Disproportionate Body Composition and Neonatal Outcome in Offspring of Mothers With and Without Gestational Diabetes Mellitus

OBJECTIVE—High birth weight is a risk factor for neonatal complications. It is not known if the risk differs with body proportionality. The primary aim of this study was to determine the risk of adverse pregnancy outcome in relation to body proportionality in large-for-gestational-age (LGA) infants stratified by maternal gestational diabetes mellitus (GDM).

RESEARCH DESIGN AND METHODS—Population-based study of all LGA (birth weight [BW] >90th percentile) infants born to women with GDM (n = 1,547) in 1998–2007. The reference group comprised LGA infants (n = 83,493) born to mothers without diabetes. Data were obtained from the Swedish Birth Registry. Infants were categorized as proportionate (P-LGA) if ponderal index (PI) (BW in grams/length in cm3) was ≤90th percentile and as disproportionate (D-LGA) if PI >90th percentile. The primary outcome was a composite morbidity: Apgar score 0–3 at 5 min, birth trauma, respiratory disorders, hypoglycemia, or hyperbilirubinemia. Logistic regression analysis was used to obtain odds ratios (ORs) for adverse outcomes.

RESULTS—The risk of composite neonatal morbidity was increased in GDM pregnancies versus control subjects but comparable between P- and D-LGA in both groups. D-LGA infants born to mothers without diabetes had significantly increased risk of birth trauma (OR 1.19 [95% CI 1.09–1.30]) and hypoglycemia (1.23 [1.11–1.37]). D-LGA infants in both groups had significantly increased odds of Cesarean section.

CONCLUSIONS—The risk of composite neonatal morbidity is significantly increased in GDM offspring. In pregnancies both with and without GDM, the risk of composite neonatal morbidity is comparable between P- and D-LGA.

From the 1Clinical Epidemiology Unit, Department of Medicine Solna, Karolinska University Hospital, Karolinska Institutet, Stockholm, Sweden; the 2School of Health and Medical Sciences, Örebro University, Örebro, Sweden; the 3Department of Obstetrics and Gynecology, University of Uppsala, Uppsala, Sweden; and the 4Women’s Health Academic Centre, King’s Health Partners, King’s College London, Guy’s and St Thomas’ NHS Foundation Trust, London, U.K.

Corresponding author: Martina Persson, martina.persson@ki.se.

Received 17 April 2013 and accepted 21 May 2013.

DOI: 10.2337/dc13-0899

© 2013 by the American Diabetes Association. Readers may use this article as long as the work is properly cited, the use is educational and not for profit, and the work is not altered. See http://creativecommons.org/licenses/by-nc-nd/3.0/ for details.
by an independent group of researchers. The conclusion from these validations is that the quality of the data is considered to be high (30,31). In Sweden, screening for GDM is universal, including all pregnant women. There are a few local variations, but the principal screening program includes random capillary glucose measured four to six times during pregnancy starting at the first antenatal visit in the first trimester. During the study period, women were selected for oral glucose tolerance test (OGTT) based on repeated random capillary plasma glucose tests ≥9 mmol/L and/or in combination with traditional risk factors, including a first-degree relative with diabetes, prior GDM, obesity, or prior delivery or positive screening criteria. This means that most non-GDM women have not performed an OGTT but do not fulfill the screening criteria for OGTT. A minor part of non-GDM women performed an OGTT with a normal result. In the southern part of Sweden, all pregnant women have been offered a simplified OGTT (omitting fasting blood glucose) as a one-step screening and diagnostic test since 1995 (33). The main diagnostic criteria for GDM applied in Sweden are based on the Diabetes in Pregnancy Study Group recommendation from 1991, i.e., a fasting capillary whole blood glucose ≥6.1 mmol/L (fasting plasma glucose ≥7.0 mmol/L) and/or 2-h capillary whole blood glucose ≥9 mmol/L (plasma glucose ≥10 mmol/L) after 75-g OGTT.

