Original Article

Does low birthweight influence the nutritional status of children at school age? A cohort study in northeast Brazil

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Abstract

Birthweight is recognized to be a determinant of a full term infant's early growth pattern; however, few studies have explored whether this effect is sustained into school age, especially in developing countries. We have used a cohort study from North East Brazil to investigate factors determining the anthropometric status of eight-year-old children born at full-term with low or appropriate weight. A cohort of 375 full-term infants was recruited at birth in six maternity hospitals between 1993 and 1994, in a poor region of the interior of the State of Pernambuco. At the age of 8 years, 86 born with low birthweight and 127 with appropriate birthweight were traced. Multivariable linear regression analyses were used to identify the net effect of socioeconomic conditions, maternal nutritional status and child factors on weight-for-age and height-for-age. An enter approach was used to estimate the contribution of different factors on child anthropometry. Birthweight had little influence on child nutritional status at school age. Maternal BMI and height together were the biggest contributors to variation in child weight-for-age (12.3%) and height-for-age (13.2%), followed by family socioeconomic conditions. Maternal height as a proxy of maternal constraint was the single factor that best explained the variation in both indices (6.2% for weight-for-age and 11.1% for height-for-age). Haemoglobin level measured at eight years made a small but significant contribution to variation in height-for-age (5.6%) and weight for age (1.4%). Maternal nutritional status, reflecting genetic inheritance and the poor socioeconomic conditions of this population, was the most important determinant of the nutritional status of children at school age, rather than birthweight.

Keywords: low birthweight, child weight-for-age, child height-for-age, maternal constraint, maternal BMI, maternal height.

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Introduction

Nutritional status *in utero* and during childhood is the result of the interaction between genetic endowment and environmental influences. During fetal life, maternal genetic potential can limit growth, and in resource-poor settings, this limitation is compounded

by inadequate inter-uterine nutrition to result in low birthweight (LBW). Once born, LBW, combined with a detrimental environment, then leads to unfavourable conditions that end up compromising nutritional status during childhood (Kramer 1987; Laurentino *et al.* 2005). The subsequent growth of low-birthweight infants shows distinct patterns related to

body proportion at birth (Villar *et al.* 1984; Cheung *et al.* 2002), with wasted infants showing less persisting growth impairment than stunted infants. During early childhood, children born with LBW are prone to increased morbidity and more frequent hospitalizations, particularly due to respiratory and diarrhoeal infections, especially in developing countries (Barros *et al.* 1992; Lira *et al.* 1996). The relationship between infection and malnutrition is complex. Resistance to infection is reduced if the child's nutritional status is compromised, but on the other hand, infections may impact on child nutrition through their influence on appetite, food acceptance and food absorption. Micronutrient deficiencies, including iron and zinc, are frequently associated with protein-calorie malnutrition and may have a marked influence on the host's response to infection. Iron deficiency anaemia predisposes towards increased child morbidity and, in turn, recurrent infections do not allow adequate catch-up growth (Rivera *et al.* 2003). In resource-poor settings, the combination of micronutrient deficits and impaired host response to infection may set up a vicious cycle of interactions between LBW, inadequate dietary and feeding practices, repeated infections, unhealthy environments, lack of maternal care and difficulty in accessing health services (Branca & Ferrari 2002).

A cohort study conducted in an economically deprived region in northeast Brazil previously showed LBW to be a determinant of nutritional

status at 12 months (Eickmann *et al.* 2006). Follow-up of this cohort at age 8 years provided an opportunity to explore whether the negative effect of LBW at term on early growth was still detectable in middle childhood. The specific aim of this follow-up study was to compare the influence of maternal, child and environmental factors on anthropometric status at 8 years of age of children born at term with low weight and appropriate weight. The principal hypothesis to be tested was that LBW had a stronger influence than environmental factors on height at age 8 years.

Materials and method

Study location

The study was conducted in five municipalities in the interior of the State of Pernambuco (Água Preta, Catende, Joaquim Nabuco, Ribeirão and Palmares). These small towns are 130 km from Recife (the state capital) and have a total population of 174 000 inhabitants. The main economic activity in the region is agriculture, especially relating to the production and processing of sugar cane. This type of work is of a seasonal nature, and there is high unemployment and widespread poverty during the periods between the sugar cane crop seasons. Illiteracy among the women was approximately 30%; the prevalence of LBW was 9%; and the infant mortality rate was 85/1000 live births (Lira *et al.* 1996).

Key messages

- The influence of low birthweight on nutritional status of infants at 1 year of age was not sustained at school age, being replaced by the predominant influence of factors relating to the mother's nutritional status.
- Mothers' height and BMI reflect the socio-economic conditions of poverty found among this population, and formed the block of variables that contributed most towards the variation in the child's weight- and height-for-age.
- The rate of previous hospitalization was much higher among the full-term low birthweight children. This is an important indicator of morbidity that leads to the worsening of nutritional status, especially in relation to deficits in micronutrients like iron.
- Haemoglobin levels, reflecting concurrent nutritional deficiencies, were also independently associated with weight and height at 8 years.
- Overall, the most important influences on the variability in weight- and height-for-age at 8 years were socio-economic conditions and maternal nutritional status.

