Reproductive Performance and Nutrition During Childhood

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Introduction

The term "reproductive performance" is often defined in terms of numbers of surviving children, that is, as a fertility measure. However, this definition is too narrow because it does not consider quality of life among survivors. An alternative is to expand the concept of reproductive performance to include health and well-being of children, using indicators such as birthweight, postnatal growth, feeding patterns and nutrient intakes, vaccination coverage and illness histories, and psychomotor performance. An even more encompassing definition also includes maternal endowment or capacity to nurture; some qualities to consider are biological, such as physique and body composition indicators predictive of intrauterine development, and others are behavioral attributes that relate to child care, such as level of education and intellectual performance. Reproductive performance is then a function, in this expanded sense, of the degree to which women are both capable and able to deliver healthy newborns and to nurture them adequately to a "safe" age. In the context of developing countries, this may be taken to be 3 years of age; it is prior to this age that malnutrition, infection, and growth failure are common and severe problems. Also, mortality is at its highest among young children.

This paper tests elements of the hypothesis that nutrition during childhood is a key determinant of future reproductive performance. The work presented is part of ongoing studies being carried in Guatemala in collaboration with the Institute of Nutrition of Central America and Panama (INCAP).

Methods

A series of studies have taken place in four villages located in the "Ladino" or Spanish-speaking part of Guatemala, in the east of the country (Martorell et al. 1995). In 1968, two pairs of villages were selected from among dozens; one pair of villages had about 900 people each and the other about 500 each. The pairs were selected on the basis of similarities in sociocultural, anthropometric, dietary, and morbidity characteristics.

Longitudinal Supplementation Trial (1969-1977)

The first longitudinal study began in 1969 when one large and one small village were selected at random to receive a nutritious supplement and the other two villages a low-energy drink. The nutritious drink was a high protein, high energy gruel called Atole, which was made with Incaparina, a vegetable protein mix developed by INCAP, dry skim milk, sugar, and flavoring. Atole was served hot in cups containing 180 mL; this amount provided 163 kcal and 11.5 g of high quality protein. The Atole was available twice daily, in midmorning and midafternoon, so as not to interfere with meal times. The feeding center was open daily for over 7 years, from 1969 to 1977. Anyone in the village could attend, but careful recording of consumption, including of additional servings as well as of leftovers, was done only for women who were pregnant or breastfeeding and for children 7 years or younger.

Because the aim of the study was to investigate the effect of protein supplementation on mental development, the setting was duplicated in the "control" villages, down to the fastidious measurement of consumption, to control for the socialization effects of attending a feeding center. The "control" villages received a drink called Fresco, which looked and tasted somewhat like Kool Aid™. It had no protein but contained sugar; a cup provided 59 kcal or about one third of the energy density of the Atole. In a further effort to create a protein contrast, a number of vitamins and minerals were added to the Fresco in equal concentration as in the Atole. Therefore, both drinks are called "supplements" in study publications. Finally, medical care was provided to all four villages by auxiliary nurses under the supervision of a physician.

Household structure, composition, and socioeconomic status were recorded for every family of the longitudinal study. Women were monitored during pregnancy, and data were collected on maternal characteristics and pregnancy outcomes, including birthweight. In children, data were collected periodically on a variety of aspects, including growth and maturation, home diet consumption, frequency and duration of illness, and psychological development.

The Follow-up Study (1988-1989)

In 1988-1989, a follow-up study of former participants of the study was conducted (Martorell et al. 1995). The subjects of study were all those who had been 7 years or younger at any point from 1969 to 1977, the duration of the feeding experiment. Out of 2169 such subjects, 1574 or 74% were examined in 1988-1989 at ages ranging from 11 to 27 years of age. Coverage was 89% for nonmigrants (n = 1278) and 41% for migrants (n = 296). Data collection included body size and composition, skeletal maturation, hand strength, work capacity, school attendance history, intellectual performance, and social, economic, and demographic information about the subject and his or her family.

The Birthweight Study (1991-1996)

Starting in 1991, pregnancies in women of the follow-up sample have been monitored and birthweights have been collected. Due to logistic difficulties, only nonmigrants who give birth in the villages or in nearby medical facilities are included. Data on age at menarche, age at first sexual experience, first pregnancy, and first birth have also recently been collected.

New Longitudinal Study (1996-1999)

In 1996, a longitudinal study will begin that will continue monitoring pregnancies and assessing birthweight and will add data collection in children during their first 3 years of life. Physical growth, diet, illness, and motor and mental development are some of the areas of data collection planned using methods similar to those of the earlier longitudinal study whenever possible. Extensive data on mothers will also be collected on knowledge and attitudes toward child care, child care behaviors (e.g., feeding practices, cleanliness of children, vaccination coverage, and health care utilization), and maternal intellectual performance. Household information will also be obtained (e.g., socioeconomic status, hygienic facilities, household structure, etc.).

