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Association of Maternal Short Sleep Duration with Adiposity and Cardio-Metabolic Status at 3 Years Postpartum

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Abstract

The purpose of this study was to examine the association of short sleep duration among women in the first year postpartum with adiposity and cardio-metabolic status at 3-years postpartum. We studied 586 women in Project Viva, a prospective cohort. At 6 months and 1 year postpartum, women reported the number of hours they slept in a 24-hour period, from which we calculated a weighted average of daily sleep. We used multivariable regression analyses to predict the independent effects of short sleep duration (≤ 5 h/d v.> 5 h/d) on adiposity, glucose metabolism, lipid metabolism, and adipokines at 3-years postpartum. Women's mean (SD) hours of daily sleep in the first year postpartum was 6.7 (0.97) hours. After adjusting for age, race/ethnicity, education, parity, pre-pregnancy body mass index, and excessive gestational weight gain, we found that postpartum sleep ≤ 5 h/d was associated with higher postpartum weight retention (β 1.50 kg; 95% CI: 0.02, 2.86), higher subscapular + triceps skinfold thickness (β 3.94 mm; 95% CI: 1.27, 6.60) and higher waist circumference (β 3.10 cm; 95% CI: 1.25, 4.94) at 3-years postpartum. We did not observe associations of short sleep duration with measures of cardio-metabolic status at 3-years postpartum. In conclusion, short sleep duration in the first year postpartum is associated with higher adiposity at 3-years postpartum.

Keywords

Sleep; Adiposity; Cardio-Metabolic Status; Postpartum women

INTRODUCTION

Mounting epidemiologic evidence indicates that short (< 5 hrs/day) duration of sleep is a risk factor for obesity, type 2 diabetes, coronary heart disease, hypertension, and all-cause mortality in adults independent of other measured risk factors.[1–7] The evidence that short

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sleep duration increases risk for obesity is strengthened by experimental studies showing altered secretion of appetite-regulating hormones in response to reductions in sleep duration.[8, 9] In addition, sleep restriction has been associated with several physiologic and behavioral mechanisms that may increase risk of obesity and cardio-metabolic disorders.[2]

The postpartum period for women may represent a critical window for long-term weight gain and the development of obesity. Compared with weight gain during other periods of life, evidence suggests that weight retained after giving birth is associated with long-term weight gain and increased risk for becoming or remaining overweight.[10] Excess weight gain associated with childbearing tends to be preferentially deposited centrally, as visceral fat, and is associated with declines in HDL cholesterol.[11–13] In addition, women who retain weight after pregnancy have a higher risk of complications such as impaired glucose tolerance and having a large for gestational age infant in a subsequent pregnancy, disadvantaging future offspring as well.[14–16] Thus, a group that may be at particularly high risk for the adverse effects of short sleep duration is women in the postpartum period.

Several published studies have reported substantial sleep restriction and reduced sleep quality in the postpartum period and a few have found insufficient sleep to be associated with women's mental health.[17, 18] In a previous study, we have also related postpartum sleep restriction to women's physical health. We have previously shown that sleeping ≤ 5 hours/day at 6 months postpartum was strongly associated with substantial weight retention at 1 year postpartum.[19] The study by Gunderson et al.[19] was the first to examine postpartum sleep duration and adiposity and additionally to show that women who reduced their sleep duration from 6 months to 1 year were two times more likely to substantially retain more weight at 1 year postpartum. No existing studies have prospectively examined the effects of postpartum short sleep duration on adiposity beyond 1 year postpartum and no study has examined the effects on cardio-metabolic status. Such information would help support interventions to improve sleep quality and quantity in the postpartum period and reduce the known adverse health effects of sleep insufficiency.

