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Gestational diabetes and adiposity are independent risk factors for perinatal outcomes: a population based cohort study in Sweden

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Abstract

Aims To evaluate the interaction effects of gestational diabetes (GDM) with obesity on perinatal outcomes.

Methods A population-based cohort study in Sweden excluding women without pre-gestational diabetes with a singleton birth between 1998 and 2012. Logistic regression was performed to evaluate the potential independent associations of GDM and BMI with adverse perinatal outcomes as well as their interactions. Main outcome measures were malformations, stillbirths, perinatal mortality, low Apgar score, fetal distress, prematurity and Erb's palsy.

Results Some 1,294,006 women were included, with a GDM prevalence of 1% (n = 14,833). The rate of overweight/obesity was 67.7% in the GDM-group and 36.1% in the non-GDM-group. No significant interaction existed. Offspring of women with GDM had significantly increased risk of malformations, adjusted odds ratio (aOR) 1.16 (95% confidence intervals 1.06–1.26), prematurity, aOR 1.86 (1.76–1. 98), low Apgar score, aOR 1.36 (1.10–1.70), fetal distress, aOR 1.09 (1.02–1.16) and Erb's palsy aOR 2.26 (1.79–2.86). No risk for stillbirth or perinatal mortality was seen. Offspring of overweight (BMI 25–29.9 kg/m^2), obese (BMI 30–34.9 kg/m^2) and severely obese women (BMI ≥ 35.0 kg/m^2) had significantly increased risks of all outcomes including stillbirth 1.51 (1.40–1.62) to 2.85 (2.52–3.22) and perinatal mortality 1.49 (1.40–1.59) to 2.83 (2.54–3.15).

Conclusions There is no interaction effect between GDM and BMI for the studied outcomes. Higher BMI and GDM are major independent risk factors for most serious adverse perinatal outcomes. More effective pre-pregnancy and antenatal interventions are required to prevent serious adverse pregnancy outcomes among women with either GDM or high BMI.

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Introduction

Overweight and obesity are public health problems in many parts of the world. In 2014, 39% of the world's population was overweight and 13% were obese [1]. The high prevalence of obesity among women of childbearing age is unprecedented [2]. The incidence of gestational diabetes mellitus (GDM) in Sweden has increased slowly as a consequence of increased rates of obesity, immigration and higher maternal age [3]. It is well known that both GDM and overweight/obesity increase risks for maternal and fetal complications in pregnancy, delivery and the neonatal period [4–10]. Whether adverse outcomes are related to GDM (hyperglycaemia) per se or to overweight/obesity (50–70% of women with GDM are overweight/obese) is known to some extent [11,12]. We have previously demonstrated that normal weight women with GDM have the same increments in risk for adverse maternal outcomes and excessive fetal growth as overweight women without GDM [13]. However, data on serious perinatal outcomes remain scant, and conflicting information on risks of malformations and perinatal mortality in offspring of women with GDM have been presented [14,15].

Visceral fat increases insulin resistance and potentiates development of the metabolic syndrome. This suggests that

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What's new?

- It is known that both gestational diabetes (GDM) and maternal overweight are associated with adverse perinatal outcomes.
- Excess maternal weight and GDM have comparable and independent effects on adverse perinatal outcomes.
- GDM is not associated with perinatal mortality and stillbirth in the Swedish population.
- There is a need for research on interventions that reduce the effects of hyperglycaemia and prevent/better manage overweight/obesity to be able to improve perinatal outcomes.

the combination of overweight and GDM could amplify the risk of adverse perinatal outcomes creating a multiplicative or additive effect [16]. Such information would be helpful in the clinical setting to identify pregnancies at higher risk of complications.

Our first aim was to evaluate possible interaction effects between maternal BMI and GDM on adverse perinatal outcomes. Second, we evaluated whether, and how, maternal excess weight (overweight, obesity, severe obesity) and GDM are independently associated with adverse perinatal outcomes.