Conceptual Framework

The overall hypothesis of the forthcoming study is as follows: Malnutrition in early childhood constrains the future capacity of women to bear healthy newborns and their ability to feed and care for them and, through these mechanisms, the growth and development of the next generation. In this paper, certain elements of this hypothesis are tested by tracing the effects of a nutrition intervention over three generations. Key relationships of possible interest are presented in **Figure 1** and serve as a guide for the analyses presented here.

First, the effects of the nutrition intervention on maternal nutrition of the first generation (F_1) and on birthweight of the second generation (F_2) are examined. Next, because the independent variable of the overall hypothesis is nutrition in early childhood in girls of the second generation (F_2), the effects of the supplementation program on length for age at 3 years of age, a global index of nutritional status, are examined. The choice of 3 years is informed by previous analyses that identify pregnancy and the first 3 years as critical phases of malnutrition and growth failure (Schroeder et al. 1995, Martorell 1995). The 1988-1989 follow-up study permits the effects of the nutrition intervention to be examined at adolescence and adulthood in the second generation (F_2). In this paper, the effects on adult body size and composition and on intellectual performance are reviewed. The latter is a proxy of maternal competence, loosely defined as ability and motivation to provide adequate child care. While this is a broader concept than intellectual performance, maternal education and literacy are consistently identified in the literature as related to child health, suggesting that intellectual performance is an important asset for child care