The purpose of this study was to examine the longitudinal association of short sleep duration in the first year postpartum with adiposity and cardio-metabolic status at 3-years postpartum. We hypothesized that short sleep duration would be associated with higher adiposity, measured as higher body mass index (BMI), postpartum weight retention, sum of subscapular and triceps skinfold thickness, and waist circumference, an adverse cardio-metabolic state at 3 years postpartum, measured as higher insulin resistance, higher fasting levels of triglycerides, LDL cholesterol, and lower HDL cholesterol.

METHODS AND PROCEDURES

Study subjects

The subjects for this study were participants in Project Viva, a prospective cohort study of gestational factors and offspring health. [20] We recruited women who were attending their initial prenatal visit at 8 obstetrical offices of a multi-specialty group practice in Massachusetts. Eligibility criteria included fluency in English, gestational age less than 22 weeks at the initial prenatal clinical appointment, and singleton pregnancy. Details of recruitment and retention procedures are available elsewhere. [20]

Of the 1579 women who were eligible for a 3-year follow-up examination; 761 of these women were eligible for the current analysis because they had not delivered another child since the birth of the index child three years previously, they did not have type 1 or type 2 diabetes, and they attended the three year visit. Of these women, 586 had complete data on

sleep duration at 6 months and 1 year; 480 provided a blood sample; fasting samples were available for 147.

After obtaining informed consent, we performed in-person study visits with the mother immediately after delivery and at 6 months and 3 years postpartum. Mothers completed mailed questionnaires at 1 and 2 years postpartum. Institutional review boards of participating institutions approved the study.

Main Exposure: Maternal Postpartum Sleep Duration

At 6 months and 1 year postpartum, we asked women to report hours of sleep duration within a 24-hour period using the question: "In the past month, how many hours of sleep do you get in an average 24-hour period?". To estimate the average number of hours that women slept from 6 months to 1 year, we summed the values for sleep duration at each time point and divided by 2.

Main Outcomes: Adiposity and Cardio-Metabolic status at three years postpartum

At 3 years postpartum, we measured women's weight to the nearest 0.1 kg using a research quality scale, measured height to the nearest 0.1 cm using a stadiometer, waist circumference to the nearest 0.1 cm using a Lefkin woven tape, and subscapular and triceps skinfold measures to the nearest 0.1 mm using a Holtain caliper. We calculated BMI as kg/m^2 and defined postpartum weight retention as the difference between measured weight at 3 years after delivery and self-reported pre-pregnancy weight.

We tested all blood samples for hemoglobin A1c, leptin, and adiponectin. We identified as fasting those participants who did not eat or drink anything other than water for 8 hours before blood samples were obtained. We tested fasting blood samples for insulin, glucose, total cholesterol, LDL cholesterol, HDL cholesterol, and triglycerides. Blood samples were collected by trained phlebotomists during visits that occurred between 9am and 5pm and transferred within 24 hours for storage in liquid nitrogen freezers. Sample testing was performed at the Children's Hospital Boston Clinical Chemistry Laboratory.

We assessed glycosylated hemoglobin using the Hitachi 917 analyzer (Roche Diagnostics, Indianapolis, IN) and calculated the $\%HbA_{1c}$. We calculated insulin resistance in fasting blood samples using the homeostasis model (HOMA-IR = (fasting insulin (μU/ml) × fasting glucose (mmol/L)/22.5). Fasting glucose was measured enzymatically using the Hitachi 911 analyzer. Fasting insulin was measured using a microparticle enzyme immunoassay on the IMZ analyzer (Abott Laboratories). Total cholesterol was measured enzymatically, and LDL cholesterol was assed by a homogenous direct method from Genzyme Corp, Cambridge, Mass. HDL cholesterol was assessed using a direct enzymatic colorimetric assay, and triglycerides were calculated enzymatically with correction for endogenous glycerol. We measured concentrations of leptin and adiponectin in plasma with radioimmunoassay as described previously.[21, 22] Inter- and intra-assay coefficients of variation for our biosamples ranged from 2 to 10%.

