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DOI
10.1136/adc.2008.137737

Publication date
2009

Document Version
Final published version

Published in
Archives of disease in childhood

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Arch Dis Child 2009 94: 587-595 originally published online March 29, 2009
doi: 10.1136/adc.2008.137737

Maternal pre-pregnancy body mass index explains infant's weight and BMI at 14 months: results from a multi-ethnic birth cohort study

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Accepted 14 March 2009
Published Online First 29 March 2009

ABSTRACT

Objective: To investigate the association between (self-reported) maternal pre-pregnancy body mass index (pBMI), and child's weight, height and BMI at age 14 months.

Design: Prospective multi-ethnic community-based cohort study.

Setting: Amsterdam, The Netherlands.

Participants: 8266 pregnant women from the Amsterdam Born Children and their Development study, filled out a questionnaire covering socio-demographic data, obstetric history, lifestyle, dietary habits and psychosocial factors, 2 weeks after their first antenatal visit. 7730 gave birth to a viable term singleton infant with information on birth weight, gender and pregnancy duration. Growth data were available for 3171 of these children.

Main outcome measures: Weight (g), height (cm) and BMI (kg/m^2) of the child at age 14 months.

Results: pBMI was linearly associated with weight and BMI of the child at age 14 months. One unit increase in pBMI resulted in an increment of 29 g (95% CI 19 to 39) in weight and 0.041 kg/m^2 (95% CI 0.030 to 0.053) in BMI. The effect size decreased after adjustment for birth weight (weight: β coefficient 19 g, 95% CI 10 to 28; BMI: β coefficient 0.034 kg/m^2, 95% CI 0.023 to 0.046) and hardly changed after adjustment for all other variables (weight: β coefficient 21 g, 95% CI 11 to 30; BMI: β coefficient 0.031 kg/m^2, 95% CI 0.019 to 0.043). pBMI was not related to height.

Conclusions: pBMI is an independent determinant of weight and BMI of the child at age 14 months. At least one third of this effect is mediated through birth weight.

What is already known on this topic

- Maternal overweight/obesity has been linked to increased birth weight, and obesity/overweight of the child in child- and adulthood.
- Little is known about the timing of these effects, particularly in fetal and infant life.

What this study adds

- Maternal pre-pregnancy body mass index (pBMI) is an independent determinant of weight and BMI of the child at age 14 months.
- At least one third of this effect is due to intrauterine influences and is reflected in birth weight.

Growth in early life has important effects on infant mortality and morbidity, childhood development and health status in adult life.[1–12] Barker *et al*[1] demonstrated in the late 1980s that low birth weight and low weight at age 1 year are associated with an increased risk for cardiovascular diseases (CVD) in adult life, which was later confirmed in the Helsinki Birth Cohort Study.[13] In particular, risk associations related to the development of non-insulin dependent diabetes and the insulin resistance syndrome[3–8] and hypertension.[9 10] Babies with very high rather than low birth weight also experience increased risk for disease.[11] Finally, recent studies show that enhanced postnatal growth rate in normal weight newborns (also called catch-up growth or accelerated growth) increases CVD risk.[12 14–16] Excessive fat deposition, in particular central fat, and the development of insulin resistance may be one of the underlying mechanisms.

A large body of evidence suggests that birth weight is a critical determinant for growth during the first year. Birth weight is the product of gestational age and fetal growth, both of which are subject to a wide range of, partially overlapping, clusters of determinants such as maternal genetic make-up (eg, maternal and paternal height), obstetric history (eg, parity, diabetes, hypertension) and social demographic background (eg, marital status, educational level, smoking, pre-pregnancy BMI).[17–19] Factors like maternal age fit into more than one cluster of determinants. To what extent these prenatal factors affect growth after birth independently from their effect on birth weight is unclear.

This paper focuses on the influence of the pre-pregnancy BMI (pBMI) of the mother on the growth of the child. Apart from the well known association between maternal obesity and increased risk for pregnancy complications and adverse outcomes[20–22] (pregnancy induced hypertension, caesarean sections, macrosomia, stillbirth and neonatal death), pBMI could have an important influence on fetal and neonatal growth.

The objective of this large prospective multi-ethnic cohort study in Amsterdam was to investigate the independent association of maternal pBMI with weight, height and BMI of the child at age 14 months, controlling for other maternal factors, infant feeding pattern and paternal height. We hypothesised that (1) the influence of pBMI on weight, height and BMI of the child in early infancy is primarily determined by its effect on birth weight, and (2) that the association is the same across ethnic groups.

