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Stunted children gain less lean body mass and more fat mass than their non-stunted counterparts: a prospective study

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The aim of the present study was to analyse the changes in body composition of stunted children during a follow-up period and to test the hypothesis of a tendency to accumulate body fat as a consequence of undernutrition early in life. We selected fifty boys and girls aged 11 to 15, who were residents of slums in São Paulo, Brazil. Twenty were stunted (S) and thirty had normal stature (NS). The children's nutritional status and body composition were assessed through anthropometry and dual-energy X-ray absorptiometry, at the beginning of the present study and after 3 years, and changes in lean mass (LM and LM%) and fat mass (FM and FM%) were calculated. Stunted boys accumulated more body fat (FM%: S = 1·62 %, NS = − 3·40 %; *P*=0·003) and gained less lean mass (LM%: S = − 1·46, NS = 3·21 %; *P*=0·004). Stunted girls gained less lean mass (S = 7·87 kg, NS = 11·96 kg; *P*=0·032) and had significantly higher values of FM% at follow-up when compared with their baseline values (*P*=0·008), whereas non-stunted girls had a non-significant difference in FM% over time (*P*=0·386). These findings are important to understand the factors involved in the increased prevalence of overweight and obesity among poor populations, which appear to be associated with hunger during infancy and/or childhood.

Undernutrition: Stunting: Body composition: Dual-energy X-ray absorptiometry

Prolonged undernutrition during gestation and extending into early childhood is common in developing countries and causes stunting. The prevalence of stunting in children in the world nowadays is 33 % (Allen & Gillespie, 2001). Stunting is caused by poor maternal nutrition status at conception, undernutrition *in utero*, inadequate breast-feeding, delayed complementary feeding, inadequate quality or quantity of complementary feeding and impaired absorption of nutrients due to intestinal infections and parasites. Stunting in adults can be used as a marker for socio-economic inequities in poverty-stricken groups (World Health Organization, 1995).

The long-term effects of stunting include metabolic alterations that can result in non-communicable illnesses, such as hypertension and other obesity-related disorders. Some studies in Brazil have shown a strong relationship between stunting and hypertension among adults, especially women (Sichieri *et al.* 2000*a*; Florêncio *et al.* 2004). This association has also been found early in life, among stunted adolescents (Fernandes *et al.* 2003).

Studies in Brazil and in other countries have shown that stunting is also related to overweight and, specifically, to increased abdominal fat. In a prospective study, our group found that stunted girls had greater gains in weight-for-height compared with non-stunted when eating diets with higher fat content (Sawaya *et al.* 1998). Velasquez-Melendez *et al.* (1999) found that stunting in adult women was an independent risk factor for overweight and a high waist:hip ratio. Sichieri *et al.* (2000*b*) showed an increased prevalence of obesity and abdominal fat in women with short stature in the city of Rio de Janeiro. In a prospective study in Guatemala, Schroeder *et al.* (1999) described an association between stunting in infancy and abdominal fatness in adulthood. By measuring skinfold thickness in a longitudinal study in Senegal, Benéfice *et al.* (2001) found that girls who were short early in life (6–18 months) stored more fat in the upper body (trunk and arms).

In a cross-sectional study of children living in slums of the city of São Paulo, we compared the RMR, postprandial energy expenditure, respiratory quotient (RQ), total energy expenditure and substrate oxidation of stunted and non-stunted children (Hoffman *et al.* 2000*a*,*b*,*c*). Particularly, compared with control children, stunted children had

Abbreviations: DXA, dual-energy X-ray absorptiometry; RQ, respiratory quotient.
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lower RMR when the results were expressed in MJ/d. However, RMR values were not significantly different from those for control children when values were expressed relative to lean body mass (Hoffman *et al.* 2000*b*). The stunted group showed normal postprandial thermogenesis; however, this group showed significantly higher fasting RQ and, thereby, fasting fat oxidation was significantly lower (Hoffman *et al.* 2000*c*). These findings show important metabolic changes related to stunting, and suggest a tendency to accumulate body fat. In the present study we followed-up for 3 years a group of these children.

The aim of the present study was therefore to investigate if stunting can promote an altered pattern of body composition over time and to investigate the relative contributions of various body components (body fat, fat-free mass) in the body composition of children exposed to undernutrition, by measuring dual-energy X-ray absorptiometry (DXA). These findings can lead to a better understanding of the progression of many non-communicable diseases in developing countries.

