RESEARCH REPORT

Maternal diet in pregnancy and offspring height, sitting height, and leg length

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J Epidemiol Community Health 2005;59:467–472. doi: 10.1136/jech.2004.029884

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Accepted for publication
3 January 2005

Study objective: To examine the association between maternal diet in pregnancy and offspring height, sitting height, and leg length.

Design: Cohort study.

Setting: South west England.

Participants: 6663 singletons (51% male) enrolled in the Avon longitudinal study of parents and children, with information on their mother's diet in late pregnancy (obtained by food frequency questionnaire) and their own height recorded at age 7.5 years.

Main results: Before adjustment, maternal magnesium, iron, and vitamin C were the nutrients most consistently associated with offspring height and its components. However, adjusting for potential confounders weakened all relations considerably. For example, a standard deviation (SD) increase in magnesium intake was associated with a 0.10 (−0.07, 0.14) SD unit increase in height before adjustment, which was reduced to 0.05 (0.01, 0.08) SD units after adjustment, and a SD unit increase in iron intake was associated with 0.08 (0.05, 0.12) and 0.04 (0.01, 0.08) SD unit increases in height before and after adjustment respectively. No other dietary variables were associated with height or its components after adjustment.

Conclusions: These findings do not provide evidence that maternal diet in pregnancy has an important influence on offspring height, sitting height, or leg length in well nourished populations, although effects may emerge as offspring become older.

Many studies have reported higher mortality in those with short stature.¹ This is mainly explained by the higher rates of cardiorespiratory disease in shorter people,² although accumulating evidence suggests that greater stature is associated with higher cancer mortality.^{2–3} Some studies have found associations between components of height, leg length in particular, and coronary heart disease and its risk factors.^{4–7} Therefore, an understanding of the determinants of height and its components is required.

Small size at birth has been associated with disease in later life,⁸ and it has been shown that it is possible to modify birth weight. For example, although only limited effects of maternal diet on birth weight have been found in well nourished populations,^{9–10} important effects have been shown in less well nourished populations such as those in low socioeconomic groups in the UK,¹¹ the Dutch Hunger Winter,¹² and the Gambia.¹³ Data on measurements other than weight at birth are scarce, but some associations with maternal diet have been found with length,^{11–14} head circumference,^{11–12} and thinness.¹⁰

Our hypothesis was that diet in pregnancy might programme growth and its components in the offspring. Few studies have looked at associations between maternal diet and later offspring growth, and most were from under-nourished populations. They were either based on randomised controlled trials (RCTs) of food or nutrient supplementation,^{15–18} or exposure to unusual dietary circumstances,^{19–20} and none assessed the effects of nutrient intakes or foods in diets typical of the population studied. In other studies, the diets of children as well as their mothers' were supplemented²¹ so it is not possible to assess maternal effects on offspring height independently. Although early life factors such as breast feeding and energy intake at 4 years of age have been associated with later leg length,²² to our knowledge, the effect of maternal diet on offspring leg length

and sitting height has not been assessed. We therefore examined whether maternal diet in late pregnancy is associated with offspring height and its components at age 7.5 years in a large contemporary cohort.

METHODS

Study population

The Avon longitudinal study of parents and children (ALSPAC) is a population based study investigating environmental and other factors that affect the health and development of children. The study methods are described in detail elsewhere²³ and on the study web site (<http://www.alspac.bris.ac.uk>). In brief, pregnant women living in three health districts in Bristol, England who had an expected date of delivery between the start of April 1991 and end of December 1992 were eligible. Altogether 14 541 women, about 85% of those eligible, enrolled in the study, and of these, 11 211 had a white singleton live born child. Detailed information was obtained from the mother using four self report questionnaires, two of which were timed to be undertaken at 18 and 32 weeks of the pregnancy, and the other two before this, at various time points depending on the gestation at enrolment. After delivery, questionnaires were tied to the age of the child. In the 32 week antenatal questionnaire, the mother was asked to record details of her current diet using a food frequency questionnaire. The whole cohort of children was invited to attend an examination that included measurement of height and its components for the first time at about age 7.5 years; at this age we could be confident that we were measuring pre-pubertal children. After restriction to white singleton live births, maternal diet in pregnancy was recorded for 10 798, and the examination at age 7.5 was attended by 6926 of which height was recorded for 6873; this allowed 6663 to be used for the analysis. Ethical

