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ORIGINAL ARTICLE

Sleep-disordered Breathing in Pregnancy and after Delivery
Associations with Cardiometabolic Health

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Abstract

Rationale: Knowledge gaps exist regarding health implications of sleep-disordered breathing (SDB) identified in pregnancy and/or after delivery.

Objectives: To determine whether SDB in pregnancy and/or after delivery is associated with hypertension (HTN) and metabolic syndrome (MS).

Methods: nuMoM2b-HHS (Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be Heart Health Study) ($N = 4{,}508$) followed participants initially recruited during their first pregnancy. Participants returned for a visit 2–7 years after pregnancy. This study examined a subgroup who underwent SDB assessments during their first pregnancy ($n = 1{,}964$) and a repeat SDB assessment after delivery ($n = 1{,}222$). Two SDB definitions were considered: *1*) apnea–hypopnea index (AHI) ≥ 5 and *2*) oxygen desaturation index (ODI) ≥ 5. Associations between SDB and incident HTN and MS were evaluated with adjusted risk ratios (aRRs).

Measurements and Main Results: The aRR for MS given an AHI ≥ 5 during pregnancy was 1.44 (95% confidence interval [CI], 1.08–1.93), but no association with HTN was found. ODI ≥ 5 in pregnancy was associated with both an increased risk for HTN (aRR, 2.02; 95% CI, 1.30–3.14) and MS (aRR, 1.53; 95% CI, 1.19–1.97). Participants with an AHI ≥ 5 in pregnancy that persisted after delivery were at higher risk for both HTN (aRR, 3.77; 95% CI, 1.84–7.73) and MS (aRR, 2.46; 95% CI, 1.59–3.76). Similar associations were observed for persistent ODI ≥ 5 after delivery.

Conclusions: An AHI ≥ 5 in pregnancy was associated with an increased risk of MS. An ODI ≥ 5 in pregnancy was significantly associated with both HTN and MS. Participants with persistent elevations in AHI and ODI during pregnancy and at 2–7 years after delivery were at the highest risk for HTN and MS.

Clinical trial registered with www.clinicaltrials.gov (NCT 02231398).

Keywords: sleep-disordered breathing; pregnancy; postpartum; cardiometabolic health; hypertension

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At a Glance Commentary

Scientific Knowledge on the Subject: We used the nuMoM2b (Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be) data to address the knowledge gap that exists regarding the health implications of sleep-disordered breathing (SDB) identified in pregnancy and/or after delivery. Specifically, our objective was to determine whether SDB in pregnancy and/or after delivery is associated with hypertension (HTN) and metabolic syndrome (MS).

What This Study Adds to the Field: In this analysis of objectively assessed SDB in pregnancy and at a 2- to 7-year follow-up visit in a large U.S. cohort, we found that SDB measured during pregnancy and in the 2- to 7-year period after delivery was associated with incident HTN and MS. Associations of SDB in pregnancy were generally stronger when SDB was defined using the oxygen desaturation index, which quantified the frequency of drops in oxygen saturation of ⩾3%, rather than the apnea–hypopnea index, which was defined by a combination of changes in airflow and oxygen saturation. Participants with persistent elevations in apnea–hypopnea index or oxygen desaturation index during pregnancy and the 2- to 7-year follow-up visits were at more than a threefold increased risk for incident HTN and more than a twofold increased risk for MS.

Sleep-disordered breathing (SDB), characterized by recurrent apneas and hypopneas, intermittent hypoxemia, and sleep disruption, is increasingly recognized in pregnancy. Pregnant individuals are at increased risk for SDB, predominantly obstructive sleep apnea, compared with their nonpregnant counterparts, due to physical and hormonal changes that occur during pregnancy (1, 2). A meta-analysis of 33 studies found that the pooled overall prevalence of SDB during pregnancy was 15% (95% confidence interval [CI], 12–18%) (3).

While epidemiologic data from cohorts of middle-aged and older adults indicate that SDB is associated with adverse cardiometabolic outcomes (4–6), less is known about how SDB in pregnancy and the period after delivery impacts maternal health. In pregnancy, increases in inflammation, oxidative stress, and sympathetic nervous system activity, all of which can be exacerbated by SDB, can lead to adverse maternal health events (2, 7). Indeed, SDB in pregnancy has been associated with a two- to threefold increased risk for preeclampsia and gestational diabetes mellitus (GDM) (3, 8). These and other adverse pregnancy outcomes are risk factors for later development of hypertension (HTN) and metabolic disease (9–12). The postpartum period is also of unique relevance regarding SDB epidemiology, given the likely impact of postpartum weight retention on SDB risk (13–15). Thus, there is a critical need to elucidate whether SDB identified in pregnancy and/or in the period after delivery is associated with cardiovascular and metabolic health in young adults.

nuMoM2b-HHS (Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be Heart Health Study) was a follow-up study of participants initially recruited during their first pregnancy to the parent nuMoM2b study, completed after delivery. A subset of women in the parent study underwent evaluation for SDB during their first pregnancy ("nuMoM2b SDB substudy") and was offered a repeat assessment after delivery (16–18). We used the nuMoM2b data to address the knowledge gap that exists regarding the health implications of SDB identified in pregnancy and/or after delivery. Specifically, our objective was to determine whether SDB in pregnancy and/or after delivery is associated with HTN and metabolic syndrome (MS). Some of the results of these studies have been previously reported in the form of an abstract (19).

Methods

Details of the nuMoM2b study and the nuMoM2b-SDB substudy have been previously published (16, 18). Inclusion criteria for the nuMoM2b study were nulliparity (no prior delivery, ⩾20 wk of gestation) and a viable singleton pregnancy at screening (6 wk and 0 d to 13 wk and 6 d of gestation). Participants were excluded from the nuMoM2b-SDB substudy if they were currently using continuous positive airway pressure (CPAP) treatment for SDB, had severe asthma, or required oxygen supplementation.

nuMoM2b-HHS Methods

The complete methods of the follow-up nuMoM2b-HHS study are described elsewhere (17). Briefly, contacts/interviews began at least 6 months after delivery. An in-person nuMoM2b-HHS visit was conducted 2–7 years after the index pregnancy ended. Participants were asked to fast for 8 hours before the visit. Blood pressure (BP), anthropometric measurements, and biological specimens were collected using standardized protocols. Participants in the nuMoM2b-HHS study were eligible to participate in a follow-up assessment of SDB if they had participated in the nuMoM2b-SDB substudy while pregnant.

nuMoM2b-HHS Outcomes

Incident HTN was defined as HTN that developed after the index pregnancy, as determined by BP measurement (systolic BP ⩾ 140 mm Hg or diastolic BP ⩾ 90 mm Hg) or use of an

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This article has an online supplement, which is accessible from this issue's table of contents at www.atsjournals.org.

antihypertensive medication for BP control at the 2- to 7-year visit after delivery.

MS was defined as the presence of three of the following five criteria: elevated waist circumference (≥88 cm [non-Asian] or ≥80 cm [Asian]); elevated triglycerides (≥150 mg/dl) or use of a triglyceride-lowering medication; elevated fasting glucose (≥100 md/dl) or use of a glucose-lowering medication; elevated BP (systolic BP ≥ 130 mm Hg or a diastolic BP ≥ 85 mm Hg) or use of an antihypertensive medication; and reduced HDL levels (<50 mg/dl) or use of medications known to increase HDL (20) (*see* online supplement for additional details).

