European Journal of Clinical Nutrition (2003) 57, 1097–1106

0954-3007/03 $25.00
www.nature.com/ejcn

ORIGINAL COMMUNICATION

Change in body water distribution index in infants who become stunted between 4 and 18 months of age

A Gartner[1]*, J Berger[1], KB Simondon[2], B Maire[1], P Traissac[1], C Ly[3], JL San Miguel[4], F Simondon[2] and F Delpeuch[1]

[1]*Nutrition, Food, Societies Unit, Institut de Recherche pour le Développement (IRD), WHO Collaborating Centre for Nutrition, Montpellier, France;* [2]*Epidemiology and Prevention Unit, Institut de Recherche pour le Développement (IRD), Montpellier, France;* [3]*Organisme de Recherche sur l'Alimentation et la Nutrition Africaines, (ORANA) Dakar, Sénégal;* *and* [4]*Instituto Boliviano de Biologia de Altura, IBBA La Paz, Bolivia*

Objective: To evaluate body composition changes using bioelectrical impedance analysis and skinfold thickness measurements in infants from tropical areas who become stunted between 4–18 months of age.
Design and measurements: Follow-up study. Extracellular water to total body water ratio index (length^2/resistance at low to high frequency), peripheral fat (tricipital and subscapular skinfold thickness), and length-for-age index were studied at 4 and 18 months of age.
Settings: Low-income areas in four tropical regions (Congo, Senegal, Bolivia and New Caledonia).
Subjects: Infants were included in the analysis provided they were neither stunted nor wasted at 4 months. Two groups of infants were compared, those that were stunted at 18 months ($n=61$) or not ($n=170$).
Results: The extracellular water to total body water ratio index and the sum of skinfold thickness measurements were similar in the two groups at 4 months, and only the extracellular water to total body water ratio index was significantly different at 18 months. When no stunting appeared between 4 and 18 months, the change in the extracellular water to total body water ratio index was not linked with variations in length-for-age, and presented the expected pattern of variation in body water compartments. When stunting occurred, variation in length-for-age was related to significant changes in the extracellular water to total body water ratio index, the biggest increase in the proportion of extracellular water being found in the most stunted infants. Variations in the sum of the two skinfold thickness measurements presented the expected pattern for the 4–18 months growth and did not differ between the two groups.
Conclusions: Multifrequency resistances suggested that stunting was associated with a lack of the expansion of the intracellular compartment that is expected during normal growth of cell mass, together with preserved fat mass.
Sponsorships: Supported by grant 92L0623 from the French Ministry of Research, and by Institut de Recherche pour le Développement (IRD).
European Journal of Clinical Nutrition (2003) **57,** 1097–1106. doi:10.1038/sj.ejcn.1601649

Keywords: body composition; length-for-age; skinfold thickness; multifrequency bioelectrical impedance analysis; infants; tropical areas; stunting

Introduction

The process of linear growth faltering, which is common among infants and children in poor areas throughout the world, begins during infancy or even during foetal life and is thought to be a result of poor dietary intake, morbidity or malabsorption owing to intestinal mucosal damage (Waterlow, 1988, 1994; Lunn, 2000). Physiological and nutritional status variations can thus be expected in stunted infants. The

*Correspondence: A Gartner, Nutrition, Food, Societies Unit, UR 106, Institut de Recherche pour le Développement, BP 64501, 911 Avenue Agropolis, 34394 Montpellier Cedex 5, France.
E-mail: gartner@dakar.ird.sn
Contributors: B Maire (Guarantor) and F Delpeuch initiated the study and contributed to writing the manuscript. A Gartner (Guarantor) was in charge of the study in Congo. J Berger and JL San Miguel were in charge of the study in Bolivia. C Ly, F Simondon and KB Simondon were in charge of the study in Senegal. A Gartner and P Traissac were responsible for data management and analysis, and contributed to writing the manuscript.
Received 17 November 2001; revised 6 August 2002; accepted 13 August 2002

concomitants and consequences of becoming stunted are quite well known. It has been previously shown in children from developing areas that stunting remains negatively correlated with cognitive and school performance, physical activity and reproductive outcome, and positively correlated with risk of infection (Neumann & Harrison, 1994). On the other hand, remarkably little is known about the specific mechanisms of linear growth retardation, and particularly the impact of growth retardation on the body composition of infants. Body compartments are altered by many factors such as nutritional status and disease. In children, an additional factor must be taken into consideration and that is the changes in body composition that take place during growth. Impairment of the lean body mass occurs in malnutrition (Pencharz & Azcue, 1996). The differentiation of the lean body mass into the body cell mass and the extracellular mass is very important in the nutritional assessment (Waterlow *et al*, 1992). As a matter of fact, the fluid balance is deranged in patients with malnutrition (Wahlqvist & Marks, 1990). The extra- to intracellular water ratio is increased, extracellular water volume being better preserved than cell mass (Forbes, 1988).

