Early Malnutrition, Growth, and Development

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A large segment of the world population lives on deficient protein-energy intakes and suffers from physical growth retardation, low psychological test performance, and a high prevalence of infant and preschool age mortality. To ascertain the extent to which these events are causally related, the available data on the relationship between early malnutrition and physical growth should be explored, and the implications of early malnutrition and growth retardation for mortality and mental development of the offspring should be analyzed.

In the following discussion, early malnutrition includes protein-energy malnutrition (PEM) during intrauterine life, breastfeeding, weaning, and postweaning periods up to the first 5 years of age. Thus it includes children of mothers malnourished during pregnancy and lactation as well as those malnourished during the weaning period and preschool years. The discussion focuses mostly on data from major intervention studies: Bogota (1), Guatemala (2), India (3), Mexico (4), Montreal (5), New York (6), Taiwan (7,8), and the Dutch famine study (9). Although emphasis is put on the integration of existent knowledge, the implications for current action programs are also reviewed.

EARLY MALNUTRITION AND PHYSICAL GROWTH

To explore the effects of early malnutrition on growth requires a better understanding of the nature of the variables used to measure prevalence and incidence of malnutrition. Data in Table 1 indicate that the risk of delivering a low birthweight (LBW) baby (below 2.5 kg) is three times higher in developing than in developed countries. Data in Table 2 clearly show that the risk of physical growth retardation as measured in terms of weight for age (categories II and III of the Gomez classification) during preschool age is 40 times higher in developing countries than in developed nations. Because of this increased risk, developing countries contribute 95 and 99% of all the growth retardation observed at birth and at 5 years of age, respectively, in the world. Further analysis suggests an association between per caput gross national product and energy available per caput per day with physical growth retardation at birth and at 5 years of age (12).

There seems to be a general pattern of physical growth retardation in poor populations, which usually begins during fetal life. In low income rural populations, where duration of breastfeeding averages more than 12 months, the prevalence of
TABLE 1. Estimated number of LBW babies born during 1980

<table>
<thead>
<tr>
<th>Degree of development</th>
<th>Populationb (millions)</th>
<th>No. of birthsc (millions)</th>
<th>LBW babiesc (%)</th>
<th>No. (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing countries</td>
<td>3,314 (75.6%)</td>
<td>109.0 (86.6%)</td>
<td>19.0</td>
<td>20.71 (95%)</td>
</tr>
<tr>
<td>Developed countries</td>
<td>1,068 (24.4%)</td>
<td>16.8 (13.4%)</td>
<td>6.8</td>
<td>1.14 (5%)</td>
</tr>
<tr>
<td>Total:</td>
<td>4,382 (100.0%)</td>
<td>125.8 (100.0%)</td>
<td>17.4</td>
<td>21.85 (100.0%)</td>
</tr>
</tbody>
</table>

aLBW, ≤2.5 kg.
bWorld Development Report (10).
cLechtig and Klein (11).

TABLE 2. Estimated number of children less than 5 years of age with moderate or severe deficit in weight for age during 1980

<table>
<thead>
<tr>
<th>Degree of development</th>
<th>No. of children less than 5 years of age (millions)b</th>
<th>Percentage with moderate or severe deficit in weight for age</th>
<th>No. of children malnourished (millions)c</th>
<th>Deaths under 5 years of agec,d</th>
<th>%</th>
<th>No. (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing countries</td>
<td>499 (86.2%)</td>
<td>28.0</td>
<td>139.7 (99.6%)</td>
<td>3.5</td>
<td>17.2 (98.3%)</td>
<td></td>
</tr>
<tr>
<td>Developed countries</td>
<td>85 (13.8%)</td>
<td>0.7</td>
<td>0.6 (0.4%)</td>
<td>0.3</td>
<td>0.3 (1.7%)</td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td>584 (100.0%)</td>
<td>24.0</td>
<td>140.3 (100.0%)</td>
<td>17.5</td>
<td>17.5 (100.0%)</td>
<td></td>
</tr>
</tbody>
</table>

aDefined by a deficit greater than 25% in weight for age (Gomez II and III).
bWorld Development Report (10).
cLechtig and Klein (11).

growth retardation increases between the third and seventh month of age and continues to increase up to the third or fourth year. In poor urban populations, where the prevalence of early weaning has been steadily increasing during the last two decades, the situation is worse: prevalence of growth retardation increases from the first month of age. Later, in those children surviving after 4 years of age, it is common to find proportionally stunted individuals, in other words, children with normal weight for height but low height for age and, therefore, low weight for age.

