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RESPONSE OF INDICATORS OF NUTRITIONAL STATUS TO NUTRITIONAL INTERVENTIONS IN POPULATIONS AND INDIVIDUALS

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SUMMARY

An intervention study designed to change the nutritional status of moderately malnourished preschool children illustrates the use of anthropometry as an indicator of nutritional status and shows that demonstrating the physiological efficacy of an intervention does not guarantee a significant total impact of that intervention on the population.[1] Careful design makes evaluation of some interventions possible, but theory and knowledge in human public health nutrition and its relation to growth in children now limits the design and especially the evaluation of many nutrition interventions. This paper contributes to recent knowledge in this area by estimating the actual energy conversion rates to growth in moderately protein-calorie malnourished children aged 1 through 3 years under field conditions. These conversion rates are even lower than those which would be estimated from normative data in the literature.

PURPOSE OF THE STUDY

The present study was an intervention designed to change the nutritional status of preschool children in order to test experimentally the hypothesis that moderate protein-calorie malnutrition is related to impaired mental development (Canosa, Salomón, and Klein 1972; Klein, Habicht, and Yarbrough 1975, p. 61). Thus the principal aim of the project was not public health intervention but rather scientific

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investigation of the causal effect of nutrition on certain variables. Whether or not the purpose of the study is scientific demonstration or public health intervention, evaluation of such a program requires a comparison between two groups. One group must have benefited from nutrition not received by the other group. Here we present appropriate comparison groups for scientific demonstration of a nutritional effect. We will show that such an effect is essential for evaluating public health intervention programs in nutrition, even though an intervention program that scientifically demonstrates the effect of nutrition does not necessarily produce a meaningful effect on nutrition of the population as a whole.

The proposed test of the basic hypothesis consisted of improving the nutritional status of children in order to look for associated changes in mental development measures. Thus, the first step in analyzing the study is to show that such nutritional improvement did in fact occur, which in turn requires the measurement of some outcome universally recognized as being related to nutrition in malnourished populations.

AREA OF CHILD HEALTH CARE

Failure to achieve maximal mean growth rates during infancy and early childhood is probably the most frequently used indicator of poor nutritional health status for populations. The use of growth rates to assess communities is widely accepted (Jelliffe 1966) and rests on a solid scientific base: Early growth rates show no apparent ethnic differences and are affected by low dietary intakes and high morbidity rates (Habicht, Martorell, Yarbrough, et al. 1974; Marsden 1964; Martorell, Habicht, Yarbrough, et al. 1975; Martorell, Yarbrough, Lechtig, et al. 1975). Thus we shall be considering here whether the intervention described below had an impact on the growth of young children between the ages of 1 and 3 years. Other nutritional effects on children's performance, health, and survival are not dealt with in this paper.

The issues to be addressed are: (1) Does this study present convincing evidence that improved nutrition improves growth in malnourished children under field conditions, where other growth-retarding influences continue to be prevalent? Previous studies on this issue have been contradictory (Martorell, Yarbrough, Lechtig, et al. 1976). (2) Does this study present convincing evidence that the nutritional effect on growth can be physiologically substantial under field conditions? Previous studies, which claim an effect on growth, have been contradictory as to whether or not the effect was substantial (Habicht and Butz in press). (3) Does the information derived from this study about the effect of nutrition on growth explain the contradictory results of previous studies and suggest strategies for future public health intervention programs?

STUDY DESIGN

Target Population

The study we are reporting was conducted in four rural Ladino[2] villages in eastern Guatemala. Since the inception of the research, free outpatient preventive and curative medical services have been made available to everyone in the villages (Habicht 1973, p. 24). The economy is subsistence agriculture; the local diet is based on corn and beans. Our principal concern is with the young child. In these villages there is considerable stunting in growth of these children, consistent with a diet in which it is estimated that the protein-calorie ratio is well above recommended limits (World Health Organization 1973, National Academy of Sciences 1974), but the energy level is at least 20 percent below the apparent requirements for children aged 1 to 3 years. Table 1 compares values for the four villages at the beginning of the study with values typical of developed countries. Note the absence of sex differences in incremental growth (Yarbrough, Habicht, Malina, et al. 1975) or diet. Although table 1 does not reflect the small dietary contribution from breast milk, we believe that the average daily intake, including breast milk, does not exceed 80 kcal/kg/day between ages 1 and 3.

