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Undernutrition in early life and body composition of adolescent males from a birth cohort study

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The evidence for an association between poor nutrition in early life and subsequent obesity is inconclusive. In the present study, we investigated the associations between stunting, wasting and underweight at 2 and 4 years of age, and body composition in adolescence in male subjects studied since birth. The 1982 Pelotas Birth Cohort Study included all children born in maternity hospitals and living in the urban area of the city of Pelotas, Southern Brazil. All males born in 1982 were legally required to enlist in the army between January and April 2000. We were thus able to track 2250 subjects in 2000 (78·9 % of the original cohort). Anthropometric measurements were collected in 1984 and 1986, and body composition was assessed in 2000. In the present analysis, we used as predictors the nutritional indices height-for-age, weight-for-height and weight-for-age presented in six categories. Outcomes included fat, lean and body mass indices and fat:lean mass ratio, derived from anthropometric and bioimpedance measurements. ANOVA and linear regression were used in the analyses to adjust for confounding. All predictors were positively associated with fat and body mass indices. Height-for-age *Z* score at age 2 or 4 years was not associated with lean mass index, but all other predictors were associated. Fat:lean mass ratio was associated only with weight-for-height *Z* score. Our results suggest that undernutrition is not a risk factor for overweight and obesity in our population and may partially protect against fatness in adolescence.

Nutritional indices: Body composition: Adolescent male: Cohort study

In face of the epidemic of overweight and obesity affecting middle- and high-income countries, growing attention is being paid to the role of early determinants of adult size (Prentice & Moore, 2005). Of particular interest is the possibility that individuals who have suffered from undernutrition in early life, but who have later been exposed to Western-type diets and lifestyle – a common situation in transitional societies – are at greater risk of overweight and chronic disease (Prentice, 2006).

The association between stunting and overweight in children was shown in a cross-sectional study conducted in four countries in nutritional transition (Russia, Brazil, South African, China). The risk of being overweight for a stunted child ranged from 1·7 to 7·8 (Popkin *et al.* 1996). In a review of early nutrition and later-life adiposity, Martorell and colleagues concluded that high birth weight was associated with subsequent obesity, whereas the evidence for poor nutrition in early life as a risk factor for increased fatness later in life was inconclusive (Martorell *et al.* 2001). In a more recent review, the increase in weight or BMI and rapid growth during infancy were associated with obesity in childhood and adulthood (Baird *et al.* 2005).

The association between nutritional indices in childhood and later body composition has been studied (Walker *et al.* 2002), stunted children having significantly less total and lean tissue than non-stunted children, although there was no difference in the percentages of fat mass and lean mass (Cameron *et al.* 2005). In Brazil, stunted boys accumulated more body fat and gained less lean mass than non-stunted boys, and stunted girls showed a significantly higher percentage of fat mass at the end of follow-up, whereas non-stunted girls showed no significant differences in the percentage of fat mass over time (Martins *et al.* 2004).

A cohort of boys has been studied since their birth (1982) in Pelotas, a city in Southern Brazil. Subjects were subsequently traced in 1984, 1986 and 2000, and nutritional status and body composition were assessed. The aim of the present analysis was to study the associations between stunting, wasting and underweight at 2 and 4 years of age, and the body composition of male adolescents. The 1982 Pelotas Birth Cohort allows for an examination of such associations using body composition indices that have not been considered in other studies.

Methods

All births taking place in the maternity hospitals in the city of Pelotas in 1982 were included in the Pelotas Birth Cohort Study. The methodological details of this study have been

Abbreviations: FM:LM, fat mass:lean mass; TBW, total body water.

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published elsewhere (Barros *et al.* 1990; Victora *et al.* 2003; Victora & Barros, 2006).

The perinatal study took place at the hospitals and included 5914 births. Our research team measured and interviewed mothers and weighed both mothers and babies. The first follow-up visit attempted to locate the 1916 children born in the first 4 months of 1982 using the home address obtained during the maternity interview. A total of 79·3 % of all children were traced, and their mothers were interviewed. The second and third follow-ups were conducted based on a census of all households in the urban area of Pelotas, in order to avoid losses. This approach resulted in follow-up rates of 87·2 % and 84·1 %, respectively.