METHODS

Study population

Prospective data from a community based cohort of pregnant women (n = 8266) in the city of Amsterdam, The Netherlands, were used (Amsterdam Born Children and their Development (ABCD) study). The ABCD study focuses on the relationship between dietary and lifestyle habits during pregnancy and birth outcomes and future health of the child, with specific attention to ethnicity (http://www.abcd-study.nl).[23 24] Between January 2003 and March 2004, all pregnant women living in Amsterdam were invited to participate in this study at their first antenatal visit (median: 13 weeks' gestation; inter-quartile range (IQR): 3 weeks). All approached women (12 373) were registered using a form covering personal data such as name, address, date of birth and country of birth. A questionnaire seeking information on socio-demographic data, obstetric history, lifestyle, dietary habits and psychosocial factors, was sent to the pregnant woman's home address 2 weeks after the visit (on average at the 14th week of pregnancy) with the request to return it by prepaid mail. A reminder was sent 2 weeks later. The questionnaires were in Dutch but were accompanied by an English, Turkish or Arabic translation depending on the woman's country of birth. With the help of caregivers, all Turkish- and Arabic-speaking women who showed reading difficulties or functional illiteracy were invited to contact a trained female interviewer for oral administration. Questionnaires were returned by 8266 women (response rate: 67%). From this group, 7730 gave birth to a viable singleton infant with information on birth weight, gender and pregnancy duration. Height and weight, measured by health workers at regular follow-up visits, were collected and digitised. Measurements of 3729 of the children have been completed and digitised. The remaining children have moved to another city or area of Amsterdam and their data will be collected in a second round. Of the 3729 children, 3372 had a measurement at age 14 months (median: 61 weeks; IQR: 5 weeks). Preterm births (<37 weeks, n = 201) were excluded from the analysis. The total number for analysis was 3171.

The study protocol was approved by the medical ethical committees of all Amsterdam hospitals and the Registration Committee of Amsterdam. All participating women gave written consent.

Measurements

Exposure measurement

Maternal pBMI was calculated using self-reported weight before pregnancy and height from the questionnaire (pBMI = maternal weight/(maternal height)^2). Missing values were imputed for maternal height (3.8% missing) and pre-pregnancy weight (9.9% missing) by a random imputation procedure using linear regression analysis and other variables known to be associated with maternal height and weight, respectively.[25] pBMI was used as a continuous and a categorical measure. Predefined categories, based on WHO standards, were: pBMI <18.5 (severely underweight), pBMI 18.5–19.9 (low normal), pBMI 20–24.9 (normal, reference group), pBMI 25–29.9 (overweight) and pBMI ⩾30 (obese). The functional form of the association of pBMI with the dependents was explored by adding pBMI as a quadratic term.

Measurement and definition of outcome

The growth measurements (height and weight) of the child were obtained from the Youth Health Care registration department of the Municipal Health Service in Amsterdam. They follow the growth of the children according to a standard protocol which means that weight and height are measured on average 12 times between 0 and 4 years by trained nurses. Primary outcome variables for this study were weight (g), height (cm) and BMI (kg/m^2) of the child at the age of 14 months as regular follow-up visits are conducted at this time and it reflects growth at a point when fastest growth has taken place.

Measurement of covariates and confounders

Intrauterine and child factors were: birth weight (kg), gestational age (in weeks, ultrasound based or, if unavailable (<10%), on the timing of the last menstrual period), gender and duration of breastfeeding (in five categories: none, <1 month, 1–3 months, 4–6 months, >6 months). All were obtained from the Youth Health Care registration department.

Self-reported socio-demographic variables from the questionnaire were: maternal age (years), maternal height (cm), paternal height (cm, 11.4% missing, imputed by the mean value of the ethnic group), parity (three categories: 0, 1, ⩾2), maternal education (years of education after primary school, three categories: <5, 5–10, >10), cohabitant status (two categories: partner/husband living in same house, not living together/single) and ethnicity (maternal country of birth; six categories: Dutch, Surinamese, Turkish, Moroccan, other non-Western country, other Western country).

Considered life style factors from the questionnaire were: smoking during pregnancy (four categories: none, <1 a day, 1–5 a day, >5 a day) and use of alcohol during pregnancy (number of drinks, dichotomised into yes or no).

Pre-existing hypertension (yes/no) and diabetes mellitus (no, pre-existing and gestational diabetes) were based on self-reported information from the questionnaire and completed with information from the national obstetric registry (Perinatal Registration centre of the Netherlands, PRN).[26] This registry was linked to the ABCD data by probabilistic record linkage.[27]

Statistical analyses

Linear regression with increasing level of adjustment was used to estimate the effects of pBMI on child weight, height and BMI at the age of 14 months, using both a continuous and a categorical measure of pBMI (categories: <18.5, 18.5–19.9, 20–24.9, 25–29.9, ⩾30). First, univariate analysis was carried out, standardised for the age of the child. Subsequently, multivariate analyses using a stepwise hierarchical approach were performed. Undisputed variables known to influence birth weight, such as gestational age, child's gender and maternal weight, were added to the model in the first step (forced entry) to determine the independent effect of, in particular, pBMI on weight, height and BMI at the age of 14 months (model 1). Thereafter, the child factor duration of breast feeding was added (forced entry), followed by all other variables, except ethnicity, in a stepwise procedure. As ethnicity is largely related to maternal and paternal factors, it was added to the model to test its additional effect in the last step. To test our second hypothesis, the interaction between pBMI and ethnicity was added to the final model. A non-significant interaction means that the

