CCEEG review was most often 2 to 3 times a day (68.0%, n = 51) (Fig. 2). When using QEEG, about half (49.3%) of the respondents continue to review every page of the raw CCEEG. However, the other half (51.7%) performs only partial CCEEG review when using QEEG (17.3% respondents review >75% of the record but not every page, 9.3% respondents review 51% to 75% of the record, 12.0% respondents review 25% to 50% of the record, and 12.0% respondents review <25% of the record).

The most frequent utilization of QEEG was for seizure detection (n = 69, 92.0%). This was followed by burst suppression monitoring (n = 44, 58.7%), monitoring depth of sedation (n = 22, 29.3%), ischemia detection (n = 21, 28.0%), vasospasm/DCI detection (n = 21, 28.0%), and prognosis for cardiac arrest (n = 16, 21.3%) (Fig. 3).

The most common preference for display of QEEG data was by hemispheres (71.6%) with fewer respondents preferring a regional electrode display (18.5%) or an individual electrode display (9.9%). Additionally, most respondents (83.8%) preferred a panel of QEEG trends rather than individual trends (16.3%).

For seizure detection, the most popular QEEG trend was rhythmicity spectrogram, which was used by 61.3% of respondents. The rhythmicity spectrogram is a proprietary trend by Persyst and displays the calculated amount of rhythmic/periodic components of the EEG waveform. This was followed by automated seizure detector (54.7%), color density spectral array (CDSA)/compressed spectral array (CSA)/density spectral array (DSA)/fast Fourier transformation (FFT) (46.7%), asymmetry index/spectrogram (42.7%), amplitude-integrated EEG (aEEG) (41.3%), envelope trend (21.3%), and burst suppression ratio (10.7%). Other QEEG trends were used by less than 10% of respondents (Fig. 4).