Effect of Early Malnutrition on Prenatal Growth

Results of recent intervention studies suggest an effect of maternal nutrition during pregnancy on fetal growth as measured by birthweight (2,13). In Bogota,
the increment was 77 g for those mothers supplemented during more than one trimester. In Guatemala, the average increment was 111 g in the well-supplemented groups. In India and Mexico, the mean increments were 298 and 180 g, respectively, while in Montreal, it was 41 g. In New York, an increment of 41 g was observed only in the group receiving the low-protein beverage (complement), while a decrement of 32 g was found in the group receiving the high-protein beverage (supplement). In the same study (New York), the expected decrease in birthweight due to heavy smoking was not observed, probably because the food supplementation overcame the decrease in birthweight produced by smoking. In Taiwan, the increment in birthweight was 100 g when newborns of women consuming more than 50% of the supplement were compared with the control group. Finally, in the Dutch famine study, the mean birthweight decreased 298 g from the prefamine levels before increasing 271 g when diet improved. All these studies reported changes in birthweight in the expected direction after the dietary modification, an impressive result given the variety of ethnic, cultural, and sociogeographic situations represented.

At least in five studies (Bogota, Guatemala, Montreal, New York, and the Dutch famine), the observed improvement in birthweight was greater in those women with poorer nutrition, as measured by lower weight for height (Bogota), lower prenatal weight (Montreal and New York), and rations below 1,500 kcal/day (Dutch famine). Data in Fig. 1 from the Guatemalan study indicate that the impact of food supplementation during pregnancy on birthweight was greater in mothers from the lower socioeconomic strata within the village and with lower height, results that add support for the nature of the relationship between the dietary changes and birthweight (14).

There remained the possibility in the Guatemalan study that mothers delivering heavier babies were those who also tended to collaborate more with the program. The sibling analysis presented in Fig. 2 explores the possibility that a constant maternal factor might be responsible for both the high consumption of food supplementation during pregnancy and heavier newborns. The figure shows that when caloric supplementation during the later pregnancy was lower than during the preceding pregnancy, the birthweight of the later babies was lower than that of the preceding ones. On the other hand, when caloric supplementation during the later pregnancy was more than 20,000 calories higher than during the preceding pregnancy, the later newborns were heavier than the preceding ones. Consequently, this analysis indicates a positive association between changes in caloric supplementation and changes in birthweight in consecutive pregnancies of the same mother ($r = 0.298$, $N = 94$, $p < 0.01$, $b = 22$ g birthweight per 10,000 supplemented calories). Data in Table 3 from sibling analyses performed with the extended sample followed up to 1977 indicate a similar result ($r = 0.111$, $N = 469$ pairs, $p < 0.01$, $b = 22$ g birthweight per 10,000 supplemented calories).

As expected, in Bogota, New York, and Taiwan, the changes in birthweight were not statistically significant ($p > 0.05$); these studies were not designed to detect changes of this magnitude and, therefore, sample sizes were inadequate. In all
FIG. 1. Influence of maternal height and caloric supplementation during pregnancy on the relationship between socioeconomic score and proportion of infants with LBW (□) low, (■) intermediate, (▲) high; number of cases in parentheses.

cases, failure to reject the null hypothesis was attributed to small numbers and not to unexpected direction of the results.

Estimates of the dose-response relationships expressed in grams of birthweight per 10,000 net supplemented calories during pregnancy (equivalent to 112 additional calories during the third trimester of pregnancy) are +41 g in Bogota, +41 g in Guatemala, +71 g in India, +36 g in Mexico, +28 g in New York (complement), +35 g in Taiwan, and +29 g in cohorts conceived and born after the famine in the Dutch study. In the latter study, the estimated dose-response relationship was +47 g per net increase of 10,000 calories during pregnancy. The dose-response values computed for Bogota, Guatemala, Mexico, and Taiwan (41, 41, 36, and 35 g, respectively), are consistent with the relatively similar nutritional conditions of these populations, as estimated by weight and height. The higher estimate for India (71 g) may be explained by the higher prevalence and severity of malnutrition in this sample and by decreased physical activity due to hospitalization of the supplemented group in order to perform the dietary intervention. The low value observed in New York (28 g) is not unexpected given the nutritional condition of this sample, the best among these studies.