Study covariates

Using a combination of self-administered questionnaires and interviews, we collected information about maternal age, education, parity, prenatal smoking (never, former, during pregnancy), household income, and race/ethnicity. We assessed maternal postpartum depression at 6 months postpartum with the Edinburgh Postpartum Depression Scale (EPDS) and dichotomized scores >=13 as depression or <13 no depression.[23] Mothers reported their pre-pregnancy weight and height. We calculated gestational weight gain as the difference between the last weight prior to delivery and the self-reported pre-pregnancy

weight. We categorized gestational weight gain as inadequate, adequate, or excessive for pre-pregnancy BMI categories using the new Institute of Medicine (IOM) guidelines.[24] We assessed the following covariates as potential intermediates in the association between sleep duration and three-year cardio-metabolic outcomes: maternal dietary intake, physical activity, television viewing, and breastfeeding. We assessed mothers' dietary intake on the 6-month questionnaire using the PrimeScreen, a brief food frequency questionnaire.[25] PrimeScreen results were used to calculate energy-adjusted intake of total fat, trans fat, saturated fat, fiber and glycemic index. We assessed maternal physical activity (walking, moderate, and vigorous activity, hours per week) and television viewing (hours per week). At 12-months postpartum, mothers also reported their total duration of breastfeeding in months.

Statistical analysis

Our main exposure of interest was maternal short sleep duration defined as an average daily sleep duration from 6 months to 1 year ≤ 5 hours/day (v. > 5 hours/day).

We first performed univariate analyses to assess the distribution of all variables included in the analyses. We then used bivariate analyses to examine the association of our exposure of interest with study covariates and outcomes. We used multiple regression models to assess the independent effects of short sleep duration on our main outcomes. We used linear regression if the outcomes were normally distributed and median regression [26] if the distribution of the outcome was non-Gaussian. In multivariable models, we included only those covariates that were of *a priori* interest or confounded associations of sleep duration with our outcomes. Model 1 was unadjusted. Model 2 was adjusted for maternal age, race/ethnicity, education, parity, pre-pregnancy BMI and excessive gestational weight gain. We assessed for the possibility of multicollinearity throughout the analyses by examining standard errors when adding potentially correlated variables to models. If standard errors increased greatly, we re-evaluated the correlations and added only one of the variables. Because postpartum depression, breastfeeding duration, postpartum diet, physical activity, and TV viewing could be in the intermediate pathway between sleep and our outcomes, in Model 3 we additionally adjusted for these variables. We report regression estimates (β) and 95% confidence intervals for the main exposure. We performed data analyses with SAS version 9.2.

RESULTS

Characteristics of study participants are shown in Table 1. The mean (SD) of daily sleep duration from 6 months to 1 year was 6.7 (0.97) hours; 74 (13%) women were sleeping ≤ 5 hours/day. At 3-years postpartum, mean (SD) for BMI was 26.2 kg/m^2 (6.1). Means, standard deviations, medians, and inter-quartile range of the cardio-metabolic markers that we examined are shown in Table 2.

In bivariate analyses, older women, multiparous mothers, and those with postpartum depression were more likely to sleep ≤ 5 hours/day. Sleep duration was not associated with breastfeeding duration, excessive gestational weight gain, or postpartum diet and physical activity (Table 1). Sleep duration ≤ 5 hours/day was associated with somewhat higher levels of leptin at 3-years postpartum (Table 2).

In multivariable analyses adjusted for maternal age, race/ethnicity, education, parity, pre-pregnancy BMI and excessive gestational weight gain, we found that postpartum sleep ≤ 5 h/d was associated with higher postpartum weight retention (β 1.50 kg; 95% CI: 0.02, 2.86), higher SS+TR thickness (β 3.94 mm; 95% CI: 1.27, 6.60) and higher waist circumference (β 3.10 cm; 95% CI: 1.25, 4.94) at 3-years postpartum (Table 3). Further adjustment for

postpartum variables including postpartum depression, breastfeeding duration, diet, physical activity, and TV viewing minimally changed the observed adiposity estimates. Thus, postpartum depression, breastfeeding, diet and physical activity in the postpartum period appear to be only partial mediators of the relationship between sleep and adiposity.

