Title: Sleep quality and nocturnal sleep duration in pregnancy and risk of gestational diabetes mellitus

Abbreviated title: Prenatal sleep and gestational diabetes risk

Authors and Affiliations: Shirong Cai, PhD[1]; Sara Tan, MD[2]; Peter D Gluckman, FRS[3,4]; Keith M Godfrey, PhD[5]; Seang-Mei Saw, PhD[6]; Oon Hoe Teoh, MBBS[7]; Yap-Seng Chong, MD[1,4]; Michael J Meaney, PhD[8]; Michael S Kramer, MD[9,10]; Joshua J Gooley, PhD[2,11] on behalf of the GUSTO study group

[1]Department of Obstetrics & Gynaecology, Yong Loo Lin School of Medicine, National University of Singapore, National University Health System
[2]Program in Neuroscience and Behavioral Disorders, Duke-NUS Medical School, Singapore
[3]Liggins Institute, University of Auckland
[4]Singapore Institute for Clinical Sciences**,** Agency for Science, Technology and Research (A*STAR)
[5]MRC Lifecourse Epidemiology Unit & NIHR Southampton Biomedical Research Centre, University of Southampton & University Hospital Southampton NHS Foundation Trust
[6]Saw Swee Hock School of Public Health, National University of Singapore
[7]Department of Pediatrics, KK Women's and Children's Hospital
[8]Department of Psychiatry, McGill University Faculty of Medicine, Montreal, Canada
[9]Department of Epidemiology, Biostatistics and Occupational Health, McGill University Faculty of Medicine, Montreal, Canada
[10]Department of Pediatrics, McGill University Faculty of Medicine, Montreal, Canada
[11]Department of Physiology, Yong Loo Lin School of Medicine, National University of Singapore, Singapore

Corresponding author:
Joshua J Gooley, PhD
8 College Road Singapore 169857
Phone: +65 6516 7430
Fax: +65 6221 8625
Email: joshua.gooley@duke-nus.edu.sg

Name and address of contact person for reprint requests: same as corresponding author above

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ABSTRACT

Objective: To examine the influence of maternal sleep quality and nocturnal sleep duration on risk of gestational diabetes mellitus (GDM) in a multi-ethnic Asian population.

Methods: 686 women (376 Chinese, 186 Malay and 124 Indian) with a singleton pregnancy attended a clinic visit at 26-28 weeks of gestation as part of the Growing Up in Singapore Towards healthy Outcomes (GUSTO) mother-offspring cohort study. Self-reported sleep quality and sleep duration were assessed using the Pittsburgh Sleep Quality Index (PSQI). GDM was diagnosed based on a 75-g oral glucose tolerance test administered after an overnight fast (1999 WHO criteria). Multiple logistic regression was used to model separately the associations of poor sleep quality (PSQI score >5) and short nocturnal sleep duration (<6 h) with GDM, adjusting for age, ethnicity, maternal education, BMI, previous history of GDM, and anxiety (State-Trait Anxiety Inventory score).

Results: 296 women (43.1%) had poor sleep quality and 77 women (11.2%) were categorized as short sleepers. 131 women (19.1%) were diagnosed with GDM. Poor sleep quality and short nocturnal sleep duration were independently associated with increased risk of GDM (poor sleep, adjusted OR = 1.75, 95% CI 1.11 to 2.76; short sleep, adjusted OR = 1.96, 95% CI 1.05 to 3.66).

Conclusions: During pregnancy, Asian women with poor sleep quality or short nocturnal sleep duration exhibited abnormal glucose regulation. Treating sleep problems and improving sleep behavior in pregnancy could potentially reduce the risk and burden of GDM.

