Early Human Development xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Early Human Development

journal homepage: www.elsevier.com/locate/earlhumdev

# Hyperglycemia and lower diet quality in pregnant overweight women and increased infant size at birth and at 13 months of age — STEPS study

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ARTICLE INFO

*Article history:*
Received 30 August 2011
Received in revised form 4 January 2013
Accepted 6 January 2013
Available online xxxx

*Keywords:*
Birth weight
Body mass index
Glucose
Insulin
Overweight
Pregnancy
Diet
Physical activity

ABSTRACT

*Aims:* To study whether maternal overweight and/or hyperglycemia combined with life-style factors in healthy women predisposes to adverse pregnancy or infant health outcomes, such as differences in growth.
*Methods:* At 26–28 weeks of gestation 82 overweight pregnant women (prepregnancy BMI ≥ 25 kg/m$^2$) and 67 normal weight pregnant women (prepregnancy BMI < 25 kg/m$^2$) participating to STEPS study attended 2-hour oral glucose tolerance test (OGTT) with measurement of plasma glucose and insulin and calculation of HOMA, QUICKI and Matsuda ISI indices. Birth weights and lengths were obtained from hospital records and weights and heights at 13 months from study visits. Maternal physical activity and diet quality were studied with questionnaires.
*Results:* Glucose concentrations were higher in overweight non-diabetic women (0 h = 4.9, 1 h = 7.7, 2 h = 6.2 mmol/l, n = 80) than normal weight women (0 h = 4.5, 1 h = 6.8, 2 h = 5.6 mmol/l, all $P<0.05$, n = 66) as were insulin concentrations at baseline (12.3 vs. 9.0 mU/l, $P<0.05$), but not later (1 h = 88.1 vs. 72.8 mU/l; 2 h = 63.5 vs. 55.5 mU/l, both $P>0.05$). Insulin resistance was higher and sensitivity lower ($P<0.05$ for all) in overweight than in normal weight women. The offspring of overweight mothers were 273 g heavier at birth and 700 g heavier at 13 months of age than the offspring of normal weight women ($P<0.001$). Normal weight women had preferable diet quality ($P=0.023$). No differences were seen in self-reported physical activity between overweight and normal weight women.
*Conclusions:* Maternal prepregnancy overweight increases risk of hyperglycemia in late-pregnancy and increased infant size at birth and 13 months possibly predisposing the infant to health risks later in life.


## 1. Introduction

Mother's health during pregnancy may influence the well-being and future health of the developing fetus and the newborn infant. Intrauterine and early postnatal environment may have lasting impact on fundamental processes of life [1]. The phenomenon called fetal programming or 'small-baby syndrome' as a consequence of maternal starvation has been widely acknowledged and known to contribute to higher risk of chronic diseases later in life [2–5] but effects of excessive maternal nutrition have been more poorly characterized. It has been postulated that hormones can act as endogenous functional teratogens by malprogramming the neuroendocrine–immune network and thereby leading to developmental disorders and diseases [6,7]. Indeed the effects on the infant of maternal glucose metabolism during pregnancy may initiate a cascade of metabolic conditions manifesting later in life. Maternal diet and physical activity during pregnancy may also have an effect on maternal glucose metabolism [8].

Glucose travels freely from the mother to the fetus and elevated maternal glucose concentration exposes the fetus to higher concentrations of glucose than normal. However, insulin does not travel freely which forces the fetus to increase its own insulin production [8]. Pregnancy is an insulin-resistant condition with increases of insulin resistance by 40–50% [9]. These metabolic adaptations aim to promote fetal growth by shunting metabolic fuels to the fetus instead of the mother and can be seen also as preparation for breast-feeding. These adaptations are sometimes exaggerated resulting in impaired glucose tolerance. Elevated insulin levels in fetal and perinatal life are pathognomonic for children of mothers with diabetes during pregnancy. Those children are at increased risk of becoming overweight or obese and developing diabetes later in life [1]. It has been shown that the effect may occur irrespectively of the genetic background and independently of birth weight. The effect seems to depend on perinatal insulin levels and hyperinsulinism.

