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SCIENTIFIC INVESTIGATIONS

Association between positive airway pressure therapy adherence and health care resource utilization in patients with obstructive sleep apnea and type 2 diabetes in the United States

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Study Objectives: There is a complex interplay between obstructive sleep apnea (OSA) and type 2 diabetes. There are minimal data regarding the effects of treating OSA with positive airway pressure (PAP) therapy on outcomes and health care resource utilization (HCRU) in patients with OSA and type 2 diabetes. We investigated the impact of PAP adherence on HCRU and costs in this population.

Methods: A retrospective analysis was conducted with a cohort of OSA patient from a US administrative claims dataset linked to objective device data (AirView, ResMed Corp., San Diego, California). Propensity score matching was used to control for potential imbalance in baseline covariates between PAP-adherent and -nonadherent patients. Newly diagnosed patients with OSA aged ≥ 18 years with type 2 diabetes were included. PAP adherence was defined as meeting Centers for Medicare and Medicaid Services compliance criteria in all 8 90-day periods over 2 years. HCRU was based on the number of all-cause doctor visits, emergency room visits, inpatient hospitalizations, and PAP equipment and supplies.

Results: In years 1 and 2 of PAP therapy, HCRU was significantly lower in adherent vs nonadherent patients (number/patient for emergency room visits 0.68 ± 1.47 vs 0.99 ± 1.91 [year 1], 0.69 ± 1.43 vs 0.95 ± 1.89 [year 2]; for hospitalizations 0.16 ± 0.58 vs 0.22 ± 0.62 [year 1], 0.15 ± 0.51 vs 0.21 ± 0.74 [year 2]; all $P < .001$). Changes in estimated total 24-month payments were higher for nonadherent patients ($2,282, 95% confidence interval: $1,368, $3,205).

Conclusions: Consistent use of PAP therapy over 2 years was associated with decreased HCRU in patients with OSA and type 2 diabetes, strongly suggesting a role for screening and treating OSA in type 2 diabetes.

Keywords: obstructive sleep apnea, positive airway pressure, diabetes, adherence, resource utilization, hospitalization

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BRIEF SUMMARY

Current Knowledge/Study Rationale: There is a complex interplay between obstructive sleep apnea (OSA) and type 2 diabetes. Minimal data are available regarding the effects of treating OSA with positive airway pressure therapy on outcomes and health care resource utilization in patients with OSA and type 2 diabetes.

Study Impact: This real-world study identified a positive association between adherence to positive airway pressure therapy and reductions in health care resource utilization and associated costs in OSA patients with type 2 diabetes. Patients with type 2 diabetes should be screened for OSA because of the potential for positive airway pressure therapy to decrease health care resource use and improve outcomes.

INTRODUCTION

Obstructive sleep apnea (OSA) is one of the most common chronic diseases and is estimated to affect up to 1 billion people worldwide.[1,2] Perturbations such as intermittent hypoxia,[3] hypercapnia, frequent arousals, and insufficient sleep cause sympathetic activation and are thought to contribute to cardiometabolic comorbidities, which occur in > 50% of patients with OSA.[4–6]

There is a complex interplay between OSA and type 2 diabetes.[7] Studies consistently demonstrate that the prevalence of OSA is up to 60% in patients with type 2 diabetes and even higher in those who are also obese.[4,8] The relative risk of incident diabetes is increased in individuals with vs without OSA.[4,9] Furthermore, untreated OSA is associated with poor glycemic control in type 2 diabetes[10] and increases the risk of microvascular complications.[11,12]

Positive airway pressure (PAP) therapy is the first-line treatment for moderate-to-severe OSA.[13–15] Randomized controlled trials investigating the effect of PAP in individuals with type 2 diabetes are scarce, have small sample sizes, and report

inconsistent results. Several meta-analyses report an inconsistent effect of PAP on glycemic control, possibly due to variable adherence to therapy, as well as differences in baseline glycemic control, study duration, and diabetes medication use.[16–18] In a substudy of the Sleep Apnea cardioVascular Endpoints (SAVE) trial[19] that randomly assigned patients with OSA and stable cardiovascular disease to PAP plus usual care or usual care alone, PAP treatment of OSA for up to 4 years did not improve glycemic control in patients with preexisting diabetes, although mean nightly PAP usage was only 3.6 hours.[20,21] However, PAP has been shown to reduce blood pressure significantly and to improve quality of life in OSA patients with type 2 diabetes.[22]

Randomized controlled trials evaluating the effects of treating OSA in patients with type 2 diabetes have several limitations, including low adherence to PAP, which is common in patients with diabetes.[23] In addition, randomized controlled trials may not be representative of what happens in real life and may be biasing populations agreeing to PAP treatment.[24] Both OSA and type 2 diabetes are associated with high health care resource utilization and costs.[25–28] Therefore, another way to address whether PAP effectively improves diabetes health trajectories would be to determine whether the economic burden of type 2 diabetes is influenced by PAP therapy adherence. A recent systematic review identified a gap in current understanding of the economic impact of OSA in the presence of diabetes.[29]

This study investigated whether PAP adherence, based on the Centers for Medicare and Medicaid Services (CMS) compliance, was associated with improved health outcomes and reduced costs in OSA patients with comorbid type 2 diabetes over a 2-year period.