Participants and methods

The study population consisted of all women with a singleton birth in Sweden between 1998 and 2012. Data were derived from the Medical Birth Register (MBR) which is maintained by the National Board of Health and Welfare. The register contains data on > 98% of births in Sweden since 1973 [17]. Information on all hospital births is collected prospectively and includes demographic data and diagnoses during pregnancy, delivery and the neonatal period, using standardized forms. The MBR is validated regularly and the quality of the variables included in the present investigation is high [17]. Women with pre-gestational diabetes (Type 1 and Type 2 diabetes mellitus) were excluded from this analysis. Records with extreme values for height and weight were excluded (weight < 35 kg or > 200 kg and height < 140 cm or > 200 cm). Maternal BMI was calculated as weight in kilograms divided by height in metres squared. BMI categories were defined according to the WHO classification as underweight (BMI < 18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2) overweight (25.0–29.9 kg/m^2), obese (30.0–34.9 kg/m^2) and severely obese (≥ 35 kg/m^2). Weight was measured at the first visit to maternity care, usually taking place in the first trimester [18]. Height was reported by recall.

In Sweden, the main screening strategy for GDM during the study period was based on repeated, random, capillary blood glucose ≥ 8 mmol/l (plasma glucose ≥ 9.0 mmol/l) and/or traditional risk factors, i.e. first-degree family history of diabetes, previous delivery of large for gestational age babies, GDM in an earlier pregnancy. Some regions also included obesity as a risk factor. Diagnosis of GDM was based on the 75-g oral glucose tolerance test (OGTT). If elevated random, capillary blood glucose (> 9 mmol/l) was detected in the first trimester, an OGTT was performed with a repeat test during the second trimester. Otherwise the OGTT was performed in gestational week 28–32. During 1998–2012, there was a shift towards performing the OGTT in gestational week 24–28 which is in line with international guidelines. The Swedish MBR does not have the timing of OGTT documented. During the study period, the main diagnostic criteria for GDM were fasting, capillary, whole-blood glucose ≥ 6 mmol/l and/or 2-h blood glucose ≥ 9 mmol/l. In the middle of the study period, there was a switch from measuring whole-blood glucose to plasma glucose. The diagnostic criteria based on plasma glucose included cut-off levels for fasting glucose of ≥ 7.0 mmol/l and for 2-h glucose of ≥ 10.0 mmol/l. A small region in Sweden has offered a simplified 75-g OGTT (including only the 2-h blood glucose measurement) to all pregnant women since 1995. The diagnostic criteria for GDM for this simplified OGTT was 2-h blood glucose ≥ 10.0 mmol/l [19]. In another region, during 1998–2010, only women with values corresponding to overt diabetes (fasting capillary plasma glucose ≥ 7 mmol/l or 2-h plasma glucose ≥ 12.2 mmol/l) were diagnosed with GDM. This region represents ∼ 20–25% of the pregnant population.

The register does not contain data on laboratory measures such as blood glucose. GDM and neonatal outcomes were identified based on International Classification of Diseases version 10 (ICD-10) codes. GDM was identified as ICD code O24.4A or O24.4B. Chronic hypertensive disease (CHD) was defined as hypertension diagnosed before pregnancy or blood pressure ≥ 140/90 mmHg before week 20 of gestation (O10.0, O10.2, O10.4 and O10.9). Preterm delivery was defined as birth before 37 completed weeks of gestation. Malformations include all ICD codes Q00–Q99. The definition of stillbirth changed during the study period. Before 2008, stillbirth was defined as birth of a dead fetus after 28 completed gestational weeks. From 2008, stillbirth was defined in the MBR as fetal death after 22 completed gestational weeks (ICD code O36.4). Perinatal mortality included both stillbirths and deaths during the first 7 days postpartum. Fetal distress was defined as a reason for intervention (i.e. Caesarean section or vacuum extraction) due to suspected fetal hypoxia during pregnancy or delivery (ICD code O68.9). Low Apgar score was defined as Apgar < 4 points at 5 min of age. Erb's palsy was identified based on ICD code P14.0. Sensitivity analysis was done to account for possible differences between regions and the effects of overt diabetes during pregnancy.

The study was approved by the Regional Ethical Committee in Uppsala, Sweden (2009/187/1).

