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SCIENTIFIC INVESTIGATIONS

Concordance between current American Academy of Sleep Medicine and Centers for Medicare and Medicare scoring criteria for obstructive sleep apnea in hospitalized persons with traumatic brain injury: a VA TBI Model System study

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Study Objectives: The objective of this study was to compare obstructive sleep apnea (OSA), demographic, and traumatic brain injury (TBI) characteristics across the American Academy of Sleep Medicine (AASM) and Centers for Medicare and Medicare (CMS) scoring rules in moderate to severe TBI undergoing inpatient neurorehabilitation.

Methods: This is a secondary analysis from a prospective clinical trial of sleep apnea at 6 TBI Model System study sites (n = 248). Scoring was completed by a centralized center using both the AASM and CMS criteria for OSA. Hospitalization and injury characteristics were abstracted from the medical record, and demographics were obtained by interview by trained research assistants using TBI Model System standard procedures.

Results: OSA was prevalent using the AASM (66%) and CMS (41.5%) criteria with moderate to strong agreement (weighted $\kappa = 0.64$; 95% confidence interval = 0.58–0.70). Significant differences were observed for participants meeting AASM and CMS criteria (concordant group) compared with those meeting criteria for AASM but not CMS (discordant group). At an apnea-hypopnea index ≥ 5 events/h, the discordant group (n = 61) had lower Emergency Department Glasgow Coma Scale Scores consistent with greater injury severity (median, 5 vs 13; $P = .0050$), younger age (median, 38 vs 58; $P < .0001$), and lower body mass index (median, 22.1 vs 24.8; $P = .0007$) compared with the concordant group (n = 103). At an apnea-hypopnea index ≥ 15 events/h, female sex but no other differences were noted, possibly because of the smaller sample size.

Conclusions: The underestimation of sleep apnea using CMS criteria is consistent with prior literature; however, this is the first study to report the impact of the criteria in persons with moderate to severe TBI during a critical stage of neural recovery. Management of comorbidities in TBI has become an increasing focus for optimizing TBI outcomes. Given the chronic morbidity after moderate to severe TBI, the impact of CMS policy for OSA diagnosis for persons with chronic disability and young age are considerable.

Clinical Trial Registration: Registry: ClinicalTrials.gov; Name: Comparison of Sleep Apnea Assessment Strategies to Maximize TBI Rehabilitation Participation and Outcome; Identifier: NCT03033901.

Keywords: obstructive sleep apnea, policy, traumatic brain injuries

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BRIEF SUMMARY

Current Knowledge/Study Rationale: The impact of the stringent nature of the traumatic brain injury Centers for Medicare and Medicare scoring criteria in a vulnerable population of persons with moderate to severe traumatic brain injury has not been previously reported. The differences reported highlight the potential impact of Centers for Medicare and Medicare policy on recovery for those with greater injury severity in need of comorbidity management to optimize outcomes.

Study Impact: Results highlight the impact of Centers for Medicare and Medicare policy on hospitalized persons with moderate to severe traumatic brain injury who struggle with lifelong disability. Findings indicate that a sizable number of persons with greater traumatic brain injury severity, younger age, lower body mass index, and female sex are at risk for denial of treatment for obstructive sleep apnea during a time of critical neural repair to promote neurologic outcome.

