https://doi.org/10.5664/jcsm.9450

JCSM | Journal of Clinical Sleep Medicine

SCIENTIFIC INVESTIGATIONS

Does testing for sleep-disordered breathing predischarge vs postdischarge result in different treatment outcomes?

Cinthya Pena Orbea, MD[1]; Hussam Jenad, MD[2]; Lena Lea Kassab, MD, MBA[3]; Erik K. St Louis, MD[4,5]; Eric J. Olson, MD[2,5]; Gaja F. Shaughnessy, MD[2]; Lillian T. Peng[6]; Timothy I. Morgenthaler, MD[2,5]

[1]Sleep Disorders Center, Neurological Institute, Cleveland Clinic, Cleveland, Ohio; [2]Division of Pulmonary and Critical Care Medicine, Mayo Clinic, Rochester, Minnesota; [3]Hospital Internal Medicine, Mayo Clinic, Rochester, Minnesota; [4]Department of Neurology, Mayo Clinic, Rochester, Minnesota; [5]Center for Sleep Medicine, Mayo Clinic, Rochester, Minnesota; [6]Mayo Clinic Alix School of Medicine, Rochester, Minnesota

Study Objectives: Treatment of sleep-disordered breathing may improve health-related outcomes postdischarge. However timely definitive sleep testing and provision of ongoing therapy has been a challenge. Little is known about how the time of testing—during hospitalization vs after discharge—affects important outcomes such as treatment adherence.

Methods: We conducted a 10-year retrospective study of hospitalized adults who received an inpatient sleep medicine consultation for sleep-disordered breathing and subsequent sleep testing. We divided them into inpatient and outpatient sleep testing cohorts and studied their clinical characteristics, follow-up, positive airway pressure adherence, pressure adherence, hospital readmission and mortality.

Results: Of 485 patients, 226 (47%) underwent inpatient sleep testing and 259 (53%) had outpatient sleep testing. The median age was 68 years old (interquartile range = 57–78), and 29.6% were females. The inpatient cohort had a higher Charlson Comorbidity Index (4 [3–6] vs 3[2–5], $P \leq .0004$). A higher Charlson Comorbidity Index (hazard ratio = 1.14, 95% confidence interval:1.03–1.25, $P = .001$), body mass index (hazard ratio = 1.03, 95% confidence interval:1.0–1.05, $P = .008$), and stroke (hazard ratio = 2.22, 95% confidence interval:1.0–4.9, $P = .049$) were associated with inpatient sleep testing. The inpatient cohort kept fewer follow-up appointments (39.90% vs 50.62%, $P = .03$); however positive airway pressure adherence was high among those keeping follow-up appointments (88.9% [inpatient] vs 85.71% [outpatient], $P = .55$). The inpatient group had an increased risk for death (hazard ratio: 1.82 95% confidence interval 1.28–2.59, $P \leq .001$) but readmission rates did not differ.

Conclusions: Medically complex patients were more likely to receive inpatient sleep testing but less likely to keep follow-up, which could impact adherence and effectiveness of therapy. Novel therapeutic interventions are needed to increase sleep medicine follow-up postdischarge, which may result in improvement in health outcomes in hospitalized patients with sleep-disordered breathing.

Keywords: sleep-disordered breathing, patient discharge, inpatient, patient readmission, follow-up studies

Citation: Orbea CP, Jenad H, Kassab LL, et al. Does testing for sleep-disordered breathing predischarge vs postdischarge result in different treatment outcomes? *J Clin Sleep Med*. 2021;17(12):2451–2460.

BRIEF SUMMARY

Current Knowledge/Study Rationale: Sleep-disordered breathing is a highly prevalent comorbid condition in hospitalized patients. Despite data suggesting that inpatient diagnosis and treatment of obstructive sleep apnea may confer clinical benefits postdischarge, little is known about postdischarge treatment outcomes.

Study Impact: This study provides insight on postdischarge treatment adherence in hospitalized patients with sleep-disordered breathing and calls for the development of innovative new treatment care models to improve outcomes in this high-risk patient population.

INTRODUCTION

Obstructive sleep apnea (OSA) is a prevalent condition that affects 29.4 million adults in the United States, with 23.5 million being undiagnosed.[1] Untreated OSA has been associated with significant morbidity and mortality, especially among those with cardiovascular diseases such as heart failure, coronary artery disease, hypertension, and stroke.[2,3] In recent years there has been an interest in developing screening methods for early diagnosis and treatment of OSA during hospitalization, given the high prevalence of comorbid OSA in this patient population.[4,5] Data have shown that for every 5 hospitalized adults, 2 are at high risk for OSA[5] comorbidity and 87% of admitted adults with obesity (≥ 30 kg/m^2) have OSA.[6]

In addition, obesity hypoventilation syndrome, chronic obstructive pulmonary disease-related hypoventilation, central sleep apnea, and other causes of hypoventilation have all been associated with worse hospital outcomes, increased readmission rates,[7–13] and often require sleep testing to qualify or optimize positive airway pressure (PAP) therapy. Several studies suggest that early treatment of sleep-disordered breathing (SDB) in hospitalized patients improves health-related outcomes. In cardiac patients with OSA, PAP initiation during hospitalization significantly reduces readmission rates and emergency visits

30 days postdischarge.[14] Likewise, patients admitted with acute decompensated heart failure with treated compared to untreated OSA have better survival rates that are similar to patients without OSA.[12] In stroke patients undergoing inpatient rehabilitation, PAP therapy seems to improve stroke-related impairments, including motor and functional outcomes.[15,16] Moreover in patients with obesity hypoventilation syndrome hospitalized with acute-on-chronic hypercapnic respiratory failure, PAP therapy reduces mortality following hospitalization.[17]

These observations suggest that treatment of SDB during hospitalization or right after discharge improves outcomes in certain at-risk populations, but SDB in many hospitalized patients remains undiagnosed and untreated.[18,19] This may be partially explained by the lack of provider awareness,[6] limited availability of inpatient sleep medicine services, or the absence of standardized guidelines to diagnose and treat SDB in the hospital. In practice, many patients with suspected SDB are empirically started on PAP therapy in the hospital, and the pragmatic question is often how to enable PAP therapy and appropriate follow-up after discharge. Coverage determinations for PAP therapy rely in part on diagnostic sleep testing. Sleep testing in United States hospitals is unfortunately generally not reimbursed as a specific service, and arranging for testing during hospitalization brings many logistical and technical challenges. However, these logistical and economic challenges must be weighed against cost savings that may accrue when sleep testing enables provision of appropriate PAP devices, which may expedite dismissal and prevent readmission.

