Injury, Sleep, and Functional Outcome in Hospital Patients With Traumatic Brain Injury

Ellita T. Williams, Diana Taibi Buchanan, Daniel J. Buysse, Hilaire J. Thompson

ABSTRACT

Problem: Uninterrupted nighttime sleep is associated with better cognition and functional outcomes in healthy adults, but the relationship between sleep and functional outcome in individuals hospitalized with severe traumatic brain injury (TBI) remains to be clarified. **Objective:** The aims of this study were to (1) describe nighttime rest-activity variables—wake bouts (counts), total wake time (minutes), and sleep efficiency (SE) (percentage; time asleep/time in bed)—in people on a neuroscience step-down unit (NSDU) post-TBI and (2) describe the association between injury and nighttime rest-activity on post-TBI functional outcome (using Functional Independence Measure [FIM] at discharge from inpatient care). **Methods:** This study is a cross-sectional, descriptive pilot study. We recruited participants from the NSDU (n = 17 [age: mean (SD), 63.4 (17.9)]; 82% male, 94% white) who wore wrist actigraphy (source of nighttime rest-activity variables) for up to 5 nights. For injury variables, we used Glasgow Coma Scale (GCS) score and Injury Severity Score (ISS). We used Spearman ρ and regression to measure associations. **Results:** Glasgow Coma Scale mean (SD) score was 8.8 (4.9), ISS mean (SD) score was 23.6 (6.7), and FIM mean (SD) score was 48 (14.5). Averages of nighttime rest-activity variables (8 PM–7 AM) were as follows: SE, 73% (SD, 16); wake bouts, 41 counts (SD, 18); total wake time, 74 minutes (SD, 47). Correlations showed significance between FIM and GCS ($P = .005$) and between SE and GCS ($P = .015$). GCS was the only statistically significant variable associated with FIM ($P = .013$); we eliminated other variables from the model as nonsignificant ($P > .10$). Sleep efficiency and FIM association was nonsignificant ($P = .40$). In a separate model (ISS, GCS, and SE [dependent variable]), GCS was significant ($P = .04$), but ISS was not ($P = .25$). **Conclusion:** Patients with severe TBI on the NSDU have poor actigraphic sleep at night. GCS has a stronger association to functional outcome than nighttime rest-activity variables.

Keywords: actigraphy, neuro step-down unit, outcome, TBI

The quality of nighttime sleep is an important yet obscure phenomenon for the nearly 300 000 people in the United States who are in the hospital for traumatic brain injury (TBI) each year.[1,2] TBI is a very serious public health issue as it contributes to about a third of all injury deaths (30%) in the United States.[1] After a severe TBI, 43% of victims experience severe lifelong disability.[3,4] Although the disability outcomes are highly variable and unpredictable between patients with a severe TBI, sleep may be an important mediator for recovery after a TBI, particularly for patients whose TBI requires hospitalization. Patients in the subacute and chronic phases of moderate and severe TBI experience a wide range of sleep disturbances and sleep disorders, including hypersomnias, parasomnias, insomnia, narcolepsy, and somnolence.[5,6] The current investigation draws its conceptual framework from principles outlined in the human ecology model.[7] The concepts of "environment," "human," and "interaction" correspond with the neuroscience step-down unit, the patient with TBI, and the association between TBI and nighttime rest-wake activity on functional outcome, respectively. The

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biological rationale for exploring the sleep behavior of patients hospitalized with TBI is this: empirical evidence associates sufficient sleep with 3 key markers in neural recovery, namely, (1) synaptic plasticity, (2) neurological functioning, and (3) increased memory consolidation.[8,9] Sleep may also be important for emotional regulation[10] and somatic function (ie, metabolic function)[11] post-TBI.

