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Sleep-Disordered Breathing and Gestational Diabetes Mellitus

A meta-analysis of 9,795 participants enrolled in epidemiological observational studies

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Sleep-disordered breathing (SDB) has emerged as an important risk factor for the development of high blood pressure, heart failure, stroke, diabetes, atrial fibrilation, and premature mortality (10–12). The risk is particularly elevated among racial/ethnic minority groups and individuals from disadvantaged neighborhoods. Mounting evidence, from observational and experimental intervention studies, indicates that sleep disturbances, such as SDB (defined as habitual snoring or sleep study–documented obstructive sleep apnea), are associated with poor glucose control and possibly GDM (13,14).

Experimental studies have shown that short sleep duration decreases insulin sensitivity compared with longer sleep (15,16). Experimental overnight intermittent hypoxemia, an essential feature of SDB, also alters glucose metabolism in animal and human studies (17,18). Epidemiological studies have shown that SDB is a risk factor for prevalent and incident diabetes, and recent clinical trials indicate that metabolic abnormalities improve with treatment of SDB (19,20).

Recently, SDB has been reported to be associated with the development of GDM (21). This finding, if confirmed across populations, has a potential large public health impact related to the increasing prevalence of obesity, a major risk factor for SDB. The objective of this meta-analysis is to examine whether SDB is associated with the occurrence of GDM and to assess the extent to which such an association is influenced by control for prepregnancy or early pregnancy BMI.

**Research Design and Methods**—This meta-analysis was conducted according to internationally accepted reporting guidelines (22).

Data sources and study selection

Studies were identified by searching the National Center for Biotechnology’s PubMed/MEDLINE database, Embase (Elsevier), the Web of Science (Thomson), BIOSIS (Thomson), CINAHL (EBSCO), Cochrane Central (Wiley), and the reviews...
and registry of the Cochrane Pregnancy and Childbirth group. Controlled vocabulary terms (e.g., MeSH or Emtree terms) were used when available and appropriate. No language or date limits were applied. Additionally, we reviewed the bibliographies of relevant articles and consulted with experts in the field to identify studies not otherwise indexed or discoverable. The terms used to interrogate each databases are presented in the Supplementary Table 1.

Criteria for study inclusion into the review
First, the titles were reviewed to exclude any studies not related to the objective of this meta-analysis. A priori articles were considered for full reading if authors reported data from an original peer-reviewed study (i.e., not case reports, comments, letters, meeting abstracts, or review articles), and study designs were prospective or retrospective cohort or case-control study.

Full texts of the selected studies were then retrieved and read in full in an unblinded and independent manner by two authors (M.A.L.-F. and B.G.). Studies were considered eligible for full manuscript data extraction if the study met all the following criteria: 1) study participants were pregnant women without a diagnosis of diabetes requiring treatment prior to pregnancy, 2) the study considered SDB as an exposure and defined and evaluated SDB as habitual snoring or an apnea hypopnea index ≥5 using overnight sleep monitoring (23,24), 3) the study considered GDM as an outcome and diagnosed participants with fasting glucose or the oral glucose tolerance test (OGTT) following international validated medical criteria (3,25,26), and 4) the study included an assessment of obesity, measured during the prepregnancy period or during early pregnancy. Disagreement was resolved by a third author (M.A.W.) who independently examined the studies.

Data extraction
We developed a modified data extraction sheet based on the Cochrane Consumers and Communication Review Group’s data extraction template and pilot tested it on two randomly selected included studies (27). Two authors (M.A.L.-F. and B.G.) extracted the data from the included studies, and the other authors reviewed the extracted data.

We extracted and recorded specific data from studies: authors, year of publication, country of origin, study design, total sample size, measure used to assess SDB, the recall period between the assessment of the exposure and the diagnosis of GDM, diagnosis criteria to evaluate GDM, whether the study restricted the sample to singleton pregnancies, adjustment or stratification by BMI in multivariate analysis, and type of BMI measurement (prepregnancy or during early pregnancy).