Finally, the smaller range observed in the dose-response relationships as compared with the range of mean increments in birthweight (28–71 compared with
FIG. 2. Relationship between food supplementation and birthweight in consecutive pregnancies. A, 40,000–0 kcal; B, 100–20,000 kcal; C, 20,000–120,000 kcal. Number of pairs of pregnancies in parentheses. Difference between groups A and C, p<0.01. (From Lechtig et al., ref. 20.)

40–298 g, respectively) is also suggestive of the nutritional nature of the observed relationship between dietary modification and birthweight. The dose-response values observed in these studies (from 28 to 71 g of birthweight per 10,000 net supplemented calories during pregnancy) are similar to the dose-responses expected from: (a) the relationship between maternal weight gain during pregnancy and birthweight (28–80 g of birthweight per 10,000 kcal); (b) the relationship between differences in prepregnant weight and differences in birthweight between two consecutive pregnancies (25–40 g of birthweight per 10,000 kcal); (c) the relationship between food intake, body composition, and physical activity (36–84 g of birthweight per 10,000 kcal); (d) the available data from the Leningrad famine
TABLE 3. Correlation between supplemented calories during pregnancy and birthweight

<table>
<thead>
<tr>
<th>Sample</th>
<th>n</th>
<th>r</th>
<th>$b$ (g birthweight/10,000 supplemented calories)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All populations</td>
<td>905</td>
<td>0.092(^b)</td>
<td>18.6</td>
</tr>
<tr>
<td>Jan. 1969–Feb. 1973</td>
<td>387</td>
<td>0.132(^b)</td>
<td>26.6</td>
</tr>
<tr>
<td>Feb. 1973–Sept. 1977</td>
<td>548</td>
<td>0.053</td>
<td>11.1</td>
</tr>
<tr>
<td>Within siblings* pairs</td>
<td>469</td>
<td>0.111(^b)</td>
<td>22.2</td>
</tr>
</tbody>
</table>

*Correlation value between differences in caloric supplementation between both pregnancies and differences in birthweight between both babies: the latter minus the preceding sibling.

\(^b\)p < 0.05; \(\ddagger\)p < 0.01.

(−33 g of birthweight per net decrease of 10,000 kcal during pregnancy); and (e) the relationship between home diet and birthweight in white, middle class populations in the United States (33 g of birthweight per 10,000 additional kcal during pregnancy) (16).

Furthermore, if in the sample from the Indian study, home diet had increased to the recommended standards for pregnant women during the last two trimesters of pregnancy (from 1,800 to 2,200 kcal/day) at the dose-response computed for that population (71 g/10,000 net supplemented kcal during pregnancy), the average birthweight would have increased from 2.5 to 3.1 kg. In Guatemala, an increment of home diet up to the recommended standards during the last two trimesters of pregnancy (from 1,400 to 2,200) with the same dose-response relationship (41 g/10,000 net supplemented calories) would increase birthweight from 2.9 to 3.5 kg. Thus the effects of food supplementation on birthweight appear to be consistent with usual expectations. An unanswered issue is why these populations did not increase their intake up to the recommended levels of energy intake.

In Guatemala, mothers with high supplementary intakes had a net increment of about 140 kcal/day over the low supplement group (1,400 kcal/day). This represents only 20% of the gap in energy intake [expected requirement: 2,200 kcal/day (17)], and about 10% only of the home dietary intake. Obviously, this was not a typically hungry population. Indeed, low energy density was not the main factor of the unexpected low amount of supplement ingested during pregnancy. Two supplements (high protein-high energy in two villages, and no protein-low energy in the other two) were freely available and accessible at central places of distribution. Although large differences in energy intakes were observed in children between the two supplements, this was not the case in pregnant women in whom no significant differences in either net or total supplement intake were observed.

It was clear in the Dutch study that mothers with intakes below 1,500 kcal could easily increase their intake of energy up to the recommended level, which in this
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case was similar to levels observed before the famine. Under conditions of chronic malnutrition, however, this increment is narrow and does not reach recommended levels of intake. Therefore, the gap (recommended minus observed) is reduced in only 20 to 50% of individuals. It appears that the same adaptative mechanisms that allowed the mother-fetus diad to survive and develop new equilibrium points at lower levels of energy intake: in other words, lower energy requirements.