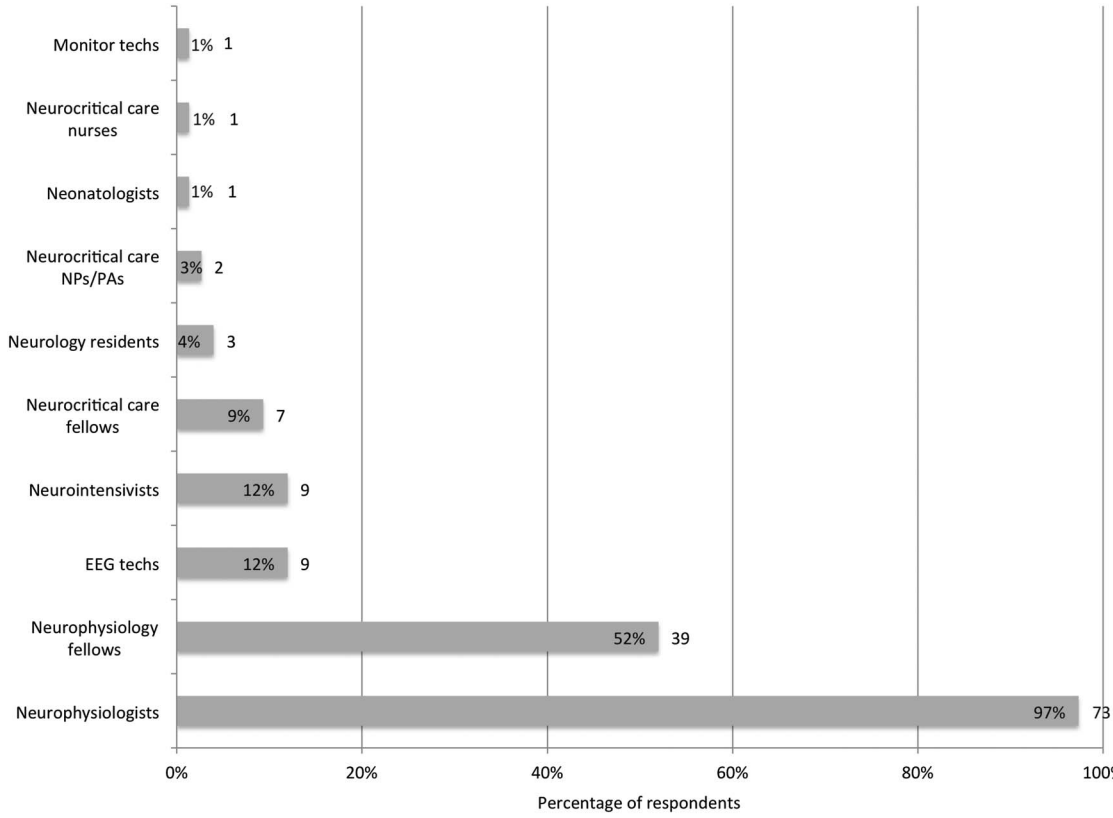

FIG. 1. Personnel participating in quantitative EEG (QEEG) interpretation. The percentage of respondents is shown within each bar and the absolute number of respondents is shown to the right of each bar. NP, nurse practitioner; PA, physician assistant.

Of the 75 respondents who stated they use QEEG at their institution, 39 (52%) stated they do not use QEEG for ischemia/DCI detection. For those who do use QEEG for ischemia/DCI detection (n = 36), the most popular QEEG trend was alpha delta ratio (ADR) (28.0%). This was followed in popularity by asymmetry index/spectrogram (21.3%), CDSA/CSA/DSA/FFT spectrogram (13.3%), and aEEG (12.0%). The other QEEG trends were used by ≤10% of respondents (Fig. 4).

Twenty-four respondents (32.0%) stated that a QEEG display is always shown at the bedside in the ICU, and 20 additional respondents (26.7%) stated that it is sometimes shown at the bedside. The rest (n = 31, 41.3%) stated that a bedside QEEG display is absent. The most common trends that are displayed at the bedside are CDSA/CSA/DSA/FFT spectrogram (30.7%), asymmetry index/spectrogram (26.7%), rhythmicity spectrogram (25.3%), aEEG (25.3%), automated seizure detector (22.7%), ADR (16.0%), and BSR (14.7%). Other QEEG trends were used by <10% of respondents.

Numerous limitations to QEEG utilization were identified. Approximately half of the respondents believed that lack of experience by nonneurophysiologists (50.7%) and neurophysiologists (46.7%) contributed as a barrier. In descending order, other barriers included concern about false-negatives (29.3%), concern about false-positives (28.0%), lack of remote capabilities for QEEG software at their institution (24.0%), lack of data showing utility of QEEG for ischemia/DCI (18.7%) and for seizure detection (14.7%), low volume of CCEEGs not high enough to necessitate the use of QEEG (12.0%), and preference of neurointensivists for more traditional methods to monitor for DCI/ischemia (12.0%). Additional barriers identified were the high cost of the software and the lack of reimbursement for QEEG software utilization.

DISCUSSION

This survey captured adult and pediatric neurophysiologists from various practice settings, with university-based practice as the most common. This is the first survey that characterizes the current practices of QEEG use for critically ill patients. In this survey, 97% of neurophysiologists use QEEG for clinical care. The results indicate that the utilization of QEEG may be increasing. A 2010 survey of neurologists reported that the use of QEEG trending software was relatively uncommon (34% utilization rate) for the monitoring of NCS or nonconvulsive status epilepticus (Abend et al., 2010). In a 2014 survey, 52% of neurophysiologists used QEEG for CCEEG monitoring for seizure detection and, to a lesser extent, for vasospasm monitoring in subarachnoid hemorrhage (Gavvala et al., 2014).

QEEG provides a compressed and simplified view of the raw EEG signals, potentially allowing for evaluation by nonneurophysiologists. This survey found that although