Overweight women have higher risk for gestational diabetes and other complications after child birth and frequently give birth to

*Abbreviations:* BMI, Body Mass Index (kg/m$^2$); HOMA, Homeostasis Model Assessment Index; Matsuda ISI, Composite Insulin Sensitivity Index; OGTT, Oral Glucose Tolerance Test; QUICKI, Quantitative Insulin Sensitivity Check Index.

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http://dx.doi.org/10.1016/j.earlhumdev.2013.01.007

heavier babies than women with normal weight [10,11]. Offspring of mothers with gestational diabetes have an increased birth weight, higher risk for hypoglycemia [12] and increased risk for early obesity, type 2 diabetes during adolescence and development of metabolic syndrome in early childhood [9]. The effect of maternal BMI and glucose metabolism on developing fetus is also evident in offspring of nondiabetic mothers [13,14]. Indeed effects on fetus may even be seen when maternal glucose levels are within normal reference range [15]. However, little is known about the combined effect of maternal prepregnancy BMI, pregnancy weight gain, glucose metabolism, diet and physical activity on the developing fetus and whether there are some effects seen during the first year of life. Our objective was to study how maternal prepregnancy BMI, pregnancy weight gain, diet and physical activity affect glucose metabolism during pregnancy and what is the effect of on the developing fetus.

## 2. Methods

### 2.1. Subjects and study design

Altogether 1797 pregnant women (mean age 30 years; range 17–43 years) and their spouses were recruited from well-women clinics or Turku University Hospital to participate in a prospective follow-up study 'STEPS' (Steps to healthy development), from August 2007 to March 2010 in South-West Finland. More detailed study design is presented by Lagström and co-workers [16]. Of those 1797 women, 144 with prepregnancy body mass index (BMI) $\geq$25 kg/m$^2$ and 108 with prepregnancy BMI<25 kg/m$^2$ were selected from the STEPS study based on parental BMI and recruited by sending an information letter and an invitation at 20 weeks of gestation to participate in more intensive follow-up study for early risk factors of childhood obesity [17]. From these 90 (63%) overweight women and 73 (68%) normal weight women participated to the study. These subjects participated in a 2-hour oral glucose tolerance test in the third trimester and answered questionnaires containing questions on physical activity, diet, health, and some background information. Weight and height records were obtained from the well-women clinic records. The follow-up of the families in STEPS study will continue until their children will become young adults; however, here, we focus on the first 13 months of these children.

Written informed consent was obtained from the participants. The study protocol was approved by the Ethics Committee of the Hospital District of South-West Finland.

### 2.2. Analytical methods

Two-hour oral glucose tolerance tests (OGTT) were performed at 26–28 weeks of gestation at Turku University Hospital Central Laboratories. OGTT with a 75 g dose of glucose included blood samples at baseline and at 1 and 2 h. Plasma glucose and insulin concentrations were measured at all time points with the Roche Modular PPEE analyzer (Roche Diagnostics GmbH, Mannheim, Germany) on the day of sampling. To evaluate insulin resistance the homeostasis model assessment (HOMA) index was calculated using a formula suggested by Matthews et al. [18]: Glucose 0 h $\times$ Insulin 0 h/22.5. The quantitative insulin sensitivity check index (QUICKI) was calculated as described by Katz et al. [19]: 1/(log Insulin 0 h + log Glucose 0 h) and the composite insulin sensitivity index (Matsuda ISI) according to Matsuda and DeFronzo [20]: 10,000/($\sqrt{}$(Glucose 0 h $\times$ Insulin 0 h) $\times$ $\sqrt{}$(Glucose mean $\times$ Insulin mean)).