While treatment of SDB with PAP therapy may confer health benefits and cost savings by speeding dismissal and preventing readmission, some data suggest that follow-up and PAP adherence postdischarge pose challenges. In patients admitted with acute decompensated heart failure with reduced left ventricular ejection fraction, less than 50% in who follow-up polysomnogram was recommended actually did so.[12] In another study, out of the 50 cardiac patients discharged with PAP therapy, only 19 patients met adherence criteria in the first 90 days of treatment.[14] Thus, further investigation on treatment adherence in patients who undergo inpatient sleep testing is needed.

The goal of our study was to investigate how performance of sleep testing during vs after hospitalization differentially impacted certain patient outcomes, including postdischarge follow-up rates of PAP therapy, PAP adherence, all-cause hospital readmission, and all-cause mortality rate. To address these knowledge gaps, we performed a retrospective study of patients evaluated by a sleep medicine specialist during hospitalization and divided them into 2 cohorts based upon the location in which the sleep study was performed: inpatient or outpatient. We hypothesized that patients undergoing inpatient sleep apnea testing would have decreased PAP follow-up rates, PAP adherence postdischarge, and increased risk readmission and mortality.

METHODS

Setting

Mayo Clinic Hospital, located in Rochester, MN, is a 2,207-bed academic medical center. The Center for Sleep Medicine offers an inpatient sleep medicine consult service that performs an average of 170 consults per year and is staffed by the same sleep medicine specialists. When there is suspicion for OSA in hospitalized patients or qualification for noninvasive ventilation for SDB is required prior to discharge, a sleep medicine consultant determines the type of sleep study, if any, to be performed and helps arrange PAP prescription and PAP-related follow-up care while the consulting service along with hospital care management coordinate PAP therapy set up.

Study design

We performed a retrospective observational cohort study. To form the 2 cohorts, we used a natural language processing tool (Advanced Cohort Explorer, "ACE") developed by Mayo Clinic that searches a unified data platform containing all clinical and hospital notes, diagnoses, medical orders, laboratory results and pathology records, and billing codes using the terms "Sleep Disorders Hospital Service". We also used sleep study procedural codes to identify patients of interest. We included all patients ≥ 18 years old who were hospitalized from January 2008 through March 2018 who received an inpatient sleep medicine consultation and subsequently had a sleep study within 90 days of consultation. Across the 10 years, an average of 170 consults were performed. All cases identified by the broad search were manually reviewed to ensure the inclusion criteria were met. This study was approved by the Institutional Review Board.

Data collection and definitions

Demographics including age, race, sex, patient residential zip code, insurance, vital status, and clinical characteristics were obtained from the medical record. Patient residential zip code was used to calculate distance in miles from patient's home to the sleep clinic, where follow-up and any outpatient sleep testing occurred. The discharge diagnoses were extracted from the hospital discharge summaries and categorized according to the main physiological systems involved. The level of comorbidity was calculated using an enhanced coding algorithm for the Charlson Comorbidity Index (CCI) that pulls relevant diagnoses from the health record using the ACE, resulting in scores ranging from 0 to 6, with higher scores indicating higher comorbidity.[20] The initial sleep medicine consult note was reviewed to determine what kind of sleep testing and treatment recommendations were recorded. Sleep study data (as available given type of test performed) were also obtained including sleep study type (diagnostic polysomnogram, full titration polysomnogram, type III home sleep apnea test, peripheral arterial tonometry test), and SDB diagnosis including OSA (apnea-hypopnea index [AHI] ≥ 5 events/h with predominantly obstructive and mixed apneas, hypopneas, or respiratory effort related arousals), central sleep apnea (AHI ≥ 5 events/h with central apneas and/or central-appearing hypopneas comprised > 50% of the total number of respiratory events), sleep-related hypoxia (oxyhemoglobin desaturation ≤ 90% for more than 5 minutes during sleep), hypoventilation (increase in the arterial PCO_2 to a value > 55 mm Hg for ≥ 10 minutes or if there is ≥ 10-mm Hg increase in arterial PCO2 [or surrogate] during sleep [in comparison to an awake supine value] to a value exceeding 50 mmHg for ≥ 10 minutes.)[21,22]

