Original Article

The Feasibility of Objective Sleep-Quality Assessment in an ICU Setting

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Background: Sleep disruptions frequently occur in hospitalized patients, especially with critically ill, mechanically ventilated patients. Severely altered sleep architectures result in unclassifiable sleep stages as listed by the conventional Rechtschaffen and Kales (R&K) criteria, and a new classification for sleep scoring including atypical sleep (AS) and pathological wakefulness (PW) has recently been proposed.

Objective: To demonstrate the feasibility of performing objective sleep qualification in patients receiving mechanical ventilation due to acute respiratory failure.

Materials and Methods: In the present prospective cohort study, polysomnography was performed in 38 patients requiring invasive mechanical ventilation due to acute respiratory failure at the respiratory care unit (RCU) of Siriraj Hospital between February and December 2017. Their sleep stages were analyzed by conventional rules and the new classifications of AS and PW. The associations between the presence of AS or PW and the patients' characteristics were analyzed. Correlations between sleep quality and clinical parameters were also determined.

Results: Most of the patients had poor sleep quality with median sleep efficiency (IQR) of 35.9% (18.5, 62.3) and significantly decreased slow-wave sleep [median (IQR) 0.4% (0.00, 5.70)] and REM [median (IQR) 1.3% (0.00, 6.43)]. According to the new classifications, 14 out of 38 (prevalence of 36.8%) mechanically ventilated patients had AS. The prevalence of PW and either AS or PW were 36.8% and 52.6%, respectively. A higher baseline respiratory rate was observed among patients who had either AS or PW at 24 versus 20 breaths/minute (p=0.02), while a longer duration of mechanical ventilator support was found in patients with PW at nine versus five (p=0.003). Patient-ventilator asynchrony was also noted in all patients.

Conclusion: Sleep quality among critically ill and mechanically ventilated patients was severely disturbed. A higher prevalence of AS and PW were noted. The technical feasibility of sleep recording in Thai intensive care unit (ICU) settings was established.

Keywords: Polysomnography, Atypical sleep, ICU

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Poor sleep quality, sleep deprivation, and disruption of sleep architecture have been recognized as common among critically ill patients. Apart from severe fragmentation, restorative sleep is markedly reduced[1-3]. These sleep disturbances result in increased sympathetic tone, elevated catecholamines, increased insulin resistance, delirium, and cognitive dysfunction. The factors contributing to sleep disruptions in the intensive care unit (ICU) setting include the different environment, the medications, the patient-ventilator asynchrony, patient-care activities, and per se critical-illness severity[4-7]. Atypical sleep (AS) patterns characterized by electroencephalograms (EEG) tracing as compatible with usual sleep but lacking specific markers of the non-rapid eye movement (NREM) stage were previously recorded in some ICU patients during polysomnography (PSG) recordings, but the clinical significance of this has to be unraveled[8].

Drouot et al described sleep studies performed on ICU patients who received both invasive and non-invasive mechanical ventilation[9]. The study found that the sleep architectures were severely disrupted and the EEG in this population, either asleep or awake, were difficult to categorize sleep stage according to conventional criteria of Rechtschaffen and Kales (R&K)[10]. About one quarter of the patients did not have usual NREM sleep characteristics. There were continuous, irregular delta waves with neither K complexes nor sleep spindles. Some patients exhibited wakefulness behavior such as eye opening, while a slow background EEG was observed. These abnormal EEG patterns were proposed as "AS" and

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"pathological wakefulness (PW)", respectively. They also found an association between the presence of AS and the occurrence of delirium thereafter. However, the standard definitions for these AS patterns have not yet been established. The sleep characteristics and prevalence of AS patterns in Thai ICU patients are unknown.

Objective

The present study aimed to demonstrate the feasibility of performing objective sleep qualifications in patients with acute respiratory failure who required invasive mechanical ventilation caring in the ICU setting of Thailand.