Design, Methods, and Data

The research design presented here is a comparison of the growth of children who voluntarily consumed different amounts of supplementation food.

In two of the four villages, "atole," a protein-calorie preparation of Incaparina, dry skim milk, and sugar, is distributed. In the other two villages, "fresco," a caloric preparation containing sugar, flavoring, vitamins, fluoride, and iron, is given. Table 2 shows the nutrient content of both preparations. Both provide the same vitamins, fluoride, and iron, but atole contains proteins and more calories. The supplementation, whether atole or fresco, is available twice daily in the local field station of each village, and attendance and consumption by all villagers are encouraged, but are entirely voluntary. A daily

[2]Of Hispanic culture, in contrast to American Indian culture.

Table 1. Growth and Diet of Study Population in Comparison with Values from Developed Countries

	Study Population		Values Typical of Developed Countries	
	Males	Females	Males	Females
Height (cm)				
12 mo.	68.9	67.3	74.1[b,c]	72.3
36 mo.	84.4	84.2	95.2	93.8
Net growth	15.5	16.9	21.1	21.5
Weight (kg)				
12 mo.	8.0	7.4	10.0	9.4
36 mo.	11.7	11.4	14.6	13.9
Net growth	3.7	4.0	4.6	4.5
Dietary intake (kcal/kg/day)				
15 mo.	66[a,d]	69		
18 mo.	73	75		
21 mo.	78	76		
24 mo.	80	78	100–103[e]	99–106
30 mo.	80	75		
36 mo.	76	75		

[a] Growth data from baseline studies prior to intervention.
[b] Data from McCammon, 1970.
[c] 12 month height adjusted by 1.7 cm to correct for differences in measuring techniques.
[d] Dietary intake data taken during time period of intervention.
[e] Values apply to ages 1 to 3 and are from Table 7 p. 34 Energy and Protein Requirements. (1973)

record of attendance and intake is kept for each individual. Because of the different relative concentrations of calories as related to the volume in the two supplements, and because of differing ingestions of supplement for similar attendance to the supplementation centers, these data can be analyzed separately for the relative contributions to growth of energy intake, attendance, and volume of supplement ingested.

Beginning in February 1969, data were collected on all children under 7 years of age, and all children born to the village populations before March 1973 were added to the sample. Data collected on children until their seventh birthdays included anthropometry, dental eruption and skeletal maturity observations, dietary and morbidity surveys, sociocultural inventories, and a large battery of infant and preschool mental tests. Other data, not presented here, were collected on pregnant and lactating mothers. Here we are discussing only growth in height and weight of the 456 children for whom data were collected at both 12 and 36 months of age.

Height was determined by measuring supine body length on a standard measuring table, and weight by a beam balance, both measurements taken by standard procedures (Martorell, Habicht,

Table 2. Nutrient Content Per Cup[a] of Supplementary Feeding (180 ml)

	Atole	Fresco
Total calories (kcal)	163.0	59.0
Protein (g)	11.0	—
Fats (g)	0.7	—
Carbohydrates (g)	27.0	15.3
Ascorbic acid (mg)	4.0	4.0
Calcium (g)	0.4	—
Phosphorus (g)	0.3	—
Thiamine (mg)	1.1	1.1
Riboflavin (mg)	1.5	1.5
Niacin (mg)	18.5	18.5
Vitamin A (mg)	1.2	1.2
Iron (mg)	5.4	5.0
Fluoride (mg)	0.2	0.2

[a] Review date: October 11, 1973; figures rounded to the nearest tenth.

Yarbrough, et al. 1975b). The observations were taken at the child's birthday ±7 days.