Table 1 Intrauterine, child and maternal characteristics by maternal pre-pregnancy body mass index (pBMI)

	pBMI <18.5 (n = 173), mean (SD) or %	pBMI 18.5–20 (n = 434), mean (SD) or %	pBMI 20–25 (n = 1794), mean (SD) or %	pBMI 25–30 (n = 546), mean (SD) or %	pBMI ⩾30 (n = 224), mean (SD) or %	Significance*
Intrauterine and child factors						
Birth weight (g)	3.26 (0.44)	3.42 (0.43)	3.52 (0.48)	3.54 (0.50)	3.60 (0.57)	p<0.001
Gestational age (weeks)	39.9 (1.3)	40.0 (1.2)	39.7 (1.2)	39.7 (1.3)	39.6 (1.3)	
Gender						
Boy	59.5	49.3	49.3	50.4	50.9	
Girl	40.5	50.7	50.7	49.6	49.1	
Duration of breastfeeding						p<0.001
None	17.3	12.3	13.5	18.7	26.3	p<0.001
<1 month	24.3	18.9	22.8	30.8	27.7	
1–3 months	19.1	26.7	21.8	19.0	17.0	
4–6 months	22.0	26.0	23.6	14.3	11.6	
>6 months	17.3	16.1	18.3	17.2	17.4	
Weight at 14 months (kg)	10.1 (1.2)	10.2 (1.1)	10.4 (1.2)	10.6 (1.3))	10.7 (1.2)	p<0.01
Height at 14 months (cm)	78.0 (3.3)	77.8 (3.2)	78.1 (3.4)	78.1 (3.5)	78.3 (3.4)	
BMI at 14 months (kg/cm^2)	16.7 (1.3)	16.9 (1.3)	17.1 (1.6)	17.3 (1.5)	17.4 (1.6)	p<0.01
Maternal factors						
Age (years)	29.5 (5.6)	30.7 (5.2)	31.2 (5.2)	30.9 (5.4)	30.7 (5.2)	p<0.001
Height (cm)	169 (7.1)	170 (6.9)	169 (7.2)	167 (7.6)	166 (7.1)	p<0.001
Parity (%)						p<0.001
0	59.5	58.3	54.0	42.5	37.5	
1	34.7	31.8	33.2	35.3	30.8	
⩾2	5.8	9.9	12.8	22.2	31.7	
Pre-existing hypertension (% yes)	1.7	1.8	2.3	6.2	12.5	p<0.001
Diabetes (%)						p<0.001
No	98.2	99.5	98.6	96.7	90.6	p<0.001
Pre-existing	1.2	0.0	0.6	0.9	4.5	
Gestational	0.6	0.5	0.8	2.4	4.9	
Smoking during pregnancy						
No	69.9	73.3	74.2	80.1	81.7	
<1 cigarette/day	2.3	6.4	6.2	3.8	3.6	
1–5 cigarettes/day	6.4	5.8	4.9	3.5	3.1	
>5 cigarettes/day	21.4	14.5	14.7	12.6	11.6	
Use of alcohol (% yes)	20.8	25.8	24.3	11.9	11.2	p<0.001
Maternal education						p<0.001
<5 years	22.0	12.4	15.7	25.1	32.6	p<0.001
5–10 years	41.0	40.8	41.4	50.5	50.9	
>10 years	37.0	46.8	42.9	24.4	16.5	
Cohabitant status						p<0.01
Partner/husband	81.5	86.8	88.8	84.0	84.3	
Living in same house						
Not living together/single	18.5	13.2	11.2	16.0	15.7	
Ethnicity (%)						p<0.001
Dutch	59.0	71.3	67.2	51.5	43.7	
Surinamese	6.4	4.8	3.3	7.0	11.2	
Turkish	4.6	2.3	4.7	7.0	7.1	
Moroccan	4.0	3.2	6.6	15.0	17.9	
Other non-Western country	13.9	9.2	9.9	14.7	16.5	
Other Western country	12.1	9.2	8.3	4.8	3.6	

*Significant difference between BMI subgroups.

relationship between pBMI and weight or BMI is the same across all ethnic groups. The interaction between pBMI and gender was also tested.

All analyses were repeated with the original dataset (pBMI not imputed). Results were essentially the same (tables are available on request). Therefore, only the results from the complete dataset are presented.

Data were analysed using SPSS 13.0; the significance level was set at 0.05. The residuals of the final linear regression models were visually checked for normal distribution and homogeneity of the variances was tested by Levene test.

With a sample size of n = 3171 and pBMI standard deviation of 4.5 kg/m^2, we were able to detect (90% power, two-sided significance level of 0.05) a change of 15.3 g in weight (SD 1200), 0.02 kg/m^2 in BMI (SD 1.5) and 0.04 cm (SD 3.4) in length per unit increase in pBMI.