Materials and Methods

The present research was a prospective cohort study conducted in the 10-bed respiratory care unit (RCU) at Siriraj Hospital between February and December 2017. The study was approved by the Human Research Protection Unit, Siriraj Institutional Review Board (Si032/2017). Adult patients aged 18 years or older with at least 48 hours of invasive mechanical ventilation due to acute respiratory failure were recruited. All patients were expected to receive mechanical ventilation for at least an additional 24 hours at the time of screening, and with no plan for ventilator-setting changes during the study period. Exclusion criteria consisted of 1) hemodynamics instability or receiving more than 0.2 mcg/kg/minute of norepinephrine, 2) end-of-life setting, 3) conditions known to cause atypical EEG such as hepatic or uremic encephalopathy, epilepsy, hemiplegic stroke less than nine months after onset[11], and 4) deeply sedated, or a Glasgow coma scale score of less than 10.

Informed consent was obtained from each patient or his or her surrogates. Patients' baseline clinical data, including the severity of disease at RCU admission using the Acute Physiology and Chronic Health Evaluation II (APACHE II), were collected. At the time of enrollment, all participants were assessed as having delirium status using the Confusion-Assessment Method for the ICU (CAM-ICU), Thai version. The standard PSG (SOMNO HD™, Randersacker, Germany) was performed continuously from 3:00 PM to 6:00 AM. The electrodes, consisting of ten EEG, three chin electromyographic (EMG), two electrooculographic (EOG), and two electrocardiographic (ECG) channels, were positioned by trained sleep technicians and conformed to the International 10 to 20 system[10]. The awake behaviors were observed via video recorder. Airflow and airway pressure at the inspiratory limb of the ventilator circuit, close to the Y-piece, were also measured. Pulse oximetry and transcutaneous CO_2 were simultaneously recorded. The delirium status was reassessed on the day after the sleep study. The researchers followed the patients until their RCU discharge to assess their clinical outcomes.

The PSG were manually scored according to the American Academy of Sleep Medicine (AASM) criteria[10] by a qualified technician and then reviewed by a certified sleep physician. If some tracings could not be clearly made using the AASM criteria, the epoch was considered as either AS or PW. The researchers set their own criteria to classify AS, if at least 20% of the epoch consisted of irregular, continuous, high-amplitude (50 to 100 μV) delta waves without typical K complexes or sleep spindles in that epoch and in the second half of the preceding epoch. The researchers also specified PW as the presence of awake behaviors for at least 50% of the epoch with slow background EEG waves (a peak EEG frequency less than or equal to 7 Hz).

Ventilator airflow and airway pressure were analyzed to detect major patient-ventilator asynchrony, consisting of ineffective triggering, double-triggering, auto-triggering, a short cycle, a prolonged cycle, and apnea. The asynchrony index was defined as[12]:

$$\frac{\text{"number of asynchrony events} \times 100\text{"}}{\text{"number of ventilator cycles + number of wasted efforts"}}$$

Data were presented as means with standard deviation (mean ± SD) or median with interquartile range [median (IQR)] where appropriated. The two-sample t-test was used to compare means. As to categorical variables, Fisher's exact test or the chi-square test was used to assess the associations between the poor sleep efficiency and the variables. All tests with a p-value of less than 0.05 were considered to be statistically significant. The PASW Statistics, version 18.0 (SPSS Inc., Chicago, IL, USA) was used for all the analyses.

Results

During the present study period, the researchers enrolled 38 patients. The mean age was 65 years old, and 50% were male. Pneumonia was the leading cause of RCU admission. Other patient characteristics are shown in Table 1.