Keywords: sleep duration, sleep quality, gestational diabetes mellitus, Asian women

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SIGNIFICANCE STATEMENT

Diabetes is a global health burden that is growing rapidly in Asia. To reduce and manage the burden of diabetes, it is imperative to identify modifiable risk factors that contribute to glucose dysregulation. Sleep deficiency results in impaired glucose metabolism and is thought to be a contributing factor to the development of Type 2 diabetes. However, few studies have examined the potential role of sleep deficiency in the etiology of gestational diabetes mellitus (GDM), which itself is a risk factor for Type 2 diabetes. In a multi-ethnic Asian population, we show that poor sleep quality and short sleep (<6 h per night) were independently associated with increased risk of GDM. These findings suggest that sleep is important for normal energy metabolism in pregnancy. Managing sleep problems and encouraging good sleep habits in pregnancy could reduce the likelihood of developing hyperglycemia and GDM.

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INTRODUCTION

Sleep disturbances and short sleep duration are common in pregnancy as a consequence of hormonal changes, physical discomfort, sleep disorders, and anxiety associated with childbearing.[1-4] Chronic exposure to short nocturnal sleep duration is a risk factor for type 2 diabetes,[5-7] but less is known about the role of insufficient sleep in the etiology of gestational diabetes mellitus (GDM). Women with GDM are at increased risk of pre-eclampsia and cesarean delivery, and their newborns are at increased risk of macrosomia and birth-related injuries, hypoglycemia, and jaundice.[8, 9] Furthermore, women with GDM are more likely to develop type 2 diabetes after giving birth,[10] and offspring of diabetic mothers are at increased risk of obesity, type 2 diabetes, and metabolic syndrome.[11, 12] To reduce the burden of GDM and its complications, it is important to identify behavioral risk factors that are treatable or preventable.

Growing evidence suggests that sleep insufficiency during pregnancy might contribute to the development of hyperglycemia and GDM.[13, 14] Short sleep duration has been associated with increased risk of GDM in samples that were predominantly Caucasian and African-American,[15-17] and these conclusions were based on a small number of GDM cases (≤26 cases per study). It is therefore unclear whether these findings are generalizable to other populations, including Asian women, in whom the prevalence of GDM is higher than among non-Hispanic whites and African Americans living in the same communities.[18-23] The greater risk of GDM in Asians can potentially be explained by ethnic differences in body composition (e.g., accumulation of visceral fat) and sensitivity to adiposity,[24, 25] or by differences in dietary and lifestyle factors that affect glucose metabolism.[26] Adults residing in urbanized Asian countries (e.g., Japan, Korea, and Singapore) sleep substantially less than their counterparts in Western countries,[27-30] hence raising the possibility that short sleep duration may contribute to the risk profile for GDM in

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Asian women. We therefore studied a multi-ethnic Asian population in Singapore to examine the relationship between sleep behavior and glucose tolerance. We hypothesized that exposure to poor sleep quality or short sleep duration (<6 h per night) would associate with increased risk of GDM.

METHODS

Study population

Pregnant women aged 18 years and older were recruited in their first trimester (<14 weeks of pregnancy) to participate in the Growing Up in Singapore Towards healthy Outcomes (GUSTO) mother-offspring cohort study. The overall aim of the GUSTO study is to identify maternal and early-life factors that affect metabolic health outcomes of children raised in Singapore.[31] A total of 1,247 women who were seeking obstetric services from KK Women's and Children's Hospital or the National University Hospital were enrolled in the GUSTO study from June 2009 to September 2010. Demographic data including maternal age, ethnicity, and education were collected using an interviewer-administered questionnaire at the time of enrollment. Height and weight were measured by trained clinical staff to calculate body mass index (BMI, kg/m^2). Women were eligible if they were Chinese, Malay, or Indian with a homogenous parental ethnic background. Informed written consent was obtained from each participant, with procedures approved by the National Healthcare Group Institutional Review Board (IRB) and the SingHealth Centralized IRB.

Measurements at 26-28 weeks of gestation

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At 26-28 weeks of pregnancy, 1,214 study participants attended a clinic visit that included questionnaire-based behavioral assessments and an oral glucose tolerance test (OGTT). Women with multiple pregnancies (n = 5) or prior diagnosis of type 2 diabetes (n = 10) were excluded. During the clinic visit, participants completed the Edinburgh Postnatal Depression Scale (EPDS) and the State-Trait Anxiety Inventory (STAI). To evaluate sleep quality in the previous month, a subset of 917 women were asked to complete the Pittsburgh Sleep Quality Index (PSQI), with a PSQI score >5 defined as poor sleep.[32] A total of 745 women responded to all questions on the PSQI, allowing a valid PSQI global score to be calculated. Previous studies have shown that the PSQI has similar psychometric properties in pregnant women and in non-pregnant populations.[33, 34] The PSQI global score (range 0-21) represents the sum of component scores for subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction. Self-reported nocturnal sleep duration was taken from the following question of the PSQI: "During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed)."

