

Sleep Monitoring Techniques within Intensive Care

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Abstract

Sleep is an essential biological function that provides important restorative psycho-physiological processes. Patients in the Intensive Care Unit are highly vulnerable to sleep disturbance which can protract their recovery. Despite sleep disturbance being widely acknowledged amongst this patient cohort, the ability to make significant changes to minimise the burden of sleep deprivation remains a challenge. This is further compounded by the difficulties faced by clinicians to identify and implement accurate and feasible sleep monitoring techniques in the intensive care. Whilst objective, behavioural and subjective methods of sleep assessment exist, all have specific limitations when applied to critically ill patients. In an attempt to illuminate these issues, current sleep monitoring techniques are appraised.

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Introduction

Sleep is considered to be an essential biological function required by all species. In humans, sleep was originally hypothesised to have been an adaptive process in promoting survival and avoiding predation [1]. More contemporary perspectives on sleep focus on its importance in regards to physical restoration and mental functioning [2]. Although total sleep function is yet to be fully elucidated, physiological quiescence provides important restorative processes to aid cognitive functioning [3-5], along with metabolic conservation [6-8] and produces an anabolic state [9]. Over the past three decades, there has been an inordinate amount of published research regarding sleep disturbance in highly vulnerable patients, such as those cared for in the Intensive Care (ICU) setting. Although the etiological causes of sleep disturbance are thought to be multi-factorial and the impact of sleep disturbance on patient recovery is widely recognised, sleep monitoring has not been implemented as standard component of clinical care. This has been attributed to the complexities confronting clinician's in identifying a method that is both accurate and feasible for widespread implementation.

Sleep Physiology of Intensive Care patients

Sleep consists of cyclic stages moving between non-rapid eye movement sleep (nREM) and rapid eye movement (REM) sleep, occurring over a duration of 90 minutes which is repeated 5-6 times per night. The physiology of sleep commences with stage N1 and is characterised by the subjective feeling of drowsiness combined with decreased ocular movements [10-11], this is followed by stage N2 (light sleep) which is the predominant sleep state of the nREM phase. During this stage the individual is decreasingly unresponsive to stimuli and ocular movements cease. The final stage of nREM sleep is referred to as N3 or Slow Wave Sleep (SWS), which is characterised by slow wave electroencephalographic (EEG) activity and has the important attributes of being anabolic and physiologically restorative [12].

In contrast, REM sleep is an active stage with a high degree of cerebral and physiological activity [13]. In this phase, heart rate increases along with the brain's metabolic rate to reflect that of a wakeful state, whilst muscle tone and thermoregulation are suppressed

[14-15]. Dreaming predominantly occurs during this phase and is purported to be an important process for mental restoration and emotional healing [16-18].

Polysomnography (PSG) studies reporting the sleep architecture of ICU patients reveal that whilst the total sleep time acquired is relatively normal (6-8 hours) [19-21]; it is often non-consolidated and highly fragmented [22-23]. Research indicates that ICU patients sleep traverses both day and night contributing to circadian disturbances [24-25]. These features lead to qualitative sleep deprivation which is bio-physiologically represented by the predominance of sleep stages N1 and N2, with little to absent SWS and REM sleep [19,24,26-28]. Previous subjective [20,29-32] studies report high rates of nocturnal clinical interactions with patients within the ICU which has been surmised as providing an environment in which quality sleep is unlikely to be achieved. Objective studies support such assertions, for example Kim et al [33] reported that sleep disturbances amongst an ICU patient cohort occurred at a rate of 14.7 ± 12 /hour over a 24 hour monitoring period, whilst Tamburri et al [30] reported a mean number of nocturnal interactions of 42.6 ± 11.3 /night with patient acuity being a significant factor for increased interaction ($r=0.32$, $p<0.05$). The impact of this on sleep was further quantified by Elliot et al [28] who conducted a 24 hour PSG study on ICU patients and reported that the median sleep time was 5 hours, with sleep disturbances occurring 3 minutely.

Survivors of critical illness report inability to sleep as a major stressor associated with their admission and this is supported consistently by biophysiological reports. Both Rotondi et al. [34] and Orwelius and colleagues [35] reported that 38% of patients experienced difficulty falling asleep, and expressed a greater need for sleep during acute

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illness. The inability to acquire restorative sleep (SWS and REM sleep) can exacerbate daytime somnolence resulting in daytime napping, and ultimately dys-synchronisation of the sleep wake patterns contributing to a phase shifting of the circadian rhythm.