SDB Assessments

SDB was assessed at all exams using the same model (Embletta-Gold device Embla) level 3 home sleep apnea test (HSAT) (18). Studies were conducted twice during pregnancy, first between 6 and 15 weeks of pregnancy and then again between 22 and 31 weeks, and then at the 2- to 7-year follow-up visit. Sleep studies were scored by a central reading center by trained polysomnologists blinded to all other data. Event definitions, scoring reliability, and the quality control protocol were previously published (18). Two SDB definitions were considered: *1*) apnea–hypopnea index (AHI): the number of apneas and hypopneas per hour of estimated sleep, inclusive of all apneas plus hypopneas accompanied by ≥3% oxygen desaturation; and *2*) oxygen desaturation index (ODI): the number of oxygen desaturations ≥3% from the before event baseline per hour of estimated sleep (*see* online supplement for additional details).

Statistical Analyses

For our primary analyses, we defined SDB using dichotomous AHI and ODI metrics: SDB by AHI (SDB-AHI) was defined as an AHI ≥ 5, SDB by ODI (SDB-ODI) was defined as an ODI ≥ 5. Among participants with valid early pregnancy and midpregnancy sleep study data, SDB in pregnancy was defined as an AHI ≥ 5 in either early pregnancy or midpregnancy (vs. AHI < 5 in both early pregnancy and midpregnancy). A similar categorization was used to define SDB during pregnancy by ODI. In secondary analyses, we separately considered SDB that was present in early pregnancy or midpregnancy. To examine exposure–response relationships, we also grouped participants at early pregnancy and midpregnancy into four categories based on their AHI or ODI values: 0, 0–4.9, 5–14.9, and 15 or more events/h (21). *Post hoc* tests using orthogonal contrasts were used to assess the exposure–response relationships for linear and quadratic trends in risk on the log scale across the SDB categories.

In a similar fashion, a secondary analysis was performed using the AHI and ODI data obtained at the 2- to 7-year follow-up visit. We also examined the trajectory of SDB (by both definitions) in pregnancy and at the follow-up visit by defining 4 groups: those with no SDB at either time point, those with SDB in pregnancy that persisted at the 2- to 7-year follow-up, those with SDB in pregnancy that resolved at follow-up, and those with new-onset SDB at the 2- to 7-year follow-up visit.

Baseline characteristics of the index pregnancy and cardiovascular characteristics at the 2- to 7-year follow-up visit were summarized according to SDB status during pregnancy. Similarly, cardiovascular characteristics at the 2- to 7-year follow-up visit were also summarized by SDB status at follow-up.

Analyses during pregnancy were restricted to participants who had an early pregnancy or midpregnancy sleep study with adequate data and attended the in-person nuMoM2b-HHS cardiovascular assessment. Participants with baseline chronic HTN in pregnancy were excluded from the HTN analyses; likewise, those with preexisting diabetes were excluded from the MS analyses.

Crude risk ratios (RRs) and adjusted risk ratios (aRRs) and 95% CI were estimated using Poisson regression with robust standard errors to relate SDB to incident HTN and MS (22). *P* values from likelihood ratio tests were reported. Adjustment covariates chosen *a priori* included: age and body mass index (BMI) in early pregnancy, self-identified race, and years from delivery of the index pregnancy to the HHS follow-up visit. Similar methods were used for the cross-sectional analyses of SDB in the period after delivery, with age and BMI at the time of the HHS follow-up visit and race used as adjustment covariates. In all our adjusted analyses, BMI was included as a linear and a quadratic term.

We also considered having a hypertensive disorder of pregnancy (HDP) (i.e., gestational hypertension and preeclampsia) during the index pregnancy as a mediator in the associations of SDB during pregnancy with HTN after delivery and HDP or GDM during pregnancy as a mediator in the associations of SDB during pregnancy with MS after delivery.

All tests were performed at a nominal significance level of $\alpha = 0.05$. All single-degree-of-freedom tests were two-sided. No correction was made for multiple comparisons. Analyses were performed using SAS 9.4 (*see* online supplement for additional details).

Results

A total of 4,508 participants attended a nuMoM2b-HHS in-person visit between February 4, 2014, and October 9, 2017. Among these, 1,964 had an HSAT from the index pregnancy, with 1,863 having adequate sleep study data available (406 with early pregnancy data only; 92 with midpregnancy data only; 1,365 with both early pregnancy and midpregnancy data) (Figure 1). The median (interquartile range [IQR]) time between delivery of the index pregnancy and the HHS in-person visit was 36 (28–42) months.

Among nuMoM2b-HHS participants who had both early pregnancy and midpregnancy sleep study data, 127 (9.3%) had an AHI ≥ 5 at either the early pregnancy or midpregnancy SDB assessment. Baseline characteristics according to AHI category during pregnancy for the nuMoM2b-HHS participants are presented in Table 1. Participants with an AHI ≥ 5 in pregnancy were older, had higher BMIs in early pregnancy, and had a lower rate of weight gain in pregnancy.

A repeat sleep study at the 2- to 7-year follow-up visit was conducted on 1,222 of the 1,964 participants who completed a sleep study during pregnancy. The participants who did not complete the follow-up sleep assessment were less likely to be non-Hispanic White and had a longer latency from delivery to the HHS follow-up (*see* Table E1 in the online supplement). Adequate follow-up sleep study data were available on 1,069 participants (Figure 2). SDB defined as an AHI ≥ 5 was found in 133 of the 1,069 (12.4%) participants with follow-up sleep data when studied at a median (IQR) of 32 (13) months after delivery. Of the 844 participants with SDB data from all time points (i.e., at both the early pregnancy and midpregnancy visits and at the follow-up visit), 710 (84.1%) did not have SDB-AHI during pregnancy or at

