

## Original Investigation

# Association Between Asthma and Risk of Developing Obstructive Sleep Apnea

Mihaela Teodorescu, MD, MS; Jodi H. Barnet, MS; Erika W. Hagen, PhD; Mari Palta, PhD; Terry B. Young, PhD; Paul E. Peppard, PhD

 Supplemental content at [jama.com](http://jama.com)

**IMPORTANCE** Obstructive sleep apnea (OSA) is more common among patients with asthma; whether asthma is associated with the development of OSA is unknown.

**OBJECTIVE** To examine the prospective relationship of asthma with incident OSA.

**DESIGN, SETTING, AND PARTICIPANTS** Population-based prospective epidemiologic study (the Wisconsin Sleep Cohort Study) beginning in 1988. Adult participants were recruited from a random sample of Wisconsin state employees to attend overnight polysomnography studies at 4-year intervals. Asthma and covariate information were assessed during polysomnography studies through March 2013. Eligible participants were identified as free of OSA (apnea-hypopnea index [AHI] of <5 events/h and not treated) by 2 baseline polysomnography studies. There were 1105 4-year follow-up intervals provided by 547 participants (52% women; mean [SD] baseline age, 50 [8] years).

**EXPOSURES** Questionnaire-assessed presence and duration of self-reported physician-diagnosed asthma.

**MAIN OUTCOMES AND MEASURES** The associations of presence and duration of asthma with 4-year incidences of both OSA (AHI of  $\geq 5$  or positive airway pressure treatment) and OSA concomitant with habitual daytime sleepiness were estimated using repeated-measures Poisson regression, adjusting for confounders.

**RESULTS** Twenty-two of 81 participants (27% [95% CI, 17%-37%]) with asthma experienced incident OSA over their first observed 4-year follow-up interval compared with 75 of 466 participants (16% [95% CI, 13%-19%]) without asthma. Using all 4-year intervals, participants with asthma experienced 45 cases of incident OSA during 167 4-year intervals (27% [95% CI, 20%-34%]) and participants without asthma experienced 160 cases of incident OSA during 938 4-year intervals (17% [95% CI, 15%-19%]); the corresponding adjusted relative risk (RR) was 1.39 (95% CI, 1.06-1.82), controlling for sex, age, baseline and change in body mass index, and other factors. Asthma was also associated with new-onset OSA with habitual sleepiness (RR, 2.72 [95% CI, 1.26-5.89],  $P = .045$ ). Asthma duration was related to both incident OSA (RR, 1.07 per 5-year increment in asthma duration [95% CI, 1.02-1.13],  $P = .01$ ) and incident OSA with habitual sleepiness (RR, 1.18 [95% CI, 1.07-1.31],  $P = .02$ ).

**CONCLUSIONS AND RELEVANCE** Asthma was associated with an increased risk of new-onset OSA. Studies investigating the mechanisms underlying this association and the value of periodic OSA evaluation in patients with asthma are warranted.

JAMA. 2015;313(2):156-164. doi:10.1001/jama.2014.17822  
Corrected on May 21, 2015.

**Author Affiliations:** Author affiliations are listed at the end of this article.

**Corresponding Author:** Mihaela Teodorescu, MD, MS, University of Wisconsin School of Medicine and Public Health, K4/910 CSC 9988, 600 Highland Ave, Madison, WI 53792-9988 (mt3@medicine.wisc.edu).

In adults, obstructive sleep apnea (OSA) is highly and increasingly prevalent.<sup>1</sup> OSA is associated with cardiovascular morbidities, insulin resistance, neural injury, and accelerated mortality.<sup>2</sup>

Accumulating evidence suggests a bidirectional relationship between asthma and OSA, whereby each disorder deleteriously influences the other.<sup>3</sup> In cross-sectional epidemiologic studies, the prevalence of sleepiness, snoring, and apnea were significantly higher in participants with asthma.<sup>4</sup> Likewise, in clinic-based studies, OSA symptoms were more frequently reported by patients with asthma<sup>5</sup> than by internal medicine patients<sup>6</sup> and the general population.<sup>5</sup> Moreover, studies with polysomnographically assessed OSA reported strikingly high OSA prevalences (~90%) in patients with difficult-to-control asthma.<sup>7,8</sup> Additionally, in a study of women with atopy, symptomatic asthma almost doubled the risk of snoring, a cardinal symptom of OSA.<sup>9</sup> One 14-year prospective study provided evidence supporting a pathogenic role for asthma in sleep-disordered breathing. Independent of confounders, incident asthma emerged as a significant risk factor for the development of habitual snoring.<sup>10</sup> Although these few studies suggest an asthma-OSA association, it remains unknown whether asthma is a causal risk factor for OSA.

Conversely, once OSA is established in patients with asthma, OSA may adversely affect asthma-related outcomes. OSA risk relates to poor overall asthma control<sup>3</sup> during daytime and nighttime.<sup>11</sup> Additionally, OSA treatment leads to improved asthma symptoms, morning peak expiratory flow rates, and quality of life,<sup>12</sup> prompting inclusion of OSA as a potential contributor to poor asthma control in the current asthma clinical guidelines.<sup>13</sup>

Therefore, understanding initiating processes of a potentially self-reinforcing asthma-OSA cycle is important to reduce the burden of both OSA and asthma. No studies, to our knowledge, have evaluated the prospective relationship of asthma with incident polysomnographically evaluated OSA. We examined this relationship in the Wisconsin Sleep Cohort Study, a population-based longitudinal epidemiologic investigation of the natural history, risk factors, and outcomes of OSA in adults. We hypothesized that pre-existent asthma is a risk factor for later development of OSA.

## Methods

### Study Participants and Design

Study protocols and informed consent documents were approved by the health sciences institutional review board of the University of Wisconsin-Madison. All participants provided written informed consent. Sampling and data collection protocols of the Wisconsin Sleep Cohort Study have been described previously.<sup>1</sup> The Wisconsin Sleep Cohort comprises 1521 randomly selected adult employees of state agencies aged 30 to 60 years in 1988. Since study inception, participants have attended in-laboratory overnight polysomnography and provided health-related questionnaires

approximately every 4 years. Data presented here were collected through March 2013.