Statistical analyses

To compare maternal characteristics and perinatal outcomes between women with and without GDM the χ^2 test was used, except for maternal age and BMI for which the unpaired *t*-test was used. To compare maternal characteristics and perinatal outcomes between BMI groups the χ^2 test for trend was used for all variables, except maternal age for which analysis of covariance was used as a trend test. Unadjusted, logistic regression was used to compare perinatal outcomes in offspring in relation to mothers' GDM and BMI separately. Adjustment was made for GDM and BMI by having the variables in the same model and further adjustment was made for other potential confounders such as maternal age, non-Nordic decent, parity, smoking and chronic hypertension. Finally, in the final adjusted model, an interaction test of GDM and BMI was assessed which evaluates whether GDM potentiates rather than simply adds to the effect of obesity on the risk of adverse outcomes. In the logistic regression models, all independent variables were entered as categorical except for maternal age which was evaluated on a continuous scale. Logistic regression gave odds ratios (OR) with 95% confidence intervals (95% CI) as measure of association. A *P*-value < 0.05 was considered statistically significant. All statistical analyses were performed using SPSS statistical software, version 22 (IBM, Armonk, NY, USA).

Results

After exclusion of women with Type 1 and Type 2 diabetes before pregnancy, and women with multiple pregnancies, the study cohort included 1,294,006 women with data on early pregnancy BMI; 14,833 women (1%) were diagnosed with GDM. Data on BMI were missing in 11% of the women; however, the proportion of GDM in women without information on BMI was the same (1%) as in women with BMI data. For detailed characteristics of women with missing data on BMI see Table S1. Of all studied women, 35.9% had a BMI ≥ 25 kg/m^2 and 11.3% had a BMI ≥ 30 kg/m^2. Among women with GDM, 67.7% were overweight or obese and 37.6% were obese. During the study period, the proportion of women with GDM increased from 0.7% in 1998 to 1.2% in 2012. The proportion of non-Nordic women also increased from 15.7% in 1998 to 24.6% in 2012. Maternal characteristics differed between women with and without GDM (Table 1), and between BMI groups (Table 2).

The proportion of perinatal outcomes in women with and without GDM are presented in Table 1. There were significantly elevated risks of malformations, fetal distress, low Apgar score, prematurity and Erb's palsy in offspring of women with GDM compared with offspring of women without GDM in the unadjusted model (Table 3). The elevated risks were present after adjusting for BMI and also in the third model with adjustment for other potential confounders (Table 3). There was no increased risk of stillbirth or perinatal mortality in the offspring of women with GDM compared with women without GDM after taking potential confounders into account, including BMI (Table 3). The proportion of perinatal outcomes in women in the different BMI categories are presented in Table 2. Elevated risks of all outcomes were significantly increased in offspring of women that were overweight, obese and severely obese compared with normal weight both unadjusted and adjusted for all potential confounders (Table 3). Risks increased with increasing BMI. The risk increase due to BMI was most pronounced when analysing perinatal death, stillbirth and Erb's palsy, especially for women with a BMI > 30 kg/m^2. Including only pregnancies beyond 37 weeks (i.e. term pregnancies) did not alter the results (data not shown). In the adjusted model there was no significant interaction between GDM and BMI for any of the studied outcomes (Table 3).

Sensitivity analysis excluding the region in Sweden diagnosing GDM on values corresponding to overt diabetes did not change the results for any studied outcome (data not shown). All analyses were repeated with BMI on a continuous scale and this also did not change the results.