The central hypothesis of the present study is that occurrence of stunting could be associated with a disturbance in expected variations in age-related body composition during growth in infants, and that it would thus be very useful to evaluate the equilibrium of aqueous body compartments. For this purpose, we chose to use multifrequency bioelectrical impedance analysis (BIA), as abnormal values for multifrequency BIA are likely a result of disturbed distribution of water between extracellular space and intracellular space (Bioelectrical Impedance Analysis in Body Composition Measurement, 2000). This method, which is portable and can be used in the field, appears suitable for use in infants because it is noninvasive, simple and reliable; however, BIA is still in the experimental phase for use in infants. Only a few previous reports have described the use of a portable BIA analyser to evaluate body composition in children living in tropical conditions. Changes in body composition have been measured with BIA in malnourished children (Fjeld *et al*, 1990; Walker *et al,* 1990). Although little is known about variations in body composition that occur during malnutrition, some studies of refeeding of malnourished children with different ages or aetiology of malnutrition, using single-frequency BIA, have shown variations in body composition (Molina *et al,* 1987; Grazioso *et al*, 1990; Vettorazzi *et al*, 1990; Kabir *et al*, 1994; Pencharz & Azcue, 1996; VanderJagt *et al*, 2000). Quirk *et al* (1997) suggested that serial BIA measures might be useful as a predictor of progressive undernutrition and poor growth in children with cystic fibrosis.

The aim of this study was to describe the variations in BIA parameters occurring in infants from developing areas who became stunted between 4 and 18 months of age. We used the ratio of resistance at high and low frequencies as an index of distribution of body water in the extracellular space. In addition to the assessment of the fat-free body components with the BIA method, body composition was assessed by local measurements of skinfold thickness to document peripheral variations in fat.

Subjects and methods

Subjects

The infants were subjects in four similar controlled randomized trials conducted simultaneously in low-income areas in Central and West Africa, South America and the South Pacific to test the effect of supplementation on growth. A description of the trials and results has been previously published (Simondon *et al*, 1996). Briefly, the Central African study was conducted in a peripheral urban neighbourhood in Brazzaville, the capital city of Congo. The West African Sahel study was conducted in a rural area in central Senegal, 150 km from the capital city of Dakar. The South American study was conducted in Pasankeri, a poor peripheral urban neighbourhood in La Paz, the capital city of Bolivia. The South Pacific study was conducted on the Melanesian island of Mare, which is part of New Caledonia. Sanitary conditions were rudimentary in all the study areas. Infants were included in the controlled trial at the age of 4 months for a duration of 3 months ($n = 447$). Breast-feeding was required for inclusion in the Congo, Senegal and Bolivia, and all infants were still breast-fed at the age of 7 months. In New Caledonia, 67% of the infants were breast-fed at the age of 4 months and 47% at 7 months. Infants were again measured 14 months after inclusion, and 240 BIA measurements were made both at 4 and 18 months ($n = 207$ subjects could not be retrieved because the subjects moved, civil unrest in Brazzaville and some refusals). Because the supplementation trial had no effect on either linear growth or on BIA parameters between 4 and 18 months, data from the two controlled trial groups (receiving a nutritional supplement or not) from each of the four sites were pooled for this study. Mothers gave their informed oral consent. All national health authorities accepted the study.

Anthropometry

As a result of the inclusion process of the controlled trial that identified eligible subjects at birth, the birth date of all subjects was confirmed by a birth certificate, which allowed us to calculate correctly the age.

Anthropometric measurements were taken at 4 months (± 7 days), then 13 and 48 weeks later. Age is referred to as 4, 7 and 18 months hereafter. Recumbent length was measured three times at each visit with a Holtain infantometer (Holtain Limited, Crymych, UK; resolution 0.1 cm) and the mean of measurements was used for analysis. If two measurements differed by > 0.5 cm, a fourth measurement was taken and the outlier discarded. The infants were weighed naked on a baby scale (Seca, Hamburg, Germany; resolution 10 g). Measurements were taken at the local health clinic (Bolivia) or in the infant's home (other countries). One anthropometrist and one assistant were present on each occasion, and measurements were performed following exactly the same protocol at all the locations. Anthropometric indices have been calculated with Epi-Info (CDC, Atlanta, GE, USA). Infants with a length-for-age (LA) index below −2 *Z*-scores of the National Center for Health Statistics reference (WHO, 1983) were defined as stunted, and those with a weight-for-length (WL) index below −2 *Z*-scores as wasted. Skinfold thickness measurements were carried out following a standard procedure on the left side of the body using a Holtain (Crymych, UK) skinfold calliper. The measurements were made to the nearest millimetre at the triceps and subscapular sites in each infant by the same observer.