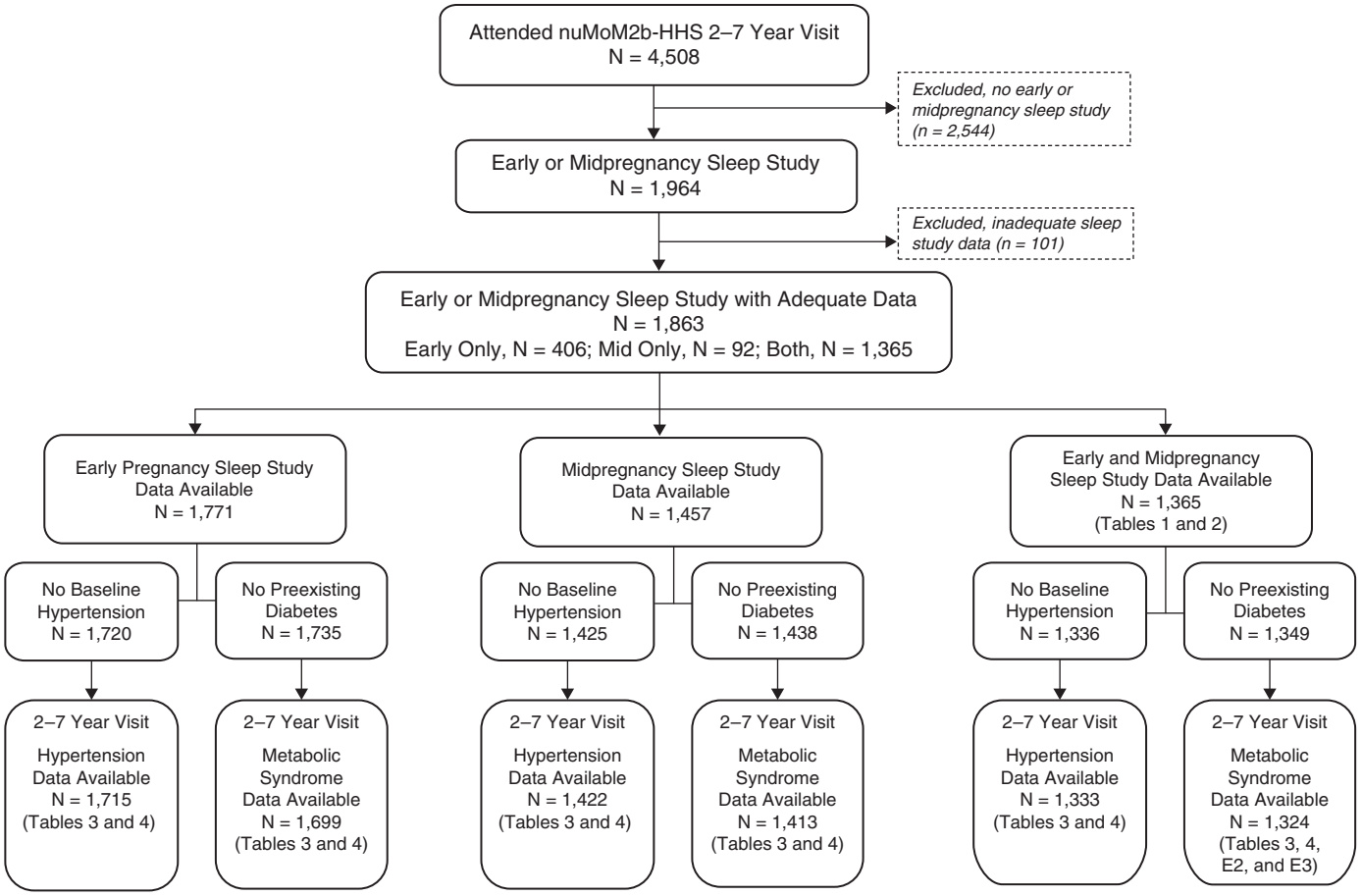

Figure 1. Inclusion in analysis of sleep study results during pregnancy in association with hypertension and metabolic syndrome 2–7 years after delivery. nuMoM2b = Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be.

follow-up, 49 (5.8%) had SDB-AHI in pregnancy that persisted at follow-up, 22 (2.6%) had SDB-AHI in pregnancy that resolved at follow-up, and 63 (7.5%) had new-onset SDB-AHI detected at the 2- to 7-year follow-up visit.

Cardiovascular and metabolic characteristics and outcome rates at the 2- to 7-year follow-up visit based on AHI status in pregnancy are presented in Table 2. Participants with SDB-AHI in pregnancy had higher BMIs; larger waist circumference; higher systolic and diastolic BP, triglyceride levels, and fasting blood glucose; and lower high-density lipoprotein cholesterol (HDL-C) levels 2–7 years after delivery. At follow-up, incident HTN was more common in participants with an SDB-AHI during pregnancy (15.7% vs. 6.2%, $P < 0.0001$), as was MS (40.2% vs. 14.2%, $P < 0.0001$).

Table 3 provides crude RRs and aRRs for incident HTN and MS, related to AHI in pregnancy. In adjusted analyses, SDB-AHI in pregnancy (early or mid) was not associated with the risk of incident HTN. Similarly, SDB-AHI in early pregnancy was not associated with a statistically significant increased HTN risk, although the midpregnancy SDB-AHI point estimate was of borderline significance (aRR, 1.73; 95% CI, 0.99–3.01; $P = 0.091$). AHI grouping by AHI = 0 (referent), $0 < \text{AHI} < 5$, $5 \leq \text{AHI} < 15$, and $\text{AHI} \geq 15$ did not reveal a statistically significant linear or quadratic trend in incident HTN risk with increasing AHI in either early pregnancy or midpregnancy.

The adjusted risk for MS given SDB-AHI in pregnancy was 1.44 (95% CI, 1.08–1.93). Separate analyses of $\text{AHI} \geq 5$ in early pregnancy or midpregnancy with MS were not statistically significant. There was, however, a significant linear trend suggesting an exposure–response relationship between increasing AHI in midpregnancy and the risk of MS ($P = 0.043$). Participants in the highest AHI group (≥ 15) had an aRR for MS of 2.32 (95% CI, 1.11–4.86).

Table 4 gives crude RRs and aRRs relating ODI in pregnancy to incident HTN and MS diagnosed at the 2- to 7-year follow-up. In adjusted analyses, SDB-ODI in pregnancy (early or middle) was associated with an increased risk for incident HTN (aRR, 2.02; 95% CI, 1.30–3.14). A similar statistically significant risk was observed separately for $\text{ODI} \geq 5$ at midpregnancy but not early pregnancy.

In adjusted analyses, SDB-ODI in pregnancy was associated with an increased risk of MS (aRR, 1.53; 95% CI, 1.19–1.97). This risk was also separately observed for both early pregnancy and midpregnancy, and the risk increased with increasing categories of ODI severity. Notably, participants with an $\text{ODI} \geq 15$ in midpregnancy had an aRR of 2.57 (95% CI, 0.82–8.01) for MS ($P = 0.02$ for linear trend).

To better understand the relationships between SDB in pregnancy and MS, we examined the individual components of MS in relation to the presence of SDB-AHI or

Table 1. Characteristics of nuMoM2b Participants with Early Pregnancy or Midpregnancy Sleep Study and Cardiovascular Assessment at 2- to 7-Year Follow-up according to Apnea–Hypopnea Index* Categories

Characteristics	AHI < 5 in Early Pregnancy and Midpregnancy (*n* = *1,238*)	AHI ⩾ 5 in Early Pregnancy or Midpregnancy (*n* = *127*)	*P* Value†
Maternal age in early pregnancy			
Mean (SD), yr	26.6 (5.2)	29.8 (5.8)	<0.0001
Category, *n* (%)			<0.0001
13–21 yr	234 (18.9)	11 (8.7)	
22–35 yr	939 (75.8)	93 (73.2)	
>35 yr	65 (5.3)	23 (18.1)	
Maternal race, *n* (%)			0.5663
White non-Hispanic	810 (65.4)	83 (65.4)	
Black non-Hispanic	133 (10.7)	18 (14.2)	
Hispanic	199 (16.1)	16 (12.6)	
Asian	34 (2.7)	5 (3.9)	
Other	62 (5.0)	5 (3.9)	
BMI in early pregnancy			
Mean, SD, kg/m^2	25.9 (5.9)	33.5 (8.2)	<0.0001
Category, *n* (%)			<0.0001
<25 kg/m^2	680 (55.8)	18 (14.4)	
25 to <30 kg/m^2	295 (24.2)	29 (23.2)	
⩾30 kg/m^2	244 (20.0)	78 (62.4)	
Smoked during pregnancy, *n* (%)	74 (6.0)	11 (8.7)	0.2332
Rate of weight gain from early pregnancy to midpregnancy, kg/wk			
Mean, SD	0.49 (0.22)	0.42 (0.26)	0.0011

Definition of abbreviations: AHI = apnea–hypopnea index; BMI = body mass index; nuMoM2b = Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be.
*Including all apneas and hypopneas with ⩾3% oxygen desaturation per hour.
†*P* values are shown for chi-square tests for AHI and the categorical baseline characteristics and from ANOVA *F* tests for AHI and continuous baseline characteristics.