Methods

Protocol

The present 36-month follow-up study included fifty boys and girls, aged 11 to 15 years, who were living in slums in the city of São Paulo, Brazil. Twenty of them were stunted and thirty had normal stature (non-stunted). They were selected out of a group of more than 400 children in slums on the south side of São Paulo who were measured in an anthropometric census, and participated in a 3 d cross-sectional metabolic study (*n* 60); details described elsewhere (Hoffman *et al.* 2000*a*,*b*,*c*). We were able to find fifty children of the original sample who had baseline data of body composition and were reassessed in the present study. The children in the stunted group had height-for-age values that were lower than $-1{\cdot}5$ *Z* score (according to National Center for Health Statistics standards). Parents in the two groups had similar stature and BMI (kg/m^2), thus precluding the influence of genetic factors in the resulting short stature. The characteristics of the children are presented in Table 1.

After their parents had signed the 'Informed Consent Form', which was approved by the Ethical Committee for Research of the Federal University of São Paulo, the children underwent screening tests consisting of a clinical examination, assessment of pubertal stage, blood sampling for analysis, and urine and stool samplings to detect infections and parasites. Children whose results were positive were treated before the beginning of the experimental protocol. After the data analysis, the families were seen in their individual homes, informed of the results, and given nutritional guidelines for preventing obesity and undernutrition.

Anthropometry

Children were brought to UNIFESP (Federal University of São Paulo) in the morning for the fasting anthropometric evaluation. Clad in underwear and barefoot, they were measured for height and weight. Body weight was measured using an electronic scale (model SD-150; Country Technologies, Gays Mills, WI, USA) with a 150 kg capacity and 10 g accuracy. Stature was measured using a standard stadiometer, with a precision to the nearest 0·1 cm. Children stood with their heels together touching the vertical pole, their arms extended alongside their bodies, and their heads on the Frankfort plane.

To assess nutritional status, height-for-age, weight-for-age, and BMI *Z* scores were calculated using the Epi-info 2000 program, which makes use of the reference standards of the National Center for Health Statistics (Centers for Disease Control and Prevention, 2000).

Pubertal stages

A child's pubertal stage was determined by a trained physician according to Tanner (1962). We used the cut-off points recommended by the WHO, breast-stage 2 for girls and genitalia-stage 3 for boys, to classify the children into pre-pubertal and pubertal groups. Children who have reached these stages have begun their pubertal growth spurts.

Body composition

Body composition was assessed by DXA, using the Hologic densitometer (model QDR-4500 A; Hologic Inc., Bedford, MA, USA). Total body fat and lean mass were measured with the *Enhanced Whole Body* software (v. 8.26; Hologic Inc.) A body composition phantom, provided by the manufacturer, was used to calibrate the equipment before each set of measurements.

DXA provides a three-component model to measure body composition; fat mass, fat-free soft tissue and bone mineral content. From these, bone mineral density and relative body fat (percentage fat mass) are calculated.

Recent advances in DXA technology have allowed this procedure to be more frequently used in body composition analysis because it measures whole-body as well as regional bone mass, lean mass and fat mass with low precision error (Bachrach, 2000; Kyle *et al.* 2001). Other advantages of DXA are the relatively quick scan time (≤ 5 min) and minimal radiation exposure (Heymsfield *et al.* 1990; Goran, 1998). The total radiation dose to the subject is $< 1{\cdot}0$ mRem (Litaker *et al.* 2003).

In addition, DXA can be used to assess changes in body composition during a follow-up period and therefore in longitudinal studies (Going *et al.* 1993; Lohman *et al.* 2000).

In the present study we did not analyse bone mass; therefore lean mass refers to fat-free soft tissue. Percentage of lean mass was also calculated, using total body mass provided by DXA.

Statistical analysis

Changes in nutritional status and body composition were calculated, and the resulting variables with a normal curve were compared using the Kolmogorov–Smirnov test. Although we did observe some variance within

Table 1. Anthropometric variables and nutritional status of the study children at baseline, follow-up and changes between the two visits

(Mean values and standard deviations)

