

**IMPACT OF MATERNAL BODY MASS INDEX ON NEONATE BIRTH  
WEIGHT AND BODY COMPOSITION**

Holly R. HULL<sup>1,2</sup>, Mary K. DINGER<sup>1</sup>, Allen W. KNEHANS<sup>3</sup>, David M.  
THOMPSON<sup>4</sup>, and David A. FIELDS<sup>2, 5\*</sup>

5 <sup>1</sup>Department of Health and Exercise Science, University of Oklahoma, Norman, OK

<sup>2</sup>Department of Pediatrics, University of Oklahoma Health Science Center, Oklahoma  
City, OK

<sup>3</sup> Department of Nutritional Sciences, University of Oklahoma Health Science Center,  
Oklahoma City, OK

10 <sup>4</sup>Department of Biostatistics and Epidemiology, University of Oklahoma Health Science  
Center, Oklahoma City, OK

<sup>5</sup>Children's Medical Research Institute's Metabolic Research Center, Oklahoma City,  
OK

Email: [hhull@ou.edu](mailto:hhull@ou.edu), [mkdinger@ou.edu](mailto:mkdinger@ou.edu), [Allen-Knehans@ouhsc.edu](mailto:Allen-Knehans@ouhsc.edu), [15 \[Thompson@ouhsc.edu\]\(mailto:Thompson@ouhsc.edu\), and \[dfields@ouhsc.edu\]\(mailto:dfields@ouhsc.edu\)](mailto:Dave-</a></p></div><div data-bbox=)

\*Corresponding author

Address for corresponding author:

David Fields, Ph.D.

Assistant Professor

20 University of Oklahoma Health Science Center

Department of Pediatrics & Children's Medical Research Institute's Metabolic Research  
Center

OUCP Diabetes and Endocrinology

940 NE 13th Street, CH 2B246

25 Oklahoma City, OK 73104

Ph: (405) 271-8001 ex:43083

Fx: (405) 271-3093

[dfields@ouhsc.edu](mailto:dfields@ouhsc.edu)

30 Abstract Word Count: 212

Text Word Count: 4298

## Condensation

Neonates born to mothers who have a normal BMI have significantly less total fat mass, and more fat-free mass than neonates born to overweight/obese mothers.

## Impact of maternal body mass index on neonate birth weight and body composition

Holly R. Hull, Mary K. Dinger, Allen W. Knehans, David M. Thompson, and David A. Fields

### **Abstract**

5 **Objective:** The purpose of this study was to compare body weight and composition (%fat, fat mass, and fat-free mass) in neonates born to mothers with a normal pre-gravid body mass index (BMI;  $<25 \text{ kg/m}^2$ ) versus neonates born to mothers with an overweight/obese pre-gravid BMI ( $\geq 25 \text{ kg/m}^2$ ).

**Study Design:** Seventy-two neonates (33 from normal mothers and 39 from  
10 overweight/obese mothers) of singleton pregnancies with normal glucose tolerance had their body weight and body composition assessed by air-displacement plethysmography.

**Results:** After controlling for neonate age at time of testing, significant differences were found between groups for %fat ( $12.5 \pm 4.2 \%$  vs.  $13.6 \pm 4.3 \%$ ;  $P \leq 0.0001$ ), fat mass ( $414.1 \pm 264.2 \text{ g}$  vs.  $448.3 \pm 262.2 \text{ g}$ ;  $P \leq 0.05$ ) and fat-free mass ( $3310.5 \pm 344.6 \text{ g}$  vs.  
15  $3162.2 \pm 343.4 \text{ g}$ ;  $P \leq 0.05$ ), with no significant differences between birth length ( $50.7 \pm 2.6 \text{ cm}$  vs.  $49.6 \pm 2.6 \text{ cm}$ ;  $P = 0.08$ ) or birth weight ( $3433.0 \pm 396.3 \text{ g}$  vs.  $3368.0 \pm 399.6 \text{ g}$ ;  $P = 0.44$ ).