Birth cohort

The original cohort consisted of 375 children born at term: 163 had LBW and 212 had appropriate birthweight (ABW). The cohort specifically excluded preterm infants and was designed to investigate the consequences of intrauterine growth restriction in full-term deliveries. The newborns were recruited within their first 24 h of life, in six maternity hospitals within the geographic area of the study, during 1993 and 1994.

Infants whose weight was from 1800 to 2499 g formed the LBW group. Each one was paired by sex with the next infant born weighing from 3000 to 3499 g (ABW). The inclusion criteria were as follows: belonging to a family with a monthly income of less than three minimum salaries for the region (equivalent at that time to US\$70) and having the intention of continuing to live in the study area. The exclusion criteria were multiple births, prematurity (gestation <37 weeks), clinical characteristics of congenital infections, genetic syndromes and congenital malformations, and the need for medical treatment during the immediate neonatal period.

A research assistant interviewed the mothers after birth using a questionnaire containing closed questions on socio-economic, environmental, demographic and maternal obstetric conditions. A paediatrician assessed the newborns' gestational age using the method of Capurro *et al.* (1978). Weight and length were measured within the first 24 h of life, using a portable digital scale with a capacity of 15 kg and sensitivity of 10 g (Soehnle model 725, Hamburg, Germany) and a neonatal anthropometer with an accuracy of 0.1 cm (Harpender Infantometer, Holtain Ltd, Crymch, UK).

Body proportion at birth for the LBW infants was calculated using the Röhrer ponderal index (PI): weight (g)/length (cm)³ × 100 (WHO 1995). LBW infants were classified as stunted (length at birth < -2 SDS and PI ≥ 2.5), wasted (length at birth ≥ -2 SDS and PI < 2.5) and both stunted and wasted (length at birth < -2 SDS and PI < 2.5). Because this last group was small (*n* = 17), it was analysed together with the group classified as stunted (*n* = 13). Five children were excluded from the analysis, as they were not classified in any of these categories.

Follow-up data collection

In 2001, two research assistants carried out an active search, based on home addresses and dates of birth, for children belonging to the cohort. When the family was not found, the search for the child was widened by seeking information from relatives, neighbours and local schools, and calls were put out on local radio networks. Children were considered suitable for inclusion in the study if they were between 8 years and 8 years 5 months on the day of the interview.

The children came to a research clinic on a prearranged date, accompanied by their mothers or legal guardians, between May 2001 and August 2002. A structured questionnaire was applied to the mother to collect information on the family's current socio-economic, demographic, and environmental conditions.

Mothers and children were weighed using a digital scale (Filizola model E-150/3P, São Paulo, Brazil), which had previously been calibrated and had a capacity of 150 kg, and the weights were recorded to a precision of 0.1 kg. Height was measured using a stadiometer with a precision of 0.1 cm (Leicester Height Measure, Child Growth Foundation, London, UK), according to World Health Organization (WHO) recommendations. The height measurements were made in triplicate, with the mean of the three values used for the final result. The standard deviation scores (SDS) for children's weight-for-age and height-for-age were calculated using the median values from the WHO Growth Standards (WHO 2006).

The child's haemoglobin level was measured using a portable photometer (HemoCue Ltd, Sheffield, UK) on a sample of capillary blood collected at 8 years of age using the Glucolet automatic digital puncture device and discardable lancets (Bayer, Ltd, Tarrytown, USA). Children with haemoglobin levels of less than 115 g L⁻¹ were considered anaemic (WHO 2001).

Data management and analyses

The questionnaires with precoded questions were checked daily to identify completion errors. Double-data entry was undertaken using Epi-Info 6.04 (CDC,

Atlanta, GA, USA), and the statistical analyses were performed with the Statistical Package for the Social Sciences, version 12.0 for Windows (SPSS Inc., Chicago, IL, USA).

The outcome variables (weight-for-age and height-for-age) were analysed as continuous variables. Analysis of variance (ANOVA) was used to compare mean differences in the bivariate analysis, and the chi-squared test for investigating associations between categorical variables. The level of statistical significance was taken as $P \leq 0.05$. The correlation matrix showed that there was little evidence of collinearity between the variables, since the Pearson correlation coefficients were less than 0.44, with the exception of weight and length at birth ($r = 0.79$).

Multivariable linear regression analyses were performed using a hierarchical approach, with the aim of evaluating the net effect of the explanatory variables on weight-for-age and height-for-age. Among the explanatory variables, mother's height and body mass index (BMI) and the child's haemoglobin were treated as continuous variables. The other variables were dichotomous, except for body proportion at birth, which was treated as a dummy variable. All the variables with $P \leq 0.20$ in the bivariate analysis were selected for initial inclusion in the regression analysis.

A staged process was then used for model selection, and at each stage variables with $P \leq 0.20$ were retained. In the first model, the nutritional status was initially adjusted for the socio-economic variables (*per capita* family income, maternal schooling, family size, number of people per room, kind of floor, type of toilet, garbage collection and ownership of a refrigerator). The second stage (model 2) included maternal BMI, height and smoking during pregnancy, and adjustment was made for the socio-economic variables from model 1. The third stage added body proportion at birth, adjusted for variables from models 1 and 2. The fourth model included previous hospitalization and haemoglobin level at 8 years, adjusted for the variables retained from the first three models.