INTRODUCTION

The prevalence of sleep disorders is greater among persons with traumatic brain injury (TBI) relative to the general population.[1] Animal and human studies have shown that sleep-wake cycle disturbances alter neurotransmitters and receptor systems, neuronal activation, and related signaling molecules, as well as physical functioning, mood, cognition, and behavior.[2–5] O'Hara et al[6] proposed that chronic sleep disturbances, including sleep apnea, contribute to premature cognitive decline in persons with TBI. Recent work has highlighted prevalent obstructive sleep apnea during acute inpatient rehabilitation, which is a time of critical neural repair[7] in persons with TBI. In a consecutive series of neurorehabilitation admissions, 37% of admissions for brain injury undergoing acute inpatient rehabilitation were found to have sleep-disordered breathing.[7] The reasons for this higher incidence of sleep apnea in TBI are poorly understood. However, large population-based studies suggest that sleep apnea may increase risk for TBI. Epidemiologic studies conducted on large samples demonstrate that the ill effects of sleep apnea were detectable several years before the clinical diagnosis being made and are associated with behaviors that increase the risk of TBI including work injuries and motor-vehicle accidents.[8,9] For example, Young et al[9] conducted a national survey with 913 non–clinic-based, employed individuals and reported severe sleep apnea was associated with a 7-fold increased risk of multiple auto accidents in the 5 years before diagnosis. The increased risk for injury associated with sleep apnea may contribute to the higher incidence in TBI. Large national database studies of sleep apnea support that sleep apnea may serve as a comorbidity that increases risk for TBI.[9] TBI can also affect the control of breathing during sleep. Although studies show a preponderance of obstructive sleep apnea (OSA) after TBI, neurologic alterations in pharyngeal muscle coordination could contribute, considering the prevalence of various forms of dysphagia after TBI. Alternatively, medications commonly prescribed after TBI could influence the occurrence of sleep apnea. Sedatives, hypnotics, opioids, and other drugs with muscle relaxant properties might alter the pliability of the hypopharyngeal musculature and/or the central nervous response to obstruction. This has the possibility of increasing the risk for sleep apnea, although 2 prior studies examining TBI in acute rehabilitation settings did not find an association between medications and sleep apnea diagnosis.[7,10] Following TBI, the chronic hypoxemia of unrecognized and untreated sleep apnea is theorized to impair cognition (eg, attention, memory, and executive functions) and contribute to early neurodegeneration.[6] Collectively, chronic nightly hypoxemia and frequent awakenings caused by cessation of breathing reduce total sleep time and potentially serve as mechanisms to explain poor neurologic recovery and chronic morbidity after TBI.

Diagnosing sleep apnea at the earliest point possible after TBI was the recommendation of a recent Galveston Brain Injury Conference Think Tank Meeting.[11] Given the significant degree of morbidity and early mortality[12–15] observed after TBI,[16,17] addressing comorbidities such as sleep apnea to enhance neurologic recovery has increasingly become a focus of TBI management.[18–21] Identifying (and treating) sleep apnea earlier in the recovery process may help minimize the effects of hypoxemia and sleep disruption to promote neural repair.[22]

The Centers for Medicare and Medicaid Services (CMS) define apneas and hypopneas according to the 2007 scoring rules[23] published by the American Academy of Sleep Medicine (AASM), and CMS authorizes coverage of positive airway pressure therapy based on these criteria.[24] Notably, in 2012, the AASM revised their criteria and processes for scoring respiratory events during diagnostic sleep studies.[25] Although CMS and AASM have equivalent definitions of apneas based on the 2012 AASM scoring manual, the criteria for scoring hypopneas differ between the two. Per the AASM, hypopneas are defined by a decrease in airflow by 30–90% accompanied by either 3% oxygen desaturation or arousal. In contrast, the CMS criteria using older scoring guidelines define hypopnea as decrease in airflow by 30–90% accompanied by a 4% oxygen desaturation and no consideration of arousal.

Recent systematic and meta-analytic review has highlighted the effect of the evolution of the scoring criteria for OSA with higher rates and severity of OSA made using the current AASM criteria[26] relative to the CMS criteria. Pooled meta-analyses from 6 studies revealed 17% of individuals met the cutoff using the AASM but not CMS scoring criteria.[26,27] Findings were mixed, but a few studies noted greater health morbidity and worse outcome for those diagnosed using the current CMS criteria relative to the AASM criteria,[28–30] whereas other studies found no differences depending on the outcome.[31,32] A recent large analysis of participants (n = 6,113) from the Sleep Heart Health Study found a significant association with hypertension when the AASM criteria for hypopnea is used in the apnea-hypopnea index (AHI).[26]

To date, no study has compared the diagnostic outcome using the AASM and CMS criteria in a TBI population. Persons with moderate to severe TBI who are hospitalized with significant injury warranting inpatient rehabilitation often experience prolonged neurologic morbidity and disability,[17,33–35] thus becoming eligible for coverage under CMS policies regardless of age. Data from a recently completed clinical trial examining sleep apnea at 6 inpatient rehabilitation centers within the United States (TBI Model System Research Network) were used to examine concordance between the CMS and AASM criteria. Demographic, behavioral health, TBI characteristics, and rehabilitation status were compared across concordant and discordant diagnostic groups.