**Conclusions:** Neonates born to mothers who have a normal BMI have significantly less total and relative fat, and more fat-free mass than neonates born to overweight/obese  
20 mothers. Though preliminary, these data suggest that the antecedents of future disease risk (e.g. cardiovascular disease, diabetes, and obesity) occur early in life.

**Key words:** Pregnancy, obesity, infant body fat, fetal programming, body mass index

## Introduction

Maternal prenatal obesity has increased significantly over the past 15 years with maternal body weight at the first prenatal visit increasing by 20%.<sup>1,2</sup> At the same time, neonate birth weight in North America and Europe has increased, with birth weight >90<sup>th</sup> percentile and >4000 grams increasing the most.<sup>3,4</sup> A body of work has emerged to show a positive relationship between maternal body mass index (BMI) and the birth weight of their off-spring<sup>5-8</sup>, with newborns at a birth weight  $\geq 90^{\text{th}}$  percentile possessing the greatest risk of obesity later in adulthood.<sup>9-12</sup>

Intrauterine life is a crucial period with epidemiologic data indicating that a sub-optimal intrauterine environment affects future chronic diseases.<sup>13, 14</sup> Barker has proposed that prenatal factors that alter or impede fetal growth in utero may have long-term ramifications and may be in part responsible for obesity<sup>15</sup>, diabetes<sup>16</sup>, hypertension<sup>17</sup>, insulin resistance<sup>18</sup>, cardiovascular<sup>13</sup>, and heart disease.<sup>13, 19-22</sup> Barker coined the hypothesis “the fetal origin hypothesis”, which refers to the induction, deletion, or impairment of fetal growth by an early event in utero that alters fetal tissue on a molecular or physiological level.<sup>23, 24</sup>

The intrauterine environment is assessed crudely by birth weight of the infant. However, birth weight is not the sole indicator of intrauterine nutritional status.<sup>25</sup> For instance, low birth weight caused by under nutrition during gestation is defined as a birth weight below 2500 grams or <10<sup>th</sup> percentile<sup>26</sup> However, birth weight does not distinguish the impact of poor maternal nutrition or whether infants failed to thrive<sup>25</sup>.

Even though some research suggests a relationship between birth weight and development of disease in adulthood, the relationship remains equivocal.<sup>27-31</sup> Other

research<sup>28</sup> suggests inadequate nutrition during pregnancy may affect health in adulthood indirectly. Consequently, the influence of birth weight on adult health is paradoxical; both low and high birth weight are associated with increased incidences of adult disease such as diabetes.<sup>18, 32, 33</sup> We designed a study to delineate the association between maternal weight and neonate birth weight and body composition. Therefore, the purpose of this study was to compare infant body weight and composition from mothers who had a normal pre-gravid BMI ( $<25 \text{ kg/m}^2$ ) or whom had an overweight/obese pre-gravid BMI ( $\geq 25 \text{ kg/m}^2$ ).

## **Materials and Methods**

### 10 *Participants*

Participants were recruited by mass emails sent to the University of Oklahoma Health Sciences Center, newspapers advertisements, announcements in birthing classes and flyers placed at pediatric clinics in the Oklahoma City area. Testing occurred in Children's Hospital in Oklahoma City. This study was approved by the Institutional Review Board for Human Participants at the University of Oklahoma Health Sciences. All participants signed both an informed consent and a HIPPA authorization prior to testing.

Participants included mothers and their infants who were healthy full-term infants  $\leq 35$  days old. Inclusion criteria were: 1) healthy infants, defined as spending  $< 3$  days in the hospital after delivery, 2) gestational age  $\geq 37$  weeks and  $< 42$  weeks and, 3) age of mother at the time of delivery between the ages of 18 to 45 years. Exclusion criteria for the study included the following: 1) any tobacco use during pregnancy, 2) excess alcohol consumption during pregnancy defined as  $> 1$  drink a week, 3) infants

with presumed or known chromosomal or severe congenital abnormalities, and 4) infants of mothers with diabetes (i.e. type 1, type 2 or gestational diabetes).

