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# Assessment of Sleep Stages in Unconscious Patients with Acute Severe Traumatic Brain Injury

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## Abstract

**Background** The existence of a sleep cycle in deeply unconscious patients with severe traumatic brain injury (TBI) remains unknown. Evaluating the sleep patterns of these patients may provide insights into their consciousness and help predict functional recovery.

**Aims and Objectives** This prospective observational study aimed to assess the usefulness of monitoring the sleep cycle in the prognostication of unconscious TBI patients.

**Materials and Methods** A purposive sampling technique was employed to include 39 patients with severe TBI (Glasgow Coma Scale [GCS] $\leq 8$). The average GCS score at admission was ($5.76 \pm 1.65$). Sleep was monitored using an actigraphy smartwatch for 4 consecutive days, ($3.15 \pm 2.49$) days postbrain injury. Sleep cycle monitoring tool and unconscious patient outcome monitoring tool were employed. An outcome assessment was done based on the GCS score.

**Results** Severe TBI patients exhibit intact sleep cycle (i.e., deep sleep, light sleep, and rapid eye movement sleep) despite being deeply unconscious, even in the acute stage. Total sleep duration was found to be significantly higher at a mean of 19.97 hours as compared to the mean of 8 hours as per the smartwatch reference value for normal individuals. Patients with improved sleep cycles had a higher likelihood of GCS improvement ($p < 0.05$).

**Conclusion** This study is the first of its kind to demonstrate that the sleep cycle is a reliable prognostic factor for the recovery of consciousness in the acute phase of severe TBI among unconscious patients, with improvement in the sleep cycle mirroring neurological improvement.

**Keywords**
- traumatic brain injury
- sleep cycle monitoring
- unconscious patients
- actigraphy smartwatch
- sleep stages

## Introduction

Traumatic brain injury (TBI) is a major concern due to its association with short-term and long-term disabilities. According to the World Health Organization, approximately 69 million cases of TBI occur annually, affecting individuals of all ages, particularly those less than 45 years old.[1,2] India has the highest rates of head injuries globally, although the exact volume of TBI cases is unknown. It is estimated that annually more than 150,000 lives succumb to death, of whom approximately 60% suffer from head injuries caused by road traffic injuries (RTI).[3,4] TBI can manifest in various forms,

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ranging from mild alterations in consciousness to unconsciousness and even death.[5] The severity of TBI is typically classified as mild, moderate, or severe using the Glasgow Coma Scale (GCS), with a score of 3 to 8 indicating severe TBI.[6] The estimated mortality rate among severe TBI patients ranges from 20 to 50%.[7] These patients exhibit a wide range of physical, cognitive, emotional, and sleep-related impairments.[8] It is well explained by certain TBI models that the injured brain itself has an immediate impact on the sleep-wake pattern by increasing sleep-wake period fragmentation.[9] Sleep disturbances are particularly prevalent in individuals with severe head injuries.[10]

The brain employs a waste clearance system called the glymphatic system, which eliminates waste products and distributes essential compounds within the central nervous system, primarily during sleep. Dysfunction of the glymphatic system may contribute to TBI-related pathology.[11] Sleep-dependent processes, such as synaptic plasticity and overall neuronal recovery, play crucial roles in the recovery following TBI, facilitating the elimination of excess and abnormal proteins from synapses. However, TBI disrupts these processes due to metabolic changes, resulting in a greater need for sleep-related recovery and synaptic plasticity.[9,12]

Sleep patterns in severely brain-injured patients differ significantly from those of healthy individuals, making it challenging to define sleep in this population. Limited data are available on sleep cycles during acute coma. The relationship between sleep and consciousness in brain-injured patients is poorly understood, with spindle coma being the primary focus of the study. The reappearance of sleep-like patterns resembling non-rapid eye movement (NREM) sleep, as well as alternating rapid eye movement (REM) sleep, is considered a positive prognostic sign, whereas the absence of such patterns predicts a poorer outcome. Sleep-like patterns, rather than GCS scores, have been shown to indicate a better prognosis.[13,14] As individuals with acute TBI progress toward recovery, their sleep cycles tend to align with those of healthy individuals, facilitating the restoration of consciousness.[9]

Most studies have primarily focused on individuals with mild-to-moderate TBI during the subacute and chronic phases of recovery, or after they have already reported sleep issues post-TBI. Only a few studies have examined sleep patterns early after injury, and the presence of typical sleep features may provide insight into the speed of recovery from severe TBI. It remains unclear whether unconscious individuals with severe TBI experience sleep cycles.

