Malnutrition, Body Size, and Skeletal Maturation: Interrelationships and Implications for Catch-Up Growth

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ABSTRACT

The hypothesis is tested that the effects of malnutrition on growth in body size are greater than those on skeletal maturation. Longitudinal data from birth to three years of age are analyzed to quantify the effects of a food supplementation program on body size, as measured by supine length and body weight, and on skeletal maturation, operationalized as the number of hand-wrist ossification centers. The study was carried out in four rural Guatemalan villages.

Protein-calorie intake was strongly related to growth in supine length and in body weight. Significant effects of the food supplementation program on skeletal maturity were also observed. However, the effects on maturity were less in comparison to those on body size. Thus, most of the effect on body size of the food supplementation program was independent of changes in maturity. It would seem, therefore, that malnutrition, by affecting body size to a greater extent than maturation, in effect hinders the possibility of catch-up growth and thereby accounts to a large degree for the smaller body size characteristic of adults of malnourished populations.

Human growth is a process resulting from the integrated action of genetic, metabolic, and endocrine mechanisms. It is an extremely complex phenomenon for which only its most general characteristics are known. Yet, simple models are often useful for understanding the ways in which chronic protein-energy malnutrition interferes with normal development. Growth may be visualized, for instance, as proceeding according to a "'time tally" (Tanner, 1963) or maturational clock which determines the velocity of growth at particular stages of development. In this model, chronic malnutrition may affect growth in two distinct ways. It may delay the maturational clock and it may also prevent the potential for growth at each stage from being achieved. In other words, chronic malnutrition may affect both the timing of growth events as well as the intensity of growth during those events.

Anthropometric variables such as stature provide simple cumulative measures of growth. Skeletal age assessments, on the other hand, have

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Human Biology, September 1979, Vol. 51, No. 3, pp. 371-389.

proven useful in predicting residual growth potential and the timing of events such as those of puberty and hence may be utilized as indicators of timing.

Comparisons between poor and well-nourished populations strongly suggest that malnutrition affects maturation as well as growth in body size. Moreover, food supplementation experiments suggest that better nutrient intake results in improved rates of growth in body size (Martorell et al. 1976). Similar evidence for skeletal maturity effects is not, however, available (Himes, 1978) as few supplementation experiments have included such measures.

An issue frequently debated is the extent to which children are able to make up for the adverse effects of malnutrition on growth. In terms of the model presented above, the potential for complete catch up would be maintained only when growth and maturation are equally delayed (Acheson and MacIntyre, 1958). If, as suggested by Tanner (1963) and by Frisancho et al. (1971), chronic malnutrition affects maturation to a lesser extent than body size, then one would expect the potential for catch up to be limited.

In the present study, data from a feeding experiment carried out in Guatemala are utilized to investigate the interrelationships among nutrition, supine length, body weight, and skeletal maturity. In particular, three questions guide the analyses:

(a) To what extent is body size more delayed than skeletal maturity in comparison to normal populations?

(b) What is the relative magnitude of the effects of food supplementation on size and maturity?

(c) To what extent are effects on body size due to accelerated maturity?

Materials and Methods

The Population

The feeding experiment was carried out from 1969 to 1977 in four poor Ladino villages of Guatemala. The villages are on the Atlantic slopes of the Guatemalan highlands at altitudes between 300 and 1,100 meters. The communities were chosen out of a larger set on the basis of their homogeneity regarding growth, nutrition, health, and demographic data. Chronic protein-calorie malnutrition was endemic and infection rates, particularly of gastrointestinal and respiratory nature, were high.

The study included monitoring the course and the outcome of pregnancies as well as the follow-up of children to their seventh birthday.

The follow-up included periodic assessments of growth, mental development, health, and home diet.

All persons in the villages were free to participate in the food supplementation and the curative and preventive medical care programs. These services were provided at no cost.

Food Supplementation

Two types of supplements were provided: atole (the name of a gruel commonly made with corn) and fresco (local word for a refreshing, cool drink). The supplements were distributed at cafeteria-like centers under the care of well-trained personnel. A cup containing 180 ml was given initially but subjects were free to consume as much as they desired. Consumption of the supplements by all individuals included in the study sample was carefully measured to the nearest 10 ml on a daily basis. Distribution was seven days a week, twice daily at mid-morning and mid-afternoon, the times thought to least interfere with intake at the regular meals.

The atole, prepared from milk and Incaparina, a protein-rich vegetable mixture, provided 6.1 g protein and 91 kcal/100 ml. The fresco, a sweetened artificially-flavored drink, contained no protein and only a third of the caloric concentration of the atole (33 kcal/100 ml). In addition, both preparations contained, since October 1971, similar concentrations of the vitamins and minerals thought to have been deficient in the diets of these populations. Table 1 shows the nutrient composition per cup (180 ml) of atole and fresco.