Maternal body weight before pregnancy, weight gain during pregnancy, total family income and maximum weight reached during pregnancy were obtained by interview during the consenting process, which occurred at the time of neonate testing. Neonate birth weight and birth length were also self-reported by the mother. The mother's pre-gravid BMI was calculated using the participants self-reported body weight prior to pregnancy and their height was measured at the visit.

*Air-displacement Plethysmography (PEA POD<sup>®</sup>)*

Infant length was measured using a length board. Infants were stretched out so that his/her head remained stable but his/her legs were extended. The adjustable portion of the stadiometer was placed against their outstretched feet. Length was recorded to the nearest 0.1 centimeter. The Pea Pod<sup>®</sup> Body Composition System (Life Measurement Instruments, Concord, CA) was used to measure body weight and body volume. The Pea Pod<sup>®</sup> was calibrated before each test or once daily during testing days where multiple tests were performed. A calibration cylinder with a known volume was used to calibrate the chamber and a 5000 gram weight was used to calibrate the scale. Testing procedures have been described in detail elsewhere.<sup>34</sup> To assess body weight, the infant's clothing and diaper were removed. The infant was placed naked on the scale and a body weight was obtained to the nearest 0.0001 kg. After body weight was measured, the infant was placed inside the Pea Pod<sup>®</sup> wearing a wig cap and a body volume measurement was performed. Assessment of the body volume required approximately 2 minutes. Body density was then converted to percentage of fat (%fat) using gender specific equations

by Foman.<sup>35</sup> At the completion of testing, body composition variables were then calculated; relative fat (%fat), total fat mass, and fat-free mass.

#### *Maternal Weight and Height*

Mothers removed all loose fitting clothing and shoes before being weighed on a physician's balance beam scale (Detecto Scales, Webb City, MO) to the nearest 0.1 kg. Height of the mother was obtained using a stadiometer (Accu-Hite Wall Stadiometer, Seca Corp., Hanover, MD). Participants removed their shoes and centered their feet on the stadiometer with their hands placed on her hips. After an inhalation, height was measured to the nearest 0.1 centimeter.

#### 10 *Statistical Analyses*

Descriptive statistics (means and standard deviations) were calculated for all outcome variables (birth weight, %fat, total fat mass and fat-free mass) within both of the two groups according to mother's pre-gravid BMI status. The groups were compared to determine if any differences existed between the two groups. For interval data, independent t-tests were calculated and for nominal data, a chi-square test was completed.

To determine whether birth weight and body composition, adjusted for infant age at visit, differed based on pre-gravid BMI (2 levels: normal and overweight/obese), analysis of covariance (ANCOVA) was performed. Stepwise multiple linear regression analysis determined which maternal factors were related to infant outcome variables. The dependent variables used in the model were: neonate birth weight, %fat, fat mass and fat-free mass; independent variables were gestational age, infant age at testing,

maternal pre-gravid body weight, BMI, maximum body weight, weight gain, gender and socioeconomic status. The alpha level was set at  $P \leq 0.05$ .

## Results

Seventy-two women (33 with a normal pre-gravid BMI ( $<25 \text{ kg/m}^2$ ) and 39 with an overweight/obese ( $\geq 25 \text{ kg/m}^2$ ) pre-gravid BMI) enrolled in the study. The majority of the sample was Caucasian (80%), with the remainder comprised of African American (3%), Native American (4%), Asian (1%), Hispanic (6%) with the remaining 6% classifying themselves as other races.

The groups did not significantly differ in age, height, weight gain during pregnancy, gender of infant, status of feeding (breast vs. formula), or family income (Table 1). Pre-gravid body weight, BMI, maximum weight during pregnancy, and body weight at the time of visit were significantly different between the two groups (Table 1).