Short nocturnal sleep duration was defined as <6 h based on epidemiological and laboratory studies demonstrating that short sleep by this definition is associated with abnormal glucose regulation. Specifically, meta-analyses of prospective studies have shown that short sleep duration (defined as ≤5 h or <6 h in most studies) is associated with increased risk of developing type 2 diabetes.[5-7] These studies included men and women across a broad range of ages, and from several geographic regions,[6, 35-42] suggesting that results for short sleep and diabetes risk are generalizable. Our definition of short sleep is also consistent with laboratory studies in which experimentally-induced sleep restriction (ranging from 4 h to 5.5 h of time in bed each night) resulted in decreased glucose tolerance, decreased insulin sensitivity, and

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increased insulin resistance.[43-48] Additionally, our cut-off for short sleep duration is consistent with recent recommendations by the National Sleep Foundation, USA, in which <6 h of sleep was categorized as "not recommended" in adults aged 18-64 years.[49]

Oral glucose tolerance test (OGTT)

Of the 745 pregnant women with a valid PSQI score, 686 participants completed a 75-g OGTT after overnight fasting (8 to 10 hours). Blood glucose levels were measured before and 2 h after administration of oral glucose. GDM was defined using the 1999 World Health Organization (WHO) diagnostic criteria: ≥7.0 mmol/L (126 mg/dL) for fasting glucose and/or ≥7.8 mmol/L (140 mg/dL) for 2-h OGTT glucose.[50] These criteria were chosen because they represent the standard clinical guidelines for diagnosing GDM in Singapore.[51] Results of the OGTT were conveyed to participants 1-2 weeks after the clinic visit.

Statistical methods

Independent Student t-tests and chi-squared tests were used to compare continuous and categorical maternal characteristics between groups of women with normal glucose levels versus women with GDM. Because prior studies have shown an inverse correlation between sleep duration and glucose levels in pregnant women,[52, 53] bivariate analyses (Pearson's correlation analysis) were used to examine the strength of the linear relationship between each sleep measure (PSQI score or nocturnal sleep duration) and glucose levels (fasting glucose or 2-h OGTT glucose levels). Separate multivariable linear regression analyses were used to model associations of 1) sleep quality (i.e., PSQI scores) with fasting glucose levels; 2) sleep quality

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with 2-h OGTT glucose levels; 3) nocturnal sleep duration with fasting glucose levels; and 4) nocturnal sleep duration with 2-h OGTT glucose levels. In each analysis, only one sleep variable (PSQI score or sleep duration) was entered into the model simultaneously (i.e., in one step) with the following independent variables: maternal age, ethnicity, maternal education, previous history of GDM, BMI at the time of enrollment (<14 weeks of pregnancy), and maternal anxiety (STAI total score).

Separate multivariable logistic regression models were used to estimate 1) the association of poor sleep quality (PSQI score >5) on GDM risk, and 2) the association of short nocturnal sleep duration (<6 h) on GDM risk. Those regression models were adjusted for maternal age, ethnicity, maternal education, previous history of GDM, BMI at <14 weeks of pregnancy, and maternal anxiety score. Data were missing for maternal education in 1.2% of women (n = 8), for history of GDM in 2.3% of women (n = 16), and for antenatal STAI scores in 5.2% of women (n = 36). Case-wise exclusion was used to handle missing data in the adjusted models. All analyses were carried out using SPSS software, version 22.0 (IBM, Armonk, NY, USA).