Study cohort
The current study included only LGA infants, defined as infants with a BW >90th percentile in relation to gestational age and sex. The study cohort comprised 1,547 live born singleton to mothers with GDM and 83,493 singletons born to mothers without a diagnosis of diabetes. Women with a diagnosis of GDM were identified by ICD-10 code O24. All the infants in the study cohort were born between 37 and 43 weeks of gestation. In Sweden, all pregnant women are offered an ultrasonic scan performed around the 17th week of gestation, with the primary aim to determine gestational age. More than 95% of pregnant women accept this offer (34). When information on ultrasound was not available, gestational age was estimated from date of last menstrual period. We excluded stillborn infants, infants with major malformations, and infants born at <37 weeks of gestation or with BW ≤90th percentile. In the current study, we used the same limits for data acceptance as in the Swedish Perinatal Quality Registry, i.e., infants with a BW <2000 or >9,998 g and a BL <15 or >65 cm. Applying these limits, no records were excluded due to BW but 90 records were excluded due to extreme values on BL. We also excluded records with missing data on BW, BL, gestational age, or sex and records with extreme values on maternal age (<13 or >54 years), weight (<40 and >200 kg), and height (<120 and >200 cm). Pregnancy-induced hypertension (PIH) was defined as a resting blood pressure ≥140/90 after the 20th week of gestation (ICD-10 code O13). Preeclampsia was defined as PIH and proteinuria of ≥0.3 g/day or ≥1+ on a urine dipstick (ICD-10 codes O14.0, O14.1, and O15).

Collection and categorization of infant anthropometry
According to standardized operation of procedures, all infant anthropometrics were measured within 12 h after birth by trained midwives. BW was registered to the nearest gram on an electronic scale; BL was measured using a standardized measuring board for length. Sex- and gestational age–adjusted reference percentiles for BW, BL, and PI were based on data from singleton infants, without major malformations and born between 28–43 weeks in the same time period to mothers without diabetes (n = 874,620). LGA was defined as BW >90th percentile. Disproportionate body composition (D) was defined as a PI (BW in grams/BL in cm²) >90th percentile and proportionate (P) as PI ≤90th percentile. LGA infants were classified as proportionate (P-LGA) and disproportionate (D-LGA).

Outcomes
The primary outcome was a composite morbidity variable including any of the following diagnoses: Apgar score 0–3 at 5 min, birth trauma in vaginally delivered infants (Erb palsy ICD-10 code P140; fractured clavicle ICD-10 code P134), acute respiratory disorders (respiratory distress syndrome ICD-10 code P220; transient tachypnea ICD-10 codes P22.1, P22.8, and P22.9; meconium aspiration), and hypoglycemia or hyperbilirubinemia requiring treatment with phototherapy or exchange transfusion. Neonatal hypoglycemia was defined as blood glucose <2.6 mmol/L after 6 h postnatal (ICD-10 code P70.4 B). The secondary outcomes included delivery by Cesarean section, and the diagnoses stated above were analyzed separately.

Statistical analysis
Given the prevalence of neonatal morbidity and of LGA in the offspring of women with GDM (15,18,19) and hypothesizing that 40% of the LGA infants are D-LGA (33), we will need a cohort size of ~339 LGA infants with disproportionate body composition and 776 LGA infants with proportionate body composition to detect a 30% increase in the prevalence of neonatal morbidity (composite outcome) comparing P-LGA and D-LGA infants with 80% power and α = 0.05. Continuous data were summarized by the median and interquartile range, and univariate analyses were performed using the Mann-Whitney U test. Univariate analyses of dichotomous data were performed using the χ² test. Odds ratios (ORs) for perinatal complications were estimated using logistic regression with P-LGA infants, born to women without diabetes, as the reference category. In the multivariate model, the estimate for the primary outcome (composite morbidity) was adjusted for maternal country of birth (Nordic yes/no), age, BMI, height, smoking in the first trimester of pregnancy, parity, mode of delivery, PIH, and preeclampsia. Multivariate regression models for the secondary outcomes included covariates significantly associated with the outcome in univariate analysis. As none of the above-stated covariates were significantly associated with three of the secondary outcomes, i.e., birth trauma, Apgar score 0–3 at 5 min, and hypoglycemia, no multivariate models were constructed for these outcomes. In the multivariate logistic regression, missing indicator variables were used for maternal age, BMI, and height. To disclose any potential differences between P-LGA and D-LGA within the GDM cohort, all regression models were also performed with P-LGA infants born to GDM mothers as the reference category. Likelihood ratio test was used to explore the interaction between maternal GDM, BW category, and the different outcomes.