Quality assessment
We assessed the methodological quality and risk of bias for each study based on the Newcastle-Ottawa quality criteria for observational studies (28) (Supplementary Table 2). In addition, a study was considered to be of high quality based on: 1) the observational design being considered a case-control, prospective, or retrospective cohort; 2) case and control subjects being well defined; 3) the recall period specified; 4) the exposure being measured using standardized SDB screening questionnaires (24) or by an objective measurement (29); and 5) in multivariate analysis the measure of association being adjusted or stratified by BMI in multivariate analysis, as SDB and GDM both are associated with increased adiposity (30,31). One author was contacted to clarify whether the association between SDB and GDM was adjusted by BMI in multivariate analysis.

After the quality assessment and prior to conducting the pooled analysis, we assumed that effect size of the association between SDB and GDM may differ according to the methodological quality of the studies. Therefore, we decided a priori to use a random effects meta-analysis approach. In addition, we assessed the overall risk of bias by conducting sensitivity analyses to explore possible sources of heterogeneity across studies.

Results
The systematic search yielded 873 total references, of which 379 were unique. With use of prespecified inclusion criteria, a title review rejected 514 references, yielding 65 candidate abstracts. A subsequent abstract review rejected 56 of these references, yielding nine candidate studies. Each of these studies was reviewed and selected for data extraction; however, based on quality criteria we decided to differentiate two groups for further subgroup analysis. One group was constituted of six studies (39–44) that included BMI in multivariate analysis, whereas the other was constituted of three studies that only presented unadjusted measures of association without adjustment by BMI (45–47). Among the BMI-adjusted studies, four used BMI in multivariate analysis as a classic confounder (39–42), while two stratified the analysis by BMI (Fig. 1) (43,44).

A total of 9,795 pregnant women were included in the analysis. Study populations included were primarily located in the U.S. (seven studies), whereas the other two study populations were from Turkey and Taiwan (42,47). All included studies were observational; seven were designed as prospective or retrospective cohorts.
Table 1 — Description of the principal characteristics of the primary studies included in the systematic review and meta-analysis (n = 9)

<table>
<thead>
<tr>
<th>First author and year</th>
<th>Type of study</th>
<th>Journal</th>
<th>Sample size</th>
<th>Country</th>
<th>Exposure: SDB measurement</th>
<th>Outcome: GDM diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bourjeily G, 2010</td>
<td>Cohort</td>
<td>European Respiratory Journal</td>
<td>938 U.S.</td>
<td>Snoring frequently 3 nights per week</td>
<td>During pregnancy</td>
<td>Multivariate analysis adjusted by BMI</td>
</tr>
<tr>
<td>Facco F, 2010</td>
<td>Cohort</td>
<td>American Journal of Obstetrics and Gynecology</td>
<td>180 U.S.</td>
<td>Snoring frequently 3 nights per week</td>
<td>During pregnancy</td>
<td>Multivariate analysis stratified by BMI</td>
</tr>
<tr>
<td>Qiu C, 2010</td>
<td>Cohort</td>
<td>BMC Women's Health</td>
<td>1,290 U.S.</td>
<td>Snoring most of the time</td>
<td>During pregnancy</td>
<td>Adaption of Berlin sleep questionnaire</td>
</tr>
<tr>
<td>Reutrakul S, 2011</td>
<td>Cohort</td>
<td>Diabetes Care</td>
<td>180 U.S.</td>
<td>Snoring frequently 3 nights per week</td>
<td>During pregnancy</td>
<td>Berlin sleep questionnaire</td>
</tr>
<tr>
<td>Louis J, 2012</td>
<td>Cohort</td>
<td>Obstetrics and Gynecology</td>
<td>178 U.S.</td>
<td>OSA (hypopnea index $\geq 5$)</td>
<td>During pregnancy</td>
<td>Objective measurement: polysomnography</td>
</tr>
<tr>
<td>Ugur M, 2012</td>
<td>Cohort</td>
<td>Clinical and Experimental Obstetrics and Gynecology</td>
<td>465 Turkey</td>
<td>Snoring frequently 3 nights per week</td>
<td>During pregnancy</td>
<td>Berlin sleep questionnaire</td>
</tr>
<tr>
<td>Facco F, 2012</td>
<td>Hospital-based case-control</td>
<td>American Journal of Perinatology</td>
<td>145 U.S.</td>
<td>OSA prior to the index pregnancy (hypopnea index $\geq 5$)</td>
<td>Before pregnancy</td>
<td>Objective measurement: polysomnography</td>
</tr>
</tbody>
</table>

‡Ref. 24.
‡‡Ref. 3.
‡‡‡Ref. 25.
‡‡‡‡Ref. 26.
while two were hospital- or population-based case-control studies (42,46). Four studies restricted the sample to singleton pregnancies (40,42,44,46).