Monitoring sleep using actigraphy smartwatch in acutely injured unconscious TBI patients can provide valuable insights into their sleep cycles and determine whether sleep patterns impact their recovery status and prognosis. This information can assist in assessing prognosis and support initiatives aimed at maximizing functional recovery.

Objective of this study is (1) to assess the sleep cycle of unconscious TBI patients monitored by smartwatch, (2) to compare if the patient is in sleep cycle stage or unconscious (deep coma) with the help of normal sleep parameters, and (3) to find out the association of sleep cycle with patient's outcome as measured by GCS score.

## Materials and Methods

Acutely injured severe TBI patients were recruited from neurosurgery intensive care unit (ICU), JPNATC, AIIMS, New Delhi, India. Ethical approval (Ref. No.: IECPG-261/27.04.2022) was obtained from the Institute Ethics Committee. Written informed consent was obtained from the legally acceptable representatives (LAR) of each patient. Thirty-nine patients were enrolled using a purposive sampling technique between September 15 to November 30, 2022. The study included patients between the ages of 19 and 70 who had a TBI and presented with a GCS score of 8 or lower upon emergency admission. Additionally, these patients were subsequently admitted to the ICU. Exclusion criteria were quadriplegia, preinjury sleep disorder, previous history of TBI, or concussion, etc., history of myocardial infarction, and lack of consent from LAR. Sociodemographic and clinical information, including causes of head injury, GCS at admission, days since the injury when watch placed, comorbidity, previous history of alcohol use (frequency and duration), type of treatment, use and type of sedatives, antiepileptics, beta-blockers, and muscle relaxants were obtained from the LAR and inpatient medical record. An actigraphy watch was placed on the wrist of the patients in the neurosurgery ICU for 4 consecutive days. Sleep cycle observation (light sleep, REM sleep, deep sleep, and awake stages) and GCS score monitoring were conducted throughout the process using a sleep cycle monitoring tool and an unconscious patient outcome monitoring schedule. The outcome assessment was based on the GCS score. (**Annexure: Tool 1** and **2**, available in the online version).

### Actigraphy (Huawei Smartwatch)

A device worn on the nondominant wrist or ankle assesses sleep patterns through movement detection using accelerometers, or heart rate detection. Sleep data can be derived from wrist movement to predict sleep and wakefulness duration, or make assumptions about sleep stages[15,16] (►**Fig. 1**). While polysomnography is the gold standard, actigraphy provides a viable alternative, particularly for critically ill patients who tolerate it well. Therefore, actigraphy is the preferred tool for studying sleep-wake patterns during the early recovery stage.[17]

The normal reference values for sleep given by the smartwatch are as follows:

Total sleep: 6–10 hours.
Deep sleep: 20–60% of total sleep.
Light sleep: > 55% of total sleep.
REM sleep: 20–22% of total sleep.

### Statistical Analysis

Data were analyzed using SPSS V.26 and STATA software. Repeated measures analysis of variance and independent sample t-tests were conducted. A $p$-value of less than 0.05 was considered statistically significant.