### Measurements

Overnight studies included polysomnography, and measurements of height and weight (used to calculate body mass index [BMI; calculated as weight in kilograms divided by height in meters squared]) and waist, hip, and neck girth (all in centimeters). Data on medical history, excessive daytime sleepiness (hereafter referred to as sleepiness), alcohol use, smoking, nasal problems (congestion or stuffiness), menopausal status (premenopausal, transitioning, and postmenopausal) for women were obtained by questionnaires. Sleepiness was evaluated with the question: Do you have feelings of excessive daytime sleepiness? Response categories were never, rarely (once a month), sometimes (2-4 times a month), often (5-15 times a month), and almost always (>15 times a month). Participants were classified as having habitual sleepiness if they responded often or almost always. Regular use of the sleepiness question in the exact form described above began in 1997; baseline sleepiness data were not available for 157 participants.

A polysomnography system (Grass Instruments) assessed sleep, respiratory parameters by pulse oximetry (Ohmeda 3740), airflow by thermocouples (ProTec), nasal pressure by a transducer (Validyne Engineering Corp), and thoracic and abdominal excursions by inductance plethysmography (Respirace, Ambulatory Monitoring). Sleep scoring used conventional criteria.<sup>14</sup> An apnea was defined as cessation of airflow lasting 10 seconds or more. A discernible reduction in the sum of thoracic plus abdominal effort amplitude associated with a 4% or more reduction in oxyhemoglobin saturation defined a hypopnea. Between 1988 and 2000, sleep studies were scored using a paper-based system; since 2000, studies have been scored on a computer. All statistical modeling adjusts for the scoring changes; this removes instrumentation-related influences on OSA assessments after the year 2000.

Asthma status was self-reported on a questionnaire, asking about physician diagnosis, year of diagnosis, and whether any treatments were received. All participants who indicated that they were ever diagnosed with asthma were adjudicated. To be defined as having asthma, participants had to have indicated that they were ever diagnosed with asthma on at least 2 interviews and provided year of diagnosis. If participants only indicated diagnosis on 1 interview but were never treated and never again mentioned diagnosis on later interviews, they were not considered to have had asthma. For calculating duration of asthma, the self-reported year of diagnosis was used; if a participant reported more than 1 year of diagnosis, the median year reported was used. Spirometry was performed from 1989 to 2000, and lung physiologic parameters were compared between participants with asthma (defined as above) and those without. Asthma medications were categorized as controllers (inhaled corticosteroids, long-acting  $\beta$ -adrenergics or anticholinergics, leukotriene modifiers, and agents that block the release of hypersensitivity mediators) or not.

### Statistical Analysis

To be included in this analysis, participants had to be free of OSA, defined as an apnea-hypopnea index (AHI) fewer than 5 events per hour and no use of continuous or bilevel positive airway pressure (hereafter referred to as positive airway pressure [PAP]) on their first 2 polysomnography studies, to establish OSA-free status at baseline (hereafter baseline sleep study refers to the second OSA-free confirmatory sleep study unless otherwise noted). Participants with OSA-free status so-established were observed for incident OSA from baseline for 1 or more 4-year follow-up periods. That is, participants could contribute multiple 4-year periods of follow-up (range: one to five 4-year follow-up intervals). For example, a participant with an AHI of 0 in 1990, 2 in 1994, 0 in 1998, 4 in 2002, and 10 in 2006 would contribute three 4-year follow-up periods: a period initiated in 1994 and followed to 1998 (outcome = no incident OSA), a period initiated in 1998 and followed to 2002 (outcome = no incident OSA), and a period initiated in 2002 and followed to 2006 (outcome = incident OSA event). In addition to the analyses of 4-year intervals for OSA risk, we also examined incidence of OSA in ancillary models over 8-year intervals. As with the analyses of 4-year OSA risk, participants were required to be OSA-free for 2 consecutive baseline sleep studies to be eligible for 8-year OSA incidence analyses. For the 8-year analyses, only one 8-year interval was used per participant—the most recent interval available.

All analyses were performed using SAS (SAS Institute), version 9.2. Repeated measures analyses were performed to calculate standard errors and *P* values for primary modeling outcomes. Poisson regression models with a logarithmic link function, accommodating repeated measures (ie, multiple 4-year intervals from 61% of participants) by robust error variance estimates, were used to measure the association of asthma with subsequent development of OSA.<sup>15,16</sup> Relative risks with 95% CIs are presented. Parameter estimates were considered statistically significantly different from null values (eg, relative risk = 1) if 2-sided tests yielded *P* values lower than .05.

The outcome, incident OSA, was defined in 2 ways: (1) as developing an AHI of 5 or more events per hour or initiating PAP for OSA treatment and (2) as developing an AHI of 5 or more events per hour or initiating PAP use with concomitant habitual sleepiness (often or almost always).

The asthma variables included (1) asthma diagnosed at any age up to the baseline polysomnography visit; (2) duration of asthma in years; (3) duration of asthma stratified as short ( $\leq 10$  years) or long ( $> 10$  years); and (4) asthma controller medication use at baseline polysomnography study.

All models include covariates measured at baseline visit (age, sex, BMI, nasal problems [congestion or stuffiness, or other problems that cause congestion at night], current smoking status, and number of alcoholic drinks/week) in addition to baseline AHI (defined as the average across the 2 OSA-free confirmatory polysomnography studies) and change in BMI over the 4-year follow-up intervals. For models that examined asthma duration strata (0 years,  $\leq 10$  years, and  $> 10$  years), the statistical significance of a linear trend in

the natural log of the relative risks associated with greater asthma duration ( $\leq 10$  years and  $> 10$  years relative to 0 years) was evaluated by including a variable in regression models that took on the values 0 (for 0 years duration), 1 (for  $\leq 10$  years duration) or 2 (for  $> 10$  years duration). Results from additional ancillary analyses examined models that accounted for asthma controller medications, menopausal status, and additional measures of body habitus (neck girth, waist girth, and waist to hip ratio).