So what? We know some studies have shown that sleep disturbances (poor sleep consolidation and architecture) are common in hospitalized patients with TBI,[12–15] but they have either all occurred in the intensive care unit (ICU), have used only subjective measures of sleep, or have included patients with only mild TBI. Therein lies a missed opportunity for exploring nighttime sleep for patients with TBI hospitalized on the neuroscience step-down unit. Why the neuroscience step-down unit? First, it is a decisive phase of care often occurring after the ICU and before clinicians discharge the patient from inpatient care. Finally, clinicians and researchers do not have a full understanding of the association between nighttime sleep with post-TBI recovery on a neuroscience step-down unit. It may seem like sleep should not be a concern in the acute phase of hospitalization for patients with TBI, but it is important because consciousness and sleep-wake consolidation, an index of sleep quality, improve in parallel during the immediate postinjury period of hospitalization.[16] This suggests that sleep may aid in the recovery process, which is why neuroscience hospital staff and clinicians as well as patients and family dealing with acute TBI should care. The inability of hospitalized patients with moderate and severe TBI to consolidate their sleep associates with poor outcomes,[17] whereas positive sleep traits associate with less disability.[18]

Previous studies have missed the opportunity to capitalize on the transformative potential of the neuroscience step-down unit's care of patients with moderate and severe TBI particularly because it is (*a*) a place where interdisciplinary teams test patients for post-hospital disposition (ie, rehabilitation, skilled nursing facility) and (*b*) most often the last phase of inpatient care and subsequently one of the final chances to centralize acute care resources for the patient's benefit.[19] Previous studies have not focused on the nighttime period of hospitalization of patients with TBI and its relationship to sleep, although there is evidence that unique care activities are under way.[20,21]

The purpose of this cross-sectional, descriptive pilot study is to generate hypotheses for subsequent studies by exploring the following aims: (1) describe nighttime rest-activity variables—wake bouts (counts), total wake time (minutes), and sleep efficiency (percentage; time asleep/time in bed)—in people hospitalized on a neuroscience step-down unit after a moderate or severe TBI and (2) describe the association between this same sample's injury and nighttime rest-activity on functional outcome (outcome/dependent variable) (measured at discharge from inpatient care).

The results suggest that GCS is still the most statistically significant predict of functional outcome.

Methods

Participants, Procedures, and Setting

Our pilot study is exploratory and cross-sectional in design. We recruited participants from June 2016 through January 2017 using consecutive convenience sampling. The study participants were patients with moderate or severe TBIs recruited from the neuroscience step-down unit of a level 1 trauma center hospital. This 36-bed unit treats adults with acute and chronic neurological/neurosurgical conditions of the brain and spinal cord. Each patient was in a private hospital room. Unlike the ICU, the patients on the neuroscience step-down unit were not hardwired to get vital signs, but some patients had telemetry monitoring and standard fluid therapy (ie, intravenous normal saline or enteral nutrition, when appropriate). Patients had neurological and vital sign checks every 4 hours, unless otherwise specified. During the months of recruitment, the unit had a high census (83% of beds occupied by patients).

Screening

We admitted eligible participants to the hospital with blunt TBI confirmed by computerized tomography of the head, who had a Glasgow Coma Scale (GCS) score between 3 and 11 (severe to moderate brain injury)[22] on admission to the emergency department, who were 18 years or older, who were less than 24 hours on the neuroscience unit at the time of enrollment, and who had a Rancho Los Amigos (RLA) cognitive functioning score of 5 or greater (to include participants who could meaningfully contribute to the assessment of rest/activity with wrist actigraphy). We excluded participants if they had a diagnosed preexisting sleep disorder based on a review of the electronic medical record, if they had a planned length of stay of less than 24 hours (which would have prevented nighttime actigraphy data collection), if they

left inpatient care before study procedures were complete, or if they or a legally authorized representative (LAR) could not consent on their behalf. All study procedures occurred after approval from the university's institutional review board, and the participant or the participant's LAR gave written, informed consent.