METHODS

Participants

Potential participants were patients enrolled in the TBI Model Systems (TBIMS) multicenter study (Tampa, Florida; Seattle, Washington; Dallas, Texas; Columbus, Ohio; Denver, Colorado; and Philadelphia, Pennsylvania) as part of a Patient-Centered Outcomes Research Institute–funded clinical trial over a 19-month period. Study inclusion/exclusion criteria for the TBIMS and Patient-Centered Outcomes Research Institute–funded clinical trial are published elsewhere.[36] All participating sites

received institutional review board approval for conduct of the study consistent with the amended Declaration of Helsinki with consent obtained by patients or designated medical proxy using TBIMS procedures. The requirement of TBIMS enrollment at time of consent into the Patient-Centered Outcomes Research Institute–funded clinical trial was eliminated at study month 11 to allow for earlier enrollment during rehabilitation, but the clinical criteria remained unchanged.[36]

Procedure

Consecutive admissions were screened for eligibility. Participants who passed the first level of screening (or their proxies) were consented and further screened for final eligibility including (1) ≥2 h sleep/night based on actigraphy placement or nursing logs/report and (2) medical stability, including no emergent medical issues precluding overnight polysomnography (PSG) and minimal to no post-traumatic agitation per the Agitated Behavior Scale.[37] Once determined eligible, an overnight PSG study was conducted by a registered polysomnography technician (RPSGT) in the participant's hospital bed. Fully attended level 1 PSG was conducted in accordance with the AASM recommended procedures.[38] Staff were instructed to allow participants to sleep their normal habitual sleep period with a minimum of 2 hours of sleep needed for adequate study.

The lead center (James A. Haley Veterans Hospital, Tampa, Florida) served as a centralized scoring center for all sleep studies. All deidentified studies were scored by 1 of 2 certified RPSGTs and interpreted by a board-certified sleep medicine physician. Because the data were deidentified, the centralized scoring center's protocol required generation of both an AASM guideline-based report and a second report based on Medicare/Medicaid (CMS) criteria. Elements of both reports were subsequently databased and included in this study's analyses.

All staff that scored and interpreted studies were masked to other sleep assessments and other potentially identifying patient data (eg, age, race, sex, nature or timing of injury, medications). Interrater agreement for scoring of sleep and respiratory events were strong to very strong (Wake, 0.94; 95% confidence interval [CI], 0.79–0.98; non–rapid eye movement, 0.85; 95% CI, 0.53–0.96; rapid eye movement, 0.91; 95% CI, 0.69–0.98; AHI, 0.95; 95% CI, 0.88–0.98; Respiratory Distress Index, 0.94; 95% CI, 0.80–0.99) as previously reported.[39] All level 1 PSG studies were scored within 7 business days of completion of PSG, with results subsequently databased and entered by research assistants.

Demographic, preinjury medical histories, and medical record abstraction were conducted by trained research assistants following the TBIMS protocol. Glasgow Coma Scale (GCS)[40,41] score in the emergency department and duration of post-traumatic amnesia (PTA) were the primary markers of injury severity. Medications on the day of PSG with sleep effects (opiates, sedatives-hypnotics, antidepressants, neurostimulants, antihypertensives, antihistamines, antiepileptics) were abstracted from the medical record, irrespective of whether they were prescribed for sleep.

Measures

Polysomnography

Severity of sleep apnea was measured by the AHI which calculates the number of apneas and hypopneas using either the AASM or CMS criteria described below. Severity of sleep apnea was graded by frequency of AHI events per hour, with sleep apnea severity denoted as follows: 5–14.9 events/h = mild, 15–29.9 events/h = moderate, and ≥30 events/h = severe sleep apnea.[42] PSG was conducted with the Philips Alice 6 LDx Diagnostic Sleep System and scored with Philips Sleepware G3 version 3.8.1 (Philips, Koninklijke Philips, NV).[43] Respiratory events were scored using both the CMS and AASM definitions with separate reports generated for data entry.