### Results

The final sample consisted of 547 participants who contributed a total of 1105 sets of 4-year intervals: 211 participants (39%) with 1 set, 173 participants (32%) with 2 sets, 105 participants (19%) with 3 sets, 57 participants (10%) with 4 sets, and 1 participant with 5 sets.

#### Baseline Characteristics

Table 1 presents the baseline characteristics summarized at the participant level for the first 4-year interval (if the participant contributed more than one 4-year interval) and stratified by asthma status and asthma duration group.

#### Incident OSA

In unadjusted analyses, 22 of 81 participants (27% [95% CI, 17%-37%]) with asthma experienced incident OSA over their first observed 4-year follow-up intervals vs 75 of 466 participants (16% [95% CI, 13%-19%]) without asthma (*P* difference = .02) (Table 2). Using all available 4-year intervals (ie, including multiple 4-year interval observations per participant), participants with asthma experienced 45 incident OSA cases during 167 4-year intervals (27% [95% CI, 20%-34%]) and participants without asthma experienced 160 incident OSA cases during 938 4-year intervals (17% [95% CI, 15%-19%], *P* difference = .007). These differences in OSA risk were observed even though there were similar average BMI changes among those with and without asthma during 4-year follow-up intervals.

Regression modeling estimated that participants with preexisting asthma compared with those without asthma had relative risks (RR) of 1.39 (95% CI, 1.06-1.82) for incident OSA and 2.72 (95% CI, 1.26-5.89) for incident OSA with habitual sleepiness, independent of baseline covariates, baseline AHI, and BMI change over time (Table 3, model 1). When the “any asthma” variable was substituted with continuous asthma duration, 5-year increments in duration were associated with a higher risk for incident OSA and OSA with habitual sleepiness (5-year asthma duration RR, 1.07 [95% CI, 1.02-1.13] for incident OSA and 1.18 [95% CI, 1.07-1.31] for OSA with habitual sleepiness) (Table 3, model 2). Reiteration of these models using asthma duration categories (no asthma,  $\leq 10$  years duration,  $> 10$  years duration) showed the highest risk for long asthma duration compared with no asthma: the long-duration RRs were 1.65 (95% CI, 1.21-2.25) for incident OSA and 3.36 (95% CI, 1.49-7.56) for OSA with habitual sleepiness (Table 3, model 3). For both OSA and OSA with habitual

Table 1. Participant Characteristics at Baseline<sup>a</sup> by Asthma Duration Status

	No. (%)				
	All	Asthma	Asthma Duration Group		No Asthma
			Short ( $\leq 10$ y)	Long ( $> 10$ y)	
Participants	547 (100)	81 (15)	39 (7)	42 (8)	466 (85)
Age, mean (SD), y	50.4 (7.7)	49.0 (6.8)	48.8 (6.2)	49.1 (7.4)	50.6 (7.8)
Women	284 (52)	50 (62)	29 (74)	21 (50)	234 (50)
BMI, mean (SD)	28.9 (5.5)	30.6 (6.4)	31.0 (6.6)	30.3 (6.2)	28.6 (5.3)
AHI (events/h), median (IQR) <sup>b</sup>	0.7 (0.3-1.7)	1.1 (0.3-2.0)	1.1 (0.3-2.1)	0.9 (0.4-1.6)	0.7 (0.2-1.6)
Incident OSA <sup>c</sup>	97 (18)	22 (27)	9 (23)	13 (31)	75 (16)
Incident OSA + habitual sleepiness <sup>d</sup>	19 (3)	7 (9)	3 (8)	4 (10)	12 (3)
Duration of asthma, y					
Mean (SD)	3 (9)	18 (16)	5 (3)	30 (13)	NA
Median (IQR)	0 (0-0)	12 (5-28)	5 (3-7)	28 (17-40)	NA
Asthma controller medication use	16 (3)	16 (20)	9 (23)	7 (17)	NA
Nasal problems <sup>e</sup>	224 (41)	45 (56)	22 (56)	23 (55)	179 (38)
Alcohol (No. of drinks/wk), median (IQR)	2.0 (0.0-4.0)	1.0 (0.3-2.0)	0.0 (0.0-3.0)	1.0 (0.0-2.0)	2.0 (0.0-5.0)
Current smoker	69 (13)	9 (11)	6 (15)	3 (7)	60 (13)
Menopause status (n = 272)					
Premenopause or perimenopause <sup>f</sup>	92 (34)	19 (38)	12 (41)	7 (33)	73 (33)
Transitioning <sup>g</sup>	53 (19)	10 (20)	6 (21)	4 (19)	43 (19)
Post menopause <sup>h</sup>	127 (47)	21 (42)	11 (38)	10 (48)	106 (48)
Excessive daytime sleepiness (n = 390) <sup>i</sup>					
Not habitually sleepy <sup>j</sup>	322 (83)	41 (75)	18 (78)	23 (72)	281 (84)
Habitual sleepiness <sup>k</sup>	68 (17)	14 (25)	5 (22)	9 (28)	54 (16)

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); IQR, interquartile range; OSA, obstructive sleep apnea.

<sup>a</sup> Collected at the second OSA-free confirmatory sleep study visit (from the first 4-y follow-up interval for participants with multiple follow-up intervals).

<sup>b</sup> Expressed as the average AHI across the 2 OSA-free confirmatory sleep study visits (both of which were, by design, fewer than 5 events per hour).

<sup>c</sup> Incident OSA from first 4-year study interval for which (1) the initial AHI was fewer than 5 events per hour (and no positive airway pressure [PAP] use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 4-y interval).

<sup>d</sup> Incident OSA + habitual sleepiness from first 4-year study interval for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 4-y interval) and follow-up excessive daytime sleepiness was reported as occurring often or almost always.