SDB-ODI in pregnancy. In adjusted analyses, an SDB-AHI in pregnancy was associated with elevated triglycerides and reduced HDL. SDB-ODI in pregnancy was associated with elevated triglycerides and elevated BP (data shown in Tables E2 and E3).

Given the associations between AHI and ODI in pregnancy and hypertensive disorders of pregnancy and GDM, and the relationship between these pregnancy complications and later life cardiometabolic disease, we performed a mediation analysis aimed at assessing the controlled direct effect of SDB in pregnancy on HTN and MS at the 2- to 7-year follow-up. In these analyses, we did not observe a statistically significant controlled direct effect (AHI only, without mediation or interaction) between SDB-AHI and the outcomes. Similarly, no direct effect was observed for SDB-ODI on HTN risk at the 2- to 7-year follow-up. However, the controlled direct effect of SDB-ODI in pregnancy on MS was statistically significant. A total excess aRR of 0.60 (95% CI, 0.10–1.09) was observed with SDB-ODI in pregnancy and the proportion explained by mediation and/or interaction was estimated at ⩾11% with 95% confidence (data in Tables E4 and E5).

Cardiovascular and metabolic characteristics and outcome rates at the 2- to 7-year follow-up by current SDB status by AHI are detailed in Table E6. In summary, participants with an SDB-AHI at the 2- to 7-year follow-up had higher BMIs; larger waist circumferences; higher systolic and diastolic BP, triglyceride levels, and fasting blood glucose levels; and lower HDL-C levels. Incident HTN was more common in participants with an SDB-AHI after delivery (19.5% vs. 5.3%, $P < 0.0001$), as was MS (44.4% vs. 14.0%, $P < 0.0001$).

Table 5 gives crude RRs and aRRs relating SDB by AHI and ODI status at the 2- to 7-year follow-up to incident HTN and MS. In adjusted analyses, an SDB-AHI after delivery was associated with an increased likelihood of HTN (aRR, 2.01; 95% CI, 1.17–3.46) and MS (aRR, 1.51; 95% CI, 1.14–2.00). Similarly, SDB-ODI was associated with increased risks for incident HTN (aRR, 1.75; 95% CI, 1.05–2.92) and MS (aRR, 1.60; 95% CI, 1.21–2.12). There were statistically significant linear trends suggesting exposure–response relationships between increasing values of AHI and risk of incident HTN and MS, and between increasing values of ODI and risk of incident HTN.

Among participants with data across all time points (826 participants), Table 6 examines the relationship between SDB trajectory by AHI and ODI criteria from pregnancy to the 2- to 7-year follow-up visit in relation to risk of incident HTN and MS. Rates of both outcomes differed by SDB trajectory. Participants with persistent SDB, defined using either the AHI or ODI, had the highest risk for incident HTN and MS (aRRs ranging from 2.3 to 3.8).

Given that the relationships between our outcomes were stronger for ODI in pregnancy compared with AHI, we sought to understand how AHI and ODI related to each other in the larger pregnancy dataset. As expected, AHI and ODI were strongly correlated (Spearman correlation coefficients at early pregnancy and midpregnancy visits

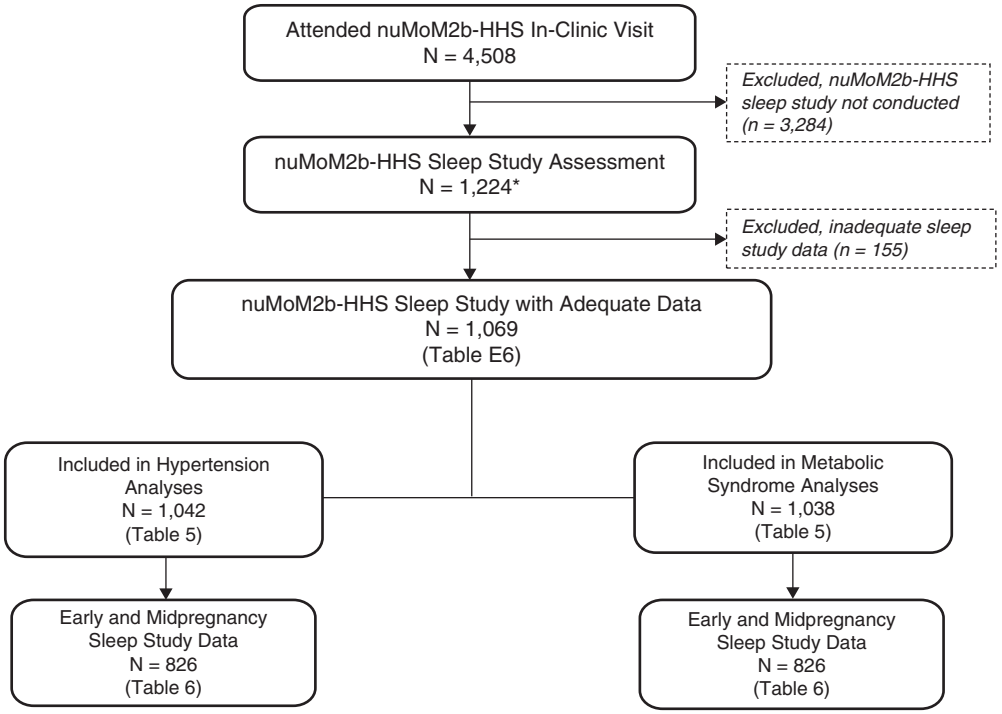

Figure 2. Enrollment and inclusion in analysis of nuMoM2b-HHS (Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be Heart Health Study) sleep study data. *There were two participants who completed a nuMoM2b-HHS home sleep apnea test (HSAT) who did not have an HSAT during pregnancy.

were 0.79 and 0.84, respectively). The median (IQR) for the difference (delta) between ODI and AHI in early pregnancy and midpregnancy were 0.65 (1.47) and 1.16 (2.11), respectively. A larger ODI-AHI delta was seen with higher BMI in pregnancy (additional data on ODI-AHI delta can be found in the online supplement).

Discussion

In this analysis of objectively-assessed SDB in pregnancy and at a 2- to 7-year follow-up visit in a large U.S. cohort, we found that SDB measured during pregnancy and in the 2- to 7-year period after delivery was associated with HTN and MS. Associations of SDB in pregnancy were generally stronger when SDB was defined using the ODI, which quantified the frequency of drops in oxygen saturation of ⩾3%, than the AHI, which was defined by a combination of changes in airflow and oxygen saturation. Participants with persistent elevations in AHI or ODI during pregnancy and 2- to 7-year follow-up visits were at more than threefold increased risk for incident HTN and more than twofold increased risk for MS. Our data suggest that the simpler measure of ODI can identify those at increased risk just as well, if not better, than AHI.