METHODS

Data sources

This study was conducted using a linked dataset that combined administrative claims data and objective individual patient usage data collected from cloud-connected PAP devices. The deidentified payer-sourced ("closed") adjudicated administrative claims data contain more than 100 geographically dispersed health plans in the United States (licensed from Inovalon Insights LLC, Bowing, Maryland). PAP therapy usage data were obtained from AirView (ResMed Corp., San Diego, California), which collects compliance and therapy data when patients use their PAP devices. Objective PAP data collected in AirView include treatment usage, clinical therapy metrics (such as leak and pressure), and residual respiratory events.[30–32] The AirView and Inovalon datasets were linked through a tokenization process via a third-party health data connectivity company. Irreversible encrypted tokens for each dataset were derived from personally identifiable information (eg, name and date of birth). Prior to linkage, each dataset was deidentified, and then the deidentified datasets were linked using the encrypted tokens. The resulting linked database underwent a Health Insurance Portability and Accountability Act (HIPAA) expert evaluation to ensure HIPAA compliance. The study design was reviewed by an Institutional Review Board (Advarra, reference number Pro0004005) and deemed exempt from Institutional Review Board oversight.

Study population

Eligible patients were adults (age ≥ 18 years) with a new OSA diagnosis between June 2014 and April 2018. OSA (*International Classification of Diseases, 9th Revision, Clinical Modification* [ICD-9-CM]: 327.23 and *International Classification of Diseases, 10th Revision, Clinical Modification* [ICD-10-CM]: G47.33) was diagnosed within 60 days of a sleep test (Healthcare Common Procedure Coding System 95808, 95810, 95811, G0398–G0400). All patients received PAP therapy (continuous or automatic PAP) using an AirSense 10 device (ResMed Corp., San Diego, California) with ≥ 1 year of claims data prior to the first sleep test and 2 years of claims data after device setup. Type 2 diabetes was identified by the presence of ≥ 2 claim dates with a diagnosis of type 2 diabetes (ICD-9-CM: 250.*0, 250.*2, 357.2, 362.0*, 366.41; ICD-10-CM E11.*) in the year prior to PAP device setup. Patients were excluded if any of the following occurred in the year before PAP device setup: evidence of PAP resupply; presence of diagnosis codes for type 1 diabetes (ICD-9-CM: 250.*1, 250.*3; ICD-10-CM: E10.*); central sleep apnea (ICD-9-CM: 327.21, 327.27; ICD-10-CM: G47.31, G47.37); nocturnal hypoventilation (ICD-9-CM: 327.26; ICD-10-CM: G47.36); pregnancy (ICD-9-CM: 630.*-679.*, 792.3, 796.5, V22.*, V23.*, V27.*, V28.*, V72.42, V91.*; ICD-10-CM: O00.*-O9A.*); end-stage renal disease (ICD-9-CM: 585.6; ICD-10-CM: N18.6); or dialysis use (ICD-9-CM: V45.11; ICD-10-CM: Z99.2).

Adherence to PAP therapy was defined based on CMS criteria, which classifies a patient as compliant if there is device usage for ≥ 4 hours/night on ≥ 70% of nights in a consecutive 30-day period within a 90-day timeframe. For our study, patients were defined as being adherent if they met CMS criteria for eight consecutive 90-day timeframes from device setup. Patients were considered nonadherent if CMS criteria were met in none of the 8 consecutive 90-day timeframes. Patients who met the CMS criteria in some, but not all, timeframes were classified as having "intermediate" adherence (**Table S1** in the supplemental material) and excluded from analyses so that comparisons of health care usage were made between two distinct adherence pattern groups (ie, nonadherent and adherent). PAP usage of the "intermediate" adherence group widely varied (number of quarters in which patients met CMS criteria ranged from 1–7).