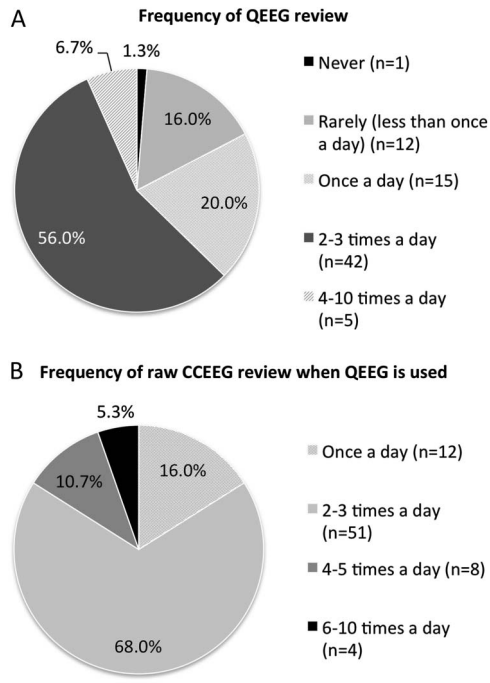

FIG. 2. Daily frequency of quantitative EEG (QEEG) and raw critical care continuous EEG (CCEEG) review. **A**, No survey respondents who performed QEEG review >10 times a day. **B**, No survey respondents who performed raw CCEEG review >10 times a day.

neurophysiologists and neurophysiology fellows remain the most common QEEG readers, nonneurophysiologists also play a role in QEEG interpretation. The primary goal of nonneurophysiologist QEEG interpretation is to alert neurophysiologists to periods of concern. Interestingly, some nonneurophysiologists are using QEEG directly for clinical care despite the absence of prospective data for this practice. Previous retrospective studies have shown that the sensitivity of nonneurophysiologist interpretation of QEEG (41%–89%) is similar to that of neurophysiologists (Abend et al., 2011; Akman et al., 2011; Nitzschke et al., 2011; Rennie et al., 2004; Shellhaas et al., 2007; Swisher et al., 2015b; Williamson et al., 2014). However, there are no prospective studies evaluating the efficacy of incorporating nonneurophysiologist QEEG interpretation into routine clinical care in the ICU. Future clinical studies identifying the optimal protocol for nonneurophysiologist QEEG review are needed.

A previous survey found that the majority of neurophysiologists still reviewed every page of the raw CCEEG record even when using QEEG (Gavvala et al., 2014). Critical care continuous EEG monitoring is a rapidly evolving technology and, therefore, the practice of CCEEG data review is changing. This survey reveals that only about half of the respondents continued to read every page of the CCEEG when QEEG was concomitantly available. One study has shown that QEEG-assisted CCEEG review may reduce review time with little loss in sensitivity when compared with traditional raw EEG review (Moura et al., 2014). This could potentially impact patient outcomes by resulting in faster seizure identification and treatment because it has been shown that NCS of longer duration