Expected Impact of Nutrition on Growth

Since there are no clinical or biochemical signs of severe vitamin-mineral deficiencies in the study population, we will immediately focus on the issue of proteins versus calories. Studies of home dietary intake, biochemical indicators, and anthropometric indicators of fat and muscle mass show a diet which appears to be limiting in calories but not in proteins (Martorell, Lechtig, Yarbrough, et al. in press; Martorell, Yarbrough, Lechtig 1976). Moreover, there is reason to believe that in such a situation caloric supplementation alone will shelter proteins and influence growth rates (Martorell, Lechtig, Yarbrough, et al., 1976); indeed analyses to date in this population show that caloric supplementation is related to birth weight (Lechtig, Habicht, Delgado, et al. 1975) and placental weight (Lechtig, Yarbrough, Delgado, et al. 1975). Thus we shall discuss the issue of growth as a response to ingested energy. This does not exclude a possible effect of other nutrients on growth in this population. Nor does it imply that the dietary problem of all populations is caloric. Many communities are in vastly different situations, and dietary interventions must be designed only after careful study of which nutrients are limiting. Indeed, interventions which are useful in one setting may be harmful in others.

What impact will additional calories have on growth? Since a comprehensive discussion of all ages is beyond the scope of this paper, we will focus on ages 1 to 3 as the youngest period with a span long enough for effects to be apparent and in which energy consumption from breast feeding is not important. What is the expected impact at this age of nutrition on growth under field conditions?

We can make some estimates as follows: Approximately 50 kcal/kg/day are necessary for basal metabolism and maintenance. In this range there is severe malnutrition and complete growth failure. The average consumption in healthy populations of the developed nations, 100 kcal/kg/day, leads to maximal growth. Thus growth occurs in the range of intake from 50 to 100 kcal/kg/day. In the four villages the typical diet of 80 kcal/kg/day is an increase of 30 kcal/kg/day above the basic need, or 67 percent of the total possible increase in consumption. Thus approximately two-thirds of the part of the diet used for activity and growth accounts for 75–85 percent of the possible growth increment from 1 to 3 years of age.

In other words, the approximately 5.6×10^5 kilocalories consumed by a village child in this 2-year period is 2.1×10^5 kilocalories over basal metabolic needs. This energy ingestion above the basal metabolic requirements leads to a growth of approximately 7.7 mm/10^4 kcal in height and 182 gm/10^4 kcal in weight. In the developed world the typical child consumes a total of 8.8×10^5 kilocalories in 2 years—4.4×10^5 kilocalories above basal needs—and uses this extra energy to grow at the lower net rate of 4.8 mm/10^4 kcal in height and 104 gm/10^4 kcal in weight. Finally, the approximately 1.4×10^5 kilocalories additional needed to bring the diet of a village child to 100 kcal/kg/day can give at most 4.6 cm of growth in height, i.e. a net rate of 0.3 mm/10^4 kcal. The comparable net rate for weight is 50 gm/10^4 kcal. This means that the greatest conversion rate of calories to growth that can be expected in the children is 25 times less efficient for height and 36 times less efficient for weight than was the conversion rate from calories to the children's growth observed at the beginning of the study.

Thus we would not expect extra food to be converted to extra growth at a rate greater than the baseline study values, and we would expect that at some point the rate of growth per unit of extra food must drop dramatically in order to bring the overall growth rate into line with the lower value of energy-to-growth conversion found in developed countries.