Covariates

Baseline covariates were derived from claims data. These included demographic factors (age, payer, sex, and obesity), comorbidities in the year before PAP setup (coronary artery disease, heart failure, atrial fibrillation, chronic obstructive pulmonary disease, asthma, cancer, anxiety, depression, psychotic mood disorders, other mood disorders, hyperlipidemia, gastroesophageal reflux disease, and hypertension), type 2 diabetes complications in the prior year (retinopathy, nephropathy, neuropathy, peripheral vascular disease, foot ulcers, amputations, circulatory, and other), prior-year health care resource use (all-cause inpatient hospitalization and all-cause emergency room

[ER] visits), and diabetes medication utilization. Diabetes-related medication use was evaluated in the 90 days prior to initiation of PAP therapy.

Outcomes

Health care resource utilization was determined based on the number of all-cause doctor (physician and outpatient hospital) visits, all-cause ER visits, all-cause inpatient hospitalizations, and PAP equipment and supplies (from claims data). Health care resource costs used for analyses do not represent charged or paid amounts but rather are calculated costs based on a proprietary Proxy Financials algorithm developed by the claims database provider Inovalon Insights LLC. The Inovalon Insights LLC algorithm is based on CMS Medicare prospective payment system fee schedules. This approach enriches the dataset with relative amounts that reflect Medicare-allowed payments across provider services and treatments. Risk-adjusted models were used to determine the impact of 2-year PAP adherence on the number of all-cause inpatient hospitalizations and all-cause ER visits.

Statistical analysis

Baseline characteristics are presented using descriptive statistics. Models were constructed on the unmatched population to determine the expected mean number of 2-year all-cause hospitalizations and all-cause ER visits using a generalized linear model with a logit link. Goodness of fit was assessed by McFadden's grouped log-likelihood *R* squared and explanatory potential by 90th percentile predicted range. The linear predictor from the model was then scaled to create a risk score to show the effects of predictors and quantify the risk group for participants. The number needed to treat to avoid an event (ER visit or hospitalization) was calculated as 1/absolute risk reduction.

A hybrid approach was used to ensure appropriate comparison between adherence groups when assessing the impact of adherence on health care resource use and costs. First, a logistic regression model based on risk of not adhering to PAP therapy was developed using baseline demographics, comorbidities, and prior-year health care resource utilization. All other covariates were not significant and therefore not included in the final model. A propensity score was calculated based on model coefficients and used in greedy matching. Additionally, exact matching of the following baseline variables was performed to ensure balanced groups: age group, sex, payer type, prior all-cause hospitalizations, and prior all-cause ER visits. Finally, to ensure that the matched cohorts resembled the original nonadherent cohort, adherent patients were matched to a randomly down-sampled subgroup of nonadherent patients without replacement. The balance between the matched cohorts was assessed using standardized mean differences of baseline covariates; a standardized mean difference of less than 0.1 indicates negligible difference.[33] Differences in health care resource use between matched samples before and after PAP setup were assessed using paired Wilcoxon tests. Difference-in-differences analysis was used to compare changes in mean health care resource use and estimated total payments in the first year immediately after PAP initiation, as well as the estimated total payments in the 2 years after PAP initiation. This comparison was used to identify changes before and after PAP use in the nonadherent group above or below the changes in the adherent group. The analysis was performed using 10,000 bootstrap samples of the difference between post and pre periods for paired differences (nonadherent – adherent) in the matched cohort.[34] Statistical analyses were performed using the R statistical package version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria).[35]

RESULTS

Study population

A total of 32,318 OSA patients with comorbid type 2 diabetes who were treated with PAP therapy were identified (mean age 57.4 years, 46.5% female, 26.7% nonadherent, 61.0% with commercial insurance) (**Table 1**). Forty percent of the population had at least 1 diabetes-related complication; the mean number of diabetes-related complications was 0.63 and the most common complication was neuropathy (21%). Covariates identified as being associated with greater risk of nonadherence included younger age (18–54 years), Medicaid insurance coverage, diabetes-related complications, being less compliant with diabetes medication (medication fill rates < 9/year), comorbid mood disorders (of which psychotic disorders were associated with the highest nonadherence risk), and comorbid chronic obstructive pulmonary disease. After matching, adherent and nonadherent patient cohorts were well-balanced (all standardized mean differences < 0.1) on all baseline characteristics (**Table 1**). Diabetes-related medication use in the 90 days prior to starting PAP was similar in the matched adherent and nonadherent cohorts, including the use of sodium-glucose cotransporter 2 inhibitors and glucagon-like peptide-1 receptor agonists (**Table S2**). Medication use remained similar during follow-up years (**Table S3**).