	Boys				Girls			
	Non-stunted (*n* 13)		Stunted (*n* 12)		Non-stunted (*n* 17)		Stunted (*n* 8)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Baseline								
Age (years)	10·32	1·58	9·96	1·34	9·91	1·16	10·50	1·40
Weight (kg)	32·06	5·77	25·30*	4·41	30·71	5·68	25·97*	5·12
Height (cm)	133·35	9·72	125·79*	8·50	135·3	9·9	126·0*	9·9
Height-for-age (*Z* scores)	−0·97	1·04	−1·91*	0·89	−0·41	1·06	−2·36**	0·92
Weight-for-age (*Z* scores)	−0·30	0·82	−1·35*	0·68	−0·37	0·78	−1·55**	0·72
BMI (kg/m^2)	17·01	1·88	16·12	2·20	16·75	1·39	16·71	1·78
BMI-for-age (*Z* scores)	−0·11	0·91	−0·53	1·17	−0·10	0·52	−0·33	1·06
Follow-up								
Age (years)	13·28	1·46	13·02	1·28	12·98	1·20	13·14	1·22
Weight (kg)	44·00	8·67	33·3**	6·4	46·4	11·0	35·7*	6·8
Height (cm)	154·3	9·14	140·42**	7·67	153·68	7·86	141·82*	7·77
Height-for-age (*Z* scores)	−0·38	0·82	−2·01**	0·67	−0·29	0·76	−2·14**	0·52
Weight-for-age (*Z* scores)	−0·44	0·67	−1·66**	0·74	−0·08	0·89	−1·42**	0·50
BMI (kg/m^2)	18·30	1·91	16·77*	1·85	19·46	3·09	17·64	2·11
BMI-for-age (*Z* scores)	−0·28	0·75	−0·93*	0·86	0·09	0·88	−0·59	0·80
Changes								
Weight (kg)	11·94††	4·96	8·00*††	2·57	15·73††	6·35	9·77*††	2·62
Height (cm)	20·94††	6·2	14·6*††	4·7	18·4††	5·4	15·8††	4·9
Height-for-age (*Z* scores)	0·59	1·03	−0·10*	0·58	0·11	0·57	0·22	0·84
Weight-for-age (*Z* scores)	−0·14	0·59	−0·32†	0·32	0·29†	0·57	0·13	0·46
BMI (kg/m^2)	1·29†	1·82	0·65	3·22	2·71†	3·12	0·94	2·76
BMI-for-age (*Z* scores)	−0·17	0·90	−0·40	1·62	0·19	1·00	−0·26	1·18

Mean value was significantly different from that for the non-stunted group: *$P<0·05$, **$P<0·001$.
Mean value, within a group, changed significantly from baseline to the follow-up visit: †$P<0·05$, ††$P<0·001$.

groups, variables did not significantly stray from the normal distribution. Differences between groups were assessed using the independent-sample Student's *t* test. Comparisons were made in the original group and after stratification by pubertal stage. As the number of pre-pubertal children, according to sex, was too small, we only show the results in pubertal children.

Differences between baseline and follow-up data within groups were assessed using the paired-sample *t* test. Analyses were carried out with the statistical software SPSS 10.0 for Windows (SPSS Inc., Chicago, IL, USA), with $\alpha < 0·05$ for all analyses.

Results

The overall prevalences of height-for-age *Z* score below −1·5 and below −2·0 in the children in the slum population surveys conducted at the beginning of the present study were 19·2 and 7·5 %, respectively.

Table 1 shows the characteristics of the children at baseline, follow-up and changes in nutritional status over time. Boys and girls with nutritional stunting did have a mean height-for-age deficit of about −2·0 *Z* score and a mean weight-for-age deficit of about −1·5 *Z* score at follow-up. Whereas the non-stunted boys experienced an increase in height-for-age, the stunted boys had a negative progression in height-for-age (*Z* score) and weight-for-age (*Z* score) indices. BMI and BMI-for-age (*Z* score) values of the study groups were similar, but non-stunted boys had a significant increase in BMI. Increased BMI, height-for-age, and weight-for-age were observed in the two groups of girls, although this was markedly greater in the non-stunted group, especially for BMI.

Table 2 shows the proportion of children in the two groups who were below or above the cut-off point for puberty. All the boys in the non-stunted group had reached puberty, but only 50 % of the boys with stunting had done so. Girls in the two groups had a similar distribution, and just one girl in each group was below the cut-off point for puberty.

Gains in body fat and lean mass were calculated by drawing on the difference between the values obtained in the DXA scans performed at the beginning of the present study and after the follow-up period of 3 years.