RESULTS—During the study period, there were 947,906 deliveries in Sweden, of which 0.94% (n = 8,929) were pregnancies to mothers with GDM. The prevalence of LGA among offspring of women with GDM was 26% (n = 1,547) and 10.6% (n = 83,493) in infants born to mothers.
without diabetes. Of the LGA infants in the GDM cohort, 44% (n = 694) had a dis-proportionate body composition, compared with 36% (n = 29,969) in the reference group (P value <0.001).

Compared with women without diabetes, women in the GDM group were more often of non-Nordic origin, older, and multiparous, had a higher prepregnancy BMI, and were more likely to be shorter. Women giving birth to a D-LGA infant had a significantly higher BMI compared with mothers of P-LGA infants (GDM group: BMI 30.5 [D-LGA] vs. 25.0 [P-LGA] kg/m²; reference group: BMI 25.5 [D-LGA] 24.9 [P-LGA] kg/m²; P value <0.05). The prevalence of smoking and hypertensive disorders in pregnancy was significantly higher in the GDM cohort (Table 1). The infants born to mothers with GDM were more likely delivered earlier with lower absolute BW compared with the non-GDM group. The incidence of LGA, however, was higher in infants of women with GDM. Furthermore, LGA infants born to mothers with GDM were more likely to be disproportionate with a slightly higher PI compared with the LGA infants born to mothers without diabetes. When BW was compared by body proportionality, BW was highest among infants who were D-LGA and born to mothers without GDM. Infants born to mothers with GDM were also more likely delivered by Cesarean section.

The frequency of the primary and most secondary outcomes was significantly higher in infants born to GDM mothers compared with infants born to mothers without diabetes (Table 2). Within both the GDM and the non-GDM cohorts, there were no significant differences in the occurrence of composite neonatal morbidity between P-LGA and D-LGA infants. D-LGA infants born to mothers with and without GDM were more often delivered by Cesarean section than P-LGA infants. In both GDM and reference groups, the incidence of birth trauma and hypoglycemia was higher in D-LGA compared with P-LGA. However, the difference reached statistical significance only in the reference group.

In comparison with P-LGA infants born to mothers without diabetes, the ORs for the primary and most secondary outcomes were significantly higher in both P-LGA and D-LGA infants born to GDM mothers (Table 3). The increased odds persisted even after adjustment for potential confounders (Table 3). In the non-GDM group, D-LGA was associated with significantly increased odds of Cesarean section, birth trauma, and hypoglycemia. Confining the regression analysis to the GDM cohort, with P-LGA infants as the reference category, D-LGA was associated with significantly increased odds of Cesarean section (P < 0.001). There were no significant differences between P-LGA and D-LGA GDM offspring for any of the other outcomes. There was no significant interaction between LGA category and GDM for any of the outcomes (Table 3).

**CONCLUSIONS**—Forty-four percent of this population-based cohort of LGA GDM offspring had a disproportionate body composition, similar to our previous finding of 46% in LGA newborns of mothers with type 1 diabetes (35). The major finding of this study was that the risk of adverse neonatal outcome did not differ significantly with body proportionality in infants born to mothers with GDM. As expected, neonatal morbidity was significantly more common in both P-LGA and D-LGA GDM offspring than in infants born to mothers without diabetes. The increased odds of complications in GDM offspring remained even after adjustment for differences in maternal characteristics and hypertensive disorders. Another important finding in the current study was that in infants born to mothers without diabetes, a disproportionate body composition was associated with significantly increased odds of birth trauma and hypoglycemia.