Children were weighed using portable mechanical scales (CMS Weighing Equipment Ltd, London, UK), and supine length (1984) and height (1986) were measured using boards manufactured locally according to international specifications (AHRTAG; Healthlink Worldwide, London, UK). The precision for weight and length:height was 100 g and 0·1 cm, respectively. Nutritional indices were expressed as the *Z* score of the National Center for Health Statistics (1977).

From January to April 2000, all males born in 1982 were legally required to enlist in the army. Of the 3037 boys in the cohort, 2047 were identified when enlisting and were linked to their birth records. Other subjects were located at their last known address, leading to a total 2250 subjects who were interviewed and subjected to physical examination, including measurements of blood pressure, height, sitting height, weight and body composition collected by the study team. Taking into account the 147 cohort members who were known to have died, we were able to track 78·9 % of the 3037 males originally included in the cohort. Ethical approval for the study was obtained from Medical Ethics Committee of the Federal University of Pelotas. The confidentiality of all the information was ensured, and verbal and written consents were obtained in 1982 and 2000, respectively.

In the present analysis, the predictors investigated were height-for-age *Z* score, weight-for-height *Z* score and weight-for-age *Z* score, at age 2 and 4 years. These variables were categorised by *Z* scores of less than -2, -2 to $-1{\cdot}1$, -1 to 0, 0·1 to 1, 1·1 to 2 and more than 2 in the analyses. Confounding variables included family income in 1982 (the sum of the monthly incomes of all working persons living in the household, expressed as multiples of the minimum wage), pre-gestational weight (from the antenatal care register or by asking the mother about her weight before pregnancy), maternal height (measured by the research team soon after admission to the maternity hospital), weight gain during pregnancy (calculated as the difference between the weight obtained immediately after birth and the pre-gestational weight) and the child's age and birth weight (measured in grams after birth by trained interviewers, using regularly calibrated paediatric scales).

Outcomes variables were fat mass index, lean mass index, BMI and fat mass:lean mass ratio ($FM:LM^{2{\cdot}3}$). Fat mass index, lean mass index and BMI were calculated by dividing fat, lean and body mass, respectively, by the square of height. When enlisting in the army, participants were weighed in their underpants using a Tanita Body Fat Analyzer Scale (Model TBF 305; Tanita, Tokyo, Japan). Fat and lean mass were estimated in kilograms using the information obtained from the Tanita scale. These measures were corrected by means of a validation substudy, conducted in a mirror sample of forty-eight participants in the age range of the study cohort, in which total body water (TBW) was assessed by ^{2}H dilution (Wells *et al.* 2003). This study showed that although Tanita predicted TBW and percentage of fat without significant bias in young male Brazilian adults as a whole, this technique overestimated TBW and underestimated fatness in subjects with lower TBW values. New algorithms were derived, predicting TBW from various combinations of data on weight, height and impedance results, and the present results incorporate this correction. Fat mass was calculated by dividing corrected TBW by 0·732, and lean mass – used as synonymous with fat-free mass – was defined as the difference between weight and fat mass.

We used ANOVA and the *F* test to examine the association between predictors and confounding variables, and outcomes. The selection of confounding factors was based on the assumption that socioeconomic conditions might influence body size and composition in children and adults. Indicators of maternal body size (pre-pregnancy weight, height and weight gain during pregnancy) were included in an attempt to adjust for genetic growth potential. Information on paternal size was not available. Because birth weight may influence size throughout life, it was also adjusted for in the analyses. Data on birth length were not collected.