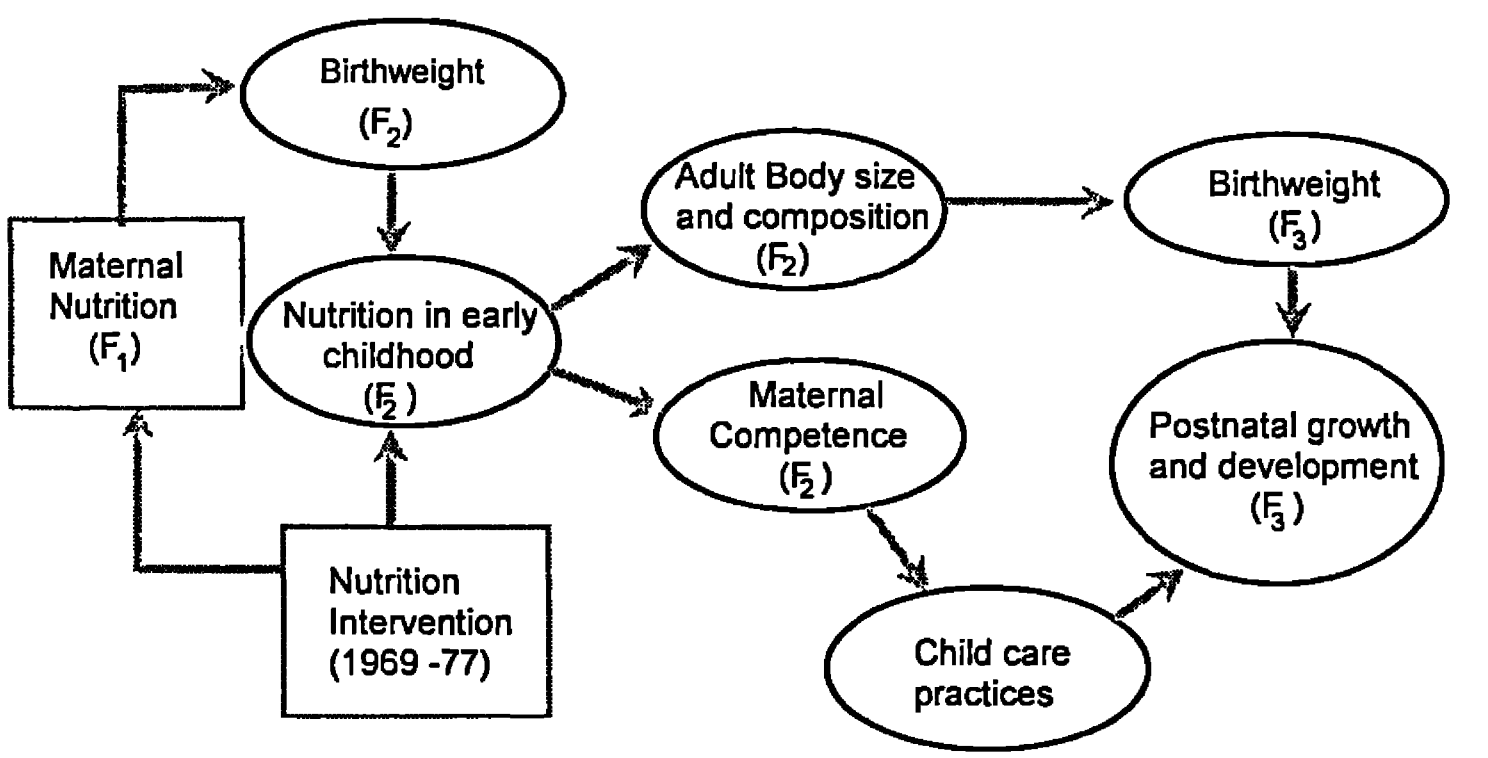


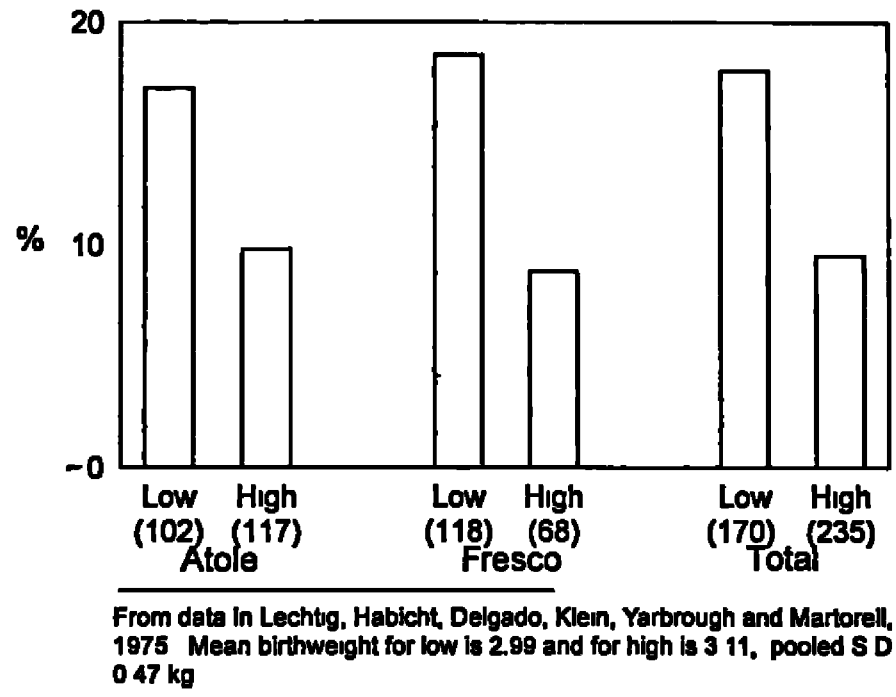
Figure 1. Malnutrition in early childhood and reproductive performance: key relationships over three generations.

(Behrman 1995). Finally, data are available to trace the effects of the nutrition supplementation (1969-1977) on birthweight of the third generation (F_3); because the second longitudinal study is yet to be implemented, effects on child care practices and on postnatal growth and development (F_3) cannot yet be tested.

In summary, the existence of long term information permits analyses of the effects of nutritional improvements in early childhood on adult characteristics, such as body size and composition, and on intellectual performance. It is also possible to test the effects of the nutrition intervention during early childhood on birthweight in the next generation.

Results

Greater amounts of Fresco than Atole were consumed by pregnant women such that levels of energy from supplement were only one fourth less in Fresco than in Atole villages, in spite of the lower energy concentration of the latter (i e , average energy from the supplements was 81 and 107 kcal/d during pregnancy in Fresco and Atole villages, respectively; Delgado et al. 1982) On the other hand, the contrast for protein was large. Women obtained on average 7.5 g of protein per day during pregnancy from the Atole; the Fresco, as noted above, lacked protein In the original longitudinal study, birthweights (F2) were greater in Atole villages by 50 g, but this difference was not statistically significant (Delgado et al. 1982). One of the well-known findings of this study is that supplementation with energy and not protein reduced the prevalence of low birthweight, defined as ≤2 5 kg (Lechtig et al. 1975). In one analysis, the sample was divided into those that ingested more or less than 20,000 kcal during pregnancy from the supplements, an amount that is one third to one fourth of the estimated energy cost of pregnancy (Lechtig et al. 1975). Differences in the prevalence of low birthweight between low and high consumers of energy