Fig. 1 summarises the overall findings, illustrating the changes of total fat and lean mass (percentage and kg) of

Table 2. Pubertal stage at follow-up*

	Boys				Girls			
	Non-stunted		Stunted		Non-stunted		Stunted	
	n	%	*n*	%	*n*	%	*n*	%
Pre-pubertal	0	0	6	50	1	5·9	1	12·5
Pubertal	13	100	6	50	16	94·1	7	87·5

* According to the cut-offs recommended by the World Health Organization (1995).

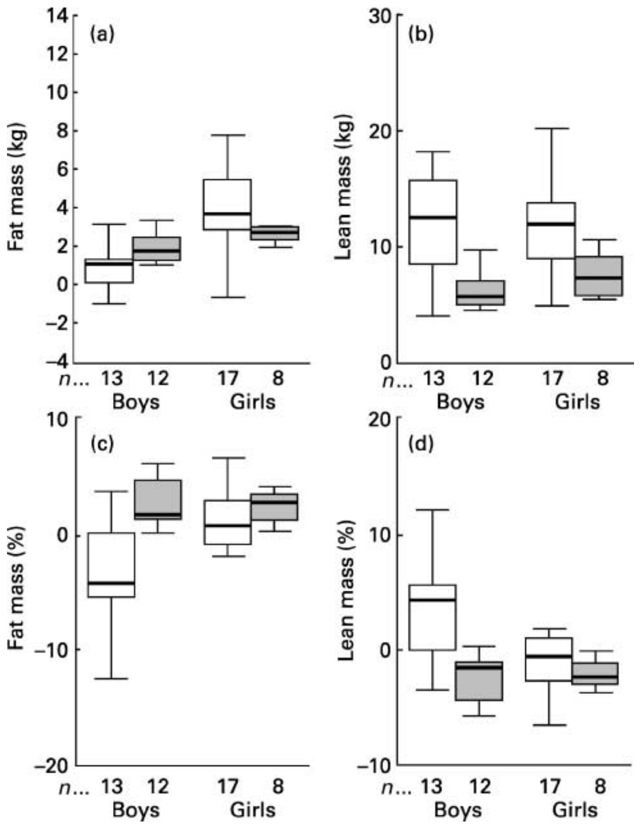

Fig. 1. Changes in body composition of stunted (■) and non-stunted children (□) (overall group) between the two study visits. (a) Fat mass; (b) lean mass; (c) fat mass percentage; (d) lean mass percentage. The boxes represent the interquartile ranges which contain 50 % of values, the whiskers are the highest and lowest values (excluding outliers), and the line across each box indicates the median.

the studied groups from baseline to follow-up. Stunted boys had significantly larger increases in absolute and percentage fat mass and smaller increases in absolute and percentage lean body mass, demonstrating that stunted boys gained more body fat and less lean mass. On the other hand, no significant differences were seen in fat gain among girls, although a tendency towards larger increases of fat mass percentage in stunted girls can be noticed. Stunted girls also gained significantly less lean mass (kg).

As a different proportion of stunted and non-stunted children, especially boys, reached puberty during the follow-up period as shown in Table 2, and the onset of puberty coincided with remarkable differences in body composition, we decided to repeat the analysis including only boys and girls who had reached puberty at the follow-up visit. The results are shown in Table 3 and they are essentially the same as shown in the overall group (Fig. 1), except for the gain in absolute fat mass (kg), which was not statistically significant in boys.

Table 3 describes the baseline, follow-up, and the changes over time in body composition. Differences between groups were analysed using the independent *t* test and differences within groups over time were done using the paired *t* test. The comparison between different nutritional groups showed that stunted boys accumulated more body fat (percentage) ($P=0{\cdot}004$) and gained less lean mass in kg ($P=0{\cdot}001$) and percentage ($P=0{\cdot}003$). Stunted girls gained less lean mass ($P=0{\cdot}032$). The comparison within groups over time showed that the percentage body fat of stunted boys was significantly higher at follow-up in relation to baseline ($P=0{\cdot}040$). On the other hand, non-stunted boys showed a decrease of body fat over time ($P=0{\cdot}023$). The percentage body fat measured at follow-up was significantly higher in stunted girls in comparison with baseline ($P=0{\cdot}008$), whereas the increase in percentage body fat of non-stunted girls was not significant ($P=0{\cdot}395$). Similar results were observed in the percentage of lean mass, with the stunted girls having a greater decrease ($P=0{\cdot}007$) comparing the follow-up with baseline, and the non-stunted ones a non-significant difference over time ($P=0{\cdot}386$).