Table 1 Maternal characteristics and perinatal outcomes according to the presence of gestational diabetes (GDM)

	No GDM (n = 1 440 834)	GDM (n = 14 833)	*P*-value*
Maternal characteristics			
BMI	24.5 ± 4.4	28.7 ± 6.3	< 0.01
Age(years)	30 ± 5.2	32 ± 5.4	< 0.01
Non-Nordic	275 592 (18.8)	5914 (39.3)	< 0.01
Primiparous	641 360 (44.4)	5299 (35.7)	< 0.01
Chronic hypertension	4274 (0.3)	196 (3.1)	< 0.01
Smoking	117 764 (8.4)	1339 (9.2)	< 0.01
Perinatal outcomes			
Malformation	49 938 (3.5)	611 (4.1)	< 0.01
Perinatal mortality	6506 (0.5)	70 (0.5)	0.69
Stillbirth	4852 (0.3)	58 (0.4)	0.26
Prematurity	70 892 (4.9)	1405 (9.5)	< 0.01
Apgar < 4 at 5 mi	4939 (0.3)	94 (0.6)	< 0.01
Fetal distress	98 360 (6.8)	1196 (8.1)	< 0.01
Erb's palsy	2526 (0.2)	85 (0.6)	< 0.01

Data are presented as n (%) or mean ± SD.
*Unpaired *t*-test was used to analyse BMI and age, the χ^2-test was used for all other maternal characteristics and outcomes. Missing data for BMI was 11%.

Discussion

In this large, population-based cohort study in Sweden, we show that, besides for prematurity, the impact of maternal,

Table 2 Maternal characteristics and perinatal outcomes according to BMI

	BMI (kg/m^2)					
	< 18.5 (n = 31 041)	18.5–24.9 (n = 794 342)	25–29.9 (n = 322 391)	30–34.9 (n = 103 942)	> 34.9 (n = 42 290)	P-value*
Maternal characteristics						
GDM	151 (0.5)	4114 (0.5)	3972 (1.2)	2786 (2.7)	2185 (5.2)	< 0.01
Age (years)	27.7 ± 5.3	29.9 ± 5.1	30.4 ± 5.2	30.3 ± 5.4	30.2 ± 5.3	< 0.01
Non-Nordic	9202 (29.6)	141 082 (17.8)	66 944 (29.8)	21 756 (20.9)	7114 (16.8)	< 0.01
Primiparous	16 798 (54.1)	375 798 (47.3)	128 140 (39.7)	37 671 (36.2)	15 033 (35.5)	< 0.01
Chronic hypertension	33 (0.1)	1310 (0.2)	1225 (0.4)	819 (0.8)	550 (1.3)	< 0.01
Smoking	3606 (11.6)	57 754 (7.3)	29 223 (9.1)	12 249 (11.8)	5838 (13.8)	< 0.01
Perinatal outcomes						
Malformation	1055 (3.4)	27 110 (3.4)	11 281 (3.5)	3752 (3.6)	1633 (3.9)	< 0.01
Perinatal mortality	91 (0.3)	2598 (0.3)	1591 (0.5)	691 (0.7)	394 (0.9)	< 0.01
Stillbirth	69 (0.2)	1945 (0.2)	1208 (0.4)	534 (0.5)	298 (0.7)	< 0.01
Prematurity	1916 (6.2)	35 542 (4.5)	15 368 (4.8)	5700 5.5)	2843 (6.7)	< 0.01
Apgar < 4 at 5 min	66 (0.2)	2124 (0.3)	1242 (0.4)	495 (0.5)	315 (0.7)	< 0.01
Fetal distress	2005 (6.5)	52 853 (6.7)	22 516 (7.0)	7804 (7.5)	3395 (8.0)	< 0.01
Erb's palsy	20 (0.1)	1025 (0.1)	727 (0.2)	343 (0.3)	191 (0.5)	< 0.01

Data are presented as n (%) or mean ± SD.
*Trend test of covariance was used to analyse age. A χ^2-test for trend was used for all other maternal characteristics and outcomes. Missing data for BMI was 11%.

excess weight on adverse perinatal outcomes did not differ significantly between the offspring of mothers with and without GDM. Maternal overweight and obesity and GDM are major, independent risk factors for most adverse perinatal outcomes. Offspring of women with GDM had increased risk of malformations, prematurity, fetal distress and Erb's palsy, but the risks of stillbirth and perinatal mortality were comparable with the risks in the reference population. This was despite being diagnosed with higher glycaemic thresholds than the current WHO criteria [20]. Overweight, obesity and severe obesity were independent risk factors for malformations, stillbirths, perinatal mortality, low Apgar score at 5 min and Erb's palsy. Of concern is that even the offspring of women who were only in the overweight BMI category had significantly increased risks of stillbirth and perinatal mortality. This large group of women (BMI 25–29.9 kg/m^2) does not usually receive any special antenatal care despite the increased risks.