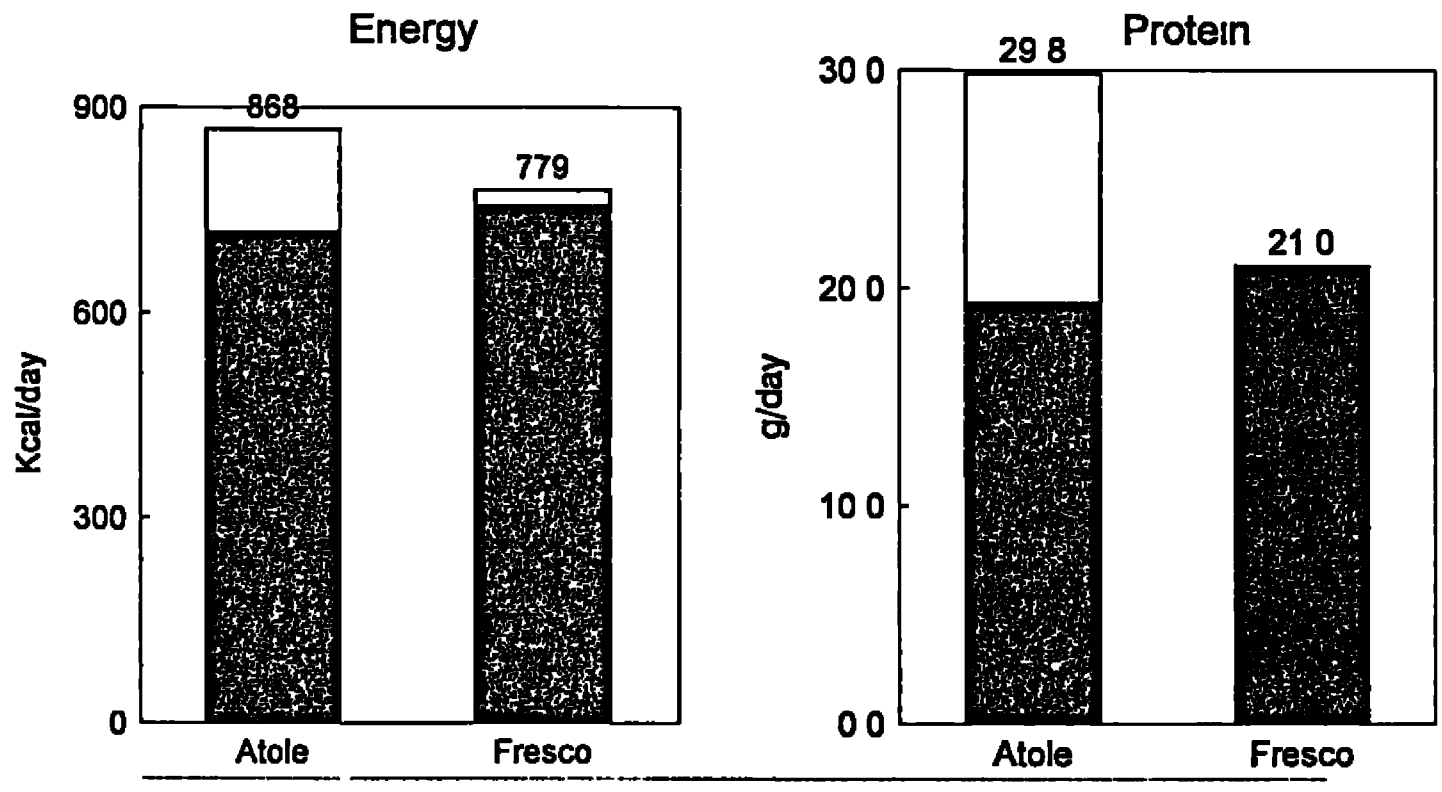


From data in Lechtig, Habicht, Delgado, Klein, Yarbrough and Martorell, 1975 Mean birthweight for low is 2.99 and for high is 3 11, pooled S D is 0 47 kg

Figure 2. Level of supplement intake during pregnancy (F_1) and low birthweight (≤2 5 kg; F_2). Low is ≤20,000 kcal, and high is ≥20,000 kcal during pregnancy.

from supplement were similar in Atole and Fresco villages. This suggests that it was energy that mattered, since the energy from the Atole also carried protein along with it (**Figure 2**). In the combined sample, the prevalence of low birthweight was 18% in the low intake group and 10% in the high intake group. Because both beverages were in effect treatments, the original design was abandoned when studying effects on birthweight It was only possible to establish that there was a relationship between energy intake and birthweight because supplement consumption was measured carefully in individuals and in both Atole and Fresco villages. However, because attendance was voluntary, control for potential confounding became an important analytical task All such analyses have led to the conclusion that the reduction in birthweight cannot be explained except by supplement consumption (Lechtig et al. 1975).