The consequences of sleep disturbance on patient recovery are not benign. It has been attributed to a number of deleterious physiological and cognitive effects that protract recovery. These range from a decrease in the immunological response [35-38], endocrine instability [6-8,39], protein catabolism [40], and respiratory muscle fatigue (41-43). Further, cognitive effects of sleep deprivation include inattention, depression, confusion, a decline in quality of life [44] and have been linked to the onset of delirium. Moreover, issues with sleep disturbance developed within the Intensive Care environment has been reported to perpetuate for months after discharge [45].

Assessment of Sleep Disturbance

Evaluation of sleep disturbance amongst ICU patients is fraught with complexity due to the presence of critical illness. Further, identifying techniques that can be readily applied within this patient cohort have not been extensively examined for widespread implementation. Even though objective, behavioural and subjective techniques exist, all still have specific limitations in regards to their application to the ICU patient population. Current biophysiological sleep monitoring technologies: polysomnography, actigraphy and bispectral index monitoring are examined, along with the utility subjective and behavioural assessments of sleep within the Intensive Care setting.

Objective Assessment of Sleep Disturbance

Polysomnography (PSG) records the biophysiological changes based on electroencephalographic (EEG) activity, combined with concurrent polygraphic monitoring of electro-oculogram (EOG) and electromyogram (EMG) activity which occurs during sleep. This method has long been regarded as the gold standard of sleep monitoring outside of the ICU, and is widely used in sleep medicine to formally diagnose sleep disorders and has been employed in ICU based sleep research to investigate sleep characteristics of complex patients. However, its ability to be integrated widely into the ICU environment is hampered by its costs and methodological complexities; further the technique is labour intensive and requires clinical expertise to interpret the data that exceeds the scope of critical care clinicians. Although portable PSG monitoring has the capacity to reduce the associated costs and the time spent preparing and setting up the device, analysis and interpretation of data remains labour intensive and time consuming, and requires personnel with clinical expertise in the area of sleep medicine. As a result PSG remains impractical and financially unviable for widespread implementation in the ICU setting. The development of computer based interpretation methods have the capacity to overcome the need for expertise to interpret the data, however these are frequently critiqued as being less than optimal as the reliability of this method ranges from 65% to 85% in the normal sleep clinic population, and their use in the ICU population is not validated [46]. Further compounding the issue is the potential reduction in EEG activity in critically ill patients secondary to conditions such as encephalopathy's (hepatic, septic, neurological), administration of sedation and acute neurological injuries, thus making it difficult to decipher between sleep states and the resultant impact of critical illness [47-49].

Subsequently, the traditional polysomnographic interpretative methods used in Sleep Medicine may have reduced utility in the ICU setting. Atypical biophysiological sleep activity has been widely reported amongst ICU patients, which confounds the ability to distinguish between NREM sleep stages [23,28,50-51]. PSG based studies reveal a lack of discernible sleep spindles and K complexes, along with challenges associated with electrical interference, and the impact of pharmacological agents in detecting submental muscle atonia [23,28,50-52]. Further, Drouet et al [53] reported that 28% of PSG recordings obtained within ICU, could not be classified based on the conventional scoring rules.

Nonetheless, PSG has been used extensively in sleep research involving ICU patients and has consistently provided information regarding alterations in sleep architecture. Many of the studies conducted have only monitored nocturnal sleep, despite ICU patients acquiring up to 50% of their total sleep time during the day [19-20]. The sleep architecture of ICU patients have been consistently reported to be fragmented with long sleep onset and REM latencies, and poor sleep efficiencies [19,25-26]. The primary etiology of these abnormalities remains unclear, and is thought to be multifactorial.

Alternative bio-physiological methods such as Bispectral index (BIS) have been investigated as an adjunct objective assessment of sleep within the ICU which may be preferable to PSG. This method employs an electroencephalogram parameters, which was initially developed to assist in the titration of anesthesia. This assessment provides a scale from 0 to 100, with scores between 90 -100 identifying a wakeful state, 70-80 being unconscious, 60-70 deep level sedation and under 60 being anaesthetised [54], based on an integration of parameters inclusive of EEG, and spectral and bispectral power analysis to determine states of consciousness [55].

Whilst BIS has cemented itself as a useful objective assessment of levels of anaesthesia, its broader application to assess sleep has only been tentatively explored. Limited studies have been conducted within the Intensive Care environment, with one study conducted by Patel, Sleight and Nicholson [56] reporting that BIS assessment of sleep levels was consistent with PSG data. However, the values employed to assess sleep stages via BIS contain overlap and therefore the accuracy of distinguishing sleep stages is potentially compromised. Further, factors that impact on the accuracy of PSG are also confounders for the accuracy of BIS. Although, this method has not been extensively explored within the critical care environment it does have a distinct advantage compared to PSG, in that the interpretation of data does not require extensive clinical expertise and can be rapidly evaluated at the bedside.