Evidence in this direction has been recently presented by Sukhatme and Margen (18). The same mechanisms, perpetuated through generations would limit the ability of chronically malnourished women to rapidly increase their usual intake up to current recommended levels. The practical implication of this hypothesis is not that current recommendations are too high but that it may take several decades or a generation to increase the dietary intake of chronically malnourished pregnant women up to the recommended levels currently ingested by middle class women in developed countries. In other words, it may become unrealistic in terms of consumption to set intake objectives for chronically malnourished populations based on current dietary energy recommendations. Similarly, it may take several decades of nutritional improvement to reach fetal growth standards similar to those accepted in developed countries.

When computed in the same way, the expected dose-response relationships in infants are 134, 55, and 34 g per 1,000 net supplemented calories during the first, second, and third year of age, respectively. Thus the magnitude of the effect of food supplementation during pregnancy on birthweight (28–71 g) is not small when compared to the expected effect of diet on infant weight during the years of most rapid physical growth. Weight gain in the mother during pregnancy is notably smaller in chronically malnourished populations than in well-nourished ones. It is not infrequent to find an average weight gain of 6 to 7 kg in the former compared with 10 to 12 kg in the latter populations (10).

When estimates of dose-response relationships are made in terms of total maternal weight gain, the resultant figures indicate high efficiency rates. Except for Taiwan, all reviewed longitudinal studies (Bogota, Guatemala, India, Mexico, Montreal, New York, and Dutch famine) showed an increment in weight gain during pregnancy associated with nutritional supplementation. In Guatemala, for 10,000 net supplemented calories during pregnancy, 1.008 kg of maternal weight gain was deposited. Of this increased maternal weight gain, 41 g corresponded to increased birthweight (19). Thus the estimated efficiency of supplemented calories was about 60%, of which 3% was increase in birthweight and 97% was maternal and related fetal tissue (16). The relationship between maternal weight gain and birthweight (41 g of birthweight per kilogram of maternal weight gain) was close to the maximum values expected for the mean prepregnant weight of the study population, which was 46.7 kg (expected range: 36–42 g of birthweight per kilogram of weight gain during pregnancy for prepregnant weight of 45.8–49.8 kg) (20).

The same dose-response relationship may have different public health implications, depending on the birthweight distribution and the net amount of supplemented
calories during pregnancy (16). In Guatemala, for example, the proportion of LBW babies decreased from 33% in a small sample at the beginning of the study to 13% at the end of the intervention. This reduction in LBW babies may be larger in populations in which the proportion of LBW babies is 40%, as in Mayan Indian populations, and very low if the proportion of LBW babies is around 7%, as in white, middle class populations of the United States.

Influence of Sex on Response of Birthweight to Dietary Change

In three studies (India, Mexico, and Montreal), there were no published data on the influence of sex of the newborn on the response of birthweight to dietary change. The New York study reported no clear sex differences, while the Bogota, Guatemala, and Taiwan studies presented data suggesting that the effect of dietary improvement is greater in males than in females. In the Bogota study, supplemented mothers who delivered male newborns gained more weight during pregnancy and had a greater dietary intake than those who delivered female newborns. In the same study, however, the influence of sex was not observed in the unsupplemented group. Finally, in the Dutch famine study, it was observed that birthweight was greater in males than in females during the famine period. In conclusion, there is some evidence that males may benefit more from prenatal supplementation. The best explanation is that the male fetus grows more rapidly in late pregnancy and therefore is more likely to be vulnerable to shortages of food supply and to benefit from extra food.

Timing of Food Supplementation During Pregnancy

In all these studies, nutritional intervention during the last trimester was sufficient to produce the observed effect in birthweight. In the Dutch study, the effects of famine on fetal growth occurred only in those women exposed in late pregnancy and not in those exposed during the first two trimesters, a finding consistent with the rapid increase in fetal weight during the last trimester. This is also in agreement with the observation that large variations in fetal weight between developed and developing countries do not exist before 36 weeks of gestational age (see Falkner, this volume). Therefore, additional food provided at least during the third trimester of pregnancy can improve birthweight.

Data from Guatemala suggest that the total amount of food supplement consumed during pregnancy is a more important factor than the gestational age at which supplementation is begun. In this context, the information available indicates that mothers with high subcutaneous fat, as measured by tricipital skinfold, had heavier and fatter newborns than mothers with low subcutaneous fat (3,667 versus 3,420 g in males and 3,491 versus 3,338 g in females, respectively), other conditions being equal. At the same time, mothers with high muscle area, as measured by arm circumference corrected by tricipital skinfold, had heavier, leaner, and longer newborns than mothers with low muscle area (3,667 versus 3,322 g in males and 3,492 versus 3,211 g in females, respectively) (21). Thus the observation that
indicators of maternal energy and protein mass are positively related to birthweight provides additional support to the hypothesis that maternal "reserves" may be used to some extent for fetal growth.