Associations between the above variables and both exposures (anthropometry at ages 2 and 4 years) and outcomes (body composition at 18 years) were tested; variables showing associations at the $P<0{\cdot}2$ level with at least one exposure and one outcome variable were considered as potential confounders (Maldonado & Greenland, 1993) and included in the adjusted analyses. Linear regression analyses were carried out for body, fat and lean mass indices and for $FM:LM^{2{\cdot}3}$. Potential confounding factors were investigated, and those showing association with the outcome and predictors ($P<0{\cdot}2$) were subjected to the multivariate analyses. Confounding factors were included as continuous variables in the linear regression models. The regression model included all potential confounding factors, and results are shown for the predictors.

Results

A comparison of the socioeconomic characteristics of boys examined in 2000 and those of the original cohort showed that the lowest income group – which included subjects with low birth weight, stunting at age 2 and 4 years, and underweight at age 2 years – were less likely to have been examined in the 2000 follow-up. The differences were, however, small: three percentage points or less. These differences were due to the fact that adolescents who were lost or deceased belonged to the lower income group – three times the minimum wages or less – and were low birth weight, stunting, wasting and underweight at age 2 and 4 years (Table 1).

Means and standard deviations for fat mass index, lean mass index, BMI and $FM:LM^{2{\cdot}3}$ were 3·7 (SD 1·5), 18·6 (SD 2·3) and 22·3 (SD 3·7) kg/m^2 and $1{\cdot}0 \times 10^{-3}$ (SD $0{\cdot}2 \times 10^{-3}$), respectively. These outcomes were correlated with a number of potential confounding factors, and the following significant associations were detected: family income and maternal

Table 1. Characteristics of the original 1982 Pelotas birth cohort and adolescents included in the analyses (Pelotas, 1982–2001)

Variable	Original cohort (*n* 3037) (%)	Included in analysis (*n* 2250) (%)	Losses (*n* 640) (%)	Deaths (*n* 147) (%)
Family income (minimum wage)				
≤ 1	21·9	18·7	28·6	44·1
1·1–3	48·2	49·1	45·7	46·2
3·1–6	17·9	19·9	13·7	6·2
6·1–10	6·1	6·4	6·0	2·1
> 10	5·5	5·6	6·1	1·4
Birth weight				
< 2500 g	8·0	5·9	8·6	39·0
2500–2999 g	20·6	20·1	21·4	24·0
3000–3499 g	37·3	38·1	37·7	22·6
3500–3999 g	26·6	27·9	25·0	13·0
≥ 4000 g	7·5	8·0	7·2	1·4
Stunting in 1984*				
No	86·9	88·8	78·6	
Yes	13·1	11·2	21·4	
Wasting in 1984*				
No	87·8	88·8	84·6	
Yes	12·2	11·2	15·4	
Underweight in 1984*				
No	93·8	95·1	88·5	
Yes	6·2	4·9	11·5	
Stunting in 1986*				
No	91·4	92·9	85·2	
Yes	8·6	7·1	14·8	
Wasting in 1986*				
No	92·3	93·1	88·4	
Yes	7·7	6·9	11·6	
Underweight in 1986*				
No	96·9	97·5	93·9	
Yes	3·1	2·5	6·1	
Total	100 %	100 %	100 %	100 %

* Most of the deaths occurred during first year of life.

weight gain during pregnancy were positively associated with three indices, whereas there was no association with FM:LM$^{2·3}$; positive associations were observed between maternal height and fat mass index and FM:LM$^{2·3}$; and maternal pre-gestational weight was positively associated with all outcomes. These variables were included as potential confounding factors in the analyses of the association of undernutrition. Current family income was also associated with fat, lean and body mass indices. There was no difference in the results when analyses were repeated with current instead of baseline family income.

Early-life anthropometric variables tended to be positively associated with the three indices measured at 18 years, and FM:LM$^{2·3}$ was not associated with any indices at either age (Table 2).

Most associations remained positive in the adjusted analysis. However, the crude association between height-for-age at 2 years and lean mass index disappeared (Table 2). Associations with the FM:LM$^{2·3}$ ratio remained NS after adjustment; the only exception was weight-for-height at age 4 years, which showed a fairly positive association.

The association between underweight and wasting, and body composition at age 18 years seems to be stronger when these exposures were measured at age 4 years than when they were measured at age 2 years, but there was no clear age effect for stunting.