Behavioural Assessment of Sleep Disturbance

Although objective bio-physical assessments are preferable due to their ability to provide specific information on sleep stages, behavioral assessments such as actigraphy have the potential to yield important information over longer periods of time. Actigraphy has emerged as a potentially viable alternative assessment to monitor sleep, and has been recognised by The American Academy of Sleep Medicine as an adjunctive clinical assessment of sleep disorders [57]. Researchers attest that there exists parallelism between the sleep-wake and rest-activity patterns suggesting that actigraphy could be a surrogate for polysomnography for sleep-wake activity [58-60].

Actigraphy (ACTG) is an accelerometer which estimates sleep-wake cycles by the measurement of activity through the use of omnidirectional omnidirectional sensors to identify movement

suggestive of wakeful or sleep states. The device is worn like a wrist watch making its application and removal uncomplicated for clinicians. This is in contrast to PSG which requires electrodes to be positioned at specific anatomical landmarks, with good skin adherence via the aid of pastes and adhesives to ensure accurate data collection. ACTG provides objective data that is independent of personal judgements of sleep and may offer a low-cost, and non-invasive assessment of sleep compared with PSG. However, the clinical utility of ACTG remains unclear in a variety of settings, with few studies investigating the sensitivity of actigraphy compared to PSG [19,61]. Studies conducted by Mullaney, Kripke and Messin [62] and Cole, Kripke, Gruen, Mullaney and Gilline [58] reported the concordance between ACTG and PSG to range between 81% to 87%, suggesting that its potential application to more diverse clinical settings is potentially viable. Although widely employed within the context of sleep laboratories, the potential of actigraphy has had limited testing within the critical care environment.

Due to the method employed by ACTG to distinguish between sleep and awake states, the information generated regarding sleep is limited in comparison to PSG. ACTG provides information regarding total sleep time, wake time and sleep fragmentation, but it provides no information about whether SWS or REM sleep are present in a recording. This device has the potential to provide valuable information regarding sleep-wake patterns, with added benefit of being able to monitor data over a 7 day period and computerised interpretation of data readily available and uncomplicated.

The application of ACTG monitoring has the potential capacity to identify circadian disturbance which is common amongst ICU patients, and in turn a patient's response to treatment interventions to improve sleep and circadian synchrony. Although previous research involving the ICU patient population is limited and frequently involved small numbers, this technology may have a useful application in specific clinical situations and may not be suitable for all ICU patients as indicated by *Beecroft et al.* [63]. In their study involving mechanically ventilated patients (n=12) the accuracy of actigraphy compared with PSG was reported to be less than 65%. However, there was no statistical difference between ACTG and PSG's ability to assess awakening from sleep. Similarly, *Van der Kooi et al.* [64] (2012) in a study involving post cardiac surgery patients (n=7) found significant correlation ($r=0.76$) between PSG and actigraphy in determining the number of awakenings. In clinical environments where the use of sedation is administered judiciously and, ICU's that provide combine services to high dependency patients the application of this device may have clinical merit. The increased emphasis on controlled sedation administration and targeted sedation scores, along with emerging sedation options, patients are increasing conscious and interacting with health professionals within the ICU environment. The ability to monitor sleep with methods other than EEG is potentially emerging as being more feasible and increasingly important in order to optimise patient outcomes. The primary limitation associated with ACTG in the Intensive Care environment is associated with immobile patients such as those with neuromuscular complications, spinal injuries, and those receiving paralyzing agents and moderate levels of sedation which impede spontaneous movement. The accuracy of both ACTG and PSG remains problematic in this patient group.

Subjective Assessment of Sleep Disturbance

Subjective assessments of sleep and sleep quality, inclusive of both clinician-based observations and patient self-reports, offer a cost effective method of evaluating sleep. These clinical approaches are

frequently implemented when sleep issues become evident, but are subject to interpreter bias. Clinicians have difficulty in determining the difference between sleep and sedation, as sedation mimics many of the features of sleep and this also confounds the interpretation of objective bio-physical measures such as PSG and BIS. Nonetheless, subjective assessments may have an important role amongst those patients who are recovering from critical illness, particularly when the assessment is not being obscured by the impact of sedating agents.