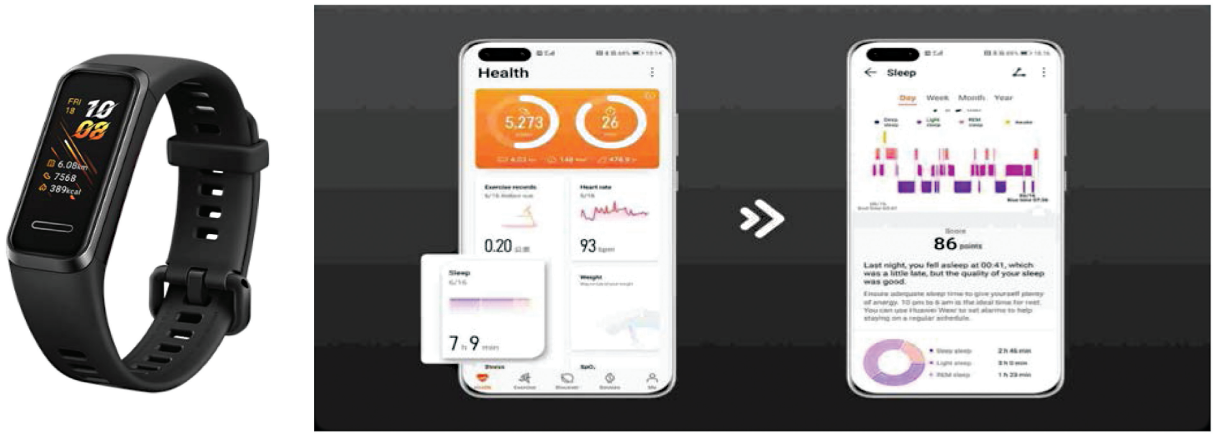


Fig. 1 Huawei smartwatch and home page of Huawei health app.

## Results

A total of 47 patients were initially enrolled but 6 patients expired and 2 patients' LAR declined to participate within 4 days (►Fig. 2). Therefore, the analysis was conducted on 39 patients. The mean age of the patients was 37.79 ± 13.96, with the majority falling in the age range of 19 to 35 years. The majority of the patients were male (97.44%). The leading cause of head injury was RTI (66.67%) followed by falls (20.51%) and other causes (12.82%). The GCS score on admission was 5.76 ± 1.65 and no. of days since the injury when the watch applied was 3.15 ± 2.49. The majority of patients (87.18%) did not have any comorbidities. Approximately half of the patients (48.72%) had a history of alcohol consumption, with the majority being occasional drinkers (68.42%). Among them, 52.63% had been drinking for 6 to 10 years. Most of the patients had undergone surgery (56.41%). The majority of patients were receiving sedatives (82.05%), with inj. fentanyl is the most common (74.36%). Similarly, the majority were receiving antiepileptics (82.05%), with inj. phenytoin is the most common (71.79%). Only 5.13% of the participants were receiving beta-blockers and muscle relaxants. The mean and standard deviation of the length of ICU and hospital stay were 9.94 ± 4.88 and 27.23 ± 18.73, respectively. The association between the clinical variable and sleep cycle of TBI patients did not yield any significant findings.

►Fig. 3 demonstrates that the total sleep and deep sleep of severely injured acute TBI patients decrease over 4 days, but this difference is not statistically significant ($p > 0.05$). This indicates that severely injured acute TBI patients maintain an intact sleep cycle with all sleep stages. Conversely, the awake period gradually increases over