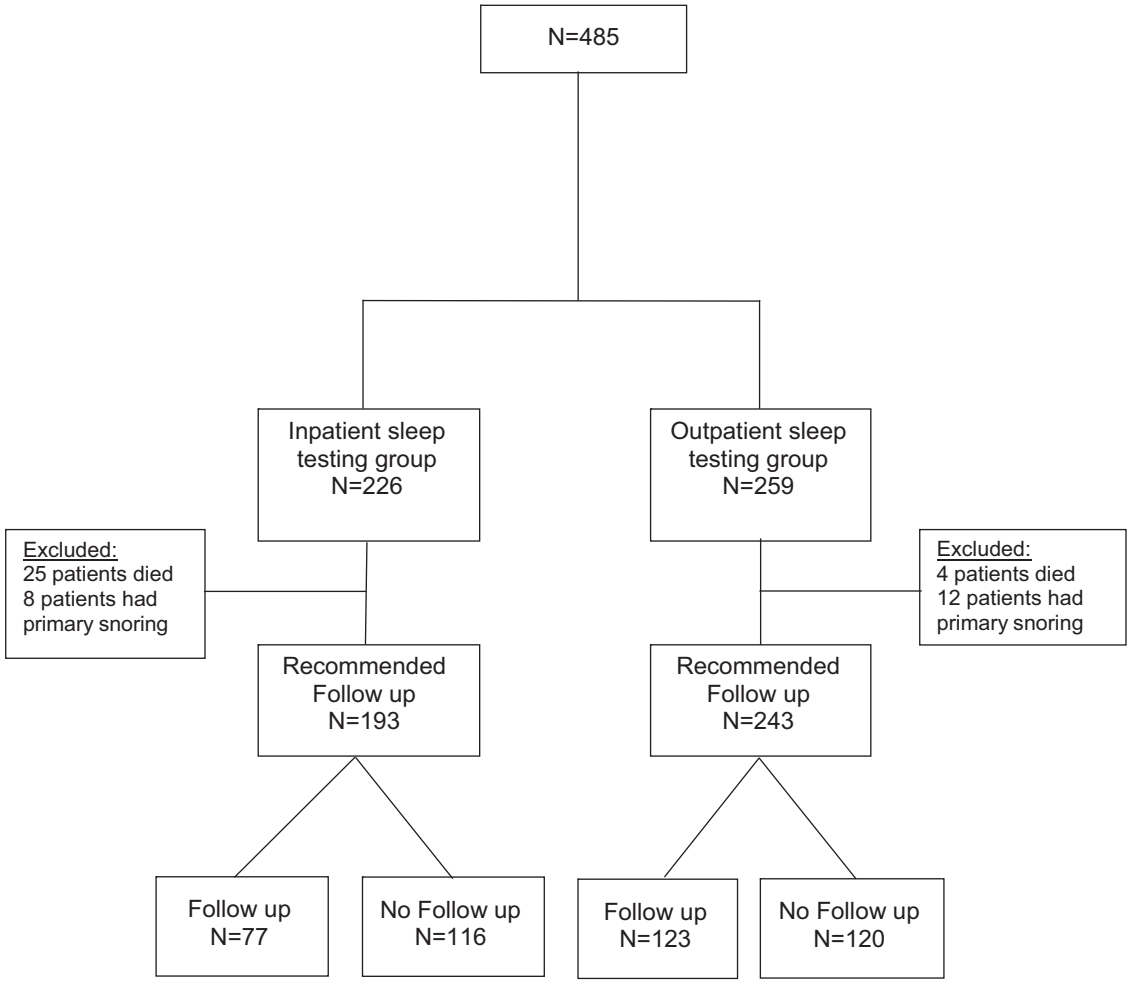
Patient outcomes

PAP follow-up was defined in the inpatient group by the presence of a PAP follow-up visit note within 90 days of discharge from the hospital and in the outpatient group by the presence of a PAP follow-up visit note within 90 days of the sleep study. At Mayo Clinic, patients get their sleep study results and a PAP prescription the morning after the sleep study was performed. The 90-day PAP follow-up period was chosen based on the Center for Medicare and Medicaid Services follow-up requirement after starting PAP therapy.[23] Patients diagnosed with primary snoring had no planned follow-up with sleep medicine and, along with those who died during hospitalization or within 90 days of discharge, were excluded from the follow-up analyses (**Figure 1**). Patients were considered adherent with PAP therapy if the sleep medicine provider's follow-up note documented "good compliance" or there was documentation of an average of 4 hours a night for at least 70% of nights. The all-cause 90-day readmission rate was defined by any hospitalization > 24 hours but within 90 days after discharge.

Statistical analysis

Patient characteristics were summarized descriptively using means and standard deviation or medians and interquartile range for continuous variables and frequencies and percentages for categorical variables. Inpatient vs outpatient groups were compared using chi-square test for categorical variables and 2-sample *t*-test or Wilcoxon rank sum test for continuous numeric variables. Odds ratios and 95% confidence intervals were calculated from unadjusted and adjusted logistic models to evaluate the association of clinical variables with the decision to perform inpatient vs outpatient sleep testing. Multivariable logistic regression model was fitted to establish the determinants of choosing to do an inpatient vs outpatient sleep study (dependent variable) and to find associations with likelihood to keep follow-up appointments for PAP adherence and efficacy (dependent variable). Clinically relevant covariates were chosen and included in the model including patient demographics and comorbidities, along with the CCI, evaluating the decision to do an inpatient vs outpatient study as candidate independent variables. For the model evaluating

Figure 1—Follow-up outcome flow chart.



likelihood to keep the follow-up appointments, we entered inpatient vs outpatient testing, demographics, sleep study results, distance from our sleep center (in 10-mile increments), and CCI. Multicollinearity between comorbidities and the CCI was assessed by calculating the variance inflation factor for each variable.

We compared all-cause mortality from the time the sleep study was performed to the date of death or last follow-up between the 2 groups using the log-rank test. Patients lost to follow-up were censored at the time of last known contact with any inpatient or outpatient contact at our medical center. In addition, a multivariable Cox proportional hazards models was used to compare the survival between the two groups with and without adjustments for covariates, including age, sex, body mass index (BMI), O_2, AHI, heart failure, stroke, CCI, race, and follow-up. A 2-sided $P < .05$ was considered statistically significant. All analyses were performed using JMP 14 (SAS Institute, Cary, NC).

RESULTS

Demographics and sleep test type and results

Out of 485 patients with inpatient sleep medicine consults, 226 (47% underwent sleep testing while hospitalized) and 259 (53%) had sleep testing after discharge. Patient characteristics, comorbidities, type of sleep testing performed, SDB diagnosis, and treatment modality recommended are summarized in **Table 1**. The median age of patients was 68 years (interquartile range = 57–78) and 29.6% were women. Multiple medical comorbidities were frequent with a median CCI of 4 (IQR = 2–6). Sleep medicine referrals were primarily requested from medicine (43.62%) and cardiology services (26.1%). Polysomnogram was the most common type of sleep study performed in both groups, and OSA was the most common diagnosis (56%) followed by sleep-related hypoxemia (16%). There were a variety of discharge diagnoses (**Table 2**). The most common discharge diagnoses in both groups were respiratory diseases (33.40% inpatient group, 29.73% outpatient group, $P < .001$), followed by heart failure (12.39% inpatient group, 26.64% outpatient group, < 0.001). Respiratory diseases most commonly included chronic obstructive pulmonary disease exacerbation, pneumonia, respiratory failure, pulmonary embolism, and obesity hypoventilation syndrome.

The AHI was similar in both cohorts (inpatient AHI 29 events/h [8–60], outpatient AHI 30 events/h [12–71.5], $P = .097$), however the mean oxyhemoglobin saturation and central apnea index were significantly different between both groups (90% [87–93] vs 91% [88–93], $P = .034$); (0 [0–4] vs 0 [0–0.9], $P \leq .0001$), respectively. Oxygen was prescribed more often in the inpatient group (57.5% inpatient group, vs 42.5% outpatient group, $P < .001$, **Table 1**).