<sup>e</sup> Nasal congestion or stuffiness or other nasal problems that cause nasal stuffiness at night.

<sup>f</sup> Women who were pre- or perimenopausal at both baseline and follow-up sleep studies.

<sup>g</sup> Women who transitioned from premenopausal or perimenopausal at baseline sleep study to postmenopausal at follow-up sleep study.

<sup>h</sup> Women who were postmenopausal at both baseline and follow-up sleep studies.

<sup>i</sup> Administration during sleep study visits of the specific excessive daytime sleepiness question used for the present analyses began in 1997; baseline sleepiness data were missing for 157 participants.

<sup>j</sup> Not habitually sleepy defined as excessive daytime sleepiness occurring never, rarely, or sometimes.

<sup>k</sup> Habitual sleepiness defined as excessive daytime sleepiness occurring often or almost always.

sleepiness, there were significant trends in RRs with longer duration asthma category (*P* values for linear trend in the natural log of the RR, .008 for incident OSA and .03 for OSA with habitual sleepiness).

### Additional Analyses

We performed a series of additional analyses to examine the robustness of our findings. First, in a smaller group of 468 participants eligible to be followed for 8-year OSA incidence, participants with preexisting asthma had a higher absolute 8-year risk of incident OSA (8-year risk, 49% [95% CI, 38%-61%]) than participants without asthma (8-year risk, 28% [95% CI, 23%-32%], *P* < .001) and OSA with habitual sleepiness (8-year risk, 12% [95% CI, 5%-19%] for participants with

asthma vs 4% [95% CI, 2%-6%] for participants without, *P* = .007) (Table 4). Regression modeling, adjusting for covariates, estimated that participants with preexisting asthma compared with those without had RRs of 1.58 (95% CI, 1.08-2.31) for incident OSA and 2.58 (95% CI, 1.12-5.97) for incident OSA with habitual sleepiness (Table 5, model 1). As with the analysis of 4-year OSA incidence, 5-year increments in continuous asthma duration (model 2) and longer duration asthma category (>10 years) (model 3) were associated with a higher risk of incident OSA and OSA with habitual sleepiness (Table 5).

Second, although we relied on self-report of physician-diagnosed asthma, we did have spirometry available on a limited subset (n = 220) of participants. In these participants,

**Table 2. Obstructive Sleep Apnea Incidence, Polysomnography Indices, and Changes in Relevant Characteristics Across All 4-Year Study Intervals**

Study Characteristics	All	Asthma	Asthma Duration Group		No Asthma	P Value for Asthma vs No Asthma
			Short (≤10 y)	Long (>10 y)		
4-y intervals (n = 547), No. <sup>a</sup>	1105	167	73	94	938	
Incident OSA, No. (%) <sup>b</sup>	205 (19)	45 (27)	15 (21)	30 (32)	160 (17)	.007
Incident OSA + habitual sleepiness, No. (%) <sup>c</sup>	33 (3)	12 (7)	3 (4)	9 (10)	21 (2)	.02
PAP user at end of 4-y interval, No. (%)	7 (1)	1 (1)	1 (1)	0 (0)	6 (1)	.95
AHI at end of 4-y interval, mean (95% CI), No. of events/h <sup>d</sup>	2.9 (2.6 to 3.1)	3.5 (2.9 to 4.1)	3.5 (2.5 to 4.5)	3.5 (2.7 to 4.3)	2.7 (2.5 to 3.0)	.03
Change in BMI over 4-y interval, mean (95% CI)	0.4 (0.3 to 0.6)	0.4 (0.3 to 0.6)	0.6 (0.1 to 1.1)	0.3 (-0.1 to 0.8)	0.4 (0.1 to 0.8)	.97

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); OSA, obstructive sleep apnea; PAP, positive airway pressure.

<sup>a</sup> The 547 participants provided 1105 4-year follow-up intervals.

<sup>b</sup> Incident OSA indicates 4-year study intervals for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 4-y interval).

<sup>c</sup> Incident OSA + habitual sleepiness indicates 4-year study intervals for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 4-y interval) and follow-up excessive daytime sleepiness was reported as occurring often or almost always.

<sup>d</sup> PAP users were not included in this calculation.

**Table 3. Adjusted Relative Risks for Asthma and Asthma Duration Predicting 4-Year Incidence of Obstructive Sleep Apnea**

	Incident OSA <sup>a</sup>		Incident OSA + Habitual Sleepiness <sup>b</sup>	
	RR (95% CI)	P Value	RR (95% CI)	P Value
Model 1: any asthma vs no asthma <sup>c</sup>				
No asthma	1 [Reference]		1 [Reference]	
Any asthma	1.39 (1.06-1.82)	.03	2.72 (1.26-5.89)	.045
Model 2: continuous duration of asthma <sup>c</sup>				
Duration (5-y increments)	1.07 (1.02-1.13)	.01	1.18 (1.07-1.31)	.02
Model 3: duration of asthma categories <sup>c</sup>				
No asthma	1 [Reference]		1 [Reference]	
Short duration (≤10 y)	1.06 (0.67-1.67)	.82	1.75 (0.49-6.26)	.39
Long duration (>10 y)	1.65 (1.21-2.25)	.002	3.36 (1.49-7.56)	.003
P value for trend in RRs	.008		.03	

Abbreviations: OSA, obstructive sleep apnea; PAP, positive airway pressure; RR, relative risk.

<sup>a</sup> Incident OSA indicates 4-year study intervals for which (1) the initial apnea-hypopnea index (AHI) was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 4-y interval).

<sup>b</sup> Incident OSA + habitual sleepiness indicates 4-year study intervals for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2)

the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 4-y interval) and follow-up excessive daytime sleepiness was reported as occurring often or almost always.