For continuous variables, we examined scatterplots of residuals against predicted dependent variables and found that the residuals were normally distributed and the variances were constant.

Ethical permission

The study was granted approval by the Research Ethics Committees of the Health Sciences Center of the Federal University of Pernambuco and the London School of Hygiene and Tropical Medicine. Informed written consent was obtained from the parents or the persons responsible for the children on the day of the interview. Sick children were referred to the local health centre.

Results

Among the 213 children followed up at 8 years of age, 86 (40.4%) were born with LBW and 127 (59.6%) with ABW. This sample represented 56.8 % of the original birth cohort. Of those lost to follow-up, 15.4% had died (17 LBW and 8 ABW); 26% were known to have migrated; and 58.6% were unaccounted for. A comparison of the socio-economic characteristics at birth between the children who were traced at 8 years of age and those who were lost to follow-up showed that, independent of birthweight, a higher loss rate occurred among the children who were living in poorer socio-economic conditions. However, although some trends were apparent, the differences between families found and those lost were not statistically significant except for ownership of a refrigerator (see Appendix 1).

The characteristics of the population studied at 8 years are presented in Table 1. Although the socio-economic conditions of the families had generally improved since birth (Emond *et al.* 2006), the mothers had low educational levels, and their families were generally poor: approximately two-thirds had incomes below the recognized poverty line in Brazil (less than 0.5 minimum wage *per capita* per month – approximately US\$35), around one-third of the homes did not have a flush toilet and a quarter did not have a refrigerator. A quarter of the mothers were below 150 cm in height, and 3.3% of them had BMI of less than 18.5 kg m^{-2} . About 11% of the children had been hospitalized during the year preceding the study and 17% had anaemia. The socio-economic conditions of the family, the mother's nutritional status and child-related morbidity were worse for the LBW chil-

Table 1. Selected characteristics of the study population at 8 years old, according to birthweight

Variables	<i>n</i>	(%)	LBW <i>n</i> = 86 (%)	ABW <i>n</i> = 127 (%)	<i>P</i>
<i>Per capita</i> family income (MW)					
<0.25	74	(34.7)	35 (40.7)	39 (30.7)	0.13
0.25–0.49	71	(33.3)	30 (34.9)	41 (32.3)	
≥0.50	68	(32.0)	21 (24.4)	47 (37.0)	
Maternal schooling (years)					
0–4	96	(45.1)	42 (48.8)	54 (42.5)	0.54
5–8	70	(32.8)	28 (32.6)	42 (33.1)	
≥9	47	(22.1)	16 (18.6)	31 (24.4)	
Kind of floor					
Cement or earth	158	(74.2)	68 (79.1)	90 (70.9)	0.24
Ceramic	55	(25.8)	18 (20.9)	37 (29.1)	
Water supply					
Not piped	19	(8.9)	8 (9.3)	11 (8.7)	0.93
Piped	194	(91.1)	78 (90.7)	116 (91.3)	
Toilet					
Latrine	68	(31.9)	24 (27.9)	44 (34.6)	0.38
Flush	145	(68.1)	62 (72.1)	83 (65.4)	
Garbage collection					
No	31	(14.6)	14 (16.3)	17 (13.4)	0.70
Yes	182	(85.4)	72 (83.7)	110 (86.6)	
Refrigerator					
No	51	(23.9)	25 (29.1)	26 (20.5)	0.20
Yes	162	(76.1)	61 (70.9)	101 (79.5)	
Smoking during pregnancy					
Yes	39	(18.3)	17 (19.8)	22 (17.3)	0.79
No	174	(81.7)	69 (80.2)	105 (82.7)	
Maternal height* (cm)					
<150	45	(24.9)	21 (30.0)	24 (21.6)	0.27
≥150	136	(75.1)	49 (70.0)	87 (78.4)	
Maternal BMI* (kg m ⁻²)					
<18.5	6	(3.3)	3 (4.3)	3 (2.7)	<0.001
18.5–24.9	84	(46.4)	44 (62.8)	40 (36.0)	
≥25	91	(50.3)	23 (32.9)	68 (61.3)	
Haemoglobin (g L ⁻¹)					
<115	36	(16.9)	12 (14.0)	24 (18.9)	0.45
≥115	177	(83.1)	74 (86.0)	103 (81.1)	
Previous hospitalization					
Yes	24	(11.3)	15 (17.4)	9 (7.1)	0.03
No	189	(88.7)	71 (82.6)	118 (92.9)	

MW, minimum wage; BMI, body mass index; **n* = 181 (32 mothers failed to come to the interview).

dren. However, the differences between the LBW and ABW groups only reached statistical significance in relation to previous hospitalization of the child, and the mother's BMI.

Table 2 contains the mean SDS for weight-for-age and height-for-age in relation to the explanatory variables associated with *P*-values ≤ 0.20 in the initial bivariate analysis. Most of the variables of interest were significantly associated with these indices.