Patients who had inpatient sleep studies had higher CCI (median=4 [3–6] vs 3 [2–5], $P < .004$), acute stroke (13.72% vs 6.15%, $P = .005$), and neuromuscular disease (7.52% vs 3.08%, $P = .026$) as a medical comorbidity. There was no difference on basic demographics, type of insurance, and distance in miles from patient home residence to the sleep laboratory between inpatient and outpatient sleep testing group ($P > .05$). In the multivariable analysis, a higher CCI (OR = 1.14, 95%CI:1.03–1.25, $P < .001$), BMI (OR = 1.03, 95%CI:1.0–1.05, $P = .008$), and stroke as a medical comorbidity (OR = 2.22, 95%CI:1–4.9, $P < .049$) were strongly associated with the decision to perform inpatient sleep testing. Covariates included in the model are detailed in **Table 3**. We did not include the referral service and reason for consult as these variables are specific to our institution and may not be generalizable. The fit of the whole model was significant ($P < .001$).

Outcomes

Ninety-eight percent of patients in whom the sleep study was recommended as an outpatient kept the appointment for their sleep study. The PAP follow-up rate at 90 days was significantly lower in the inpatient cohort (39.90% inpatient group, 50.62% outpatient group [$P = .03$]). Additionally, out of 123 patients who did not follow up in the inpatient sleep study group, 9 (7%) patients had an active encounter at Mayo Clinic within 90 days of discharge and 11 (9%) patients had an encounter at Mayo Clinic within 180 days of discharge. Among the 120 patients who did not follow up in the outpatient group, 12 (10%) patients had an active encounter within 90 days post sleep study at Mayo Clinic and this number did not increase at 180 days. Factors associated with follow-up were assessed using univariate and multivariable logistic analysis (**Table S1** in the supplemental material and **Table 4**). In the multivariable analysis (**Table 4**), inpatient sleep testing remained significantly associated with decreased odds for follow up (OR = 0.62, 95%CI: 0.40–0.9), $P = .03$), but severity of OSA was not. PAP adherence rates at follow-up visits were high in both groups (88.9% inpatient group, 85.71% outpatient group, $P = .55$). Rehospitalization rates did not differ between inpatient or outpatient groups (26.42% vs 20.25%, $P = .13$) or between PAP-adherent vs nonadherent groups (19.74% vs 30.43% $P = .26$)

The all-cause mortality rate in the inpatient group was higher than in the outpatient group (43% vs 31%, $P = .012$). Without adjustment, the inpatient group had about 2-fold higher mortality than the outpatient group (hazard ratio: 1.91, 95% confidence interval [CI] 1.39–2.62, $P < .001$). The higher mortality during follow-up interval remained elevated after adjustment for covariates that included age, sex, race, BMI, oxygen therapy, AHI, heart failure, stroke, CCI and follow-up (hazard ratio: 1.82 95%CI 1.28–2.59, $P \leq .001$).

DISCUSSION

Our study was designed to examine our 10-year clinical experience of hospital sleep medicine consultation to better understand what patient factors determined the performance of inpatient rather than outpatient sleep studies and evaluate outcomes after discharge. From this analysis we can draw several important conclusions: 1) hospitalized patients with OSA and other SDB diagnoses had multiple medical comorbidities; 2) medically complex patients, higher BMI, increased age, and stroke were strongly associated with the decision to perform inpatient sleep testing; 4) those receiving inpatient sleep testing were less likely to keep postdischarge follow-up plans, but PAP

Table 1—Comparison of baseline demographics, clinical variables and sleep characteristics of patients that underwent inpatient vs outpatient sleep testing.

	Total (n = 485)	In-Patient Sleep Study (n = 226)	Out-Patient Sleep Study (n = 259)	*P**
Age, years, median (IQR)	68 (57-78)	69 (60-79)	67 (55-77)	.08
Female, n (%)	144 (29.6)	73 (32.30)	71(27.31)	.229
Race				.232
Caucasian	470 (96.9)	220 (97.35)	250(96.53)	
African American	4 (0.82)	3 (1.33)	1 (0.39)	
American Indian	1 (0.20)	1 (0.44)	0 (0)	
Asian	3 (0.62)	1 (0.44)	2 (0.7)	
Hispanic	7 (1.44	1 (0.44)	6 (2.32)	
Insurance				.548
Private	210 (56.8)	109 (58.3)	101(55.12)	
Government	160 (43.24	78 (41.71)	82(44.81)	
Distance, miles (IQR)[a]	62 (29-169)	60(28-140)	64(30-189)	.381
BMI kg/m^2, median (IQR)	36.5 (30–46.9)	38 (30–50)	36 (30–45)	.112
Charlson Comorbidity Index, median (IQR)	4 (2–6)	4 (3–6)	3 (2–5)	< .0004
Comorbidities, n (%)				
Coronary artery disease	107 (22.1)	46 (20.35)	61(23.46)	.408
Congestive heart failure	228 (46.91)	96(42.48)	132 (50.77)	.067
Stroke		31 (13.72)	16 (6.15)	.005
COPD	47 (9.67)	57 (25.22)	59 (22.69)	.514
Diabetes mellitus	116 (23.87) 178(36.70)	90 (40)	88 (33.85)	.168
Atrial fibrillation	158 (32.51)	69 (30.53)	89 (34.24)	.385
Hypertension	296 (60.9)	147 (65.04	149 (57.31)	.081
Restrictive lung disease	35 (7.2)	16 (7.08)	19 (7.31)	.922
Pulmonary hypertension	80 (16.4)	32 (14.16)	48 (18.46)	.202
Neuromuscular disease	25 (5.14)	17 (7.52)	8 (3.08)	.026
Consulting service				< .0001
Medicine	212 (43.62)	111 (49.12)	101 (38.85)	
Cardiology	127 (26.13)	32 (14.16)	95 (36.54)	
Medical intensive care unit	39 (8.02)	22 (9.73)	17 (6.54	
Respiratory care unit	55 (11.32)	39 (17.26)	16 (6.15)	
Surgery	49 (10.08)	20 (8.85)	29 (11.15)	
Surgical intensive care unit	4 (0.82)	2 (0.88)	2 (0.77)	
Reason for consult				< .0001
Rule out OSA	278 (57.32)	109 (48.23)	169 (65.25)	
PAP optimization	87(17.94)	32 (14.16)	55(21.24)	
Bilevel qualification	87(17.94)	62 (27.43)	25(9.65)	
Hypercapnic respiratory failure	33 (6.80)	23 (10.18)	10(3.85)	
Sleep study type				< .0001
Diagnostic polysomnogram	396 (81.69)	165 (73.01%)	231 (89.23)	
Positive airway titration	46 (9.5)	26 (11.50)	20 (7.69)	
Type III sleep study	37 (7.6)	30 (13.37)	7 (2.69)	