We conclude, therefore, that the conversion of energy to growth must follow a function similar to that depicted in figure 1, which shows a curve of decreasing conversion of each unit of energy to growth with increasing total caloric consumption. The data for this curve do not, however, exist in the literature, so that no exact numerical values can be given. Thus the predictions are at best only

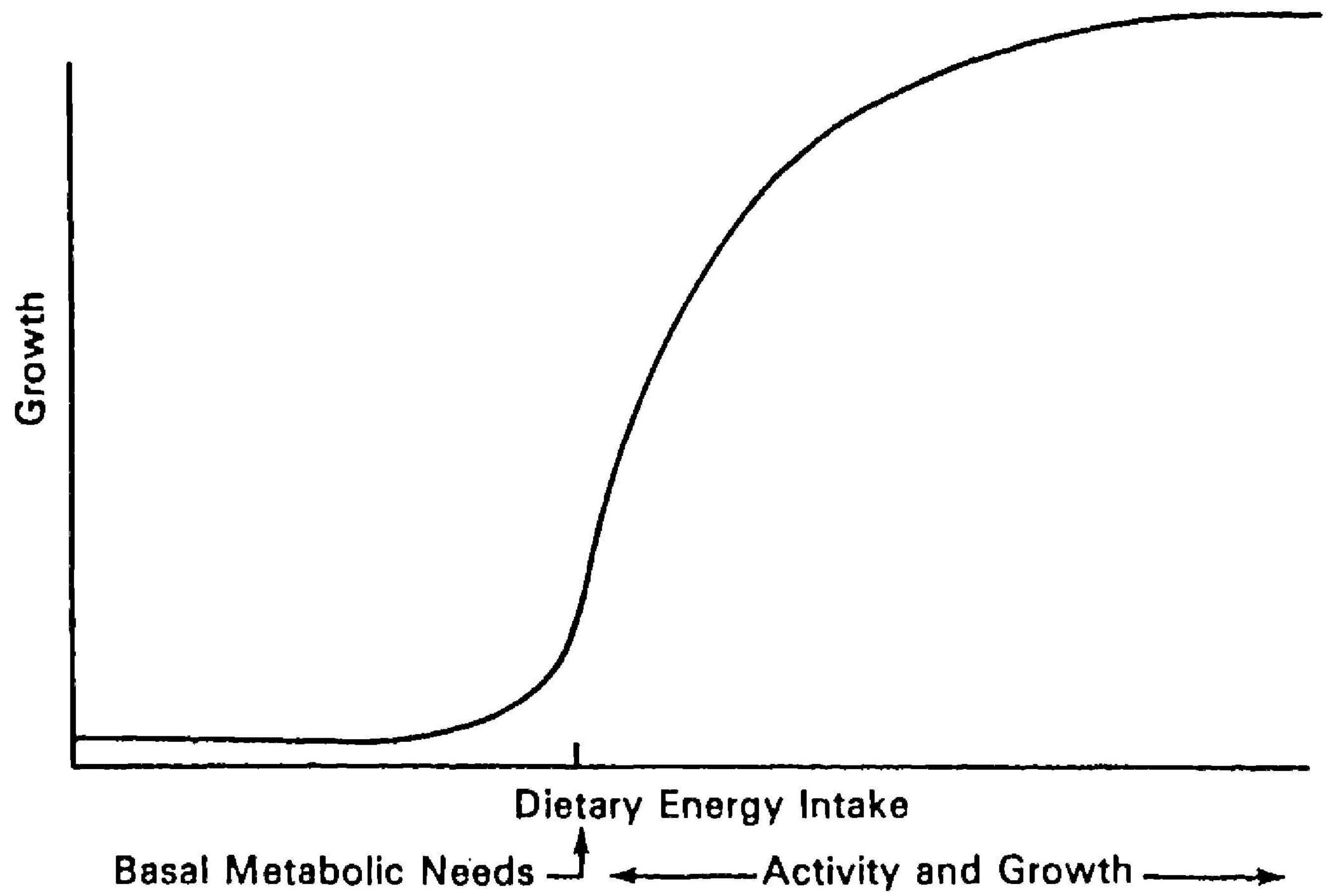

Figure 1. Hypothetical rate of conversion of dietary energy to growth

approximate. Furthermore, there is no information about the effect of other nondietary, growth-stunting influences such as morbidity or endemic parasites on this curve.