In multivariable models, postpartum sleep ≤ 5 h/d was associated with higher HOMA-IR in unadjusted models (β 0.26; 95% CI: 0.04, 0.76). Adjustment for potential confounders strengthened the effect estimate, although confidence intervals were wide (Table 4). Further adjustment for postpartum variables did not substantially change many of our observed estimates. However, adjustment for postpartum variables appeared to have large effects on the HOMA-IR, fasting insulin, and LDL cholesterol estimates. We observed no associations of short sleep duration with other measures of glucose metabolism (hemoglobin A1c, fasting glucose), measures of lipid metabolism (total cholesterol, LDL, HDL, triglycerides) or adipokines (leptin and adiponectin) (Table 4).

DISCUSSION

In this prospective study of women, we found that short sleep duration in the first year postpartum was associated with higher adiposity independent of maternal sociodemographic characteristics. Our observed estimates were independent of pre-pregnancy BMI and excessive gestational weight gain and were not substantially influenced by postpartum depression or postpartum health behaviors including breastfeeding, diet, physical activity, and TV viewing. Short sleep duration was not associated with measures of glucose metabolism (hemoglobin A1c, fasting insulin, fasting glucose), measures of lipid metabolism (total cholesterol, LDL, HDL, triglycerides) or adipokines (leptin and adiponectin).

A large number of epidemiologic studies have shown an association between short sleep duration and adiposity, including 4 longitudinal studies [3, 27–29] showing that sleep duration is associated prospectively with weight and weight change. Previous longitudinal results may not be applicable to the postpartum period because the studies focused on sleep habits over a long period of time and also because the changes in sleep during the early postpartum period have a very different origin than the origin of the changes in sleep in other published studies. Two studies have examined the relationship between sleep duration and adiposity among postpartum women. In a study by Siega-Riz et al.[30], fewer hours of sleep during the night was associated with moderate or high weight retention at 3 months postpartum. The study by Gunderson et al. [19] found that sleeping ≤ 5 hours/day at 6 months postpartum was strongly associated with substantial weight retention at 1 year postpartum (adjusted odds ratio of substantial postpartum weight retention was 3.13 (95% CI: 1.42, 6.94) for sleeping ≤ 5 hours/day v. 7 hours/day).[19] These studies extend research on sleep and adiposity to the postpartum period which is marked by substantial decreases in sleep duration and quality. Our adiposity findings are consistent with these previous studies and extend the results to 3-years postpartum. In this study, we found that short sleep duration was associated with higher postpartum weight retention, higher subscapular + triceps skinfold thicknesses, a measure of overall adiposity, and higher waist circumference, a measure of centrally-deposited fat. Our findings suggest that efforts to increase sleep duration among mothers in the postpartum period could prevent both short- and long-term adverse effects of short sleep duration on maternal health.

Several mechanisms have been proposed to explain the relationship between short sleep duration and adiposity, including changes in appetite regulating hormones that influence energy intake.[2] Although decreases in leptin levels have been associated with acute sleep restriction in experimental studies,[9] few studies have examined the longitudinal association

of sleep curtailment with leptin levels. In this study, short sleep duration was not associated with leptin levels. It is possible that short sleep duration in the first year postpartum could be related to low leptin levels during the same period which could lead to increased BMI and adiposity at 3 years, but we did not have concurrent measures of leptin and sleep duration to examine this. Further prospective studies are needed to examine the association of sleep curtailment and leptin, independent of BMI and fat mass distribution.