Almost all the patients had poor sleep efficiency. The median sleep efficiency was 35.9% (18.5, 62.3). Frequent arousals and severe sleep disruptions were

Table 1. Baseline patient characteristics

Characteristics	Results (n=38); n (%)
Age (years); mean±SD	65±15
Sex: male	19 (50.0)
Body mass index (kg/m^2); mean±SD	23.2±5.6
Co-morbidities	
Hypertension	21 (55.3)
Chronic kidney disease	17 (44.7)
Diabetes mellitus	13 (34.2)
Chronic airway disease	9 (23.7)
Previous stroke (>9 months)	4 (10.5)
Heart failure	2 (5.3)
Coronary artery disease	1 (2.6)
Type of acute respiratory failure	
Hypoxemia	23 (60.5)
Hypercapnia	9 (23.7)
Shock	6 (15.8)
Cause of RCU admission	
Pneumonia	17 (44.7)
COPD exacerbation	3 (7.9)
Acute asthmatic attack	3 (7.9)
Congestive heart failure	2 (5.3)
Massive pulmonary embolism	2 (5.3)
Life-threatening hemoptysis	2 (5.3)
Myasthenic crisis	2 (5.3)
APACHE II; mean±SD	15.0±6.9
Days of hospital admission; median (IQR)	7.5 (5, 19.3)
Days of RCU admission; median (IQR)	4.0 (2.8, 6.5)
Mechanical ventilation (days); median (IQR)	5.0 (4.0, 8.3)
Medications	
Vasopressors	1 (2.6)
Sedatives	1 (2.6)
Analgesics	8 (21.1)
Antipsychotics	7 (18.4)
Systemic corticosteroids	18 (47.4)
Glasgow coma scale; mean±SD	14.6 (2.6)
Ventilator mode	
Pressure-controlled	8 (21.1)
Volume-controlled	1 (2.6)
Pressure support	29 (76.3)
Respiratory rate (breaths/minute); mean±SD	22±6

RCU=respiratory care unit; COPD=chronic obstructive pulmonary disease; APACHE=acute physiology and chronic health evaluation; SD=standard deviation; IQR=interquartile range

Table 2. Sleep analysis and clinical outcomes

Outcomes	Results (n=38); mean±SD
Time in bed (minutes)	880±68
Total sleep time (minutes); median (IQR)	322 (170, 538)
Sleep efficiency (%); median (IQR)	35.9 (18.5, 62.3)
Arousal index (events/hour)	32.3±14.3
Sleep stage (%); median (IQR)	
N1	52.8 (32.3, 68.5)
N2	39.5 (28.3, 47.6)
N3	0.4 (0.0, 5.7)
REM	1.3 (0.0, 6.4)
Nursing care (events per recording time)	9.9±2.3
Asynchrony index (%); median (IQR)	0.6 (0.3, 1.9)
Prevalence of delirium (n=37); n (%)	2 (5.4)
RCU successful weaning; n (%)	31 (81.6)
Ventilator days after sleep study; median (IQR)	2 (1, 4)
Alive status at RCU discharge; n (%)	33 (86.8)

REM=rapid eye movement; RCU=respiratory care unit; SD=standard deviation; IQR=interquartile range

also noted. The subjects spent nearly all their sleep time in superficial sleep [N1 52.8% (32.3, 68.5) and N2 39.5 (28.3, 47.6)] (Table 2). AS (Figure 1) was found in 14 out of 38 patients (36.8%). The prevalence of PW (Figure 2) was the same at 36.8%. Twenty patients (52.6%) had either AS or PW. The baseline respiratory rate before sleep recording was higher in patients with either AS or PW (24 versus 20 breaths/minute, p=0.02). The duration of mechanical ventilation prior to enrollment was longer in patients with PW (nine versus five days, p=0.003).

The present study analyses of the ventilator airflow and airway pressure revealed a patient-ventilator asynchrony in all subjects, including phenomena such as ineffective triggering, double-triggering, a delayed cycle, or apnea that usually occurred while awakening. However, during the recording-sleep period, patients had an asynchrony index of 0.56% (IQR 0.27, 1.89).