<sup>c</sup> Models adjusted for baseline AHI (average of the 2 confirmatory OSA-free sleep study visits), sex, baseline age, body mass index (BMI, calculated as weight in kilograms divided by height in meters squared), percent change in BMI, nasal congestion or stuffiness, current smoking, and number of alcoholic drinks per week.

even though in the normal range, the adjusted mean forced expiratory volume in first second of a forced expiratory maneuver to forced vital capacity (FEV<sub>1</sub>/FVC) was lower for participants with asthma (n = 33) than those without (n = 187) (0.77 [95% CI, 0.74-0.79] for participants with asthma vs 0.82 [95% CI, 0.81-0.83] for participants without, P < .001). Likewise, even though in the normal range, the adjusted mean percent predicted FEV<sub>1</sub> was also lower for participants with asthma than those without asthma (0.92 [95% CI, 0.88-0.97] for participants with asthma vs 1.00 [95% CI, 0.98-1.02] for participants without, P = .003). Thus, in our sample, self-reported asthma was associated with worse objective measures of lung function.

Third, we examined whether the association of asthma and incident OSA was related to the use of asthma controller medications. The association between asthma and OSA did not vary significantly by asthma controller-use status (eTables 1 and 2 in the Supplement).

Fourth, we investigated whether there was a selection bias related to asthma status—specifically, if availability of 4-year follow-up polysomnography studies was related to baseline asthma status. There was no association between asthma and availability of follow-up polysomnography: 64% of baseline participants with asthma and 65% of those without asthma had follow-up data available as of March 2013.

**Table 4. Obstructive Sleep Apnea Incidence, Polysomnography Indices, and Changes in Relevant Characteristics Across Participants' Most Recent Available 8-Year Study Intervals**

Study Characteristics	All	Asthma	Asthma Duration Group		No Asthma	P Value for Asthma vs No Asthma
			Short (≤10 y)	Long (>10 y)		
8-y interval sleep studies (n = 468), No.	468	77	34	43	391	
Incident OSA, No. (%) <sup>a</sup>	146 (31)	38 (49)	14 (41)	24 (56)	108 (28)	<.001
Incident OSA + habitual sleepiness, No. (%) <sup>b</sup>	25 (5)	9 (12)	3 (9)	6 (14)	16 (4)	.007
PAP user at end of 8-y interval, No. (%)	15 (3)	4 (5)	3 (9)	1 (2)	11 (3)	.28
AHI at end of 8-y interval, mean (95% CI), No. of events/h <sup>c</sup>	4.3 (3.7-4.8)	5.6 (4.3-6.8)	5.0 (3.0-7.1)	6.0 (4.4-7.5)	4.0 (3.4-4.6)	.05
Change in BMI over 8-y interval, mean (95% CI)	0.6 (0.4-0.9)	0.5 (-0.2-1.2)	-0.0 (-1.2-1.1)	0.9 (0.0-1.8)	0.6 (0.4-0.9)	.69

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); OSA, obstructive sleep apnea; PAP, positive airway pressure.

<sup>a</sup> Incident OSA indicates 8-year study interval for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 8-y interval).

<sup>b</sup> Incident OSA + habitual sleepiness indicates 8-year study interval for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 8-y interval) and follow-up excessive daytime sleepiness was reported as occurring often or almost always.

<sup>c</sup> PAP users were not included in this calculation.

**Table 5. Adjusted Relative Risks for Asthma and Asthma Duration Predicting 8-Year Incidence of Obstructive Sleep Apnea**

	Incident OSA <sup>a</sup>		Incident OSA + Habitual Sleepiness <sup>b</sup>	
	RR (95% CI) <sup>c</sup>	P Value	RR (95% CI) <sup>c</sup>	P Value
Model 1: any asthma vs no asthma <sup>c</sup>				
No asthma	1 [Reference]		1 [Reference]	
Any asthma	1.58 (1.08-2.31)	.02	2.58 (1.12-5.97)	.04
Model 2: continuous duration of asthma <sup>c</sup>				
Duration (5-y increments)	1.07 (1.00-1.14)	.06	1.17 (1.04-1.31)	.02
Model 3: duration of asthma categories <sup>c</sup>				
No asthma	1 [Reference]		1 [Reference]	
Short duration (≤10 y)	1.40 (0.79-2.48)	.25	2.06 (0.58-7.34)	.27
Long duration (>10 y)	1.71 (1.09-2.69)	.02	2.94 (1.13-7.66)	.03
P value for trend in RRs	.003		.06	

Abbreviations: OSA, obstructive sleep apnea; PAP, positive airway pressure; RR, relative risk.

<sup>a</sup> Incident OSA indicates 8-year study intervals for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over the 8-y interval).

<sup>b</sup> Incident OSA + habitual sleepiness indicates 8-year study intervals for which (1) the initial AHI was fewer than 5 events per hour (and no PAP use); and, (2) the follow-up AHI was 5 or more events per hour (or initiation of PAP use over

the 8-y interval) and follow-up excessive daytime sleepiness was reported as occurring often or almost always.

<sup>c</sup> Models adjusted for baseline apnea-hypopnea index (average of the 2 confirmatory OSA-free sleep study visits), sex, baseline age, body mass index (BMI, calculated as weight in kilograms divided by height in meters squared), percent change in BMI, nasal congestion or stuffiness, current smoking, and number of alcoholic drinks per week.

Fifth, we tested whether bias could have been introduced by the contribution of multiple 4-year follow-up intervals from 61% of the participants. A reiteration of the analyses presented in Table 3, but restricted solely to the first 4-year intervals from all 547 individual participants, showed only small changes to the relative risks (eg, using all 4-year intervals, the RR for incident OSA among participants with asthma was 1.39, and, using only the first interval, the RR was 1.34 [95% CI, 0.90-1.97]; similarly, the RR for OSA among patients with asthma and habitual sleepiness was 2.72 when all 4-year intervals were included, and 2.74 [95% CI, 1.00-7.50] when only the first 4-year interval was used).

Sixth, in addition to BMI, we examined models that adjusted for other anthropometric parameters including baseline and 4-year changes in neck girth, waist girth, and waist to hip ratio. The addition of these variables to presented models had no substantive statistical effect (beyond the adjustment for BMI and change in BMI) on coefficients relating asthma to risk of new-onset OSA (eTable 3 in the Supplement).