Only three studies used an objective measurement of SDB (obstructive sleep apnea defined as an elevated apnea hypopnea index on polysomnography), while the others identified habitual snoring during pregnancy using standardized questions (24). Four studies did not specify the criteria used to diagnose GDM (42,44,46,47), and three studies did not present an adjusted measure of association (45–47) (Table 1).

Overall, SDB (determined by habitual snoring or polysomnography-documented obstructive sleep apnea) during the index pregnancy were statistically significantly associated with the diagnosis of GDM. The unadjusted OR for the risk of developing GDM in women with SDB for each of the nine individual studies included in the meta-analysis ranged from 1.44 (95% CI 1.00–2.10) to 7.63 (95% CI 1.21–48.25), with a summary pooled unadjusted OR of 2.18 (95% CI 1.59–2.99). Approximately 53% of the variability between studies’ measures of association was due to the presence of a moderate heterogeneity, assessed through the statistic I² (53% [95% CI 0–78%]), Cochran Q test P value = 0.031 (Fig. 2).

The pooled BMI-adjusted OR of the six studies analyzing the effect of SDB on GDB (37–42) was 3.06 (95% CI 1.89–4.96), and the studies’ specific measures of association ranged from 1.63 (95% CI 1.07–2.48) to 6.90 (95% CI 1.40–33.95). Approximately 62% of the variability between studies was due to moderate heterogeneity, with an I² 61% (95% CI 5–84), Cochran Q test P value = 0.024 (Supplementary Fig. 1).

CONCLUSIONS—To our knowledge, this is the first meta-analysis examining...
the evidence for an association between SDB and GDM. Overall, in a pooled analysis we observed a significant association between SDB (defined as habitual snoring or an increase in the measured apnea hypopnea index) and risk of GDM. Women with SDB during pregnancy had more than a threefold increased risk of GDM. Furthermore, a significant association was demonstrated in analyses that considered confounding or effect modification by BMI.

Strengths and limitations
The primary strengths of this meta-analysis include the expansive literature search and inclusion of ~10,000 pregnant women, pooled from nine peer-reviewed published articles. Our findings, consistent with prior hypotheses in the literature, suggest SDB as a novel risk factor for GDM. Women with SDB during pregnancy had more than a threefold increased risk of GDM. Furthermore, a significant association was demonstrated in analyses that considered confounding or effect modification by BMI.

Results from this meta-analysis must be interpreted in light of the following limitations. First, the nature of the evidence of this meta-analysis is based on observational studies. Meta-analyses are not designed to address problems with residual confounding or effect modification by BMI.

Strengths and limitations
The primary strengths of this meta-analysis include the expansive literature search and inclusion of ~10,000 pregnant women, pooled from nine peer-reviewed published articles. Our findings, consistent with prior hypotheses in the literature, suggest SDB as a novel risk factor for GDM. Women with SDB during pregnancy had more than a threefold increased risk of GDM. Furthermore, a significant association was demonstrated in analyses that considered confounding or effect modification by BMI.

Results from this meta-analysis must be interpreted in light of the following limitations. First, the nature of the evidence of this meta-analysis is based on observational studies. Meta-analyses are not designed to address problems with residual confounding that may be inherent in the original studies and does not address causality. Following international guidelines, we have used the Meta-analysis of Observational Studies in Epidemiology (MOOSE) statement and the Newcastle-Ottawa criteria to assess the quality of the selected studies.

Therefore, based on quality criteria for observational studies, we have some confidence that the selected studies are not biased and our pooled measure of association has sufficient power to avoid a systematic statistical type II error. In addition, we have presented stratified analyses by BMI, type of SDB measurement (polysomnography or questionnaire), and type of study (case-control or cohort) in order to explore sources of variability across studies.

Second, while the majority of studies to date have been conducted in U.S., two studies were conducted in Taiwan and Turkey, respectively. Thus, given the growing problem of SDB and GDM globally, more variability in terms of geographical representation of the populations of pregnant women is needed.