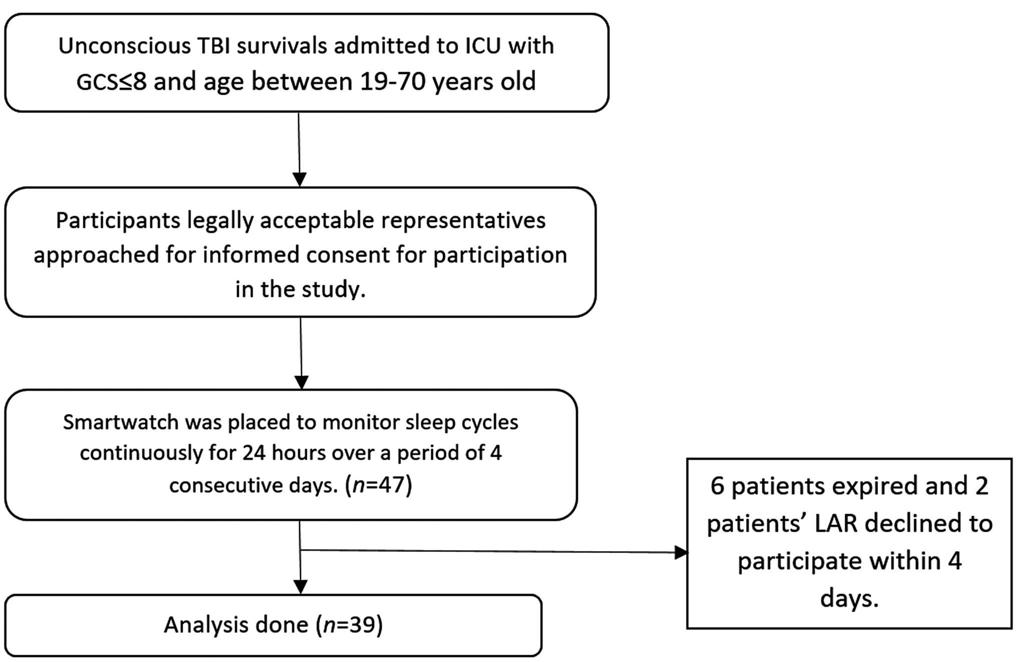


Fig. 2 Illustration of sample size.

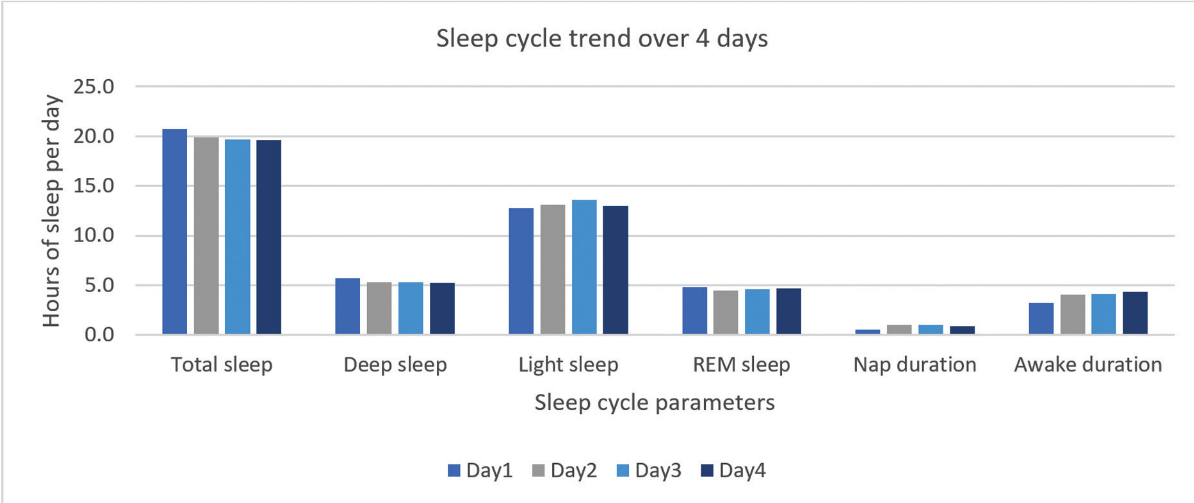


**Fig. 3** Bar chart showing sleep cycle trend of unconscious traumatic brain injury patients over 4 days.

4 days; however, this change is not statistically significant ($p$-value: 0.52). It suggests that all patients experience variable periods of wakefulness on actigraphy, which may be an artifact or could be attributed to the hand movement of the patients while receiving routine care from healthcare professionals, such as X-rays, computed tomography scans, and positioning. Considering that this watch operates based on body movement. Nevertheless, the significance of this observation remains unknown.