The results of the glucose tolerance tests were considered pathological if the test resulted in one or more abnormal values. The diagnostic pathological values for plasma glucose concentrations were $\geq$5.3 mmol/l after fasting, $\geq$10.0 mmol/l at 1 h, and $\geq$8.6 mmol/l at 2 h according to reference values in Finnish current care guidelines and Turku University Central Hospital Laboratories. A high HOMA index was considered to indicate insulin resistance. For insulin sensitivity indices, low QUICKI and low Matsuda ISI were considered to indicate poor insulin sensitivity.

### 2.3. Measurement of weight and length/height and questionnaires

Background information concerning education, work, household incomes, health, parity and maternal height and weight before pregnancy was collected by a self-administered questionnaire in the first trimester. The subjects also answered a questionnaire containing questions of physical activity and diet in the third trimester. Physical activity was determined by self-administered questionnaire about leisure time activities, self-oriented physical activity, and exercise frequency, type of exercise and duration of exercise before and during pregnancy. Diet was assessed with the Index of Diet Quality (IDQ) that has been validated with 7-day food records and has been described in detail previously [21]. In brief, IDQ measures the adherence to health promoting diet and nutrition recommendations with a set of 18 questions resulting in total scores from 0 to 15 points, the higher the points the better the adherence to nutrition recommendations.

Maternal weight and height were measured at well-women clinics. Body mass index (BMI) was calculated as body weight (kg)/body height (m)$^2$. Total gestational weight gain was defined by subtracting self-reported pre-pregnancy weight from that recorded at the hospital before delivery or at the last visit before delivery at well-women clinics. Information regarding children's birth weights and lengths and the course of pregnancy and delivery was obtained from hospital records and from well-baby and well-women clinics. Weight and height at 13 months were measured at study visits by health care professionals. For children, Ponderal Index (PI) was calculated as kg/m$^3$. The information on duration of pregnancy was obtained from hospital records and the delivery was defined as premature if the pregnancy lasted less than 37 weeks.

### 2.4. Statistical methods

The data were analyzed with SPSS statistical software package (version 16.0; SPSS Inc., Chicago, IL, USA). *T*-Test for independent samples was used for studying maternal prepregnancy weight's effect on infant's birth size and for comparison of the characteristics of the overweight and normal weight women except for the smoking, sex and premature birth occurrences where a Chi-square test was used. ANOVA was used to compare glucose metabolism during pregnancy. For preterm delivery analysis we controlled for factors possibly confounding to preterm deliveries: smoking, pre-eclampsia and high blood pressure.

Pearson's correlation coefficients were used in studying the effects of maternal prepregnancy BMI on glucose metabolism and infant's weight and length. Spearman's correlation was used to analyze maternal BMI and diet and physical activity. Pre-term infants (gestational age<37 weeks) were excluded from the analysis regarding infant's weight and length and pregnant women with insulin sensitivity medication were excluded from glucose metabolism analyses. Multivariable regression analysis was used for analyzing the combined effect of diet quality, physical activity, maternal prepregnancy BMI and weight gain during pregnancy to glucose and insulin metabolism and to study the influence of diet quality, physical activity, maternal prepregnancy BMI, maternal weight gain during pregnancy and maternal glycemia to infant's weight and length. Statistical significance was set at $P<0.05$.

## 3. Results

### 3.1. Maternal characteristics, diet quality and physical activity

Women in this follow-up study did not differ from other women participating to the STEPS study (n = 1797) in age, parity, prenatal

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smoking, twin pregnancies, education, employment or household incomes [data not shown]. In this follow-up study of 163 women, overweight and normal weight women did not differ in age, height, prenatal smoking or the occurrence of twin pregnancies (Table 1). Normal weight women were more educated than overweight women. Overweight women gained on average 2 kg less weight during pregnancy than normal weight women.

The adherence to dietary recommendations at third trimester of pregnancy was more frequent in normal weight (mean 10.6 points) than in overweight women (mean 9.5 points) measured with IDQ points (P = 0.023). Higher maternal prepregnancy BMI correlated with lower consumption of fish (r = −0.17, P = 0.049) and whole grain products (r = −0.21, P = 0.017). Overweight women ate less vegetables (P = 0.02) and more frequently fast food (P = 0.01) and had less regular meal pattern (P = 0.04) than normal weight women. Physical activity assessed with a questionnaire was similar in overweight and normal weight women before (P = 0.31) and during pregnancy (P = 0.99). The mean exercise frequency was 2–3 times per week with an average duration of 1/2–1 h.

