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Tolerability of a comprehensive cardiorespiratory monitoring protocol in an epilepsy monitoring unit

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Abstract

Background: Recent reports of fatal or near-fatal events in the EMU and an increasing awareness of the effects of seizures on breathing have stimulated interest in cardiorespiratory monitoring for patients undergoing video EEG recording. Patient and provider acceptance of these extra recording devices has not previously been studied and may represent a barrier to widespread adoption.

Methods: We queried EMU subjects regarding their experiences with a monitoring protocol that included the continuous measurement of oral-nasal airflow, respiratory effort (chest and abdominal respiratory inductance plethysmography), oxygen saturation, and transcutaneous CO₂. Surveys were returned by 71.4% (100/140) of eligible subjects.

Results: Overall, 73% of participants reported being moderately to highly satisfied with the monitoring, and 82% reported moderate to strong agreement that advance knowledge of the

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Declaration of interest:

The SenTec Digital Monitoring System was provided to the investigators by SenTec AG, Therwil, Switzerland. The company was not involved in the design, execution, analysis, or reporting of this study. The authors report no other conflicts of interest.

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monitoring would not have changed their decision to proceed with the video-EEG study. Except for nasal airflow, none of the additional monitoring devices caused more discomfort than EEG electrodes.

Conclusion: Patient acceptance of an EMU comprehensive cardiorespiratory monitoring protocol is high. The information obtained from “multimodality recording” should help clinicians and investigators understand the effect of seizures on both cardiac and respiratory physiology, may enhance safety in the EMU, and may aid in the identification of biomarkers for SUDEP.

Keywords

Epilepsy; Video-EEG monitoring; cardiorespiratory monitoring; tolerability; sudden unexpected death in epilepsy

1. INTRODUCTION

The modern Epilepsy Monitoring Unit (EMU) was made possible by the digitalization of video electroencephalography (EEG) and by advances in automated signal processing. These advances have occurred largely within the past 20 years, marking the EMU as a relative newcomer in the creation of dedicated inpatient units focused on the rapid identification of acute clinical changes. Accordingly, while coronary care units have been around for over 50 years, the approach to monitoring inpatients with epilepsy has evolved over a relatively short period of time. Core monitoring components have typically involved dedicated nursing staff and EEG seizure monitoring technicians, as well as real-time computerized seizure detection algorithms. Electrocardiographic (ECG) signals are frequently recorded as part of the EEG record [1], and cardiac telemetry is employed by some EMUs. Despite an increasing awareness of the effects of seizures on breathing [2,3], and human and animal data suggesting that peri-ictal hypoventilation/apnea is the cause of some cases of SUDEP [4–6], the systematic monitoring of respiration has been neither routine nor recommended [7–9].

Recent reports of people with epilepsy (PWE) suffering fatal or near-fatal events while being cared for in an EMU [6,10] have stimulated interest in cardiorespiratory monitoring. Analysis of the events reported in the MORTEMUS study demonstrates that terminal apnea precedes terminal asystole in such cases [6]. Thus, the early identification of peri-ictal hypoventilation may afford an opportunity for intervention prior to arrest. So-called “multimodality” monitoring may also increase the diagnostic yield of video-EEG monitoring in cases where peri-ictal cardiorespiratory phenomena constitute the only clinical sign of seizure [11]. Patient acceptance of dedicated cardiorespiratory monitoring during long-term video-EEG recording has not been previously studied. Indeed, the perception that such measures may be tolerated poorly could serve as a barrier to implementation [12].

We studied patient tolerance of a comprehensive cardiorespiratory monitoring protocol involving ECG and the measurement of airflow (using an oral/nasal thermistor and nasal pressure transducer), respiratory effort (via respiratory inductance plethysmography, RIP), capillary oxygen saturation (SpO₂), and transcutaneous CO₂ (tcCO₂). We hypothesized that additional cardiorespiratory monitoring would be as well tolerated as EEG, not only in

patients with epilepsy but in those patients ultimately diagnosed with non-epileptic spells. This report describes overall patient satisfaction with this protocol and suggests strategies for implementation.