Glasgow Coma Scale

The GCS is scored from 3 to 15, with 15 being the best score. Scores from 3 to 8 denote severe injury, 9 to 12 denote moderate injury, and 13 to 15 denote mild TBI.[40,44] However, mild TBI scores must have abnormal neuroimaging findings on computed tomography scan (complicated mild) to be considered eligible for this study. The GCS score obtained on admission to the designated level 1 trauma center associated with each TBIMS site is the GCS used for initial medical documentation of TBI severity. Individuals who were chemically paralyzed, sedated, or intubated on admission were retained by imputing/replacing the respective GCS subscale scores with 1, consistent with prior TBIMS studies,[45,46] to retain the relatively more severely impaired in study samples.

Functional independence measure

The functional independence measure (FIM) measures functional independence or burden of care with 18 items that assess self-care and mobility (13 items) and cognition (5 items). Items are scored 1–7, with a score of 1 representing complete dependence and a score of 7 indicating complete independence.[47] The FIM motor and cognitive subscales at rehabilitation admission are further used to characterize degree of disability in the sample after TBI.

PTA status

Clearance from PTA (period of confusion after TBI) was assessed prospectively by repeated administration of the Galveston Orientation and Amnesia Test (GOAT) or Orientation Log (*O*-Log) 24–72 hours apart until 2 consecutive scores were achieved at or above the threshold for clearing PTA.[48] For persons who are admitted to inpatient rehabilitation having already emerged from PTA, a chart review procedure was used that documented 2 consecutive evaluations indicating orientation within 72 hours.[48] To minimize missing data, length of PTA was calculated as the length of stay plus 1 day for persons discharged from inpatient rehabilitation still in PTA.[48] Although this procedure underestimates true PTA duration for many participants, it permits inclusion of participants with the most severe injuries and has been used in previous research.[49] For the purposes of this study, the PTA status on the day of PSG was used for study purposes.

Statistical methods

Descriptive statistics were used to summarize characteristics of the overall sample (n = 248) and PSG-related respiratory indices of groups of participants with positive OSA diagnosis by AASM and CMS criteria. Wilcoxon ranked-sum tests and χ^2 tests were used to compare the distributions of the characteristics between concordant and discordant cohorts across the AASM and CMS scoring criteria.

RESULTS

Participant and sleep diagnostic characteristics

Between May 2017 and January 2019, 896 patients were screened, with 449 initially eligible and 345 consented (77%). Ineligibility occurred for the following reasons: (1) not dually enrolled in the TBIMS longitudinal study (n = 268), (2) in active treatment for sleep apnea (n = 20), (3) missed because of abbreviated length of stay/abrupt transfer/death (n = 92), (4) having medical issues delaying approach for study screening (n = 30), and (5) being in police custody (n = 1). Enrollment criteria were relaxed for the requirement of TBIMS consent in study month 11, resulting in the following additionally excluded: (6) having mild TBI (n = 24), (7) being age less than 16 (n = 4), and (8) missed by study staff (n = 8). After consent, ineligibility for PSG included the following: (1) medical instability precluding PSG (n = 14), (2) abbreviated length of stay resulting and/or technologist unavailable to conduct study on the rehabilitation unit (n = 45), and (3) declined PSG portion of the study (n = 23). Of the 263 completing PSG, an additional 15 were excluded, leaving a final analytic sample of 248 (see original article for detailed flow diagram of the study group[36] and final analytic sample). **Table 1** summarizes participant demographics, injury characteristics, and medical and physical status at time of PSG for the overall sample. PSG occurred a median of 47 days after TBI (interquartile range, 29–86.5 days) with most having emerged from PTA (acute confusion; 85%).

Concordance groupings

Results of PSG revealed elevated (≥5 events/h) total and obstructive AHI for most of the sample (68% and 66%, respectively). The cross-tabulation of OSA severity across AASM and CMS criteria is summarized in **Table 2** and **Figure 1**. A weighted κ = 0.64 (95% CI, 0.58–0.70) indicated moderate to substantial agreement of OSA severity diagnoses between AASM and CMS criteria (**Figure 1**). As expected, the AASM criteria resulted in a larger portion of the sample being diagnosed with sleep apnea (n = 164; 66%) compared with the CMS criteria (n = 103; 41.5%), with a larger number of cases with mild sleep apnea detected by the AASM criteria (n = 86 vs 49). Twenty-five percent (n = 61) of cases did not meet CMS criteria for sleep apnea but did meet criteria using the AASM criteria (primarily mild).