In nonpregnant populations that have been followed after an SDB diagnosis, such as the Wisconsin Sleep Cohort, increasing AHI has been linked to higher rates of incident HTN (23). In our prospective analysis of SDB in pregnancy, we did not find an association between AHI in pregnancy and incident HTN. However, there was an association between the ODI in pregnancy and incident HTN. AHI and ODI are very tightly correlated, but we found that the ODI tended to be slightly higher than AHI, meaning that there were oxygen desaturation events that were not associated with clearly evident respiratory events (apneas and hypopneas). In our analysis, the difference between ODI and AHI during pregnancy could not be explained by an asthma diagnosis or restless legs syndrome symptoms (*see* online supplement). However, it was correlated with BMI, as was AHI. It may be that there were subtle respiratory flow events that did not reach the amplitude criteria for hypopnea but impaired ventilation, leading to oxygen desaturations. Other researchers found that the difference between AHI and ODI increases progressively with obesity level and similarly postulated that higher BMI may result in desaturation events even in the absence of notable changes in breathing amplitude as measured during routine sleep studies (24).

Our data demonstrated a relationship between pregnancy ODI and MS and a weaker association (demonstrated only in the analysis of AHI in early pregnancy or midpregnancy) between pregnancy AHI and MS. This association has been reported in prior cohorts, but this is the first large prospective study in young women to confirm this association (25). It is important to note that, unlike the HTN analyses, we cannot assert that the MS was incident in the follow-up period as we do not have assessments of fasting blood glucose and lipids before pregnancy for comparison. Furthermore, how best to interpret this relationship between SDB and MS is complicated by the very tight relationship of both SDB and MS with BMI. Yet, even after

Table 2. Cardiovascular Characteristics at 2–7 Years after nuMoM2b Index Pregnancy, according to Apnea–Hypopnea Index* Categories

Cardiovascular Characteristic 2–7 Years after nuMoM2b Index Pregnancy	AHI < 5 in Early Pregnancy and Midpregnancy (*n* = *1,238*)	AHI ⩾ 5 in Early Pregnancy or Midpregnancy (*n* = *127*)	*P* Value†
BMI			
n	1,225	126	
Mean (SD), kg/m^2	27.0 (7.1)	35.2 (9.0)	<0.0001
Category, *n* (%)			<0.0001
<25 kg/m^2	599 (48.9)	17 (13.5)	
25 to <30 kg/m^2	314 (25.6)	19 (15.1)	
⩾30 kg/m^2	312 (25.5)	90 (71.4)	
Waist circumference over iliac crest			
n	1,230	127	
Mean (SD), cm	94.6 (15.1)	111.6 (19.3)	<0.0001
⩾88 cm (non-Asian) or ⩾80 cm (Asian), *n* (%)	768 (62.4)	115 (90.6)	<0.0001
SBP			
n	1,235	127	
Mean (SD), mm Hg	110.8 (10.8)	116.1 (12.2)	<0.0001
DBP			
n	1,235	127	
Mean (SD), mm Hg	71.7 (9.5)	77.4 (9.8)	<0.0001
Hypertension			
SBP ⩾ 140, DBP ⩾ 90, or on antihypertensive medication, *n* (%)	76 (6.2)	20 (15.7)	<0.0001
Triglycerides			
n	1,223	127	
Mean (SD), mg/dl	93.0 (60.6)	134.5 (83.8)	<0.0001
⩾150 mg/dl or on lipid-lowering medication, *n* (%)	124 (10.1)	41 (32.3)	<0.0001
HDL-C			
n	1,223	127	
Mean (SD), mg/dl	55.6 (12.7)	49.6 (11.5)	<0.0001
<50 mg/dl or on HDL-raising medication, *n* (%)	405 (33.1)	73 (57.5)	<0.0001
Blood glucose (fasting)			
n	1,220	127	
Mean (SD), mg/dl	89.9 (14.9)	96.4 (25.2)	<0.0001
⩾100 mg/dl or on glucose-lowering medication, *n* (%)	175 (14.3)	31 (24.4)	0.0027
Metabolic syndrome, *n* (%)‡	172 (14.2)	51 (40.2)	<0.0001
Time from delivery to HHS cardiovascular assessment			
n	1,236	127	
Mean (SD), yr	3.0 (0.8)	2.9 (0.8)	0.1812

Definition of abbreviations: AHI = apnea–hypopnea index; BMI = body mass index; DBP = diastolic blood pressure; HDL-C = high-density lipoprotein cholesterol; HHS = Heart Healthy Study; nuMoM2b = Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be; SBP = systolic blood pressure.

*Including all apneas and hypopneas with ⩾3% oxygen desaturation per hour.

†*P* values are shown for chi-square tests for AHI and the categorical baseline characteristics and from ANOVA *F* tests for AHI and continuous baseline characteristics.

‡Metabolic syndrome is defined based on the presence of three of five of the following criteria: elevated waist circumference, elevated triglycerides or associated medication, elevated fasting glucose or associated medication, elevated blood pressure or associated medication, and reduced HDL-C or associated medication.

adjustment for BMI (linear and quadratic), the associations between SDB measures and MS remained statistically significant. Also, notably, in our mediation analysis, we considered pregnancy complications and found that ODI ⩾ 5 in pregnancy had a significant controlled direct effect on MS risk unrelated to the impact of HDP and GDM.

In our cross-sectional analyses of AHI and ODI at the 2- to 7-year follow-up period, we demonstrated strong associations between AHI and ODI with both HTN and MS. We found significant exposure–response relationships between increasing AHI values and higher rates of both outcomes

Table 3. Crude and Adjusted Risk Ratios* for Incident Hypertension and Metabolic Syndrome† at 2- to 7-Year Follow-up according to Apnea–Hypopnea Index‡ in Early Pregnancy and Midpregnancy