All analyses were repeated including birth weight as a confounding factor, with similar results (data not shown). Birth weight was positively associated with fat, lean and body mass indices, and inversely associated with FM:LM$^{2·3}$.

Discussion

Our cohort has the advantage of being population-based and of including several measurements at different ages. The overall rate of follow-up was reasonably high (78·9 %), the sample size was large, and body composition was assessed. Recently proposed indices of body composition (Wells & Victora, 2005) were used to separate fatness from sheer body size. The validation study using ^{2}H dilution to correct TBW is another advantage of our study. Body composition indices were corrected through algorithms predicting TBW from combinations of data on weight, height and impedance.

On the negative side, adolescents who were effectively examined tended to be somewhat wealthier and less likely to have been malnourished in childhood. Part of this difference is due to survival bias: about 5 % of the cohort is known to have died before this date, and deaths were more common among the poor, those with a low birth weight and malnourished children (Victora & Barros, 2006). Other limitations were that the study was restricted to males because of the army recruitment scheme, and that the outcome was measured in late adolescence rather than among adults. Although height velocity rises sharply to a peak before age 18 years, young adults may still grow 2–3 cm between the ages of 19 and 20 (Tanner, 1990).

Table 2. Adjusted mean and 95 % CI of fat, lean and body mass indices and fat:lean mass ratio in 2000 according to predicting factors (Pelotas, 1982–2000)