### 3.2. Glucose metabolism in pregnant women overweight or normal weight in prepregnancy

A total of 82 prepregnancy overweight women and 67 prepregnancy normal weight women completed the 2 h oral glucose tolerance test (OGTT) with measurement of plasma glucose and insulin. From all 149 women participating to oral glucose tolerance test 16 (10% from all women, 13 overweight and 3 normal weight) were diagnosed with gestational diabetes and from them 3 received medication affecting insulin sensitivity together with lifestyle counseling whereas for others the treatment was lifestyle counseling according to current care guidelines in Finland. In Table 2, the women who participated to the OGTT and who were not on medication affecting insulin sensitivity are presented. As shown in Table 2 overweight women had higher serum glucose concentrations at 0 h, 1 h and 2 h and higher insulin at 0 h than normal weight women (P for all <0.05). Insulin resistance described with HOMA-index was more prevalent in overweight than normal weight women (P = 0.022). Overweight women also had lower insulin sensitivity than normal weight women when measured with QUICKI and Matsuda ISI indices (P<0.001 for both).

Table 3 shows the results of multivariable regression analysis that investigates the combined effect of diet quality, physical activity, maternal prepregnancy BMI and weight gain during pregnancy to glucose and insulin metabolism at third trimester of pregnancy. The results show that maternal prepregnancy BMI and weight gain during pregnancy are statistically significantly associated with maternal glucose concentrations during the third trimester of pregnancy.

### 3.3. Maternal prepregnancy BMI, risk of prematurity and infant's weight and length at birth

The mean duration of pregnancy did not differ between prepregnancy-overweight (39.6 weeks) and prepregnancy-normal weight women (39.3 weeks). However 14% of overweight pregnant women gave birth prematurely whereas the occurrence was 4% in normal weight women (Table 1, P = 0.034). All premature deliveries were spontaneous. The higher risk for premature delivery remained even after confounding for factors related to higher risk of premature births such as high blood pressure or maternal smoking (data not shown). As shown in Table 2 overweight women who gave birth prematurely had higher plasma glucose measured in oral glucose tolerance test than other overweight women at 2 h (7.2 vs. 6.2 mmol/l, P = 0.03).

From the 149 full-term babies (gestational age ≥ 37 weeks) 51% were boys. Infants born to overweight mothers were on average 273 g heavier than infants born to normal weight mothers (P<0.001, Table 4). Offspring of overweight women were also taller and they

**Table 1**
Characteristics of the women participating in the study. Values are represented as mean values (SD) or the number of cases (percents).

| | Overweight women (prepregnancy BMI ≥ 25, n = 90) | Normal weight women (prepregnancy BMI<25, n = 73) | P[a] |
|---|---|---|---|
| *Maternal characteristics* | | | |
| Age (years) | 30.6 (4.6) | 30.3 (4.6) | 0.76 |
| Height (cm) | 166.2 (6.2) | 166.3 (5.4) | 0.91 |
| Prepregnancy weight (kg) | 83.7 (12.0) | 58.6 (6.7) | <0.001 |
| Prepregnancy BMI (kg/m$^2$) | 30.3 (4.2) | 21.1 (1.9) | <0.001 |
| Weight at the end of pregnancy (kg) | 95.1 (12.6) | 72.3 (18.4) | <0.001 |
| Total weight gain over pregnancy (kg) | 11.5 (5.5) | 13.5 (4.0) | 0.023 |
| Educational status: bachelor's degree or higher | 40/90 (45%) | 55/73 (77%) | <0.001 |
| Index of diet quality (total points) | 9.5 (3.3) | 10.6 (2.0) | 0.023 |
| Exercise frequency (mean times/week) | | | |
| Before pregnancy | 2 (1) | 3 (1) | 0.31 |
| During pregnancy | 2 (1) | 2 (1) | 0.99 |
| Prenatal smoking (any) | 4 (4%) | 2 (3%) | 0.36 |
| Twin pregnancies | 3 (3%) | 3 (4%) | 0.79 |
| Duration of pregnancy (weeks) | 39.6 (2.6) | 39.3 (1.8) | 0.53 |
| Preterm deliveries (<37 weeks of gestation) | 13/90 (14%) | 3/73 (4%) | 0.034 |
| From these twin pregnancies | 1/13 | 2/3 | |