AHI Characteristic	*n/N* (%)	Crude Risk Ratios		Adjusted Risk Ratios	
		Estimate (95% CI)	*P* Value	Estimate (95% CI)	*P* Value
Incident hypertension					
Early pregnancy or midpregnancy					
AHI < 5 in both early pregnancy and midpregnancy (referent)	67/1,215 (5.5)	1.00	0.0402	1.00	0.3344
AHI ⩾ 5 in early pregnancy or midpregnancy	14/118 (11.9)	2.15 (1.25–3.71)		1.39 (0.75–2.56)	
Early pregnancy					
AHI < 5 (referent)	96/1,647 (5.8)	1.00	0.0463	1.00	0.6015
AHI ⩾ 5	10/68 (14.7)	2.52 (1.38–4.62)		1.21 (0.61–2.41)	
AHI = 0 (referent)	18/391 (4.6)	1.00	0.1280	1.00	0.9606
0 < AHI < 5	78/1,256 (6.2)	1.35 (0.82–2.22)	Trend tests:	1.03 (0.63–1.68)	Trend tests:
5 ⩽ AHI < 15	9/63 (14.3)	3.10 (1.46–6.60)	0.3931 linear	1.26 (0.55–2.88)	0.8631 linear
AHI ⩾ 15	1/5 (20.0)	4.34 (0.71–26.55)	0.9702 quadratic	1.11 (0.19–6.61)	0.8672 quadratic
Midpregnancy					
AHI < 5 (referent)	72/1,308 (5.5)	1.00	0.0070	1.00	0.0908
AHI ⩾ 5	17/114 (14.9)	2.71 (1.66–4.43)		1.73 (0.99–3.01)	
AHI = 0 (referent)	9/189 (4.8)	1.00	0.0547	1.00	0.3871
0 < AHI < 5	63/1,119 (5.6)	1.18 (0.60–2.34)	Trend tests:	0.86 (0.44–1.69)	Trend tests:
5 ⩽ AHI < 15	14/100 (14.0)	2.94 (1.32–6.55)	0.1325 linear	1.43 (0.62–3.30)	0.3511 linear
AHI ⩾ 15	3/14 (21.4)	4.50 (1.37–14.77)	0.7140 quadratic	1.92 (0.49–7.60)	0.5638 quadratic
Metabolic syndrome					
Early pregnancy or midpregnancy					
AHI < 5 in both early pregnancy and midpregnancy (referent)	165/1,200 (13.8)	1.00	<0.0001	1.00	0.0211
AHI ⩾ 5 in early pregnancy or midpregnancy	48/124 (38.7)	2.82 (2.16–3.66)		1.44 (1.08–1.93)	
Early pregnancy					
AHI < 5 (referent)	260/1,630 (16.0)	1.00	<0.0001	1.00	0.1214
AHI ⩾ 5	32/69 (46.4)	2.91 (2.20–3.84)		1.28 (0.95–1.73)	
AHI = 0 (referent)	43/383 (11.2)	1.00	<0.0001	1.00	0.4454
0 < AHI < 5	217/1,247 (17.4)	1.55 (1.14–2.11)	Trend tests:	1.07 (0.80–1.43)	Trend tests:
5 ⩽ AHI < 15	29/63 (46.0)	4.10 (2.78–6.05)	0.1141 linear	1.38 (0.92–2.07)	0.5643 linear
AHI ⩾ 15	3/6 (50.0)	4.45 (1.91–10.40)	0.4084 quadratic	1.25 (0.50–3.13)	0.7232 quadratic
Midpregnancy					
AHI < 5 (referent)	178/1,292 (13.8)	1.00	<0.0001	1.00	0.0754
AHI ⩾5	45/121 (37.2)	2.70 (2.06–3.53)		1.33 (0.99–1.79)	
AHI = 0 (referent)	13/189 (6.9)	1.00	<0.0001	1.00	0.1497
0 < AHI < 5	165/1,103 (15.0)	2.17 (1.26–3.74)	Trend tests:	1.31 (0.78–2.21)	Trend tests:
5 ⩽ AHI < 15	37/107 (34.6)	5.03 (2.80–9.03)	0.0053 linear	1.64 (0.91–2.97)	0.0432 linear
AHI ⩾15	8/14 (57.1)	8.31 (4.15–16.62)	0.4603 quadratic	2.32 (1.11–4.86)	0.8503 quadratic

Definition of abbreviations: AHI = apnea–hypopnea index; BMI = body mass index; CI = confidence interval; HDL-C = high-density lipoprotein cholesterol; HHS = Heart Healthy Study.

*Poisson regression models are used for the analyses with robust error covariance used to compute CIs and to test for trends. *P* values are based on likelihood ratio tests. Analyses are adjusted for age and BMI (linear and quadratic) in early pregnancy, race, and time from delivery to HHS cardiovascular assessment.

†Metabolic syndrome is defined based on the presence of three of five of the following criteria: elevated waist circumference, elevated triglycerides or associated medication, elevated fasting glucose or associated medication, elevated blood pressure or associated medication, and reduced HDL-C or associated medication. Analyses are adjusted for age and BMI in early pregnancy, race, and time from delivery to HHS cardiovascular assessment.

‡Including all apneas and hypopneas with ⩾3% oxygen desaturation per hour.

and a significant exposure–response relationship between increasing ODI and incident HTN. When we examined these associations in relation to prior sleep data from pregnancy, we found that participants who had persistent SDB (defined either by AHI or ODI) were at the highest risk.

A major strength of this study is the combined prospective and cross-sectional design from pregnancy through 2 to 7 years of follow-up in which the pregnancy AHI and ODI results were blinded to the care providers, investigators, and participants (unless an urgent alert was identified [*see* online supplement for details]). This limited the possibility of ascertainment bias. Our SDB ascertainment was optimized using an independent and blinded central reading center. We were able to control for important confounding factors, including BMI (BMI in early pregnancy for prospective analysis, BMI at HHS visit for

Table 4. Crude and Adjusted Risk Ratios* for Incident Hypertension and Metabolic Syndrome† at 2- to 7-Year Follow-up according to Oxygen Desaturation Index‡ in Early Pregnancy and Midpregnancy

ODI Characteristic	*n/N* (%)	Crude Risk Ratios		Adjusted Risk Ratios	
		Estimate (95% CI)	*P* Value	Estimate (95% CI)	*P* Value
Incident hypertension					
Early pregnancy or midpregnancy					
ODI < 5 in both early pregnancy and midpregnancy (referent)	41/984 (4.2)	1.00	<0.0001	1.00	0.0041
ODI ⩾ 5 in early pregnancy or midpregnancy	40/349 (11.5)	2.75 (1.81–4.18)		2.02 (1.30–3.14)	
Early pregnancy					
ODI < 5 (referent)	82/1,521 (5.4)	1.00	0.0048	1.00	0.2918
ODI ⩾ 5	24/194 (12.4)	2.29 (1.49–3.53)		1.32 (0.81–2.13)	
ODI = 0 (referent)	5/141 (3.5)	1.00	0.0220	1.00	0.6595
0 < ODI < 5	77/1,380 (5.6)	1.57 (0.65–3.82)	Trend tests:	1.30 (0.53–3.19)	Trend tests:
5 ⩽ ODI < 15	21/174 (12.1)	3.40 (1.32–8.80)	0.1462 linear	1.73 (0.63–4.75)	0.5806 linear
ODI ⩾ 15	3/20 (15.0)	4.23 (1.09–16.36)	0.7345 quadratic	1.41 (0.33–6.11)	0.5015 quadratic
Midpregnancy					
ODI < 5 (referent)	47/1,094 (4.3)	1.00	<0.0001	1.00	0.0013
ODI ⩾ 5	42/328 (12.8)	2.98 (2.00–4.44)		2.16 (1.41–3.30)	
ODI = 0 (referent)	4/57 (7.0)	1.00	0.0002	1.00	0.0092
0 < ODI < 5	43/1,037 (4.1)	0.59 (0.22–1.59)	Trend tests:	0.50 (0.18–1.39)	Trend tests:
5 ⩽ ODI < 15	35/287 (12.2)	1.74 (0.64–4.70)	0.0605 linear	1.09 (0.39–3.08)	0.3663 linear
ODI ⩾ 15	7/41 (17.1)	2.43 (0.76–7.77)	0.2666 quadratic	1.37 (0.40–4.74)	0.2533 quadratic
Metabolic syndrome					
Early pregnancy or midpregnancy					
ODI < 5 in both early pregnancy and midpregnancy (referent)	106/972 (10.9)	1.00	<0.0001	1.00	0.0014
ODI ⩾ 5 in early pregnancy or midpregnancy	107/352 (30.4)	2.79 (2.19–3.54)		1.53 (1.19–1.97)	
Early pregnancy					
ODI < 5 (referent)	219/1,505 (14.6)	1.00	<0.0001	1.00	0.0188
ODI ⩾ 5	73/194 (37.6)	2.59 (2.08–3.22)		1.35 (1.06–1.70)	
ODI = 0 (referent)	10/137 (7.3)	1.00	<0.0001	1.00	0.0456
0 < ODI < 5	209/1,368 (15.3)	2.09 (1.14–3.85)	Trend tests:	1.49 (0.82–2.71)	Trend tests:
5 ⩽ ODI < 15	63/173 (36.4)	4.99 (2.66–9.35)	0.0021 linear	2.02 (1.07–3.81)	0.0917 linear
ODI ⩾ 15	10/21 (47.6)	6.52 (3.09–13.76)	0.1995 quadratic	1.77 (0.82–3.78)	0.1362 quadratic
Midpregnancy					
ODI < 5 (referent)	121/1,083 (11.2)	1.00	<0.0001	1.00	0.0031
ODI ⩾ 5	102/330 (30.9)	2.77 (2.19–3.49)		1.48 (1.15–1.90)	
ODI = 0 (referent)	3/54 (5.6)	1.00	<0.0001	1.00	0.0148
0 < ODI < 5	118/1,029 (11.5)	2.06 (0.68–6.28)	Trend tests:	1.38 (0.47–4.04)	Trend tests:
5 ⩽ ODI < 15	82/286 (28.7)	5.16 (1.69–15.74)	<0.0001 linear	1.94 (0.65–5.75)	0.0214 linear
ODI ⩾ 15	20/44 (45.5)	8.18 (2.60–25.75)	0.6269 quadratic	2.57 (0.82–8.01)	0.9481 quadratic