PAP usage

Mean PAP usage during the first year of therapy for the overall population was 4.1 days/week, 3.7 hours/day, and 5.3 hours per use day. Patients who adhered to PAP used the device almost every day of the week (mean 6.7 days/week) and consistently for 7 hours each day based on both hours per day or hours per use day (6.8 and 7.1, respectively). In contrast, matched nonadherent patients used their PAP devices infrequently (0.9 days/week) and for a short period of time on days when the device was used (0.4 hours/day and 3.0 hours/use day).

Diabetes complications

Compared with baseline, the number of diabetes-related complications increased in the year after PAP therapy initiation in both the adherent and nonadherent matched cohorts, with no statistically significant between-group difference (mean 0.76 vs 0.80, $P = .20$) (**Table S4**). Approximately 20% of patients in both cohorts who did not have complications at baseline had an emergent complication in the year after PAP therapy initiation; the most common incident complications in the adherent and nonadherent cohorts were neuropathy (8.4% and 9.3%) and

Table 1—Baseline characteristics of the study population, overall and for propensity score–matched adherence subgroups.

Characteristics	Overall (n = 32,318)	Matched Cohort*		
		Adherent (n = 3,203)	Nonadherent (n = 3,203)	SMD
Female sex, n (%)	15,034 (46.5)	1,546 (48.3)	1,546 (48.3)	0
Age, years	57.4 ± 11 (57)	56.7 ± 10.6 (57)	56.3 ± 11.2 (56)	
Age group, n (%)				
18–54 years	12,455 (38.5)	1,388 (43.3)	1,388 (43.3)	0
55–69 years	15,300 (47.3)	1,421 (44.4)	1,421 (44.4)	0
≥70 years	4,563 (14.1)	394 (12.3)	394 (12.3)	0
Payer, n (%)				
Commercial	19,716 (61.0)	1,752 (54.7)	1,752 (54.7)	0
Medicare Advantage	6,459 (20.0)	891 (27.8)	891 (27.8)	0
Medicaid	6,143 (19.0)	560 (17.5)	560 (17.5)	0
Obesity, n (%)				
Morbidly obese	12,731 (39.4)	1,319 (41.2)	1,230 (38.4)	0.06
Obese	9,529 (29.5)	908 (28.3)	912 (28.5)	<0.01
No listed obesity	10,058 (31.1)	976 (30.5)	1,061 (33.1)	0.06
Comorbidities, n (%)				
Mean number†	1.9	2.0	2.0	0.03
Coronary artery disease	7,954 (24.6)	795 (24.8)	801 (25.0)	<0.01
Heart failure	4,368 (13.5)	441 (13.8)	487 (15.2)	0.04
Cerebrovascular disease	2,995 (9.3)	274 (8.6)	341 (10.6)	0.07
Asthma	6,243 (19.3)	649 (20.3)	688 (21.5)	0.03
COPD	5,475 (16.9)	606 (18.9)	640 (20.0)	0.03
Pneumonia	2,162 (6.7)	243 (7.6)	210 (6.6)	0.04
Depression	8,153 (25.2)	884 (27.6)	911 (28.4)	0.02
Anxiety	6,667 (20.6)	690 (21.5)	732 (22.9)	0.03
Psychotic disorders	1,656 (5.1)	188 (5.9)	189 (5.9)	<0.01
Other mood disorders	2,401 (7.4)	244 (7.6)	273 (8.5)	0.03
Hypertension	28,164 (87.1)	2,768 (86.4)	2,794 (87.2)	0.02
Hyperlipidemia	25,794 (79.8)	2,526 (78.9)	2,513 (78.5)	<0.01
Gastroesophageal reflux disease	10,335 (32.0)	1,081 (33.7)	1,115 (34.8)	0.02
Diabetes complications, n (%)				
Mean number	0.63	0.68	0.70	0.03
Any complication	12,925 (40.0)	1,370 (42.8)	1,383 (43.2)	<0.01
Retinopathy	3,131 (9.7)	339 (10.6)	323 (10.1)	0.02
Nephropathy	3,725 (11.5)	440 (13.7)	350 (10.9)	0.09
Neuropathy	6,800 (21.0)	734 (22.9)	793 (24.8)	0.04
Circulatory	1,865 (5.8)	184 (5.7)	227 (7.1)	0.05
Peripheral vascular disease	2,150 (6.7)	202 (6.3)	256 (8.0)	0.07
Foot ulcers	570 (1.8)	55 (1.7)	75 (2.3)	0.04
Diabetes medications‡, n (%)	**26,915 (83.3)**			
≥ 1 oral or noninsulin medication	18,646 (69.3)	1,924 (70.7)	1,903 (69.6)	0.01
≥ 1 insulin medication	5,352 (19.9)	545 (20.0)	606 (22.1)	0.05
None	7,166 (26.6)	680 (25.0)	714 (26.1)	0.03