		Fat mass index*			Lean mass index†			Body mass index*			Fat/lean mass ratio‡§		
Variable	*n*	Mean	95 % CI	*P* value	Mean	95 % CI	*P* value	Mean	95 % CI	*P* value	Mean	95 % CI	*P* value
Length for age *Z* score at age 2 years													0·9
< −2	224			<0·001			0·15			0·008			
−2 to −1·1	520	3·3	3·0, 3·5		18·4	18·0, 18·7		21·6	21·1, 22·1		1·05	1·03, 1·09	
−1 to 0	734	3·5	3·3, 3·6		18·4	18·2, 18·7		21·9	21·6, 22·2		1·05	1·03, 1·07	
0·1 to 1	404	3·7	3·6, 3·9		18·6	18·4, 18·7		22·3	22·0, 22·6		1·05	1·03, 1·07	
1·1 to 2	125	4·0	3·8, 4·1		18·7	18·5, 19·0		22·7	22·3, 23·0		1·02	1·00, 1·05	
> 2	12	4·4	4·1, 4·7		19·1	18·7, 19·5		23·5	22·9, 24·2		1·03	0·99, 1·07	
		5·1	4·3, 5·9		20·2	18·9, 21·5		25·4	23·3, 27·4		1·03	0·91, 1·15	
Weight for length *Z* score at age 2 years				<0·001			<0·001			<0·001			0·47
< −2	20	2·9	2·1, 3·6		16·6	15·5, 17·7		19·5	17·7, 21·2		1·11	1·00, 1·22	
−2 to −1·1	198	3·0	2·8, 3·3		17·3	17·0, 17·7		20·3	19·8, 20·9		1·04	1·00, 1·07	
−1 to 0	646	3·5	3·3, 3·6		18·1	18·0, 18·3		21·5	21·3, 21·8		1·05	1·03, 1·06	
0·1 to 1	726	3·8	3·7, 3·9		18·8	18·6, 18·9		22·5	22·3, 22·8		1·04	1·02, 1·05	
1·1 to 2	331	4·2	4·1, 4·4		19·5	19·2, 19·7		23·7	23·3, 24·1		1·04	1·02, 1·05	
> 2	98	4·8	4·5, 5·1		20·3	19·8, 20·7		25·1	24·4, 25·9		1·04	1·00, 1·09	
Weight for age *Z* score at age 2 years				<0·001			<0·001			<0·001			0·58
< −2	97	2·7	2·4, 3·0		17·2	16·7, 17·7		19·9	19·1, 20·7		1·01	0·96, 1·06	
−2 to −1·1	398	3·3	3·2, 3·5		18·0	17·8, 18·3		21·4	21·0, 21·7		1·05	1·03, 1·08	
−1 to 0	724	3·5	3·4, 3·6		18·3	18·2, 18·5		21·9	21·6, 22·1		1·04	1·02, 1·06	
0·1 to 1	512	4·0	3·9, 4·2		18·9	18·7, 19·1		22·9	22·6, 23·3		1·05	1·03, 1·07	
1·1 to 2	216	4·3	4·1, 4·5		19·5	19·1, 19·8		23·7	23·2, 24·2		1·02	0·99, 1·05	
> 2	72	5·1	4·8, 5·5		20·5	19·9, 21·0		25·6	24·8, 26·5		1·03	0·97, 1·08	
Height for age *Z* score at age 4 years				<0·001			0·01			<0·001			0·69
< −2	138	3·1	2·8, 3·4		18·2	17·7, 18·6		21·4	20·6, 22·1		1·05	1·01, 1·09	
−2 to −1·1	401	3·4	3·2, 3·5		18·3	18·0, 18·5		21·6	21·2, 22·0		1·06	1·04, 1·08	
−1 to 0	750	3·7	3·6, 3·8		18·6	18·4, 18·8		22·2	21·9, 22·5		1·04	1·03, 1·06	
0·1 to 1	510	4·0	3·9, 4·1		18·7	18·5, 18·9		22·7	22·3, 23·0		1·04	1·02, 1·06	
1·1 to 2	164	4·4	4·2, 4·7		19·2	18·8, 19·6		23·6	23·0, 24·2		1·01	0·98, 1·05	
> 2	20	5·0	4·4, 5·7		20·2	19·2, 21·2		25·3	23·7, 26·9		0·96	0·86, 1·06	
Weight for height *Z* score at age 4 years				<0·001			<0·001			<0·001			0·05
< −2	3	1·8	0·2, 3·3		15·4	13·1, 17·8		17·2	13·7, 20·7		0·86	0·62, 1·10	
−2 to −1·1	129	2·9	2·6, 3·2		17·0	16·6, 17·4		19·8	19·2, 20·4		1·03	0·99, 1·07	
−1 to 0	593	3·3	3·1, 3·4		17·8	17·6, 18·0		21·0	20·8, 21·3		1·03	1·01, 1·05	
0·1 to 1	866	3·7	3·6, 3·8		18·6	18·5, 18·8		22·3	22·1, 22·6		1·04	1·03, 1·06	
1·1 to 2	289	4·6	4·4, 4·8		20·1	19·8, 20·3		24·7	24·3, 25·1		1·06	1·03, 1·09	
> 2	100	5·6	5·3, 5·9		21·3	20·9, 21·8		26·9	26·2, 27·7		1·09	1·05, 1·14	
Weight for age *Z* score at age 4 years				<0·001			<0·001			<0·001			0·55
< −2	47	2·5	2·0, 3·0		16·6	15·8, 17·3		18·9	17·7, 20·0		1·02	0·95, 1·09	
−2 to −1·1	308	3·0	2·8, 3·2		17·6	17·3, 17·8		20·6	20·2, 21·0		1·04	1·01, 1·06	
−1 to 0	732	3·5	3·4, 3·6		18·2	18·1, 18·4		21·6	21·4, 21·9		1·04	1·03, 1·06	
0·1 to 1	597	4·0	3·9, 4·1		18·9	18·7, 19·1		22·9	22·6, 23·1		1·04	1·02, 1·06	
1·1 to 2	204	4·6	4·4, 4·8		19·9	19·5, 20·2		24·5	24·0, 25·0		1·04	1·01, 1·07	
> 2	94	5·7	5·4, 6·0		21·2	20·7, 21·7		26·8	26·1, 27·6		1·07	1·02, 1·12	

* Adjusted for family income, pre-gestational weight, maternal height, weight gain during pregnancy and child's age.
† Adjusted for family income, pre-gestational weight, weight gain during pregnancy and child's age.
‡ Adjusted for pre-gestational weight, maternal height and child's age.
§ Fat mass:lean mass$^{2·3} \times 10^{-3}$.