Definition of abbreviations: BMI = body mass index; CI = confidence interval; HDL-C = high-density lipoprotein cholesterol; HHS = Heart Healthy Study; ODI = oxygen desaturation index.

*Poisson regression models are used for the analyses with robust error covariance used to compute CIs and to test for trends. *P* values are based on likelihood ratio tests. Analyses are adjusted for age and BMI (linear and quadratic) in early pregnancy, race, and time from delivery to HHS cardiovascular assessment.

†Metabolic syndrome is defined based on the presence of three of five of the following criteria: elevated waist circumference, elevated triglycerides or associated medication, elevated fasting glucose or associated medication, elevated blood pressure or associated medication, and reduced HDL-C or associated medication. Analyses are adjusted for age and BMI in early pregnancy, race, and time from delivery to HHS cardiovascular assessment.

‡Number of desaturations with ⩾3% per hour of sleep.

cross-sectional analysis), and we had objective assessments of cardiovascular and metabolic outcomes at the 2- to 7-year follow-up visit. However, given the observational and voluntary nature of the study and moderate aRRs, the possibility of residual confounding due to selection bias and unmeasured confounders cannot be definitively excluded. Additionally, given sample size limitations, we were unable to perform a meaningful analysis considering the impact of intercurrent pregnancies on the HTN and MS risk. Also, we do not have objective SDB data from all of our participants at the 2- to 7-year follow-up. While it was offered to most nuMoM2b-SDB substudy participants, only 62.2% repeated sleep

Table 5. Crude and Adjusted Risk Ratios* for Incident Hypertension† and Metabolic Sydrome‡ at 2- to 7-Year Follow-up according to Apnea–Hypopnea Index and Oxygen Desaturation Index§ at the Follow-up Assessment

		Crude Risk Ratios		Adjusted Risk Ratios	
Sleep Characteristic	***n/N* (%)**	**Estimate (95% CI)**	***P* Value**	**Estimate (95% CI)**	***P* Value**
AHI					
Incident hypertension					
AHI < 5 (referent)	45/918 (4.9)	1.00	0.0008	1.00	0.0271
AHI ⩾ 5	21/124 (16.9)	3.45 (2.13–5.60)		2.01 (1.17–3.46)	
AHI = 0 (referent)	4/118 (3.4)	1.00	0.0048	1.00	0.0580
0 < AHI < 5	41/800 (5.1)	1.51 (0.55–4.14)	Trend tests:	1.11 (0.39–3.15)	Trend tests:
5 ⩽ AHI < 15	11/94 (11.7)	3.45 (1.14–10.49)	0.0015 linear	1.67 (0.50–5.57)	0.0131 linear
AHI ⩾ 15	10/30 (33.3)	9.83 (3.31–29.19)	0.3869 quadratic	4.18 (1.19–14.76)	0.2783 quadratic
Metabolic syndrome					
AHI < 5 (referent)	122/911 (13.4)	1.00	<0.0001	1.00	0.0073
AHI ⩾ 5	54/127 (42.5)	3.18 (2.45–4.12)		1.51 (1.14–2.00)	
AHI = 0 (referent)	11/116 (9.5)	1.00	<0.0001	1.00	0.0073
0 < AHI < 5	111/795 (14.0)	1.47 (0.82–2.65)	Trend tests:	1.00 (0.57–1.75)	Trend tests:
5 ⩽ AHI < 15	34/96 (35.4)	3.73 (2.00–6.97)	<0.0001 linear	1.32 (0.71–2.46)	0.0079 linear
AHI ⩾ 15	20/31 (64.5)	6.80 (3.66–12.65)	0.5670 quadratic	2.14 (1.11–4.15)	0.1936 quadratic
ODI					
Incident hypertension					
ODI < 5 (referent)	28/695 (4.0)	1.00	0.0002	1.00	0.0349
ODI ⩾ 5	38/347 (11.0)	2.72 (1.70–4.35)		1.75 (1.05–2.92)	
ODI < 5 (referent)‖	28/695 (4.0)	1.00	0.0004	1.00	0.0244
5 ⩽ ODI < 15	23/279 (8.2)	2.05 (1.20–3.49)	Trend tests:	1.52 (0.86–2.68)	Trend tests:
ODI ⩾ 15	15/68 (22.1)	5.48 (3.08–9.74)	0.0010 linear 0.5825 quadratic	2.89 (1.50–5.57)	0.0080 linear 0.6403 quadratic
Metabolic syndrome					
ODI < 5 (referent)	71/689 (10.3)	1.00	<0.0001	1.00	0.0009
ODI ⩾ 5	105/349 (30.1)	2.92 (2.22–3.83)		1.60 (1.21–2.12)	
ODI = 0 (referent)	2/22 (9.1)	1.00	<0.0001	1.00	0.0014
0 < ODI < 5	69/667 (10.3)	1.14 (0.30–4.35)	Trend tests:	0.74 (0.20–2.79)	Trend tests:
5 ⩽ ODI < 15	68/280 (24.3)	2.67 (0.70–10.18)	<0.0001 linear	1.10 (0.29–4.16)	0.3061 linear
ODI ⩾ 15	37/69 (53.6)	5.90 (1.55–22.52)	0.4812 quadratic	1.57 (0.41–6.01)	0.4813 quadratic

Definition of abbreviations: AHI = apnea–hypopnea index; BMI = body mass index; CI = confidence interval; HDL-C = high-density lipoprotein cholesterol; HHS = Heart Healthy Study; ODI = oxygen desaturation index.

*Poisson regression models are used for the analyses with robust error covariance used to compute CIs and to test for trends. *P* values are based on likelihood ratio tests. Analyses are adjusted for age and BMI (linear and quadratic) at the time of the HHS cardiovascular assessment, and race.

†Women with baseline hypertension are excluded from the hypertension analyses.

‡Women with preexisting diabetes are excluded from the metabolic syndrome analyses. Metabolic syndrome is defined based on the presence of three of five of the following criteria: elevated waist circumference, elevated triglycerides or associated medication, elevated fasting glucose or associated medication, elevated blood pressure or associated medication, and reduced HDL-C or associated medication.

§AHI is all apneas and hypopneas with ⩾3% oxygen desaturation per hour; ODI is the number of desaturations ⩾3% per hour of sleep.