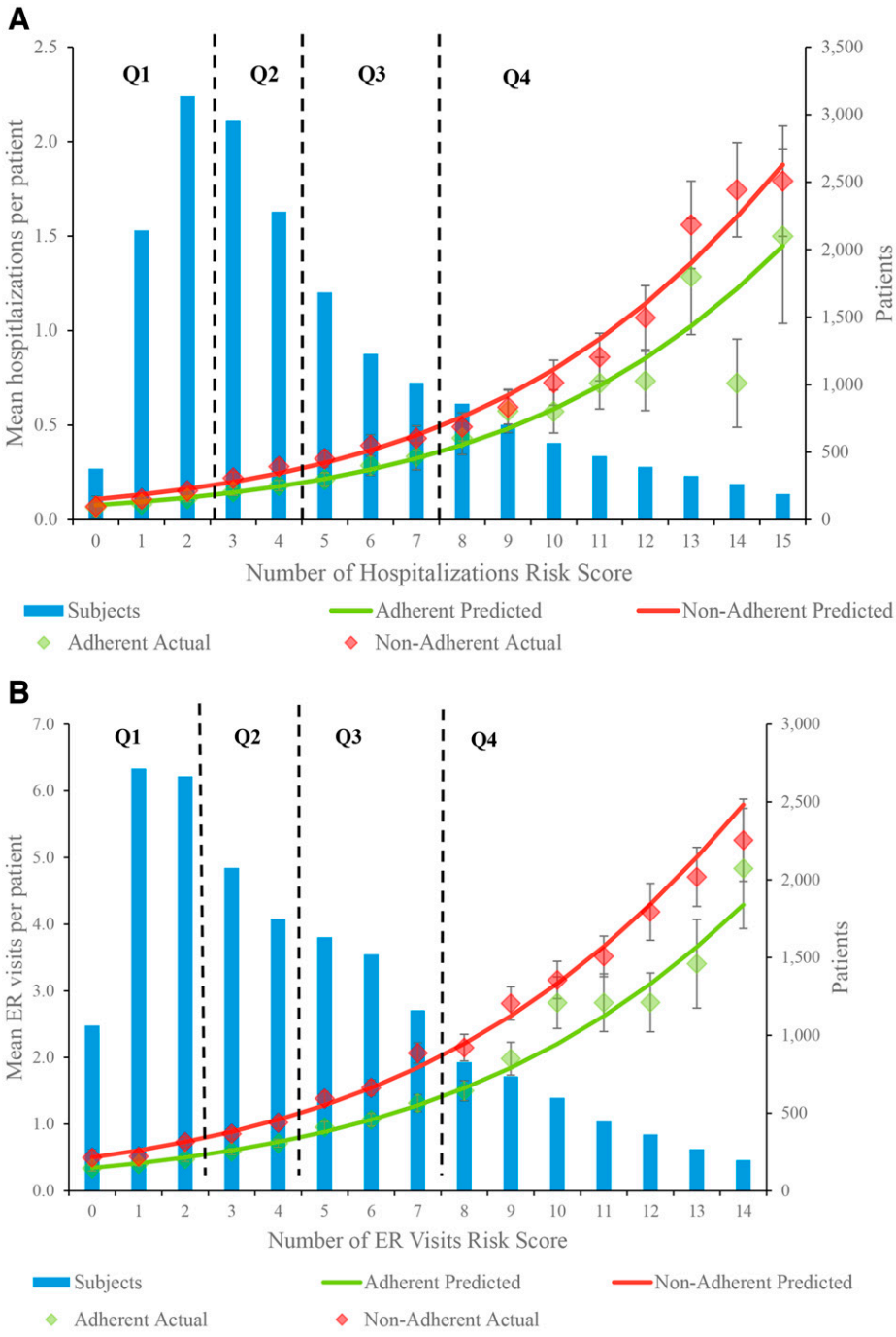
Values are mean ± SD (median) or number of patients (%). *Matched cohort created based on propensity model (risk of not adhering to the positive airway pressure therapy model) and exact matching on age group, sex, payer type, prior all-cause hospitalizations, and prior all-cause emergency room visits. †Excluding hyperlipidemia, hypertension, and obesity. ‡Denominators for percentages represent the number of patients with available medication information. COPD = chronic obstructive pulmonary disease, SMD = standardized mean difference.

nephropathy (4.4% and 4.6%) (**Table S4**). For patients with complications at baseline, 29.6% of the adherent cohort and 33.0% of the nonadherent cohort had an emergent complication in the year after PAP initiation (**Table S4**). Statistical comparisons were not performed on subgroups due to covariate imbalance when limiting to subgroup comparisons.