In children, consumption of the Atole was greater than that of the Fresco (Schroeder et al. 1992) For example, at



Atole (n = 118), Fresco(n=104), ■Home diet □Supplement
Data from Martorell, Habicht and Klein, 1982

Figure 3. Net contribution of the supplements to the diets of girls 15 to 36 months of age

24 months, on average, children consumed about 120 mL of Atole but only about 60 mL of Fresco. At this age, average attendance rates were about 65% of days in Atole villages but only 45% in Fresco villages. As a result, the contribution of the Fresco to total nutrient intakes in young children was small compared with that of the Atole. This is illustrated by estimates of energy and protein intakes from home diet and from the supplements for girls 15 to 36 months of age (**Figure 3**). Values for boys are similar and can be found elsewhere (Martorell et al. 1982). The base of the bars represents the contribution from home diet consumption, obtained through 24-hour recall surveys every 3 months, and the top segment represents the contribution of supplement. Home dietary intakes are slightly greater in Fresco villages, suggesting a minor substitution effect. Nonetheless, differences between village types, taking both diet and supplement into account, favored Atole villages by 89 kcal and 8.9 g of protein per day. These amounts represent increases of 11% in energy and of 42% in protein in Atole villages over those of Fresco villages. Because differences between Fresco and Atole existed for both energy and protein, and because there was so little energy consumed from the Fresco, it is impossible to test for the relative importance of energy and protein on child growth.

Numerous analyses using a variety of analytical procedures have established that exposure to and consumption of Atole led to improvements in growth. Initially, the four study villages were selected from among many on the basis of similarities in health and nutrition characteristics, including anthropometry. Mothers (F_1) of children in the 1969-1977 study were nearly identical in stature in Atole and Fresco villages: 149.0 ± 0.5 cm and 149.3 ± 0.6 cm, respectively (x ± SE) (Rivera et al. 1995). Using cross-sectional data collected prior to the intervention in 1968, it was estimated that 3-year-old girls were 82.9 cm tall in Atole villages compared with 83.2 cm in Fresco villages (Martorell et al. 1982). These very small differences in women and girls were not statistically significant.

As a result of the supplementation program, growth improved in children in Atole but not in Fresco villages (see **Figure 4** for the results in girls). The first two bars represent differences in length at 3 years of age in the large and in the small Fresco village for girls exposed to the Fresco during their entire lives relative to unexposed girls from the same villages measured in 1968, prior to the supplementation program. Little or no change is observed in Fresco villages following the intervention; length increased by 0.5 cm in the large village and decreased by 0.7 cm in the small village. In contrast, changes in length in girls in Atole villages were larger and positive, 3.6 cm in the large and 2.5 cm in the small village.

A variety of statistical tests have been used to show that these changes in Atole villages, but not in Fresco villages, are statistically significant, even when village is used as the unit of analysis, appropriate for the original design of the study (Habicht et al. 1995). In the last four bars, the population of girls in Atole villages has been divided into four groups depending on intake, from low to very high levels (Figure 4). Each group is progressively taller; the last group, for example, made up of children who ingested on average more than 200 kcal/d from the Atole, was taller by 5.8 cm compared with baseline values (i.e., combined value for age 3 years for the large and the small village). This suggests a clear dose-response relationship. Another important finding is that supplementation improved growth rates only in the first 3 years of life (Schroeder et al. 1995). One possible reason for why there was little effect from 4 to 7 years of age is that unsupplemented children were growing adequately at these ages, suggesting that nutrition interventions only help when children are failing to grow.