Stunting has been suggested as a factor contributing to high rates of obesity in developing countries. The cross-sectional study of children from the four countries mentioned earlier (Popkin *et al*. 1996) showed significant associations between stunting and overweight at the individual level. Other cross-sectional studies have also shown concurrent stunting and overweight or obesity in children (Koziel & Jankowska, 2002; Mukuddem-Petersen & Kruger, 2004; Jinabhai *et al.* 2005; Mamabolo *et al.* 2005). Findings from cross-sectional analyses may, however, be at least partly explained by a mathematical artefact in that, other things being equal, height will tend to be inversely related to a ratio of weight over height.

On the other hand, evidence from analyses of longitudinal studies is conflicting (Schroeder *et al.* 1999; Benefice *et al.* 2001; Walker *et al.* 2002; Martins *et al.* 2004; Cameron *et al.* 2005). A review in 2001 concluded that 'the evidence linking undernutrition to future risk of fatness is limited and contradictory' (Martorell *et al.* 2001).

The influence of undernutrition on body composition has also been investigated in a prospective study from Guatemala (Li *et al.* 2003). Linear growth retardation in early life (between 15 days and 2 years of age) was associated with a lower lean mass in young adulthood (between 21 and 27 years of age), but not with fat mass or percentage of body fat. In our study, stunting at age 2 and 4 years was not associated with lean mass index or FM:LM$^{2\cdot3}$ ratio, but was associated with lower fat and body mass indices. Potential mechanisms for why early nutritional stunting may lead to an increased risk of obesity were studied in a selected group of children in Sao Paulo, Brazil (Hoffman *et al.* 2000; Martins *et al.* 2004; Grillol *et al.* 2005), but the findings were inconclusive.

The association between stunting and abdominal fatness was also analysed in the Guatemalan study, with contradictory results. In adults measured between 1988 and 1994, waist:hip ratio increased by 0·65 in men and 0·29 in women for each point decrease in height-for-age *Z* score at 3 years of age (Schroeder *et al.* 1999), whereas waist:hip ratio measured in a follow-up studied carried out in 1998–99 was unrelated to growth in childhood (Li *et al.* 2003). In a longitudinal study carried out in a developed country (Laitinen *et al.* 2004), children who were small for gestational age showed a higher risk of abdominal adiposity at age 31 years. We did not investigate measures of fat distribution in the present study.

Our results showed no evidence that boys who were undernourished at age 2 or 4 years were more likely to be fatter when aged 18. On the contrary, such children had lower fat, lean and body mass indices, as well as a lower FM:LM$^{2\cdot3}$ ratio. Our results suggest that undernutrition may partially protect against fatness at this age, and are consistent with those obtained when overweight and obesity – based on BMI and skinfolds – were assessed in the same cohort at the age of 15–16 years (Monteiro *et al.* 2003). These previous analyses did not, however, evaluate body composition outcomes.

The stronger association between outcomes measured at 18 years and anthropometric variables assessed at 4 years, when compared with those assessed at 2 years, may be interpreted as reflecting the 'horse-racing effect' (Peto, 1981). Horses – or children – who are leading a race at a point closer to the finish line are more likely to win it than those leading at earlier parts of the track.

Confounding factors were selected to express socioeconomic and genetic determinants of child and adult anthropometry. Adjustment for these factors led to slight reductions in regression coefficients, suggesting that although these variables had positively confounded the association, they were far from explaining the findings of the present study.

In conclusion, the present results suggest that undernutrition in early life is not a risk factor for overweight or obesity. Our study differed from other longitudinal studies in the literature with respect to length of follow-up and number of subjects included in the analysis. In the present analyses, the associations between early nutrition and adolescent body composition were studied using fat, lean and body mass indices, and FM:LM$^{2\cdot3}$ ratio; fat distribution was not, however, considered. Finally, only males were included in our study. Further analyses should be conducted including females and fat distribution measures.

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