►**Fig. 4** indicates that unconscious severely injured TBI patients do not follow the normal sleep pattern, as they sleep more than twice the normal reference values determined by the smartwatch in a 24-hour day. This suggests that although severely injured TBI patients have an intact sleep cycle, they are deeply unconscious.

►**Table 1** When comparing the sleep cycles of severe TBI patients who had improved GCS with those who experienced deterioration in GCS by day 4. Patients with improved GCS scores had shorter total sleep, deep sleep, and light sleep ($p < 0.05$) compared to patients with impaired GCS scores. This indicates that patients with improved sleep cycles have a higher probability of GCS improvement.

►**Table 2** suggests that heart rate does not significantly affect the sleep cycle of TBI patients or its impact may be masked by other medicines as some patients were receiving inj. propranolol 40 mg and inj. noradrenaline 8mg.

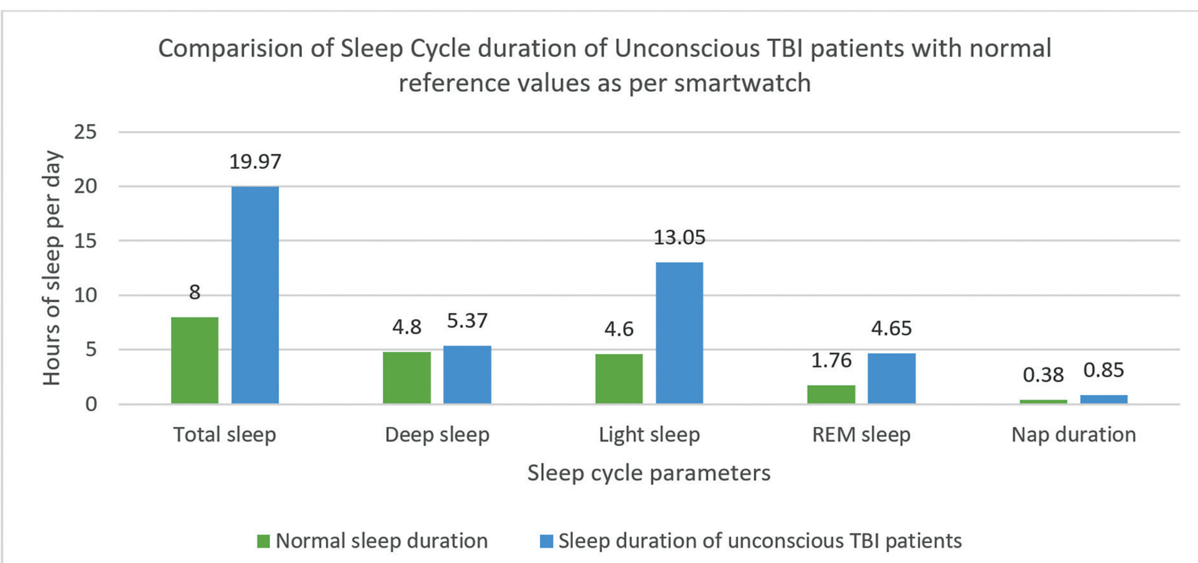


**Fig. 4** Bar chart showing the comparison of mean of sleep cycle of unconscious traumatic brain injury patients with normal sleep duration of the smartwatch.