Table 1 (A) Summary of maternal diet variables (32 weeks' gestation) for 6663 white singleton children enrolled in ALSPAC with information on height at age 7.5 years

	Mean	SD
Energy (KJ/day)	7508	1964
Carbohydrate (g/day)	223	61
Protein (g/day)	68	18
Total fat (g/day)	71	23
Saturated fat (g/day)	29	11
Polysaturated fat (g/day)	25	8
Monounsaturated fat (g/day)	13	6
Calcium (mg/day)	950	275
Potassium (mg/day)	2620	634
Magnesium (mg/day)	260	74
Iron (mg/day)	11	3
Retinol (mg/day)	3448	2367
Vitamin C (mg/day)	83	34
Vitamin D (mg/day)	3	1
Folate (μ g/day)	256	70
Omega-3 fatty acids (g/day)	0.2	0.1
Milk (ml/day)	371	159
Meat (portions/day)	0.8	0.4
Fish (portions/day)	0.3	0.2
Fruit (portions/day)	0.8	0.5
Vegetables (portions/day)	1.6	0.8

approval of the study was obtained from the ALSPAC law and ethics committee and local research ethics committees.

Maternal diet

The foods chosen for the food frequency questionnaire (110 questions) were based on those used by Yarnell *et al*,²⁴

Table 1 (B) Summary of non-dietary variables for 6663 white singleton children enrolled in ALSPAC with information on maternal diet and height at age 7.5 years

	Number	Mean	SD
Child age (months)	6663	89.8	2.2
Maternal age (years)	6663	29.2	4.5
Maternal height (cm)	6458	164.3	6.6
Maternal BMI (kg/m^2)	6159	22.9	3.7
Sex	Number	%	
Male	3376	50.7	
Female	3287	49.3	
Mother smoked in pregnancy			
No	5722	86.5	
Yes	893	13.5	
Parity			
Primip	2938	45.0	
Multip	3589	55.0	
Breast fed			
No	892	13.8	
Yes	5577	86.2	
Social class			
I	239	3.7	
II	1690	25.8	
III NM	1762	26.9	
III M	1759	26.8	
IV	880	13.4	
V	226	3.5	
Maternal education			
CSE/none	848	12.8	
Vocational	569	8.6	
O levels	2394	36.0	
A levels	1770	26.6	
Degree	1067	16.1	
Currently married			
No	1061	16.1	
Yes	5536	83.9	

modified in the light of a more recent weighed dietary survey.²⁵ Mothers were asked how often they were currently eating each type of food, and from this, nutrient intakes based on standard sized portions were estimated using the 5th edition of McCance and Widdowson's *The Composition of Foods* and its supplements.²⁶⁻³² A full description of the methods used is given elsewhere.³³ For this analysis, estimated daily intakes of 16 nutrients from food sources were included (energy, carbohydrate, protein, total fat, saturated fat, polyunsaturated fat, monounsaturated fat, calcium, potassium, magnesium, iron, retinol, vitamin C, vitamin D, folate, and marine omega-3 fatty acids); associations with all of these had been investigated with offspring growth in the literature, and/or with offspring blood pressure in previous analysis of the ALSPAC cohort.³⁴ Five food groups were included in analysis, each of which was an important source of a specific nutrient, to enable diet to be described in more detail (milk in millilitres per day, and meat, fish, fruit, and vegetables in number of portions per day).

The mother was asked if she had taken any dietary supplements during the pregnancy so far at 18 weeks, and in the previous three months at 32 weeks; this information was combined to show whether she had taken any dietary supplements in the first 32 weeks of pregnancy. Additionally, in three of the antenatal questionnaires the mother was asked to list any pills or medicines taken, hence indication of any nutrient intake from these was derived for the first 32 weeks of pregnancy. As dose and frequencies were not available for supplements or medication, these were not combined with dietary intakes.