(continued on following page)

Table 1—Comparison of baseline demographics, clinical variables and sleep characteristics of patients that underwent inpatient vs outpatient sleep testing. (*Continued*)

	Total (n = 485)	In-Patient Sleep Study (n = 226)	Out-Patient Sleep Study (n = 259)	*P**
Peripheral arterial tonometry test	6 (1.2)	5 (2.21)	1 (0.38)	
Sleep study diagnosis				.005
OSA	259 (53.43)	119 (52.91)	140 (53.88)	
CSA	58(11.98)	17 (7.62)	41 (15.89)	
Hypoventilation	73 (15.08)	45 (20.18)	28 (10.85)	
Sleep-related hypoxemia	74 (15.29) 20	36 (16.14)	38 (14.73)	
Primary snoring	(4.13)	8 (3.16)	12 (4.65)	
AHI events/h, median (IQR)	32 (12-68)	29 (8-60)	30 (12–71.5)	.097
CAI events/h, median (IQR)	0 (0-2)	0 (0-0.9)	0 (0.38)	< .0001
Mean sleep O^2 saturation (%), median (IQR)	90 (87-93)	90 (87-92)	91 (88-93)	.034
Treatment modality recommended				< .0001
Auto-CPAP	57 (13.26)	35 (17.33)	22 (9.65)	
CPAP	127 (29.53)	43 (21.29)	84 (36.84)	
Bilevel-S	141 (32.79)	77 (38.12)	64 (28.07)	
Bilevel-ST	41 (9.53)	24 (11.88)	17 (7.46)	
ASV	52 (12.09)	13 (6.44)	39 (17.11)	
Positional Therapy	1 (0.23)	0 (0)	1 (0.44)	
O^2 therapy recommended	200 (41.2)	115 (57.50)	85 (42.50)	< .0001

*The 2-sample Wilcoxon test was used to calculate *P* values for continuous variables. The Pearson X^2 test was used to calculate *P* values for categorical variables. [a]Distance from patient's residence to sleep clinic. AHI = apnea-hypopnea index, ASV = adaptive servo-ventilator, Bilevel ST = bilevel spontaneous timed mode, Bilevel-S = bilevel spontaneous mode, BMI = body mass index, CAI = central apnea index, COPD = chronic obstructive pulmonary disease, CPAP = continuous positive airway pressure, CSA = central sleep apnea, IQR = interquartile range, OSA = obstructive sleep apnea, PAP = positive airway pressure.

adherence did not differ by testing location; and 5) the inpatient group had increased mortality risk but a similar readmission rates compared to the outpatient group. While our results pertain to a single academic center's experience and unique capabilities, our findings raise important implications for hospital sleep medicine practices and inform considerations for inpatient or outpatient sleep testing for SDB.

There is consistent clinical evidence suggesting that treatment of SDB in hospitalized patients improves patient outcomes. Despite these data, inpatient sleep testing is not established standard care and practices vary. Whereas outpatient sleep testing is well established, testing during acute illness seems to be evolving. In our study we found that the majority of the patients (53%) who underwent an outpatient sleep study had their study performed shortly after discharge, but still a large number of patients were tested while hospitalized (44%). One of the associated factors with inpatient sleep testing was a higher CCI score. In contrast to other studies,[24,25] the medical complexity of our patient population was high. In a study performed in hospitalized older adults with risk of OSA, the CCI score reported was 2.[5] Moreover, the cohorts of our hospital sleep referrals had higher comorbidity than our previously evaluated outpatient sleep laboratory population (CCI 1.88).[26] It seems likely that our sample may be more representative of hospitalized patients with SDB in the contemporary era, therefore, testing for SDB during hospitalization confers an opportunity to have access to the necessary equipment, ie, bariatric medical supplies, and skilled staff to provide the care that medically complex patients require. Additionally, patients with increased comorbidities also require more care coordination postdischarge, such as set up of nursing home or home health services for extra home monitoring or therapeutic interventions, increasing the number of barriers to receive timely outpatient evaluation and treatment for SDB consequently increasing the risk for deterioration. For example, in patients with stroke, which was also found to be associated with the likelihood of inpatient sleep testing, early use of PAP therapy within a few days of stroke onset appears to accelerate neurological recovery and reduce cardiovascular events.[27,28] Similarly in patients with acute chronic obstructive pulmonary disease exacerbation and hypercapnia, noninvasive positive pressure ventilation reduces readmissions and prolongs time to death.[29–31] Moreover, PAP therapy in heart failure patients during hospitalization confers reduction of readmission rates.[32,33] We found an all-cause readmission rate of 20–26%, and these results were not different among patients who were PAP adherent. Mayo Clinic's overall Center for Medicare and Medicaid Services readmission rate during the same study period was not significantly different from the national readmission rate of 12.5% of Center for Medicare and Medicaid Services patients.[34] This suggests

Table 2—Discharge diagnosis.

Discharge Diagnosis	Total (n = 485)	In-Patient Sleep Study (n = 226)	Out-Patient Sleep Study (n = 259)	P
Respiratory diseases	162 (33.40)	85 (33.40)	77 (29.73)	< .001
Heart failure	97 (20)	28 (12.39)	69 (26.64)	
Nonheart failure cardiovascular disease	60 (12.37)	16 (7.08)	44 (16.99)	
Miscellaneous[a]	39 (8.04)	26 (11.50)	13 (5.02)	
Infectious and parasitic disorders	34 (7.01)	23 (10.18)	11 (4.25)	
Diseases and disorders of the digestive system	21 (4.33)	10 (4.42)	11 (4.25)	
Nonneuromuscular diseases	27 (5.57)	17 (7.52)	10 (3.86)	
Diseases and disorders of the thorax	11 (2.27)	4 (1.77)	7 (2.70)	
Diseases and disorders of the MSK system	10 (2.06)	6 (2.65)	4 (1.54)	
Neoplastic disorders	10 (2.06)	7 (3.10)	3 (1.16)	
Diseases and disorders of the kidney and urinary tract	4 (0.82)	2 (0.88)	2 (0.77)	
Neuromuscular disorders	4 (0.82)	1 (0.44)	3 (1.16)	
Poisoning	2 (0.41)	1 (0.42)	1 (0.40)	
Mental diseases and disorders	1 (0.21)	0 (0.00)	1 (0.39)	

[a]Alcohol intoxication, falls, trauma due to motor vehicle accident, adrenal insufficiency, bone marrow transplant. MSK = musculoskeletal.

once again that hospitalized patients with SDB are at higher risk for poor postdischarge outcomes than the general population, stressing the importance of interventions that target comorbidities like SDB.