The strength with the current study is the large national cohort, including >1,500 LGA infants born to women with GDM and >80,000 LGA infants born to women without diabetes. The large sample size enabled adjustment for several important confounders and also a stratified risk analysis for subgroups of LGA infants. The population-based design limits the risk of selection bias regarding the exposure (GDM) and reference groups. However, in the current

**Table 1—Maternal and infant characteristics**

| Characteristic                | GDM (n = 1,547) | Non-GDM (n = 83,493) | P value |
|------------------------------|-----------------|----------------------|---------|
| **Maternal characteristics** |                 |                      |         |
| Nordic origin                | 1,111 (71.8%)   | 74,857 (89.7%)       | <0.001  |
| Primipara                    | 336 (21.7%)     | 23,161 (27.7%)       | <0.001  |
| Age (years)                  | 32 (29–36)      | 31 (27–34)           | <0.001  |
| BMI (kg/m²)                  | 30.0 (25–34.8)  | 25.1 (22.7–28.5)     | <0.001  |
| Overweight-obese: P-LGA      | 80.6%           | 57.2%                | <0.001  |
| Overweight-obese: D-LGA      | 85.8%*          | 61.3%*               | <0.001  |
| Height (cm)                  | 166 (162–170)   | 169 (164–173)        | <0.001  |
| Height, P-LGA (cm)           | 167             | 168                  | <0.001  |
| Height, D-LGA (cm)           | 165*            | 169*                 | <0.001  |
| Smoking first trimester      | 135 (8.7%)      | 4,631 (5.6%)         | <0.001  |
| PIH                          | 33 (2.1%)       | 671 (0.8%)           | <0.001  |
| Preeclampsia                 | 95 (6.1%)       | 1,899 (2.3%)         | <0.001  |
| **Infant characteristics**   |                 |                      |         |
| LGA                          | 1,547 (100%)    | 83,493 (100%)        |         |
| Male                         | 776 (50.2%)     | 42,907 (51.4%)       | 0.338   |
| Gestational age (weeks)      | 39 (38–40)      | 40 (39–41)           | <0.001  |
| BW (g)                       | 4,400 (4,202–4,675) | 4,410 (4,200–4,630) | <0.001  |
| PI                           | 3.0 (2.87–3.22) | 2.98 (2.82–3.15)     | <0.001  |
| P-LGA                        | 873 (56.4%)     | 53,524 (64.1%)       | <0.001  |
| D-LGA                        | 674 (43.6%)     | 29,969 (35.9%)       | <0.001  |
| BW, P-LGA (g)                | 4,360 (4,180–4,575) | 4,385 (4,185–4,590) | <0.001  |
| BL, P-LGA (cm)               | 53 (53–54)      | 54 (53–55)           | <0.001  |
| BW, D-LGA (g)                | 4,480 (4,245–4,785) | 4,450 (4,230–4,690) | <0.001  |
| BL, D-LGA (cm)               | 52 (51–53)      | 52 (51–53)           | 0.08    |
| Mode of delivery             |                 |                      |         |
| Cesarean section             | 555 (35.9%)     | 16,940 (20.3%)       | <0.001  |
| Ventouse/forceps             | 89 (5.8%)       | 5,471 (6.6%)         | 0.207   |

Data are n (%) or medians (interquartile range) unless otherwise indicated. BMI: at insubscription to antenatal care (first trimester), missing data 16% in GDM and 14% in reference group. *Significant difference between mothers to D-LGA and P-LGA, within GDM and reference group, respectively.
Body composition and neonatal outcome

Table 2—Neonatal outcomes

|                      | GDM, P-LGA | GDM, D-LGA | Non-GDM, P-LGA | Non-GDM, D-LGA | P value |
|----------------------|------------|------------|---------------|---------------|---------|
| Composite morbidity  | 99 (11.3%) | 94 (14.0%) | 3,745 (7.0%)  | 2,184 (7.3%)  | 0.117   |
| Apgar 5 <4           | 7 (0.8%)   | 5 (0.7%)   | 106 (0.2%)    | 44 (0.2%)     | 0.094   |
| Cesarean section     | 277 (31.8%)| 278 (41.3%)| 9,691 (18.1%) | 7,249 (24.2%) | <0.001  |
| Birth trauma         | 35 (6.5%)  | 22 (6.6%)  | 1,315 (3.2%)  | 792 (3.8%)    | 0.630   |
| Respiratory disorders| 8 (0.9%)   | 12 (1.8%)  | 774 (1.5%)    | 421 (1.4%)    | 0.136   |
| Hypoglycemia         | 48 (5.5%)  | 51 (7.6%)  | 843 (1.6%)    | 579 (1.9%)    | <0.001  |
| Hyperbilirubinemia   | 13 (1.5%)  | 10 (1.5%)  | 849 (1.6%)    | 430 (1.4%)    | 0.088   |

Data are n (%).