Another proposed mechanisms relating short sleep duration to adiposity suggest that sleep curtailment may increase energy intake via influences on eating behavior. For example, in one study of normal weight adults, short sleep duration was found to be associated with increased hunger and greater desire to eat calorie-dense foods with high carbohydrate content.[8] Sleep restriction may also lead to time spent in sedentary activities such as TV viewing where snacking is common.[31] Finally, short sleep duration has been associated with reduced physical activity levels.[2] In our study, we did not find that differences in postpartum diet, physical activity, or TV viewing explained the relationship between sleep duration and adiposity. It is still possible that short sleep duration could have led to higher energy intake by changes in eating behavior, but these were not measured in this study.

Few studies have examined the longitudinal relationship of sleep duration and biomarkers of cardio-metabolic disease. In a study of 935 women with type 2 diabetes, Williams et al. [4] found that HDL cholesterol was decreased among hypertensive women who slept ≤ 5 hours/day. Short sleep duration was not associated with other cardio-metabolic disease biomarkers, including total and LDL cholesterol and triglycerides. Consistent with the study by Williams et al., we did not find an association between short sleep duration and cardio-metabolic disease markers.

Our study had several strengths including the ability to adjust our analyses for a large number of potential sociodemographic and environmental determinants of short sleep duration including postpartum depression. We also analyzed both skinfold thicknesses as well as waist circumference, and we examined a wide range of cardio-metabolic biomarkers. Most previous studies of sleep duration and obesity have used BMI as the only obesity-related outcome and few studies have prospectively examined the full range of cardio-metabolic biomarkers we had available in this study. Our study also had limitations. First, although we had measures of total sleep duration, we did not have direct measures of sleep (i.e. from actigraphs) nor did we have measures of snoring or of other signs of obstructive sleep apnea (OSA). Thus, we are not able to determine whether our observed effects were independent of snoring and OSA, both of which have been found to be associated with adverse cardio-metabolic biomarkers.[4, 32] Second, we did not have measures of sleep before or during pregnancy or beyond 1 year postpartum. Thus, it is possible that postpartum sleep is a marker of sleep at 3 years. Also, we did not measure central adiposity or cardio-metabolic biomarkers before pregnancy to control for differences in these measures that may have preceded changes in postpartum sleep. Third, our sample size for fasting insulin, glucose, and LDL cholesterol was small, and our null results can not rule out a true association. Fourth, although women in the study had diverse racial/ethnic backgrounds, their education and income levels were relatively high. Our results may not be generalizable to more socioeconomically disadvantaged populations. Finally, in any observational study it is possible that unmeasured characteristics might explain the observed associations between exposure and outcome. In particular, we did not measure total energy intake or eating behaviors which might have partially explained the observed relationship between short sleep duration and adiposity.

Conclusions

Short sleep duration in the first year postpartum is associated with higher overall and central adiposity at 3-years postpartum. Given the adverse physiological effects of central adiposity, our findings suggest that there may be significant public health impact among the sizable number of women who experience prolonged sleep curtailment in the first postpartum year.

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Table 1

Unadjusted and bivariate associations of maternal characteristics with short sleep duration from 6 months to 1 year postpartum. Data from 586 participants in Project Viva who presented for follow-up at three years postpartum without an intervening birth.

Characteristic	N	Overall	Average Daily Sleep Duration (hrs/d), 6 Months to 1 Year Postpartum		
			≤ 5 hours (N = 74)	> 5 hours (N = 512)	*p*- value*
		Mean (SD) or %			
Sociodemographics					
Maternal age at 3 years postpartum, years	586	37.7 (5.0)	38.8 (4.0)	37.6 (5.1)	0.02
Breastfeeding duration, months	586	6.2 (4.6)	6.9 (4.9)	6.1 (4.6)	0.21
Institute of Medicine gestational weight gain category					
Adequate/inadequate	259	45	44	45	0.88
Excessive	321	55	56	55	
Glucose tolerance status during pregnancy					
Normal	482	83	82	83	0.97
Impaired glucose tolerance	76	13	14	13	
Gestational diabetes	24	4	4	4	
Race/ethnicity					
White	432	74	72	74	0.07
Black	67	11	11	12	
Hispanic	38	7	9	6	
Asian	25	4	0	5	
Other	23	4	8	3	
Parity					
1	175	30	23	31	0.05
2	276	47	43	48	
3+	135	23	34	23	
College graduate					
No	175	30	35	29	0.29
Yes	410	70	65	71	
Household income					