Delirium occurred in only two patients, and none of them had AS or PW. Successful liberation from the mechanical ventilator and an alive status at RCU discharge were observed in 31 and 33 patients, respectively. The clinical parameters and sleep efficiency were analyzed to identify their relationship (Table 3). Systemic steroid administration showed a trend toward poor sleep quality, defined by sleep efficiency of less than 60%, although that rate did not reach statistical significance (OR 0.188, 95% CI 0.034 to 1.048, p=0.067). The patient-ventilator asynchrony in the present study population was quite

Figure 1. Polysomnographic features of atypical sleep (AS): This epoch demonstrates continuous, irregular, high-amplitude (50 to 100 µV) delta waves with neither K complexes nor sleep spindles, and low submental muscle activity. F3:M1 and F4:M1 are left and right frontal EEG, C3:M1 and C4:M1 are left and right central EEG. O1:M2 and O2:M1 are left and right occipital EEG. E2:M1 and E1:M2 are right and left EOG, respectively. EMG1 is submental EEG. The width of the inner horizontal lines in the frontal channels represents a 50 µV-amplitude.

EEG=electroencephalography

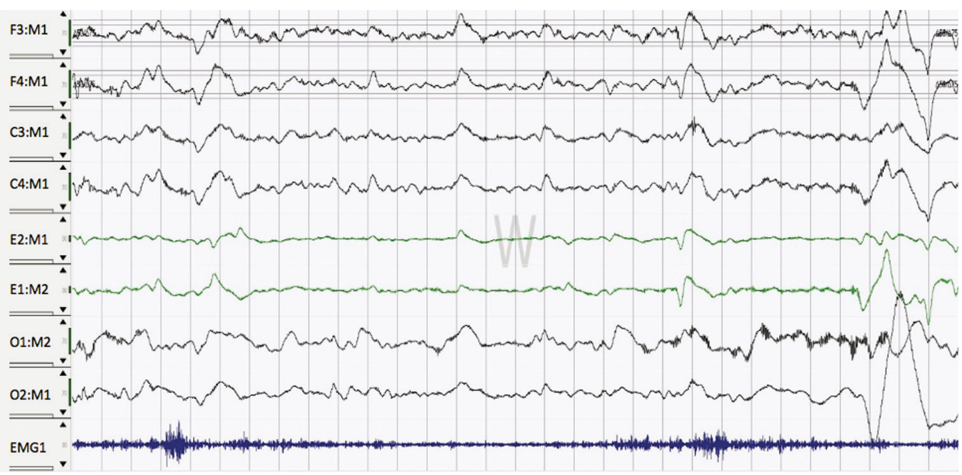

Figure 2. Polysomnographic features of pathological wakeful-ness (PW): Slow background EEG is observed with rapid eye movement and submental muscle activity. The video-recording reveals intentional eye openings with eye blinks during this epoch.

EEG=electroencephalography

infrequent, as reflected by the lower asynchrony index, as compared to other studies, ranging from 2.1 to 3.4[12,13].

Discussion

Poor sleep quality and severe disruption of sleep architecture among mechanically ventilated patients in an ICU setting was established in the present study, concordant with previous reports[4-7]. Atypical patterns of EEG, either during wake or sleep, were frequently found at a higher prevalence than in the study Drouot et al[9]. The simplicity and enhanced practicality of the present study diagnostic rule for AS and PW might have contributed to these different results.

A higher respiratory rate at the beginning of the sleep study was observed among patients with AS. This may reflect their sense of fear or an inappropriate mental readiness for weaning. However, the patient-ventilator asynchrony during sleep did not account for this association. This may result from the optimum ventilator settings in this RCU population. Since delirium rarely occurred in the present study,