The results of the four regression models with weight-for-age as the dependent variable are shown in Table 3. Among the socio-economic variables of model 1, only *per capita* family income and maternal years of schooling remained significant after adjusting for each of the other socio-economic variables. Model 2 shows that the effect of mother's BMI and height were highly significant after adjusting for the socio-economic variables and for smoking during preg-

Table 2. The influence of socio-economic, maternal and child conditions on mean weight-for-age SDS (WAZ) and height-for-age SDS at 8 years old

Variables	<i>n</i> = 213	WAZ	<i>P</i>	HAZ	<i>P</i>
<i>Per capita</i> family income (MW)					
<0.25	74	-0.80	0.001	-0.80	0.009
0.25–0.49	71	-0.44		-0.49	
≥0.50	68	-0.06		-0.30	
Maternal schooling (years)					
0–4	96	-0.72	0.008	-0.75	0.02
5–8	70	-0.22		-0.37	
≥9	47	-0.21		-0.35	
Family size					
≥7	54	-0.79	0.009	-0.78	0.002
5–6	73	-0.50		-0.70	
≤4	86	-0.17		-0.25	
People per room					
≥2	36	-0.77	0.07	-0.77	0.13
<2	177	-0.37		-0.49	
Kind of floor					
Cement or mud	158	-0.55	0.02	-0.63	0.02
Ceramic	55	-0.11		-0.28	
Toilet					
Latrine	68	-0.58	0.24	-0.68	0.14
Flush	145	-0.37		-0.47	
Garbage collection					
No	31	-0.63	0.33	-0.79	0.13
Yes	182	-0.41		-0.49	
Refrigerator					
No	51	-0.74	0.04	-0.77	0.06
Yes	162	-0.35		-0.47	
Smoking during pregnancy					
Yes	39	-0.75	0.07	-0.72	0.22
No	174	-0.37		-0.50	
Maternal height* (cm)					
<150	45	-0.83	0.02	-1.02	<0.001
≥150	136	-0.31		-0.38	
Maternal BMI* (kg m ⁻²)					
<18.5	6	-1.54	0.001	-0.65	0.04
18.5–24.9	84	-0.73		-0.74	
≥25.0	91	-0.09		-0.35	
Birthweight (g)					
<2500	86	-0.76	0.001	-0.74	0.01
3000–3499	127	-0.22		-0.40	
Birth length (cm)					
<46.5	51	-1.01	<0.001	-1.05	<0.001
46.5–48.0	53	-0.37		-0.50	
>48.0	109	-0.21		-0.32	
Body proportion at birth [†]					
LBW stunted	30	-0.95	0.005	-0.96	0.02
LBW wasted	51	-0.63		-0.55	
ABW	127	-0.22		-0.40	
Haemoglobin at 8 years (g L ⁻¹)					
<115	36	-0.88	0.02	-1.01	0.002
≥115	177	-0.35		-0.44	
Previous hospitalization					
Yes	24	-0.93	0.03	-0.75	0.27
No	189	-0.38		-0.51	

SDS, standard deviation score; MW, minimum wage; BMI, body mass index; LBW, low birthweight; ABW, appropriate birthweight; **n* = 181 (32 mothers failed to come to the interview). Sensitivity analyses indicated that these missing cases did not affect the associations between maternal height/BMI and WAZ and HAZ. [†]*n* = 208 (5 children were neither wasted nor stunted).

Table 3. Hierarchical linear regression models to show combined effects of variables associated with weight-for-age SDS in 8-year-old children

Variables	Unadjusted β^*	Adjusted β	[IC 95%]	R ² %
Model 1 [§]				
Maternal schooling (0–4 years) [¶]	–0.52**	–0.45*	[–0.83; –0.07]	5.4 (5.4)
<i>Per capita</i> family income (<0.25 MW) [¶]	–0.56***	–0.55**	[–0.94; –0.15]	3.3 (8.7)
Model 2				
Maternal BMI (kg m ^{–2})	0.06***	0.07***	[0.03; 0.10]	6.1 (14.8)
Maternal height (10 cm)	0.63***	0.55***	[0.27; 0.84]	6.2 (21.0)
Smoking during pregnancy [¶]	–0.37 ^f	–0.12	[–0.55; 0.32]	0.0 (21.0)
Model 3				
LBW stunted [¶]	–0.65**	–0.52 ^f	[–1.05; 0.00]	0.6 (21.6)
LBW wasted [¶]	–0.26	–0.05	[–0.47; 0.37]	
Model 4				
Haemoglobin at 8 years (g L ^{–1})	0.16*	0.17*	[0.01; 0.32]	1.4 (23.0)
Previous hospitalization [¶]	–0.55*	–0.55*	[–1.11; –0.01]	1.3 (24.3)

SDS, standard deviation score; MW, minimum wage; BMI, body mass index; LBW, low birthweight; ABW, appropriate birthweight; Significance levels: $f \leq 0.10$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$. [†]Unstandardized regression coefficient. [‡]Coefficient of determination. [§]Model 1 – Adjusted for: family size, people per room, type of floor, kind of toilet and ownership of a refrigerator. [¶]Reference categories for the categorical variables: maternal schooling: ≥ 5 years; *per capita* family income: ≥ 0.25 MW; smoking during pregnancy: no; LBW stunted, LBW wasted and ABW; LBW wasted, LBW stunted and ABW; previous hospitalization: no.

nancy. The coefficients for maternal BMI and height were not any different with or without PI or length included in the model. Model 3 shows that the significant effect of LBW stunted children on weight-for-age was lost after adjusting for socio-economic conditions and maternal nutritional status. In model 4, inclusion of the variables relating to child morbidity – haemoglobin level and occurrence of previous hospitalization – maintained the significance of the model after adjusting for the other variables. Taken together, the independent variables explained 24.3% of the variation in weight-for-age: the mother's BMI and height contributed to the greatest proportion of this variation (12.3%), followed by the socio-economic factors (8.7%).