RESULTS

The group without growth data (n = 4227) and the group with growth data (n = 3171) were similar with respect to maternal age (30.6 (SD 5.1) vs 30.9 (SD 5.3) years), pBMI (23.0 (SD 3.9) vs 23.3 (SD 4.3)), birth weight (3493 (SD 487) vs 3501 (SD

Table 2 The association between maternal pre-pregnancy BMI (pBMI) and birth weight (g)

	Univariable effects (adj R^2 0.012), β coefficient (95% CI)	Multivariable effects† Model 1 (adj R^2 0.171), β coefficient (95% CI)	Multivariable effects† Final model (adj R^2 0.263), β coefficient (95% CI)
pBMI (kg/m²)	13 (9 to 17)***	13 (9 to 17)***	15 (11 to 18)***
<18.5	−264 (−340 to −189)***	−258 (−331 to −185)***	−238 (−307 to −169)***
18.5–19.9	−104 (−154 to −53)***	−87 (−134 to −39)***	−94 (−139 to −49)***
20–24.9	Reference	Reference	Reference
25–29.9	16 (−31 to 62)	31 (−12 to 75)	46 (4 to 86)
⩾30	79 (12 to 146)*	103 (39 to 167)**	116 (54 to 178)**
Pregnancy duration (weeks)	152 (139 to 165)***	149 (136 to 162)***	147 (135 to 160)***
Female gender	−124 (−158 to −90)***	−125 (−157 to −94)***	−129 (−159 to −99)***
Maternal age (years)	11 (8 to 14)***		–
Maternal height (cm)	14 (12 to 17)***		13 (10 to 15)***
Paternal height (cm)	9 (7 to 11)***		7 (5 to 9)***
Parity			
0	Reference		Reference
1	114 (77 to 152)***		119 (86 to 153)***
⩾2	134 (85 to 184)***		185 (139 to 232)***
Diabetes			
No	Reference		Reference
Pre-existing	164 (−17 to 345)		419 (249 to 589)***
Gestational	218 (69 to 368)**		310 (176 to 445)***
Alcohol use			–
No	Reference		
Yes	77 (36 to 118)***		
Smoking			
No	Reference		–
<1 cigarette/day	−8 (−84 to 67)		
1–5 cigarettes/day	−57 (−137 to 24))		
>5 cigarettes/day	−91 (−140 to −43)***		
Maternal education			–
<5 years	−105 (−153 to −57)***		
5–10 years	−77 (−115 to −40)***		
>10 years	Reference		
Cohabitant status			
Partner/husband living in same house	Reference		–
Not living together/single	−109 (−160 to −59)***		
Ethnicity			
Dutch	Reference		Reference
Surinamese	−240 (−310 to −152)***		−117 (−194 to −41)**
Moroccan	−60 (−123 to 2)		−1.3 (−64 to 61)
Turkish	−102 (−180 to −23)*		28 (−47 to 102)
Other non-Western country	−121 (−167 to −67)***		−6 (−61 to 48)
Other Western country	−68 (−133 to −3)*		21 (−39 to 80)

†Multivariable effects are results with pBMI continuous in the model.
*p<0.05; **p<0.01; ***p<0.001.
All adjusted for pregnancy duration. The residuals from all models were normally distributed and variances were homogeneous. Pre-existing hypertension was not significantly associated with birth weight in any model.

487) g) and gestational age (39.7 (SD 1.3) vs 39.7 (SD 1.3) weeks), % of Dutch origin (62.4 vs 62.9), % single (14.0 vs 13.0) and % with low education (18.2 vs 18.4). The mothers of children with growth data were more likely to smoke (10.4 vs 8.2) and were more often multiparous (48.2 vs 43.4) (results not shown).

Socio-demographic background data of the women, stratified by pBMI, are shown in table 1. Underweight women were younger and more smoked during pregnancy. They also had children with lower birth weights, as did women with low normal weights. Obese women had a higher prevalence of pre-existing hypertension and diabetes. They were also more often of non-Dutch ethnicity and had lower education.

Mean pBMIs for different ethnic groups were: Dutch 22.7 (SD 3.7), Surinamese 24.9 (SD 6.1), Moroccan 25.4 (SD 4.7), Turkish 24.4 (SD 4.6), other non-Western country 24.2 (SD 5.0) and other Western country 22.0 (SD 3.3).

Birth weight

Univariate analysis (table 2) shows a strong positive association between pBMI and birth weight. One unit increase in pBMI was associated with an increase in birth weight of 13 g (95% CI 9 to 17). Besides pBMI, pregnancy duration (+), gender of the child (boys were heavier), maternal age (+), maternal and paternal height (+), parity (+), gestational diabetes (+), alcohol use (+), smoking (−), maternal education (+), cohabitant status (not

Table 3 Univariable and multivariable associations between maternal pre-pregnancy BMI (pBMI), intrauterine, child and maternal factors, and weight (g) of the child at age 14 months