[a] Statistical test used: *T*-Test for independent samples, except for smoking and preterm deliveries Chi-square test.

**Table 2**
The results (mean (SD)) of the 2-hour oral glucose tolerance test. Only women who participated in the test and were not on medication affecting insulin sensitivity are presented. Maternal overweight was determined as prepregnancy BMI ≥ 25 and normal weight as prepregnancy BMI<25.[a]

| | Normal weight women with normal duration of pregnancy (n = 66) | Overweight women with normal duration of pregnancy (n = 67) | Overweight women with preterm delivery (n = 13) | P[b] | Group comparisons P[c] |
|---|---|---|---|---|---|
| Glucose 0 h (mmol/l) | 4.5 (0.4) | 4.9 (0.5) | 5.1 (0.6) | <0.001 | <0.001; 0.14 |
| Glucose 1 h (mmol/l) | 6.8 (1.6) | 7.7 (2.3) | 8.6 (1.8) | 0.004 | 0.01; 0.23 |
| Glucose 2 h (mmol/l) | 5.6 (1.2) | 6.2 (1.4) | 7.2 (1.6) | <0.001 | 0.045; 0.03 |
| Insulin 0 h (mU/l) | 9.0 (10.0) | 12.3 (6.9) | 12.8 (7.8) | 0.001 | 0.001; 0.99 |
| Insulin 1 h (mU/l) | 72.8 (40.3) | 88.1 (52.6) | 94.9 (56.7) | 0.17 | 0.31; 0.91 |
| Insulin 2 h(mU/l) | 55.5 (33.1) | 63.5 (37.9) | 76.7 (44.7) | 0.19 | 0.80; 0.87 |
| HOMA | 1.8 (2.1) | 2.7 (1.7) | 2.6 (1.8) | <0.001 | <0.001; 0.97 |
| QUICKI | 0.36 (0.03) | 0.34 (0.03) | 0.33 (0.02) | <0.001 | <0.001; 0.97 |
| Matsuda ISI | 7.0 (3.4) | 5.1 (2.6) | 4.8 (2.8) | 0.004 | 0.005; 0.97 |

[a] Women (n = 3) receiving medication affecting to insulin sensitivity were excluded from the analysis.
[b] ANOVA.
[c] The group comparison (normal weight women v. overweight women with normal duration of pregnancy; overweight women with normal duration of pregnancy v. overweight women with preterm delivery) is given as Bonferroni corrected.

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**Table 3**
The results of multivariable regression analysis for glucose and insulin metabolism and maternal BMI and weight gain and lifestyle factors diet quality and physical activity.