‖There were no women in the ODI = 0 with hypertension, so the ODI = 0 group was combined with the 0 < ODI < 5 group for this analysis.

testing at the 2- to 7-year follow-up assessment. We also recognize the limitations of utilizing a level 3 HSAT for measuring AHI. Unattended home sleep apnea testing may modestly underestimate the AHI and ODI values due to overestimation of sleep time, leading to some degree of misclassification bias (26). Unlike full polysomnography, our home sleep testing procedures did not employ an electroencephalogram so that events associated with arousals (without desaturations) were not ascertained. Finally, because many analyses were done and adjustment for multiple statistical testing was not performed, chance alone might be responsible for some statistically significant results.

Although we found associations with AHI, ODI, and incident HTN and MS, we cannot conclude that universal screening for and treatment of SDB in pregnancy and/or in the period after delivery would reduce the risks of these adverse outcomes. The most widely prescribed treatment for SDB is CPAP. The benefit of treatment with CPAP has been reliably demonstrated when excessive daytime sleepiness and sleep quality are used as endpoints (27, 28). CPAP has also been demonstrated in randomized controlled trials to reduce BP (29, 30). However, data conflict regarding whether treatment of SDB can reduce the risk of developing HTN, other cardiovascular disease, or diabetes (31–34). This is especially true for milder forms of SDB (AHI < 30), which our study confirms represent the vast majority of SDB cases in young pregnant persons.

In summary, in this prospective analysis of objectively assessed SDB in pregnancy, ODI but not AHI ⩾ 5 in pregnancy was associated with incident HTN 2–7 years after the index pregnancy. Both AHI and ODI were associated with MS, though associations were stronger for

Table 6. Crude and Adjusted Risk Ratios* for Incident Hypertension† and Metabolic Sydrome‡ at 2- to 7-Year Follow-up according to Apnea–Hypopnea Index and Oxygen Desaturation Index§ during the nuMoM2b Pregnancy and at the Follow-up Assessment

		Crude Risk Ratios		Adjusted Risk Ratios	
Sleep Characteristic	***n/N* (%)**	**Estimate (95% CI)**	***P* Value**	**Estimate (95% CI)**	***P* Value**
AHI					
Incident hypertension					
Never: AHI < 5 in early pregnancy and midpregnancy and after delivery (referent)	31/702 (4.4)	1.00	0.0130‖	1.00	0.0327‖
New-onset: AHI < 5 in early pregnancy and midpregnancy; AHI ⩾ 5 after delivery	8/59 (13.6)	3.07 (1.48–6.37)		2.18 (1.07–4.48)	
Resolved: AHI ⩾ 5 in early pregnancy or midpregnancy; AHI < 5 after delivery	0/20 (0.0)	Not applicable		Not applicable	
Persistent: AHI ⩾ 5 in early pregnancy or midpregnancy; AHI ⩾ 5 after delivery	10/45 (22.2)	5.03 (2.64–9.60)		3.77 (1.84–7.73)	
Metabolic syndrome					
Never: AHI < 5 in early pregnancy and midpregnancy and after delivery (referent)	81/697 (11.6)	1.00	<0.0001	1.00	0.0033
New-onset: AHI < 5 in early pregnancy and midpregnancy; AHI ⩾ 5 after delivery	20/60 (33.3)	2.87 (1.90–4.33)		1.81 (1.18–2.80)	
Resolved: AHI ⩾ 5 in early pregnancy or midpregnancy; AHI < 5 after delivery	4/22 (18.2)	1.56 (0.63–3.89)		1.12 (0.49–2.54)	
Persistent: AHI ⩾ 5 in early pregnancy or midpregnancy; AHI ⩾ 5 after delivery	24/47 (51.1)	4.39 (3.11–6.22)		2.46 (1.59–3.79)	
ODI					
Incident hypertension					
Never: ODI < 5 in early pregnancy and midpregnancy and after delivery (referent)	15/468 (3.2)	1.00	0.0029	1.00	0.0401
New-onset: ODI < 5 in early pregnancy and midpregnancy; ODI ⩾ 5 after delivery	9/144 (6.3)	1.95 (0.87–4.36)		1.69 (0.76–3.74)	
Resolved: ODI ⩾ 5 in early pregnancy or midpregnancy; ODI < 5 after delivery	5/68 (7.4)	2.29 (0.86–6.11)		1.81 (0.71–4.60)	
Persistent: ODI ⩾ 5 in early pregnancy or midpregnancy; ODI ⩾ 5 after delivery	20/146 (13.7)	4.27 (2.25–8.13)		2.94 (1.50–5.77)	
Metabolic syndrome					
Never: ODI < 5 in early pregnancy and midpregnancy and after delivery (referent)	38/468 (8.1)	1.00	<0.0001	1.00	0.0004
New-onset: ODI < 5 in early pregnancy and midpregnancy; ODI ⩾ 5 after delivery	28/143 (19.6)	2.41 (1.54–3.78)		1.93 (1.24–3.01)	
Resolved: ODI ⩾ 5 in early pregnancy or midpregnancy; ODI < 5 after delivery	9/65 (13.8)	1.71 (0.87–3.36)		1.17 (0.62–2.18)	
Persistent: ODI ⩾ 5 in early pregnancy or midpregnancy; ODI ⩾ 5 after delivery	54/150 (36.0)	4.43 (3.06–6.43)		2.42 (1.59–3.67)	

Definition of abbreviations: AHI = apnea–hypopnea index; BMI = body mass index; CI = confidence interval; HDL-C = high-density lipoprotein cholesterol; HHS = Heart Healthy Study; nuMoM2b = Nulliparous Pregnancy Outcomes Study: Monitoring Mothers-to-be; ODI = oxygen desaturation index.

*Poisson regression models are used for the analyses with robust error covariance used to compute CIs and to test for trends. *P* values are based on likelihood ratio tests. Analyses are adjusted for age and BMI (linear and quadratic) in early pregnancy, race, and time from delivery to HHS cardiovascular assessment.

†Women with baseline hypertension are excluded from the hypertension analyses.

‡Women with preexisting diabetes are excluded from the metabolic syndrome analyses. Metabolic syndrome is defined based on the presence of three of five of the following criteria: elevated waist circumference, elevated triglycerides or associated medication, elevated fasting glucose or associated medication, elevated blood pressure or associated medication, and reduced HDL-C or associated medication.

§AHI is all apneas and hypopneas with ⩾3% oxygen desaturation per hour; ODI is the number of desaturations ⩾3% per hour of sleep.

‖None of the 20 participants with AHI ⩾5 during the nuMoM2b pregnancy study and AHI <5 at the 2- to 7-year assessment had hypertension at the follow-up assessment. To compute relative risk estimates and an upper bound on the *P* value for differences between the AHI categories, one observation among the 20 was categorized as having hypertension, such that the observation selected resulted in the smallest estimate of adjusted relative risk for this group compared to the referent group.

ODI in pregnancy. AHI and ODI ⩾ 5 at 2–7 years after delivery were strongly associated with both incident HTN and MS, and participants who had persistent AHI and ODI elevations (present at pregnancy and after-delivery visit) were at the highest risk for these adverse outcomes. Further longitudinal studies are needed to examine the temporal or causal relationships between SDB and cardiometabolic risk, to determine if simple oximetry monitoring can reliably be used to identify individuals at risk, and to study if treatment with CPAP during or after pregnancy can modify these risks. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

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