Third, although we found no statistically significant evidence for publication bias, we cannot exclude the possibility that publication bias may have affected the results.

Finally, given that some studies used habitual snoring rather than objective recordings of obstructive sleep apnea, it is possible that there may be some misclassification in SDB status, although sensitivity analysis stratified by the objective and subjective measurement of SDB did not show significant differences. Snoring, an indicator of airflow limitation, is in general a fairly sensitive but not specific symptom of obstructive sleep apnea, which characteristically causes overnight intermittent hypoxemia. Self-reported snoring also does not provide quantitative data on the severity of overnight hypoxemia, which may be a critical driver of metabolic disturbances (48). Thus, if the relevant exposure increasing risk of GDM is related to intermittent hypoxemia rather than due to less severe airflow limitation, there may have been an underestimation of the associations. Future research using quantitative metrics of overnight hypoxemia may elucidate whether there are “exposure-response” associations or thresholds of SDB severity that are associated with increased risk of GDM. Nonetheless, snoring history is a readily accessible measure that can be identified in routine clinical obstetrical care and thus is directly relevant for clinicians as an initial step in assessing risk.

Interpretation
The results from subgroup analysis comparing effect estimates for analyses that adjusted for BMI compared with those two that stratified by obesity suggest that the association between SDB and GDM

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Crude OR (95%CI)</th>
<th>Cases/Total (sub-group)</th>
<th>% (Weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bourjeily G. 2010</td>
<td>1.92 (1.25, 2.95)</td>
<td>52/94</td>
<td>331/844</td>
</tr>
<tr>
<td>Facco F. 2010</td>
<td>3.86 (1.06, 14.07)</td>
<td>5/10</td>
<td>35/170</td>
</tr>
<tr>
<td>Qiu C. 2010</td>
<td>5.49 (2.40, 12.51)</td>
<td>8/37</td>
<td>60/1253</td>
</tr>
<tr>
<td>Louis J. 2012</td>
<td>1.60 (0.48, 5.29)</td>
<td>4/17</td>
<td>26/161</td>
</tr>
<tr>
<td>Facco F. 2012</td>
<td>7.63 (2.12, 28.25)</td>
<td>3/5</td>
<td>23/140</td>
</tr>
<tr>
<td>Uglur M. 2012</td>
<td>3.86 (1.54, 9.71)</td>
<td>8/21</td>
<td>61/444</td>
</tr>
<tr>
<td>Reutrakul S. 2011</td>
<td>2.32 (1.05, 5.13)</td>
<td>13/38</td>
<td>26/142</td>
</tr>
<tr>
<td>Chen Y-H. 2012</td>
<td>1.44 (0.99, 2.10)</td>
<td>37/167</td>
<td>75/4579</td>
</tr>
<tr>
<td>O’Brien L. 2012</td>
<td>1.52 (1.17, 1.97)</td>
<td>115/284</td>
<td>430/1389</td>
</tr>
<tr>
<td>Overall (I-squared = 52.7%, p = 0.031)</td>
<td>2.18 (1.59, 2.99)</td>
<td>245/673</td>
<td>1746/9122</td>
</tr>
</tbody>
</table>

Figure 2—Forest plots showing studies’ unadjusted ORs of the association between SDB and GDM and the pooled summary OR (n = 9).
may be stronger in obese women. However, these results have to be interpreted cautiously owing to the relatively small number of studies and their observational design that precludes delineation of the temporal relation between SDB and GDM. These associations may result from bidirectional relationships or they may be the outcome of a third factor affecting both glucose metabolism and breathing during sleep, such as weight gain during pregnancy or psychosocial stress—both areas that warrant further investigation using observational causal inference methodological tools (49). Nonetheless, we consider the fact that all crude estimates of the analyzed studies showed higher odds of GDM for women with SDB to be a consistent finding that strengthens the evidence of the observed association.

