Maternal Malnutrition, Birth Weight, and Child Development

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Nutrition and development are intimately intertwined. Defining these relationships is the challenge faced by research scientists and practicing physicians alike.

In approaching the subject of nutrition and development it is important to emphasize that human malnutrition exists in varying degrees of severity [1]. The majority of studies have been concerned with severe deprivation such as clinical protein-calorie malnutrition early in life. In this paper the emphasis will be on mild to moderate malnutrition which affects manyfold more children than does severe malnutrition.

It also must be emphasized that nutrition, health, environment and behavior all interact to influence child development. Each of these major categories can, of course, be broken down into a myriad of components for study. The complexity of these interrelationships is beyond the scope of this paper but has been touched upon by CRAVIOTO [2] elsewhere in this volume. Nevertheless, they must be taken into account in demonstrating the effects of malnutrition on human development. We will concern ourselves primarily with the somewhat more limited range of variables of special importance during the perinatal period. In particular we will attempt to show how a role can be attributed to nutrition in human processes.

Obviously many important leads may be obtained through animal research where the environment can be closely controlled. Comparable control is not obtainable with humans except for institutionalized individuals who volunteer for specific research projects. At least three alternative approaches may be identified for human investigations at a population level:

Catastrophes

A careful study is done of the consequences of natural disasters such as famine where the nature and severity of the stress may be reasonably well characterized in time. Unfortunately, opportunities for such case studies occur all too often. When they do occur, necessary data for a careful evaluation of outcomes usually are not available.

Ecological

A multidisciplinary study is conducted involving a wide range of individuals living under varied but normal conditions. The central issues here are variations in life style (including nutritional status) and changes over time in such parameters as growth, illness rate, or mental development.

Intervention

This method involves provision of a known supplement or other intervention with careful documentation of the resultant changes. It is essential that intervention studies include a comparably well-studied control group not given any, or perhaps only partial, intervention for comparison.

Each of these approaches has its own advantages and disadvantages. Each has contributed immeasurably to advancement of knowledge and medical practice. All involve complicated analytic approaches requiring full knowledge of the potential interacting factors.

The data in this paper will be drawn from the results of a nutrition intervention study of child development currently underway in Guatemala. The Guatemala project is directed primarily to the impact of mild to moderate malnutrition (or alternately, of nutritional supplementation) on mental development. It is well known that the incidence of mental retardation is higher among prematures and babies with low birth weight. Malnutrition has been shown to affect adversely both birth weight and brain development in many species of experimental animals. The impact of acute and/or of severe dietary restriction on human birth weight and brain weight also has been documented in studies of such disasters as the famines of World War II. The impact of chronic undernutrition is considerably less clear, however. Therefore the question of maternal nutrition and birth weight is a major question for resolution by the Guatemala project.

The study of nutrition and birth weight is complicated by a variety of factors which have been shown to be involved. These include parity, the height and weight of the mother before pregnancy, maternal nutrition during pregnancy, smoking, illness, duration of pregnancy, and sex of the offspring.

A critical evaluation of the literature as it bears directly on malnutrition and birth weight has been published elsewhere [3]. As pointed out by HABICHT *et al.* [4], conclusions drawn from many previous studies may not apply generally for a number of reasons. These include: (1) the imprecision of measuring maternal dietary intake; (2) the role of the nutritional status of the mother before pregnancy in providing maternal stores to meet the nutritional needs of the fetus; and (3) the possibility that there may be a threshold effect of malnutrition. The Guatemala study offers an excellent opportunity to assess some of these criticisms.

This study is being conducted in rural Guatemala where the total median family income (cash plus produce) is $200 per annum. Food is simple, centering around corn and beans plus coffee, sugar and occasional meat and fruit. Housing is primitive, with the houses usually constructed of cane and thatch or a simple adobe brick structure for the more affluent. Indoor plumbing is nonexistent, and latrines and other rudiments of public health are rare. Chickens, pigs, and domestic animals have free reign of the home and yard, thus compounding problems of hygiene.

The design of the study involves four small villages, roughly comparable in socio-economic status. All villages are provided a unique and effective clinic-centered medical care system that is lower in cost (less than $2.50 per inhabitant per year) than any other reported in the literature [5]. Central to this system is a standardized simplified diagnostic schema for referral to a physician or treatment by well-trained aides having relatively little formal education.