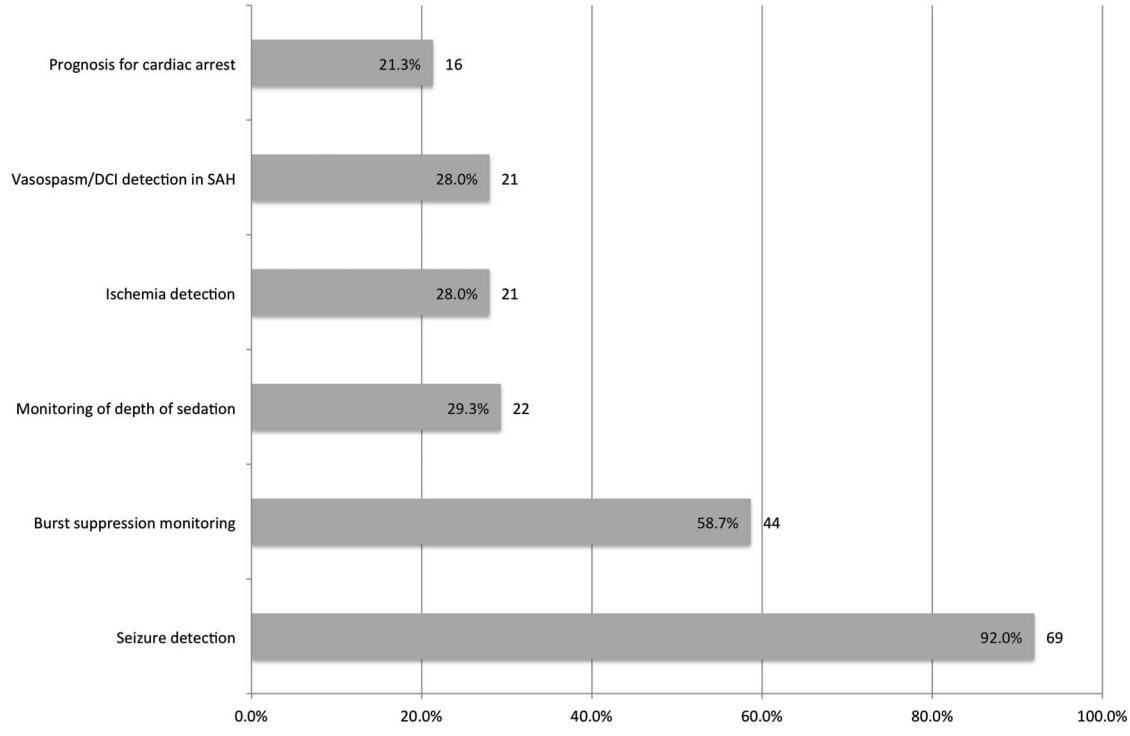

FIG. 3. Clinical indications for quantitative EEG (QEEG) utilization. The percentage of respondents is shown within each bar and the absolute number of respondents is shown to the right of each bar. DCI, delayed cerebral ischemia; SAH, subarachnoid hemorrhage.

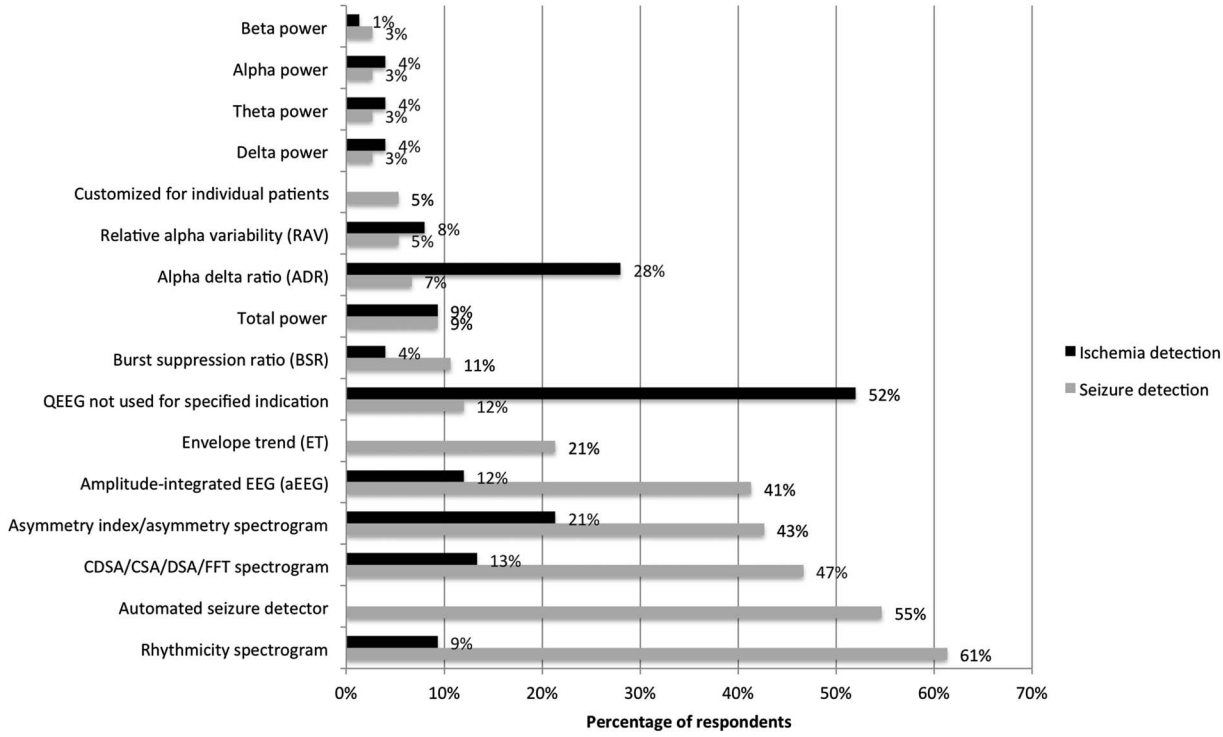

FIG. 4. Quantitative EEG (QEEG) trends used for seizure and ischemia detection. The percentage of respondents is shown to the right of each bar. CDSA, color density spectral array; CSA, compressed spectral array; DSA, density spectral array; FFT, fast Fourier transformation.

are associated with worse outcomes (De Marchis et al., 2016; Payne et al., 2014; Young et al., 1996).