Comparisons across concordance groups

Given the sizeable proportion of participants not meeting CMS criteria, participants were further categorized into concordant (AASM positive and CMS positive) and discordant (AASM positive and CMS negative) subgroups across AHI levels. **Table 3** summarizes the respiratory indices across the 2 subgroups using the CMS scoring results. Consistent with prior studies, those meeting CMS criteria for OSA (concordant group) had greater disease severity across most respiratory parameters compared with the discordant group. **Table 4** summarizes comparisons made across the concordant (n = 103) and discordant (n = 61) at AHI ≥ 5 events/h subgroups. Participants in the discordant subgroup had greater severity of TBI using the GCS ordinal category ($P = .0019$) and continuous score with replacement scores for those intubated and chemically sedated and paralyzed (median, 13 vs 5; $P = .0050$). The discordant group was also younger (median, 58 vs 38; $P < .0001$) and had a lower body mass index (BMI; median, 24.8 vs 22.1; $P = .0007$). There were no differences between the groups in terms of remaining demographic (sex, military service history) or injury characteristics (PTA status, time since injury to PSG, and FIM cognitive and motor subscales at time of rehabilitation admission).

Table S1 in the supplemental material summarizes exploratory comparisons made across concordant (n = 54) and discordant (n = 24) at AHI ≥ 15 events/h subgroups. No differences between the concordant and discordant subgroups were found except for sex ($P = .0320$), with more females in the discordant group (n = 25% vs 7%). Given the large number of mild sleep apnea cases detected by the AASM criteria, exploratory subanalyses were examined between concordant (n = 27) and discordant (n = 59) groups for those with mild sleep apnea only (total AHI 5 and <15 events/h; **Table S2**). The discordant group had a lower BMI (median, 27 vs 22; $P = .005$), with no other statistical differences noted.

DISCUSSION

This is the first study to examine the diagnostic impact of CMS scoring criteria for sleep-disordered breathing in hospitalized neurorehabilitation patients with TBI in early neurologic recovery. Significant discrepancy between the incidence of sleep-disordered breathing across scoring criteria was observed. Specifically, 25% of participants with less severe sleep-disordered breathing were ineligible for a diagnosis using the CMS criteria yet eligible under the AASM criteria. This finding is slightly higher but relatively consistent with recent meta-analytic work highlighting underdiagnosis (17%) of sleep-disordered breathing using the CMS criteria[26] in various clinical populations.[26]

Furthermore, participants with younger age, lower BMI, and greater severity of TBI were less likely to receive a diagnosis at any severity level (mild-severe) under the CMS criteria (**Table 4**). Most sample participants were young (median age, 40 years) and competitively employed or a student (74%) at the time of sustaining a moderate or severe TBI, consistent with other normative data highlighting that most of those undergoing inpatient rehabilitation across the United States are younger persons[50,51] who are employed. Indeed, the AASM scoring rules have been associated with better response to treatment

Table 1—Participant characteristics for total sample completing level 1 PSG (n = 248).

Participant Characteristics	
Demographics	
Age at PSG	43.6 (17.9) [16.4, 27.8, 40.4, 58.7, 92.6]
Sex, male, n (%)	203 (81.8)
Race/ethnicity, n (% yes)	
Hispanic	33 (13.3)
White	184 (74.2)
Black	49 (19.8)
Asian	12 (4.8)
Marital status, n (%)	
Single (never married)	101 (40.9)
Married	102 (41.3)
Separated/divorced/widowed	44 (17.8)
Education, n (%)	
Less than high school	40 (16.3)
High school	74 (30.2)
Some college	72 (29.4)
Bachelor's or higher	59 (24.1)
Served in military, n (% yes)	63 (25.7)
Preinjury employment status, n (%)	
Student/competitively employed	183 (73.8)
Retired	41 (16.7)
Other	22 (8.9)
Missing	2 (0.8)
Injury characterization	
Mechanism of TBI, n (%)	
Motor	11 (44.8)
Fall	79 (31.8)
Other	58 (23.4)
Rehabilitation length of stay (days)	47.5 (44.0) [6, 20, 33, 59, 288]
Admission FIM motor score	36.0 (19.3) [13, 18, 34, 50, 91]
Admission FIM cognitive score	15.0 (7.6) [5, 8, 14, 20, 34]
Medical/physical status at time of PSG	
Time since injury to PSG (days)	120.6 (534.5) [6, 29, 47, 86.5, 7652]
Body mass index	24.4 (5.4) [15.0, 20.8, 23.2, 27.4, 50.9]
Medication status on day of PSG, n (% yes)	
Opioids	53 (21.4)
Benzodiazepines	35 (14.1)
Hypnotics	20 (8.1)
Antidepressants	160 (64.5)
Antipsychotic/tranquilizer/neuroleptics	51 (20.6)
Antiepileptic	122 (49.2)
Antihistamines	14 (5.7)
Stimulants	47 (19.0)
Other (sedating or muscle relaxing)	32 (12.9)