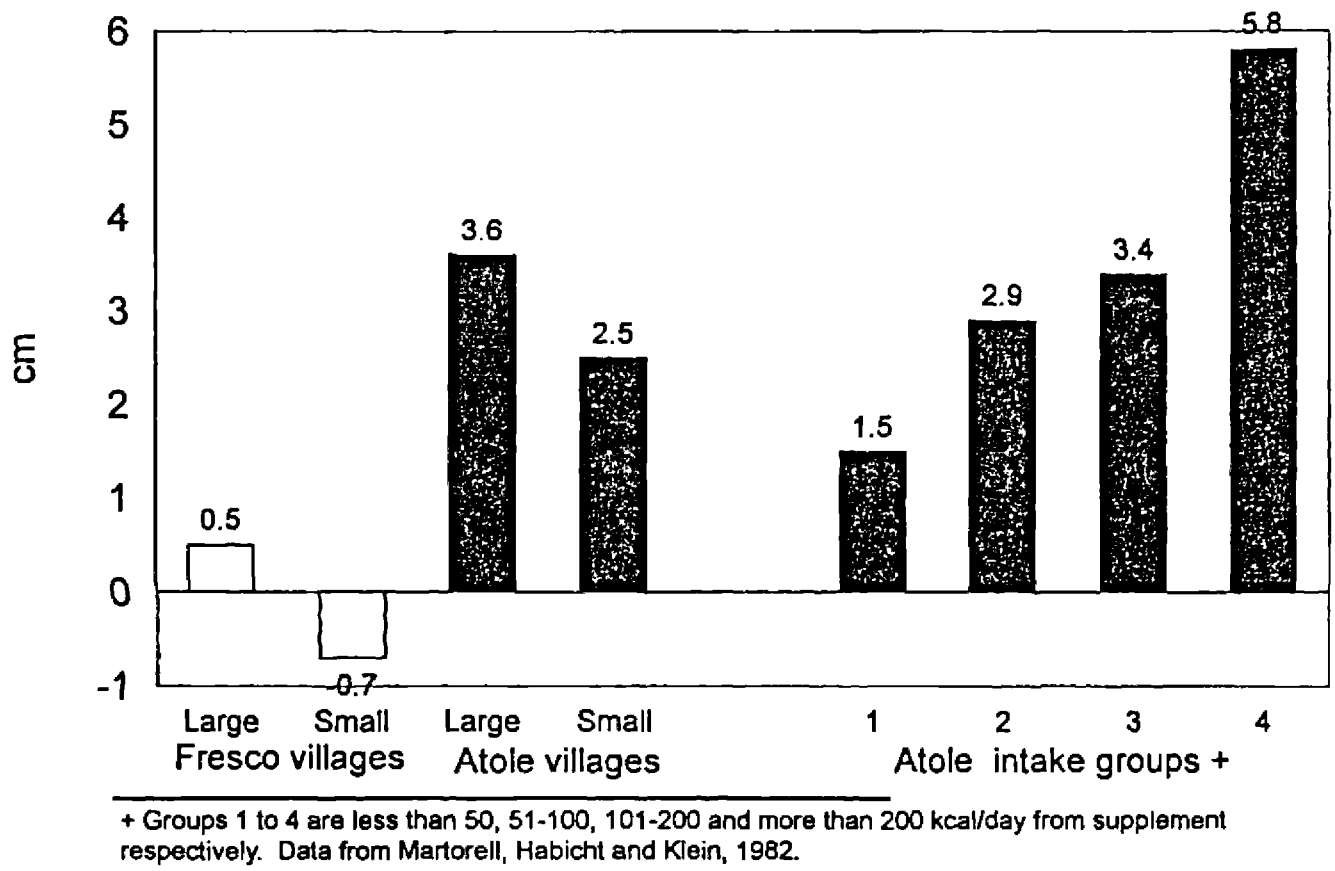


Figure 4. Changes in length (cm) at 3 years of age with respect to 1968 baseline values in girls exposed to supplement during gestation and the first 3 years of life.

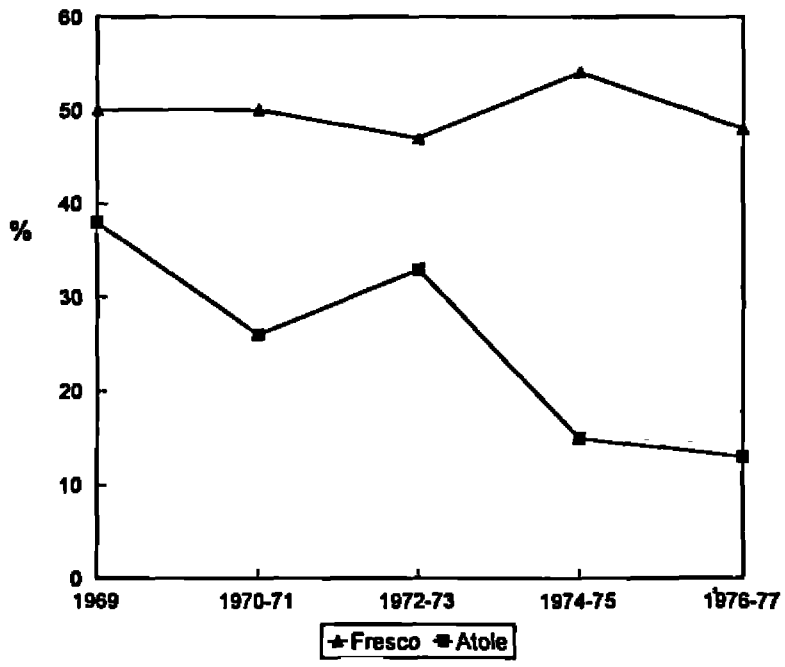


Figure 5. Changes over time in percentages of 3 year olds with severe growth failure by supplement type.

The percentage of girls whose size can be characterized as severely stunted at 3 years of age, defined as lengths three standard deviations or more below the reference median, also changed over time (**Figure 5**). In well-nourished children, one would expect to find about 1 in 1000 children below this value, but in Guatemala, 1 in 2 children is below the value. In 1969, during the first year of the study, the prevalence of severe stunting at 3 years of age in girls was about 50% in Fresco and about 40% in Atole villages, a difference that was not statistically significant if only this year is analyzed. However, a declining trend in severe stunting was observed in Atole but not in Fresco villages. By 1976-1977, the last 2 years of the study, the prevalence of severe stunting at 3 years remained high in Fresco villages at around 48% but was only about 15% in Atole villages.