Bioelectrical impedance

BIA was performed on the left side of the body with a body composition analyser (Model TVI-10, Danninger Medical, Columbus, OH, USA) with a four-electrode arrangement. The electrodes were paired, one pair acting as current electrodes, the other pair acting as detector electrodes. The analyser applies an imperceptible current of 800 μA at three different frequencies of 5, 50 and 100 kHz at the distal electrodes. Voltage was detected by the proximal electrodes. The need for standardization of electrode placement in BIA in young children has been reported previously (Gartner *et al*, 1992), and the placement of the sensor electrodes represents a high source of error in the BIA method. As in our previous studies (Gartner *et al*, 1994) and in studies by another team using BIA in malnourished children (Grazioso *et al*, 1990; Vettorazzi *et al*, 1990, 1994), we chose to place the signal electrode on the dorsal side of the wrist and the sensor electrode 6 cm along the forearm; the leg signal electrode was placed on the dorsal side of the ankle and the sensor electrode 6 cm away in the pre-tibial region. By connecting the analyser clips to the electrodes, electrical current passed through the whole body. Subjects were supine with their hands and their thighs apart. The infant was comforted and pacified, if necessary, the arm or leg being held using a cloth to avoid contact with the operator's skin that could lead to a reduction in the impedance measurement (data not shown). The resistance (*R*) values of measurement at a frequency of 5 kHz (R_5), 50 kHz (R_{50}) and 100 kHz (R_{100}) for each subject were read to the nearest 0.1 Ω from a digital display and recorded. The calibration of the instrument was checked daily with standard resistors included in the analyser. All BIA measurements were performed by the same measurer at each location immediately after anthropometric measurements.

Electrical theory indicates that length^2/R can be assumed to reflect conductor volume. In man, the value of height^2/R_{50} has been found to correlate highly with laboratory estimates of total body water (TBW) volume and fat-free mass (Lukaski *et al*, 1985; Segal *et al*, 1985; Kushner & Schoeller, 1986). At low frequencies, the current cannot pass through the cell membrane and *R* will be inversely related to the amount of extracellular water (ECW). At high frequencies, the current is able to pass through cell membranes and body *R* will be inversely related to the amount of TBW. ECW and TBW could be predicted independently at 5 and 100 kHz, respectively (Deurenberg *et al,* 1995). Differences in body water distribution over the intra- and extracellular spaces are reflected by impedance ratios of 5–100 kHz frequencies (Lusseveld *et al*, 1993). In our subjects, the length^2/R_5 is assumed to reflect the ECW volume, and length^2/R_{100} the TBW volume. Their ratio has been used as a simple index of ECW/TBW ratio.

A reliability study was performed on 78 young Congolese children aged 0–47 months by repositioning the four electrodes between the replicate measurements. The formula used for estimating technical error of measurement was $\sqrt{\Sigma d^2/2n}$, where *d* was the difference between two observations, *n* was the number of pairs of observations, and percentage reliability was the technical error × 100/overall mean of the measurements.

Statistical analysis

Statistical software used for data entry, validation and analysis was Epi-Info (CDC, Atlanta, GE, USA) and the SAS system (SAS Institute Inc., Cary, NC, USA), release 6.12. Values are expressed as means and standard deviations or confidence intervals. Differences in variables between groups were tested using the general linear model. Correlations are Pearson's product moment, calculated between the body composition parameters and the anthropometrical data. First type error risk was set at 0.05 for all analyses.

Results

In the reliability study, values for R_{50} ranged from 367 to 673 Ω (mean 542, s.d. 71). Absolute value of the difference between replicates ranged from 0 to 49 Ω. Mean difference was 8.6 Ω (s.d. 9.5), technical error was 8.9 Ω, and percentage reliability was 1.6%. The repeatability of *R* measurement was high, as previously observed in other studies in children (Houtkooper *et al*, 1989). The result was better than the percentage reliability of 2.3% we previously obtained on a sample of younger infants (Gartner *et al*, 1994). On the other hand, the value of our technical error of measurement was somewhat higher than values (below 7.5 Ω) obtained by Vettorazzi *et al* (1994) on a series of 10 measurements on four infants.