Discussion

The present study is the first longitudinal study on chronically undernourished children to utilise DXA to analyse the changes in body composition. The results confirm previous suggestions that these children have a preference to accumulate or spare body fat to the detriment of lean body mass (Hoffman *et al.* 2000*c*). The increased body-fat gain observed in the group of boys with stunting was associated with lower gains in lean mass even after prepubertal boys had been excluded from the analysis. In stunted girls the results are less evident but, even so, a higher increment in percentage body fat was seen over time.

Few longitudinal studies evaluating changes by using anthropometry in undernourished children have been published. Ashworth (1969) observed that severely hospitalised undernourished children gained more fat mass and less lean body mass during nutritional recovery. In the study of Benéfice *et al.* (2001) described previously, Senegalese girls with a history of undernutrition showed recovery in weight but not in stature, suggesting a higher gain in fat than in lean mass. Walker *et al.* (2002) showed a slightly higher subscapular:triceps skinfold ratio in stunted children than non-stunted at 11 years.

Since changes in body composition during adolescence are related to the rapid growth spurt that occurs at the onset of puberty (Malina & Bouchard, 1988), we controlled for this effect performing analyses only in children who had reached puberty at the follow-up visit. The results did not differ from the analysis in the overall group.

Although it is generally accepted that DXA is a safe method for routine use (Brodie *et al.* 1998), and its estimates of fat and fat-free soft tissue are fairly precise (Bachrach, 2000; Fuller *et al.* 2001), some questions have been raised about its limitations, mostly related to the use of different models of DXA and software versions. Recently Tylavsky *et al.* (2003) showed that the Holigic QDR4500A densitometer produces higher total and regional fat-free-mass estimates compared with previous generations of Hologic whole-body scanners that use pencil-beam technology. For the present study, we used the same instrument (Hologic QDR4500A) and the same

Table 3. Body fat, body fat percentage, lean body mass, lean body mass percentage of stunted and non-stunted pubertal children at baseline, follow-up and changes between the two study periods

(Mean values and standard deviations)

	Boys				Girls			
	Non-Stunted (*n* 13)		Stunted (*n* 6)		Non-Stunted (*n* 16)		Stunted (*n* 7)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Baseline								
Body fat (kg)	6·09	2·68	3·25*	0·53	7·42	2·79	5·07*	1·66
Body fat (%)	18·75	5·79	12·65*	1·94	23·58	5·80	19·47	5·10
Lean body mass (kg)	24·41	3·85	21·65	3·10	22·46	3·54	20·25	4·77
Lean body mass (%)	77·78	5·57	83·70*	1·83	72·98	5·69	77·31	4·97
Follow-up								
Body fat (kg)	6·94	2·07	4·88*	1·18	11·92	4·93	8·07	2·42
Body fat (%)	15·34	3·65	14·27	2·67	24·29	5·09	21·70	4·26
Lean body mass (kg)	36·58	7·03	28·17*	4·28	34·43	5·78	28·12*	5·90
Lean body mass (%)	80·99	3·42	82·24	2·60	72·29	5·00	75·25	4·12
Changes								
Body fat (kg)	0·84	1·77	1·63†	0·69	4·49††	2·73	3·00††	0·80
Body fat (%)	−3·40†	4·70	1·62*†	1·43	0·71	3·23	2·23†	1·52
Lean body mass (kg)	12·16††	4·14	6·52**††	1·99	11·96††	3·56	7·87*††	1·99
Lean body mass (%)	3·21†	4·61	−1·46*†	1·45	−0·69	3·10	−2·06†	1·36

Mean value was significantly different from that for the non-stunted group: *$P<0·05$, **$P<0·01$.
Mean value, within a group, changed significantly from baseline to the follow-up visit: †$P<0·05$, ††$P<0.001$.

software version in the two measurements, which probably eliminates most of this problem.

Another source of concern is the question of whether DXA is an adequate method to measure children's body composition. Wong *et al.* (2002) found that Hologic DXA has poor limits of agreement in comparison with the four-compartment model for body composition assessment in children. On the other hand, this technique has been frequently tested in paediatric subjects, including soft-tissue analysis (Chan, 1992; Ellis *et al.* 1993; Faulkner *et al.* 1993; Kooh *et al.* 1993; Rico *et al.* 1993; Skinner *et al.* 2003), even in small infants and newborns (Venkataraman & Ahluwalia, 1992; Brunton *et al.* 1993). It is considered a technique to measure body composition of potential use to the paediatric population (Goran, 1998). DXA is able to detect small individual changes in soft-tissue mass and is also useful for detecting group changes in lean mass (Going *et al.* 1993). In the present study, the lack of precision on the measurements of soft tissue using DXA is minimised, as comparisons over time are made in the same individuals.