**Table 1** Association of sleep cycle of unconscious TBI patients with their motor score of GCS

| Variable | Days | Category (no. of patients) | Mean ± SD | | | |
|---|---|---|---|---|---|---|
| | | | Total sleep | Deep sleep | Light sleep | REM sleep |
| GCS (Motor score) | Day 1 | Poor (12) | 22.29 ± 1.79 | 5.29 ± 2.28 | 13.15 ± 2.49 | 3.80 ± 2.15 |
| | | Good (27) | 20.03 ± 3.51 | 4.83 ± 1.71 | 10.27 ± 2.52 | 4.41 ± 1.68 |
| | | *p*-Value | 0.02[a] | 0.49 | 0.002[a] | 0.34 |
| | Day 2 | Poor (11) | 22.19 ± 2.93 | 5.10 ± 2.03 | 12.86 ± 2.90 | 4.02 ± 1.42 |
| | | Good (28) | 19.03 ± 5.82 | 4.51 ± 2.63 | 10.22 ± 3.69 | 3.77 ± 1.98 |
| | | *p*-Value | 0.02[a] | 0.50 | 0.04[a] | 0.71 |
| | Day 3 | Poor (12) | 21.20 ± 5.13 | 4.75 ± 2.07 | 12.25 ± 3.59 | 3.73 ± 1.73 |
| | | Good (27) | 19.10 ± 4.96 | 4.34 ± 1.92 | 10.33 ± 3.19 | 3.79 ± 1.75 |
| | | *p*-Value | 0.50 | 0.55 | 0.10 | 0.92 |
| | Day 4 | Poor (15) | 21.06 ± 4.92 | 4.48 ± 2.11 | 12.30 ± 3.34 | 4.03 ± 1.61 |
| | | Good (24) | 18.77 ± 5.17 | 4.26 ± 2.03 | 9.88 ± 3.48 | 3.90 ± 1.89 |
| | | *p*-Value | 0.32 | 0.74 | 0.03[a] | 0.82 |

Abbreviations: GCS, Glasgow Coma Scale; REM, rapid eye movement; SD, standard deviation; TBI, traumatic brain injury.
Independent sample *t*-test; [a]significant at $p < 0.05$, poor (GCS 1, 2, and 3), good (GCS 4, 5, and 6).

**Table 2** Association of sleep cycle of unconscious TBI patients with heart rate

| Variable | Days | Category (no. of patients) | Mean ± SD | | | |
|---|---|---|---|---|---|---|
| | | | Total sleep | Deep sleep | Light sleep | REM sleep |
| Heart rate | Day 1 | Normal (11) | 21.67 ± 2.69 | 5.32 ± 1.89 | 11.60 ± 3.03 | 4.59 ± 2.21 |
| | | Abnormal (28) | 20.36 ± 3.39 | 4.84 ± 1.90 | 10.99 ± 2.78 | 4.07 ± 1.68 |
| | | *p*-Value | 0.26 | 0.48 | 0.61 | 0.51 |
| | Day 2 | Normal (9) | 17.97 ± 6.38 | 4.44 ± 2.49 | 10.04 ± 3.69 | 3.14 ± 1.50 |
| | | Abnormal (30) | 20.51 ± 4.94 | 4.75 ± 2.49 | 11.24 ± 3.65 | 4.05 ± 1.88 |
| | | *p*-Value | 0.21 | 0.74 | 0.39 | 0.19 |
| | Day 3 | Normal (13) | 21.31 ± 3.32 | 4.83 ± 1.43 | 12.33 ± 2.84 | 4.06 ± 1.36 |
| | | Abnormal (26) | 18.97 ± 5.61 | 4.29 ± 2.17 | 10.21 ± 3.47 | 3.62 ± 1.89 |
| | | *p*-Value | 0.17 | 0.42 | 0.06 | 0.46 |
| | Day 4 | Normal (13) | 19.71 ± 6.01 | 4.77 ± 2.07 | 10.55 ± 4.32 | 3.91 ± 1.59 |
| | | Abnormal (26) | 19.62 ± 4.77 | 4.13 ± 2.03 | 10.94 ± 3.25 | 3.97 ± 1.87 |
| | | *p*-Value | 0.96 | 0.36 | 0.75 | 0.92 |

Abbreviations: REM, rapid eye movement; SD, standard deviation; TBI, traumatic brain injury.
Independent sample *t*-test;