Infants of mothers with a normal pre-gravid BMI had a greater gestational age and birth length than infants from overweight/obese mothers  $P \leq 0.05$  (Table 2). ANCOVA controlled for maternal factors that potentially affect fetal growth and subsequent neonate body weight and composition. Covariates investigated were gestational age, infant age at testing, maternal pre-gravid body weight and BMI, maximum body weight, weight gain, gender, and socioeconomic status. Only neonate age at testing was significant. Therefore, anthropometric variables body weight and composition data for infants from both the normal and overweight/obese groups were adjusted for infant age at testing (Table 2). The groups did not differ for birth weight or length, however differences between groups were found in infant body composition

variables. Offspring of the normal group had lower body fat and fat mass and greater fat-free mass than offspring of mothers who were overweight/obese (Table 2).

Multiple stepwise regression analysis assessed the relationship between maternal factors to infant body weight and composition in the normal (Table 3) and  
5 overweight/obese (Table 4) groups. We examined the two groups using separate stepwise approaches entering gestational age, infant age at testing, maternal pre-gravid body weight, BMI, maximum body weight, weight gain, gender, and socioeconomic status as independent predictor variables. We examined separate models for each of the four dependent variables: birth weight, %fat, fat mass, and fat-free mass as dependent  
10 variables. In the analysis of birth weight, no significant correlations existed with any of the independent predictor variables for either group. In the analysis of %fat for both the normal and overweight/obese groups, the only significant association was with infant age at testing (Tables 3 and 4). Lastly in the analysis, fat-free mass in the normal group was associated with infant gender (Table 3). In the overweight/obese group, fat-free  
15 mass was associated with feeding status, infant age at visit, and gestational age (Table 4).

### **Comments**

The primary purpose of this study was to better understand the impact of maternal BMI on infant birth weight and body composition. Our main findings were that  
20 infants born to mothers with a normal pre-gravid BMI had less fat mass and greater fat-free mass than infants born to mothers who were overweight/obese.

Our study showed no difference in birth weight between groups. However, numerous studies have reported maternal BMI and neonate birth weight having a

positive linear relationship.<sup>5-8, 36-41</sup> This association has been shown in European samples as well. In an Austrian sample of 10,240 singleton births, Kirchengast et al.<sup>7</sup> reported a positive relationship between pre-pregnancy BMI and birth weight and in a Swedish sample Rossner and Ohlin<sup>39</sup> reported that maternal weight gain and initial maternal body weight predicted infant birth weight. The consensus in all of these studies clearly demonstrates a strong positive relationship between maternal BMI and birth weight.

Our data showed neonates from mothers with a normal pre-gravid BMI had significantly less %fat, total fat mass, and more fat-free mass than neonates from overweight/obese mothers. Similar results were reported by Sewell et al.<sup>41</sup> who showed no significant difference in birth weight in offspring from mothers with a pre-gravid BMI <25 kg/m<sup>2</sup> and a pre-gravid BMI ≥25 kg/m<sup>2</sup>. Their body composition data (determined by total body electrical conductivity) revealed a significantly greater amount of fat mass and %fat in the neonates from overweight/obese mothers though no difference in fat-free mass was found. They concluded pre-gravid obesity played a significant role in infant fat mass, but interestingly, not in fat-free mass.<sup>41</sup>

To further refine the relationship between body composition and maternal BMI, we performed multiple stepwise regression to determine which independent variables were associated with the increased total fat mass and decreased fat-free mass in the neonates born to mothers who were overweight/obese. In neonates from overweight/obese mothers, the variable that explained the most variability in %fat was the infant's age at the time of the visit. Infant age at visit in our study ranged from 5 days up to 35 days. This may indicate that the influence of the ex-utero life has already begun

to take hold, thus future studies should mitigate this by testing as close to birth as possible.