| Model 1[a] | $R^2$ | F | P for model | β BMI | β Weight gain | β IDQ | β Exercise before pregnancy | β Exercise during pregnancy |
|---|---|---|---|---|---|---|---|---|
| Glucose 0 h | 0.27 | 5.88 | 0.0001*** | 0.038*** | −0.027** | 0.028 | −0.094 | −0.009 |
| Glucose 1 h | 0.18 | 3.66 | 0.005** | 0.098** | −0.129** | 0.088 | 0.249 | −0.861 |
| Glucose 2 h | 0.21 | 4.37 | 0.001*** | 0.094*** | −0.075* | 0.010 | −0.119 | −0.220 |
| Insulin 0 h | 0.05 | 0.63 | 0.68 | 0.273 | −0.031 | 0.609 | 0.660 | 0.559 |
| Insulin 1 h | 0.06 | 0.83 | 0.53 | 1.196 | −0.946 | −2.097 | −19.448 | 5.014 |
| Insulin 2 h | 0.11 | 1.51 | 0.19 | 1.744 | −0.779 | −1.928 | −2.382 | −1.863 |
| HOMA | 0.07 | 0.79 | 0.56 | 0.069 | −0.022 | 0.151 | 0.154 | −0.001 |
| QUICKI | 0.19 | 2.25 | 0.06 | −0.038* | 0.009 | −0.018 | 0.067 | 0.097 |
| CISI | 0.18 | 2.47 | 0.04* | −0.248** | 0.074 | −0.022 | 0.963 | 0.309 |

[a] Contains variables: diet quality, physical activity before and during pregnancy, maternal prepregnancy BMI, maternal weight gain during pregnancy.
* $P<0.05$.
** $P\leq0.01$.
*** $P\leq0.001$.

had larger head circumference and higher BMI than the offspring of normal weight women ($P<0.05$ for all). However, no difference was seen in PI at birth in children of overweight or normal weight women. At 13 months of age infants born to overweight women weighted more at and had a higher BMI and PI when compared to infants born to normal weight women (Table 4, $P<0.05$ for all). Also their weight gain from birth to 13 months was significantly higher.

Higher maternal prepregnancy BMI correlated positively to infant's weight ($r=0.31$, $P<0.0001$) and length ($r=0.24$, $P=0.005$) at birth. In addition higher maternal fasting glucose concentration at third trimester of pregnancy correlated positively to infant's weight at birth ($r=0.24$, $P=0.006$) but no associations were found between other plasma glucose or insulin concentrations and infant's weight, height, BMI or head circumference at birth. No significant correlations were found between glucose and insulin concentrations during pregnancy and infant's weight, height and BMI at 13 months of age.

The regression analysis investigating the combined influence of maternal diet quality, physical activity, maternal prepregnancy BMI, maternal weight gain during pregnancy and maternal glucose and insulin metabolism to infant's birth size revealed that the most strong predictors for infant's birth weight was maternal plasma glucose at 1 h, plasma insulin at 2 h, maternal prepregnancy BMI and diet quality ($R^2=0.15$, $P=0.02$) and for birth length maternal prepregnancy BMI and regular exercise during pregnancy ($R^2=0.11$, $P=0.002$).

**Table 4**
Characteristics of the full-term neonates and the effect of maternal prepregnancy BMI on infant's anthropometrics at birth. Values presented as mean (SD) or number of cases (percents).

| | Offspring of overweight women | Offspring of normal weight mothers | P[a] |
|---|---|---|---|
| *Full-term neonates* | n = 78 | n = 72 | |
| *Birth characteristics* | | | |
| Gestational age, birth at weeks of gestation | 39.6 (2.6) | 39.3 (1.8) | 0.53 |
| Sex (male) | 49 (53%) | 38 (52%) | 0.53 |
| Birth weight (g) | 3712 (487) | 3439 (365) | <0.001 |
| Birth length (cm) | 51.3 (2.2) | 50.3 (2.0) | 0.002 |
| Head circumference at birth (cm) | 35.4 (1.5) | 34.7 (1.2) | 0.002 |
| BMI at birth ($kg/m^2$) | 14.1 (1.2) | 13.7 (1.2) | 0.038 |
| Ponderal Index at birth ($kg/m^3$) | 27.5 (2.4) | 27.3 (3.1) | 0.43 |
| *13 mo characteristics* | | | |
| Weight (kg) | 10.7 (1.2) | 10.0 (0.9) | <0.001 |
| Length (cm) | 78.0 (2.8) | 77.2 (2.6) | 0.124 |
| BMI ($kg/m^2$) | 17.6 (1.2) | 16.8 (1.1) | <0.001 |
| Ponderal Index ($kg/m^3$) | 22.6 (1.5) | 21.8 (1.7) | 0.010 |
| Weight gain from 0 to 13 mo (kg) | 7.2 (1.0) | 6.6 (0.9) | 0.003 |

[a] Statistical test used: *T*-test for independent samples, except for sex Chi-square test.