2. MATERIALS AND METHODS

The University of Iowa Comprehensive Epilepsy Program is accredited as a level 4 program by the National Association of Epilepsy Centers. The program's adult EMU is a 9-bed unit located within the main hospital and staffed by a core group of nurses, EEG technologists, seizure monitoring technicians, a neurology resident, and an epileptologist. Safety protocols include realtime 24-hour automated seizure detection and visual monitoring, ECG recording, and a fall prevention protocol. Telemetry and pulse oximetry are utilized at the discretion of the admitting physician.

The data reported in this paper were acquired as part of a larger, ongoing study investigating mechanisms of peri-ictal respiratory depression in patients with epilepsy. Subjects were typically approached by the study team within 12 hours after admission to the EMU and, if enrolled, underwent continuous respiratory monitoring from this point on until the conclusion of video-EEG monitoring. Oral-nasal airflow was measured using a nasal pressure transducer (BiNAPS, Salter Labs) and oral/nasal thermistor (ThermiSense, Salter Labs). Chest and abdominal excursions were measured using respiratory inductance plethysmography (zRIP, Pro-Tech Services). SpO₂ and tcCO₂ were measured using the SenTec Digital Monitoring System (SenTec AG, Therwil, Switzerland) with the sensor applied to the cheek. All data were saved and time-synchronized with the video-EEG recording. The SenTec was programmed to alarm at the bedside when values for SpO₂, tcCO₂, or heart rate were out of range.

Subjects completed a written questionnaire provided by EMU staff after respiratory monitoring was completed. This questionnaire assessed a) level of comfort with each component of monitoring, b) overall satisfaction with monitoring, c) interference with sleep and daily activity due to monitoring, and d) likelihood of proceeding with the video-EEG study, had the subjects been provided advance information regarding the additional monitoring procedures. Subjects were also provided with an opportunity to report their experience or comments as free text. This study was approved by the University of Iowa Institutional Review Board, and all subjects provided written consent.

2.1. Clinical variables:

Medical records were reviewed to obtain clinical information. Variables included for analyses were age, gender, body mass index (BMI), duration of video EEG monitoring, duration of respiratory monitoring, history of obstructive sleep apnea (OSA), prior long-term (≥ 24 hrs) inpatient video-EEG monitoring, prior sleep study, the recording of seizures or spells during the video-EEG study, and final diagnosis of epilepsy vs non-epileptic spells.

2.2. Statistics

SPSS software (IBM Analytics, Somers, NY) was used for statistical analyses. Student's t-test (two tailed) was used to evaluate normally distributed variables and Mann Whitney U

test was used for comparing median differences of non-Gaussian distributed variables, with $\alpha = 0.05$ Chi-square (X^2) was used to compare proportions. Spearman's rho correlation coefficient test (two tailed with $\alpha = 0.05$), was used for univariate analyses to examine the relationship between clinical variables. The Bonferroni correction was used to adjust for multiple comparisons.

3. RESULTS

3.1. Subject characteristics and protocol adherence

Table 1 summarizes the characteristics of the study subjects. One hundred of 140 (71.4%) eligible respondents completed the survey. Of this total, 71% (71/100) received a discharge diagnosis of epilepsy, while 29% (29/100) were diagnosed with non-epileptic spells. All participants wore EEG and ECG continuously throughout the study. Nine subjects (9%) did not wear the nasal pressure transducer or oro-nasal thermistor, one subject (1%) did not wear RIP due to recent thoracic surgery, and 6 (6%) subjects did not undergo transcutaneous CO_2 monitoring due to lack of equipment availability or patient preference.

Thirty-one subjects had previously diagnosed OSA. Four additional subjects were identified by respiratory monitoring as having a high likelihood of OSA and were referred for polysomnography for confirmation and treatment.

No serious adverse events were recorded. One subject developed a local reaction to an EKG electrode.

3.2. Analysis of survey questionnaire

Eighty-eight of 100 (88%) subjects completed all the survey questions, while the remainder did not answer one or more questions.