Seventh, the analyses were repeated to include menopausal status as a covariate in the models (using the subset of 1071 4-year intervals for which this information was available). No evidence of confounding by menopause of the asthma-OSA association was observed (eTables 4 and 5 in the Supplement).

## Discussion

This study prospectively examined the relationship of asthma with OSA assessed with laboratory-based polysomnography and found that preexistent asthma was a risk factor for the development of clinically relevant OSA in adulthood over a 4-year period. Furthermore, the asthma-OSA association was significantly dose-dependent on duration of asthma.

Although a focus of our investigation was on incident OSA per se, we also examined OSA with concomitant sleepiness because OSA in the presence of sleepiness is of particular clinical interest (excessive daytime sleepiness is often used as a diagnostic criterion of clinically significant OSA warranting treatment). We found significantly higher risks of OSA (with or without sleepiness) related to asthma, especially when examining asthma in relation to risk of developing OSA with sleepiness. However, our findings do not distinguish a direct association between asthma and sleepiness vs an association between asthma and sleepiness mediated by OSA. That is, a stronger association of asthma with OSA and concomitant habitual sleepiness (vs OSA without regard to the presence of sleepiness) might plausibly reflect 1 or more of the following: (1) an association of asthma with greater severity of OSA; (2) an interaction of asthma and OSA whereby the presence of both conditions synergistically enhance sleepiness; and, (3) an additional OSA-independent effect of asthma on sleepiness. Future studies aimed at measuring the longitudinal association of asthma with the development of sleepiness, while accounting for OSA, are warranted.

A few cross-sectional community<sup>4,9</sup> and clinic-based studies<sup>5,6</sup> have shown an association of asthma with OSA symptoms or polysomnography-based OSA diagnosis.<sup>7,8</sup> One study examined the longitudinal association of self-reported asthma and habitual snoring.<sup>10</sup> In this large (n = 967) sample, followed up for 14 years, 6% of the participants developed asthma during follow-up. Incident asthma was a strong predictor for development of habitual snoring (RR, 2.8), independent of baseline BMI and BMI change during the interval, whereas preexistent asthma was not. Furthermore, 1 cross-sectional study found that in asthma patients, asthma control, use of inhaled corticosteroids—in a dose-dependent fashion—and gastroesophageal reflux disease were each associated with habitual snoring or high OSA risk, independent of traditional risk factors including excess weight and nasal congestion.<sup>17</sup> A role of asthma in OSA pathogenesis is also supported by the study by Julien and colleagues<sup>7</sup> in which age, sex, and BMI-matched patients with severe and moderate asthma (n = 26/group) underwent overnight polysomnography. In this study, OSA (AHI  $\geq$ 5/h) was significantly more prevalent among those with severe asthma (50%) vs moderate disease (23%) or controls (12%).<sup>7</sup> These findings are consistent with ours and lend further support to a potential causal role of asthma in OSA development.

Asthma, its treatment, or comorbidities may alter pharyngeal airway patency, setting the stage for development of OSA. Asthma may change the fine balance between the forces that promote collapse and those maintaining the patency of

the pharyngeal airway—a region lacking any bone or cartilaginous support and, thus, vulnerable to collapse.<sup>18</sup> Although the underlying mechanistic links between asthma and OSA remain to be tested, several pathways seem plausible: (1) augmented inspiratory negative intraluminal pressure in the deformable pharyngeal airway could occur during asthma attacks, along with active contraction of the respiratory muscles during forced expiration, yielding increased pressure in the surrounding pharyngeal airway tissues,<sup>19</sup> with both phenomena promoting upper airway collapse; (2) alterations in pharyngeal airway stiffness during sleep resulting from reduction in its tracheal tug<sup>20</sup> due to the more abrupt decline in lung volumes observed in sleeping patients with asthma<sup>21</sup>; (3) sleep loss and fragmentation—caused by asthma—could affect upper airway collapsibility<sup>22</sup>; and (4) the “spill-over” systemic inflammation resulting from the asthmatic process<sup>23</sup> may weaken the respiratory muscles,<sup>24</sup> and, furthermore, trigger central nervous system inflammatory responses that could impair protective mechanisms of pharyngeal upper airway patency and destabilize the central breathing controller, as has been shown in response to other inflammatory insults.<sup>25</sup> An additional pathway from asthma to OSA may be the effect of systemic<sup>8</sup> and inhaled corticosteroid therapy on the pharyngeal airway, as suggested by a recent study.<sup>26</sup> Corticosteroids, which are prescribed for the treatment of asthma, may affect the deformable pharyngeal airway by raising the surrounding tissue pressure from centripetal fat accumulation, redistribution, or both, and by diminishing the contractile properties of its protective, dilator muscles (myopathy),<sup>26</sup> similar to the postulated mechanism underlying dysphonia.<sup>27</sup> Additionally, in *in vivo* studies, 2-hour incubation of canine tracheal muscle strips with dexamethasone significantly augmented forced fluctuations-induced relengthening of contracted muscle.<sup>28</sup> Although this outcome would favor bronchodilation in the pharyngeal airway, such effect of corticosteroids would render pharyngeal dilators more “floppy,” hampering their ability to protect upper airway patency during sleep. Our small sample of asthma participants using controller medications (n = 16) likely precluded finding significant associations with incident OSA, and thus our study does not negate such effects of corticosteroid medications on the upper airway. In addition, pharyngeal upper airway dysfunction resulting from commonly comorbid gastroesophageal reflux disease may compound the above effects,<sup>17,29</sup> because proximal migration of gastric acid in the upper airway combined with extended acid clearance during sleep<sup>30</sup> could trigger pharyngeal spasm and cause mucosal exudative neurogenic inflammation.<sup>31</sup> How these effects arising from multiple factors interact on the upper airway in individual patients remains to be further examined in future studies.