Analyses of the relationship between food supplement intake and home dietary survey data, which consisted of 24-hour recall surveys collected every three months from 15 to 36 months of age (Martorell et al. 1978), indicate that on an average, 10 kcal provided by the supplements displaced 1 kcal of home consumption. In other words, the level of replacement was small and more than compensated by the supplement intake.

One of the unexpected findings of the study was that calories were more limiting than protein in the home diets. For instance, the needs at two years of age, according to the latest FAO/WHO report, are 100 kcal and 0.9 g of ideal protein per kg of body weight (WHO, 1973). The measured home dietary intakes at two years of age are low for energy, 76 kcal per kg, but adequate for protein, 1.4 g of ideal protein per kg of body weight. Under this situation, protein will be burned to satisfy energy needs and amino acids may in fact become limiting at the cellular level. Providing calories serves to spare protein for synthesis and repair. It was

Table 1
Nutrient Content of the Supplements per Cup (180 ml)

	January 1, 1969 to September 30, 1971		October 1, 1971 to February 28, 1977	
	Atole	Fresco	Atole	Fresco
Energy (kcal)	163	59	163	59
Protein (g)	11.5	—	11.5	—
Fats (g)	.7	—	.7	—
Carbohydrates (g)	27.8	15.3	27.8	15.3
Ascorbic acid (mg)	—	—	4.0	4.0
Calcium (g)	.4	—	.4	—
Phosphorus (g)	.3	—	.3	—
Thiamine (mg)	.4	—	1.1	1.1
Riboflavin (mg)	.5	—	1.5	1.5
Niacin (mg)	1.3	—	18.5	18.5
Vitamin A (mg)	.5	—	1.2	1.2
Iron (mg)	1.2	—	5.4	5.0
Flourine (mg)	—	—	.2	.2

found that it was the calories in the supplements, and not the protein or the vitamins or minerals, which influenced a variety of outcomes such as placental weight (Lechtig et al. 1975b), birthweight (Lechtig et al. 1975a), and perhaps postnatal growth as well (Martorell et al. 1978). Consequently, we have expressed supplement intake as average daily kcal ingested, regardless of whether they were accompanied by protein. In many of the analyses, however, data for atole and fresco villages are analyzed separately.

Size and Maturity Indicators

Anthropometric examinations as well as left-hand and wrist radiographs were periodically collected on children seven years of age or younger. The examinations were programmed longitudinally at exact ages with an allowed maximum deviation in time of ± three days for examinations up to and including two years of age and ± seven days for examinations on older children.

Supine length and body weight were chosen as estimates of body size. Supine length was measured at all ages on a standard measuring table to the nearest mm. Beam scales were used to weigh the children with a precision of 0.01 kg.

The number of ossified centers (NOCs) present in each radiograph, a measure which compares favorably over the age range studied with those derived from the Greulich and Pyle and Tanner-Whitehouse methods (Yarbrough et al. 1973), was chosen as an indicator of maturity. With the exception of the pisiform and sesamoids, every ossified center (carpals plus epiphyses) in each radiograph was identified and counted.

Rigorous standardization and quality control procedures were maintained throughout the course of the study. Supine length, body weight, and NOCs were measured with reliabilities in excess of .9 (Martorell et al. 1975; Yarbrough et al. 1973). Unusual values were discarded prior to data analyses, a fact explaining the minor differences in sample size for supine length and weight.

Age Range Studied

Analyses are restricted to size and maturity data collected at six-month intervals from 12 to 36 months of age. This is an age range where we find a clear impact of food supplementation on growth in body size and where variability in NOCs is highest (Yarbrough et al. 1973; Blanco et al. 1972). In addition, skewdness in NOCs is obviated by not including data on infants (skewed to the left) and older children (skewed to the right). Thus, untransformed data are utilized in all analyses.

Sample Sizes

Anthropometric and X-ray assessments were carried out on all children three years or younger from March 1969 to February 1973. From March 1973 to the end of the study, in February 1977, the study concentrated on the follow-up of children who were born prior to March 1973. An analysis of the census shows that a total of 580, 616, 680, 725, and 786 children should have been examined at 12, 18, 24, 30, and 36 months of age respectively. Coverage rates for anthropometry and NOCs were approximately 90%, a figure not differing significantly by age, sex, and village. The sample studied is, therefore, of a mixed longitudina' nature, with many children having examinations at more than one point in time but not necessarily at all ages.

Relative Retardation

Some of the analyses to be presented assess the relative retardation or the relative differences between two populations in terms of body size and NOCs.

Relative retardation was defined as:

$$R.D. = (\bar{X}_1 - \bar{X}_2) / S_1$$

where

$\bar{X}_1$ = age-sex specific mean of the standard.

$\bar{X}_2$ = age-sex specific mean of the Guatemalan population.

S_1 = standard deviation of the normal population.