The combined effect of the independent variables on height-for-age is shown in Table 4. Model 1 shows that *per capita* family income and maternal years of schooling were significantly associated with height-for-age after adjusting for each of the socio-economic variables. Model 2 shows that maternal BMI and height remained significant after adjusting for the socio-economic variables. Model 3 shows that the combination of LBW and stunting had a significant effect on height-for-age after adjusting for the variables of blocks 1 and 2. In model 4, the introduction of

haemoglobin level remained significant after adjusting for the variables in the other three blocks. Together the variables in these models explained 25.9% of the variation in height-for-age, with maternal height accounting for the greatest proportion of this variation (11.1%), followed by the socio-economic conditions (6.0%) and haemoglobin level (5.6%).

Discussion

This study has several strengths: it was conducted prospectively from birth with reliable data on family's socio-economic and environmental conditions, mother's reproductive history, and infant's gestational age, weight and length, and the follow-up adopted a rigorous methodology to ensure the data were reliable. The main limitation of the study is that there were missing data, with a high loss rate from the cohort 8 years after recruitment. This is a frequent problem in cohort studies, especially in developing countries. Northeast Brazil is historically a deprived region, from where many families migrate to other parts of Brazil in search of better living conditions. Also, although we were able to adjust for many of the important confounders of the relationship between

Table 4. Hierarchical linear regression models to show combined effect of variables associated with height-for-age SDS in 8-year-old children

Variables	Unadjusted $\beta^{\dagger}$	Adjusted β	[IC 95%]	R ² %
Model 1[§]				
Maternal schooling (0–4 y) [‡]	–0.39**	–0.32*	[–0.64; –0.01]	3.9 (3.9)
<i>Per capita</i> family income (<0.25 MW) [‡]	–0.42**	–0.37*	[–0.70; –0.05]	2.1 (6.0)
Model 2				
Maternal BMI (kg m ^{–2})	0.03*	0.04*	[0.01; 0.06]	2.1 (8.1)
Maternal height (10 cm)	0.66***	0.60***	[0.36; 0.84]	11.1 (19.2)
Model 3				
LBW stunted [‡]	–0.55**	–0.36 ^f	[–0.79; 0.07]	1.1 (20.3)
LBW wasted [‡]	–0.05	0.15	[–0.20; 0.49]	
Model 4				
Haemoglobin at 8 years (g L ^{–1})	0.22***	0.23***	[0.11; 0.36]	5.6 (25.9)

MW, minimum wage; BMI, body mass index; LBW, low birthweight; ABW, appropriate birthweight; Significance levels: $f \leq 0.10$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$. [†]Unstandardized regression coefficient. [‡]Adjusted coefficient of determination. [§]Model 1 – Adjusted for: family size, people per room, type of floor, kind of toilet, garbage collection and ownership of a refrigerator. [‡]Reference categories for the categorical variables: maternal schooling: ≥ 5 years; *per capita* family income: ≥ 0.25 MW; LBW stunted, LBW wasted and ABW; LBW wasted, LBW stunted and ABW.

birthweight and height at 8 years, some (e.g. child's diet) were not available in the dataset.

The results showed that, after adjustment, birthweight did not have much impact on anthropometry at 8 years. LBW children who were wasted recovered their weight more rapidly than those LBW who were stunted, reflecting that their growth faltering only occurred at the end of gestation (Villar *et al.* 1984). Stunting is the result of a longer period of maternal malnutrition during pregnancy, and is a predominant type of intrauterine growth retardation in developing countries (Villar & Belizan 1982). Using this same cohort, Ashworth *et al.* (1997) reported that LBW stunted infants showed impaired nutritional status at 12 months of age. At age 8, the LBW stunted group still had significantly lower height-for age, but birthweight only accounted for a small proportion of the explanatory power of the model. The theoretical concept of a 'thrifty phenotype' (Hales & Barker 2001) would predict that signs of the metabolic syndrome would accompany a catch-up in bodyweight and central adiposity. This was not observed in our cohort by age 8 years.