The inpatient group kept fewer PAP follow-up appointments than the outpatient group. However, those who kept the PAP follow-up appointment had similar high PAP adherence rates of 88–86%. This finding differs from Sharma et al[32] who reported a

Table 3—Multivariable analysis of predictors for in-patient sleep study.

Predictors	Odds Ratio (95% CI)	*P*
Charlson Comorbidity Index	1.14 (1.04–1.25)	.001
Age	1.02 (0.9–1.03)	.08
Sex	0.97 (0.60–1.58)	.91
BMI	1.03 (1.0–1.05)	.008
Race	0.54 (0.10–2.83)	.47
Heart Failure	0.66 (0.41–1.06)	.08
Coronary Artery Disease	0.71 (0.40–1.26)	.24
Hypertension	1.59 (0.99–2.57)	.055
Stroke	2.22 (1–4.9)	.049
Neuromuscular disease	2.12 (0.74–6.08)	.16
Diabetes mellitus	0.72 (0.44–1.72)	.19
Pulmonary hypertension	0.66 (0.36–1.21)	.18
Restrictive lung disease	0.94 (0.40–2.23)	.88
Atrial fibrillation	0.74 (0.44–1.24)	.26
COPD	1.48 (0.87–2.51)	.15

BMI = body mass index, CI = confidence interval, COPD = chronic obstructive pulmonary disease.

Table 4—Multivariable analysis of factors associated with follow-up.

Predictors	Odds Ratio (95% CI)	*P*
Age	1.01 (1.00–1.03)	.04
Sex	0.94 (0.59–1.51)	.802
Distance by 10 miles increment	1.00 (0.99–1.00)	.055
Charlson Comorbidity Index	1.00 (0.96–1.03)	.942
BMI kg/m^2	1.00 (0.98–1.02)	.778
AHI events/h	1.00 (0.99–1.00)	.939
SDB diagnosis		
OSA vs CSA	1.89 (0.94–3.76)	.071
OSA vs sleep related hypoxia	1.94 (1.04–3.62)	.04
OSA vs hypoventilation	1.11 (0.59–2.08)	.746
O_2 therapy	0.97 (0.61–1.57)	.928
Inpatient sleep testing	0.62 (0.40–0.90)	.03

AHI = apnea-hypopnea index, BMI = body mass index, CI = confidence interval, CSA = central sleep apnea, SDB = sleep-disordered breathing.

lower 3-month PAP adherence of 55% among 92 of 132 patients with acute decompensated heart failure who were asked to complete a postdischarge sleep study. In another study with hospitalized cardiac patients with newly diagnosed OSA, only 45% were full PAP users at 90 days posthospital discharge.[14] Similar low follow-up rates postdischarge have been seen in other studies.[12,32,35] In our study, of those who did not follow-up from the inpatient sleep testing group, only 11 patients had an active encounter in Mayo Clinic within 180 days postdischarge. This finding may suggest that some of these patients are more generally nonadherent or that they may have sought follow-up at other facilities closer to home. However, the distance of the patient's residence to our medical center by 10-mile increment was not associated with likelihood of follow-up, while inpatient sleep testing and increased age were. We speculate that the decreased PAP follow-up rate following inpatient study is due in part to limited education and understanding regarding the importance of SDB and PAP therapy on health outcomes for the inpatient cohort. Chervin et al[36] found that patients who received education on OSA, used PAP therapy 1.5 hours more per night than those receiving supportive phone calls. At our center, the education for outpatients diagnosed with SDB is fairly standardized and supported by video, printed, and verbal information. This contrasts with the inpatient situation, where we have not routinely employed use of these materials. This suggests one avenue for improvement and the importance of developing new care delivery models for this patient population.

We found that a high proportion of patients in whom we recommended outpatient testing kept their sleep study appointments, which may in part result from the relatively high degree of discharge planning and care coordination integrated into our hospital practice.[37] In our practice many of the sleep studies are scheduled for the same night of discharge, especially for those who live far away from our medical center, or when it seems imperative to ensure ongoing treatment for SDB as soon as possible. If the sleep study is scheduled for a later date, it is generally scheduled within 2 weeks of discharge with detailed instructions found in written discharge instructions.[37] This information is discussed with the patient, and the primary team also reminds the patient of sleep medicine instructions right before discharge. Similar findings were observed in a large population of patients discharged following admission for heart failure, where 94% of patients had documentation that an outpatient follow-up was scheduled before hospital discharge. Among these, 82% of the patients kept some follow-up appointment by 28 days.[38]

We chose to classify patients tested in our outpatient sleep center as outpatients (27%), even if they were discharged earlier that same day. It is reasonable to consider whether these patients might be more similar to the inpatient group. To evaluate that, we compared clinical characteristic of both outpatient groups, those who were tested on the night of discharge, and those tested on subsequent nights. We found no significant differences between these 2 outpatient groups in most regards (age, BMI, race, insurance, AHI, coronary artery disease , heart failure, chronic obstructive pulmonary disease, diabetes mellitus, atrial fibrillation, hypertension, interstitial lung disease, and pulmonary hypertension). We did find that the CCI was similar between these 2 outpatient groups, but lower than in the inpatient group. Finally, regarding our main conclusion, the proportion of follow-up visits is very similar between the 2 outpatient groups (same day outpatient 50.4%, other outpatients 50.8%) but much lower in the inpatient group (39.9%). We believe that the difference in follow-up between the outpatient groups and the inpatient group likely reflects differences in the readiness of the patient to learn and the increased emphasis on education and motivational aspects of care rendered in the outpatient environment, but these hypotheses must be tested in future studies.