No difference was seen in APGAR points at 1 min, 5 min or 15 min after birth (data not shown).

We conducted multivariable regression analysis that investigated the combined effect of glucose and insulin concentrations to children's weight, height and BMI at 13 months of age and weight gain from birth to 13 months but discovered no associations between these data and maternal glucose and insulin concentrations (data not shown).

## 4. Discussion

Maternal overweight is a known risk factor for abnormal glucose metabolism during pregnancy [9]. Normal glucose metabolism during pregnancy reduces the risk of pregnancy-related complications [22] and confers long-term health benefits on both the mother and the child. This report demonstrates how maternal prepregnancy overweight affects glucose and insulin concentrations, pregnancy outcome and infant's birth size in otherwise healthy pregnant women. In our study otherwise healthy overweight women had higher plasma glucose and insulin concentrations, increased prevalence of insulin resistance and lower insulin sensitivity than normal weight women, which may contribute to health risks and adverse health outcomes for both the mother and the fetus. Interestingly, in the regression analysis the strongest predictors for maternal glucose metabolism were prepregnancy BMI and maternal weight gain during pregnancy whereas life-style factors had smaller influence.

Our results support the hypothesis that increased glucose concentrations, even before reaching levels traditionally considered as gestational diabetes, are associated with accelerated fetal growth, since effects were seen in these healthy women [14]. Maternal glucose transported from mother to the fetus may raise fetal insulin levels resulting in fetal overgrowth which may have long-term health effects: data show that increased size at birth is associated with an increased likelihood of adiposity in later life and with alterations in glucose metabolism and β-cell function [23]. Maternal hyperglycemia is associated with childhood obesity and glucose intolerance later in life [24]. Indeed, overweight women who had elevated plasma glucose and insulin concentrations gave birth to infants with increased birth size compared to infants of normal weight women.

Maternal prepregnancy BMI had an independent effect on infant's birth size. In the present study we discovered that offspring of overweight women had higher birth weight and length than offspring of normal weight women. Also their BMI was higher, but for PI no difference was seen. According to Perinatal Statistics in the Nordic Countries [25] the mean birth weight in Finland in 2006 was 3504 g. In our study the mean birth weight was 3712 g in offspring of overweight women and 3439 g in offspring of normal weight women. This result indicates that infant's birth weight was significantly increased when maternal prepregnancy BMI exceeded 25 $kg/m^2$. Indeed parental size and infant birth weight are related through various genetic and environmental

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mechanisms and the link between maternal and fetal size may represent contributions of the intrauterine environment [26]. Part of the effect may be related through maternal glucose metabolism and raised fetal insulin levels, but we also discovered that maternal BMI is itself a strong predictor of birth size. Previously the researchers in HAPO study found also a strong relation between maternal BMI and birth weight, fetal adiposity and hyperinsulinism [27,28]. They also demonstrated that both maternal BMI and glycemia have strong independent associations with a range of clinically important pregnancy outcomes. It has been postulated that maternal BMI influences offspring weight and length rather than fetal adiposity which is more influenced by maternal hyperglycemia [14]. Indeed, in our analysis we discovered that for maternal plasma glucose at 1 h, plasma insulin at 2 h, maternal prepregnancy BMI and diet quality influenced most infant's birth weight while maternal prepregnancy BMI and regular exercise during pregnancy influenced most infant's birth length. The influence of maternal overweight on children's weight was also seen at the age of 13 months: children born to overweight mothers were heavier and had higher BMI and PI than children born to normal weight mothers.