		Multivariable effects†	
	Univariable effects (adj R^2 0.085), β coefficient (95% CI)	Model 1 (adj R^2 0.251), β coefficient (95% CI)	Final model (adj R^2 0.313), β coefficient (95% CI)
pBMI (kg/m²)	29 (19 to 39)***	19 (10 to 28)***	21 (11 to 30)***
<18.5	−358 (−550 to −167)***	−205 (−380 to −30)	−266 (−434 to −98)*
18.5–19.9	−208 (−333 to −83)**	−129 (−243 to −16)*	−140 (−250 to −32)*
20–24.9	Reference	Reference	Reference
25–29.9	133 (18 to 248)*	101 (−3 to 205)	70 (−32 to 173)
⩾30	221 (52 to 390)*	127 (−26 to 281)	147 (−4 to 298)
Birth weight (kg)	862 (783 to 940)***	857 (773 to 944)***	791 (705 to 876)***
Gestational age (weeks)	51 (18 to 84)**	−82 (−116 to −49)***	−62 (−95 to −30)***
Female gender	−609 (−688 to −531)***	−518 (−595 to −442)	−525 (−595 to −452)***
Duration of breastfeeding			
None	Reference		Reference
<1 month	138 (6 to 271)*		65 (−56 to 186)
1–3 months	83 (−53 to 218)		−28 (−152 to 95)
4–6 months	−125 (−261 to 11)		−223 (−348 to −98)***
>6 months	−115 (−256 to 27)		−267 (−397 to −136)***
Maternal age (years)	−12 (−20 to −4)**		−18 (−25 to −10)***
Maternal height (cm)	25 (19 to 30)***		24 (18 to 30)***
Paternal height (cm)	19 (14 to 24)***		21 (15 to 26)***
Maternal education			
<5 years	196 (80 to 311)**		–
5–10 years	−15 (−105 to 75)		
>10 years	Reference		
Ethnicity			
Dutch	Reference		Reference
Surinamese	−187 (−377 to 2)		84 (−98 to 267)
Moroccan	322 (173 to 472)***		478 (324 to 633)***
Turkish	512 (323 to 701)***		749 (561 to 938)***
Other non-Western country	5 (−125 to 135)		298 (165 to 430)***
Other Western country	−164 (−318 to −10)*		73 (−71 to 213)

†Multivariable effects are results with pBMI continuous in the model.
*p<0.05; **p<0.01; ***p<0.001.
All adjusted for age of the child at measurement weight 14 months. The residuals from all models were normally distributed and variances were homogeneous. Parity, pre-existing hypertension, diabetes, alcohol use, smoking and cohabitant status were not significantly associated with child weight at age 14 months in any model.

living together/single −) and ethnicity (children with mothers from Surinam, Turkey, other non-Western countries and other Western countries were smaller) were all associated with birth weight in univariate analysis.

After adjustment for gestational age, birth weight and child's gender, the effect of pBMI remained the same. After adjustment for all other covariates, the effect of pBMI increased a small amount (β coefficient 15, 95% CI 11 to 18) and remained highly significant. Other entered variables were pregnancy duration (+), gender of the child (girls were smaller), maternal and paternal height (+), parity (+), diabetes (+) and ethnicity (Surinamese children were smaller).

Child weight at 14 months

Univariate analysis (table 3) shows a strong association between pBMI and weight of the child at age 14 months. In analyses in which pBMI was a categorical and in those where it was a continuous variable, the association between pBMI and weight of the child was linear rather than quadratic.

One unit increase in pBMI was associated with an increase of 29 g (95% CI 19 to 39) in weight. Apart from pBMI, birth weight (+), gestational age (+), gender of the child (girls were smaller), duration of breast feeding (−), maternal age (−), maternal and paternal height (+), maternal education (−) and ethnicity (Moroccan and Turkish children were heavier, children from other Western countries were smaller) were all associated with weight of the child at age 14 months in univariate analysis.

After adjustment for gestational age, birth weight and child's gender, the effect of pBMI decreased but remained significant (β coefficient 19 g, 95% CI 10 to 28), implying that 10 of the 29 g (1/3) of the pBMI effect is mediated through birth weight. After adjustment for all other variables, the effect of pBMI did not change and remained highly significant (β coefficient 21 g, 95% CI 11 to 30). The other variables in the final model were duration of breastfeeding (−), maternal age (−) and maternal and paternal height (+). Ethnicity, as the last factor, appeared to be a strong independent factor, even after full adjustment for maternal, paternal and child factors. Mothers of Moroccan, Turkish or other non-Western origin had children with a significantly higher weight at the age of 14 months compared to children of mothers of Dutch origin. The interaction between pBMI and ethnicity was insignificant, suggesting that the same relationship exists between pBMI and child weight in all ethnic groups. Also, the interaction between pBMI and gender was not significant.

Child height at 14 months

Univariate analysis showed no association between pBMI and height of the child at age 14 months (table 4). Covariates which

Table 4 Univariable and multivariable associations between maternal pre-pregnancy BMI (pBMI), intrauterine, child and maternal factors, and height (cm) of the child at age 14 months