**Maternal Nutrition Threshold**

A clear association has been observed between energy intake and birthweight below 1,800 kcal/day. As a consequence, the probability of detecting an effect on birthweight in populations with chronic malnutrition will increase, the lower the home diet intake is below 1,800 kcal/day and the higher the net increase in nutrient intake achieved by the program. When famine occurs in a previously well-nourished population, maternal stores will help to adapt to the shortage in energy intake; therefore, the threshold would be lower, around 1,500 kcal/day, as suggested by the Dutch study.

A related question refers to the ability of these populations to survive under chronically energy-restricted diets. In developing countries, it is usual to find women populations with average energy intakes during pregnancy within the range of 1,400 to 1,800 kcal. Despite this intake being at least 700 kcal below the commonly accepted energy requirements (17), it is usually able to protect the prepregnancy weight against a steady decrease. Thus in Guatemala, pregnant women with an average daily intake of 1,500 kcal had a mean prepregnant weight of 47 kg and mean weight gain of 6 kg during pregnancy. They delivered babies with a mean birthweight of 2.9 kg, with a rate of LBW babies around 20% (16). The usual values for well-nourished populations are 64, 12, and 3.3 kg, and 7%, respectively (10).

Increased efficiency of utilization of dietary energy from an average of 37% to upper levels of 55% could also play a key role in this adaptive process (18). Thus if other conditions are equal, two populations may have similar pregnancy outcomes with grossly different mean dietary intakes (i.e., 2,500 and 2,000 kcal) if they develop proportionally improved efficiency rates to use dietary energy. Therefore, it appears that in these chronically malnourished populations, survival is achieved at the price of low prepregnancy weight. However, this ability of the reproductive process to adapt to chronic energy restriction, remarkable as it is, should not serve as an excuse for public health inaction. When the limits of this capacity for homeostasis are exceeded, because of either lower intake or greater expenditure (increased physical activity or infectious disease during pregnancy), the adaptative balance achieved may disappear and acute malnutrition may occur. The implication is that thresholds, as requirements, are probably of a dynamic nature and not fixed conditions, since equilibrium may be achieved at different levels of intake (18).

**Effects on Other Parameters of Prenatal Growth**

The Dutch famine study reported an effect of prenatal famine exposure during the third trimester of pregnancy on infant length and head circumference at birth. Except for this study, no information is available on the effect of maternal food
supplementation on other anthropometric parameters besides birthweight. Birthweight was the main outcome investigated because of its known relationship with infant mortality and because measurement error was lower than for circumference, skinfold, length, and length/weight ratio. Information on the effect of maternal malnutrition on other anthropometric measurements may shed light on the nature of fetal growth affected by maternal nutrition and on the predictivity of parameters of fetal growth on later outcomes in childhood. For example, data in Table 4 from a recent study in Guatemala clearly indicate that a low arm circumference at birth (less than 9.0 cm) has equal or better value than low birthweight (<2.5 kg) to predict mortality during the first 15 days of life (22).

**Stability of the Long-Term Impact of Improved Maternal Nutrition on Birthweight**

Little is known of the long-term stability of the food supplementation effects. Data in Table 4 from the Guatemalan study suggest that the impact of supplementation per additional calorie decreased as the intervention continued over a period of 9 years. Although no clear explanation is available, the observation does not appear to be produced by a systematic decrease in measurement reliability; indeed, it may be related to the inhibition of adaptive mechanisms.