Former participants of the 1969-1977 study were examined in 1988-1989 when they were adolescents and young adults. These data, collected at an average age of 16.5 years, allow testing of whether differences in growth that were observed in early childhood persisted in adolescence and adulthood. As shown in **Table 1**, women of the follow-up were taller in Atole than in Fresco villages, but the average difference had declined from 2.9 cm at 3 years of age to 2.1 cm at follow-up. Significant differences in favor of women in Atole villages were also observed at follow-up in weight and in fat-free mass, the latter estimated using a predictive equation based on underwater weighing developed specifically for the Guatemalan population (Conlisk et al. 1992).

Table 1. Body size ($\bar{X} \pm$ S.E.) at follow-up in Atole and Fresco villages for female subjects (average age 16.5 yrs) exposed to supplement during gestation and the first three years of life.*

	Atole (n=116)	Fresco (n=99)	Diff (A-F)	P (A-F)
Height (cm)	150.7±0.4	148.6±0.5	2.1	0.001
Weight (kg)	48 2±0.6	46.0±0.6	2 2	0.009
FFM (kg)	37.3±0.4	35.2±0.5	2.1	0.002

* Data from Rivera, Martorell, Ruel, Habicht and Haas, 1995. Adjusted for home dietary energy intake and percent of time ill with diarrhea (<3 years), socioeconomic status (1975 measure), maternal height (F1) and maturation.

Information about fertility milestones was collected recently; analyses of these variables are still in progress. The analyses for age at menarche are finished, and the results are that age at menarche was similar in both populations. The value was exactly 13.8 years in both Atole and Fresco villages, more than a year later than in better-off Latin American populations (Khan et al. 1995). Thus, while average age at menarche is delayed in the sample, the nutrition intervention did not influence this event. Moreover, preliminary analyses indicate that the intervention did not influence ages at first sexual experience, first pregnancy, or first birth. On the other hand, analyses in progress indicate that women who reached menarche earlier experienced fertility milestones earlier.

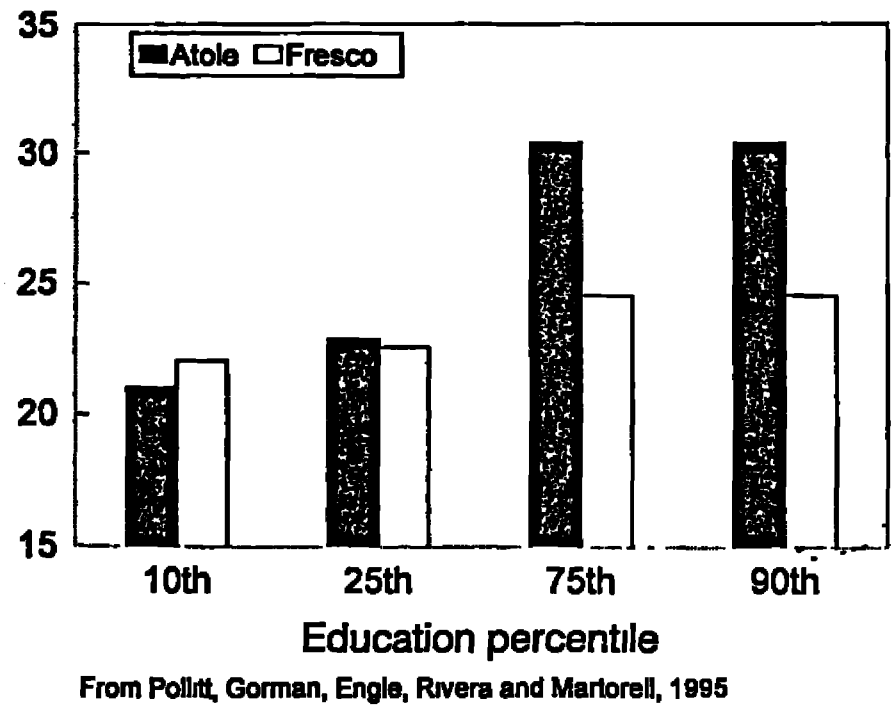
In addition to Atole's effect on biological outcomes, it also had long term effects on psychoeducational tests. Pollitt et al. (1993) found that exposure to Atole during early childhood improved performance on most of the psychoeducational tests administered (**Table 2**). A number of significant interaction terms were found (see last two columns of Table 2) that permit the identification of subgroups among whom effects were greatest. In several cases, effects were concentrated in subjects with the highest levels of education. Also, in almost all instances, the effects of Atole were greatest on children from the poorest families.