The study of disease is further complemented by regular biweekly home visits. In this way it is possible to identify the nature and duration of the frequent but relatively minor illnesses which may interfere with food intake and/or growth and development. The biweekly home visits also permit early identification of missed menses so that onset of pregnancy can be estimated within 15 days for most women. A midwife attends all births, most of which occur in the home. Birth weight is recorded within 24 h of birth by trained staff members. At the beginning of this study the average birth was 3.0 kg with a third of those with normal gestational age (37 + weeks) weighing 2.5 kg or less. Evidence of maternal illness and intrauterine infection rates have been found to be high (60%) in all villages [6].

Two supplements are being provided. One is a protein-calorie-vitamin-mineral mixture called 'atole' containing 50% milk solids plus 50% Incaparina (cottonseed meal, corn flour, lysine, yeast, vitamins, and minerals). The other is called 'fresco' and has about one-third the calorie level plus the same vitamins and minerals. The nutritional composition of these is presented in table I.

Each supplement is provided *ad libitum* in a central facility with the consumption measured accurately. Special attention is given in the supplementation program to reaching the pregnant and lactating women as well as the children up through 7 years of age. Home dietary surveys (24-hour recall) are done quarterly on the pregnant and lactating women and on the preschool children. These have shown that the supplement is consumed in addition to the home diet and is not a replacement.

At the outset of the study, participation by the pregnant women was low as the supplement was viewed primarily as child-oriented. The home visitors have concentrated on this misunderstanding so that currently about 60% of the women attend regularly with a high level of consumption. As the percentage of women participating in the supplement program has gone up, there has been a concomitant increase in the percentage of birth weights greater than 3.0 kg and a decrease in birth weights below 2.5 kg [7]. This observation has, of course, provoked considerable speculation. The central question is whether there is a direct correlation between calorie supplementation and birth weight.

To explore this area, 288 women who delivered full-term babies in all

Table I. Nutrient content of atole and fresco per cup (180 ml) [from HABICHT *et al.*, 4[1]]

	Atole	Fresco
Total calories, Kcal	163	59
Proteins, g	11.46	-
Fat, g	0.74	-
Carbohydrates, g	27.77	15.30
Ascorbic acid, g	0.02	0.02
Calcium, g	0.37	-
Phosphorus, g	0.31	-
Thiamine, mg	1.14	1.10
Riboflavin, mg	1.50	1.50
Niacin, mg	18.50	18.50
Vitamin A, mg	1.20	1.20
Iron, mg	5.80	5.00
Fluoride, F mg equivalents	0.20	0.20

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four villages during the period January 1, 1969 and February 28, 1972 were combined. The total supplement consumption during pregnancy, expressed in terms of calories, was determined. As shown in figure 1, as calorie consumption increased, the percentage of babies with birth weights of 2.5 kg or less decreased; conversely, the percentage of babies with birth weights over 3.0 kg increased. Consumption of more than 20,000 calories appeared to have much less impact on the percentage of low birth weight although increments in median birth weight were seen as calorie level increased. Furthermore, consumption of more than 20,000 calories appeared to result in a distribution of birth weights roughly comparable to full-term infants born to white middle-class North Americans. In addition, analysis of 13 premature births (less than 36 weeks gestation) showed that 11 of these were born to women consuming less than 20,000 calories of supplement. Although the numbers are too small to give confidence, the trend is consistent with a possible effect of nutrition on prematurity.

Interestingly enough, comparisons of women who consumed the protein-containing supplement with those who did not (fig. 2) indicated that, at a given calorie level, there was little or no effect of added protein on birth weight, at least up to levels of 30,000 calories [4]. No differences were found between the four calorie groups in terms of maternal age, days of illness