**Table 3** Association of sleep cycle of unconscious TBI patients with body temperature

| Variable | Days | Category (no. of patients) | Mean ± SD | | | |
|---|---|---|---|---|---|---|
| | | | Total sleep | Deep sleep | Light sleep | REM sleep |
| Body temperature | Day 1 | Normal (31) | 20.12 ± 3.34 | 4.90 ± 1.84 | 10.52 ± 2.60 | 4.25 ± 1.96 |
| | | Abnormal (8) | 23.09 ± 0.87 | 5.27 ± 2.16 | 13.65 ± 2.32 | 4.11 ± 1.33 |
| | | *p*-Value | 0.01[a] | 0.63 | 0.004[a] | 0.85 |
| | Day 2 | Normal (27) | 19.86 ± 5.60 | 4.50 ± 2.40 | 10.90 ± 3.87 | 3.87 ± 1.94 |
| | | Abnormal (12) | 20.07 ± 4.89 | 5.07 ± 2.67 | 11.10 ± 3.26 | 3.78 ± 1.63 |
| | | *p*-Value | 0.91 | 0.51 | 0.87 | 0.88 |
| | Day 3 | Normal (24) | 19.87 ± 4.03 | 4.74 ± 2.03 | 10.27 ± 3.21 | 3.78 ± 1.94 |
| | | Abnormal (15) | 19.55 ± 6.50 | 4.02 ± 1.81 | 11.96 ± 3.51 | 3.75 ± 1.94 |
| | | *p*-Value | 0.85 | 0.27 | 0.13 | 0.94 |
| | Day 4 | Normal (27) | 19.20 ± 5.43 | 4.14 ± 1.93 | 10.93 ± 3.86 | 3.65 ± 1.75 |
| | | Abnormal (12) | 20.67 ± 4.45 | 4.79 ± 2.29 | 10.55 ± 3.03 | 4.64 ± 1.66 |
| | | *p*-Value | 0.41 | 0.36 | 0.76 | 0.10 |

Abbreviations: REM, rapid eye movement; SD, standard deviation; TBI, traumatic brain injury.
Independent sample *t*-test; [a]significant at $p < 0.05$.

**Table 4** Association of unconscious TBI patients' sleep cycle with their progress

| Sleep parameters | Progress (no. of patients) | Mean ± SD | | | | *p*-Value |
|---|---|---|---|---|---|---|
| | | Day 1 | Day 2 | Day 3 | Day 4 | |
| Total sleep | Improved (32) | 20.43 ± 3.33 | 19.76 ± 5.41 | 19.86 ± 4.75 | 19.06 ± 5.35 | 0.46 |
| | Expired (7) | 21.59 ± 2.82 | 20.12 ± 5.58 | 18.73 ± 6.66 | 21.66 ± 3.90 | 0.78 |
| Deep sleep | Improved (32) | 5.75 ± 1.73 | 5.28 ± 2.15 | 5.33 ± 1.55 | 5.49 ± 1.72 | 0.58 |
| | Expired (7) | 5.53 ± 2.15 | 5.47 ± 2.08 | 5.21 ± 2.11 | 4.30 ± 2.56 | 0.44 |
| Light sleep | Improved (32) | 12.73 ± 2.31 | 12.86 ± 2.69 | 13.43 ± 3.99 | 12.76 ± 2.42 | 0.59 |
| | Expired (7) | 13.37 ± 2.01 | 14.29 ± 3.31 | 14.49 ± 3.05 | 14.15 ± 1.84 | 0.76 |
| REM sleep | Improved (32) | 4.95 ± 1.96 | 4.68 ± 1.67 | 4.78 ± 2.02 | 4.71 ± 1.57 | 0.87 |
| | Expired (7) | 4.59 ± 1.82 | 4.07 ± 1.82 | 4.07 ± 2.05 | 5.09 ± 1.73 | 0.57 |

Abbreviations: ANOVA, analysis of variance; REM, rapid eye movement; SD, standard deviation; TBI, traumatic brain injury.
Repeated measure ANOVA with a general linear model.

►**Table 3** demonstrates that compared to patients with abnormal body temperatures, patients with normal body temperatures had shorter total and light sleep durations on day 1, which was statistically significant (*p*-value 0.01 and 0.004, respectively). Patients with abnormal body temperature experience more disturbed sleep compared to those with normal body temperature.