Offspring height

Height and sitting height of the child were measured to the nearest 0.1 cm using a Harpenden stadiometer. Leg length was derived by subtracting sitting height from height.

Confounding factors

At enrolment, the mother was asked to record her height and pre-pregnancy weight, from which body mass index (BMI) was calculated using $\text{weight}/\text{height}^2$, with weight in kilograms and height in metres. She was also asked her date of birth, from which her age at delivery was calculated. In the 18 week antenatal questionnaire she was asked whether she had smoked in the previous two weeks. She was also asked to detail all her previous pregnancies, from which the number of pregnancies resulting in either a live birth or stillbirth was derived. This was collapsed into none (primips) or one or more (multips) for analysis. The 32 week antenatal questionnaire asked the mother to record her marital status, her highest education level (collapsed into CSE/none, vocational, O level, A level, or degree), and the occupation of both the mother and her partner. The latter was used to allocate the mother and partner to social class groups (classes I to V with III split into non-manual and manual) using the 1991 OPCS classification,³⁵ and the lowest class was used in analysis. In the 4 week, 6 month, and 15 month postnatal questionnaires, the mother was asked if she had breast fed her child.

Statistical analysis

Means and standard deviations (SDs) were calculated for continuous variables and proportions for categorical variables. The effects of confounding factors on offspring height, sitting height, and leg length were assessed using linear regression.

Associations between each maternal dietary variable and each offspring outcome were firstly examined using separate minimally adjusted models (child's sex, child's age at the time of height measurement, maternal energy intake in pregnancy). Adjustment was made for energy intake as it is

Table 2 Univariate regressions of offspring height, sitting height, and leg length at age 7.5 years on non-dietary variables

	Height (cm)			Sitting height (cm)			Leg length (cm)		
	β	95% CI	P	β	95% CI	p	β	95% CI	p
Age (months)	0.46	0.41, 0.52	<0.001	0.19	0.16, 0.22	<0.001	0.28	0.24, 0.31	<0.001
Maternal age (years)	0.05	0.02, 0.08	0.001	0.02	0.003, 0.03	0.02	0.03	0.01, 0.05	<0.001
Maternal height (cm)	0.31	0.30, 0.33	<0.001	0.14	0.13, 0.15	<0.001	0.18	0.16, 0.19	<0.001
Maternal BMI (kg/m ²)	0.05	0.02, 0.09	0.01	0.04	0.03, 0.06	<0.001	0.01	-0.01, 0.03	0.5
Sex (v male)									
Female	-0.88	-1.13, -0.62	<0.001	-0.66	-0.79, -0.53	<0.001	-0.23	-0.38, -0.07	0.01
Mother smoked in pregnancy (v no)									
Yes	-0.49	-0.86, -0.11	0.01	-0.11	-0.30, 0.09	0.3	-0.39	-0.62, -0.16	0.001
Parity (v primip)									
Multip	-0.47	-0.73, -0.21	<0.001	-0.21	-0.35, -0.08	0.002	-0.25	-0.41, -0.10	0.002
Breast fed (v no)									
Yes	0.59	0.21, 0.96	0.002	0.23	0.03, 0.42	0.02	0.36	0.13, 0.59	0.002
Social class (v I)									
II	-0.18	-0.90, 0.54		-0.07	-0.44, 0.30		-0.10	-0.54, 0.34	
III NM	-0.03	-0.75, 0.69		-0.01	-0.38, 0.35		-0.02	-0.45, 0.42	
III M	-0.49	-1.21, 0.23		-0.24	-0.61, 0.12		-0.24	-0.68, 0.20	
IV	-0.24	-1.00, 0.52		-0.09	-0.48, 0.30		-0.15	-0.61, 0.31	
V	-1.43	-2.40, -0.46	0.01	-0.62	-1.12, -0.13	0.02	-0.81	-1.39, -0.22	0.01
Maternal education (v CSE/none)									
Vocational	0.64	0.07, 1.20		0.29	-0.002, 0.58		0.35	0.01, 0.69	
O levels	0.52	0.10, 0.94		0.23	0.02, 0.45		0.29	0.03, 0.54	
A levels	0.78	0.34, 1.22		0.41	0.18, 0.63		0.38	0.12, 0.65	
Degree	0.96	0.48, 1.44	<0.001	0.45	0.21, 0.70	<0.001	0.51	0.21, 0.80	0.001
Currently married (v no)									
Yes	0.19	-0.16, 0.54	0.3	0.08	-0.10, 0.26	0.4	0.11	-0.10, 0.32	0.3

p Values for trend given if more than two categories.