Choosing to expedite an inpatient test was associated with higher comorbidity, as evidenced by the increased CCI. Additional evidence that these patients were sicker is that the adjusted mortality rate was higher in this cohort of patients. Interestingly AHI, oxygen therapy, BMI, CCI, or follow-up were not associated with increased risk for death. Further studies with

bigger sample size are needed to better understand the possible causal pathway for increased death among this patient population and investigate whether PAP adherence will change treatment outcomes. We were not able to evaluate whether PAP adherence influenced mortality because PAP adherence was unknow as a result of the lack of follow-up in a large number of patients.

Our study has several limitations. Common to all retrospective, single-center studies, ours is susceptible to referral and selection biases. The patient population at our midwestern referral medical center has a high proportion of white Americans and is not representative of national diversity or demographics. Furthermore, practice patterns have evolved over many years within a complex health care system, which may not resemble those found elsewhere. As noted, it is possible that some of our patients received follow-up and adherence evaluations at another medical center. As an international referral center, it is not uncommon to see that patients from distant regions follow-up elsewhere after initiation of therapy. However, in our analysis, distance from patient's residence to the sleep laboratory was not different between the 2 groups and was not associated with follow-up. In addition, there is no a priori reason to believe that patients keeping follow-up appointments elsewhere would behave in different ways from those seeking follow-up in our center. We lacked data regarding discharge to a skilled nursing facility, which can be another potential barrier for follow-up. However, we expanded our follow-up analysis to 180 days and only 11 patients more had some type of interaction with Mayo Clinic. Although remote compliance is now feasible through modem connection, due to our study period, PAP adherence data would not have been feasible to obtain in patients who underwent sleep testing more than 7 years ago.

This study also has several strengths. This is the first study to look at treatment adherence postdischarge in hospitalized patients tested for SDB while inpatient. Our results highlight the importance developing interventions and new care models to improve treatment adherence in patients who undergo sleep testing for SDB during hospitalization. Also, having both cohorts (inpatient and outpatient) allowed for comparison of clinical characteristics and treatment outcomes. We included patients with a variety of medical comorbidities, which resembles a typical sleep medicine consult service allowing us to be more generalizable than single disease-focused studies, like those aimed toward heart failure or stroke only.

In conclusion, hospitalized patients with SDB are a high-risk patient population, with poor postdischarge outcomes, hence inpatient sleep testing confers a timely opportunity to identify and treat modifiable comorbidities such as SDB. Even though follow-up with sleep medicine after discharge is challenging, PAP adherence might be optimal and similar regardless of the setting of the sleep study when patients follow-up. Novel patient-centered care delivery models are needed to improve treatment adherence which may result in improvement of health outcomes.

ABBREVIATIONS

AHI, apnea-hypopnea index
BMI, body mass index
CCI, Charlson Comorbidity Index
CI, confidence interval
OSA, obstructive sleep apnea
PAP, positive airway pressure
SDB, sleep-disordered breathing

REFERENCES

1. American Academy of Sleep Medicine. Frost & Sullivan. Hidden Health Crisis Costing America Billions Underdiagnosing and Undertreating Obstructive Sleep Apnea Draining Healthcare System. 2016. https://aasm.org/advocacy/initiatives/economic-impact-obstructive-sleep-apnea/. Accessed May 20, 2021.
2. Tietjens JR, Claman D, Kezirian EJ, et al. Obstructive sleep apnea in cardiovascular disease: A review of the literature and proposed multidisciplinary clinical management strategy. *J Am Heart Assoc.* 2019;8(1):e010440.
3. Shahar E, Whitney CW, Redline S, et al. Sleep-disordered breathing and cardiovascular disease: cross-sectional results of the Sleep Heart Health Study. *Am J Respir Crit Care Med.* 2001;163(1):19–25.
4. Goring K, Collop N. Sleep disordered breathing in hospitalized patients. *J Clin Sleep Med.* 2008;4(2):105–110.
5. Shear TC, Balachandran JS, Mokhlesi B, et al. Risk of sleep apnea in hospitalized older patients. *J Clin Sleep Med.* 2014;10(10):1061–1066.
6. Sharma S, Mather PJ, Efird JT, et al. Obstructive sleep apnea in obese hospitalized patients: A single center experience. *J Clin Sleep Med.* 2015;11(7):717–723.
7. Jennum P, Kjellberg J. Health, social and economical consequences of sleep-disordered breathing: a controlled national study. *Thorax.* 2011;66(7):560–566.
8. Bülbül Y, Ayik S, Ozlu T, Orem A. Frequency and predictors of obesity hypoventilation in hospitalized patients at a tertiary health care institution. *Ann Thorac Med.* 2014;9(2):87–91.
9. Marik PE, Chen C. The clinical characteristics and hospital and post-hospital survival of patients with the obesity hypoventilation syndrome: analysis of a large cohort. *Obes Sci Pract.* 2016;2(1):40–47.
10. D'Cruz RF, Murphy PB, Kaltsakas G. Sleep disordered breathing and chronic obstructive pulmonary disease: a narrative review on classification, pathophysiology and clinical outcomes. *J Thorac Dis.* 2020;12(suppl 2):S202–S216.
11. Patel N, Porter K, Englert J, Khayat R. Impact of central sleep apnea on the cost of heart failure readmissions. *J Card Fail.* 2020;26:S116.
12. Khayat R, Jarjoura D, Porter K, et al. Sleep disordered breathing and post-discharge mortality in patients with acute heart failure. *Eur Heart J.* 2015;36(23):1463–1469.
13. Naranjo M, Willes L, Prillaman BA, Stuart M, Quan F, Sharma S. undiagnosed OSA may significantly affect outcomes in adults admitted for COPD in an inner-city hospital. *Chest.* 2020;158(3):1198–1207.
14. Kauta SR, Keenan BT, Goldberg L, Schwab RJ. Diagnosis and treatment of sleep disordered breathing in hospitalized cardiac patients: a reduction in 30-day hospital readmission rates. *J Clin Sleep Med.* 2014;10(10):1051–1059.
15. Bravata DM, Concato J, Fried T, et al. Continuous positive airway pressure: evaluation of a novel therapy for patients with acute ischemic stroke. *Sleep.* 2011;34(9):1271–1277.
16. Ryan CM, Bayley M, Green R, Murray BJ, Bradley TD. Influence of continuous positive airway pressure on outcomes of rehabilitation in stroke patients with obstructive sleep apnea. *Stroke.* 2011;42(4):1062–1067.
17. Mokhlesi B, Masa JF, Afshar M, et al. The effect of hospital discharge with empiric noninvasive ventilation on mortality in hospitalized patients with obesity hypoventilation syndrome. An individual patient data meta-analysis. *Ann Am Thorac Soc.* 2020;17(5):627–637.
18. Spurr K, Morrison DL, Graven MA, Webber A, Gilbert RW. Analysis of hospital discharge data to characterize obstructive sleep apnea and its management in adult patients hospitalized in Canada: 2006 to 2007. *Can Respir J.* 2010;17(5):213–218.
19. Nowbar S, Burkart KM, Gonzales R, et al. Obesity-associated hypoventilation in hospitalized patients: prevalence, effects, and outcome. *Am J Med.* 2004;116(1):1–7.
20. Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. *Med Care.* 2005;43(11):1130–1139.