The controlled trial included infants with a WL index ≥−2 *Z*-scores (ie not wasted) and an LA index ≥−2.5 *Z*-scores. The present study included infants who were neither stunted ($n=9$ excluded) nor wasted at 4 months ($n=231$: 84 from Congo, 50 from Senegal, 58 from Bolivia, 39 from New Caledonia) and compared infants who had become stunted at 18 months (Stunted-at-18 months, $n=61$) with those with normal (≥−2 Z-scores) anthropometrical LA index at 18 months of age (Controls, $n = 170$). Characteristics of the subjects are presented in Table 1. Infants who had become stunted at 18 months had significantly lower LA when compared to Controls as early as 4 months (Table 1). Even if the two groups differed on the basis of LA index at the age of 4 months, we were interested in detecting changes in body composition parameters that occur during growth with an increase in the difference in LA. In the tropical study areas, LA index decreased significantly during the 4–18 months study period even in the Control group (Table 1). Body composition parameters are presented in Table 2. Results in Table 2 were obtained from a general linear model in which the response variable is the sum of skinfolds or the ECW/TBW ratio index, and the explanatory variables are group, WL index and country. For all the six comparisons between groups tested, no interactions were observed between group and country, so the data from the four countries were pooled for our analysis. We also checked that no interactions existed between this study group and the initial group in the controlled trial. The contribution of the WL index to difference in the sum of skinfolds or in ECW/TBW ratio indices is indicated by its significance in each model (Table 2). This contribution was not significant for the ECW/TBW ratio index at 4 months and for its change. Moreover, in subjects stunted at 18 months, the ECW/TBW ratio index was not significantly correlated with the WL index at 4 months ($P = 0.44$) or at 18 months ($P = 0.18$), and the 4–18 months change in the ECW/TBW ratio index was not correlated with change in the WL index ($P = 0.53$). The ECW/TBW ratio index was similar in the two groups at the age of 4 months and was significantly higher in the Stunted-at-18 months infants at the age of 18 months (Table 2). From 4 to 18 months, the ECW/TBW ratio index decreased in the Control infants while it increased in the Stunted-at-18 months ones, and this change was significantly different between the two groups (Table 2). At the same time, there was no significant difference in the decrease in the sum of the two skinfold thickness measurements in the Control infants and the Stunted-at-18 months ones (Table 2). The trend in the change was already clear at the age of 7 months (Figure 1). In the two groups, the change in the sum of skinfolds was significant. In Control infants, the change in ECW/TBW ratio index was significant whereas this was not the case in the infants stunted at 18 months (Table 2).

The Pearson correlation of the ECW/TBW ratio index at 18 months or of the sum of the two skinfold thickness measurements at 18 months with the LA index at 18 months was calculated. Correlations between changes in body composition variables and changes in LA between 4 and 18 months were also calculated (Table 3). For each Pearson correlation presented in Table 3, we verified that there was a linear relation between the two variables by plotting data

Table 1 Characteristics (mean (s.d.)) of the 231 infants followed from 4 to 18 months of age[a]

	Controls (n=170)	*Stunted at 18 months (n=61)*	*Comparison between groups*
Length-for-age (*Z*-scores)			
At 4 months	−0.36 (0.67)	−1.16 (0.53)	$P<10^{-4}$
At 18 months	−0.94 (0.70)	−2.60 (0.47)	$P<10^{-4}$
Weight-for-length (*Z*-scores)			
At 4 months	0.46 (0.83)	0.39 (0.78)	*P*=0.58
At 18 months	−0.59 (0.91)	−1.02 (0.91)	*P*=0.0021
Resistance at 5 kHz (Ω)			
At 4 months	503 (63)	508 (75)	*P*=0.56
At 18 months	559 (84)	592 (87)	*P*=0.011
Resistance at 100 kHz (Ω)			
At 4 months	459 (62)	464 (67)	*P*=0.61
At 18 months	497 (91)	551 (98)	*P*=0.0001

[a]All changes between 4 and 18 months were significant ($P<10^{-4}$).

Table 2 Anthropometric and BIA parameters of the 231 infants followed from 4 to 18 months of age

	Controls (n=170)		*Stunted-at-18 months (n=61)*			
Dependent variable	*Adjusted mean*	*95% confidence interval*	*Adjusted mean*	*95% confidence interval*	*Comparison between groups*	*Contribution of WL in the model*
Sum of two skinfolds (mm)						
At 4 months[a]	16.15	[15.81; 16.49]	16.05	[15.46; 16.64]	*P*=0.78	$P<10^{-4}$
At 18 months[b]	13.74	[13.42; 14.06]	13.90	[13.35; 14.45]	*P*=0.61	$P<10^{-4}$
Change[c]	−2.47 [d]	[−2.84; −2.10]	−2.08[d]	[−2.72; −1.44]	*P*=0.31	$P<10^{-4}$
ECW/TBW ratio index						
At 4 months[a]	0.912	[0.906; 0.918]	0.907	[0.896; 0.918]	*P*=0.37	*P*=0.68
At 18 months[b]	0.884	[0.868; 0.900]	0.922	[0.894; 0.950]	*P*=0.024	*P*=0.0053
Change[c]	−0.031[d]	[−0.049; −0.014]	+0.020[NS]	[−0.010; 0.051]	*P*=0.0045	*P*=0.74