Our results are similar to the findings of a previous survey in that the majority of neurophysiologists review the raw CCEEG record 1 to 3 times a day (Gavvala et al., 2014). Occasional CCEEG review likely limits the application of CCEEG to seizure detection, which this survey identifies as the most common use for QEEG. Although there is significant heterogeneity, studies report that neurophysiologists have a sensitivity of 44% to 83% for seizure detection using individual QEEG trends (Abend et al., 2011; Akman et al., 2011; Dericioglu et al., 2015; Evans et al., 2010; Moura et al., 2014; Nitzschke et al., 2011; Pensirikul et al., 2013; Rennie et al., 2004; Shah et al., 2008; Shellhaas et al., 2007; Stewart et al., 2010; Williamson et al., 2014). Although the majority of studies have focused on individual QEEG trends for seizure detection, this survey provides evidence that most QEEG readers prefer to use a panel of QEEG trends. There may be an improved sensitivity (87%) when a panel of QEEG trends is used by neurophysiologists for seizure detection (Swisher et al., 2015b). Knowledge of the current utilization of QEEG can help frame clinical study design to ensure that results will have direct applicability to QEEG users.

There are several other applications of QEEG beyond seizure detection. Because EEG and QEEG are sensitive in detecting changes in cerebral blood flow (Diedler et al., 2009; Finnigan et al., 2007), QEEG has been shown to be a tool for detection of ischemia (Claassen et al., 2004a; Gollwitzer et al., 2015; Kondziella et al., 2015; Labar et al., 1991; Rathakrishnan et al., 2011; Rots et al., 2015; Vespa et al., 1997). Other areas of QEEG research include prognosis after cardiac arrest (Ruijter et al., 2015). This survey provides evidence that QEEG is being used for numerous clinical indications for brain monitoring in critically ill patients that include seizure detection, burst suppression monitoring, monitoring depth of sedation, ischemia detection, vasospasm/DCI detection, and prognosis after cardiac arrest.

For neurophysiologists who do not yet have QEEG at their institution and are interested in incorporating it into their practice, this survey may help guide their initial utilization. Although various QEEG trend preferences were identified in this study, early QEEG users may consider the following QEEG trends for seizure detection: rhythmicity spectrogram, automated seizure detection, CDSA/CSA/DSA/FFT, asymmetry index/spectrogram, and aEEG. Additionally, users new to QEEG use may consider the following QEEG trends for ischemia detection: ADR, asymmetry index/spectrogram, CDSA/CSA/DSA/FFT, and aEEG. The trend preference variability in this survey highlights the need for standardization of QEEG methods and practices to facilitate clinical research and optimize patient care.

Lack of QEEG experience by nonneurophysiologists and neurophysiologists is the primary limitation to QEEG utilization noted in this survey. Efforts to decrease this knowledge gap are needed. A significant number of neurophysiologists believe that the number of false-positives and false-negatives is unacceptably high. Some neurophysiologists do question the clinical utility of QEEG. To date, no prospective interventional trials have been performed that evaluate ways in which QEEG can directly enhance patient care.

A significant limitation of this survey was the low response rate. However, the survey invitation was sent to all members of the ACNS membership database, which includes nonphysicians. It is possible that the practices of QEEG utilization of survey responders are not reflective of all neurophysiologists because survey responders may represent neurophysiologists with a special interest in QEEG. Furthermore, the survey responses were obtained from individual neurophysiologists, making it possible that there were multiple survey respondents from one institution.

CONCLUSION

The responses from this survey indicate that nonneurophysiologists, in addition to neurophysiologists, currently play a role in clinical interpretation of QEEG. There is a high degree of practice variation regarding the clinical indications for QEEG utilization, the frequency of QEEG trend review, and QEEG trend display options. The lack of uniformity in QEEG monitoring deserves attention by the neurophysiology and neurocritical care communities. Quantitative EEG monitoring guidelines and training materials for neurophysiologists and nonneurophysiologists will advance uniformity of our clinical practice and facilitate QEEG applications in clinical research.

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