A potential weakness with this study is that the MBR does not contain data on maternal glycemic control. Accordingly, the influence of different degrees of maternal hyperglycemia on the risk of neonatal complications could not be assessed. The incidence of GDM in Sweden is low (0.9%) compared with other countries, reflecting differences in screening strategies, diagnostic criteria, and above all a low rate of type 2 diabetes in the background population. The screening strategies in Sweden do not detect all cases of GDM. There is evidence that with the screening strategies used in most of Sweden, ~50% of cases with GDM (mainly impaired glucose tolerance) are not diagnosed, but the more severe cases and overt diabetes are found by this screening strategy (32). By comparing data from a population study in Sweden where all pregnant women were offered an OGTT (32) with data from the MBR, the rate of undiagnosed GDM in the non-GDM group was estimated to be ~0.7%. This proportion of undiagnosed milder GDM in the background population is low and unlikely to affect the results. If any effect, the differences between the groups in the current study may have been underestimated. We are aware of the potential limitation regarding the measurement of infant length. However, in Sweden, BL is measured according to a standardized procedure using a measure board for length. We consider it unlikely that any potential systematic error of length measurement would differ between infants born to mothers with and without diabetes; i.e., the possible misclassification is nondifferential. It is noteworthy that the number of infants excluded due to extreme BL in the current study was very low (0.01%).

This study is, to our knowledge, the first to analyze the risk of neonatal complications by body proportionality in GDM offspring. A high BW-to-BL ratio was not associated with an increased risk of composite neonatal morbidities in infants born to GDM mothers. This finding

Table 3—Logistic regression analysis for adverse outcomes stratified by maternal GDM and infant size

|                      | Reference* | Non-GDM, D-LGA | GDM, P-LGA | GDM, D-LGA | Interaction P value |
|----------------------|------------|---------------|------------|------------|---------------------|
| Composite morbidity  | Crude OR   | 1.0           | 0.97 (0.93–1.01) | 1.52 (1.26–1.83) | 1.76 (1.44–2.15) | 0.22                |
|                      | Adjusted OR| 1.0           | 1.00 (0.95–1.06) | 1.47 (1.18–1.83) | 1.75 (1.38–2.21) |                     |
| Cesarean section**   | Crude OR   | 1.0           | 1.44 (1.39–1.49) | 2.11 (1.82–2.43) | 3.18 (2.72–3.71) |                     |
|                      | Adjusted OR| 1.0           | 1.40 (1.35–1.45) | 1.77 (1.53–2.05) | 2.59 (2.21–3.04) | 0.17                |
| Apgar 5 <4           | Crude OR   | 1.0           | 0.74 (0.52–1.05) | 4.07 (1.89–8.78) | 3.77 (1.53–9.27) | 0.13                |
| Birth trauma         | Crude OR   | 1.0           | 1.19 (1.09–1.30) | 2.10 (1.49–2.97) | 2.11 (1.36–3.26) | 0.37                |
| Hypoglycemia         | Crude OR   | 1.0           | 1.23 (1.11–1.37) | 3.64 (2.70–4.90) | 5.12 (3.81–6.86) | 0.39                |
| Respiratory disorders| Crude OR   | 1.0           | 0.97 (0.86–1.09) | 0.63 (0.31–1.27) | 1.24 (0.69–2.20) |                     |
|                      | Adjusted OR| 1.0           | 0.90 (0.86–1.02) | 0.54 (0.27–1.08) | 0.96 (0.54–1.70) | 0.14                |
| Hyperbilirubinemia   | Crude OR   | 1.0           | 0.90 (0.80–1.02) | 0.94 (0.54–1.63) | 0.93 (0.50–1.75) |                     |
|                      | Adjusted OR| 1.0           | 0.88 (0.78–0.99) | 0.80 (0.46–1.39) | 0.76 (0.41–1.43) | 0.75                |