RESULTS

Table 3 gives the relationship between four categories of calorie ingestion from the supplement by children aged 1 to 3 and their growth in height and weight. The increasing values of growth in height by category of supplementary energy intake are statistically significant ($F = 20.8$, $df = 3{,}452$, $P \leq 0.001$) and biologically important (figure 2).

The lower categories are, as we might expect, essentially at the baseline levels given in table 1, while the top category shows a growth rate in which over half the deficit has been eliminated. Finally, we note that prevailing levels of morbidity make growth at the maximal rates unlikely (Martorell, Habicht, Yarbrough, et al. 1975a; Martorell, Yarbrough, Lechtig, et al. 1975). Essentially the same situation applies to growth in weight ($F = 18.7$, $df = 3.452$, $P \leq 0.001$) (figure 3).

Table 3 shows the overall rate of conversion of calories to growth by level of intake. These rates were obtained from multiple regression analyses in which we calculated the partial slope of growth on

Table 3. Relationship of Supplemental Caloric Intake and Growth from Ages 1 to 3

	Level of Ingestion (kcal/day)				
	0–10	11–50	51–100	101 and up	Total
Sample size	66	169	76	145	456
Height increment (cm)[a]	15.7 (±2.7)	16.5 (±2.6)	17.2 (±2.4)	18.3 (±2.2)	17.1 (±2.6)
Weight increment (cm)[a]	3.67 (±0.98)	3.85 (±0.89)	4.05 (±0.76)	4.50 (±0.94)	4.06 (±0.95)
Supplemental caloric ingestion (kcal/day)	5.6	26.7	73.6	200.0	86.2
Slope of growth in *height* to calorie ingestion (mm/10[4] kcal)[a]	—	2.9 (±2.6)	2.3 (±2.8)	0.1 (±1.7)	1.3 (±0.2)
Slope of growth in *weight* to caloric ingestion (gm/10[4] kcal)[a]	—	124 (±87)	44 (±84)	11 (±14)	47 (±9)

[a] Mean (± standard deviation)