Risk-adjusted outcomes

The results of models predicting the number of 2-year all-cause hospitalizations and all-cause ER visits based on PAP adherence are shown in **Figure 1**. Being adherent to PAP was significantly associated with reduced number of all-cause hospitalizations ($P < .001$), with a number needed to treat of 4. The magnitude of

Figure 1—Impact of positive airway pressure therapy adherence on the number of all-cause hospitalizations **(A)** and all-cause emergency room (ER) visits **(B)**.



Red and green solid lines represent values predicted by the respective health care resource risk model. Blue vertical bars represent number of patients in each risk group. Dots represent the actual mean values from the observed data, with error bars representing the 90% confidence interval. Q1 = first quartile, Q2 = second quartile, Q3 = third quartile, Q4 = fourth quartile.

benefit varied by patient health state, from a number needed to treat of 23.2 in those with a score of 0–3 (low hospitalization risk; 30% of the population) to a number needed to treat of 2.7 for those with a score > 8 (high hospitalization risk; 21% of the population).

Being adherent to PAP also significantly reduced the number of ER visits ($P < .001$), with an average of 0.7 ER visits avoided per adherent patient. Again, the magnitude of benefit varied by patient health state, from 1 ER visit avoided for every 4.7 treated in low-risk patients (score of 0–2; 34% of the population) to 2 ER visits avoided for every adherent patient in the highest risk group (score ≥ 8; 23% of the population).

Two-year health care resource utilization

The number of ER visits and inpatient hospitalizations in year 1 and year 2 of PAP usage was significantly lower in adherent vs nonadherent patients from the matched cohort (**Table 2** and **Figure 2**). Reductions in health care resource utilization seen in year 1 were maintained in year 2. Similarly, the difference-in-difference analyses demonstrated that in the first year of PAP use nonadherent patients had a significantly larger increase in ER visits per person (mean 0.30, 95% confidence interval [CI]: 0.23, 0.37) and inpatient hospitalizations (mean 0.06, 95% CI: 0.04, 0.09) and fewer doctor visits (mean −1.21, 95% CI: −1.60, −0.81). There was a 0.7 difference in doctor visits per patient between adherent and nonadherent patients in PAP year 1 when analyzing doctor visits associated with an OSA diagnosis, accounting for more than half of the difference-in-difference.

Baseline health care resource costs were similar between matched adherent and nonadherent patients (**Table S5**). In the matched cohort, adherent patients had lower ER visit costs in PAP year 1 ($P < .001$) and PAP year 2 ($P < .001$) compared with nonadherent patients; there was a similar trend for inpatient hospitalization costs (**Table S5**). OSA-related test costs prior to PAP therapy initiation were similar in the adherent and nonadherent groups ($P = .62$) but, as expected, equipment-related costs in PAP years 1 and 2 were significantly higher for adherent vs nonadherent patients (year 1: $1,246 vs $794, $P < .001$; year 2: $509 vs $97, $P < .001$). The difference-in-difference analysis of estimated total payments for the first year after PAP therapy initiation demonstrated statistically higher estimated total payments for the nonadherent cohort: $675 (95% CI: $107, $1,249) and higher payments when OSA-related expenses are not included ($1,135, 95% CI: $565, $1,702) (**Table 3**). Greater differences in estimated total payments were observed when assessing the 24-month period after PAP therapy initiation with or without OSA-related expenses included ($1,410, 95% CI: $500, $2,335; without OSA-related expenses: $2,282, 95% CI: $1,368, $3,205).