ORs adjusted for variables associated with outcomes in univariate analysis; for birth trauma, Apgar <4 at 5 min, and hypoglycemia, no significant associations were found with any of the potential confounders and therefore only the crude estimate is reported. *Reference = non-GDM, P-LGA. **Significant difference between P-LGA and D-LGA within GDM cohort.
was unexpected and not in line with our prespecified hypothesis. We speculated that infants with a disproportionate largeness (D-LGA) had been subjected to a more profound fetal hyperinsulinemia compared with infants who are proportionally large (P-LGA). This view is supported by previous studies that have demonstrated an increasing linear relationship between maternal fasting glucose levels and cord blood levels of C-peptide, neonatal fat mass, and fetal macrosomia in pregnancies with mild GDM (36). In this context, it is of interest that the incidence of neonatal hypoglycemia was higher in D-LGA, compared with P-LGA, infants in both cohorts, although the difference reached statistical significance only in the reference group. It cannot be excluded that fetal hyperinsulinemia, which is known to be associated with increased risk of neonatal hypoglycemia, could explain the higher prevalence of hypoglycemia in disproportionately grown infants. It is unclear to what extent the absence of difference in composite neonatal outcome between P- and D-LGA GDM offspring can be attributed to differences in time of GDM diagnosis and treatment. All mothers in the current study received treatment that may well have modified the risk of neonatal complications. Results from two randomized, controlled studies of GDM demonstrate a positive effect of treatment on the infant’s size, fat mass at birth, and risk of neonatal complications (18,37).

It is noteworthy that the incidence of D-LGA infants was also high (36%) in the non-GDM population. Studies on pregnant women without diabetes have demonstrated a linear association between maternal glucose values (fasting and 1- and 2-h values from 75-g OGGT at 24–32 weeks of gestation) and cord blood levels of C-peptide, neonatal fat mass, and BW >90th percentile (38). Additional findings of the Hyperglycemia and Adverse Pregnancy Outcome (HAPO) study also indicate that maternal BMI per se is associated with increased risk of neonatal fat mass and BW >90th percentile, independent of maternal glycemia (12). Accordingly, we found a higher proportion of overweight/obesity in women delivering a D-LGA infant (Table 1) compared with mothers of P-LGA infants. This association was found both in the GDM and non-GDM groups. In contrast to the findings in GDM offspring, D-LGA infants born to mothers without diabetes had increased risk of birth trauma and hypoglycemia. One might speculate that this difference is attributed to the lower rate of Cesarean section in the non-GDM cohort. One might speculate that D-LGA infants were more likely to be delivered by Cesarean section due to a higher absolute BW. However, it is well recognized that methods used for antenatal prediction of fetal macrosomia are considered inaccurate, and the odds of Cesarean section remained significantly increased even after adjusting for differences in absolute BW (data not shown).

In conclusion, the risk of composite neonatal morbidity is significantly increased in GDM offspring compared with infants born to mothers without diabetes. In pregnancies both with and without GDM, the risk of composite neonatal morbidity is comparable between P-LGA and D-LGA. The lack of difference observed between D-LGA and P-LGA may reflect other metabolic effects of GDM independent of neonatal body proportionality.

Acknowledgments—This study was supported by unrestricted research grants from the Samaritene Foundation and the Stockholm City Council. D.P. was funded by the National Institute for Health Research, U.K., and Tommy’s Charity, U.K.

No potential conflicts of interest relevant to this article were reported.

M.P. conceived and designed the research, analyzed data, interpreted results, and drafted the manuscript. H.F. and D.P. interpreted results and critically revised the manuscript. U.H. acquired the data, interpreted results, and critically revised the manuscript. D.P. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

An abstract for this study has been submitted to the 45th Annual Meeting of the Diabetes in Pregnancy Study Group, Msida, Malta, 3–6 October 2013. The authors appreciate the help from the Swedish MBR, which provided them with data.