ECW, extracellular water; TBW, total body water; WL, weight-for-length.
[a]Explanatory variables were group, weight-for-length index value at 4 months and country.
[b]Explanatory variables were group, weight-for-length index value at 18 months and country.
[c]Explanatory variables were group, weight-for-length index change between 4 and 18 months and country.
[d]Change was significant (0 value not in the 95% confidence interval); NS, change was not significant.

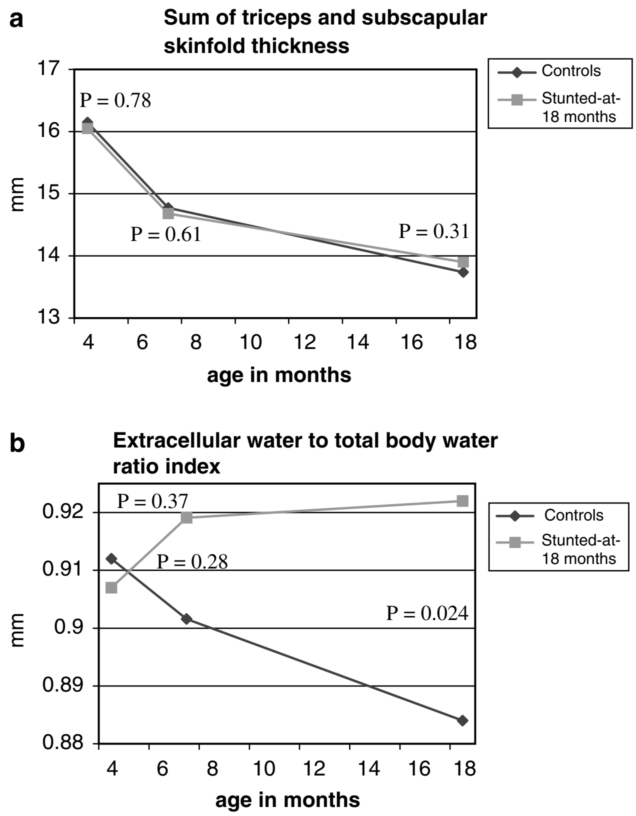

Figure 1 Sum of two skinfolds thickness (a) and extracellular water to total body water ratio index (b) at 4, 7 and 18 months of age by group. At each age, means were adjusted for weight-for-height value at the age and for country. The only significant difference between groups was observed for the extracellular to total body water ratio index at the age of 18 months.

from all subjects in each group. In each case, the scattergram of the two variables approximately followed a straight line. The ECW/TBW ratio index at 18 months of age was not correlated with the LA index value in either group. During normal growth in the Control group, that is, when no stunting appeared between 4 and 18 months, the change in the BIA index was not linked to variations in the LA index. On the other hand, in the case of stunting, variations in the LA index were related to changes in the ECW/TBW ratio index value. In Stunted-at-18 months infants, the equilibrium in the two aqueous body compartments was impaired. In the Stunted-at-18 months group, the sum of the two skinfold thickness measurements at 18 months was significantly correlated with the LA index value at 18 months, whereas there was no correlation in the Control group. There was no correlation between variations in the LA index and changes in the sum of the two skinfold thickness measurements in either group.

Discussion

In this study, we used BIA measurements parallel to anthropometry in infants at 4 and 18 months of age in four low-income areas, that is, in situations where changes in nutritional status are of interest. The use of BIA measurements in equations to predict body composition is complicated by the changes in children's body composition with growth, necessitating age-specific equations, which, at present, do not exist. For these reasons, we conducted follow-up comparative analysis by using crude BIA parameters. BIA is often used to estimate body fat and muscle, but it is important to recall that the conductor of the body is its water content, and a BIA analyser actually measures the impedance of this fluid conductor (Bioelectrical Impedance Analysis in Body Composition Measurement, 2000). That is why we chose the resistances ratio to reflect the proportion of body water compartments in the infants.