The strengths of our study rely on its prospective design with a minimum of 4 years of follow-up per participant (most participants [61%] had a minimum of 8 years' follow-up [ie, contributed 2 or more 4-year intervals]), and use of the gold-standard laboratory-based polysomnography with and without symptoms to diagnose OSA. Our study has some important limitations. First, we used participant-

recalled physician-diagnosed asthma (including dates of diagnosis) and do not have details (doses or frequency) on medications used over time for asthma treatment. However, as we found with the pulmonary testing in our study, Senthilselvan and colleagues<sup>32</sup> also reported a significant relationship of self-reported asthma with measures of airways obstruction concurrently obtained on spirometry. Furthermore, Oksanen and colleagues<sup>33</sup> found that self-reported physician diagnosis of asthma had 91% sensitivity and 97% specificity for presence of asthma diagnoses in medical records. If these sensitivity and specificity parameters are applicable to our asthma assessment, then we would expect slight underestimates of asthma-OSA associations due to asthma misclassification in our study. Although self-report of physician-made asthma diagnosis has been typical in related epidemiologic studies,<sup>9,29,34</sup> future studies should incorporate objective assessments to confirm and characterize control of asthma, along with its treatment over

time. Second, we lack detailed characterization of asthma comorbidity with rhinitis (and treatment of rhinitis with nasal steroids) and gastroesophageal reflux disease, commonly found co-occurring with asthma. Likewise, in future studies, these conditions need to be characterized in detail by incorporating objective confirmatory and control methods. Finally, we had insufficient numbers of participants transitioning from OSA-free status to more severe OSA disease (eg, AHI >30/h) over 4-year intervals to include analyses of incident moderate-severe OSA.

## Conclusions

Asthma was associated with increased risk of new-onset OSA. Studies investigating the mechanisms underlying this association and the value of periodic OSA evaluation in patients with asthma are warranted.

### ARTICLE INFORMATION

**Author Affiliations:** James B. Skatrud Pulmonary/Sleep Research Laboratory, William S. Middleton Memorial Veteran's Hospital, Madison, Wisconsin (Teodorescu); Department of Medicine, University of Wisconsin School of Medicine and Public Health, Madison (Teodorescu); Center for Sleep Medicine and Sleep Research, University of Wisconsin School of Medicine and Public Health, Madison (Teodorescu); Population Health Sciences, University of Wisconsin School of Medicine and Public Health, Madison (Barnet, Hagen, Palta, Young, Peppard); Biostatistics and Medical Informatics, University of Wisconsin School of Medicine and Public Health, Madison (Palta).

**Author Contributions:** Dr Peppard had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

**Study concept and design:** Teodorescu, Young, Peppard.

**Acquisition, analysis, or interpretation of data:** Teodorescu, Barnet, Hagen, Palta, Young, Peppard.

**Drafting of the manuscript:** Teodorescu, Barnet, Hagen, Peppard.

**Critical revision of the manuscript for important intellectual content:** Teodorescu, Hagen, Palta, Young, Peppard.

**Statistical analysis:** Barnet, Hagen, Palta, Peppard.

**Obtained funding:** Young, Peppard.

**Administrative, technical, or material support:** Hagen, Peppard.

**Study supervision:** Teodorescu, Peppard.

**Conflict of Interest Disclosures:** All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest and none were reported.

**Funding/Support:** This work was funded by the National Heart, Lung, and Blood Institute (RO1HL62252), National Institute on Aging (RO1AG036838), and the National Center for Research Resources (1UL1RR025011) at the National Institutes of Health (NIH); additional resources were from the William S. Middleton Memorial VA Hospital, Madison. This work was performed at the University of Wisconsin and William S. Middleton Memorial VA Hospital, Madison.

**Role of the Funder/Sponsor:** The funders had no role in the design and conduct of the study;

collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

**Disclaimer:** The content of this article is solely the responsibility of the authors and does not represent the views of the Department of Veterans Affairs, NIH, or the United States government.

**Additional Contributions:** We thank K. Mae Hla, MD (Wisconsin Sleep Cohort medical director), Jerome Dempsey, PhD (study design), Steven Weber, PhD (participant communications, technical consulting), and Steven R. Barczi, MD (participant medical evaluations), for their valuable assistance. We also thank Tricia Denman, Nicole Salzieder, BS, Kathy Stanback, BA, Mary Sundstrom, BS (data collection), Laurel Finn, MS (data quality control and analysis), Kathryn Pluff, BS (participant recruitment, data collection, laboratory management), Amanda Rasmuson, MS (laboratory management, data collection), and Robin Stubbs, BS (database programming and data security). These contributors are affiliated with the University of Wisconsin-Madison and they were funded with NIH grants.

**Correction:** This article was corrected online May 21, 2015, for revisions to Table 4, which contained incorrect values for the mean (95% CI) of the following 2 rows: apnea-hypopnea index at the end of the 8-year interval and change in body mass index over 8-year interval.

### REFERENCES

1. Peppard PE, Young T, Barnet JH, Palta M, Hagen EW, Hla KM. Increased prevalence of sleep-disordered breathing in adults. *Am J Epidemiol*. 2013;177(9):1006-1014.
2. Dempsey JA, Veasey SC, Morgan BJ, O'Donnell CP. Pathophysiology of sleep apnea. *Physiol Rev*. 2010;90(1):47-112.
3. Teodorescu M, Polomis DA, Hall SV, et al. Association of obstructive sleep apnea risk with asthma control in adults. *Chest*. 2010;138(3):543-550.
4. Alkhalil M, Schulman E, Getsy J. Obstructive sleep apnea syndrome and asthma: what are the links? *J Clin Sleep Med*. 2009;5(1):71-78.

5. Teodorescu M, Consens FB, Bria WF, et al. Correlates of daytime sleepiness in patients with asthma. *Sleep Med*. 2006;7(8):607-613.

6. Auckley D, Moallem M, Shaman Z, Mustafa M. Findings of a Berlin Questionnaire survey: comparison between patients seen in an asthma clinic vs internal medicine clinic. *Sleep Med*. 2008;9(5):494-499.