Measures

Rest-Activity Cycles

Actiwatch Spectrum Plus (Phillips Respironics) actigraphs were used to assess wake bouts, total wake time, and sleep efficiency (percentage of time in bed spent asleep). We used these measures of rest/activity to characterize sleep continuity and nighttime awakenings because of their relevance to understanding functional outcomes in human and animal models of TBI.[5,16,23,24] Actigraphy is a reliable and valid way to capture sleep, wake, and light exposure in the acute rehabilitation phase of TBI and during hospitalization of patients with TBI across the continuum of severity.[25] We set the Actiwatch to sample data in 30-second epochs and continuously collected data from 8 PM to 7 AM. The participants wore the Actiwatch on the nondominant wrist or the uncluttered wrist (intravenous lines, slings, or casts).

We did not collect sleep diaries or use subjective questionnaires because we expected our sample to have cognitive impairments; these impairments reduce the completeness and reliability of diaries.[26] Second, it was not feasible to require staff to complete diaries. We determined the start and end of the nighttime period using the University of Washington's Center for Innovation in Sleep Self-Management scoring algorithm.[27] The scoring algorithm provided a hierarchy for using actigraphy-measured activity and light levels to determine bedtimes and rise times. We scored each epoch within each nighttime period as "sleep" or "wake" using the automated algorithm in Actiware 6. Outcome measures included wake bouts, total wake time, and sleep efficiency for each night. We only used nighttime data in the analysis. We did not examine daytime naps because our scientific goal was to focus on rest-activity cycles exclusive to the nighttime period.

Injury Variables

Rancho Los Amigos scale

The first author used the RLA scale to screen the participants for study eligibility. The RLA score yields a reliable assessment of the awareness, cognition, and behavior[28–30] needed for purposeful interaction in patients with TBI. The RLA scale score ranges from 1 to 8; a score of 1 means the participant has no response to external stimuli, whereas a score of 8 means the participant responds purposefully and appropriately. Studies show that the RLA has good reliability and validity in the brain-injured population.[31] An RLA score of greater than or equal to 5 was the cutoff for eligibility. A score of 5 or greater would mean that the participant has purposeful enough wrist movement for a reliable actigraphy assessment. We used the RLA to screen patients, and we did not include RLA in our analyses because of its bias toward patients with purposeful movements and minimal variability.

Glasgow Coma Scale

The GCS score, ranging from 3 (worst) to 15 (better), indicates the level of consciousness. We extracted GCS from the medical record during screening for study eligibility.[22] We used the worst GCS score the participant received from the clinical care team while in the emergency department. GCS reliability is high ($\alpha = .85$)[32] when used in patients with TBI.

Injury Severity Score

The Injury Severity Score (ISS), extracted from the trauma registry, reflects the overall intensity of a participant's injuries[33] and ranges from 1 (least severe) to 75 (most severe). The ISS has a high interrater reliability (intraclass correlation coefficient > 0.80) and a high intrarater reliability ($\kappa > 0.80$).[34]

Functional Outcome

Functional Independence Measure

The Functional Independence Measure (FIM), assigned to the participant by the first author, blinded to actigraphy data, is an 18-item scale (13 motor tasks and 5 cognitive tasks) used to assess the participant's level of disability at hospital discharge. We collected the FIM in the hours leading up to the patient's departure from the neuroscience step-down unit. The FIM is sensitive to patient progress and includes tasks affected by sleep including memory, comprehension, and problem solving.[35] FIM developers rate each item on a scale of 1 to 7 (total range, 18–126), with lower scores showing more dependence and subsequently greater disability. Studies demonstrated construct and predictive validity (predictive of long-term disability severity) of the FIM in patients with TBI; interrater reliability of the FIM is greater than 0.90, with a test-retest reliability of greater than 0.90.[35]

Demographic and Clinical Data

We extracted demographic and clinical data from 3 main sources: the electronic medical record, the hospital's trauma registry, and interview/observations of the patient, the LAR, or the bedside staff nurse assigned to the patient by the first author. We

then entered data into data management software (REDcap).