Although patient's self-appraisal of sleep is considered an optimal assessment of sleep quality as it acknowledges the subjective nature of sleep quality, it is not always achievable amongst the ICU population due to the impact of illness, surgical intervention and pharmacological agents. Furthermore, there are reported discrepancies between how long individuals report that they have slept for compared to the physiological data reporting total sleep time in studies that have employed concurrent PSG monitoring and patient self-reports [20,65]. The ability to implement self-reports is limited to a small population of patients (< 50%) in the ICU setting who have capacity to complete these [17], which significantly compromises their efficacy.

As a result, observational assessments performed by clinical staff are often the first point of call when there is concern regarding a patient's sleep characteristics, and is the most practical and cost effective method available to clinicians. However, nursing assessments have been found to consistently over-estimate sleep compared to objective, subjective and behavioural assessments [66-68], in addition to problems associated with missing data [68].

A number of self-report methods have been applied to the ICU environment to assess patient's quality of sleep, the most commonly employed assessments are the Pittsburgh Sleep Quality Index (PSQI), Verran and Synder- Halpern Sleep Scale (VSH) and the Richardson-Campbell Sleep Questionnaire (RCSQ). These three scales have been widely researched and utilised within ICU environment that affirmed sleep is of a poor quality and subjected to frequent interruptions. The RCSQ was developed specifically for the critical care environment [69], unlike PSQI which was originally developed to assess sleep disturbance in psychiatric populations [70] and VSH which was developed to assess sleep quality for hospitalized patients without pre-existing sleep disorders [71]. Although, all three report similar domains such as sleep quality, sleep disturbance, sleep time and sleep latency, the PSQI and VSH are more labor intensive for critically ill patients due to the higher number of questions and the need for cognitive acumen and ability to recall information. Comparatively, the 5 item visual analogue RCSQ that has been tested for its reliability against PSG and proxy assessors reported mixed results regarding quality of patients' sleep.

Original research conducted by Campbell [72] reported that there was a high correlation ($r=0.869$, $P<.001$) between patient self-reports and nurse sleep rating, however more contemporary studies [17,73] suggest that staff continue to overestimate patient sleep when completing RCSQ compared to patient self-reports. Kamdar et al [73] investigated the inter-rater patient-nurse reliability of the RCSQ and found overall that nurses scored higher, perceiving sleep to be of a better quality than patients for sleep depth and quality. This suggests that using nursing staff to complete the questionnaire in lieu of patients would produce a moderate representation of the patient's experience at best. Despite efforts to devise strategies to enhance subjective assessments of sleep, findings consistently identify this technique as one that over estimates patient sleep.

Conclusion

The clinical importance of sleep in the recovery of critically ill patients is frequently acknowledged and is associated with a sequelae of complications, yet remains an issue within Intensive Care Units that has not been remedied. Numerous strategies have been devised ranging from behaviour modifications approaches, curtailing the impact of environmental stimuli through to non-invasive strategies such as ear-plugs and pharmacological intervention, along with diversional therapy approaches. Despite these efforts reduce sleep disturbance; the ability to accurately monitor sleep continues to elude clinicians, as current biophysical and behavioural assessment approaches have significant limitations in the ICU setting. Self-appraisals of sleep quality can only be completed by a small proportion of patients and clinician observations over-estimates quality and quantity of sleep. Whilst biophysiological methods are hampered by the impact of critical illness and clinical management strategies that obfuscates the ability to distinguish between sleep stages and impedes the sensing of movement. As a result, there is currently no one viable and accurate sleep monitoring tool suitable for widespread ICU application. Further research is required to devise algorithms that permit the ability to decipher sleep stages within the ICU patient population, in order to be able to accurately quantify sleep, along with developing methods that are feasible for widespread implementation.

The development of reliable biophysiological monitoring techniques is imperative in order to fully elucidate the impact of external and internal factors that contribute to sleep disturbance during critical illness. Presently, studies are hampered by small sample sizes with limited capacity to performed large comparative studies in order to ascertain the impact of interventions in improving sleep disturbance amongst critically ill patients. Cost effective bio-physiological monitoring, which produces easily interpretable data will provide clinician with important clinical information regarding an important facet of patient recovery, and promote a greater understanding and awareness of sleep in the overall well-being of patients.

Competing Interests

The author(s) declare that they have no competing interests.

Author Contributions

Lori J. Delaney-Conception of the article and manuscript preparation.

Frank Van Haren-Revising and drafting the manuscript.

Marian Currie and Violeta Lopez-Editing of manuscript

Hsin-Chia Carol Huang-Revising and editing of the manuscript.

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