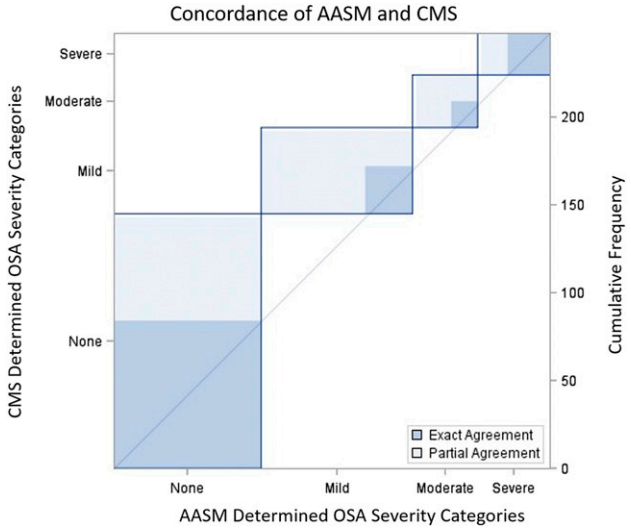
Values presented as mean (SD) [P0, P25, P50, P75, P100] or n (%). FIM = functional independence measure, PSG = polysomnography, TBI = traumatic brain injury.

Table 2—Crosstabs of AASM versus CMS criteria for OSA.

		AASM OSA				Total
		None	Mild	Moderate	Severe	
Medicare (CMS) OSA	None	84	*59*	*2*	0	145
	Mild	0	**27**	**20**	**2**	49
	Moderate	0	0	**15**	**15**	30
	Severe	0	0	**0**	**24**	24
	Total	84	86	37	41	248

Bold numbers indicate concordant group (agreement that AHI ≥ 5 events/h, n = 103) and italic numbers indicate discordant group (disagreement that AHI ≥ 5 events/h, n = 61). AASM = American Academy of Sleep Medicine, AHI = apnea-hypopnea index, CMS = Centers for Medicare and Medicaid Services, OSA = obstructive sleep apnea.

Figure 1—Flow chart of study sample.



Weighted κ = 0.6432.

outcome in younger leaner samples[30] similar to this population. Finally, consistent with prior studies, females with TBI were less likely to receive a diagnosis when examining AHI > 15 events/h using the CMS criteria (**Table S1**[31,52]). Poor recognition for the presence or severity of sleep-disordered breathing and the impact on treatment initiation or selection in this vulnerable population with moderate to severe brain injury is unknown. This population is at high risk for chronic morbidity[17,33] and early mortality,[12–15] primarily because of circulatory issues in the first year after TBI[53] and are likely to become CMS beneficiaries after injury.[54–56] As such, the impact of these scoring criteria on treatment access for sleep-disordered breathing may worsen the potential for survival and maximal recovery.