This procedure allows for comparisons between variables because it expresses the differences between both populations in terms of similar conceptual units, the standard deviation of the normal population. Anthropometric data from the Denver longitudinal study (Hansman, 1970) and NOCs data from the Fels Research Institute (Yarbrough et al. 1973) are utilized as the standard populations for anthropometry and NOCs respectively, as was done on prior publications dealing with the same Guatemalan population (Yarbrough et al. 1973, 1975).

Relative differences in body size and NOCs between atole and fresco villages were assessed in similar fashion.

$$R.D. = (\bar{X}_A - \bar{X}_F) / S_P$$

where

$\bar{X}_A$ = age-sex specific mean of atole villages.

$\bar{X}_F$ = age-sex specific mean of fresco villages.

S_P = age-sex specific pooled standard deviation.

Results

Comparisons with Well-Nourished Populations

As expected, the study children are of smaller body size (Yarbrough et al. 1975) and are retarded in NOCs (Yarbrough et al. 1973; Blanco et al. 1972) when compared to children from developed nations.

In relative terms, retardation is greater for supine length than for NOCs. For example, Figure 1 presents the relative retardation of Guatemalan boys in body size and in NOCs. Relative retardation is greater for supine length, amounting to more than three standard deviations, and is less for NOCs which at two years of age is slightly over 1.5 S.D. units. Comparable NOCs data for girls ($\bar{X}$ and S.D.) are not available from Fels but analyses with the 50th percentile (Garn and Rohman, 1960) show a similar patterns as in boys. This pattern of differences probably represents the result of environmental rather than genetic differences (Habicht et al. 1974). If this is accepted, the environment, among which

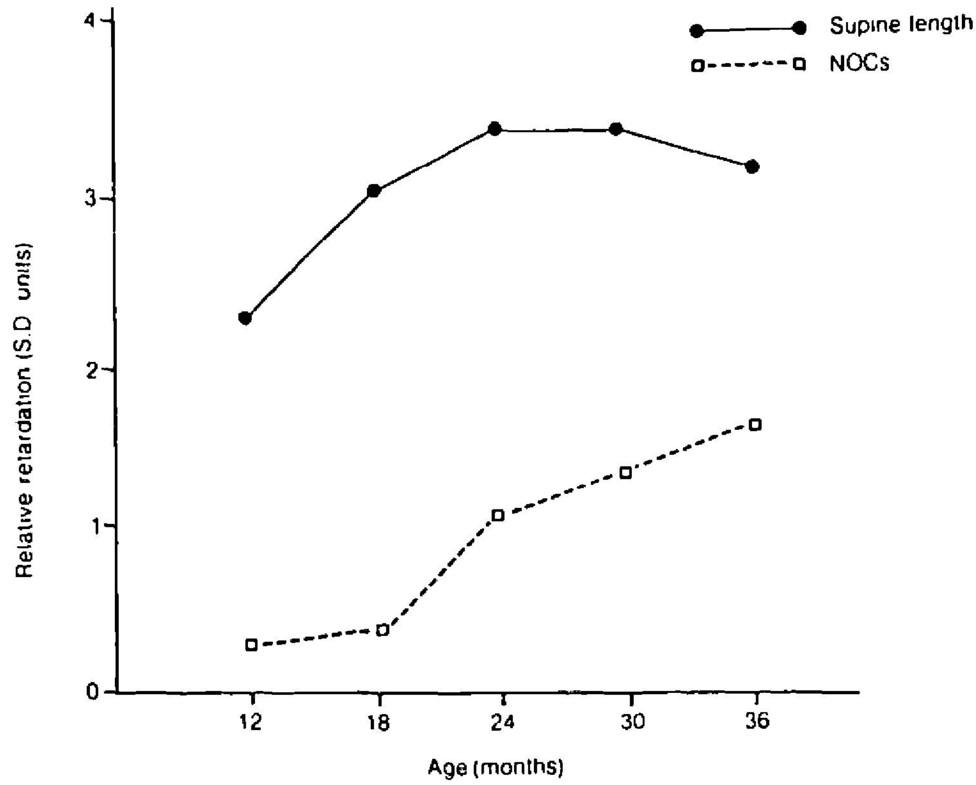

FIG. 1. Relative retardation in Guatemalan males in supine length and in number of ossified centers (NOCs).

nutrition would be included, would seem to affect size to a greater extent than skeletal maturity.

Village Type Comparisons

Atole and fresco villages differ in terms of energy intake from the food supplement program. For example, the average daily amount ingested during the first three years of life was 94 ± 76 kcal in atole villages and 16 ± 13 kcal in fresco villages ($p < .001$). The lower values in fresco are due in part to the lower energy concentration of the fresco and to lower intakes per se in terms of volume. Since the fresco contains no protein while the atole does, the differences are also significant for protein intake. These are real differences in total nutrient intake because home dietary intakes are similar in atole and fresco villages (i.e., Table 7).