RESULTS

Participant characteristics

Of the 1,214 women who attended the clinic visit at 26-28 weeks of gestation, 686 women completed the PSQI and underwent the OGTT. Women who did not have PSQI and/or OGTT data were similar to participants who were included in the present analysis with respect to maternal age, ethnicity, BMI, EPDS score, alcohol consumption, and smoking, but had significantly lower educational attainment (28.6% versus 38.2% with university and above, p <

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0.001), lower household income (19.9% versus 36.9% with household income >$6000 SGD, $p <$ 0.001), and higher STAI scores (72.9 ± 16.6 versus 69.9 ± 18.5, $p = 0.004$).

Of the 686 pregnant women included in our analysis, 131 (19.1%) were diagnosed with GDM. All of these women met the diagnostic criterion for GDM based on their 2-h OGTT result (i.e., plasma glucose ≥7.8 mmol/L), while 2 of the women also met the diagnostic criterion for fasting glucose levels (i.e., plasma glucose ≥7.0 mmol/L). Ethnic distribution differed for groups with normal glucose levels versus GDM (Table 1), with a higher percentage of GDM cases observed in Indian and Chinese participants (25.0% and 20.5%) than in Malay participants (12.4%). Women with GDM were older (32.1 ± 4.8 years versus 30.3 ± 5.1 years), had a higher BMI at <14 weeks of pregnancy (24.6 ± 4.6 kg/m^2 versus 23.6 ± 4.9 kg/m^2), and had lower anxiety scores (66.5 ± 17.5 versus 70.6 ± 18.7), whereas maternal education, household income, nulliparous pregnancy, alcohol consumption, and smoking were similar between groups (Table 1). In univariable analyses, women with GDM tended to have poorer sleep quality than participants without GDM (PSQI score, 5.89 ± 3.07 versus 5.36 ± 2.76), but the difference in PSQI global scores did not reach statistical significance ($p = 0.054$). Based on PSQI component scores, women with GDM rated their sleep quality as significantly worse than women without GDM (1.15 ± 0.70 versus 1.02 ± 0.60; $p = 0.045$), whereas the other PSQI component scores did not differ between groups (Supplementary Table 1). Nocturnal sleep duration and the proportion of short sleepers (<6 h per night) did not differ significantly in women with GDM versus women with normal glucose levels (Table 1).

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Influence of sleep quality and sleep duration on blood glucose levels and risk of GDM

The absolute frequency of GDM was higher in women with poor sleep quality (PSQI >5; 22.0%) compared with women with better sleep quality (PSQI ≤5; 16.9%). A significant bivariate correlation was observed between fasting glucose levels and PSQI scores (Pearson's r = 0.094, p = 0.014), but not for 2-h glucose levels and PSQI scores (Pearson's r = -0.003, p = 0.94). In the multivariable linear regression model, pregnant women with poorer sleep quality (i.e., higher PSQI scores) exhibited higher fasting glucose levels, but not 2-h OGTT glucose levels, adjusting for ethnicity, maternal age, education, BMI, previous history of GDM, and anxiety score (Fasting glucose: Unstandardized regression coefficient, B = 0.016, 95% CI 0.003 to 0.029; 2-h glucose: B = 0.030, 95% CI -0.013 to 0.073).

Based on OGTT results across different sleep duration subgroups (<6 h, 6-6.99 h, 7-7.99 h, 8-8.99 h, ≥9 h), the absolute frequency of GDM was highest in women who reported sleeping <6 h per night (27.3%) and lowest in women with 7-7.99 h of sleep per night (16.8%) (Fig. 1A). Fasting glucose levels, but not 2-h glucose levels, decreased linearly with increasing sleep duration (Fasting glucose: Pearson's r = -0.099, p < 0.01; 2-h glucose: Pearson's r = -0.048, p = 0.21) (Fig. 1B-C). In multivariable linear regression models, however, nocturnal sleep duration was not associated with either fasting glucose levels or 2-h OGTT glucose levels, after adjusting for covariates (Fasting glucose: B = -0.017, 95% CI -0.041 to 0.007; 2-h glucose: B = -0.009, 95% CI -0.088 to 0.069).