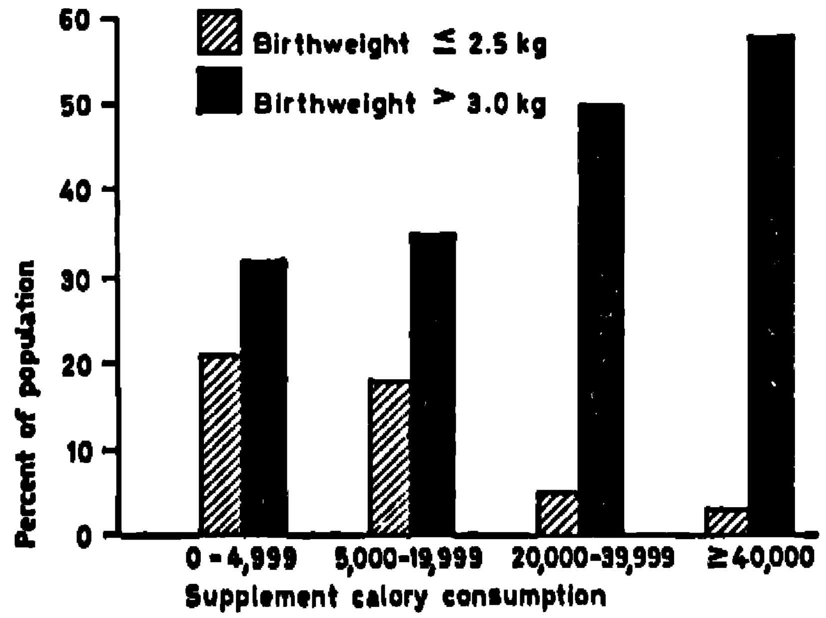

Fig. 1. Maternal caloric supplementation versus full-term birthweight in four Guatemalan villages [from LECHTIG *et al.*, 7].

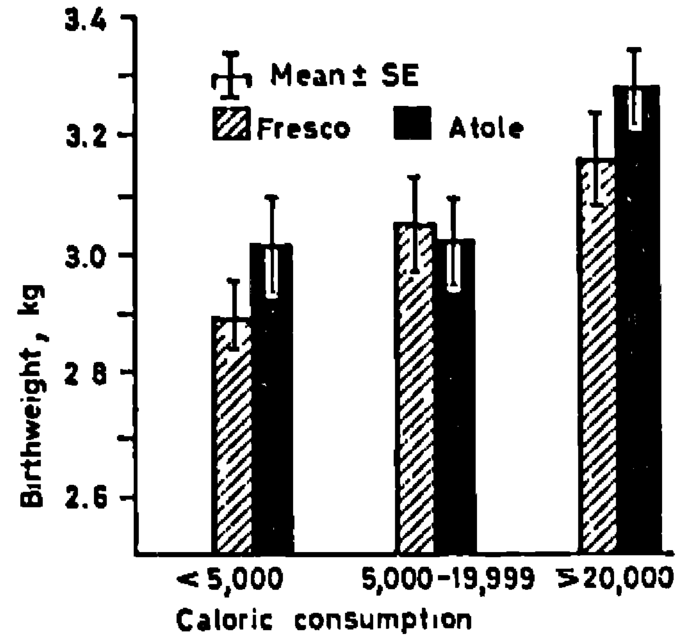

Fig. 2. Birth weight versus maternal caloric consumption from 'atole' or 'fresco' 288 pregnancies in four Guatemalan villages [from HABICHT *et al.*, 4].