3.2.1. Level of comfort with different monitoring components—Figure 1 shows levels of comfort as reported by the participants for each component of the monitoring. The percentage of subjects who reported no or mild discomfort for each component was 73.7% for EEG, 84.8% for EKG, 45.5% for nasal airflow, 71.7% for RIP and 74.7% for $tcCO_2$ monitor. These rates were not different ($p = NS$, Table 2) between patients with and without epilepsy. When compared with EEG electrodes, a significantly smaller proportion of subjects reported no or mild discomfort with airflow monitoring (73.7% vs 45.5%, Bonferroni adjusted $p = 0.004$), while other components were comparable ($p = NS$). In univariate analyses, level of discomfort with airflow monitoring was independent of age, epilepsy diagnosis, duration of EMU stay, length of respiratory monitoring, gender, BMI, prior video EEG, and prior sleep study (all with p value greater than the Bonferroni adjusted significance level of 0.00625). Two variables—history of prior video-EEG and duration of EMU stay—were significantly different between patients with or without epilepsy, and therefore were selected for further analysis to determine their effect on patients' comfort or satisfaction with the monitoring protocol. These variables showed no significant associations with any outcome (data not shown).

Sixty percent of subjects generally agreed (with variable strength of agreement) that comprehensive monitoring did not interfere with their sleep, and 63% agreed that it did not interfere with daily activity. These rates were not significantly different between subjects with or without epilepsy (data not shown).

3.2.2. Level of satisfaction with the monitoring—Seventy-three percent of the participants reported being moderately to highly satisfied with the comprehensive monitoring protocol. Univariate analyses showed level of satisfaction to be unrelated to diagnosis of epilepsy, age, gender, duration of video-EEG monitoring, duration of respiratory monitoring, BMI, seizures or spells captured during the study, history of prior video-EEG, and history of prior polysomnography (all with $p=NS$).

3.2.3. Advanced knowledge of additional monitoring and decision for long-term video-EEG study—Eighty-two percent of the participants reported moderate to strong agreement that advance knowledge of the monitoring would not have changed their decision to proceed with the video-EEG study, a rate that did not differ between patients with or without epilepsy (84.5% vs 72.4%, $p=NS$).

3.2.4. Additional comments by subjects—Subjects occasionally commented on aspects of the protocol that bothered them. Examples included “equipment frequently beeping”, “nasal airflow hard to keep in place”, “belts needed frequent checks” “too many wires, often crossed or tangled”.

4. DISCUSSION

We present our experience with 100 subjects who underwent comprehensive cardiorespiratory monitoring during their inpatient video-EEG study in an EMU. There were no serious adverse events with additional multimodal monitoring, and the protocol was well tolerated overall.

Most of the participants reported that multimodal monitoring did not interfere with their sleep or daily activity, while 73% were moderately to highly satisfied with the protocol. The level of satisfaction was unrelated to diagnosis of epilepsy, age, gender, duration of video-EEG monitoring, duration of respiratory monitoring, BMI, seizures or spells captured during the study, or history of prior video-EEG or sleep study. Eighty two percent of the participants reported moderate to strong agreement that advance knowledge of the monitoring would not have changed their decision to proceed with the video-EEG study. Research team members as well as EEG technologists frequently acknowledged the participants' efforts and encouraged them to continue to wear all the monitoring equipment. On occasion, when the participants were hesitant to wear one or more components, we would suggest they try it out for a while before making a final decision. Some patients were also provided with short breaks from the components—typically the airflow sensors, and frequently around mealtimes—when the patient felt one was needed. In most cases these short breaks allowed the patient to resume monitoring. These strategies may have promoted adherence with the protocol as well as satisfaction with the monitoring procedure.

Tolerability of individual components was rated quite similarly, except for nasal airflow measurement, which was tolerated less well. While the measurement of nasal airflow allows for the detection of obstructive respiratory events during sleep and following seizures, the added clinical benefit of this information is not yet clear. Interestingly, level of discomfort due to nasal airflow was not associated with duration of video-EEG monitoring or respiratory monitoring, age, gender, diagnosis of epilepsy, or prior video EEG or sleep study. Tolerability of all the other components of monitoring was similar between patients with or without epilepsy, suggesting broad acceptance within the EMU population.

Our study has certain limitations, including its performance in a single center, the absence of a control group, and the relatively small number of patients without epilepsy who were studied. We also did not systematically record the time some patients spent taking “breaks” from one or more components (typically the airflow sensors), information that may have proved useful to other centers implementing such protocols. Finally, as with any study involving self-report, our results are subject to response bias, particularly if patients receiving ongoing care felt pressured to give an “acceptable answer”. To minimize this possibility, the written survey was provided to the patients at the time of hospital discharge by hospital staff; still, we cannot exclude such an effect.