Characteristic	N	Overall	Average Daily Sleep Duration (hrs/d), 6 Months to 1 Year Postpartum		
			≤ 5 hours (N = 74)	> 5 hours (N = 512)	*p*- value*
< $40,000/year	69	12	15	12	0.46
≥ $40,000/year	486	88	85	88	
Smoking					
Never	406	70	70	70	
Former	123	21	19	22	0.64
During pregnancy	48	8	11	8	
Depression score at 6 months postpartum					
No, <13	505	93	81	95	<.0001
Yes, ≥13	37	7	19	5	
Diet and Physical Activity at 6 Months Postpartum					
Total fat, g/d†	546	34.0 (7.7)	33.8 (7.7)	34.0 (7.7)	0.85
Saturated fat, g/d†	546	13.4 (3.5)	13.1 (3.9)	13.5 (3.4)	0.39
Trans fat, g/d†	546	1.3 (0.59)	1.3 (0.70)	1.3 (0.57)	0.63
Glycemic index†	546	281.4 (76.8)	281.9 (77.0)	281.3 (76.8)	0.95
Fiber, g/d†	546	8.5 (3.0)	8.9 (3.5)	8.4 (2.9)	0.18
Walking, hrs/week	541	5.0 (4.7)	5.6 (5.6)	4.9 (4.6)	0.30
Moderate, hrs/week	537	1.3 (2.5)	1.6 (3.3)	1.2 (2.4)	0.35
Vigorous, hrs/week	541	1.1 (2.1)	0.91 (2.0)	1.1 (2.2)	0.47
Total physical activity, hrs/week	534	7.3 (7.1)	8.1 (8.5)	7.2 (6.9)	0.38
Television viewing, hrs/week	541	11.2 (8.9)	12.5 (11.4)	11.0 (8.5)	0.32
Anthropometrics					
Pre-pregnancy BMI, kg/m^2	586	24.8 (5.2)	25.3 (5.4)	24.8 (5.1)	0.38
BMI at 3 years postpartum, kg/m^2	574	26.2 (6.1)	27.1 (6.3)	26.1 (6.1)	0.19
Postpartum weight retention at 3 years, kg	560	2.4 (5.4)	3.5 (6.4)	2.2 (5.2)	0.11
Subscapular + triceps skinfold thickness, mm	577	43.9 (15.3)	48.0 (16.4)	43.3 (15.1)	0.01
Waist circumference, cm	579	86.4 (12.4)	90.1 (14.9)	85.8 (11.9)	0.02

*P-value from t-test for continuous and chi-square for categorical characteristics.

† Energy-adjusted using the nutrient residual method.

Table 2

Unadjusted and bivariate associations of maternal cardio-metabolic markers at 3-years postpartum with short sleep duration from 6 months to 1 year postpartum.