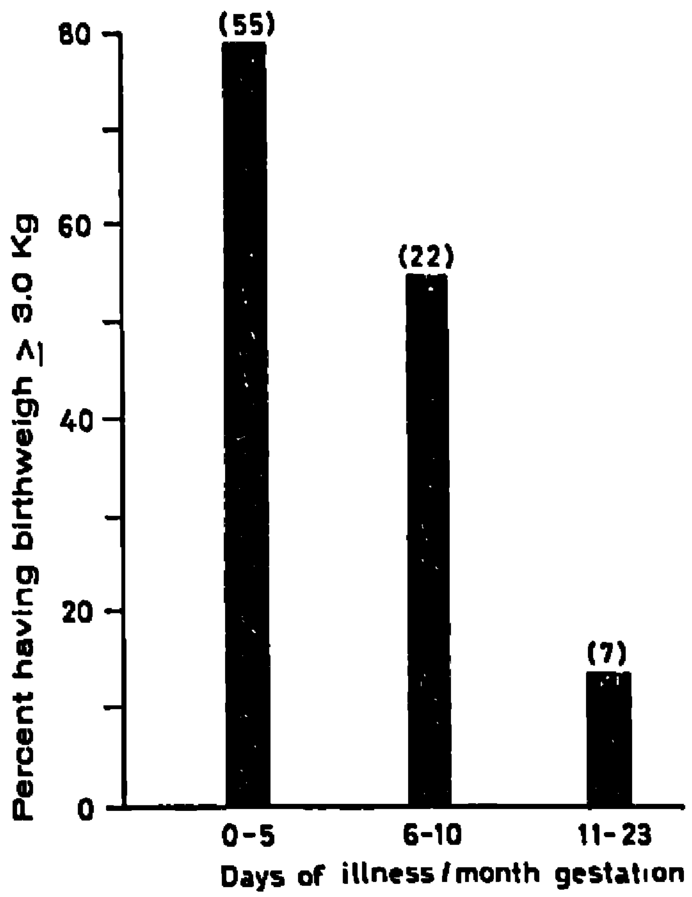

Fig. 3. Maternal morbidity and fetal growth in four Guatemalan villages [from LECHTIG *et al.*, 6].

during pregnancy, interval between deliveries, and socio-economic status. Furthermore, the contribution of supplement calorie consumption far outweighed the birth weight differences associated with variations in home diet, except for those women with very low home food consumption. Regression analysis of the birth weights versus maternal caloric consumption indicated that birth weight was increased 50 g/10,000 calories of supplement consumed during pregnancy.

During the course of this study there have been a few mothers who did not participate well in supplementation efforts during a first pregnancy but who did participate during a second [7]. Nine such women consumed more than 20,000 calories during the second pregnancy; the birth weights from the second pregnancy were 0.4 kg greater than the first infant. A comparable group of women who did not participate well during either pregnancy had second babies on the average the same or slightly smaller than the first.

During the first year of the Guatemala study, participation of the mothers was much lower. Data for women who did not participate well in the supplementation program have been analyzed in terms of maternal illness and birth weight [6]. The group comprised 70% of all pregnancies in the villages during 1970. The number of days of illness and severity of illness were recorded and home dietary surveys were conducted quarterly. As seen in figure 3, an inverse relationship was found between days of illness per month and birth weight. A small subsample was followed longitudinally in detail. In these cases the mother's dietary intake decreased by approximately 400 calories daily during illness. Correcting the birth weights for this difference in maternal diet suggested that the impact of maternal illness was mediated through changes in nutrient intake.

Other investigators have noted a correlation between maternal height and weight at the beginning of pregnancy and birth weight, presumably as indices of prior nutritional status and of available maternal reserves, respectively. This relationship has been found true in the Guatemala study when caloric intake was held constant. However, there was no difference in height or weight between the three caloric consumption levels, so that these factors do not explain the observed differences in birth weight. Surprisingly there was a slight increase in numbers of days of illness per month and a shorter interval between successive births in the high-caloric group. The women who consumed more calories also had poorer home diets. These observations plus others on the sociological level indicate that the women who drank more supplement came from a lower socio-economic strata where nutritional status was somewhat lower and potential benefits from the supplement somewhat greater. This benefit is borne out in the increased birth size attributable to increased supplement consumption, even in the face of other adverse high-risk conditions.

To what extent does all of this contribute to the outcome of pregnancy? Answers to this question still lie in the future of this study. However, some possibilities may be identified.

It has already been noted that, among the 288 pregnant mothers separated into groups according to calorie consumption, there was a significant decrease in the proportion of birth weights below 2.5 kg as calorie consumption increased. At the same time, there were fewer premature infants. Whether these benefits carry over to infant mortality is not yet proven. The data in table II are highly suggestive, however, that increased maternal calorie consumption decreased subsequent infant mortality at least for full term infants [8]. Another way to consider this question is to compare infant mortality in these villages with comparable data from Guatemala and representative other countries. During the first few years of this study, infant mortality dropped in the villages compared to Guatemalan national figures, particularly for survival of newborns (table III). A more extensive study of this phenomenon is now underway to identify the major contributions of maternal nutrition versus other factors.