The study population had chronic moderate malnutrition, which gradually developed adaptative mechanisms resulting in survival at lower levels of energy intake. In other words, this population increased its efficiency to use energy, the main limiting nutrient in dietary intake. The nutritional intervention increased energy intake, which was reflected in improved growth and other functions with a relatively high level of efficiency due to the adaptative mechanisms mentioned before. Over several years, however, nutritional improvement gradually became a routine component of dietary intake. In some way, this routine provision of supplementary food inhibited some of the mechanisms that had protected essential living functions over

<table>
<thead>
<tr>
<th>Arm perimeter</th>
<th>Early death (0–15 days)</th>
<th>Alive at 15 days</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low birthweight (&lt;2.5 kg)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (&lt;9.0 cm)</td>
<td>25</td>
<td>238</td>
<td>263</td>
</tr>
<tr>
<td>High (≥9.0 cm)</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>243</td>
<td>268</td>
</tr>
<tr>
<td><strong>High birthweight (≥2.5 kg)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (&lt;9.0 cm)</td>
<td>2</td>
<td>90</td>
<td>92</td>
</tr>
<tr>
<td>High (≥9.0 cm)</td>
<td>0</td>
<td>370</td>
<td>370</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>460</td>
<td>462</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>27</td>
<td>703</td>
<td>730</td>
</tr>
</tbody>
</table>
decades of chronic nutritional deprivation. The final result was a decline in the efficiency of using the additional energy for growth, as measured by dose-response estimates. Independent of the mechanisms responsible for the apparent diminished impact, these data provide additional support to the recommendation that food supplementation programs be implemented as short-term interventions dealing with acute, emergency situations. As soon as possible, they should gradually be replaced by long-lasting interventions aimed at increasing food purchasing power, food availability, nutrition education, and self-sufficiency at the family level.

**Implications of LBW for Postnatal Growth**

Studies on long-term effects of intrauterine growth retardation (IUGR) indicate different degrees of recovery when the environment is favorable in terms of food and sanitation, a finding explained by the existence of different types of IUGR infants. These infants with adequate weight for their shorter height or stunted babies show a trend to remain shorter and lighter during the first years after birth (23–25), suggesting that height has a lower probability for recovery than does weight. In contrast, “wasted” IUGR infants (with low weight for their height) may be able to recover by gaining weight during the first months after birth. Thus under appropriate nutritional conditions, postnatal growth tends to stabilize the relationship between weight and height. Similar to postnatal growth retardation, IUGR represents a mixture of different conditions depending on the onset, duration, and severity of the nutritional deprivation during pregnancy (25). These factors are important to determine the prognosis in terms of physical growth and functional outcomes and the most appropriate type of nutritional and health interventions.

In populations with chronic moderate malnutrition, about two-thirds of the LBW babies are babies with low weight for gestational age. Of these babies, two-thirds show proportionate body size. In other words, about one-half of the LBW babies are stunted infants, with high probability of long-term growth retardation. Despite compensatory mechanisms resulting in higher growth rates than normals, most tend to remain below the 10th percentile of the international standards for weight and height up to 3 years of age (26–28). In contrast, in populations suffering in famine, where most LBW babies are wasted, there is a greater probability of compensation if appropriate nutritional programs are implemented after birth.

**Early Malnutrition and Postnatal Growth**

A positive impact of food supplementation on physical growth of the offspring has been observed in studies in Bogota, Guatemala, and Mexico. However, differentiation between the relative importance of prenatal versus postnatal maternal supplementation has proved difficult. No effect of supplementation during pregnancy on postnatal physical growth was detected in the New York study, where data suggest that there was no severe PEM. No data on this question are available from the studies from India, Montreal, and Taiwan. Finally, in the Dutch study, a small excess in frequency of obesity was reported in males born to women exposed
to famine early in pregnancy. On the contrary, severe nutritional deprivation in the latter part of pregnancy and the first few months of life led to a lower rate of obesity. In Colombia, the investigators reported an effect of supplementation on weight and height, beginning at between 3 and 6 months and continuing up to 36 months of age. The prevalence of severe physical growth retardation at 36 months of age, as measured by adequacy of weight for age (Gomez II and III), was reduced from 20.6 to 8.8%, with a corresponding increment in category I and normals. Similar changes were observed in terms of height for age: the proportion of children with adequacy of less than 90% decreased from 54.0 to 39.7%.

Data from the Guatemalan study indicate that the proportion of children with physical growth retardation in weight, height, and head circumference at 1 year of age was lower at the end (1976) than at the beginning (1969) of the program.

A supplementary intake was clearly associated with better growth in height and weight up to the first 5 years of life (29). No clear trends were detected in arm and calf circumferences. All skinfold measures (triceps, subscapular, and medium calf) decreased with increased supplementation, mainly due to the increment in height and length of the extremities. These data also suggest that height and weight may be useful indicators of the effect of nutritional intervention in children up to 5 years of age. Head circumference may be a useful indicator of nutritional impact, particularly during the first year of life, even better than weight or height.