DISCUSSION

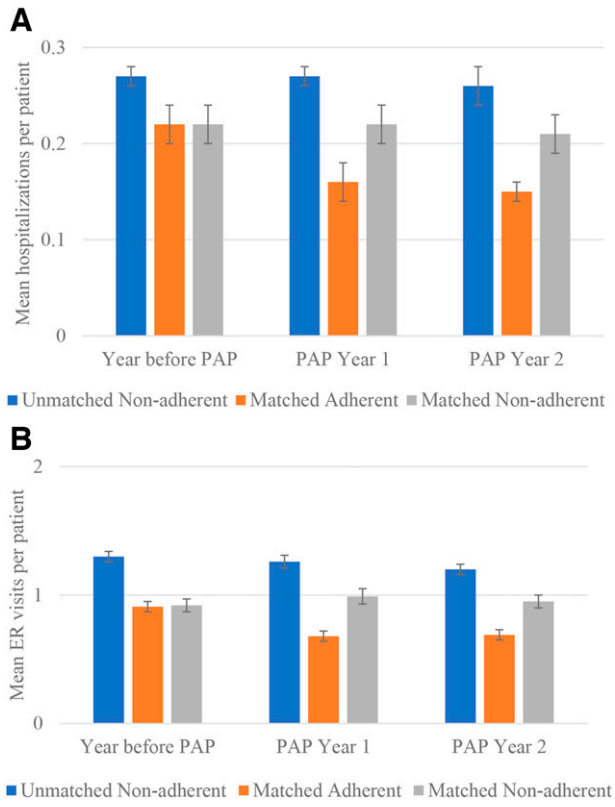
Our study identified a positive association between adherence to PAP therapy and reductions in health care resource utilization in patients with OSA and comorbid type 2 diabetes. These findings highlight an opportunity that may exist for improved health outcomes for patients treated with PAP therapy, particularly since health care utilization by patients with diabetes has been estimated to be high, $327 billion in 2017.[36–39] Adherence to PAP therapy was associated with the avoidance of 4 all-cause hospitalizations and 0.7 all-cause ER visits per adherent patient on average. These values were favorable and suggest the value of encouraging nonadherent patients to adhere to therapy, especially in high-risk type 2 diabetes patients, where benefits appeared to be even greater.

Table 2—Health care resource use in the unmatched and matched cohorts.

Resource Use (Mean Number per Patient)	Unmatched		Matched*		
	Adherent (n = 10,235)	Nonadherent (n = 8,622)	Adherent (n = 3,203)	Nonadherent (n = 3,203)	*P*†
Year before PAP					
Doctor visits	10.24 ± 8.00	13.70 ± 11.15	11.93 ± 9.44	13.05 ± 10.90	<.001
ER visits	0.57 ± 1.13	1.30 ± 2.47	0.91 ± 1.49	0.92 ± 1.62	.21
Inpatient hospitalizations	0.17 ± 0.52	0.27 ± 0.75	0.22 ± 0.59	0.22 ± 0.59	.32
PAP year 1					
Doctor visits	11.0 ± 9.0	14.0 ± 12.0	13.13 ± 10.99	13.05 ± 11.36	.76
ER visits	0.46 ± 1.09	1.26 ± 2.57	0.68 ± 1.47	0.99 ± 1.91	<.001
Inpatient hospitalizations	0.13 ± 0.51	0.27 ± 0.79	0.16 ± 0.58	0.22 ± 0.62	<.001
PAP year 2					
Doctor visits	10.46 ± 9.25	12.31 ± 11.42	12.31 ± 11.15	11.69 ± 10.59	.99
ER visits	0.47 ± 1.08	1.20 ± 2.49	0.69 ± 1.43	0.95 ± 1.89	<.001
Inpatient hospitalizations	0.12 ± 0.48	0.26 ± 0.90	0.15 ± 0.51	0.21 ± 0.74	<.001

Values are mean ± SD. *Matched cohort created based on propensity model (risk of not adhering to PAP therapy model) and exact matching on age group, sex, payer type, prior all-cause hospitalizations, and prior all-cause ER visits. †*P* values are for the adherent vs nonadherent comparison in the matched population. ER = emergency room, PAP = positive airway pressure.

Figure 2—Mean number of hospitalizations **(A)** and emergency room (ER) visits **(B)** in the different patient cohorts.



Error bars represent 90% confidence intervals. Blue, orange, and gray vertical bars represent the mean number of health care resource uses per patient in cohort. PAP = positive airway pressure.

To our knowledge, this is the largest health care economic analysis of OSA patients with comorbid type 2 diabetes. Previous analyses have identified a positive association between PAP adherence and both glycemic and blood pressure control.[17,40–44] In a proof-of-concept mechanistic study, PAP treatment in a laboratory setting to ensure full compliance for 1 week improved 24-hour mean glucose levels, especially overnight and in those with poor glycemic control at baseline.[40] The duration of PAP usage might play a significant role in glucose metabolism because OSA during rapid eye movement sleep was more strongly related to glycemic control than OSA during non-rapid eye movement sleep.[41] Babu et al analyzed sleep clinic patients and found that PAP usage of > 4 hours/day was associated with glycemic control, but no such association was found when PAP usage was < 4 hours/day.[42] A retrospective analysis of 1,295 sleep clinic medical records in type 2 diabetes with OSA showed that adherent PAP users had significantly lower blood pressure than nonadherent PAP users and demonstrated a dose response with greater hours of PAP usage.[43] A UK case-control study also reported better blood pressure and glycemic control during PAP therapy and determined that PAP treatment in OSA patients with type 2 diabetes was a cost-effective use of National Health Services resources.[44]