To date, no treatment exists to ameliorate the adverse consequences of TBI. Addressing comorbidities to enhance outcome has become an increased focus of rehabilitation efforts.[18] In a review paper on sleep and TBI, O'Hara et al[6] proposed that, in addition to sleep loss and fragmentation, sleep apnea may also be associated with hypoxemia that may contribute to the early neurodegeneration observed in those with TBI. This is consistent with a growing body of work highlighting a relationship between TBI and comorbidities including OSA linked to poor cognitive and functional outcomes.[57–60] Unfortunately, sleep apnea in those with TBI is largely undiagnosed.[1] First-line therapies for OSA are delivery of positive airway pressure[61] and not the pharmacologic treatments that are commonly used in TBI rehabilitation settings.[62,63] Given that sleep is critical for neural repair and disordered sleep may play a role in slowing functional recovery and prolonging rehabilitation, early detection of sleep apnea is critical.[6,64] This is further compounded by the nocturnal hypoxemia of untreated sleep apnea, a secondary neurologic insult associated with impaired alertness, cognition, mood, function, and health. Indeed, successful treatment for sleep apnea has been associated with improvements across these domains in patients without TBI.[65] Furthermore, the extreme daytime sleepiness associated with sleep apnea can interfere with patient participation in the rehabilitation process.[66] For individuals with TBI, early identification of sleep apnea is vital to maximize benefit from rehabilitation.

Finally, improved recognition for this comorbidity after TBI may help improve outcomes at a cellular and functional level, unlike management of other comorbidities. Indeed, earlier detection and successful treatment could change the trajectory of both acute and chronic outcomes after TBI.

This is the first study to examine the diagnostic impact of the CMS scoring criteria for OSA in a cohort with TBI undergoing inpatient rehabilitation. Additional strengths include the prospective, multicenter design with a large, well-characterized cohort, enhancing generalizability. A key strength is the diagnostic outcome using level 1 PSG (gold standard) administered by trained RPSGT staff and with centralized scoring and interpretation by a board-certified sleep medicine physician. However, there are several limitations to the study. The study sample may not represent the full population of inpatient rehabilitation patients with TBI because many were excluded as described in our prior work.[32] Initially, short lengths of stay (insurance related) resulted in a number of eligible participants discharged before RPSGT availability; increasing the number of RPSGT staff (ie, contractors) at each site addressed this limitation. As a result, the study enrolled and completed PSG on 263 TBI admissions over 19 months.

In conclusion, this study found high rates of disagreement for recognition of sleep-disordered breathing in a vulnerable cohort

Table 3—PSG-related respiratory and sleep indices for concordance groups using CMS scoring criteria.

	Concordant Group	Discordant Group
Obstructive AHI	22.4 (18.3) [5.1, 8.1, 15.9, 29.1, 77.5]	9.1 (3.6) [5.0, 6.7, 8.2, 10.6, 26.0]
Mild (OSA AHI 5–14.9 events/h), n (%)	27 (26.2)	59 (96.7)
Moderate (OSA AHI 15–29.9 events/h), n (%)	35 (34.0)	2 (3.3)
Severe (OSA AHI > 30 events/h), n (%)	41 (39.8)	0 (0.0)
NREM OAHI	19.8 (19.4) [0, 5.3, 12.5, 27.0, 73.4]	7.8 (4.4) [2.4, 4.8, 6.4, 10.0, 26.8]
REM OAHI	28.3 (19.0) [0, 14.9, 26.3, 43.1, 77.8]	13.9 (11.0) [1.9, 7.2, 11.5, 16.9, 64.0]
Supine OAHI	19.8 (18.0) [0, 7.1, 12.7, 26.8, 71.3]	11.7 (6.4) [5.1, 7.8, 10.1, 13.4, 34.8]
Not applicable, n	4	2
Non-supine OAHI	6.1 (9.9) [0, 0, 0.9, 7.6, 43.7]	4.6 (4.7) [0.0, 0.9, 2.9, 7.1, 19.2]
Not applicable, n	42	18
Desaturation index: AASM = At 3%, #/h, CMS = At 4%, #/h	20.9 (19.9) [0.0, 7.5, 12.3, 30.8, 93.6]	6.7 (4.3) [0.2, 3.8, 6.2, 8.4, 20.3]
Central AHI	3.4 (7.3) [0, 0, 0.2, 3.2, 48.6]	0.3 (0.6) [0.0, 0.0, 0.0, 0.3, 2.5]

Values presented as mean (SD) [P0, P25, P50, P75, P100] or n (%). AASM = American Academy of Sleep Medicine, AHI = apnea-hypopnea index, CMS = Centers for Medicare and Medicaid Services, OAHI = obstructive apnea-hypopnea index, OSA = obstructive sleep apnea, TST = total sleep time

Table 4—Comparison of concordant and discordant groups across AASM and CMS scoring criteria for AHI ≥ 5 events/h (mild, moderate, and severe OSA).