Next, we used multivariable logistic regression analysis to model the association between poor sleep quality and GDM risk, and the association between short nocturnal sleep duration and GDM risk (Table 2). In our sample, 296 women (43.1%) were categorized as having poor sleep quality (PSQI global score >5). These women had a higher risk of GDM relative to women with

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better sleep quality, after adjusting for ethnicity, maternal age, education, BMI, previous history of GDM, and anxiety scores (adjusted OR = 1.75, 95% CI 1.11 to 2.76). There were 77 women (11.2%) in our study who reported sleeping <6 h per night. These women had an increased risk of GDM compared to women with longer sleep duration (≥6 h), after adjusting for covariates (adjusted OR = 1.96, 95% CI 1.05 to 3.66).

DISCUSSION

Poor sleep quality and short nocturnal sleep duration during pregnancy were independently associated with increased risk of GDM. Our results for sleep quality are consistent with previous studies of type 2 diabetes that used the PSQI in non-pregnant populations. For example, poorer sleep quality in diabetic patients has been associated with higher levels of hemoglobin A1c,[54, 55] a marker reflecting increased blood glucose levels, after adjusting for age, sex, and BMI. Recent studies suggest that poor sleep quality (PSQI >5) is associated with increased risk of metabolic syndrome,[56] which is defined in part by impaired glucose tolerance. PSQI-defined poor sleep quality has also been associated with increased homeostatic model assessment-insulin resistance in Chinese patients with type 2 diabetes.[57] Our results therefore extend previous findings in non-pregnant adults to show that poor sleep quality in pregnancy is associated with hyperglycemia. Additionally, our findings are consistent with a recent study performed in pregnant Chinese women, in which it was reported that risk of GDM was greater in subjects who rated their sleep quality as either 'poor' compared with subjects who rated their sleep quality as 'good'.[58]

Similar to previous studies that included predominantly Caucasian and African-American women,[15-17] we found short sleep duration to be associated with increased risk of GDM in Asian

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women. The small sample sizes and moderate participant diversity in prior studies limited the generalizability of the results, and estimates of relative risk were imprecise with large confidence intervals. Hence, important strengths of our study were inclusion of women from 3 major Asian ethnic groups not studied previously, and a larger number of GDM cases which allowed for a more precise estimate of risk. Prior studies in non-pregnant populations have demonstrated a U-shape relationship between sleep duration and relative risk for type 2 diabetes,[7] in which either short sleep duration or long sleep duration was associated with greater risk. Also, a recent study that included a large sample of pregnant Chinese women (*n* = 12,506; including 919 GDM cases) found that sleep duration ≥9 h per day associated with increased risk of GDM relative to women who reported sleeping ≥7 h to <9 h per day.[58] Although we did not observe a U-shape relationship between sleep duration and frequency of GDM, fasting glucose levels, or 2-h OGTT glucose levels (Fig. 1), our sample included few women with long sleep duration (only 32 women reported sleeping >9 h per night).

We used the 1999 WHO diagnostic criteria for GDM, but many countries and organizations have now adopted the diagnostic criteria recommended by the International Association of Diabetes and Pregnancy Study Groups (IADPSG): fasting glucose ≥5.1 mmol/L and/or 1-h OGTT glucose ≥10.0 mmol/L and/or 2-h OGTT glucose ≥8.5 mmol/L.[59] The IADPSG recommendations are largely based on results of the Hyperglycemia and Adverse Pregnancy Outcome (HAPO) study, which examined associations between maternal glucose and risk of several adverse pregnancy outcomes.[9, 26, 59] Compared with the 1999 WHO diagnostic criteria, the IADPSG recommends a lower fasting glucose threshold and a higher 2-h OGTT glucose threshold for diagnosing GDM. Consequently, if we had used the IADPSG diagnostic criteria in our study, more women would have met the diagnostic threshold for fasting glucose

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(33 women, 4.8% of the sample), whereas fewer women would have met the diagnostic threshold for 2-h OGTT glucose (68 women, 9.9% of the sample). Because our OGTT did not include a 1-h blood sample, we could not retroactively apply the IADPSG criteria to diagnose women with GDM. In supplementary analyses, however, we found that the percentage of women whose fasting glucose or 2-h OGTT glucose levels met the IADPSG diagnostic thresholds was highest in the subgroup exposed to <6 h of sleep per night (fasting glucose, 9.1%; 2-h OGTT glucose, 14.3%) and lowest in the subgroup that reported 7-7.99 h of sleep per night (fasting glucose, 2.6%; 2-h OGTT glucose, 7.9%) (Supplementary Fig. S1). These findings suggest that our results based on the 1999 WHO diagnostic criteria are likely to apply to other screening guidelines, including the IADPSG criteria, for diagnosing GDM.