		Multivariable effects†	
	Univariable effects (adj R^2 0.027), β coefficient (95% CI)	Model 1 (adj R^2 0.081), β coefficient (95% CI)	Final model (adj R^2 0.100), β coefficient (95% CI)
pBMI (kg/m²)	0.017 (−0.008 to 0.042)	−0.004 (−0.027 to 0.019)	0.006 (−0.017 to 0.029)
<18.5	−0.27 (−0.75 to 0.21)	0.062 (−0.39 to 0.51)	−0.18 (−0.60 to 0.24)
18.5–19.9	−0.23 (−0.54 to 0.082)	−0.056 (−0.35 to 0.23)	−0.15 (−0.42 to 0.12)
20–24.9	Reference	Reference	Reference
25–29.9	0.026 (−0.26 to 0.31)	−0.040 (−0.31 to 0.23)	−0.083 (−0.34 to 0.17)
⩾30	0.22 (−0.20 to 0.64)	0.037 (−0.35 to 0.20)	0.14 (−0.24 to 0.52)
Birth weight (kg)	1.9 (1.7 to 2.1)***	1.8 (1.6 to 2.0)***	1.5 (1.3 to 1.7)***
Gestational age (weeks)	0.23 (0.15 to 0.31)***	−0.059 (−0.14 to 0.026)	0.019 (−0.062 to 0.099)
Female gender	−1.4 (−1.6 to −1.2)***	−1.2 (−1.4 to −1.0)***	−1.3 (−1.4 to −1.0)***
Duration of breastfeeding			
None	Reference		Reference
<1 month	−0.027 (−0.36 to 0.30)		−0.15 (−0.45 to 0.15)
1–3 months	−0.081 (−0.42 to 0.25)		−0.33 (−0.63 to −0.016)*
4–6 months	−0.50 (−0.83 to −0.16)*		−0.77 (−1.1 to −0.46)***
>6 months	−0.59 (−0.94 to −0.24)*		−0.93 (−1.3 to −0.6)***
Maternal age (years)	−0.027 (−0.046 to −0.008)*		−0.038 (−0.057 to −0.019)***
Maternal height (cm)	0.090 (0.077 to 0.10)***		0.091 (0.076 to 0.11)***
Paternal height (cm)	0.073 (0.061 to 0.085)***		0.071 (0.059 to 0.084)***
Maternal education			
<5 years	0.39 (0.11 to 0.68)*		0.51 (0.19 to 0.83)*
5–10 years	0.10 (−0.12 to 0.32)		0.29 (0.078 to 0.51)*
>10 years	Reference		Reference
Ethnicity			
Dutch	Reference		Reference
Surinamese	−0.2 (−0.69 to 0.26)		0.71 (0.25 to 1.2)*
Moroccan	0.008 (−0.36 to 0.38)		0.83 (0.44 to 1.2)***
Turkish	0.55 (0.080 to 1.0)*		1.6 (1.1 to 2.1)***
Other non-Western country	0.32 (−0.002 to 0.65)		1.4 (1.0 to 1.7)***
Other Western country	−0.41 (−0.79 to −0.026)*		0.31 (−0.045 to 0.67)

†Multivariable effects are results with pBMI continuous in the model.
*p<0.05; **p<0.01; ***p<0.001.
All adjusted for age of the child at measurement height 14 months. The residuals from all models were normally distributed and variances were homogeneous. Parity, pre-existing hypertension, diabetes, alcohol use, smoking and cohabitant status were not significant associated with child height at age 14 months in any model.

had an association with height of the child at age 14 months were: birth weight (+), gestational age (+), gender of the child (girls were smaller), duration of breastfeeding (−), maternal age (−), maternal and paternal height (+), maternal education (−) and ethnicity (Turkish children were taller and children of mothers from other Western countries were smaller).

In multivariate analysis, the same covariates were associated with height at age 14 months. Children with mothers from Surinam, Morocco, Turkey and other non-Western countries were all taller than Dutch children.

Child BMI at 14 months

Univariate analysis (table 5) showed a strong association between pBMI and BMI of the child at age 14 months; as with weight, the association was linear. One unit increase in pBMI was associated with an increase in BMI of 0.041 kg/m² (95% CI 0.030 to 0.053). Apart from pBMI, birth weight (+), gestational age (−), gender of the child (girls had lower BMI), duration of breast feeding (−), maternal age (−), parity (+), maternal education (−) and ethnicity (Moroccan and Turkish children had higher BMIs) were associated with BMI at age 14 months in univariate analysis.

After adjustment for gestational age, birth weight and child's gender, the effect of pBMI decreased but remained statistically significant (β coefficient 0.034 kg/m², 95% CI 0.023 to 0.046). After adjustment for all other variables, the effect of pBMI did not change and remained highly significant (β coefficient 0.031 kg/m², 95% CI 0.019 to 0.043). The other variables in the final model were: birth weight (+), gestational age (−), gender of the child (girls had lower BMI) and duration of breast feeding (−). Ethnicity, as the last factor, appeared to be a strong independent factor. The BMI of children of Moroccan and Turkish mothers was significantly higher at the age of 14 months compared to children with mothers of Dutch origin. No interaction was observed between pBMI and ethnicity. Also no interaction was observed between pBMI and gender.

DISCUSSION

The results of this large, community-based cohort study showed that maternal pBMI was a major independent determinant of the weight and BMI of the child at age 14 months. This effect can be partly explained by the influence of pBMI on growth during the intrauterine period (reflected in birth weight), but the greatest effect is after birth. The child's weight can be mediated by postnatal factors (eg, feeding) but also by other unknown intrauterine factors which do not influence birth weight. The effects were similar equal across all ethnic groups, but ethnicity had a large additional effect on the weight and BMI of the child, even after full adjustment for maternal, paternal and child factors.