7. Julien JY, Martin JG, Ernst P, et al. Prevalence of obstructive sleep apnea-hypopnea in severe vs moderate asthma. *J Allergy Clin Immunol*. 2009;124(2):371-376.

8. Yigla M, Tov N, Solomonov A, Rubin AH, Harlev D. Difficult-to-control asthma and obstructive sleep apnea. *J Asthma*. 2003;40(8):865-871.

9. Kalra M, Biagini J, Bernstein D, et al. Effect of asthma on the risk of obstructive sleep apnea syndrome in atopic women. *Ann Allergy Asthma Immunol*. 2006;97(2):231-235.

10. Knuiman M, James A, Divitini M, Bartholomew H. Longitudinal study of risk factors for habitual snoring in a general adult population: the Busseton Health Study. *Chest*. 2006;130(6):1779-1783.

11. Teodorescu M, Polomis DA, Teodorescu MC, et al. Association of obstructive sleep apnea risk or diagnosis with daytime asthma in adults. *J Asthma*. 2012;49(6):620-628.

12. Alkhalil M, Schulman ES, Getsy J. Obstructive sleep apnea syndrome and asthma: the role of continuous positive airway pressure treatment. *Ann Allergy Asthma Immunol*. 2008;101(4):350-357.

13. Linder N, Kuint J, German B, Lubin D, Loewenthal R. Hypertrophy of the tongue associated with inhaled corticosteroid therapy in premature infants. *J Pediatr*. 1995;127(4):651-653.

14. Rechtschaffen A, Kales A, eds. *A Manual of Standardized Terminology, Techniques, and Scoring System for Sleep Stages of Human Subjects*. Washington, DC: Government Printing Office; 1968.

15. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika*. 1986; 73:13-22. [http://www.biostat.jhsph.edu/~fdominic/teaching/bio655/references/extra/liang\\_bka\\_1986.pdf](http://www.biostat.jhsph.edu/~fdominic/teaching/bio655/references/extra/liang_bka_1986.pdf). Accessed December 12, 2014.

16. Zou G. A modified Poisson regression approach to prospective studies with binary data. *Am J Epidemiol*. 2004;159(7):702-706.
17. Teodorescu M, Consens FB, Bria WF, et al. Predictors of habitual snoring and obstructive sleep apnea risk in patients with asthma. *Chest*. 2009; 135(5):1125-1132.
18. White DP. Pathogenesis of obstructive and central sleep apnea. *Am J Respir Crit Care Med*. 2005;172(11):1363-1370.
19. Jensen OE. Flows through deformable airways. <http://www.biomatematica.it/urbino2002/programmi/oejnotes.pdf>. Accessed on October 7, 2014.
20. Van de Graaff WB. Thoracic influence on upper airway patency. *J Appl Physiol* (1985). 1988;65(5): 2124-2131.
21. Ballard RD, Irvin CG, Martin RJ, Pak J, Pandey R, White DP. Influence of sleep on lung volume in asthmatic patients and normal subjects. *J Appl Physiol* (1985). 1990;68(5):2034-2041.
22. Sériès F, Roy N, Marc I. Effects of sleep deprivation and sleep fragmentation on upper airway collapsibility in normal subjects. *Am J Respir Crit Care Med*. 1994;150(2):481-485.
23. Bjermer L. Time for a paradigm shift in asthma treatment: from relieving bronchospasm to controlling systemic inflammation. *J Allergy Clin Immunol*. 2007;120(6):1269-1275.
24. Reid MB, Lännergren J, Westerblad H. Respiratory and limb muscle weakness induced by tumor necrosis factor- $\alpha$ : involvement of muscle myofilaments. *Am J Respir Crit Care Med*. 2002;166(4):479-484.
25. Huxtable AG, Vinit S, Windelborn JA, et al. Systemic inflammation impairs respiratory chemoreflexes and plasticity. *Respir Physiol Neurobiol*. 2011;178(3):482-489.
26. Teodorescu M, Xie A, Sorkness CA, et al. Effects of inhaled fluticasone on upper airway during sleep and wakefulness in asthma: a pilot study. *J Clin Sleep Med*. 2014;10(2):183-193.
27. Williams AJ, Baghat MS, Stableforth DE, Cayton RM, Shenoi PM, Skinner C. Dysphonia caused by inhaled steroids: recognition of a characteristic laryngeal abnormality. *Thorax*. 1983;38(11):813-821.
28. Lakser OJ, Dowell ML, Hoyte FL, et al. Steroids augment relengthening of contracted airway smooth muscle: potential additional mechanism of benefit in asthma. *Eur Respir J*. 2008;32(5):1224-1230.
29. Emilsson ÖI, Bengtsson A, Franklin KA, et al. Nocturnal gastroesophageal reflux, asthma, and symptoms of obstructive sleep apnoea: a longitudinal, general population study. *Eur Respir J*. 2013;41(6):1347-1354.
30. Orr WC, Elsenbruch S, Harnish MJ, Johnson LF. Proximal migration of esophageal acid perfusions during waking and sleep. *Am J Gastroenterol*. 2000;95(1):37-42.
31. Demeter P, Pap A. The relationship between gastroesophageal reflux disease and obstructive sleep apnea. *J Gastroenterol*. 2004;39(9):815-820.
32. Senthilselvan A, Dosman JA, Chen Y. Relationship between pulmonary test variables and asthma and wheezing: a validation of self-report of asthma. *J Asthma*. 1993;30(3):185-193.
33. Oksanen T, Kivimäki M, Pentti J, Virtanen M, Klaukka T, Vahtera J. Self-report as an indicator of incident disease. *Ann Epidemiol*. 2010;20(7):547-554.
34. Janson C, De Backer W, Gislason T, et al. Increased prevalence of sleep disturbances and daytime sleepiness in subjects with bronchial asthma: a population study of young adults in 3 European countries. *Eur Respir J*. 1996;9(10):2132-2138.