References
1. Mocanu EV, Greene RA, Byrne BM, Turner MJ. Obstetric and neonatal outcome of babies weighing more than 4.5 kg: an analysis by parity. Eur J Obstet Gynecol Reprod Biol 2000;92:229–233
2. Boulet SL, Sahlu HM, Alexander GR. Mode of delivery and birth outcomes of macrosomic infants. J Obstet Gynecol 2004;24:622–629
3. Jolly MC, Sebire NJ, Harris JP, Regan L, Robinson S. Risk factors of macrosomia and its clinical consequences: a study of 350,311 pregnancies. Eur J Obstet Gynecol Reprod Biol 2003;101:9–14
4. Zhang X, Decker A, Platt RW, Kramer MS. How big is too big? The perinatal consequences of fetal macrosomia. Am J Obstet Gynecol 2008;198:e1–e6
5. Esakoff TF, Cheng YW, Sparks TN, Caughey AB. The association between birthweight 4000 g or greater and perinatal outcomes in patients with and without gestational diabetes mellitus. Am J Obstet Gynecol 2009;200:e1–e4
6. Koyanagi A, Zhang J, Dagvady A, et al. Macrosomia in 23 developing countries: an analysis of a multicountry, facility-based, cross-sectional survey. Lancet 2013;381:476–483
7. Nesbitt TS, Gilbert WM, Herchen R. Shoulder dystocia and associated risk factors with macrosomic infants born in California. Am J Obstet Gynecol 1998;179:476–480
8. Dahlquist GG, Ivarsson S, Lindberg B, Forsgren M. Maternal enteroviral infection during pregnancy as a risk factor for childhood IDDM. A population-based case-control study. Diabetes 1995;44:408–413
9. Sparano S, Ahrens W, De Henauw S, et al. Being macrosomic at birth is an independent predictor of overweight in children: results from the IDEFICS study. Matern Child Health J 14 September 2012 [Epub ahead of print]
10. Henriksen T. The macrosomic fetus: a challenge in current obstetrics. Acta Obstet Gynecol Scand 2008;87:134–145
11. Jensen DM, Damm P, Sørensen B, et al. Pregnancy outcome and prepregnancy body mass index in 2459 glucose-tolerant Danish women. Am J Obstet Gynecol 2003;189:239–244
12. HAPO Study Cooperative Research Group. Hyperglycaemia and Adverse Pregnancy Outcome (HAPO) Study: associations with maternal body mass index. BJOG 2010;117:575–584
13. Persson M, Pastapathy D, Hanson U, Westgren M, Norman M. Pre-pregnancy body mass index and the risk of adverse outcome in type 1 diabetic pregnancies: a population-based cohort study. BMJ Open 2012;2:e000601
14. Stuebe AM, Landon MB, Lai Y, et al.; Eunice Kennedy Shriver National Institute of Child Health and Human Development Maternal-Fetal Medicine Units Network, Bethesda, MD. Maternal BMI, glucose tolerance, and adverse pregnancy outcomes. Am J Obstet Gynecol 2012;207:e1–e7
15. Most O, Langer O. Gestational diabetes: maternal weight gain in relation to fetal growth, treatment modality, BMI and glycemic control. J Matern Fetal Neonatal Med 2012;25:2458–2463
16. Catalano PM, McIntyre HD, Cruckshank JK, et al.; HAPO Study Cooperative Research Group. The Hyperglycaemia and Adverse...
Body composition and neonatal outcome

Pregnancy Outcome Study: associations of GDM and obesity with pregnancy outcomes. Diabetes Care 2012 35:780–786

17. Disse E, Graeppi-Dulac J, Joncour-Mills G, Dupuis O, Thivolet C. Heterogeneity of pregnancy outcomes and risk of LGA neonates in Caucasian females according to IADPSG criteria for gestational diabetes mellitus. Diabetes Metab 2013, 39:132–138

18. Crowther CA, Hiller JE, Moss JR, McPhee AJ, Jeffries WS, Robinson JS, Australian Carbohydrate Intolerance Study in Pregnant Women (ACHOIS) Trial Group. Effect of treatment of gestational diabetes mellitus on pregnancy outcomes. N Engl J Med 2005;352:2477–2486