The findings of our study help to address a gap identified in a 2019 systematic review[29] regarding the economic impact of OSA in the presence of comorbid diseases, including diabetes. Our results are in alignment with previous studies suggesting that PAP adherence was associated with a reduction in health care cost in acute care and inpatient settings, and in overall health care utilization in patients with OSA, with and without preexisting cardiovascular disease or associated chronic obstructive pulmonary disease (overlap syndrome).[36] We further extend previous findings by including a longer 2-year duration of PAP use, incorporating for the first time in the literature objective PAP usage metrics to define adherence and focusing on patients with high documented health care utilization.[36–39] The use of a linkage of data from a national claims database and objective PAP usage data is a key strength of this study. In contrast, previous studies have often estimated PAP adherence using surrogate measures rather than objectively recorded device usage. Based on its strengths and taken together with previous studies, our data support the benefits of OSA treatment in patients with type 2 diabetes.

There are also some limitations of our study worth noting. While we were able to use statistical methods to control for many

Table 3—Difference-in-differences for estimated total payments in matched cohort.

Estimated Total Payments ($)	Year Before PAP (Nonadherent – Adherent)	Year(s) After PAP (Nonadherent – Adherent)	Difference-in-Differences*
12 months after PAP			
Estimated total payments	47 (−340, 431)	722 (216, 1,226)	675 (107, 1,249)
Estimated total payments – no OSA†	39 (−342, 419)	1,174 (671, 1,677)	1,135 (565, 1,702)
24 months after PAP			
Estimated total payments	47 (−340, 431)	1,457 (518, 2,364)	1,410 (500, 2,335)
Estimated total payments – no OSA†	39 (−342, 419)	2,321 (1,386, 3,223)	2,282 (1,368, 3,205)

Values are mean (95% confidence interval). *Difference-in-differences estimates of mean estimated total payments using 10,000 bootstrap samples of the difference between post and pre year for paired differences (nonadherent – adherent) in the matched cohort. The 95% bootstrap confidence interval for the estimate is also shown. †Does not include sleep test and apnea equipment estimated payments. OSA = obstructive sleep apnea, PAP = positive airway pressure.

potential differences in baseline characteristics of the patient population, some minor imbalances remained after matching, notably for obesity, fills of insulin medications, and some diabetes-related complications. Additionally, due to the imbalance of subgroups, we were unable to conduct statistical comparisons to assess the association of PAP adherence with diabetic complications. Further research is needed to understand this relationship. It is also important to note that medication costs were not available and therefore were not included in total cost estimates. However, given the similarities in diabetes medication use for adherent and nonadherent patients throughout the study, we believe this is unlikely to have substantially affected results around the differences in total costs. Other potentially important factors in a patient's overall health, including lifestyle factors (eg, smoking, alcohol intake, nutrition, physical activity, and overall sleep duration), laboratory tests, and patient-reported outcomes are not captured in our data.

Our dataset did not include Medicare fee-for-service patients, potentially limiting the generalizability of our findings. There was also heterogeneity in adherence across payer types observed in the data, with Medicaid patients being less likely to adhere. This may reflect differences in the quality of follow-up pathways. Given this, further research is needed to better understand the association between payer and adherence.

Finally, use of the CMS definition of compliance for adherence in our study is conservative as patients had to achieve CMS compliance in all 8 quarters over a 2-year period. Thus, our adherent cohort represents a phenotype of highly adherent patients and were compared with those who had very limited PAP usage. Further research is needed to understand whether there is a dose–response relationship between PAP usage and health outcomes. This would allow for better understanding of patients with intermediate adherence, who were excluded from the current analysis, as their usage varied widely enough that we were unable to identify an appropriate cut-off point for classification.

CONCLUSIONS

This real-world analysis demonstrated a positive association between adherence to PAP therapy and reductions in all-cause hospitalizations, all-cause ER visits, and corresponding health care costs in patients with OSA and comorbid type 2 diabetes compared to patients who are not adherent to PAP therapy. This finding provides additional evidence to support clinical screening and treating type 2 diabetes patients for OSA and the importance of encouraging patients to be adherent to prescribed PAP therapy.

ABBREVIATIONS

CI, confidence interval
CM, clinical modification
CMS, Centers for Medicare and Medicaid Services
ER, emergency room
HIPAA, Health Insurance Portability and Accountability Act
ICD, *International Classification of Diseases*
OSA, obstructive sleep apnea
PAP, positive airway pressure

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