Although limited in number, these data gain added importance when the results of the Montreal Diet Dispensary Study [9] are recalled. This study involved 1,636 women living under poverty conditions in Montreal. All had borne premature or babies with low birth weight previously. Upon

Table II. Relationship of infant mortality to maternal supplementation during pregnancy [8]

Supplement calorie consumption	Children born[1]	Deaths	Infant mortality per 1,000 births
<5,000	71	4	56
5,000–19,999	74	4	54
>20,000	85	2	24

1 Full term: born January 1, 1969 – October 27, 1971.

referral to a dietary clinic they were instructed concerning desirable food intakes and were given specific additional foods. It was estimated that the average daily intake was increased by 524 calories and 32 g of protein. The unsupplemented group also increased their intake during pregnancy, but not nearly so much: 293 calories and 16 g of protein per day. Among the supplemented women, premature births (live-born over 500 g) dropped from 9.0 to 6.7 per 1000; neonatal mortality declined from 19.7 to 14.9 per 1000 live births. Although the study population contained a high percentage of teenage and high-risk women, the rates achieved were comparable to those obtained from more affluent populations treated by private practitioners. As in other studies, the birth weight was correlated with weight before pregnancy. More importantly, however, the more the weight gain and longer the participation in the study, the greater the increase in birth weight.

And what about the outcome for the Guatemala mothers? In these villages, maternal weight gain during pregnancy was a function of supplementary calorie consumption from supplement. As may be seen in figure 4, maternal weight gain in turn influenced weight loss during lactation and the duration of lactation [10]. This suggests that the better nourished mothers lactated longer. Inasmuch as breast milk is the major source of protein for the infant, premature termination of lactation would be expected to have adverse effects on growth. This has, in fact, been demonstrated for the Guatemalan village populations. Preliminary analysis of the data further suggests that protein supplementation during lactation, and perhaps even during pregnancy, was more important than calories in terms of infant growth. This is consistent with the concept that the lactating mother con-

Table III. Neonatal, infant and preschool mortality in Guatemala compared to other countries, rate/1,000/year

	Guatemala national	Guatemalan study villages		Holland	USA
		1964–1969	1970–1971[1]		
Births	43.3[2]	–	49.0	14.8[3]	17.5[3]
Neonatal deaths, 28 days	33.9	48.7	16.0	–	–
Infant deaths, 0–11 months	97.1	104.0	48.0	12.9[3]	22.4[3]
Preschool deaths, 0–7 years	–	183	72.0	–	–

1 After introduction of nutritional supplement and health care program.
2 1968.
3 1967.

centrates protein into breast milk, drawing either upon her body stores at the time of delivery or on exogenous dietary sources during lactation.

In another study done by CHAVEZ *et al.* [11] in Mexico, some very provocative findings have been obtained in terms of infant development following supplementation during pregnancy and lactation. Data have been obtained from 36 children living under normal but low socio-economic conditions in rural Mexico. 19 of these children were born to mothers who were given food supplements from the 45th day of pregnancy on through lactation; the children themselves also were supplemented. By 12 months of age the physical activity of the supplemented children was significantly greater than for nonsupplemented. A 6-fold difference was observed at 2 years of age. This relation between malnutrition and inactivity has also been quantified in Uganda by RUTISHAUSER and WHITEHEAD [12]. Using an observational technique they found that rehabilitated, previously malnourished Ugandan preschool children (age 1½–3 years) engaged significantly more in standing and sitting and significantly less in play activities such as running, jumping, etc., than did same-age well-nourished European children. Surprisingly, during the 6-month period of study, increments in height and weight were equal in the two groups even though calorie intakes among the Ugandan youngsters were as much as 30% below recommended levels. These authors