Table 3. Associations of sleep quality and clinical parameters

Parameters	Sleep efficiency; mean±SD		p-value
	<60% (n=28)	≥60% (n=10)	
Age (years)	63.7±15.9	67.7±12.6	0.479
Body mass index (kg/m^2)	22.6±5.4	24.9±6.0	0.267
Type of respiratory failure; % (n)			
Hypoxemic (n=23)	69.6 (16)	30.4 (7)	0.709
Hypercapnic (n=9)	88.9 (8)	11.1 (1)	0.396
APACHE II	14.3±6.6	17.1±7.6	0.271
Days of admission; median (IQR)	7 (5, 19)	9 (4, 26)	0.829
Days of RCU stay; median (IQR)	4 (2, 6)	4 (3, 9)	0.439
Days of ventilator; median (IQR)	5 (4, 7)	6 (4, 9)	0.711
Using of any sedative agents; % (n)			0.709
Yes (n=13)	69.2 (9)	30.8 (4)	
No (n=25)	76.0 (19)	24.0 (6)	
Using of systemic steroid; % (n)			0.067
Yes (n=18)	88.9 (16)	11.1 (2)	
No (n=20)	60.0 (12)	40.0 (8)	
Heart rate (bpm)	87.7±18.7	93.1±11.4	0.401
Ventilator mode; % (n)			0.205
Pressure support (n=29)	79.3 (23)	20.7 (6)	
Others (n=9)	55.6 (5)	44.4 (4)	
Respiratory rate (/minute)	21.4±5.7	22.6±6.0	0.585
Tidal volume (mL)	422.2±101.2	451.2±113.4	0.456
Arousals (events/hour); median (IQR)	29.6 (23.4, 39.6)	38.5 (22.2, 49.6)	0.304
Asynchrony index (%); median (IQR)	0.6 (0.3, 2.0)	0.8 (0.2, 1.6)	0.842
Successful weaning; % (n)			1.000
Yes (n=31)	74.2 (23)	25.8 (8)	
No (n=7)	71.4 (5)	28.6 (2)	

RCU=respiratory care unit; APACHE=acute physiology and chronic health evaluation; SD=standard deviation; IQR=interquartile range

an association between AS and delirium was not evaluated. Differences in the patients' baseline characteristics such as disease severity and chronicity, could play a part in the low prevalence of delirium in the present study.

PW, a state of less reaction to stimuli, was confirmed to associate with a longer duration of mechanical ventilation, as cause and consequence. The clinical importance of this state should be further verified. Patient-ventilator asynchrony during sleep in the present study was less than what was observed in prior reports comparing sleep quality in different modes of mechanical ventilation[14,15]. However, the methods to identify asynchrony were different. The Cabello et al[14] study used the airway pressure-flow signal and the thoracoabdominal plethysmography to detect ineffective triggering, while the Delisle et al[15] study observed the ventilator air flow, airway pressure, and electrical activity of the diaphragm (EAdi). In the present study, ineffective triggering was possibly underestimated, since the analysis was only based on the airway pressure-flow signal, without using esophageal-pressure monitoring or the EAdi. On the contrary, the ventilator settings in these patients might be appropriately adjusted and may have led to a lower prevalence of asynchrony in the present study.

Technical feasibility in establishing objective sleep quality in mechanically ventilated patients was demonstrated in an academic ICU setting in Thailand. This data may be significant for the planning of proper ventilator strategies to ease the patients for synchronization with the machine and in coming up with an environmental design to promote their well-being. The existence of an abnormal EEG unclassifiable with conventional criteria suggests that a simplified standard rule for sleep scoring in these critically ill patients is clearly needed.

The potential limitations in the present study must be mentioned. First, environmental factors disturbing sleep quality in an ICU setting, such as noise and light levels, were not assessed. Second, the artifacts from other electrical monitoring devices in an ICU setting may interfere with the quality of EEG waveforms. Lastly, a 15-hour PSG recording may not be enough to reflect overall sleep and patients' clinical outcomes, due to the abnormal sleep-wake cycle in ICU patients.

Conclusion

The sleep quality among critically ill and mechanically ventilated patients was severely disturbed. A higher prevalence of AS and PW were noted. The technical feasibility of sleep recording in Thai ICU settings was established.

What is already known on this topic?

The ICU patients usually have sleep disturbances and poor sleep quality. AS and pathological wakefulness have been proposed to describe some sleep architectures unable to be clearly categorized sleep stage using conventional rules.

What this study adds?

This study confirms the practicability of PSG for objective sleep quality assessment in Thai ICU settings. Poor sleep quality and high prevalence of AS recording features in critically ill patients exist. Further studies are needed to evaluate the clinical significance.

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Conflicts of interest

The authors declare no conflict of interest.

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