We also developed a model to examine which factors predicted fat-free mass. In infants from normal mothers, infant gender was highly related to fat-free mass accounting for 23% of the variance between the two variables. However, in 5 overweight/obese infants, the greatest predictors of fat-free mass were feeding status (breast versus formula), infant age at visit and gestational age. This model accounted for 42% of the variance in fat-free mass.

Despite compelling epidemiological data, vigorous debate disputes the veracity 10 of the fetal origin hypothesis and its linking of maternal weight, neonate birth and future disease risk.<sup>41-43</sup> Generally speaking, it is accepted that maternal weight is associated with birth weight<sup>44</sup>, and evidence shows that the incidence of neonates weighing >4,000 grams increases as mothers BMI increases from normal (8%) to morbidly obese (15%).<sup>45</sup>

Perhaps the fetal origins hypothesis and the relationship between maternal weight 15 and their offspring is obfuscated because of a lack of accurate assessment tools available to assess confounding variables, namely fat mass and fat-free mass. It is our theory that fat mass and fat-free mass (lack there of) at birth, rather than body weight *per se*, is what mediates the adult consequences of variations in fetal growth.

The implementation of body composition assessment in neonates is rare, partly 20 because of a lack of valid instruments. However, elegant work by Catalano<sup>46</sup> and Sewell<sup>41</sup> has shown that 83% of the variability in birth weight is explained by fat-free mass.. However, more studies that use body composition are needed to fully understand

the role maternal weight plays on neonate weight and the subsequent risk of future chronic diseases.

Future work is needed to expand our understanding of maternal pre-gravid weight on infant outcomes. It would be ideal to assess maternal body composition prior to or during pregnancy to clearly delineate the role of maternal nutrition on metabolic disturbances in the offspring. Research has shown that in cases of gestational diabetes or impaired glucose tolerance, the fetus is exposed to increased levels of nutrients resulting in hyperglycemia, hyperinsulinemia. These exposures increase the risk of obesity in childhood and adulthood.<sup>47</sup> Furthermore, detailed and careful nutrient intake and physical activity levels are needed to discern specific associations with the intent of establishing cause and effect relationships. Rat models have shown that a diet high in saturated fat during gestation resulted in offspring with abnormal vascular function and altered plasma lipid and fatty acid content.<sup>48</sup>

In conclusion, infants born to overweight/obese mothers had a greater %fat and fat mass and less fat-free mass than infants from mothers with a normal BMI. Though provocative, further work taking a panoptic view is needed. This would be particularly important for understanding the impact of maternal diet on neonate body weight and composition.

### **Acknowledgements**

We are indebted to the participants of this study. Additionally, we would like to acknowledge Lauren Pratt for her work in coordinating participant visits and in data collection. We would also like to thank Joel Cramer, PhD for his help in data analysis

and interpretation. This study was funded in part by a College of Medicine Alumni Association grant (University of Oklahoma Health Sciences Center).

**Table 1:** Maternal demographics of the normal (<25 kg/m<sup>2</sup>) and overweight/obese groups (≥25 kg/m<sup>2</sup>).

	<b>Normal (N=33)</b>	<b>Overweight/ Obese (N=39)</b>	<b>P Value</b>
Age at delivery (yrs)	27.9 ± 5.3	28.0 ± 5.6	0.94
Pre-gravid body weight (kg) <sup>†</sup>	58.9 ± 6.7	87.0 ± 21.6	0.000
Pre-gravid BMI (kg/m <sup>2</sup> ) <sup>†</sup>	21.7 ± 1.9	31.8 ± 6.9	0.000
Maximum weight during pregnancy (kg) <sup>†</sup>	73.5 ± 8.3	98.5 ± 20.4	0.000
Weight gained during pregnancy (kg) <sup>†</sup>	14.8 ± 4.3	13.0 ± 4.7	0.82
Body weight at visit (kg)	66.1 ± 8.4	92.4 ± 22.4	0.000
Height at visit (cm)	164.5 ± 5.3	164.9 ± 7.0	0.75
Income (%)			0.32
<\$30,000	27%	46%	
\$30,001 to \$60,000	31%	22%	
\$60,001 to \$90,000	18%	8%	
>\$90,000	24%	24%	

Mean ± standard deviation

<sup>†</sup>Self report by the mother

**Table 2:** Demographics and neonate outcome variables of neonates from normal (<25 kg/m<sup>2</sup>) and overweight/obese study groups (≥25 kg/m<sup>2</sup>). Differences are based on results of analysis of covariance and means of infant outcome variables were adjusted for infant age at visit.