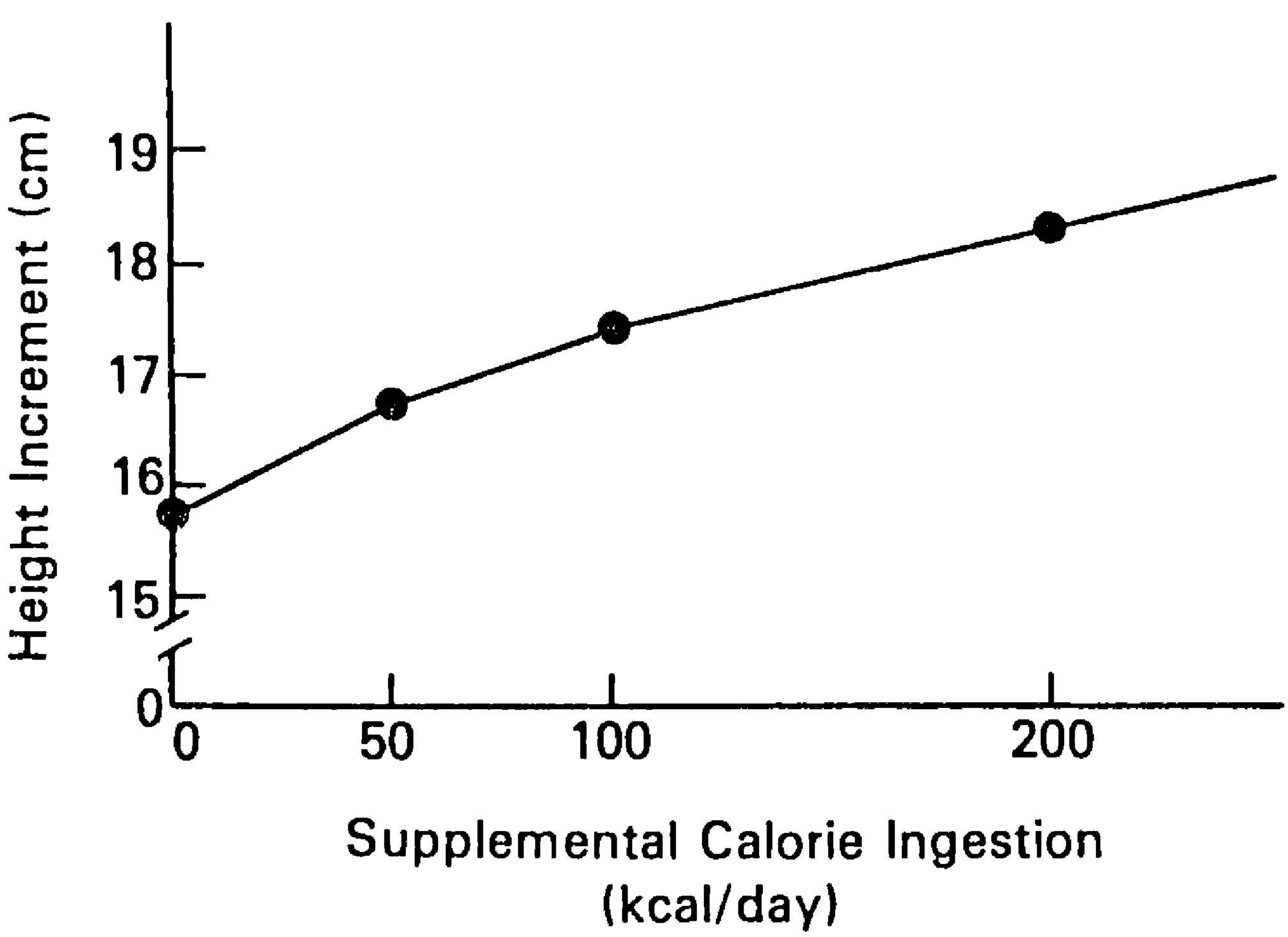

Figure 2. Growth in height of children ages 1 to 3 as a function of supplemental calorie ingestion