positively correlated with the consumption of most nutrients, so it was necessary to account for the variation in nutrient intake attributable to individual differences in total energy intake, which is unrelated to dietary composition.³⁶ Analyses were repeated with additional adjustment for maternal factors (age, height, BMI, smoking in pregnancy), parity, breast feeding, social class, maternal education, and marital status. For all analyses relating maternal diet to offspring outcomes, SD scores were used for all variables to enable comparisons to be made across nutrients/food groups and across height and its components. These were calculated by subtracting the mean from the person's value, then dividing by the SD (mean and SD based on whole sample). Analyses were performed using Stata version 8.

RESULTS

The mean (SD) height, sitting height, and leg length were 126.6 (5.4) cm, 67.9 (2.7) cm, and 57.7 (3.2) cm respectively, based on 6663 for height and 6659 for sitting height and leg length. Table 1A summarises the dietary variables and table 1B the non-dietary variables. Children who attended the examination did not differ from those who did not, with respect to sex, number of older siblings, and maternal BMI. However, they were more likely to have been breast fed and come from more affluent and better educated families. Also, their mothers were slightly taller, older, and were less likely to have smoked during pregnancy.³⁷

All the analysed non-dietary variables were univariately associated with height and its components, with the exception of marital status (table 2). Hence adjustment was made for all these factors in models investigating the relation between maternal diet and offspring height, sitting height, and leg length.

After minimal adjustment (sex, age, and maternal energy intake), maternal magnesium, iron, vitamin C, and fruit intakes were the most consistently associated with offspring height and its components (table 3). However, full adjustment (maternal factors, parity, breast feeding, and social factors) weakened all relations considerably. The only

remaining associations were between magnesium and iron intakes and the offspring outcomes, but effect sizes had been halved. The effects of magnesium and iron intake were unchanged after excluding those who took supplements (iron only) or drugs containing these nutrients during pregnancy (data not shown). If men and women were analysed separately, findings were similar for all nutrients and food groups except vitamin C and fruit; associations with offspring outcomes remained after full adjustment for men but not women (p for interaction between sex and vitamin C/fruit ranged from 0.002 to 0.06). No associations were seen between maternal diet and offspring leg to trunk ratio after minimal or full adjustment (mean (SD) 85.0 (3.9) %) (data not shown).

DISCUSSION

This study, based on a large, contemporary population, does not provide convincing evidence that maternal diet in late pregnancy is associated with offspring height and its components at age 7.5 years. The nutrient effect sizes were of a similar order of magnitude for all three outcomes, so specific nutrients affecting each component of height were not identified. The strongest associations were seen with maternal magnesium, iron, and vitamin C intakes, although these were substantially weakened after adjustment for potential confounders. This is not surprising as diet is known to be socially patterned,³⁸ so adjusting for social factors is likely to remove a large proportion of any associations found. Rogers *et al*³⁹ have shown that financial difficulties are associated with a lower intake of most nutrients, using the dietary data from the ALSPAC mothers that we have used in this paper. It is possible that poor maternal nutrition may be part of the causal chain from low social class to impaired childhood growth. If this is the case, adjustment for social class would not be appropriate and unadjusted models may better estimate the association.

It is possible that different results would have been obtained if all children whose mothers originally enrolled in the study were able to be included in the analysis.