All age-sex-specific mean differences between both v.llage types, as shown in Table 2, are statistically significant for supine length and weight. Similarly, except for boys at 18 months and girls at 12 and 18 months, differences between atole and fresco in skeletal age are significant as well.

The relative differences between the village types, as shown in Table 3, are more marked for supine length than for NOCs. This suggests again that nutrition affects body size to a greater extent than skeletal maturity.

Table 2

Weight, Supine Length, and Number of Ossified Centers in the Study Villages

Age (Months)	Weight (kg)						Supine Length (cm)						Number of Ossified Centers (NOCs)					
	Atole			Fresco			Atole			Fresco			Atole			Fresco		
	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.
										Males								
12	145	8.10	0.90	143	7.75	1.14***	145	69.6	3.0	141	68.7	3.2***	142	2.83	1.72	132	2.60	1.41*
18	154	9.04	0.94	158	8.67	1.12***	154	74.1	3.4	156	73.4	3.6***	149	4.40	3.16	156	4.27	3.72
24	174	10.18	0.95	167	9.68	1.20***	174	78.6	3.5	167	77.5	3.6***	166	7.37	4.38	160	6.59	4.20**
30	162	11.32	1.08	181	10.71	1.22***	162	82.9	4.0	181	81.4	3.8***	174	11.13	5.07	180	10.10	4.85***
36	188	12.40	1.18	201	11.80	1.25***	190	86.9	3.8	201	85.6	3.9***	199	14.74	4.96	201	13.50	4.91***
										Females								
12	125	7.64	0.98	114	7.23	1.05***	1.25	67.8	2.6	114	67.2	2.8*	131	5.25	3.66	114	5.35	4.05
18	133	8.50	1.04	16	8.04	1.10***	132	72.6	3.0	116	71.4	3.4***	132	9.59	5.26	103	10.11	5.56
24	147	9.67	1.10	127	8.90	1.03***	146	77.0	3.4	126	75.5	3.4***	148	14.07	5.51	121	13.34	6.13*
30	166	10.91	1.22	137	9.94	1.13***	167	81.6	3.7	138	79.3	4.0***	162	18.03	4.70	136	16.96	5.58***
36	178	11.90	1.36	153	10.90	1.15***	178	85.8	3.9	153	83.2	4.1***	188	20.51	3.62	149	19.66	4.39***

Differences between atole and fresco means significant at *p < .05, **p < .01, ***p < .001.

Table 3

Relative Differences in Standard Deviation Units† Between Atole and Fresco Villages

Age (Months)	Males Supine Length	Males NOCs	Females Supine Length	Females NOCs
12	.29	.15	.22	−.03
18	.20	.04	.36	−.10
24	.31	.18	.43	.13
30	.38	.21	.58	.21
36	.33	.25	.62	.21

†Relative differences are as defined in the methodology section.

Comparisons Between Individuals

It can also be asked whether variability in supplement energy intake is related differentially to body size and skeletal age. This question can be answered at two levels. The first level is given by the relationship between cumulative or lifetime supplement intake and the size and skeletal age attained at specified ages. The second level examines the relationship between supplement intake during a given interval of time and changes in body size and skeletal maturity during the same time interval.

Cumulative Supplementation and Attained Size and Skeletal Maturity

Table 4 shows the relationship between cumulative food supplementation, expressed as average daily energy intake, and attained size and skeletal maturity. In general, it appears that energy intake is related to body size and skeletal age. As expected of a cumulative process, the correlations rise with age. In terms of the hypothesis regarding differential effects, it is also evident that the percent of variance explained by supplement intake is several times larger for body size than that for skeletal age.

As expected, NOCs is significantly related to measures of body size (Table 5). Since supplement intake is related to both body size and NOCs, one can ask to what extent the effects on body size are mediated through effects on skeletal age.

Table 6 shows how the relationship between energy intake and supine length and weight is modified after accounting for NOCs. Only those

Table 4

Correlations Between Cumulative Caloric Supplementation and Supine Length, Weight and Number of Ossified Centers†

Age (Months)	Supine Length		Weight		NOCs	
	Males	Females	Males	Females	Males	Females
12	.126*	.045	.065	.058	.120*	−.026
18	.131*	.133*	.175**	.127*	.018	.022
24	.153**	.252***	.299***	.326***	.098	.095
30	.226***	.289***	.257***	.292***	.122*	.129*
36	.271***	.338***	.271***	.331***	.186***	.175**

†Sample sizes per correlation are around 325; the exact number per correlation may be obtained from Table 2 by adding the cases in atole and fresco villages.