Cardio-Metabolic Markers at 3 Years Postpartum	N*	Overall		Average Daily Sleep Duration (hrs/d), 6 Months to 1 Year Postpartum				
				≤ 5 hours		> 5 hours		
		Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	p†
Hemoglobin A1c	477	5.1 (0.28)	5.1 (4.9, 5.3)	5.1 (0.29)	5.1 (4.9, 5.3)	5.1 (0.28)	5.1 (4.9, 6.6)	0.68
HOMA-IR	147	1.8 (1.9)	1.4 (0.9, 2.0)	2.0 (1.6)	1.6 (1.2, 2.2)	1.7 (1.9)	1.3 (0.9, 1.9)	0.11
Fasting insulin, u/mL	147	9.4 (7.4)	7.8 (5.3, 10.1)	10.8 (7.1)	9.1 (6.6, 10.3)	9.2 (7.4)	7.4 (5.0, 10.1)	0.17
Fasting glucose, mg/dL	147	74.6 (15.4)	77.0 (66.0, 84.0)	77.1 (17.6)	81.5 (66.0, 87.0)	74.3 (15.1)	76.0 (66.0, 83.0)	0.48
Total cholesterol, mg/dL	147	178.0 (29.9)	174.0 (158.0, 195.0)	179.1 (27.1)	173.0 (158.0, 191.0)	177.9 (30.3)	175.0 (158.0, 198.0)	0.88
LDL cholesterol, mg/dL	147	106.7 (27.8)	105.4 (90.4, 121.2)	108.6 (24.7)	106.8 (94.0, 119.2)	106.4 (28.3)	104.7 (87.8, 121.2)	0.75
HDL cholesterol, mg/dL	147	54.3 (12.1)	52.8 (45.1, 61.7)	54.0 (8.3)	55.1 (49.2, 59.8)	54.3 (12.5)	52.8 (45.1, 61.7)	0.93
Triglycerides, mg/dL	147	86.5 (45.9)	74.0 (54.0, 105.0)	80.0 (37.1)	72.5 (55.0, 105.0)	87.5 (47.1)	74.0 (54.0, 104.0)	0.68
Leptin, ng/ml	474	8.8 (6.1)	6.9 (4.2, 12.2)	10.3 (6.9)	8.5 (5.0, 14.0)	8.5 (5.9)	6.8 (4.1, 11.7)	0.07
Adiponectin, μg/ml	476	20.2 (8.7)	20.3 (14.0, 26.0)	20.4 (9.3)	20.3 (13.2, 26.0)	20.2 (8.6)	20.3 (14.1, 26.1)	0.85

*Fasting samples were available for 147 participants.

†P-value are from Fisher's exact t-test for normally distributed variables (hemoglobin A1c, fasting glucose, total cholesterol, LDL cholesterol, HDL cholesterol, and adiponectin) and Wilcoxon rank-sum test for non-normally distributed variables (HOMA-IR, fasting insulin, triglycerides, and leptin).

Table 3

Anthropometric measures at three-years postpartum, by average daily sleep duration from 6 months to 1 year postpartum.

		Average Daily Sleep Duration (hours/day), 6 Months to 1 Year Postpartum	
	N	**≤ 5 hours**	**> 5 hours**
		Effect Estimate (95% Confidence Interval)	
Body mass index (kg/m^2)	574		
Model 1. Unadjusted		1.02 (−0.49, 2.53)	0.00 (ref)
Model 2. Multivariable Adjusted†		0.42 (−0.45, 1.30)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		0.66 (−0.25, 1.57)	0.00 (ref)
Postpartum weight retention at 3 years (kg)	560		
Model 1. Unadjusted		1.27 (0.08, 2.61)	0.00 (ref)
Model 2. Multivariable Adjusted†		1.50 (0.15, 2.84)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		1.44 (0.02, 2.86)	0.00 (ref)
Subscapular + Triceps Skinfold Thickness (mm)	577		
Model 1. Unadjusted		4.76 (1.02, 8.49)	0.00 (ref)
Model 2. Multivariable Adjusted†		3.94 (1.27, 6.60)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		4.81 (2.00, 7.62)	0.00 (ref)
Waist circumference (cm)	579		
Model 1. Unadjusted		4.29 (1.27, 7.31)	0.00 (ref)
Model 2. Multivariable Adjusted†		3.10 (1.25, 4.94)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		3.48 (1.55, 5.42)	0.00 (ref)

†Model 2 is adjusted for maternal age, race/ethnicity, education, parity, pre-pregnancy BMI and excessive gestational weight gain. Model 3 is additionally adjusted for postpartum variables including postpartum depression, breastfeeding duration, diet, physical activity, and TV viewing.