A major limitation of the present study was the small number of boys and girls studied, a fact that has hindered the analysis of other factors that could be associated with the body composition changes. However, there are many difficulties associated with following up a group of children in the slum population we studied, since they frequently move from their houses impelled by socio-economic factors.

Additionally, the statistical power to detect differences in the gains of body fat and lean mass between stunted and non-stunted girls was limited. Even so, several differences were detected comparing baseline and follow-up data within groups, particularly in stunted girls.

No easy explanation can be drawn to describe the preference for body-fat accumulation in relation to lean body mass. Various factors could be involved. Some authors have suggested that undernourished individuals frequently use up protein stores in the muscular mass as a source of energy due to insufficient nutritional intake (Waterlow, 1999). Muscle tissue catabolism is highly increased during protein–energy malnutrition and causes a reduction in the muscle mass in these individuals (Shetty, 1999).

In spite of the nutritional guidance and medical care received at the beginning of the present study, the nutritional condition of the stunted boys and girls, as measured by height-for-age, weight-for age, and BMI indices (in *Z* score), deteriorated slightly. This indicates that the diet consumed during the follow-up was probably insufficient to supply the energetic needs throughout the present study, and thus these children probably needed to use their energy stores.

However, the population studied showed a gain in body fat. For this reason, another factor to explain the higher body-fat gain could be low animal-protein intake and insufficient consumption of minerals and vitamins but not energy.

Moreover, the tendency to preserve fat stores can be due to a biological adaptation to better metabolic efficiency. One factor that may explain the present results is the increased RQ, the ratio between the volume of O_2 consumption and CO_2 production by the organism (VO_2:VCO_2), measured by indirect calorimetry. RQ is used to estimate the type and quantity of substrate oxidation for the production of energy (carbohydrates and lipids) (Ferrannini, 1992). As mentioned before, we found significantly higher values of fasting RQ in these stunted children at baseline, indicating lower fat oxidation (Hoffman *et al.* 2000*c*). A lower rate of fat oxidation, which favours the accumulation of body fat, is probably one of the mechanisms involved in better metabolic efficiency (i.e. more efficient use of the available energetic substrates) that conserves energy stores in the body despite low energy expenditure and energy intake (Shetty, 1999).

The hypothesis of metabolic efficiency was investigated in studies conducted on rats subjected to food restriction. In 1993, we verified that female rats born from dams subjected to food restriction during gestation had higher levels of fat in the carcasses compared with the female control rats (Anguita *et al.* 1993). The increased fat mass was accompanied by a reduction in the relative weight of brown adipose tissue, protein content and activity, without changes in body weight or food intake, thus indicating increased metabolic efficiency. Another study in rats has shown that during nutritional recovery, the total energy expenditure of the previously malnourished group was significantly lower than in the control group (7–9 %) and this economy was oriented to a larger accumulation of body fat (Dulloo & Girardier, 1993). Furthermore, two recent studies from our group, conducted on human subjects, also indicated greater metabolic efficiency in stunted adults. Florêncio *et al.* (2001) found a large proportion of women who had both short stature and obesity (30 %). This condition prevailed even when energy intake was 65 % of the estimated energy requirements for these individuals (Florêncio *et al.* 2003).

The results found in the present study are in line with those described in several cohort studies investigating the effects of intra-uterine malnutrition. They have shown evidence that impaired intra-uterine growth, reflected by low weight or small size at birth, leads to a lower proportion of lean body mass in adult life. This evidence indicates a positive association of weight at birth with lean mass, but no association with body fat (Phillips, 1996; Hediger *et al.* 1998; Kahn *et al.* 2000; Gale *et al.* 2001).

Finally, the findings of the present study help to clarify the greater susceptibility to obesity (and related disorders) evidenced in developing countries under nutritional transition.

Further studies in this area will be necessary to provide solid evidence regarding the consequences of stunting and the appropriate types of treatment and prevention to ensure adequately established policies of intervention.

Conclusion

In the population studied, a greater accumulation of body fat and a lower gain in lean mass were observed in stunted children, markedly in the boys. These findings may contribute to the understanding of why there is an increased prevalence of overweight and obesity among poor populations and, most of all, point to the need for prevention and treatment of early mild undernutrition.

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