*$p < .05$, **$p < .01$, ***$p < .001$.

cases having both NOCs and size data are included. The results at 12 and 18 months are erratic because the relationship between supplement intake and growth is weaker at these ages. If the first two age groups are disregarded, it would appear that around 20% of the variance in body size originally explained by supplement intake is related to NOCs. In other words, 80% of the effect of energy intake on body size is due to intensity effects alone while at the most 20% is due to timing effects.

Table 5

Correlations Between Number of Ossified Centers (NOCs) and Body Size

Age (Months)	Supine Length				Weight			
	Males		Females		Males		Females	
	n	r	n	r	n	r	n	r
12	248	.259***	216	.365***	250	.206**	217	.323***
18	276	.281***	211	.446***	278	.287***	212	.363***
24	298	.447***	240	.542***	298	.381***	242	.407***
30	312	.518***	282	.545***	312	.369***	280	.406***
36	373	.507***	309	.609***	371	.335***	309	.434***

**$p < .01$, ***$p < .001$.

Table 6

Relationship Between Supplement Intake and Supine Length and Weight After Accounting for NOCs (Sample Sizes as in Table 5)†

Age (Months)	Supine Length r_1	Supine Length r_2	Supine Length Δv	Weight r_1	Weight r_2	Weight Δv
			Males			
12	.107	.074	−52	.052	.023	−80
18	.141*	.143*	+ 3	.173**	.176**	+ 3
24	.166**	.133*	−36	.230***	.206***	−20
30	.241***	.204***	−28	.284***	.260***	−16
36	.281***	.223***	−37	.281***	.239***	−28
			Females			
12	.068	.090	+75	.087	.104	+43
18	.104	.108	+ 8	.106	.108	+ 4
24	.261***	.257***	− 3	.328***	.321***	− 4
30	.290***	.263***	−18	.298***	.269***	−19
36	.333***	.289***	−25	.326***	.282***	−25

*p < .05, **p < .01, ***p < .001.

†Where:

r_1 = simple correlation between supplement intake and supine length or weight

r_2 = partial correlation between supplement intake and size given NOCs

Δv = change in r^2

$$\left(\frac{r_2^2 - r_1^2}{r_1^2}\right) \times 100$$

Supplement Intake from Twelve to Thirty-Six Months and Increments in Supine Length, Weight, and NOCs from Twelve to Thirty-Six Months

Means and standard deviations for energy and protein intake from 12 to 36 months of age are shown in Table 7 for boys and girls of atole and fresco villages. The home diet measure represents the average of 24-hour recall surveys collected every three months while the supplement variable is the average of daily measurements throughout the entire period of time. Children in atole villages had larger supplement and total nutrient intakes than children in fresco villages ($p < .01$). Table 8 shows that children of atole villages also have larger increments in (twelve to thirty-six months) supine length, weight, and NOCs ($p < .05$). As before, rela-

Table 7

Mean Energy and Protein Intakes in the Study Villages from 12 to 36 Months of Age

	Males		Females		
	Atole (n=128)	Fresco (n=135)	Atole (n=118)	Fresco (n=104)	Pooled Standard Deviation
Energy (kcal/day)					
Home diet	785	814	718	756	213
Supplement	156	26***	150	23***	79
Total intake	941	840***	868	779**	226
Protein (g/day)					
Home diet	20.1	22.5	19.3	21.0	5.9
Supplement	11.0	0.0***	10.5	0.0***	5.4
Total intake	31.1	22.5***	29.8	21.0***	7.5

**p < .01, ***p < .001.

tive differences between atole and fresco villages are greater for body size than for NOCs.

Correlations between average energy intake from the supplements and increments are shown in Table 9. In almost all instances, the percent of variance explained by supplement is greater for body size than for NOCs.

As was done in Table 6, Δv was calculated and these reusults show decrements in the percent of body size variance explained by supplement of −29% and −7% for supine length and weight in boys and of −12% and −7% for height and weight in girls. These findings, therefore, suggest again, that around 80% of the effect of nutrition on body size is due to intensity effects.

In other analyses, the range of energy intake from the supplements from 12 to 36 months of age was divided into quartiles, a procedure carried out separately for atole and fresco villages. The mean energy intake and the mean changes in supine length, weight, and NOCs from 12 to 36 months were then calculated for each quartile. These data are plotted in Figures 2 and 3 for boys and girls respectively. Energy intake is always on the abscissa and dark dots represent atole data while light ones represent fresco data. The sample size per dot is approximately 39 cases. The data

Table 8

Increments from 12 to 36 Months of Age for Supine Length (cm), Weight (kg), and Number of Ossified Centers (#)

	Males†						Females†					
	Atole			Fresco			Atole			Fresco		
	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.	n	$\bar{X}$	S.D.
Supine length (cm/24 months)	128	17.4	2.3	133	16.4	2.6**	108	18.3	2.7	92	16.2	2.4***
Weight (kg/24 months)	128	4.37	0.87	134	3.90	0.90***	108	4.32	1.00	93	3.59	0.86***
NOCs (#/24 months)	127	12.6	4.1	120	11.2	4.6*	116	15.5	3.9	93	14.1	4.2*

Differences between atole and fresco means significant at $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.