The systematic measurement of breathing during long-term video-EEG recording has advanced our understanding of the cardiorespiratory changes evoked by seizures [10,11]. Future studies may lead to the identification of biomarkers for SUDEP, opening a door for intervention. Routine cardiorespiratory monitoring may also augment clinical care by increasing the diagnostic yield of the EMU stay, given that peri-ictal cardiorespiratory phenomena may constitute the only clinical sign of seizure and may also help to localize the epileptogenic zone [11]. This approach may also detect untreated OSA, an important and common co-morbidity that is also associated with pharmaco-resistant epilepsy [13]. Finally, peri-ictal cardiorespiratory abnormalities may serve as a seizure alarm to alert nursing staff or seizure monitoring technicians for prompt assessment [14].

5. CONCLUSION

We conclude that patient acceptance of an EMU comprehensive cardiorespiratory monitoring protocol is high. The information obtained from such a protocol is valuable for both clinical care and research. These data provide evidence that the institution of new cardiorespiratory monitoring procedures by EMUs would be broadly accepted, may enhance patient safety in the EMU, and should be routinely instituted unless specifically contraindicated in particular patients.

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Highlights

- In patients admitted to an epilepsy monitoring unit, acceptance of a comprehensive cardiorespiratory monitoring protocol was high.
- Most participants reported no interference with sleep or daily activity with multimodal recording.
- These data provide evidence that the institution of new cardiorespiratory monitoring procedures by EMUs would be widely accepted, increasing both the yield and safety of longterm video-EEG monitoring.

Figure 1.

Level of comfort with different monitoring components. EEG = electroencephalography, EKG = electrocardiography, NPT/thermistor = nasal pressure transducer and oronasal thermistor (airflow), RIP = respiratory inductance plethysmography, tcCO₂/SpO₂ = transcutaneous CO₂ and SpO₂ monitor (SenTec Digital Monitoring System).

Table 1.
Patient characteristics

Variables	Epilepsy (N=71)	Non-epileptic spells (N=29)	p value	Adjusted p value
Age (year; median, lower and upper quartile)	39 (30,50)	35 (23.5,48)	0.1	0.8
Female sex——no. (%)	44 (62)	18 (62)	0.99	1.0
Prior video EEG study——no. (%)	26 (37)	2 (7)	0.0026	0.02081
Prior sleep study——no. (%)	14 (20)	5 (17)	0.77	p=1.0
Number of EMU days (Median, lower and upper quartile)	4 (3, 6)	3 (2, 3)	0.00026	0.00208
Number of respiratory monitoring days in EMU (Median, lower and upper quartile)	3 (2, 4)	2 (1, 3)	0.019	0.152
Seizure/spell captured during VEEG study——no. (%)	53 (75)	21 (72)	0.818	1.0
Obstructive sleep apnea——no. (%)	10 (14)	5 (17)	0.689	1.0

Table 2.**Main results**

Variables	Total subjects	Epilepsy (n=71)	Non-epileptic spells (N=29)	p value	Adjusted p value
Advance knowledge of additional monitoring would not have changed decision to proceed with VEEG study (moderately to strongly agree) —no. (%)	81 (82)	60 (84.5)	21 (72.4)	0.163	1.0
Moderately to highly satisfied with the monitoring—no. (%)	73 (77.7)	52 (73.2)	21 (72.4)	0.935	1.0
Reported no or mild discomfort due to:					
EEG electrodes (%)	73.7	80.0	58.6	0.028	0.196
EKG electrodes (%)	84.8	85.7	82.7	0.705	1.0
NPT and oro-nasal thermistor (%)	45.5	47.2	41.3	0.592	1.0
Abdomen and chest belts (%)	71.7	77.3	65.5	0.225	1.0
Transcutaneous CO ₂ and SpO ₂ (%)	74.7	71.4	82.8	0.236	1.0
Compared to EEG (73.7%), no or mild discomfort due to					
EKG (%)	84.8	-	-	0.054	0.216
NPT and thermistor (%)	45.5	-	-	0.0001	0.004
Abdomen and chest belts (%)	71.7	-	-	0.679	1.0
Transcutaneous CO ₂ and SpO ₂ (%)	74.7	-	-	0.871	1.0