There are several possible pathophysiological mechanisms that may explain the observed relationship of SDB and GDM. SDB causes recurrent arousals from sleep (50); sleep fragmentation with a resultant decrease in slow-wave sleep (stage N3) has been shown to alter the effectiveness of both glucose tolerance and insulin sensitivity (21). Reduced stage N3 has been linked to increased risk of impaired glucose tolerance and insulin sensitivity (51), presumably as a result of the disruption of the hypothalamic-pituitary-adrenal axis or through increased activity of the sympathetic nervous system. Alterations in cortisol synthesis and release may also represent a mechanism through which altered sleep disrupts glucose metabolism (21). And finally, intermittent hypoxemia occurring in association with recurrent apneas and hypopneas facilitates the generation of reactive oxidative species resulting in increased oxidative stress and proinflammatory cascade, dyslipidemia, and insulin resistance (21). Intermittent hypoxemia also may negatively influence pancreatic β-cell function (52). Since the majority of normal pregnancies are accompanied with some degree of insulin resistance and a reduction in the duration or quality of sleep, which independently of SDB may impair glucose metabolism (13), pregnancy may be a time of particular vulnerability to SDB-related stresses and adverse metabolic outcomes.

Implications
The prevalence of GDM in the U.S. continues to be a major concern for public health, as the number of affected women is expected to rise as a result of the high prevalence of obesity in women as they enter pregnancy. Results of this study suggest that even after considering the effects of prepregnancy obesity, SDB is a factor risk of GDM. In addition, the association between SDB and GDM may be stronger in obese or overweight women. The recognition and treatment of SDB early during pregnancy may lead to improved outcomes.

Currently, there are no specific guidelines for screening pregnant women for SDB. The results of this meta-analysis indicate the potential importance of considering screening for SDB in high-risk pregnancies, especially among obese women or women who gain excessive weight during pregnancy. The usefulness of current pregnancy guidelines for reducing SDB in pregnancy—such as sleeping in a lateral sleeping position or with head elevation, treatment of nasal congestion, and avoidance of sedatives, alcohol, excessive gestational weight gain, and sleep deprivation—as well as the utility of formal sleep apnea testing and treatment, needs evaluation (48).

Some studies of the general population with SDB that have shown clear

### Table

<table>
<thead>
<tr>
<th>Author, (year)</th>
<th>Adjusted OR (95%CI)</th>
<th>%, Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI adjusted:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bourjeily G. (2010)</td>
<td>2.10 (1.30, 3.40)</td>
<td>23.34</td>
</tr>
<tr>
<td>Facco F. (2010)</td>
<td>6.90 (1.40, 33.95)</td>
<td>7.06</td>
</tr>
<tr>
<td>Reutarakul S. (2011)</td>
<td>3.40 (1.31, 8.85)</td>
<td>13.87</td>
</tr>
<tr>
<td>Chen Y-H. (2012)</td>
<td>1.63 (1.07, 2.48)</td>
<td>24.69</td>
</tr>
<tr>
<td>Subtotal (I-squared = 32.6%, p = 0.217)</td>
<td>2.17 (1.45, 3.25)</td>
<td>68.96</td>
</tr>
</tbody>
</table>

### Analysis stratified by BMI:

<table>
<thead>
<tr>
<th>Author, (year)</th>
<th>Adjusted OR (95%CI)</th>
<th>%, Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qiu C. (2010)</td>
<td>6.90 (2.87, 16.59)</td>
<td>15.17</td>
</tr>
<tr>
<td>O’Brien L. (2012)</td>
<td>4.12 (1.78, 9.53)</td>
<td>15.86</td>
</tr>
<tr>
<td>Subtotal (I-squared = 0.0%, p = 0.405)</td>
<td>5.27 (2.87, 9.66)</td>
<td>31.04</td>
</tr>
</tbody>
</table>

### Pooled summary OR:

| Overall (I-squared = 61.2%, p = 0.024) | 3.06 (1.89, 4.96) | 100.00 |

NOTE: Weights are from random-effects analysis

Figure 3—Subgroup analysis: Forest plots showing studies' adjusted ORs of the association between SDB and GDM and the pooled summary OR (n = 6).
improvement in insulin resistance and glycemic control after nasal continuous positive airway pressure (CPAP) treatment, while others have not (53). Nasal CPAP therapy has been used and tolerated during pregnancy (54), and no adverse events were reported among pregnant women with obstructive sleep apnea who were treated with nasal CPAP (55,56). Our analysis also indicates the need for research to evaluate the role of CPAP in modifying risk of GDM (53).

In summary, this systematic review and meta-analysis contributes to the growing evidence of the increased risk of GDM in women with preexisting or pregnancy-associated SDB.

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57. Closed.