The results of this study indicate that the ECW/TBW ratio index, which was similar in the two groups at the age of 4 months, became different at 18 months, the variation in the ECW/TBW ratio index being significant in the Control group and not in the subjects stunted at 18 months. The LA index clearly had no relation with the distribution of body water compartments during normal growth, whereas stunting appeared to be related to body composition BIA parameters, the biggest increase in the proportion of ECW compartment being found in the most stunted infants. On the other hand,

Table 3 Correlation coefficients (*R* and *P*) of anthropometric and BIA parameters with length-for-age index at 18 months of age and correlation coefficients of the changes in these parameters with change in length-for-age index between 4 and 18 months of age

		Controls (n=170)		*Stunted-at-18 months (n=61)*	
	Correlation with	R	P	R	P
Sum of two skinfolds					
At 18 months	LA at 18 months	0.14	0.071	0.32	0.012
Change	LA 4–18 months change	−0.052	0.50	0.22	0.082
ECW/TBW ratio index					
At 18 months	LA at 18 months	0.062	0.42	−0.16	0.23
Change	LA 4–18 months change	−0.081	0.30	−0.26	0.042

ECW, extracellular water; TBW, total body water; LA, length-for-age index.

no relationship appeared between the occurrence of stunting and the age-related development of peripheral body fat. The relationship observed between the sum of skinfolds and the LA index at 18 months in the Stunted-at-18 months subjects could be explained by the fact that the sum of skinfolds was significantly correlated with the WL index ($P = 0.0016$).

In all mammals, fat-free mass hydration, of which the ratio of extracallular to intracellular water is a good indicator, declines from early life until maturity (Wang *et al*, 2000). For comparative purposes, for example, reference data on infant body composition were taken from the study of Butte *et al* (2000) in which TBW was determined by deuterium dilution, and ECW by TBW and total body potassium data and the known concentration of potassium in ECW compartment. It shows that during normal growth between 3 and 18 months, the ECW/TBW ratio effectively decreases, reflecting an increase in the intracellular mass with maturation, and also that the percentage of body fat decreases (Butte *et al*, 2000). In our study, the ECW/TBW ratio index decreased in the Control infants, as expected, while it increased on average in the Stunted-at-18 months group, the trend of the change already being apparent at age 7 months. Moreover, in the Control infants, body composition indices were not linked to the LA index value, whereas variations in LA were linked to variations in the ECW/TBW ratio index when stunting occurred. The biggest increases in the ECW/TBW ratio index were observed in the most stunted children. We assume that the most important consequence is the lack of expansion of the intracellular compartment that is expected during the growth of cell mass in normal infants. This could be because of a disturbance in cell multiplication or in cell growth. Occurrence of stunting did not influence the expected age-related change in fat mass. So stunting seemed to predominantly affect the fat-free mass since variations in body fat appeared unaltered. In 7 to 8 y-old Jamaican children, Soares-Wynter & Walker (1996) showed that there was no difference in the percentage of body fat between stunted and nonstunted subjects.

It should be noted that since the conductivity of an aqueous solution depends on the number and type of dissolved ions present, observed variations in resistance could also be because of a change in electrolyte balance, another possible consequence of malnutrition. The BIA parameters can reflect volume, proportion and/or composition of the body water compartments. However, the volume of ECW is closely related to its content in sodium, the major cation in extracellular fluid (Randall, 1988). Other solute variations could not be plausible causes for the variation in the ECW/TBW ratio index, and we can conclude that our results are valid in the studied infants.

Although the lack of standardization in the placement of electrodes when using BIA in infants prevents comparison of crude BIA values among studies (Gartner *et al*, 1992), the conclusions of the few comparative or follow-up studies performed in newborns and young children (Table 4) showed the BIA method to be a useful tool to measure body composition in infants. Indeed a higher resistance was observed in the case of acute *in utero* malnutrition (Grazioso *et al*, 1990), when body water has decreased during early postnatal growth (Mayfield *et al*, 1991; Gartner *et al*, 1994), in dehydrated infants (Molina *et al*, 1987), and in case of marasmus (Vettorazzi *et al*, 1990). On the other hand, kwashiorkor, that is, greater depletion of intracellular than extracellular mass and oedema, was associated with lower resistance (Vettorazzi *et al*, 1990). Moreover, one study has shown, on the basis of transversal data, a higher resistance in stunted than nonstunted children (Walker *et al*, 1990). These earlier studies used single-frequency BIA measurements at 50 kHz. A 50 kHz signal penetrates the cell membranes and the current is carried by extracellular fluid plus some components of intracellular fluid (Bioelectrical Impedance Analysis in Body Composition Measurement, 2000). Deurenberg *et al* (1995) showed that high-frequency impedance at 50 or 100 kHz is predictive for TBW. Results at 50 kHz can be considered as reflecting the electrical conduction in the TBW compartment. In the present study, the R_{50} value at 18 months was also significantly higher ($P = 0.0002$) in Stunted-at-18 months infants when compared to Control ones (Table 4). This could be because of reduced height in the case of stunting, but does not enable characterization of a relationship between body water compartments and stunting. At single frequency, the BIA method without prediction equations was not suitable for the assessment of body water equilibrium, which is an important indicator of malnutrition. By using multifrequency BIA in the present study, we wanted to assess compartmental distribution of body water when stunting occurred during the course of growth.