Although previous studies conducted in Brazil have identified LBW to be a significant determinant of nutritional status at 12 months of age (Motta *et al.* 2005; Eickmann *et al.* 2006), in the present study this

effect was not sustained at 8 years of age and was replaced by the predominant influence of factors relating to the mother's nutritional status. Maternal anthropometry can serve as an indicator of both genetic (transmission of genes determining height and weight) and environmental factors (uterine size, prenatal nutrition, child diet). Mothers' height and BMI reflect the socio-economic conditions found among this population, and formed the block of variables that contributed most towards the variation in the child's weight-for-age and height-for-age. This finding is similar to the observations made by Leger *et al.* (1998) regarding the importance influence of maternal nutritional status, rather than birthweight, on the final height of infants born at term with low weight. Maternal height is recognized to have an important influence on the length of infants born with LBW at term. (Karlberg & Albertsson-Wikland 1995; Leger *et al.* 1998; Jaquet *et al.* 2004), so the shorter mothers were more likely to have stunted infants, who were lighter and shorter at age 8. There is thus an intragenerational association between the nutritional status of mothers and children because they share both a genetic predisposition and exposure to the same socio-economic and environmental conditions (Engstrom & Anjos 1999).

As well as being linked to maternal nutrition, socio-economic conditions have independently contributed to the child's nutritional status at 8 years, with these variables explaining 8.7% of the variation in weight-for-age and 6% in height-for-age. The influence of socio-economic and environmental determinants on the nutritional status of children is observed mainly in poor regions, where the effects are mediated through food availability and infectious morbidity, and are most obvious among those with LBW (Delpuech *et al.* 2000). Data from a population-based cross-sectional study in northeast Brazil showed social inequality to play a prominent role in maintaining height-for-age deficits in school-aged children of poor families (Laurentino *et al.* 2005). The chronic poverty resulting from the limited employment and income-generating opportunities in this region of Brazil has a negative impact on the nutritional status of these families.

Another possible mechanism underlying the influence of maternal nutrition on child growth could be intrauterine constraint. Recently several authors have highlighted the importance of the uterus constraint mechanism on human fetal growth (Gluckman & Hanson 2004; Cnattingius 2008; Hanson & Godfrey 2008; Leon 2008; Magnus 2008). The variation in height-for-age of children at school age in our sample may be attributed, at least partially, to the mechanism of maternal intrauterine constraint that can occur in very short mothers.

The predominant influences on the variability in weight- and height-for-age were socio-economic conditions and maternal nutritional status. The nutritional status of children at school age resulted from a combination of determinants reflecting the conditions of poverty among the study population. However, the influence of such conditions began before the antenatal period, as a result of the mother's malnutrition during her own infancy, childhood and adolescence. To avoid the perpetuation of nutritional deficits between successive generations (Stein *et al.* 2004; Agnihotri *et al.* 2008), interventions are needed to improve nutrition in childhood and adolescence with a view towards improving the nutrition of their future offspring, as well as programmes that improve the nutrition of pregnant women.

In developing regions of the world where the nutritional transition has been occurring, there appears to be less direct correspondence between the nutritional status of the mother and her child. In these regions there is a visible paradox between malnourished children and overweight or obese mothers (Faber *et al.* 2005). In the geographical area of our study, the nutritional transition is in the early stages (Batista Filho & Rissin 2003) and maternal nutritional status can still be considered an important indicator of the socio-economic conditions of a population (Ashworth *et al.* 1997). The relatively high prevalence of LBW in our study reflects the genetic background of the population, the young age of the mothers and the chronic undernutrition experienced by the mothers in their own childhood and adolescence and during pregnancy.

The rate of previous hospitalization was much higher among the full-term LBW children than their ABW controls. Much of the morbidity leading to hospitalization is due to diarrhoeal and respiratory infections (Barros *et al.* 1992; Lira *et al.* 1996). LBW stunted children who suffer prolonged nutritional impairments during pregnancy are more prone to repeated episodes of infections due to immunological deficits (Chandra 1981). The vicious circle of repeated infections and chronic nutritional shortfall, especially in relation to deficits in micronutrients like iron, make them unable to recover from the growth restriction suffered during intrauterine life.

Iron deficiency anaemia has been reported to be the most common nutritional shortfall in regions with social inequality (Shell-Duncan & McDade 2005; Tympa-Psirropoulou *et al.* 2005) and shows a high prevalence in Brazil (Batista Filho & Rissin 2003; Lima *et al.* 2004). This deficiency affects not only women and young children but also children of school age (Shell-Duncan & McDade 2005; Gunnarsson *et al.* 2005). Although 17% of our sample at 8 years were anaemic, we were not able to confirm if they were iron deficient. There were no significant differences in anaemia rates between the LBW and ABW groups; however, haemoglobin level was independently associated with both weight-for-age and height-for-age in the final models.

In conclusion, this study has identified several determinant factors of nutritional status at school age among children born full term with LBW and ABW. Maternal height, reflecting genetic inheritance and chronic poor socio-economic conditions, had more influence on growth in childhood than the weight at birth. The implications of these findings for health policy are: first, to adopt public policies aimed at improving the poor economic conditions of mothers and children, and second, to prioritize access to health services and nutritional support programmes during pregnancy. Policies for child health should include anthropometric surveillance, a simple tool that if widely utilized by health professionals can promote the early detection of child growth problems and the prevention of subsequent morbidity and mortality.

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Conflicts of interest

The authors are independent of the funding bodies, and no conflicts of interest have been declared.