The strength of this study is that it is a nationwide registry-based study, in which data are collected from medical records. BMI is based on weight measured by the midwife, not self-reported. Data on BMI was missing in 11% of the women, but rate of GDM did not differ significantly between women with and without information on BMI. Because of the large study population, we were able to analyse interaction effects and the risks of less common outcomes such as mortality and malformations.

A limitation is that there are no laboratory data from the OGTTs or measures of glycaemia during pregnancy. In Sweden, the screening strategies for GDM have also varied over the years, and the effects of these differences are difficult to evaluate. Because Swedish GDM criteria have been high by international standards, many women that elsewhere would have been diagnosed with GDM were considered 'normal' in this study. This might have resulted in an underestimation of the differences between the groups. It is possible that the study cohort included a few women with Type 2 diabetes detected for the first time during pregnancy. However, the rate of Type 2 diabetes in pregnant women in Sweden is very low [3]. The MBR does not include data on induced abortions due to malformations, which allowed us to study only malformations in pregnancies after 22 gestational weeks.

This study shows that there is no interaction effect between BMI and GDM status for the studied outcomes. This is the first study on the interaction effects between GDM and maternal weight on perinatal outcomes.

We also confirm that overweight and obesity are associated with increased rates of severe adverse perinatal outcomes independent of GDM. The same independent association has been reported for maternal outcomes and large for gestational age [11,13].

Hyperglycaemia in early pregnancy is associated with an increased risk of major malformations [21–23]. The observed increased risks of major malformations in offspring of women with GDM were still low, and most likely due to undiagnosed cases of Type 2 diabetes. Overweight/obesity were independent risk factors of malformations, but the absolute risk increase was small. Feig *et al.* [24] also found increased risk of congenital malformations among offspring of women with GDM, but wondered if this was due to overweight and obesity.

Obese women have an increased risk for both stillbirth and perinatal mortality [25,26]. In this study, we found no significant independent effect of GDM after adjusting for potential confounding factors including BMI. There are few large studies with data on rates of perinatal mortality and

Table 3 Gestational diabetes (GDM) and BMI associations on perinatal outcomes analysed with logistic regression