	<b>Normal (N=33)</b>	<b>Overweight/ Obese (N=39)</b>	<b>P Value</b>
Male gender (%)	42%	44%	0.56
Breast fed (%)	79%	72%	0.40
Gestational age (weeks) <sup>†</sup>	39.5 ± 1.2	38.9 ± 1.0	0.03
Infant age at time of testing (days) <sup>†</sup>	19.5 ± 8.5	19.8 ± 9.3	0.91
<i>Infant Out-Come Variables</i>			
Birth length (cm) <sup>†</sup>	50.7 ± 2.6	49.6 ± 2.6	0.08
Birth weight (g) <sup>†</sup>	3433.0 ± 396.3	3368.0 ± 399.6	0.44
%fat	12.5 ± 4.2	13.6 ± 4.3	0.000
Fat mass (g)	414.1 ± 264.2	448.3 ± 262.2	0.04
Fat-free mass (g)	3310.5 ± 344.6	3162.2 ± 343.4	0.03

5 Mean ± standard deviation

<sup>†</sup>Self report by the mother

**Table 3:** Multiple stepwise regression analysis for factors that affected infant outcome variables in 33 women with a pre-gravid BMI <25 kg/m<sup>2</sup>.

<b>Factor</b>	<b>r<sup>2</sup></b>	<b>Δ r<sup>2</sup></b>	<b>P Value</b>
%fat			
Infant age at visit	0.29	-	0.003
Fat-free mass			
Infant gender	0.23	-	0.000

**Table 4:** Multiple stepwise regression analysis for factors that affected infant outcome variables in 39 women with pre-gravid BMI  $\geq 25$  kg/m<sup>2</sup>.

<b>Factor</b>	<b>r<sup>2</sup></b>	<b><math>\Delta</math> r<sup>2</sup></b>	<b>P Value</b>
%fat			
Infant age at visit	0.28	-	0.000
Fat-free mass			
Feeding status	0.22	-	0.007
Infant age at visit	0.31	0.09	0.007
Gestational age	0.42	0.11	0.021