Table 3 Regressions of offspring height, sitting height, and leg length at age 7.5 years on maternal dietary variables (32 weeks' gestation)

Daily dietary intake (SD units)	Height (SD units)				Sitting height (SD units)				Leg length (SD units)			
	β^*	95% CI*	p*	pt	β^*	95% CI*	p*	pt	β^*	95% CI*	p*	pt
Energy	-0.01	-0.04, 0.01	0.2	0.2	-0.01	-0.04, 0.01	0.2	0.2	-0.01	-0.03, 0.01	0.4	0.4
Carbohydrate	-0.05	-0.12, 0.01	0.1	0.02	-0.06	-0.12, 0.01	0.08	0.08	-0.04	-0.10, 0.03	0.3	0.3
Protein	0.07	0.03, 0.11	0.001	0.02	0.06	0.02, 0.10	0.003	0.3	0.06	0.02, 0.10	0.004	0.6
Total fat	-0.03	-0.08, 0.03	0.3	-0.04	-0.10, 0.01	-0.02	0.5	0.5	-0.03	-0.08, 0.03	0.3	0.4
Saturated fat	-0.002	-0.01, 0.002	0.3	-0.002	-0.01, 0.002	-0.002	0.3	0.2	-0.002	-0.01, 0.002	0.4	0.2
Polysaturated fat	0.01	-0.02, 0.04	0.4	0.002	0.02	-0.01, 0.05	0.1	0.2	0.003	-0.03, 0.03	0.8	0.6
Monounsaturated fat	-0.01	-0.07, 0.04	0.6	-0.01	-0.0005	-0.06, 0.06	0.99	0.8	-0.02	-0.08, 0.03	0.4	0.6
Calcium	0.04	0.01, 0.08	0.02	0.02	0.05	0.01, 0.08	0.01	0.3	0.03	-0.001, 0.07	0.06	0.5
Potassium	0.06	0.02, 0.10	0.004	0.03	0.06	0.02, 0.10	0.01	0.2	0.05	0.01, 0.09	0.02	0.2
Magnesium	0.10	0.07, 0.14	<0.001	0.05	0.09	0.06, 0.13	<0.001	0.01	0.09	0.06, 0.13	<0.001	0.05
Iron	0.08	0.05, 0.12	<0.001	0.04	0.07	0.04, 0.11	<0.001	0.05	0.07	0.04, 0.11	<0.001	0.1
Retinol	-0.01	-0.04, 0.02	0.4	-0.01	-0.001	-0.03, 0.02	0.9	0.9	-0.02	-0.04, 0.01	0.2	0.3
Vitamin C	0.05	0.03, 0.08	<0.001	0.02	0.05	0.02, 0.07	<0.001	0.02	0.04	0.02, 0.07	0.001	0.4
Vitamin D	0.04	0.02, 0.07	0.002	0.01	0.04	0.02, 0.07	0.001	0.02	0.03	0.01, 0.06	0.01	0.5
Folate	0.05	0.01, 0.08	0.01	0.02	0.04	0.01, 0.07	0.01	0.3	0.04	0.01, 0.07	0.01	0.5
Omega-3 fatty acids	0.04	0.01, 0.06	0.004	0.01	0.04	0.02, 0.06	0.001	0.02	0.03	0.003, 0.05	0.03	0.8
Milk	-0.002	-0.03, 0.03	0.9	0.01	-0.002	-0.02, 0.03	0.9	0.7	-0.005	-0.03, 0.02	0.7	0.4
Meat	-0.02	-0.04, 0.01	0.2	-0.005	-0.02	-0.05, 0.002	0.07	0.2	-0.01	-0.04, 0.02	0.4	0.6
Fish	0.03	0.01, 0.05	0.02	0.01	0.03	0.01, 0.06	0.01	0.2	0.02	-0.002, 0.05	0.08	0.98
Fruit	0.00	0.03, 0.08	<0.001	0.01	0.06	0.03, 0.08	<0.001	0.02	0.05	0.02, 0.07	0.001	0.6
Vegetables	0.01	-0.01, 0.04	0.3	-0.0003	0.02	-0.004, 0.04	0.1	0.1	0.01	-0.02, 0.03	0.6	0.5

*Minimally adjusted (sex, child's age for height measurement, maternal pregnancy energy intake), †Fully adjusted (sex, age, energy intake, maternal factors (age, height, BMI, smoking in pregnancy), parity, breast feeding, social class, maternal education, and marital status).