Data Management and Analysis

We computed the nighttime rest-activity variables for each participant's individual nighttime periods with Actiware 6 software and exported it to [R]Studio software ([R] version 3.3.1) and SAS for data analysis. For our modest sample size of N = 17, we used nonparametric analyses to underscore the relationship between the variables measuring nighttime sleep, injury, and functional outcome. We calculated the averages of the median values of nighttime rest-activity variables for our analyses. We conducted a Spearman ρ rank correlation test to identify variables that were statistically significant. We followed our Spearman ρ correlation with an exact significance test, a complementary nonparametric test, to ensure we extracted the exact *P* values for the correlation coefficients for our nighttime sleep, injury, and functional outcome variables. Next, to select the variables most associated with functional outcome in this sample of hospitalized patients with TBI, we conducted a backward stepwise linear regression (outcome/dependent variable: functional outcome). First, we put all the independent variables in the model (nighttime rest-activity variables and injury variables). Second, we deleted the variable with a *P* value that was greater than .10. Third, we reran the model without the recently deleted variable and repeated this step until we reached the independent variable(s) that met our cutoff ($P \leq .05$). We also conducted descriptive statistics on clinical and demographic data and report these data hereinafter. *P* values of .05 or less indicate statistical significance.

Results

Clinical and Demographic Data

Thirteen of the 17 participants needed an LAR to provide informed consent. The sample was predominantly male, and average age was 63.4 years (SD, 17.9), with severe GCS scores on admission (mean [SD], 8.8 [4.9]). The most common type of injury was fall. The average FIM at discharge was 48 (SD, 14.5) indicating severe disability.[36] See Table 1 for the complete sample description.

The average within-participant number of nights of observation was 2.6 (SD, 1.3; range, 1-5), and the average length of Actiwatch measurement was 8.3 hours (SD, 2.78) or 8 hours 18 minutes. Frequent wake bouts, high total wake time, and poor sleep efficiency[37,38] (Table 1) characterized participants' sleep. On average, participants woke up 41 times (SD, 18 times), were awake for 1 hour 14 minutes (SD, 47 minutes), and had sleep efficiency of 73% (SD, 16%). Specifically, in a night, a participant woke up 41 times during the designated period as evidenced by the sleep measure "wake bouts." Conversely, the average time a participant was awake was more than an hour during the designated sleep period, evidenced by the sleep measure "total wake time," in a night. Finally, the percentage of sleep quality, evidenced by the sleep measure "sleep efficiency," was 73%.

TABLE 1. Demographic and Summary Statistics of Study Sample

Measure	Mean ± SD or n (%)
Demographics	
Patient age, mean ± SD, y	63.4 ± 17.9
Sex: male, n (%)	14 (82.4)
Race: white, n (%)	16 (94.1)
Mechanism of injury, n (%)	
Assault	1 (5.8)
Motor vehicle accident	1 (5.8)
Pedestrian hit by a vehicle	2 (11.8)
Sporting activity	3 (17.6)
Falling	10 (59.0)
Neuroimaging result, n (%)	
Epidural hemorrhage	1(5.8)
Intraparenchymal hemorrhage	1(5.8)
Subarachnoid hemorrhage	3 (17.6)
Diffuse/complex	2 (11.8)
Subdural hemorrhage	10 (59.0)
Injury variables, mean ± SD	
GCS	8.8 ± 4.9
ISS	23.6 ± 6.7
Functional outcome, mean ± SD	
Functional Independence Measure	48 ± 14.5
Nights of observation, mean ± SD	
Nights	2.6 ± 1.3
Discharge destination, n (%)	
Rehabilitation care	3 (17.7)
Skilled nursing facility	6 (35.2)
Home	8 (47.1)
Obtaining written informed consent, n (%)	
Legally authorized representative	13 (76.5)
Participant	4 (23.5)
Nighttime rest/activity variables, mean ± SD	
Wake bouts (across nights), counts	41 ± 18
Total wake time (across nights), min	74 ± 47
Sleep efficiency (across nights), %	73 ± 16
Length of Actiwatch measurement (across nights), h	8.3 ± 2.7

Supplemental Digital Content 1 (Figure 1, available at http://links.lww.com/JNN/A164) and Supplemental Digital Content 2 (Figure 1 Legend, available at http://links.lww.com/JNN/A165) show raw actigraphy data with the best sleep efficiency (participant 1A; 93%) and the participant with the worst sleep efficiency (1B; 38%). Participant 1A has a rhythmic nighttime decrease and a daytime increase in movement and light, showing an organized rest-and-wake activity pattern. Conversely, light and movement data in participant 1B show poor day-night consolidation has frequent wake bouts at night and highly variable sleep timing.