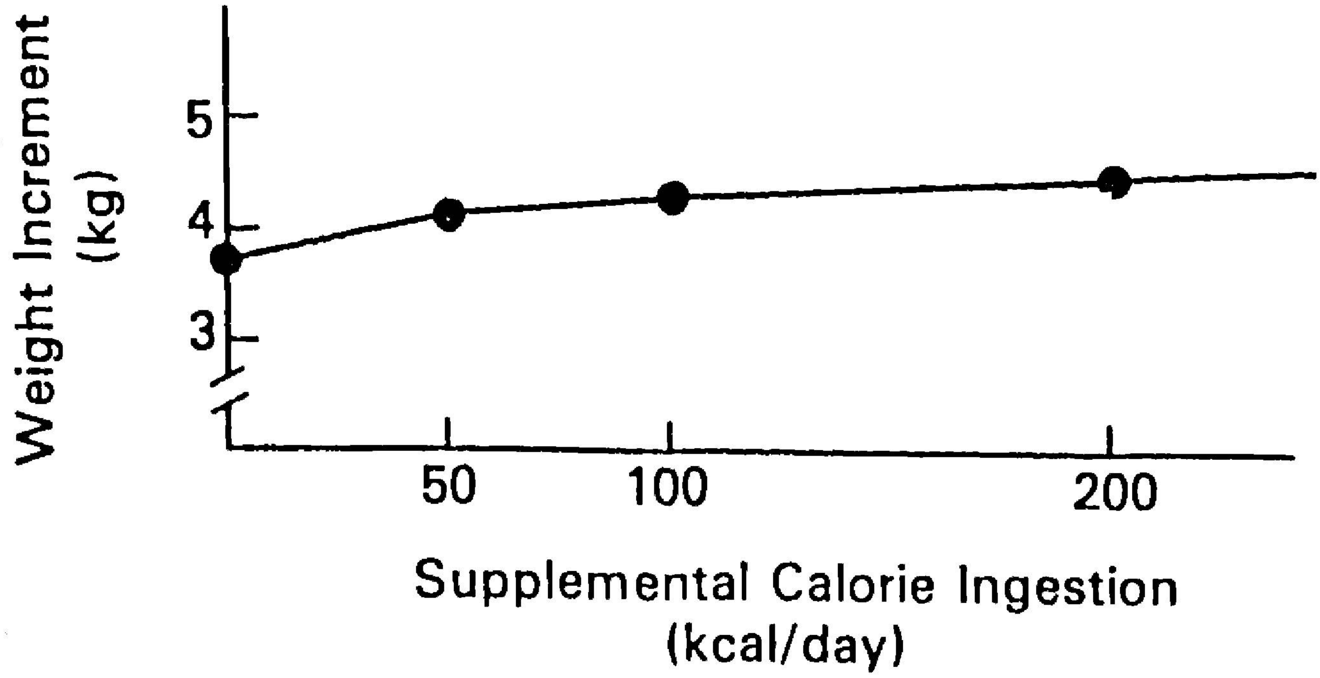

Figure 3. Growth in weight of children ages 1 to 3 as a function of supplemental calorie ingestion

calories, controlling for initial size. Controlling for initial size means that negligible influences of size at 1 year of age (correlation coefficient of weight at 1 year of age and subsequent gain in weight is $r = -0.094$; $P \geq 0.10$; and for height and subsequent growth in height, $r = 0.003$, $P \geq 0.10$) which might affect subsequent growth have been taken into account and, therefore, size at 1 year of age cannot be an explanation for the findings.

Similarly, one would like to be sure that no factors other than the nutrient intake from the supplement could be the cause of the relationship between supplement ingestion and growth. Factors which influence a person to cooperate with a study could also affect growth quite independently of any benefits received from the supplementation. To reject this possibility, one must introduce measures of cooperation into the energy-to-growth regression and show that they do not affect the findings in table 3.

An unequivocal measure of cooperation with the supplementation program is the amount of energy ingested by drinking the supplement. Infant calorie ingestion from the supplement is associated ($r = 0.72$; $P \geq 0.01$) with calorie ingestion from 1 to 3 years of age and, therefore, infant consumption should reflect many of the influences which affect later supplement consumption. Including infant calorie ingestion from the supplement in the regression relating growth to the energy consumption from 1 to 3 years of age had no influence on the energy-to-growth conversion slopes in table 3. This was reflected by statistically nonsignificant partial correlation coefficients, r_p, of infant energy intake from supplementation into the energy-to-growth conversion equation (for growth in weight $r_p = 0.05$, $P \geq$

0.10; for growth in height $r_p = -0.02$, $P \geq 0.10$). Other measures of cooperation are the number of days a child attended the supplementation center and the amount of supplement ingested. Introducing these measures of cooperation separately into the regression analysis of the effect of calorie intake on growth revealed that neither days attended ($r_p = 0.01$ for growth in weight, $P \geq 0.10$; $r_p = 0.06$ for growth in height, $P \geq 0.10$) nor amount of supplement ingested ($r_p = -0.05$ for growth in weight, $P \geq 0.10$; $r_p = 0.00$ for growth in height, $P \geq 0.10$) had any significant effect on the slopes in table 3. When all these indicators of cooperation were entered together into the regression, thus taking them all into account at once, the rates of energy conversion to growth were essentially the same as those shown in table 3. The energy-to-weight gain was 64 gm/10^4 kcal ($P \leq 0.01$) and the energy-to-height gain was 1.6 mm/10^4 kcal ($P \leq 0.01$) when all the above measured indicators of cooperation were taken into account. Therefore, the significant effect of calories on growth could not be explained by anything except the nutrients in the supplements themselves.

These analyses assume that there is no substitution of the supplements for the home diets. In other words, every calorie ingested from the supplement is a calorie added to the dietary mean at every level of supplementary intake. This is in fact almost the case, because the dietary intake decreases only 1 calorie for every 10 calories of supplement ingested. Such a small dietary replacement effect of the supplement does not affect the figures in table 3.