## References

- 5 1. Lu GC, Rouse DJ, DuBard M, Cliver S, Kimberlin D, and Hauth JC. The effect of the increasing prevalence of maternal obesity on perinatal morbidity. *Am J Obstet Gynecol* 2001;185:845-9.
2. Ehrenberg HM, Dierker L, Milluzzi C, and Mercer BM. Prevalence of maternal obesity in an urban center. *Am J Obstet Gynecol* 2002;187:1189-93.
- 10 3. Surkan PJ, Hsieh CC, Johansson AL, Dickman PW, and Cnattingius S. Reasons for increasing trends in large for gestational age births. *Obstet Gynecol* 2004;104:720-6.
4. Ananth CV and Wen SW. Trends in fetal growth among singleton gestations in the United States and Canada, 1985 through 1998. *Semin Perinatol* 2002;26:260-7.
5. Ehrenberg HM, Mercer BM, and Catalano PM. The influence of obesity and diabetes on the prevalence of macrosomia. *Am J Obstet Gynecol* 2004;191:964-8.
- 15 6. Szostak-Wegierek D, Szamotulska K, and Szponar L. [Influence of maternal nutrition on infant birthweight]. *Ginekol Pol* 2004;75:692-8.
7. Kirchengast S and Hartmann B. Maternal prepregnancy weight status and pregnancy weight gain as major determinants for newborn weight and size. *Ann Hum Biol* 1998;25:17-28.
- 20 8. Shapiro C, Sutija VG, and Bush J. Effect of maternal weight gain on infant birth weight. *J Perinat Med* 2000;28:428-31.
9. Rasmussen F and Johansson M. The relation of weight, length and ponderal index at birth to body mass index and overweight among 18-year-old males in Sweden. *Eur J Epidemiol* 1998;14:373-80.
- 25 10. Sorensen HT, Sabroe S, Rothman KJ, Gillman M, Fischer P, and Sorensen TI. Relation between weight and length at birth and body mass index in young adulthood: cohort study. *Bmj* 1997;315:1137.
11. Eide MG, Oyen N, Skjaerven R, Nilsen ST, Bjerkedal T, and Tell GS. Size at birth and gestational age as predictors of adult height and weight. *Epidemiology* 2005;16:175-81.
- 30 12. Tuvemo T, Cnattingius S, and Jonsson B. Prediction of male adult stature using anthropometric data at birth: a nationwide population-based study. *Pediatr Res* 1999;46:491-5.
13. Barker DJ. The intrauterine environment and adult cardiovascular disease. *Ciba Found Symp* 1991;156:3-10; discussion 10-6.
- 35 14. Barker DJ and Osmond C. Infant mortality, childhood nutrition, and ischaemic heart disease in England and Wales. *Lancet* 1986;1:1077-81.
15. Barker M, Robinson S, Osmond C, and Barker DJ. Birth weight and body fat distribution in adolescent girls. *Arch Dis Child* 1997;77:381-3.
16. Barker DJ, Eriksson JG, Forsen T, and Osmond C. Fetal origins of adult disease: strength of effects and biological basis. *Int J Epidemiol* 2002;31:1235-9.
- 40 17. Barker DJ. The fetal origins of adult hypertension. *J Hypertens Suppl* 1992;10:S39-44.
18. Barker DJ, Hales CN, Fall CH, Osmond C, Phipps K, and Clark PM. Type 2 (non-insulin-dependent) diabetes mellitus, hypertension and hyperlipidaemia (syndrome X): relation to reduced fetal growth. *Diabetologia* 1993;36:62-7.
- 45 19. Barker DJ, Winter PD, Osmond C, Margetts B, and Simmonds SJ. Weight in infancy and death from ischaemic heart disease. *Lancet* 1989;2:577-80.