The high frequency of GDM in our study is consistent with prior findings in the HAPO study, in which the prevalence of GDM in Singapore was 25.1% based on the IADPSG diagnostic criteria.[60] In addition, the 2010 National Health Survey in Singapore found a prevalence of diabetes in non-pregnant adults aged 18-69 years of 11.3% (2-h OGTT glucose levels ≥11.1 mmol/L).[61] The high prevalence of GDM and type 2 diabetes in Singapore may be explained by ethnic differences in body composition and lifestyle factors.[24, 62] For example, Chinese and South Indian populations tend to accumulate more abdominal fat compared with Europeans at the same BMI, which could contribute to increased insulin resistance in these Asian ethnic groups.[24, 25] Lifestyle factors such as increased sedentary behavior, decreased physical labor, voluntary sleep curtailment, and easy access to energy-dense foods might also be contributors to the rise in obesity and diabetes in Singapore. Additional studies are needed to assess the relative contribution of these lifestyle factors to GDM risk, and to determine why risk of GDM varies across ethnic groups.[21]

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Interestingly, diagnosis of GDM in our sample was established almost exclusively by 2-h OGTT glucose levels, rather than fasting glucose levels. The reason for this finding is unclear, but has also been noted in our prior work examining the frequency of GDM in participants of the GUSTO study.[62] Even though few women met the diagnostic criterion for GDM based on their fasting glucose levels (using either the 1999 WHO criteria or the IADPSG criteria), a significant bivariate correlation was observed between sleep quality/duration and fasting glucose values. The effect size of PSQI scores on fasting glucose was very small, however, and the negative association between sleep duration and fasting glucose was not significant after adjusting for covariates in the multivariable regression model. The sleep variables we examined did not associate linearly with 2-h OGTT glucose levels, but a higher proportion of women with poor sleep quality and short sleep duration met the 2-h diagnostic criterion for GDM. Taken together, our results suggest that exposure to poor sleep quality and short sleep duration can affect fasting glucose levels and glucose tolerance in pregnant women. However, additional studies are needed to establish whether fasting and 2-h glucose levels are differentially affected by individual differences in sleep quality or duration.

In the present study, sleep quality in the previous month was assessed by questionnaire near the end of the second trimester, coincident with the OGTT. However, because we did not evaluate sleep behavior earlier in pregnancy or prior to conception, we do not know if poor sleep quality was pre-existing or a consequence of pregnancy. Additionally, we did not collect information on the frequency or duration of daytime naps, which could potentially ameliorate effects of nocturnal sleep disturbances on glucose metabolism. It is possible that the association between PSQI-assessed sleep quality and risk of GDM can be explained by the occurrence of sleep disorders during pregnancy. Some but not all studies have found that symptoms of sleep-

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disordered breathing, including self-reported habitual snoring, high risk of obstructive sleep apnea (OSA) using the Berlin Questionnaire, or polysomnographically-assessed OSA, are associated with an increased risk of GDM.[63, 64] In non-pregnant women, OSA has been reported to be associated with decreased insulin sensitivity after adjusting for age and waist-hip ratio,[65] but a recent meta-analysis did not find a significant difference in the prevalence of GDM between pregnant women with OSA versus those without OSA.[66] Because we did not screen for sleep disorders polysomnographically or collect information on risk of OSA, these factors could not be included in our analyses. Although the PSQI includes a question on the frequency of snoring/coughing (with the highest frequency listed as "3 or more times a week"), it does not capture specific information on habitual snoring, which is usually defined as every night or almost every night.[67] Therefore, habitual snoring could not be examined as a risk factor for GDM in our study.