References

- Agnihotri B., Antonisamy B., Priya G., Fall C.H.D. & Raghupathy P. (2008) Trends in human birth weight across two successive generations. *Indian Journal of Pediatrics* **75**, 111–117.
- Ashworth A., Morris S.S. & Lira P.I.C. (1997) Postnatal growth patterns of full-term low birth weight infants in northeast Brazil are related to socioeconomic status. *Journal of Nutrition* **127**, 1950–1956.
- Barros F.C., Huttly S.R.A., Victora C.G., Kirkwood B.R. & Vaughan J.P. (1992) Comparison of the causes and consequences of prematurity and intrauterine growth retardation: a longitudinal study in southern Brazil. *Pediatrics* **90**, 238–244.
- Batista Filho M. & Rissin A. (2003) Nutritional transition in Brazil: geographic and temporal trends. *Cadernos de Saúde Pública* **19**, 181–191.
- Branca F. & Ferrari M. (2002) Impact of micronutrient deficiencies on growth: the stunting syndrome. *Annals of Nutrition & Metabolism* **46** (suppl. 1), 8–17.
- Capurro H., Konichezky S., Fonseca D. & Caldeyro-Barcia R. (1978) A simplified method for diagnosis of gestational age in the newborn infant. *Journal of Pediatrics* **93**, 120–122.
- Chandra R.K. (1981) Serum thymic hormone activity and cell-mediated immunity in healthy neonates, preterm infants, and small-for-gestational age infants. *Pediatrics* **67**, 407–411.
- Cheung Y.B., Albertsson-Wikland K., Luo Z.C., He Q. & Karlberg J. (2002) Benn Index at birth is associated with postnatal linear growth. *Journal of Pediatric Endocrinology & Metabolism* **15**, 1161–1166.
- Cnattingius S. (2008) On 'transmission through the female line of a mechanism constraining human fetal growth' – does it exist? *International Journal of Epidemiology* **37**, 250–252.
- Delpeuch F., Traissac P., Martin-Prével Y., Massamba J.P. & Maire B. (2000) Economic crisis and malnutrition: socio-economic determinants of anthropometric status of pre-school children and their mothers in African urban area. *Public Health Nutrition* **3**, 39–47.
- Eickmann S.H., Lima M.C., Motta M.E.F., Romani S.A.M. & Lira P.I.C. (2006) Growth of full term low and adequate birth weight infants during the first two years of life. *Revista de Saúde Pública* **40**, 1073–1081.
- Emond A.M., Lira P.I., Lima M.C. *et al.* (2006) Development and behaviour of low-birthweight term infants at 8 years in northeast Brazil: a longitudinal study. *Acta Paediatrica* **95**, 1249–1257.
- Engstrom E.M. & Anjos L.A. (1999) Stunting in Brazilian children: relationship with social-environmental conditions and maternal nutritional status. *Cadernos de Saúde Pública* **15**, 559–567.
- Faber M., Swanevelde S. & Spinnler Benadé A.J. (2005) Is there an association between the nutritional status of the mother and that of her 2-year-old to 5-year-old child? *International Journal of Food Sciences and Nutrition* **56**, 237–244.