20. Barker DJ, Osmond C, and Law CM. The intrauterine and early postnatal origins of cardiovascular disease and chronic bronchitis. *J Epidemiol Community Health* 1989;43:237-40.
21. Byrne CD and Phillips DI. Fetal origins of adult disease: epidemiology and mechanisms. *J Clin Pathol* 2000;53:822-8.
22. Barker DJ. The developmental origins of insulin resistance. *Horm Res* 2005;64 Suppl 3:2-7.
23. Hales CN and Barker DJ. Type 2 (non-insulin-dependent) diabetes mellitus: the thrifty phenotype hypothesis. *Diabetologia* 1992;35:595-601.
24. Lucas A. Programming by early nutrition in man. *Ciba Found Symp* 1991;156:38-50; discussion 50-5.
25. McMillen IC and Robinson JS. Developmental origins of the metabolic syndrome: prediction, plasticity, and programming. *Physiol Rev* 2005;85:571-633.
26. Bernstein I. Fetal body composition. *Curr Opin Clin Nutr Metab Care* 2005;8:613-7.
27. Huxley RR. Early nutritional determinants of coronary artery disease: a question of timing? *Am J Clin Nutr* 2006;84:271-2.
28. Roseboom TJ, van der Meulen JH, Ravelli AC, Osmond C, Barker DJ, and Bleker OP. Effects of prenatal exposure to the Dutch famine on adult disease in later life: an overview. *Mol Cell Endocrinol* 2001;185:93-8.
29. Kannisto V, Christensen K, and Vaupel JW. No increased mortality in later life for cohorts born during famine. *Am J Epidemiol* 1997;145:987-94.
30. Huxley RR and Neil HA. Does maternal nutrition in pregnancy and birth weight influence levels of CHD risk factors in adult life? *Br J Nutr* 2004;91:459-68.
31. Stanner SA, Bulmer K, Andres C, Lantseva OE, Borodina V, Poteen VV, et al. Does malnutrition in utero determine diabetes and coronary heart disease in adulthood? Results from the Leningrad siege study, a cross sectional study. *BMJ* 1997;315:1342-8.
32. Catalano PM, Thomas A, Huston-Presley L, and Amini SB. Increased fetal adiposity: a very sensitive marker of abnormal in utero development. *Am J Obstet Gynecol* 2003;189:1698-704.
33. Dietz WH. Critical periods in childhood for the development of obesity. *Am J Clin Nutr* 1994;59:955-9.
34. Urlando A, Dempster P, and Aitkens S. A new air displacement plethysmograph for the measurement of body composition in infants. *Pediatr Res* 2003;53:486-92.
35. Fomon SJ, Haschke F, Ziegler EE, and Nelson SE. Body composition of reference children from birth to age 10 years. *Am J Clin Nutr* 1982;35:1169-75.
36. Kanadys WM. [Pre-pregnancy body mass, gestational weight gain and birth weight]. *Ginekol Pol* 1998;69:1223-7.
37. Shao D. [The relationship between maternal body weight index and fetal weight and delivery mode]. *Zhonghua Fu Chan Ke Za Zhi* 1995;30:718-20.
38. Sun B, Li J, and Song Q. [Influence of prepregnancy weight and maternal weight gain on pregnancy outcome]. *Zhonghua Fu Chan Ke Za Zhi* 1998;33:71-3.
39. Rossner S and Ohlin A. Maternal body weight and relation to birth weight. *Acta Obstet Gynecol Scand* 1990;69:475-8.
40. Abrams BF and Laros RK, Jr. Prepregnancy weight, weight gain, and birth weight. *Am J Obstet Gynecol* 1986;154:503-9.

41. Sewell MF, Huston-Presley L, Super DM, and Catalano P. Increased neonatal fat mass, not lean body mass, is associated with maternal obesity. *Am J Obstet Gynecol* 2006;195.
42. Kramer MS and Joseph KS. Enigma of fetal/infant-origins hypothesis. *Lancet* 1996;348:1254-5.
- 5 43. Andreasyan K, Ponsonby AL, Dwyer T, Morley R, Riley M, Dear K, et al. Higher maternal dietary protein intake in late pregnancy is associated with a lower infant ponderal index at birth. *Eur J Clin Nutr* 2007;61:498-508.
44. Catalano PM. Management of obesity in pregnancy. *Obstet Gynecol* 2007;109:419-33.
- 10 45. Weiss JL, Malone FD, Emig D, Ball RH, Nyberg DA, Comstock CH, et al. Obesity, obstetric complications and cesarean delivery rate--a population-based screening study. *Am J Obstet Gynecol* 2004;190:1091-7.
46. Catalano PM, Tyzbit ED, Allen SR, McBean JH, and McAuliffe TL. Evaluation of fetal growth by estimation of neonatal body composition. *Obstet Gynecol* 1992;79:46-50.
- 15 47. Plagemann A, Harder T, Kohlhoff R, Rohde W, and Dorner G. Overweight and obesity in infants of mothers with long-term insulin-dependent diabetes or gestational diabetes. *Int J Obes Relat Metab Disord* 1997;21:451-6.
48. Ghosh P, Bitsanis D, Ghebremeskel K, Crawford MA, and Poston L. Abnormal aortic fatty acid composition and small artery function in offspring of rats fed a high fat diet in pregnancy. *J Physiol* 2001;533:815-22.
- 20