21. American Academy of Sleep Medicine. *International Classification of Sleep Disorders.* 3rd ed. Darien, IL: American Academy of Sleep Medicine; 2014.
22. Berry RB, Budhiraja R, Gottlieb DJ, et al. Deliberations of the Sleep Apnea Definitions Task Force of the American Academy of Sleep Medicine. Rules for scoring respiratory events in sleep: update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events. *J Clin Sleep Med.* 2012;8(5):597–619.
23. Centers for Medicare and Medicaid Services. Local Coverage Determination: Positive Pressure Airway Devices for the Treatment of Obstructive Sleep Apnea. Published 2020. https://www.cms.gov/medicare-coverage-database/details/lcd-details.aspx?LCDId=33718&ver=20&TAId=99&NCDId=330&ncdver=1&SearchType=Advanced&CoverageSelection=Both&NCSelection=NCA%7CCAL%7CNCD%7CMEDCAC%7CTA%7CMCD&ArticleType=Ed%7CKey%7CSAD%7CFAQ&PolicyType=Fi. Accessed February 8, 2021.
24. Morrish E, Shneerson JM, Smith IE. Why does gender influence survival in obstructive sleep apnoea? *Respir Med.* 2008;102(9):1231–1236.
25. Kreivi H-R, Itäluoma T, Bachour A. Effect of ventilation therapy on mortality rate among obesity hypoventilation syndrome and obstructive sleep apnoea patients. *ERJ Open Res.* 2020;6(2):00101–2019.
26. Colaco B, Herold D, Johnson M, Roellinger D, Naessens JM, Morgenthaler TI. Analyses of the complexity of patients undergoing attended polysomnography in the era of home sleep apnea tests. *J Clin Sleep Med.* 2018;14(4):631–639.
27. Parra O, Sánchez-Armengol A, Bonnin M, et al. Early treatment of obstructive apnoea and stroke outcome: a randomised controlled trial. *Eur Respir J.* 2011;37(5):1128–1136.
28. Aaronson JA, Hofman WF, van Bennekom CAM, et al. Effects of continuous positive airway pressure on cognitive and functional outcome of stroke patients with obstructive sleep apnea: A randomized controlled trial. *J Clin Sleep Med.* 2016;12(4):533–541.
29. Murphy PB, Rehal S, Arbane G, et al. Effect of home noninvasive ventilation with oxygen therapy vs oxygen therapy alone on hospital readmission or death after an acute COPD exacerbation: A randomized clinical trial. *JAMA.* 2017;317(21):2177–2186.
30. Coughlin S, Liang WE, Parthasarathy S. Retrospective assessment of home ventilation to reduce rehospitalization in chronic obstructive pulmonary disease. *J Clin Sleep Med.* 2015;11(6):663–670.
31. Galli JA, Krahnke JS, James Mamary A, Shenoy K, Zhao H, Criner GJ. Home non-invasive ventilation use following acute hypercapnic respiratory failure in COPD. *Respir Med.* 2014;108(5):722–728.
32. Sharma S, Chakraborty A, Chowdhury A, Mukhtar U, Willes L, Quan SF. Adherence to positive airway pressure therapy in hospitalized patients with decompensated heart failure and sleep-disordered breathing. *J Clin Sleep Med.* 2016;12(12):1615–1621.
33. Khayat RN, Javaheri S, Porter K, et al. In-hospital management of sleep apnea during heart failure hospitalization: A randomized controlled trial. *J Card Fail.* 2020;26(8):705–712.
34. Find and compare nursing homes, hospitals and other providers near you. Centers for Medicare and Medicaid Services. https://www.medicare.gov/care-compare/details/hospital/240010?city=Rochester&state=MN&zipcode=. Accessed August 26, 2021.
35. McAlister FA, Youngson E, Kaul P, Ezekowitz JA. Early follow-up after a heart failure exacerbation: The importance of continuity. *Circ Heart Fail.* 2016;9(9):e003194.
36. Chervin RD, Theut S, Bassetti C, Aldrich MS. Compliance with nasal CPAP can be improved by simple interventions. *Sleep.* 1997;20(4):284–289.
37. Moore C, McGinn T, Halm E. Tying up loose ends: discharging patients with unresolved medical issues. *Arch Intern Med.* 2007;167(12):1305–1311.
38. Hernandez AF, Greiner MA, Fonarow GC, et al. Relationship between early physician follow-up and 30-day readmission among Medicare beneficiaries hospitalized for heart failure. *JAMA.* 2010 May 5;303(17):1716–1722.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication February 23, 2021
Submitted in final revised form May 18, 2021
Accepted for publication May 19, 2021
Address correspondence to: Cinthya Pena Orbea, MD, Sleep Disorders Center, Neurological Institute, Cleveland Clinic, 9500 Euclid Avenue, Cleveland, OH 44119; Email: cinthya_pena@hotmail.com

DISCLOSURE STATEMENT

All authors have seen and approved this manuscript. Work for this study was performed at Mayo Clinic, Rochester, MN. This study was funded by Grant Number UL1 TR002377 from the National Center for Advancing Translational Sciences (NCATS). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH. Timothy I. Morgenthaler has consulted for Respicardia, Inc., and Withings. The other authors report no conflicts of interest.