Table 5 Univariable and multivariable associations between maternal pre-pregnancy BMI (pBMI), intrauterine, child and maternal factors, and BMI of the child (kg/m^2) at age 14 months

		Multivariable effects†	
	Univariable effects (adj R^2 0.027), β coefficient (95% CI)	Model 1 (adj R^2 0.081), β coefficient (95% CI)	Final model (adj R^2 0.100), β coefficient (95% CI)
pBMI (kg/m^2)	0.041 (0.030 to 0.053)***	0.034 (0.023 to 0.046)***	0.031 (0.019 to 0.043)***
<18.5	−0.46 (−0.69 to −0.23)***	−0.36 (−0.59 to −0.13)*	−0.36 (−0.58 to −0.13)*
18.5–19.9	−0.20 (−0.35 to −0.045)*	−0.14 (−0.29 to 0.003)	−0.12 (−0.27 to 0.026)
20–24.9	Reference	Reference	Reference
25–29.9	0.21 (0.069 to 0.35)**	0.18 (0.049 to 0.33)*	0.14 (−0.001 to 0.27)
⩾30	0.35 (0.14 to 0.55)**	0.27 (0.075 to 0.47)*	0.24 (0.035 to 0.44)*
Birth weight (kg)	0.56 (0.46 to 0.66)***	0.60 (0.49 to 0.71)***	0.63 (0.52 to 0.75)***
Gestational age (weeks)	−0.23 (−0.63 to −0.018)***	−0.11 (−0.15 to −0.066)***	−0.11(−0.15 to −0.067)***
Female gender	−0.38 (−0.48 to −0.28)***	−0.32 (−0.42 to −0.22)***	−0.31 (−0.41 to −0.21)***
Duration of breastfeeding			
None	Reference		Reference
<1 month	0.26 (0.094 to 0.42)*		0.16 (000 to 0.32)*
1–3 months	0.14 (−0.022 to 0.31)		0.067 (−0.98 to 0.23)
4–6 months	−0.015 (−0.18 to 0.15)		−0.058 (−0.23 to 0.11)
>6 months	0.037 (−0.13 to 0.21)		−0.079 (−0.25 to 0.095)
Maternal age (years)	−0.010 (−0.019 to 0.000)*		−0.012 (−0.022 to −0.002)*
Maternal education			
<5 years	0.18 (0.043 to 0.32)*		–
5–10 years	−0.044 (−0.15 to 0.065)		
>10 years	Reference		
Ethnicity			
Dutch	Reference		Reference
Surinamese	−0.14 (−0.37 to 0.088)		−0.13 (−0.37 to 0.11)
Moroccan	0.57 (0.39 to 0.75)***		0.46 (0.26 to 0.66)***
Turkish	0.61 (0.38 to 0.84)***		0.51 (0.27 to 0.75)***
Other non-Western country	−0.10 (−0.26 to 0.056)		−0.11 (−0.28 to 0.059)
Other Western country	−0.041 (−0.23 to 0.15)		0.037 (−0.15 to 0.23)

†Multivariable effects are results with pBMI continuous in the model.
*p<0.05; **p<0.01; ***p<0.001.
All adjusted for age of the child at measurement BMI 14 months. The residuals from all models were normally distributed and variances were homogeneous. Maternal and paternal height, parity, pre-existing hypertension, diabetes, alcohol use, smoking and cohabitant status were not significant associated with BMI of the child at age 14 months in any model.

The effect of maternal pBMI has been demonstrated previously.[28–34] Griffiths and co-workers[34] showed that maternal weight and height were both predictors for birth weight and infant weight gain during the first 9 months, but to our knowledge, this is the first study which separates the effect size of maternal BMI into effects before and after birth. While the effect of pBMI on birth weight can be thought of as a result of maternal nutrient supply (direct) and fetal regulation (indirect) mechanisms, the effect on infant weight depends on feeding and neonatal regulation, where a carry-over effect of fetal regulation may exist. The mechanism appears universal, but varying ethnicity related weight distributions will result in different infant weight distributions.

Strengths of our study were the large study population with sufficient numbers in the ethnic groups and the ability to control for maternal, paternal and infant factors. A limitation was that calculations of the women's pBMI were based on self-reported weight and height. Self-reported height tends to be slightly overestimated and self-reported weight underestimated, resulting in an underestimation of BMI.[35] However, since we used BMI as a continuous variable this has little effect.[35] Also this would lead to an underestimation rather than an over-estimation of the association. A second limitation was that we did not have any information on paternal weight, gestational weight gain, the age complementary feeding was started or maternal diet and physical activity during pregnancy. Griffiths *et al*[34] demonstrated in 2007 that the influence of parental height and weight on birth weight and infant weight gain is similar for both parents, with the exception of the influence of weight on birth weight where the mother has a greater effect than the father. Our results with respect to parental height are in agreement with these findings. Gestational weight gain, specifically in combination with maternal pBMI, has been shown to be associated with birth weight.[36 37] The age at starting complementary feeding was demonstrated to be related to infant weight. Baker *et al*[30] showed that the age at starting complementary feeding was negatively associated with infant weight gain at age 1 year. Unfortunately, at this time, we have incomplete information about the age when complementary feeding was started in our cohort, so we could not impute it in the analysis. Existing studies have never controlled for maternal diet and physical activity during pregnancy. Also our study did not control for these covariates, but it should be considered that these may influence the infants' weight. Finally, BMI at age 14 months should be interpreted carefully. Firstly, BMI is based on total weight and not on fat mass as such, hence it is not a direct measure of adiposity. Percentage of fat would be a better measurement, but this is not measured by the child health care services. Secondly, we should be careful with the definition of obesity as at this young age there are no unequivocal cut-off points to define obesity.[38] Finally, we do not know how predictive actual BMI at this age is for later life.