Table 2. Effects of Atole exposure during early childhood on a battery of psychoeducational tests*

	Treatment (Rx)	Rx X Grade	Rx X SES
Numeracy +	<0.01	N.S.	<0.001
Knowledge +	<0.01	N.S.	<0.01
Raven's Test ++	N.S.	N.S.	<0.01
Reading Achievement +++	<0.001	<0.001	<0.001
Vocabulary +++	<0.001	<0.01	<0.001
Reading +	N.S.	<0.05	N.S.
Literacy +	N.S.	N.S.	N.S.

* From table 20 in Pollitt, Gorman, Engle, Martorell and Rivera (1993). The analyses include both sexes and control for age at testing, gender, attendance, SES, age at school entry and maximum grade attained Subjects received full exposure during pregnancy and the first 2 years of life with variable exposure later. Criteria of significance is 0 05 for main effects and .10 for interactions. All treatment effects favor Atole.
+ Tests developed locally.
++ Test of intelligence consisting of scales A, B and C of the Raven's Progressive Matrices.
+++ Part of the Inter-American series.

The interaction between treatment and education, in the case of the standardized vocabulary test, is presented in **Figure 6**. Education refers to years of primary school, which on average was less than 4 years, and was scaled as percentiles. There are no differences in vocabulary between Atole and Fresco villages at low levels of education. However, at higher levels of schooling, the performance of Atole subjects over that of Fresco subjects is increased dramatically.



From Pollitt, Gorman, Engle, Rivera and Martorell, 1995

Figure 6. Education by treatment interactions for vocabulary

Preliminary analyses of birthweight data from the third generation suggest that the nutrition improvement girls experienced in early childhood translates into greater birthweight in their children. The prevalence of low birthweight is currently 12% in Atole villages (n = 65) and 28% in Fresco villages (n = 58) among women exposed to the supplements during the intrauterine period and the first 3 years of life. Mean birthweights are 2 90 kg in Atole villages and 2.73 in Fresco villages

Discussion

A broad definition of reproductive health was developed in the introduction that includes the biological and behavioral capacity or endowment of women to nurture children as well as actual evidence of "good" nurturing as indicated by health outcomes in the child The goal of this paper was to test the hypothesis that nutrition in early childhood is an important determinant of reproductive performance using data from a nutrition intervention study carried out in Guatemala

Several elements of the conceptual framework guiding the analyses were examined. Evidence was presented that energy supplementation during pregnancy led to improvements in birthweight However, because women in both Atole and Fresco villages received similar amounts of energy during pregnancy, differences between these village types in birthweight could not be demonstrated. The nutrition intervention did create an important contrast between village types in terms of energy and protein intakes (as well as in other nutrients) in children less than 3 years of age, and it was possible to show that length for age increased in Atole but not in Fresco villages. The population studied exhibited a remarkable degree of growth retardation at the beginning of the study, nearly 50% of the sample was severely growth retarded at 3 years of age in 1969, defined as lengths three standard deviations or more below the reference median. The proportion of such children decreased to about 13% in Atole villages but remained unchanged in Fresco villages.

Follow-up study of these children established that the effects on child growth translated into greater adult height, weight, and fat-free mass in women. Using the cut-off point of <149 cm in stature as a measure of obstetric risk, 34% of women in Atole villages and 49% of women in Fresco villages were identified as at risk. The differences in weight and in fat-free mass between village types exceeded 2 kg in each case. These differences would be expected to matter in terms of intrauterine growth. In poor societies such as Guatemala, prenatal weight and size is as important a predictor of low birthweight as is diet during pregnancy (Kramer 1987).

The follow-up study also provided evidence about exposure to the supplements and its repercussion on intellectual performance. Consistent relationships were observed between exposure to Atole, particularly in reading and achievement vocabulary. The consistency and magnitude of the effects were surprising because the Atole had few demonstrable effects on psychological test performance prior to age seven. It is only years later in the follow-up that these effects emerge Also, an interaction was detected between exposure to Atole and education The fact that no effect was detected at low levels of education suggests that in order for benefit to be derived from the nutrition intervention, children must go to school and stay in school.

Finally, birthweights are greater in children born to mothers exposed to Atole during pregnancy and the first 3 years than in children born to mothers exposed to Fresco. However, these analyses are preliminary and based on small sample sizes, considerably more data will be collected in the coming years to confirm these findings. In addition, analyses will be carried out to explore possible mechanisms, for example, is the effect on birthweight mediated through height and/or fat-free mass? These analyses will control for potential confounding, such as socioeconomic status, birth order, and gender

Data from the pending longitudinal study will allow the breadth of possible analyses to be expanded. Aspects such as the role of improvements in intellectual performance in shaping knowledge, attitudes, and practices toward child care, for example, will become a focus of analysis. Regardless of whether future analyses fully support our hypotheses about intergenerational effects, the evidence already accumulated strongly suggests that improving the nutrition of little girls is one of the most important avenues through which safe motherhood and healthy child development can be achieved

Acknowledgment

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