19. Fadl HE, Ostlund IK, Magnuson AF, Hanson US. Maternal and neonatal outcomes and time trends of gestational diabetes mellitus in Sweden from 1991 to 2003. Diabet Med 2010;27:436–441

20. Gillman MW, Rifas-Shiman S, Berkey CS, Field AE, Colditz GA. Maternal gestational diabetes, birth weight, and adolescent obesity. Pediatrics 2003;111:e221–e226

21. Plagemann A. Maternal diabetes and perinatal programming. Early Hum Dev 2011;87:743–747

22. Plagemann A, Harder T, Kohlhoff R, Rohde W, Dörner G. Glucose tolerance and insulin secretion in children of mothers with pregestational IDDM or gestational diabetes. Diabetologia 1997;40:1094–1100

23. Silverman BL, Metzger BE, Cho NH, Loeb CA. Impaired glucose tolerance in adolescent offspring of diabetic mothers. Relationship to fetal hyperinsulinism. Diabetes Care 1995;18:611–617

24. Voehr BR, Boney CM. Gestational diabetes: the forerunner for the development of maternal and childhood obesity and metabolic syndrome? J Matern Fetal Neonatal Med 2008;21:149–157

25. Boney CM, Verma A, Tucker R, Voehr BR. Metabolic syndrome in childhood: association with birth weight, maternal obesity, and gestational diabetes mellitus. Pediatrics 2005;115.e290–e296

26. Sewell MF, Huston-Presley L, Super DM, Catalano P. Increased neonatal fat mass, not lean body mass, is associated with maternal obesity. Am J Obstet Gynecol 2006;195:1100–1103

27. Ahlsson F, Lundgren M, Tuvemo T, Gustafsson J, Haglund B. Gestational diabetes and offspring body disproportion. Acta Paediatr 2010;99:89–93

28. Durnwald C, Huston-Presley L, Amini S, Catalano P. Evaluation of body composition of large-for-gestational-age infants of women with gestational diabetes mellitus compared with women with normal glucose tolerance levels. Am J Obstet Gynecol 2004;191:804–808

29. McFarland MB, Trylovich CG, Langer O. Anthropometric differences in macrosomic infants of diabetic and nondiabetic mothers. J Matern Fetal Med 1990;7:292–295

30. The National Board of Health and Welfare (Socialstyrelsen). The Swedish Medical Birth Register. A summary of content and quality 2003-112-3. Available from http://www.socialstyrelsen.se/publikationer2003/2003-112-3. Accessed 5 March 2013

31. Crantingsius S, Ericson A, Gunnarskog J, Källén B. A quality study of a medical birth registry. Scand J Soc Med 1990;18:143–148

32. Ostlund I, Hanson U. Repeated random blood glucose measurements as universal screening test for gestational diabetes mellitus. Acta Obstet Gynecol Scand 2004;83:46–51

33. Anderberg E, Källén K, Berntorp K, Frid A, Aberg A. A simplified oral glucose tolerance test in pregnancy: compliance and results. Acta Obstet Gynecol Scand 2007; 86:1432–1436

34. Högberg U, Larsson N. Early dating by ultrasound and perinatal outcome. A cohort study. Acta Obstet Gynecol Scand 1997;76:907–912

35. Persson M, Pasupathy D, Hanson U, Norman M. Birth size distribution in 3,705 infants born to mothers with type 1 diabetes: a population-based study. Diabetes Care 2011;34:1145–1149

36. Landon MB, Mele L, Spong CY, et al.; Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) Maternal–Fetal Medicine Units (MFMU) Network. The relationship between maternal glycemia and perinatal outcome. Obstet Gynecol 2011;117:218–224

37. Landon MB, Spong CY, Thom E, et al.; Eunice Kennedy Shriver National Institute of Child Health and Human Development Maternal–Fetal Medicine Units Network. A multicenter, randomized trial of treatment for mild gestational diabetes. N Engl J Med 2009;361:1339–1348

38. HAPO Study Cooperative Research Group. Hyperglycemia and Adverse Pregnancy Outcome (HAPO) Study: associations with neonatal anthropometrics. Diabetes 2009; 58:453–459