The intermediate role of birth weight in the relationship between pBMI and weight during infancy is in accordance with numerous animal and human studies.[39] As regards its relevance for obesity and adiposity in later life, many different relationships have been suggested.[32 40 41] Low and high birth weight were both demonstrated to be associated with high weight at a later age. Our results support a linear association across the full range of predictive maternal BMI within the given time frame of 14 months.

Our results show that longer duration (>3 months) of breast feeding was associated with a lower weight at age 14 months. This is in accordance with previous studies which demonstrated that longer duration of breast feeding was associated with slower growth resulting in lower weight at age 1 year.[30 42 43] Also our results show that height at this age is influenced by duration of breast feeding. Children who were breast fed for more than 6 months were smaller at age 14 months.

Several mechanisms could explain the association between BMI before pregnancy and the weight/BMI of the child. First of all, it may be the result of a genetic mechanism.[34] The influence of the height of father and mother on the weight of the child after birth indicates a genetic component in growth. However, twin studies showed that an obesogenic environment during pregnancy also effects the offspring. Numerous animal as well as human studies show that programming during pregnancy, and during infancy, is associated with changes in the set-point of regulatory systems resulting in adverse adipocyte metabolism.[1 44] A high maternal BMI could result in enhanced exposure of the fetus to insulin and leptin with effects on energy balance and appetite regulation programming.[1 44] There is also evidence that the constitution of breast milk of obese mothers is different, resulting in increased risk for overweight in their children.[45 46] Apart from these physiological mechanisms, there could also be a behavioural factor. Obese mothers might introduce foods too early (before 4 months) or give more (hypercaloric) food. The opposite could be true for underweight mothers.

The relationship between pBMI and the weight/BMI of the child was the same for all ethnic groups; however, ethnicity appeared to be a highly independent factor for weight and BMI at 14 months. Children from Turkish and Moroccan mothers were heavier and had higher BMI at the age of 14 months. There were no differences in birth weight between these groups, which indicated that children of Turkish and Moroccan ethnicity grow faster than Dutch children. Ethnic differences in growth have been previously reported but mostly at older ages.[47 48] Our results show that these differences could have their origin in early life. Feeding patterns could play a role but more studies are needed to elucidate these differences.

It is tempting to conclude that increased maternal BMI has negative effects, but the evidence so far is limited. As average BMI changes rapidly during early childhood, and individual patterns of growth may differ, it is difficult to define overweight or obesity at 14 months, or to select cut-offs for prediction of overweight in later life. A recent systematic review by Baird[49] concluded that children with the highest weight or BMI during infancy and children with rapid growth were both at increased risk of obesity in adulthood (relative risk (RR) 1.4–9.4 for infant obesity, RR 1.2–5.7 for rapid early growth). Our results showed pBMI is related to both higher birth weight and higher weight and BMI at 14 months given the birth weight; hence children of obese mothers not only have a higher birth weight but also grow faster compared to children of non-obese mothers. According to Baird, these children should have double the risk of obesity in later life, but direct evidence is lacking.

In conclusion, our study shows that maternal pBMI is a strong determinant of the weight and BMI of the child at the age of 14 months due to the influence of pBMI on fetal growth and growth during the first year of life. More studies are needed to explore this complex relationship and its possible consequences. However, if high weight or BMI at this early age is predictive of obesity later in life, prevention of obesity should start before pregnancy by reducing BMI in overweight and obese women. Special attention should be paid to women from ethnic minorities as they have the highest prevalence of overweight and obesity and their children grow faster.

Acknowledgements: We thank the women who participated in the Amsterdam Born Children and their Development study. We also thank all the midwife practices and hospitals in Amsterdam, The Netherlands, for their continued assistance.

Funding: This study was supported by a research grant from The Netherlands Organisation for Health Research and Development (ZonMw), The Hague.

Competing interests: None.

Ethics approval: The study protocol was approved by the medical ethical committees of all Amsterdam hospitals and the Registration Committee of Amsterdam.

Patient consent: Obtained.

Contributors: MFW and GJB designed and initiated the cohort study. MFW and TGMV coordinated the data collection, and IM and TGMV analysed the data. All authors met regularly and contributed to the study management, and all participated in the interpretation of the results and in writing of the paper. TGMV is the guarantor.

Statement of independence of researchers from funders: All authors declare they are independent from funders.

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