It is clear from the above longitudinal studies that food supplementation of malnourished and lactating mothers and their offspring resulted in significant increases in rate of growth in terms of weight, height, and head circumference during fetal and postnatal life up to the first 3 to 5 years of age. This effect was also reflected in important reductions in the prevalence of children with severe malnutrition (II and III as measured by Gomez) (weight for age), as well as in the prevalence of less than 90% of adequacy in height for age. Notwithstanding the validity of these effects, the increments observed represent only one-third to one-half of the difference between the control groups and samples from high socioeconomic strata in the same countries or according to international growth standards. This modest impact of well-conducted nutritional programs could be explained by the high rate of substitution of home dietary intake (probably including breast milk) by the food supplements. In many food supplementation programs carried out in chronically malnourished populations, this replacement is about one-half or more of the supplemented energy intake. Estimations made during pregnancy suggest that if all the differential in energy intake could be fulfilled, most of the gap in birthweight could be covered. The inference with respect to postnatal growth, however, is different. In Bogota and Guatemala, where total nutrient intake was estimated, the supplements fulfilled two-thirds of the differential in energy intake and all the differential in protein intake, but only one-third of the gap in postnatal growth was filled.

The best explanation for this observation is the high incidence of common infectious diseases of mild to moderate severity, particularly diarrhea. In Guatemala, it was found that 10% of the retardation in growth was associated with
diarrheal disease (30). Further analysis of these data suggest that this figure was conservative, the real effect of diarrhea being about 30% or more of the gap in physical growth. Much of the nutritional impact of diarrhea is mediated through decreased dietary intake in mothers and children (31,32). In children, the presence of these infectious episodes is associated with a decrement of 19% of the dietary intake, or about 175 kcal and 4.8 g of protein per day. When the prevalence of these clinical infections is taken into account, this figure represents at least one-fifth of the mean energy deficit for the same population (33). In pregnant mothers, infectious diseases account for a decrease of about 400 kcal/day, or 25% of usual dietary intake (31). Other mechanisms of the impact of infections on growth are related to food utilization and include vomiting, malabsorption, and unfavorable metabolic effects (34,35). These common infections are important causes of the growth deficit observed in low income populations. Their prevention and treatment should be considered in all programs aimed at improving nutrition.

The IUGR and ethnic differences among groups could also contribute to the modest impact of nutritional programs. As mentioned before, stunted IUGR babies show a trend toward long-term growth retardation, despite appropriate postnatal nutrition and health care. On the other hand, ethnic differences in the growth of preschool children have been reported. In a recent study, children of African and European descent were heavier and taller than Chinese and Indian children. African children were also of greater weight for height than Indian children (36). The conclusion is that although most of the differences in size at preschool age is attributable to malnutrition and infection, the contribution of ethnic differences may become increasingly important as nutrition and general health conditions improve.

The practical implication of the above findings is that food supplementation programs may have a greater impact on physical growth when they are integrated with the following:

1. Primary health care programs aimed at preventing and treating common infections, including immunizations, environmental sanitation, and oral rehydration treatment for diarrhea;
2. Effective promotion of breastfeeding, protection against early weaning, and appropriate weaning practices;
3. Nutrition and health promotion programs, including monitoring of physical growth to decrease home diet substitution and improved food utilization and distribution within the family;
4. Increased self-sufficiency in food availability at the family level.

Early Malnutrition and Permanent Stunting

There are indications that suboptimal nutrition during early life can lead to permanent stunting. Adult populations who suffer from early PEM are consistently shorter and lighter, suggesting long-term stunting as a consequence of early malnutrition (14). The difference of 12 cm at 7 years of age between Guatemalan girls
from poor rural villages and middle class girls from the United States is similar to that observed between adult women from both population groups (14). Data from Indian populations indicate that girls who were severely malnourished at preschool age grew faster in height than the standards after 5 years of age (37). However, the difference in weight did not disappear; it went from 20.1 cm at 5 years to 15.3 cm at 18 years of age.

The most important compensatory mechanism reported in populations with chronic malnutrition is the delay of 1 to 2 years in the onset of menarche in girls and about 3 years in the onset of sexual maturation in boys (38-40). As a consequence, the delayed pubertal growth spurt and epiphyseal fusion allow for a longer period of higher rate of growth in the malnourished girls and boys. Nevertheless, most of the growth retardation observed at 7 years of age in chronically malnourished children seems to persist up to adult age, making stunting the most commonly detectable effect of early malnutrition. When stunting is not accompanied by wasting, there may not be current malnutrition but only a long-term effect or a sequela of early malnutrition.