Associations of Sleep, Injury, and Functional Outcome

Table 2 shows a Spearman ρ correlation matrix of coefficient for sleep, injury, and functional outcome variables. The correlation matrix shows that there is a statistically significant relationship between functional outcome, as measured by the FIM, and the injury variable, GCS (exact test $P = .005$). Of the 3 sleep domains, there is a statistically significant relationship also between GCS and sleep efficiency (exact test $P = .01$). The other injury variable, ISS, has a negative, statistically significant relationship with GCS (exact test $P = .02$) and age (exact test $P = .001$). There is a statistically significant relationship between wake bouts and sleep efficiency (exact test $P = .001$).

Regression Analysis Output: Injury Is Associated With Functional Outcome

The regression model included only the injury and sleep variables, based on statistically significant correlations found between these 2 categories of variables (Table 2). With our modest sample size, we chose the most scientifically relevant variables to include in the regression model. Our multiple linear regression analysis (backward stepwise model) showed that GCS was the only statically significant variable related to functional outcome ($P = .05$). This same model also included ISS ($P = .37$), wake bouts ($P = .13$), total wake time ($P = .23$), and sleep efficiency ($P = .40$), none of which was significantly associated with functional outcome.

In a model that included only the injury variables, the results showed that GCS was still the only statistically significant variable of functional outcome ($P = .02$), compared to ISS ($P = .61$). Finally, in a model with injury variables and sleep efficiency as the dependent variable, GCS was a statistically significant variable of sleep efficiency ($P = .04$) compared to ISS ($P = .25$).

Discussion

Patients hospitalized with moderate and severe TBI have frequent nighttime awakenings and poor rest-activity cycles,[37,38] even as they prepare for discharge on the neuroscience step-down unit. Although only a "snapshot" of sleep quality during the nighttime hours, the low sleep efficiency observed raises the possibility that patients hospitalized with TBI may experience the consequences of nighttime wakefulness. We also found that GCS close to the time of admission is the strongest correlate of functional outcome after initial TBI. Although nighttime sleep efficiency associates with functional outcome in the simple correlations, regression analyses suggest that this effect was less robust than initial injury severity.

Nighttime Rest/Activity for Patients Hospitalized With TBI

The sleep characteristics in the present sample are consistent with those of other samples after TBI in

TABLE 2. Spearman ρ Correlation Matrix Coefficients of Sleep, Injury, and Functional Outcome Variables

	FIM	GCS	ISS	Age	Sex	WB	TWT	Sleep Eff	Night
FIM									
GCS	0.66[a]								
ISS	−0.33	−0.58[b]							
Age	−0.11	0.24	−0.72[a]						
Sex	0.19	−0.02	−0.29	0.20					
WB	0.03	−0.14	−0.11	0.02	0.02				
TWT	0.10	−0.05	−0.05	−0.12	−0.06	0.84[a]			
Sleep Eff	−0.25	−0.58[a]	0.22	−0.05	0.28	0.30	0.02		
Night	−0.12	0.034	0.23	−0.02	0.34	0.37	0.30	0.66	

Abbreviations: FIM, Functional Independence Measure; GCS, Glasgow Coma Scale; ISS, Injury Severity Scale; Sleep Eff, sleep efficiency; TWT, total wake time; WB, wake bouts.
[a]$P \leq .01$. [b]$P \leq .05$.

posthospital phases.[5,15,39,40] Specifically, the average sleep efficiency of the participants in this sample was 73%, lower than the 80% to 90% sleep efficiency recognized as normal in adults without TBI.[37,38] Despite evidence that poor sleep is a common symptom of TBI[5] and that poor sleep can undermine rehabilitative efforts,[3,39] none of the nighttime rest/activity measures associates with functional outcome in a comprehensive model. Any potential effects of sleep on functional outcomes may have been limited by the relatively small sample size and limited variability in the sample.