When comparing the sleep cycle between agitated and nonagitated patients, it was observed that nonagitated patients had a statistically significant increase in total sleep duration and a decrease in light sleep duration compared to agitated patients ($p < 0.05$). Additionally, analysis of spastic and nonspastic patients indicated that nonspastic patients displayed a sleep pattern trending toward normal.

Patients receiving sedatives had a deep sleep. Patients not receiving sedatives had higher light sleep duration. REM sleep was more prominent among patients receiving sedatives, with statistical significance ($p < 0.05$).

### Additional Findings

Patients' sleep patterns did not exhibit a specific increasing or decreasing trend, regardless of whether their condition improved or deteriorated (►**Table 4**).

## Discussion

In this study, the most common mechanism of injury among 39 patients was RTI (66.67%), followed by falls (20.51%) and other causes (12.82%). Similar findings were reported by Rosyidi et al[18] and Abio et al,[19] highlighting traffic accidents as the leading cause of TBI. However, a study by Sandsmark et al[20] found falls to be the most frequent cause, which contrasts with the study.

Consistent with previous research by Rosyidi et al[18] and Abio et al,[19] this study showed a higher incidence of brain injury in men compared to women. Among the 39 patients, 38 were males (97.44%) and 1 was female (2.56%).

A study by Valente et al[14] using 24 hours polysomnographic recordings in subacute posttraumatic unconscious patients, suggested that the organization of sleep patterns was a better indicator of outcome than other traditional parameters like GCS. Similarly in this study, it is found that severe TBI patients in their acute stage, with improved sleep cycle, had a higher probability of improvement in their GCS.

It is also observed that patients with poor GCS, although they exhibited all sleep stages, did not follow a normal sleep pattern, which is a poor prognostic indicator. This aligns with the findings of a review by Cologan et al,[13] where poor outcomes were associated with monophasic electroencephalogram or cyclic alternating patterns with absence of sleep elements.

In this study, it is found that unconscious severely injured acute TBI patients experienced hypersomnia, with a significantly increased sleep duration of 19.97 hours per day. This finding supports a study by Wiseman-Hakes et al[21] on sleep in the acute phase of severe TBI, which reported increased sleep duration and earlier sleep onset in TBI patients compared to orthopaedic and/or spinal cord injuries. They suggested that brain damage increases the need for sleep and/or reduces the ability to stay awake, possibly due to the requirement for sleep in brain repair processes.

### Strength of the Study

This pioneering study demonstrates that severe TBI patients in the acute phase maintained an intact sleep cycle, highlighting the utility of sleep cycle assessment for predicting their level of consciousness using actigraphy smartwatch monitoring.

### Limitations

It is a single-center study with small sample size, limiting generalizability. Variability in watch placement postinjury may affect the comparability of sleep patterns among patients.

### Recommendations

Further exploration of the study title can be done as research in this area is very limited and holds great potential for benefits for the TBI patients. It is recommended to replicate the study on a larger sample size to enhance generalizability.

Extending sleep monitoring for longer durations and conducting multiple follow-ups can provide valuable insights into sleep patterns. A randomized controlled trial comparing the sleep cycle of severe TBI patients in the acute phase with those of mild-to-moderate TBI and non-TBI patients would be valuable. The increased sleep needs following severe TBI requires further investigation. Effect of antiepileptic, sedation, body temperature, heart rate, spasticity, and agitation can be assessed on the sleep of such patients.

## Conclusion

Deeply unconscious severe TBI patients exhibit an intact sleep cycle, including light sleep, deep sleep, and REM sleep. Initially, their sleep duration is significantly higher than normal but gradually moves toward normal levels. Improvements in the sleep cycle are associated with better GCS scores, indicating a positive prognosis. However, due to the limited duration of sleep monitoring, it is unclear if these changes correlate with patients' overall condition. Therefore, the sleep cycle emerges as a prognostic factor for consciousness recovery in acute-phase of unconscious TBI patients.

**Conflict of Interest**
None declared.

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