- Gluckman P.D. & Hanson M.A. (2004) Maternal constraint of fetal growth and its consequences. *Seminars in Fetal & Neonatal Medicine* **9**, 419–425.
- Gunnarsson B.S., Thorsdottir I. & Palsson G. (2005) Iron status in 6-y-old children: associations with growth and earlier iron status. *European Journal of Clinical Nutrition* **59**, 761–767.
- Hales C.N. & Barker D.J. (2001) The thrifty phenotype hypothesis. *British Medical Bulletin* **60**, 5–20.
- Hanson M.A. & Godfrey K.M. (2008) Maternal constraint is a pre-eminent regulator of fetal growth. *International Journal of Epidemiology* **37**, 252–254.
- Jaquet D., Collin D., Lévy-Marchal C. & Czernichow P. (2004) Adult height distribution in subjects born small for gestational age. *Hormone Research* **62**, 92–96.
- Karlberg J. & Albertsson-Wikland K. (1995) Growth in full-term small-for-gestational-age infants: from birth to final height. *Pediatric Research* **38**, 733–739.
- Kramer M.S. (1987) Determinants of low birth weight: methodological assessment and meta-analysis. *Bulletin of the World Health Organization* **65**, 663–737.
- Laurentino G.E.C., Arruda I.K.G., Raposo M.C.F. & Batista Filho M. (2005) Height deficit in school aged children: a multivariate analysis of possible risk factors, Pernambuco – 1997. *Archivos Latinoamericanos de Nutrición* **55**, 144–153.
- Leger J., Limoni C., Collin D. & Czernichow P. (1998) Prediction factors in the determination of final height in subjects born small for gestational age. *Pediatric Research* **43**, 808–812.
- Leon D.A. (2008) The development of the Ounsted's theory of maternal constraint—a critical perspective. *International Journal of Epidemiology* **37**, 255–259.
- Lima A.C.V.M.S., Lira P.I.C., Romani S.A.M., Eickmann S.H., Piscoya M.D. & Lima M.C. (2004) Determinant factors of haemoglobin levels in 12 months old infants in the South of the Zona da Mata of Pernambuco. *Revista Brasileira de Saúde Materno Infantil* **4**, 35–43.
- Lira P.I.C., Ashworth A. & Morris S.S. (1996) Low birth weight and morbidity from diarrhea and respiratory infection in northeast Brazil. *Journal of Pediatrics* **128**, 497–504.
- Magnus P. (2008) A need for unconstrained thinking on foetal growth. *International Journal of Epidemiology* **37**, 254–255.
- Motta M.E.F., da Silva G.A.P., Araújo O.C., Lira P.I.C. & Lima M.C. (2005) Does birth weight affect nutritional status at the end of first year of life? *Journal de Pediatria* **81**, 377–382.
- Rivera A.J., Hotz C., González-Cossío T., Neufeld L. & García-Guerra A. (2003) The effect of micronutrient deficiencies on child growth: a review of results from community-based supplementation trials. *Journal of Nutrition* **133**, 4010S–4020S.
- Shell-Duncan B. & McDade T. (2005) Cultural and environmental barriers to adequate iron intake among northern Kenyan schoolchildren. *Food and Nutrition Bulletin* **26**, 39–48.
- Stein A.D., Barnhart H.X., Wang M., Hoshen M.B., Ologoudou K., Ramakrishnan U. *et al.* (2004) Comparison of linear growth patterns in the first three years of life across two generations in Guatemala. *Pediatrics* **113**, 270–275.
- Tympa-Psirropoulou E., Vagenas C., Psirropoulos D., Dafni O., Matala A. & Skopouli F. (2005) Nutritional risk factors for iron-deficiency anaemia in children 12–24 months old in the area of Thessalia in Greece. *International Journal of Food Sciences and Nutrition* **56**, 1–12.
- Villar J. & Belizan J.M. (1982) The timing factor in the pathophysiology of the intrauterine growth retardation syndrome. *Obstetrical and Gynecological Survey* **37**, 499–506.
- Villar J., Smeriglio V., Martorell R., Brown C.H. & Klein R.E. (1984) Heterogeneous growth and mental development of intrauterine growth-retarded infants during the first 3 years of life. *Pediatrics* **74**, 783–791.
- WHO (1995) *Physical Status: The Use and Interpretation of Anthropometry*. WHO Technical Report Series 854. World Health Organization: Geneva.
- WHO (2001) *The Clinical Use of Blood in Medicine, Obstetrics, Paediatrics, Surgery & Anaesthesia, Trauma & Burns*. World Health Organization: Geneva.
- WHO (2006) Child growth standards. *Acta Paediatrica* **95** (suppl. 450), 76–85.

Appendix I

Socio-economic and maternal characteristics at birth of children traced at 8 years old and those lost to follow-up, according to birthweight

Variables	LBW			ABW		
	Traced <i>n</i> = 86 (%)	Lost <i>n</i> = 77 (%)	<i>P</i>	Traced <i>n</i> = 127 (%)	Lost <i>n</i> = 85 (%)	<i>P</i>
Family income (MW)						
≤1.0	48 (55.8)	54 (70.1)	0.09*	68 (53.5)	45 (52.9)	0.90*
1.01–2.0	30 (34.9)	18 (23.4)		39 (30.7)	26 (30.6)	
>2.0	8 (9.3)	5 (6.5)		20 (15.8)	14 (16.5)	
Maternal literacy						
No	17 (19.8)	22 (28.6)	0.26	22 (17.3)	21 (24.7)	0.26
Yes	69 (80.2)	55 (71.4)		105 (82.7)	64 (75.3)	
Water supply						
Not piped	20 (23.3)	29 (37.7)	0.07	21 (16.5)	21 (24.7)	0.20
Piped	66 (76.7)	48 (62.3)		106 (83.5)	64 (75.3)	
Kind of toilet						
Latrine	40 (46.5)	44 (57.1)	0.23	47 (37.0)	35 (41.2)	0.64
Flush	46 (53.5)	33 (42.9)		80 (63.0)	50 (58.8)	
Refrigerator ownership						
No	43 (50.0)	60 (77.9)	<0.001	63 (49.6)	55 (64.7)	0.04
Yes	43 (50.0)	17 (22.1)		64 (50.4)	30 (35.3)	
Prenatal care						
No	17 (19.8)	24 (31.2)	0.14	24 (18.9)	20 (23.5)	0.52
Yes	69 (80.2)	53 (68.8)		103 (81.1)	65 (76.5)	
Work during pregnancy						
Yes	23 (26.7)	17 (22.1)	0.61	29 (22.8)	18 (21.2)	0.91
No	63 (73.3)	60 (77.9)		98 (77.2)	67 (78.8)	
Smoking during pregnancy						
Yes	17 (19.8)	24 (31.2)	0.14	22 (17.3)	17 (20.0)	0.75
No	69 (80.2)	53 (68.8)		105 (82.7)	68 (80.0)	
Maternal age (years)						
≤19	32 (37.2)	34 (44.1)	0.67*	31 (24.4)	28 (32.9)	0.08*
20–24	33 (38.4)	23 (29.9)		50 (39.4)	35 (41.2)	
≥25	21 (24.4)	20 (26.0)		46 (36.2)	22 (25.9)	

MW, minimum wage; LBW, low birthweight; ABW, appropriate birthweight; *X² for trend.