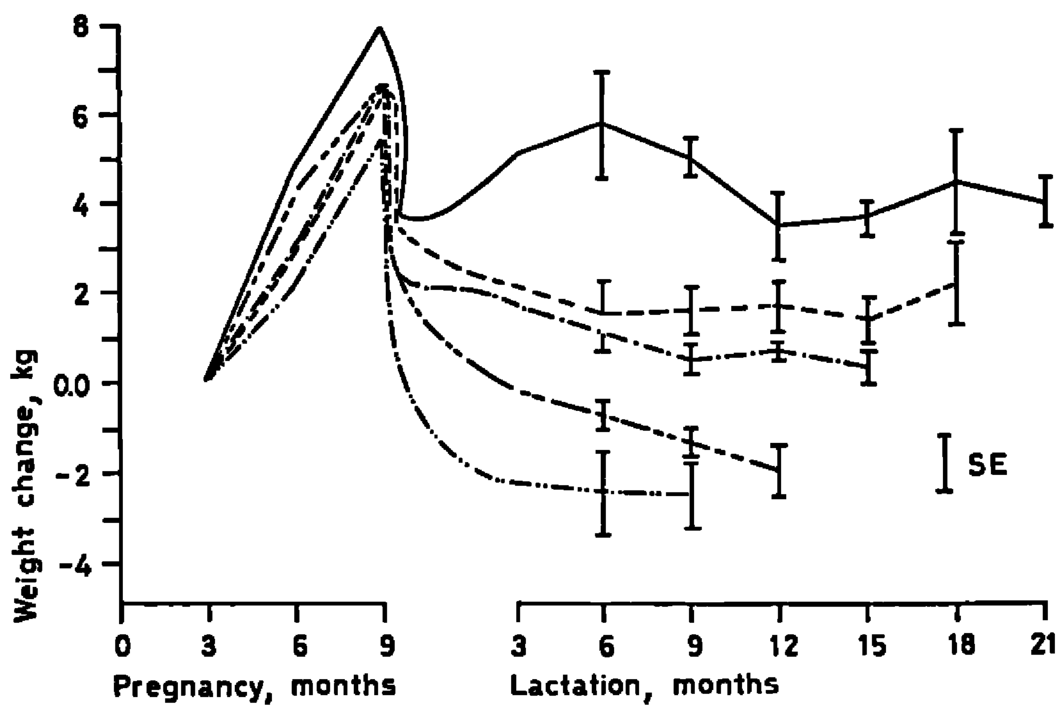

Fig. 4. Weight changes in women during pregnancy and lactation.

suggest that the limited calorie intake of the undernourished children preferentially was utilized for growth rather than for energy-demanding play. Both the Mexican and the Ugandan researchers have further pointed out that such a low level of activity would be expected to elicit less response from the mother, in turn contributing to retarded behavioral development as well as contributing to worsened nutritional status.

It is pertinent to note here that GRAVES [13] has explored mother-infant interactions in malnourished children in West Bengal and Nepal. She also reports that the well-nourished child was more active than the malnourished one, particularly for boys. Furthermore, the maternal response was greater for well-nourished children, both from the viewpoint of mother-initiated and infant-initiated interactions. Significant differences were not seen in these parameters during the first 6–8 months of age; progressively more significant differences were seen up to 18 months of age. Interestingly enough, no differences in infant cognitive development were obtained at these ages. Whether this reflects the difficulty of assessing mental development at these young ages or indicates that intellectual changes due to malnutrition in infancy do not develop until later in life is not clear.

It is still too early to assess mental development of the Guatemalan children born to mothers who were followed from pregnancy onward. It is apparent from studies with older children in these villages that supplementation can influence the rate of weight gain at all ages [14]. Comparable psychological data have not yet been analyzed. However, a portion of the 3- to 7-year-old data have been examined and a correlation found between physical growth (as an index of nutrition) and certain psychological variables [15]. In particular, the poorly nourished children did less well on those tests involving a high level of attentional involvement. In the Knox Cube Test, for instance, performance was poorer when the tapping rate was increased thereby calling for a greater level of mental involvement.

Time does not permit us to review the extensive literature on malnutrition and mental development. However, in closing this review, it might be well to summarize current conclusions and speculations [1, 16, 17]. Available data indicate that severe malnutrition during pregnancy and/or infancy significantly decreases the number of brain cells in animals and man. Similar levels of malnutrition are accompanied by behavioral change in animals and possibly in man; the 'failure-to-thrive' child is representative of the type of malnutrition meant here. The permanence or irreversibility of any behavior change in severely malnourished children is still open to question. Effects of mild to moderate malnutrition on behavior or neurological development are less well established, particularly in man where other environmental changes frequently accompany malnutrition. Accumulating evidence suggest that these environmental factors may be equally important in terms of mental development and behavioral change.

The interaction between nutrition and other stresses should be constantly viewed from the perspective of the life cycle. An undernourished mother probably will give birth to an infant with low birth weight at high risk of failure. Raised under poor nutritional and hygienic conditions, this child will not develop to its full potential. Sexual maturation may be delayed and the females may reach the reproductive period with low body reserves at the outset of pregnancy. Several animal studies suggest that these effects may be cumulative over successive generations. Furthermore, two or more generations of rehabilitation may be necessary to overcome the behavioral deficits in animals.

Obviously nutrition is an important part of medical practice. This is particularly true in terms of pregnant and lactating women, young children, and the adolescent in the final formative stages for parenthood. Good nutrition, as a central component of preventive medical care, can help assure that each child enters life with a real chance to achieve his innate potential.

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