	Unadjusted OR (95% CI)	Adjusted for GDM/BMI* OR (95% CI)	Adjusted for all possible confounders† OR (95% CI)	*P*-value
Malformations				
GDM	1.20 (1.10–1.30)	1.15 (1.06–1.26)	1.16 (1.06–1.26)	
No GDM	1 (reference)	1 (reference)	1 (reference)	
BMI groups (kg/m$^{2)}$				
< 18.5	1.00 (0.94–1.06)	1.0 (0.94–1.06)	1.02 (0.95–1.08)	
18.5–24.9	1 (reference)	1 (reference)	1 (reference)	
25–29.9	1.03 (1.00–1.05)	1.03 (1.00–1.05)	1.04 (1.01–1.06)	
30–34.9	1.06 (1.02–1.10)	1.06 (1.02–1.09)	1.08 (1.04–1.11)	
≥ 35.0	1.14 (1.08–1.20)	1.13 (1.07–1.19)	1.15 (1.09–1.21)	
Interaction test				0.56
Perinatal mortality				
GDM	1.05 (0.83–1.32)	0.90 (0.70–1.14)	0.79 (0.62–1.01)	
No GDM	1 (reference)	1 (reference)	1 (reference)	
BMI groups (kg/m$^{2)}$				
< 18.5	0.90 (0.73–1.11)	0.90 (0.73–1.11)	0.89 (0.72–1.09)	
18.5–24.9	1 (reference)	1 (reference)	1 (reference)	
25–29.9	1.51 (1.42–1.61)	1.51 (1.42–1.61)	1.49 (1.40–1.59)	
30–34.9	2.04 (1.88–2.22)	2.04 (1.88–2.22)	2.01 (1.85–2.19)	
≥ 35.0	2.87 (2.58–3.19)	2.88 (2.59–3.21)	2.84 (2.55–3.17)	
Interaction test				0.86
Stillbirth				
GDM	1.16 (0.90–1.51)	1.0 (0.77–1.31)	0.87 (0.66–1.13)	
No GDM	1 (reference)	1 (reference)	1 (reference)	
BMI groups (kg/m$^{2)}$				
< 18.5	0.91 (0.71–1.15)	0.91 (0.71–1.15)	0.90 (0.70–1.14)	
18.5–24.9	1 (reference)	1 (reference)	1 (reference)	
25–29.9	1.53 (1.43–1.65)	1.53 (1.43–1.65)	1.51 (1.40–1.62)	
30–34.9	2.10 (1.91–2.32)	2.10 (1.91–2.32)	2.06 (1.87–2.27)	
≥ 35.0	2.89 (2.56–3.27)	2.89 (2.56–3.27)	2.85 (2.52–3.22)	
Interaction test				0.38
Prematurity				
GDM	2.02 (1.91–2.14)	1.91 (1.80–2.03)	1.87 (1.76–1.98)	
No GDM	1 (reference)	1 (reference)	1 (reference)	
BMI groups (kg/m$^{2)}$				
< 18.5	1.40 (1.34–1.47)	1.41 (1.34–1.47)	1.37 (1.31–1.44)	
18.5–24.9	1 (reference)	1 (reference)	1 (reference)	
25–29.9	1.07 (1.05–1.09)	1.06 (1.04–1.08)	1.08 (1.06–1.10)	
30–34.9	1.24 (1.20–1.28)	1.22 (1.18–1.25)	1.24 (1.20–1.27)	
≥ 35.0	1.54 (1.48–1.60)	1.48 (1.42–1.54)	1.49 (1.43–1.55)	
Interaction test				0.30
Apgar < 4 at 5 min of age				
GDM	1.85 (1.51–2.26)	1.54 (1.24–1.91)	1.36 (1.10–1.70)	
No GDM	1 (reference)	1 (reference)	1 (reference)	
BMI groups (kg/m$^{2)}$				
< 18.5	0.80 (0.62–1.02)	0.80 (0.62–1.02)	0.78 (0.61–1.00)	
18.5–24.9	1 (reference)	1 (reference)	1 (reference)	
25–29.9	1.44 (1.35–1.55)	1.44 (1.34–1.54)	1.45 (1.35–1.56)	
30–34.9	1.79 (1.62–1.97)	1.76 (1.60–1.95)	1.80 (1.63–1.98)	
≥ 35.0	2.80 (2.49–3.15)	2.73 (2.42–3.08)	2.81 (2.49–3.17)	
Interaction test				0.38
Fetal distress				
GDM	1.20 (1.13–1.27)	1.15 (1.08–1.22)	1.09 (1.02–1.16)	
No GDM	1 (reference)	1 (reference)	1 (reference)	
BMI groups (kg/m$^{2)}$				
< 18.5	0.97 (0.93–1.01)	0.97 (0.93–1.02)	0.96 (0.92–1.01)	
18.5–24.9	1 (reference)	1 (reference)	1 (reference)	
25–29.9	1.05 (1.04–1.07)	1.05 (1.04–1.07)	1.14 (1.12–1.15)	
30–34.9	1.14 (1.11–1.17)	1.14 (1.11–1.16)	1.29 (1.26–1.32)	
≥ 35.0	1.23 (1.18–1.27)	1.22 (1.17–1.26)	1.40 (1.35–1.46)	
Interaction test				0.16
Erb's palsy				
GDM	3.28 (2.64–4.08)	2.36 (1.87–2.98)	2.26 (1.79–2.86)	
No GDM	1 (reference)	1 (reference)	1 (reference)	
BMI groups (kg/m$^{2)}$				

Table 3 (*Continued*)