†Relative differences between atole and fresco villages are .40 for supine length, .53 for weight, and .32 for NOCs in the case of males and .81, .83, and .35 respectively for supine length, weight, and NOCs in the case of females.

Table 9

Correlations Between Average Daily Energy Intake from the Supplements from 12 to 36 Months and Increments in Supine Length, Weight, and NOCs from 12 to 36 Months (Sample Sizes as in Table 8)

	Supine Length	Weight	NOCs
Fresco			
Males	.146	.087	−.126
Females	.199	.086	.205*
Total	.168*	.091	−.045
Atole			
Males	.249**	.206*	.184*
Females	.261**	.204*	.131
Total	.232***	.205**	.120
All males	.276***	.280***	.185**
All females	.403***	.356***	.197**

*p < .05, **p < .01, ***p < .001.

show clearly that supplement intake is related to growth in supine length, weight, and NOCs.

Discussion

The central issues addressed in the present paper deal with the differential effects of a food supplementation program on body size and maturity. Body size was measured in terms of supine length and weight and maturation was evaluated in terms of the number of hand-wrist ossification centers (NOCs). While all three variables were recorded with reliabilities in excess of .9, there is an important measurement distinction between them. Supine length and weight are direct measures of body size. NOCs, on the other hand, are only an indicator of maturity. However, over the age range studied in this paper, NOCs is as good a measure of skeletal maturity as the Greulich and Pyle and Tanner-Whitehouse methods (Yarbrough et al. 1973).

The results showed clearly that the food supplementation program had substantial effects on growth in body size and on NOCs, a unique but not unexpected finding. It is well known that preschool children with severe as well as with mild and moderate protein energy malnutrition (PEM) have fewer centers present than adequately nourished children of