Key points

- Our data suggest that maternal magnesium, iron, and vitamin C intakes during pregnancy may be associated with offspring height, sitting height, and leg length at age 7.5 years.
- However, adjusting for potential confounders substantially weakened these possible associations.
- No other associations between maternal diet in pregnancy and offspring height and its components were seen.

However, it is unlikely that inclusion of more children would create associations between maternal diet and offspring height and its components, and those who attended the physical examination and hence used in this analysis have been shown to be similar to those that did not in many respects.³⁷ In addition, findings were similar if the unadjusted analysis was restricted to those with complete data on all confounders rather than including any with available data, providing some reassurance that attrition is unlikely to have biased results.

Diet was recorded at 32 weeks' gestation, and assessment before conception, or earlier in pregnancy may have been preferable. Because of the large number of subjects it was necessary to use unquantified food frequency questionnaires to assess maternal diet—that is, no portion sizes were recorded. Food and nutrient intakes derived from these may be less accurate than those obtained from weighed intakes. The food frequency questionnaire in the form used has not been formally calibrated against diet diaries or biomarker levels in this study. However, the questionnaire on which it was based has been validated in another population.²⁴ Furthermore, the women's intakes in this study were generally very similar to the reported intakes for all women aged 16–64 in the last dietary and nutritional survey of British adults, based on a seven day weighed intake.^{33–40} Also, Williams *et al*⁴¹ have shown a relation between consumption of oily fish in pregnancy and measures of red cell DHA in the maternal blood in the ALSPAC cohort, supporting the validity of the dietary data.

The lack of strong associations between maternal diet and offspring height found in our data supports the sparse published data on this topic. Studies comparing 50 year olds who were exposed to the Siege of Leningrad¹⁹ or the Dutch Famine²⁰ in utero with those who were not exposed did not find differences in height. RCTs of protein and/or vitamin supplementation,¹⁵ protein supplementation,¹⁶ and vitamin A supplementation¹⁸ of mothers during pregnancy did not show associations with length in infancy. However, energy supplementation in pregnancy was related to increased height in children up until age 5 years in another RCT,¹⁷ although this inconsistency with our findings may be explained by the poorer nutritional status of the mothers in the East Java study. We were unable to identify any previous studies that assessed the effect of maternal diet of offspring sitting height or leg length.

Policy implications

Our findings do not suggest that in well nourished populations, changes in maternal diet in late pregnancy have any effect on offspring height and its components.

It is possible that effects of maternal diet on height and its components may begin to emerge as the children grow older. However, as height tracks over time, the overall ranking of subjects according to their height is likely to remain similar, and hence associations with maternal diet in pregnancy would not change substantially. Our data do not suggest that dietary recommendations for pregnancy should be changed because of any effect on offspring height. Other cohorts with good quality data at different stages in pregnancy are needed to confirm that there is indeed no association between maternal diet in pregnancy and offspring height and its components in well nourished populations. It would also be informative to investigate associations with maternal dietary patterns using a composite index, in addition to specific nutrients and food groups.

ACKNOWLEDGEMENTS

We are grateful to all the women and children who took part in this study, the midwives for their help in recruiting them, and the whole ALSPAC team, which includes interviewers, computer and laboratory technicians, clerical workers, research scientists, volunteers, managers, receptionists, and nurses. SDL extracted the data from the main database, performed all analyses, and wrote the first draft of the paper. AN and GDS helped plan the analyses with SDL and commented on drafts of the manuscript. PE oversaw the collection and coding of the dietary data and commented on drafts of the manuscript. All authors saw and approved the final draft.

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Funding: this study would not have been undertaken without the financial support of the Medical Research Council, the Wellcome Trust, the UK Department of Health, the Department of the Environment, the DfEE, the National Institutes of Health, and a variety of medical research charities and commercial companies. ALSPAC is part of the World Health Organisation initiated European longitudinal study of parents and children.

Conflicts of interest: none declared.

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