Finally, as expected, there are statistically significant nonlinearities in the overall rate ($P \leq 0.002$), which is reflected in the differences in the slopes with category of consumption as shown in figures 2 and 3. In other words, the more calories ingested from the supplement, the less the efficiency of conversion into growth.

UTILIZATION OF RESULTS

The purpose of the analyses was to confirm that the intervention used in this study did have an impact on the nutritional status of the child, an aim which would seem to be achieved. We must note, however, that what is being confirmed is that the supplemental food, *when it is being consumed*, has an impact on the child's nutritional status. This is not the same thing as confirming that the intervention affected an important number of children. That would require a different study design, one contrasting the villages with other nonsupplemented villages, which was not done. Even so, the small number of children in the highest supplement category makes it clear that our intervention was not very successful as an effort to treat populations, despite its success as a confirmation that an intervention had effect. Indeed it gave biologically meaningful utilization rates which were in accord with our prior notions of diminishing returns.

DISCUSSION

Three conclusions that are pertinent to the evaluation of child health services may be drawn from our presentation.

The first is already well known: The evaluation of an intervention should depend on its purposes. As a confirmation of the biological effectiveness of the supplementary feeding, the study is a success. Were this program to be evaluated as a public health intervention to improve the growth rates of the children in the four villages, however, it would not rate very highly, either absolutely or cost-effectively. This is not surprising, because the program was not designed for this purpose.

The second conclusion is that in the area of nutritional indicators the adequacy with which the efficacy of an intervention can be evaluated is sharply limited by the state of present knowledge. This results in uncertainties as to program effectiveness and efficiency. Careful design can perhaps in part face this problem, but most interventions will be practically rather than scientifically designed. For these, the lack of useful information as to what the response should be will severely limit evaluation. The lack of adequate baseline data is of course often a limiting factor as well, but currently the most serious limitation to evaluation is the absence of more theory based on experimental data from field studies which can be applied to make numerical predictions of response. This study, for instance, revealed a constraint on growth, due to nondietary factors, which corresponds in magnitude to the deleterious effect of diarrhea on growth (Martorell, Habicht, Yarbrough, et al. 1975a; Martorell, Yarbrough, Lechtig, et al. 1975).

The third conclusion is that in many cases there is an inevitable tension between demonstration of an impact of a multifaceted intervention and the evaluation of its components. The confirmation that an agent has had an effect requires either an unambiguous prediction, which current theory cannot provide, or a range of variation in the treatment which will lead to less than maximal possible impact on the population as a whole. The fact that practical interventions tend to introduce simultaneously such variables as nutrition, education, medical care, and economic changes, increases the complexity of this problem manyfold. Thus we see the absence of a careful theory of nutrition and physiological response to nutrition as a fundamental practical limitation to the evaluation of programs, and not just a scientific nicety.

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DISCUSSION

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The objective of this study was to examine the effect of a caloric supplement on height and weight of children whose anthropomorphic measurements fall below standards for North American children. As such, it is an effectiveness study because it examines the relationship between a process of care and the result of that process on health status.

The major limitation of the study was its possible inappropriateness. The goal of improving height and weight to North American standards was not one expressed by the community, but rather one derived from the researchers. Whether the failure of the research to "sell" the intervention (supplementary caloric feeding) resulted from lack of community participation or whether it was due to other factors is unclear. Thus the researchers were faced with a situation where the intervention was efficacious (it produced the desired result under carefully controlled conditions), but not effective (in the community setting, it could not be implemented).

The applicability of the intervention was considered inappropriate, because the intervention did not appear to be a useful one in the community. There are, however, lessons to be learned about the method of research. If it is the intention of the researcher that the results of a study be applied, it is necessary that the goal be explicitly recognized as legitimate by those for whom it is intended. The goal of generalizability in this research was attained at the expense of implementability of the intervention. The latter might have been realized by participation of the target population in its planning.