	Unadjusted OR (95% CI)	Adjusted for GDM/BMI* OR (95% CI)	Adjusted for all possible confounders† OR (95% CI)	*P*-value
< 18.5	0.50 (0.32-0.78)	0.50 (0.32-0.78)	0.49 (0.32-0.76)	
18.5–24.9	1 (reference)	1(reference)	1(reference)	
25–29.9	1.75 (1.59–1.92)	1.73 (1.58–1.91)	1.72 (1.56–1.89)	
30–34.9	2.56 (2.27–2.90)	2.49 (2.20–2.82)	2.48 (2.20–2.81)	
≥ 35.0	3.55 (3.01–4.10)	3.31 (2.83–3.87)	3.37 (2.98–3.95)	
Interaction test				0.69

OR, odds ratio; CI, confidence interval
*With GDM and BMI in the same model adjusted for each other.
†With GDM and BMI in the same model adjusted for each other and for maternal age, non-Nordic origin, parity, smoking and chronic hypertension.

stillbirth in women with GDM. Billionnet *et al.* [14] showed an increased risk for perinatal mortality for women with GDM after 37 weeks; however, they were not able to adjust for maternal BMI in their analyses. Feig *et al.* [24] reported decreased risks of perinatal mortality in women with GDM compared with pregnancies without diabetes. They argue that this might be due to more intense management in pregnancies of women with GDM. This is in contrast to the findings in our study, which is more in line with the results of Ovesen *et al.* [27]. The finding is interesting because women with GDM in this study were diagnosed using higher cut-off values for plasma glucose than the International Association of Diabetes in Pregnancy Study Group (IADPSG) criteria [28].

There are few studies reporting risks of fetal distress and low Apgar scores in offspring of pregnancies in women with GDM. Ovesen *et al.* [27] found no significant differences in Apgar score < 7 at 5 min in offspring of women with or without GDM. In the ACHOIS study, a randomized controlled trial of women with GDM receiving active treatment (dietary advice, blood glucose monitoring and insulin therapy) or routine care, there was no difference in risk of low Apgar score between the offspring of mothers in the routine care and the intervention groups [29]. In the current study, we used Apgar < 4 at 5 min because it is a strong predictor of neonatal complications [30]. We found a slightly elevated risk of low Apgar scores in offspring of women with GDM compared with women without GDM. Offspring of mothers with GDM also had a slightly elevated risk of fetal distress, and in offspring of mothers without GDM risks increased with maternal BMI. This is in contrast to the finding of a markedly increased risk of fetal distress in offspring of mothers with Type 1 diabetes [31].

The risk of Erb's palsy has been studied previously with contradictory results. There are studies reporting no increased risks of Erb's palsy in offspring of women with GDM [32,33]. In a previous Swedish study, the risk of Erb's palsy was more than doubled in offspring of women with GDM, even after taking maternal BMI into account [34]. We confirm these results and also show that overweight/obesity had a similar impact on the relative risk of Erb's palsy as GDM. Because we have shown that there was no interaction, the risks of Erb's palsy associated with overweight/obesity are additional to the risk conveyed by GDM.

We also repeated all calculations including only women with a term pregnancy (> 37 weeks) because that is the vast majority of women seen in the clinics. This did not change the conclusions.

The rate of GDM in Sweden is low due to screening policies, strict diagnostic criteria and generally, a low background prevalence of Type 2 diabetes. Whether a more extensive GDM screening programme and a more stringent treatment regimen would reduce the risks of neonatal morbidity need to be further studied and explored. Further research is also needed into pre-pregnancy and antenatal interventions that will reduce the risk of adverse neonatal outcomes among overweight and obese women [35,36].

Improvements in uncommon, but serious outcomes such as stillbirth and perinatal mortality need research into interventions that both reduce the effects of hyperglycaemia and prevent/better manage overweight/obesity.

Author contributions

The study was conceived by KH, HF and UH; planned by KH, HF and UH; performed by KH, HF and MP; analysed by KH, HF and AM; and written by KH, HF, MP, AM, DS and UH.

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Competing interests

None declared.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Odds ratios (95% CI) for maternal characteristics and perinatal outcomes in women with missing BMI compared with normal weight women.