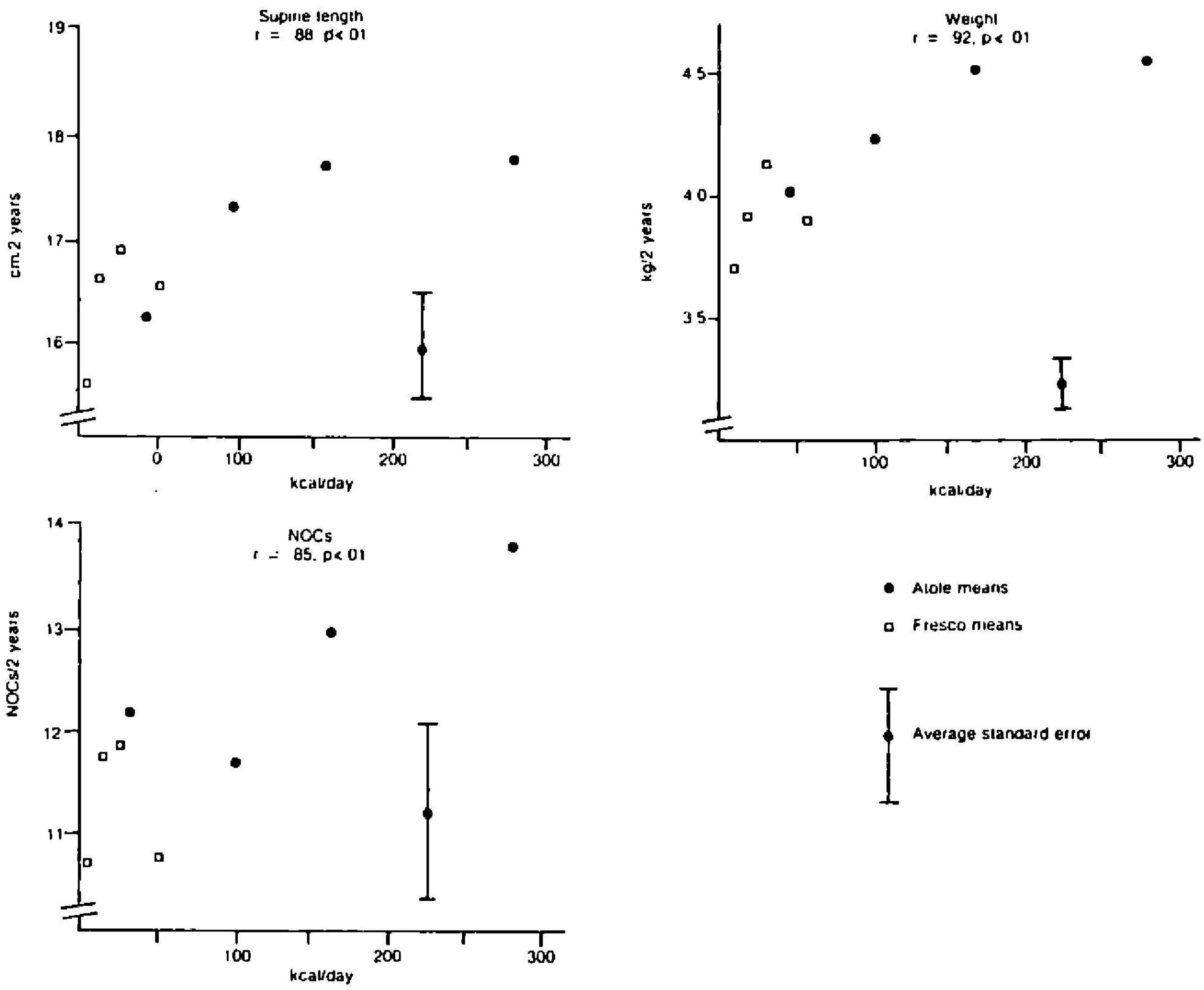

FIG. 2. Relationship between energy intake from the supplements and growth from 12 to 36 months of age: males.

the same sex (Blanco et al. 1972; Himes, 1978). In addition, investigations by Guzmán et al. (1964) suggest that food supplementation programs lead to accelerated maturity.

The question arises as to whether the supplement effects observed in this study were caused by more energy, protein, or both. For the sake of convenience, supplement intake was expressed in terms of energy, the most important dietary limitation in the study communities as well as in the rest of Central America (Valverde et al. 1975). In prior analyses, we were able to show that, for a fixed amount of energy supplement intake during pregnancy, the effect on birthweight was the same independent of whether the energy came from the atole (protein-energy) or the fresco (energy) supplement (Lechtig et al. 1975a). Protein in the atole, therefore, did not seem to add to the effects observed. In addition, the results did not fit a vitamin or mineral interpretation for a calorie from the fresco was accompanied by nearly three times more vitamins and minerals than