Previous studies found statistical significance between outcomes, particularly cognitive functioning and rest-activity cycles in patients with TBI.[12] However, there were associations during the patient's daytime sleep period; a majority of their participants had mild TBI (67%), and those who needed ICU care postinjury were excluded.[12] Similarly, findings from an actigraphic study by Duclos et al[16] showed an association between cognitive functioning and a linear decrease in nighttime fragmentation in ICU patients with TBI in a 24-hour rest-activity cycle; in these studies, injury severity was not an independent variable.

Glasgow Coma Scale Score: Functional Outcome

Glasgow Coma Scale is associated with an array of outcome measures, including functional outcome, in TBI.[41] It is also a strong predictor of in-hospital mortality and poor neurological outcome.[32,42] We assessed functional outcome at discharge from the inpatient neuroscience step-down unit, whereas the aforementioned studies assessed functional outcome between 14 days and 6 months postinjury. Although the association between injury severity and outcome in patients with moderate and severe TBI is well known, what we can conclude about initial injury severity and functional outcome in this sample is this: GCS could be a signal for subsequent functional outcome but cannot supplant other important clinical factors.

Strengths and Limitations

The lack of association of sleep characteristics and outcome in this study may result from a combination of the outcomes chosen and the time we assessed them (at discharge).[3] More sensitive methods, such as continuous EEG monitoring or polysomnography, may have identified stronger associations of sleep with injury and functional outcome. Previous studies have shown relationships between specific sleep EEG features, such as K-complexes, sleep spindles, and vertex waves, and functional outcomes, specifically the modified Rankin Scale,[18] which may be an even keener assessment of disability than FIM. As relates to actigraphy, patients with more severe injuries may not show the same actigraphic features that were the basis for algorithm development in healthy participants. In this way, the range and sensitivity of the outcomes may have been a limitation.

Variability between and within participants on actigraphy is limited by the hospital setting. Our modest sample size limits the generalizability of our study, and we chose only the most scientifically relevant variables to include in our regression model and could not afford, statistically, to enter covariates; however, we attempted to mitigate this by using within-person analysis. Incorporating daytime sleep in future analyses, despite the methodological challenge of noting exact wake and sleep times, may also be important. Future studies should have postdischarge assessment and outcome measures such as neuropsychological tests and tests that assess memory and information consolidation because these are more likely to be impacted by poor sleep. Exploring sleep changes and FIM scores during rehabilitation and nonrehabilitation settings beyond acute care may also be useful. However, we have shown that it is feasible to access this niche and understudied population. Also by explaining 3 different domains of sleep, we have been able to show the pattern of nighttime awakenings (wake bouts, total wake time) and its relation to sleep quality (sleep efficiency).

Nursing Implications

For clinicians, the results suggest that patients with moderate and severe TBI have disturbed nighttime sleep even while hospitalized on a neuroscience step-down unit. Clinicians can explore taking precautions to reduce nighttime interruptions, specifically, where appropriate for the safety and well-being of the patient, bundle and administer extensive care treatments toward the beginning or end of the night shift. Informing ancillary staff of these intentions is very important so they can consider following suit. For day shift, keeping the patient engaged and active may be helpful for promoting more restful nighttime sleep.

Summary

Our study adds to the growing body of literature about sleep disturbances among people with TBI by focusing on patients with moderate and severe injury hospitalized on the neuroscience unit. Clinicians should know that patients with TBI are prone to disturbed nighttime sleep during their hospitalization. Our study and others like it aim to generate empirical data to develop clinically accessible guidelines for identifying sleep disturbances in this population. These data may better inform the anecdotal or "checklist" list

type of tools that are more relevant to direct care staff and the hard work they put in.

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