Another limitation of our study is that sleep quality and sleep duration were assessed by self-report, rather than using objective measures of sleep behavior. A recent study that used actigraphy to estimate nocturnal sleep duration found that shorter sleep was associated with increased risk of hyperglycemia (defined as non-fasting 1-h OGTT glucose ≥130 mg/dL), but the sample included only 7 women who were classified as having hyperglycemia.[52] Nonetheless, nocturnal sleep duration was shown to correlate inversely with 1-h OGTT glucose levels in the full sample (r = -0.28, n = 63), and similar results were obtained in a study that used actigraphy to assess nocturnal sleep duration in women diagnosed with GDM (n = 37), in which each hour of additional sleep was associated with a ~2 mg/dL decrease in fasting glucose levels.[53] In contrast to these findings, a study that assessed sleep in the first trimester using polysomnography found that nocturnal sleep duration was not associated with hyperglycemia

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later in pregnancy (defined as non-fasting 1-h OGTT glucose ≥135 mg/dL), but only 11 participants were classified as having hyperglycemia, including 6 women diagnosed with GDM.[68] These studies help to establish the feasibility of using objectively-determined sleep measurements to examine the impact of sleep duration on glucose metabolism in pregnancy. In future studies, objective measures of sleep behavior should be collected at multiple time points across pregnancy in larger samples to assess whether pregnancy-induced changes in sleep quality and sleep duration alter glucose regulation and risk of GDM.

In summary, we found that poor sleep quality and <6 h of sleep per night during pregnancy were associated with increased risk of GDM in a multi-ethnic Asian population. Future studies should examine the pathways by which sleep disturbances in pregnancy contribute to hyperglycemia and other adverse maternal health outcomes. Early screening and interventions for sleep problems in pregnancy could potentially reduce the risk of developing maternal hyperglycemia and GDM. The importance of healthy sleep habits and obtaining sufficient sleep should also be emphasized by prenatal care providers, with the aim of improving pregnancy outcomes.

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Table 1. Characteristics of women with normal glucose levels (NGL) and gestational diabetes mellitus (GDM).

	Total (*n*=686)	**NGL (*n*=555)**	**GDM (*n*=131)**	***p*-value**
Demographic and lifestyle factors				
Maternal age (years)	30.7 ± 5.1	30.3 ± 5.1	32.1 ± 4.8	<0.001
Ethnicity, *n* (%)				
Chinese	376 (54.8)	299 (53.9)	77 (58.8)	0.013
Malay	186 (27.1)	163 (29.4)	23 (17.6)	
Indian	124 (18.1)	93 (16.8)	31 (23.7)	
Maternal Education, *n* (%)				
Primary and below	28 (4.1)	25 (4.5)	3 (2.3)	0.283
Secondary	143 (20.8)	120 (21.6)	23 (17.6)	
Diploma/technical	248 (36.2)	202 (36.4)	46 (35.1)	
University and above	259 (37.8)	200 (36.0)	59 (45.0)	
Missing/ refused	8 (1.2)	8 (1.4)	0 (0.0)	
Monthly Household Income, *n* (%)				
SGD 0 to 1,999	80 (11.7)	69 (12.4)	11 (8.4)	0.226
SGD 2,000 to 3,999	171 (24.9)	143 (25.8)	28 (21.4)	
SGD 4,000 to 5,999	155 (22.6)	119 (21.4)	36 (27.5)	
SGD 6,000 and above	237 (34.5)	188 (33.9)	49 (37.4)	
Missing or refused	43 (6.3)	36 (6.5)	7 (5.3)	
Nulliparous, *n* (%)	333 (48.5)	275 (49.5)	58 (44.3)	0.269
BMI at <14 weeks (kg/m^2)	23.8 ± 4.8	23.6 ± 4.9	24.6 ± 4.6	0.034
Previous history of GDM	23 (3.4)	11 (2.0)	12 (9.2)	<0.001
Alcohol consumption, *n* (%)	6 (0.9)	4 (0.7)	2 (1.5)	0.538
Smoking, *n* (%)	22 (3.2)	20 (3.6)	2 (1.5)	0.229
Sleep and mood				
EPDS score	7.41 ± 4.47	7.53 ± 4.55	6.93 ± 4.09	0.176
STAI total score	69.9 ± 18.5	70.6 ± 18.7	66.5 ± 17.5	0.027
PSQI global score	5.47 ± 2.83	5.36 ± 2.76	5.89 ± 3.07	0.054
Poor sleepers (PSQI >5), *n* (%)	296 (43.1)	231 (41.6)	65 (49.6)	0.096
Nocturnal sleep duration (h)	7.21 ± 1.48	7.25 ± 1.48	7.03 ± 1.47	0.124
Short sleepers (<6h), *n* (%)	77 (11.2)	56 (10.1)	21 (16.0)	0.053
Blood glucose at 26-28 weeks				
Fasting glucose (mmol/L)	4.35 ± 0.49	4.28 ± 0.37	4.65 ± 0.75	<0.001
2-h glucose (mmol/L)	6.54 ± 1.52	6.00 ± 1.00	8.84 ± 1.19	<0.001