Table 4

Cardio-metabolic markers at three-years postpartum, by average daily sleep duration from 6 months to 1 year postpartum.

		Average Daily Sleep Duration (hours/day), 6 Months to 1 Year Postpartum	
	N	**≤ 5 hours**	**> 5 hours**
		Effect Estimate (95% Confidence Interval)	
Hemoglobin A1c	477		
Model 1. Unadjusted		−0.02 (−0.09, 0.06)	0.00 (ref)
Model 2. Multivariable Adjusted†		−0.03 (−0.10, 0.04)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		−0.02 (−0.09, 0.05)	0.00 (ref)
HOMA-IR*	147		
Model 1. Unadjusted		0.26 (0.04, 0.76)	0.00 (ref)
Model 2. Multivariable Adjusted†		0.32 (−0.01, 0.79)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		0.09 (−0.38, 0.77)	0.00 (ref)
Fasting insulin, u/mL*	147		
Model 1. Unadjusted		1.70 (−0.69, 2.36)	0.00 (ref)
Model 2. Multivariable Adjusted†		1.46 (−0.87, 4.27)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		0.41 (−3.33, 2.36)	0.00 (ref)
Fasting glucose, mg/dL	147		
Model 1. Unadjusted		2.75 (−4.91,10.40)	0.00 (ref)
Model 2. Multivariable Adjusted†		2.48 (−5.45,10.40)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		3.13 (−4.98, 11.25)	0.00 (ref)
Total cholesterol, mg/dL	147		
Model 1. Unadjusted		1.16 (−13.70,16.07)	0.00 (ref)
Model 2. Multivariable Adjusted†		−2.08 (−17.40, 13.21)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		−6.56 (−24.20, 11.03)	0.00 (ref)
LDL cholesterol, mg/dL	147		
Model 1. Unadjusted		2.21 (−11.70,16.07)	0.00 (ref)
Model 2. Multivariable Adjusted†		−0.16 (−14.10, 13.75)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		−3.19 (−19.50, 13.16)	0.00 (ref)
HDL cholesterol, mg/dL	147		
Model 1. Unadjusted		−0.27 (−6.29, 5.74)	0.00 (ref)
Model 2. Multivariable Adjusted†		−1.56 (−7.54, 4.42)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		−1.92 (−8.90, 5.05)	0.00 (ref)
Triglycerides, mg/dL*	147		
Model 1. Unadjusted		−1.00 (−20.90, 12.64)	0.00 (ref)
Model 2. Multivariable Adjusted†		−10.8 (−23.40, 15.09)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		−17.2 (−31.4,0, 10.68)	0.00 (ref)

		Average Daily Sleep Duration (hours/day), 6 Months to 1 Year Postpartum	
	N	**≤ 5 hours**	**> 5 hours**
Leptin, ng/mL*	476		
Model 1. Unadjusted		1.57 (−0.75, 5.47)	0.00 (ref)
Model 2. Multivariable Adjusted†		1.51 (−0.14, 2.51)	0.00 (ref)
Model 3. Model 2 + Postpartum Variables		1.38 (−0.06, 2.82)	0.00 (ref)
Adiponectin, μg/mL	478		
Unadjusted		0.21 (−2.04, 2.47)	0.00 (ref)
Model 1. Multivariable Adjusted†		0.18 (−2.05, 2.41)	0.00 (ref)
Model 2. Model 2 + Postpartum Variables		−0.59 (−2.99, 1.81)	0.00 (ref)

† Model 2 is adjusted for maternal age, race/ethnicity, education, parity, pre-pregnancy BMI and excessive gestational weight gain. Model 3 is additionally adjusted for postpartum variables including postpartum depression, breastfeeding duration, diet, physical activity, and TV viewing.

* Effect estimates for the non-normally distributed variables are from multivariable median regression. Estimates reflect the difference from the median of each outcome associated with sleep duration ≤ 5 hours/day.