	Concordant Group (n = 103): AASM+ and CMS+ at AHI ≥ 5+ events/h	Discordant Group (n = 61): AASM+ and CMS– at AHI ≥ 5 events/h	*P*
Demographics			
Age	55.79 (16.36) [19.1, 44.7, 57.6, 66.9, 92.6]	41.4 (14.4) [18.1, 30.1, 38.3, 48.4, 79.3]	<.0001
Body mass index	26.0 (6.1) [15.0, 21.5, 24.8, 28.8, 50.9]	23.2 (4.5) [16.8, 20.2, 22.1, 24.7, 39.4]	.0007
Sex, n (%)			.9471*
Male	84 (81.6)	50 (82.0)	
Female	19 (18.4)	11 (18.0)	
Served in military, n (% yes)	28 (27.5)	11 (18.6)	.2088*
TBI characterization			
GCS category (with imputation for chemically sedated/intubated), n (%)			.0019*
Complicated mild	40 (45.5)	12 (22.2)	
Moderate	13 (14.8)	4 (7.4)	
Severe	35 (39.8)	38 (70.4)	
Missing	15	7	
Total GCS (imputed score)	9.8 (5.2) [3, 3, 13, 14, 15]	7.0 (4.7) [3, 3, 5, 12, 15]	.0050
PTA status, n (% yes)	17 (16.5)	7 (11.5)	.3784*
Time since injury to PSG	70.5 (102.4) [6, 27, 43, 74, 753]	197.1 (973.4) [10, 31, 52, 98, 7652]	.1746
Rehabilitation length of stay	44.1 (41.6) [6, 20, 32, 50, 288]	47.7 (39.4) [7, 19, 29.5, 72, 175]	.8516
Days before admitted to inpatient rehab after injury	43.9 (96.1) [3, 10, 22, 37, 737]	194.4 (1014.9) [4, 12, 30, 50, 7644]	.0613
FIM Cog: admission to rehabilitation	15.7 (7.1) [5, 11, 16, 20, 34]	13.9 (7.4) [5, 7, 12.5, 19, 33]	.1033
FIM Mot: admission to rehabilitation	34.3 (18.8) [13, 17, 29, 48, 85]	36.1 (17.7) [13, 20, 35.5, 49, 75]	.4728

Values presented as mean (SD) [P0, P25, P50, P75, P100] or n (%). *P* values reported for 2-sided nonparametric Wilcoxon sum rank test. **P* value reported from a χ^2 test. Cog = cognitive subscale, FIM = functional independence measure, GCS = Glasgow Coma Scale Score on emergency department admission, Motor = motor subscale, PSG = polysomnography, PTA = post-traumatic amnesia (duration of disorientation), TBI = traumatic brain injury.

during a critical time of neural repair after moderate to severe TBI. A high proportion of individuals with mild to moderate OSA using the AASM criteria were classified as having no or mild OSA using the CMS criteria. Risk factors for treatment ineligibility using the current CMS scoring criteria include younger age, lower BMI, and more severe TBI at AHI ≥ 5 events/h and female sex at AHI ≥ 15 events/h. Further studies are needed to determine whether treatment of OSA in patients with TBI results in improved patient outcomes.

ABBREVIATIONS

AASM, American Academy of Sleep Medicine
AHI, apnea-hypopnea index
BMI, body mass index
CI, confidence intervals
CMS, Centers for Medicare and Medicaid Services
FIM, functional independence measure
GCS, Glasgow Coma Scale
TBI, traumatic brain injury
TBIMS, TBI Model System
OSA, obstructive sleep apnea
PSG, polysomnography
PTA, post-traumatic amnesia
RPSGT, registered polysomnography technician

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DISCLOSURE STATEMENT

All authors have seen and approved the manuscript. Work for this study was performed at James A. Haley Veterans' Hospital, Tampa, Florida; Wexner Medical Center at Ohio State University, Columbus, Ohio; Harborview Medical Center, Seattle, Washington; Craig Hospital, Englewood, Colorado; Rehabilitation Hospital of Indiana, Indianapolis, Indiana;

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