The major impact of malnutrition occurred prior to 18 months of age (Allen, 1994). Linear growth faltering occurred within a few months of birth and was substantially complete by about 18–22 months of age. The childhood phase of growth starts around 8 months of life in well-nourished children and several months later in those who are malnourished. A delay in the onset of the childhood phase of growth seems to be the main determinant of the faltering in early growth (Karlberg *et al*, 1994). As suggested by Hansen *et al* (1965), the relative increase in ECW we observed in the case of stunting could correspond to an earlier stage of development. This is a first possible hypothesis. However, looking for associations between the ECW/TBW ratio index and attained height, we found no correlation, at 18 months, between the ECW/TBW ratio index and height neither in Controls ($P = 0.88$) nor in Stunted-at-18 months infants ($P = 0.55$), as well as between the 4–18 months change in the EWC/TBW ratio index and the height at 18 months in Controls ($P = 0.71$) and in Stunted-at-18 months infants ($P = 0.66$). So we could conclude that the observed difference in ECW/TBW ratio index could also reflect a disturbance in lean body composition. This should be further explored alternatively.

Most stunted children are of normal weight for length or height (Waterlow, 1994). In the context of this study, the

Table 4 Bioelectrical impedance analysis using BIA parameters in the few studies on newborns or young children

Study	*Conclusions*	*Reference*
Groups comparison		
Subjects compared		
Small-for-gestational-age term newborns with acute (*R*=494 (53)) and chronic intrauterine growth retardation (*R*=442 (48)) at age <24 h	Results are sufficiently reliable for differences to be compatible with the distinct biological processes of each *in utero* type of malnutrition	Grazioso *et al* (1990)
Stunted (*R*=756 (92)) and nonstunted (*R*=714 (76)) infants (age 9–24 months)	Significant difference in resistance even after controlling for anthropometry and age	Walker *et al* (1990)
Follow-up growth study		
Subjects followed		
Preterm newborns at age <24 h (*R*=778 (76)) and then at age 4–7 days (*R*=957 (109))	BIA resistance and reactance are good indices of TBW and ECW	Mayfield *et al* (1991)
Small-for-gestational-age newborns at age 3 days (*R*=439 (53)) and age 19 days (*R*=432 (51)) Appropriate-for-gestational-age newborns at age 3 days (*R*=388 (69)) and at age 19 days (*R*=419 (60))	Evolution of BIA values is in agreement with the expected decrease in body water that occurs after birth in healthy newborns, and with the known increase in TBW linked to regrowth of cell mass in small-for-gestational age infants	Gartner *et al* (1994)
Infants nonstunted at 4 months (*R*=474 (62)) and nonstunted at 18 months (*R*=520 (90)) Infants non stunted at 4 months (*R*=480 (67)) and stunted at 18 months (*R*=571 (48))	Using multifrequency measurements, the ratio of resistances at 100 to 5 kHz frequency allows one to show significant difference in change in the ECW/TBW ratio index when stunting occurred or not between 4 and 18 months of age	This study
Follow-up treatment study		
Subjects treated		
Dehydrated infants aged 3–20 months before (*R*=772 (159)) and after (*R*=684 (133)) rehydration	There is a relationship between rehydration of diarrhoeal children and a decrease of resistance	Molina *et al* (1987)
Kwashiorkor infants aged 2–60 months before (*R*=388 (94)) and after (*R*=568 (1 0 5)) treatment Marasmus infants aged 2–60 months before (*R*=553 (3)) and after (*R*=511 (87)) treatment Mixed form infants aged 2–60 months before (*R*=519 (120)) and after (*R*=633 (141)) treatment	The expected responses to differential changes in body water are demonstrable in the acute stage of clinical protein-energy malnutrition	Vettorazzi *et al* (1990)

R, resistance (means (s.d.)) at 50 kHz, in Ω.

mean WL index decreased during the 4–18 months study period in the two groups. Among the children who became stunted, only $n = 11$ (18.0%) had a WL index lower than −2 *Z*-scores at the age of 18 months, and the change in their ECW/TBW ratio index did not differ from that in non wasted subjects ($P = 0.43$). We can conclude from our study that stunted children present a perturbed age-related variation in the equilibrium of body compartments, mainly in the fat-free mass, independently of wasting. This may change our appreciation of the mechanisms of stunting and further studies are required to document this. Our results suggest that stunted children present physiological disturbances. Since fat mass seemed less affected by stunting that fat-free mass, the use of BIA measurements in infants could provide information on disturbance of body composition during growth and additional information on nutritional status beyond that provided by anthropometry only. However, it remains to be tested to what extent the BIA indicator is sensitive to changes when stunting is reversed, for example.