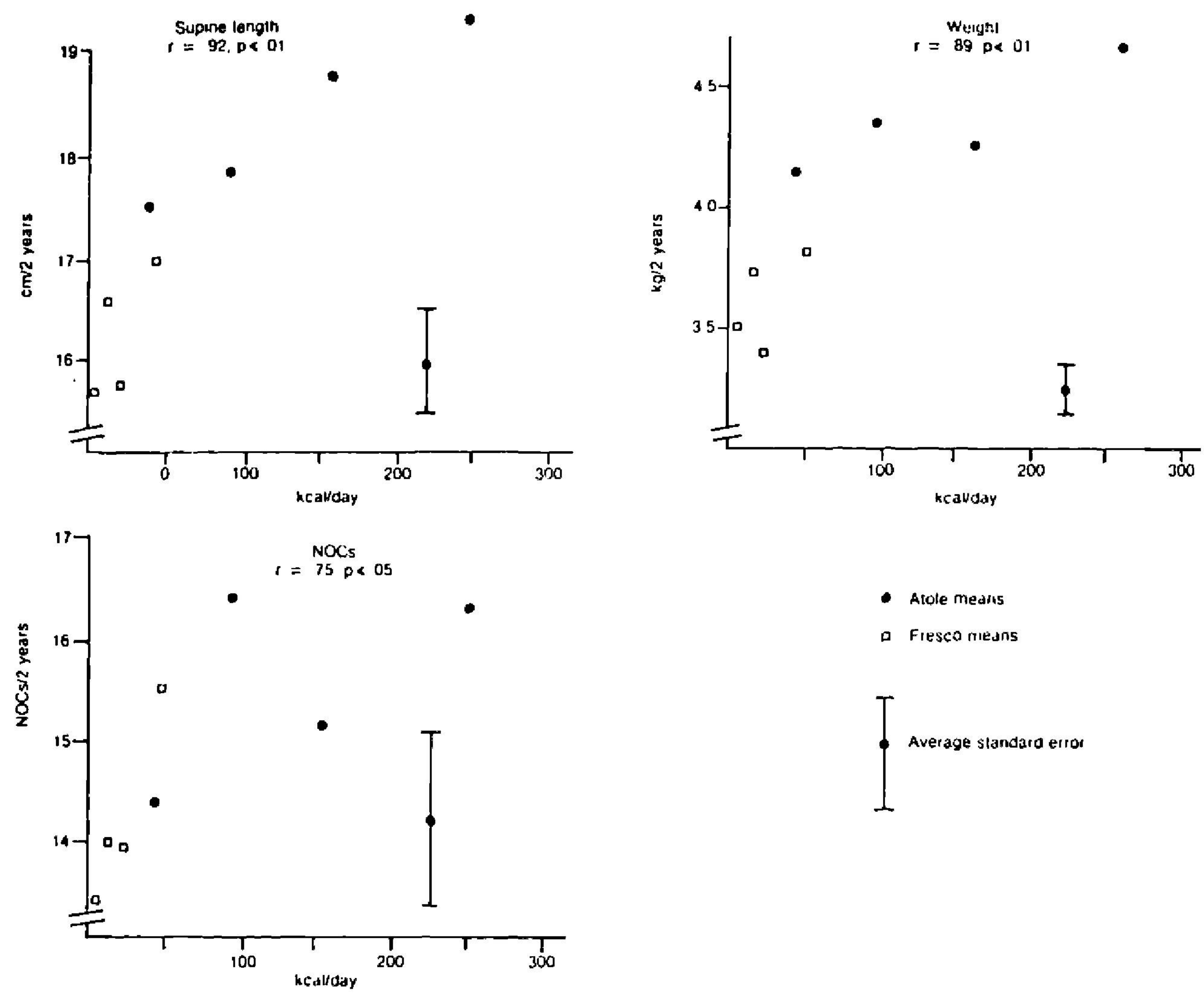

FIG. 3. Relationship between energy intake from the supplements and growth from 12 to 36 months of age: females.

one from the atole (Table 1). Such strong inferences cannot be made with regards to the data on children because there was little overlap in the range of intake of the two types of supplements. In other words, the extent to which the effects observed were due to energy, protein, or to the vitamins and minerals contained in the supplements cannot be established with certainty. What is clear, however, is that a supplement containing protein, energy, and vitamins and minerals did have a significant impact on growth and on skeletal maturation.

All the analyses presented indicated that the nutritional effects on growth in body size were more pronounced than those on NOCs. At three years of age, boys from the study villages were, when compared to well-nourished children, 3.3 standard deviations behind the supine length but only 1.7 standard deviations behind in terms of the number of hand-wrist ossification centers present. The effects of the supplements were also substantially greater for supine length and weight than for NOCs. Body size and NOCs were positively correlated as shown in other studies (Anderson et al. 1975). Analyses of partial correlations showed that around 80% of the effects of the supplement on body size were due to intensity effects and 20% were due to accelerated maturity.

The inference from the statistical findings in this study is that chronic malnutrition, particularly during periods of rapid growth, results in irreversible growth stunting, as originally suggested by Tanner (1963). If conditions improve, the child will be unable to catch up completely for all lost growth because biological time has passed and with it, the opportunity for some growth. The catch up that can take place is a function of the extent to which maturation was delayed and more "time" exists for growing.

Children recuperating from severe protein-energy malnutrition (PEM) (Hansen et al. 1971) and severe illness (Prader et al. 1963) can catch up in growth in yet another way. Severe PEM includes the syndromes of kwashiorkor and marasmus, both relatively rare conditions in developing nations, usually afflicting less than 5% of all children less than five years of age. Hormonal alterations and improvements in the ability to retain nitrogen have been observed in severe but not in mild and moderate PEM. As Hansen et al. (1971) have stated with regard to severe PEM, "protein and calorie depletion can thus be said to be strong stimuli for growth hormone secretion and this ensures efficient nitrogen retention and catch-up growth when proteins and calories become available." Accordingly, self-limiting, above-normal growth rates are usually observed in children during the early weeks of recovery from severe malnutrition. Perhaps as a result of this compensatory phenomenon, school age children who suffered from severe malnutrition but who grew up in their original homes tend to be similar in stature to children in the same environment (Hansen et al., 1971; Richardson, 1975). Moreover, severely malnourished children who are transferred to an ideal environment at an early age will eventually be taller than their former playmates (Winick et al. 1975). These findings should not be interpreted to mean that all losses have been made up for the reference population, "children from the same environment," are themselves suffering from chronic malnutrition, the kind of malnutrition that is responsible for much of the growth retardation seen in developing nations.

The potential for catch-up growth in chronic malnutrition is a matter that deserves careful consideration. The report of the 1971 Joint FAO/WHO Expert Committee on Protein and Energy Needs makes the explicit assumption that chronically malnourished children retain the capacity to make up for *all* lost growth up to the age of puberty (WHO, 1973). Therefore, they reason, protein and energy needs up to 13 years of age should not be estimated on the basis of actual body weights as in the case of adults. Instead, the report suggests that allowances for full catch-up growth should be made and hence that ideal weights, in other words the weights of normal children the same age, should be utilized. We contend that this is clearly an overestimate of the potential for catch up which in turn leads to an overestimate of nutrient needs. We argue that catch-up growth in chronically malnourished children is limited and related to maturity delays. If so, the nutrient amounts required for this extra growth may be too small to warrant an additional allowance.

Acknowledgement

This project was supported by Contract NO1-HD-5-0640 from the National Institute of Child Health and Human Development (NICHD), National Institutes of Health, Bethesda, Maryland.

Received: 24 October 1978.
Revision received: 28 January 1979.

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