EPDS, Edinburgh Postnatal Depression Scale; PSQI, Pittsburgh Sleep Quality Index; SGD, Singapore Dollars; STAI, State-Trait Anxiety Inventory. Data are presented as mean ± SD unless otherwise stated.

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Table 2. Associations between poor sleep quality and short sleep duration with risk of gestational diabetes mellitus.

	Unadjusted	Adjusted*
	OR (95% CI)	**OR (95% CI)**
Poor sleep quality (PSQI >5)	1.38 (0.94 to 2.02)	1.75 (1.11 to 2.76)
Short sleep duration (<6 h)	1.70 (0.99 to 2.93)	1.96 (1.05 to 3.66)

*Adjusted for maternal age, ethnicity, education, BMI at < 14 weeks of gestation, previous history of gestational diabetes, and State-Trait Anxiety Inventory total score. PSQI, Pittsburgh Sleep Quality Index.

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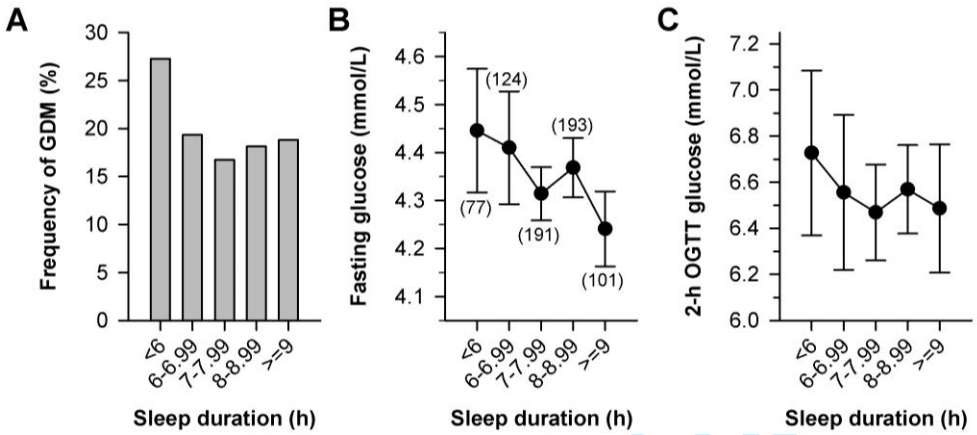
Figure Legends

Fig. 1. Relationships between blood glucose and sleep duration in pregnant women. Participants completed a 75-g oral glucose tolerance test (OGTT) and reported their nocturnal sleep duration by questionnaire. (**A**) The frequency of gestational diabetes mellitus (GDM), (**B**) fasting glucose levels, and (**C**) 2-h OGTT glucose levels are shown across different sleep duration categories. The number of subjects in each sleep duration bin is indicated in parentheses in panel **B**. The mean and 95% CIs are shown in panels **B** and **C**.

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FIGURES

Figure 1.



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