Now the question arises as to the real consequences of this modification observed in stunted children. Nutritional stunting may be caused by various food alterations, either chronic energy deficiency or imbalance of various nutrients, mainly the so-called ‘growth’ nutrients, for example, nitrogen, sulphur, zinc, magnesium, potassium or various amino acids (Golden, 1991). Moreover, the picture can be more or less complicated by coexisting infections (Kossmann *et al*, 2000) or previous intra-uterine malnutrition (Allen, 1994). It has been postulated that reduced growth associated with economy of expenditure was a physiological response to a nutritionally unfavourable environment (Spurr *et al*, 1986). However, there has been debate about the consequences of this kind of response (Waterlow, 1986). Boutton *et al* (1987) were the first to mention increased TBW in stunted Peruvian children under the age of five and they postulated this to be mainly ECW expansion linked to previous genetic, environmental or nutritional experience. Cheek *et al* (1989) observed a significant reduction of intracellular water, measured by using isotopic dilution and corrected bromide space, in 6–13.5 y growth retarded Aboriginal children of a poor settlement in Australia. Further observations on various populations failed to demonstrate any specific alteration of their TBW in proportion to size (Walker *et al*, 1990; Wren *et al*, 1997) nor of their resting metabolic rate nor of their total energy expenditure, once adjusted to fat-free mass (Soares-Wynter & Walker, 1996; Wren *et al*, 1997). In this study, we did not measure directly the TBW volume, but we observed that conductance obtained at 100 kHz ($1/R$, Ω^{-1}), which reflects the conducting TBW volume (Smith, 1993), was similar in the two groups at 4 months (2.24×10^{-3} in Controls and 2.23×10^{-3} in Stunted-at-18-months infants, $P = 0.74$) as well as at 18 months (2.08×10^{-3} and 1.99×10^{-3}, $P = 0.58$). However, various functional impairments have been described in stunted children: either physical performances (Benefice, 1992), spirometric parameters (Nair *et al*, 1999; Zverev, 2001) or cognitive tests (Mendez & Adair, 1999; Berkman *et al*, 2002) have been reported to be affected. But it is not certain whether there is any specific metabolic defect linked with such impairments. However, accumulating evidence shows that malnourished children may be at higher risk of obesity or nutrition-related chronic diseases in adulthood once they live in satisfactory conditions, which implies a functional metabolic defect set off either *in utero* or early in childhood (Barker, 1998). Recent observations in Brazil indicate that stunted children present impaired fat oxidation (Hoffman *et al*, 2000), while Gaskin *et al* (2000), in Jamaica, have described a higher systolic blood pressure in 7 to 8 y-old children who had been recorded as stunted at age 9–24 months, which is associated with increased central fat distribution, only partially explained by a lower birth weight (Walker *et al*, 2002). According to Hoffman *et al* (2000), nutritional stunting (which is usually caused by chronic undernutrition) is positively associated with adult fatness. Sawaya *et al* (1998) observed an association between excess weight gain and dietary fat content in stunted Brazilian children but not in nonstunted control children.

Metabolic disturbance that can be associated with occurrence of stunting is far less known than for adult chronic energy deficiency (Shetty, 1999). However, it seems to be mediated by various hormonal mechanisms of which a constant feature is a decreased insuline-like growth factor I (IGF-I) circulating level and an increase in resistance to peripheral growth-hormone action (Underwood *et al*, 1989; Bouhaddioui *et al*, 1989; Flyvbjerg *et al*, 1991; Roth & Kirchgessner, 1994; Cutfield *et al*, 2002). Besides its effect on calcium homeostasis and bone growth, either directly or through IGF-I, growth hormone has a wide range of physiological effects on fat and lean body mass, and on sodium and water homeostasis (Ogle *et al*, 1992). Whether these different observations and ours have a common underlying mechanism is unknown. What our study shows is that some kind of metabolic alteration seems to be common in young stunted children in different countries; it remains to be seen if it can be linked to some kind of metabolic imprinting (Waterland & Garza, 1999), or if it is merely a transitory effect, or even simply a delay in the onset of the normal course of growth at such early ages.

Acknowledgements

We thank Rozenn Nicolas and Jean-Pierre Massamba for their participation in the Congolese setting, Aldiouma Diallo for medical care of ill infants in the Senegalese setting, Wilma Tellez, Carmen Lujan and Myriam Perez for their help in Bolivia, and Isabelle Missotte for her help in the New Caledonia study

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