There were no significant differences in self-reported physical activity in overweight or normal weight women before or during pregnancy. Exercise frequency and duration was assessed only once, which can lead to problems associated with memory and reporting. We also studied the adherence to nutrition recommendation with a validated Index of Diet Quality (IDQ) [21] and discovered that normal weight women were following dietary recommendations better than the overweight women. We also found small differences in consumption of fish, whole grain products, fast food and meal patterns between overweight women and normal weight women indicating more healthier diet in the normal weight women. Women in general tend to improve their diet quality during the pregnancy. Interestingly in multivariable regression analysis maternal diet quality was one of the significant predictors of infant birth weight. Further, questionnaires may be subject to under- or over-reporting. Even though effects of exercise and diet quality on glucose concentrations found in this study were minor, further studies with larger number of subjects might deliver more knowledge about the relationship between exercise, diet quality, maternal glucose metabolism and infant health.

Maternal obesity is reported to increase the risk of macrosomia, induced labor, cesarean section and other maternal and neonatal complications [9,10]. Indeed, maternal obesity has been shown to increase the risk of medically indicated preterm birth but not spontaneous preterm birth in both singletons and twins [9,29]. Previously also maternal metabolic syndrome, especially high blood pressure, has been shown to be a risk factor for preterm birth [30]. Controversial to previous results in HAPO study [27], in our study maternal overweight increased the risk of spontaneous preterm delivery and the effect remained even after controlling for other related factors such as prenatal smoking, pre-eclampsia and high blood pressure. In addition overweight women with preterm delivery had higher plasma glucose at 2 h compared to overweight women with normal duration of pregnancy. This is unsurprising since previously higher plasma glucose and gestational diabetes have been shown to be positively associated with premature delivery [31]. However, our sample size and the number of subjects who had preterm delivery are too small and inadequate for making conclusions. This phenomenon may be partially related to higher maternal BMI and requires further studies.

Women participating to this more intensive follow-up study did not differ between the other women in the STEPS study. Overweight and normal weight women did not differ in age, height or prenatal smoking. There were no differences in mean duration of pregnancies or the number of twin pregnancies, but spontaneous premature delivery was more frequent in overweight women. Lower socio-economical status is known to be a risk factor for obesity [32] and the phenomenon was also seen in these pregnant women. Weight gain during pregnancy is known to be associated with prepregnancy BMI and in concordance to previous study [33] normal weight women gained more weight [mean 13.5 kg] during pregnancy than overweight women [mean 11.5 kg]. However, U.S. Institute of Medicine [IOM] recommends higher weight gain for normal weight women and the weight gain in both groups was on average within recommendations.

In conclusion, maternal prepregnancy overweight increased the risk of hyperglycemia, preterm delivery and increased infant size at birth and at 13 months and higher weight gain from birth to 13 months which may predispose the fetus to increased risk of obesity in later life. The prevalence of childhood obesity being increasing during the past few decades, it has become clear that the course of pregnancy and mother's health has important roles on infant's health and may even affect infant's weight development and later obesity risk [34]. These results focus on the first 13 months and further studies will show what are the effects later in life regarding childhood obesity. Adherence to dietary recommendations during pregnancy may further enhance beneficial health outcomes in both mother and infant. Normal weight during pregnancy influences beneficially not only pregnancy outcomes but also later health of the offspring.

## Author statements

All authors have seen and approved the manuscript. HL, OS and HN were responsible for the design of the study, JM for data collection and writing of the manuscript and AK conducted the statistical analysis. All authors contributed to the data analysis and writing and revising of the manuscript and approved the final draft.

## Conflict of interest

The authors have no conflict of interest.

## Acknowledgments

We thank the Academy of Finland [grant number 121569], Päivikki and Sakari Sohlberg Foundation, Juho Vainio Foundation and Alfred Kordelin Foundation for financial support.

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Please cite this article as: Mäkelä J, et al, Hyperglycemia and lower diet quality in pregnant overweight women and increased infant size at birth and at 13 months of age — STEPS study, Early Hum Dev (2013), http://dx.doi.org/10.1016/j.earlhumdev.2013.01.007

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