There are indications that permanent stunting could occur across generations. In Guatemala, parent-child correlations in attained height were similar to those reported for well-nourished populations, a finding explained through similarities in environmental conditions. Thus parents who suffered early malnutrition and infection are likely to have offspring with similar problems (41). In girls, permanent stunting is reflected in shorter mothers with higher risk of delivering IUGR babies, thus perpetuating stunting through generations (42). As a consequence, generational stunting may be the result not only of parent-child similarities in environmental conditions but also of biological mechanisms operating at least during pregnancy.

It should be noted that adult stunting may increase the probability of surviving and carrying out physical work with lower dietary intake because of smaller body size. The available data also indicate smaller differences in life expectancy after 7 years of age between developing and developed countries and between high and low socioeconomic strata within the same country, despite large differences in availability of health services among the compared groups. Consequently, the main goal from a public health point of view must be to eradicate physical growth retardation not for the sake of bettering growth in itself but because growth retardation is associated with morbidity, mortality, and suboptimal mental development in present and future generations. It should be remembered when combating early malnutrition that disease and suboptimal development are associated also with overnutrition. There may exist an optimal zone between these two extremes, and there may be variations across populations in the location of this optimal zone.

**Energy or Protein**

Another important question is whether the addition of energy or protein is associated with the increase in growth rate. In India, there was no additional effect
Early Malnutrition

The effect of the high-protein-energy supplement was similar to the energy supplement in terms of birthweight, placenta weight, and postnatal growth in weight and height (16,20,29,44,45). In New York, the high-protein supplement did not produce an effect on birthweight.

In Bogota, Guatemala, India, Mexico, Taiwan, and the Netherlands during the famine, the average home energy intake during pregnancy (1,400–2,000 kcal/day) was below requirements (about 2,200 kcal/day) and provided a small margin for physical activity. In contrast, with the exception of Bogota, mean protein intake (43–80 g/day) was usually similar or higher than that required for maintenance and tissue synthesis (about 54 g/day). Thus analysis of the dietary data in these populations showed that energy rather than protein was the main limiting nutrient in mothers and children. Under conditions of energy limitation observed in Guatemala, a daily net supplementation of 200 kcal during the last trimester of pregnancy with no additional protein would increase the daily retention of nitrogen and produce a corresponding increment in birthweight (from 72 to 168 g) in addition to the associated increment in weight gain during pregnancy. Under these conditions, a very large increment of protein intake would be required to produce a similar increment in nitrogen retention and birthweight. Results from Guatemala on the relationship between food supplementation and urea/creatinine ratio in the urine in lactating mothers and their breastfed babies support this hypothesis (13).

This conclusion is also corroborated by analysis of postnatal growth suggesting adequacy of protein and deficiency of energy in preschool children (46). As net supplemented energy increases, protein intake may gradually become the main limiting nutrient, and further energy supplementation alone would not produce an effect on birthweight unless accompanied by protein supplementation.

The relative importance of protein and energy for physical growth depends on which is the main limiting nutrient in the home diet. Other factors, such as placental and mammary gland transport, body composition, physical activity, prevalence of common infections, and nutrient availability from maternal stores during pregnancy and lactation, may also be important in determining the relative contribution of deficiencies in energy and protein to physical growth. Thus it is inappropriate to infer from the Guatemalan and Indian studies that protein-rich supplements will not be needed or that the dietary energy gap should be filled exclusively with energy-rich supplements. The protein/calories ratio usually reached by populations with unlimited access to a wide choice of foods is 11%, a ratio that probably represents the physiological equilibrium of the diet. There are no reasons to lower the protein content of the supplements beyond this level. Protein-rich supplements may be desirable in populations where the protein/calorie ratio is notably below 11%, such as in the New Guinean population, where the main staple is sweet potato. The implication is that the nutrient content of each supplement must be defined in terms of the characteristics of the diet of that population. Where this information
is missing, calories from protein should account for 11% of total calories. When designing interventions to meet the nutritional needs of the population at risk, care should also be taken to meet the self-perceived needs of the target group by involving participants and program workers in program planning, implementation, and evaluation.

**PHYSICAL GROWTH RETARDATION**

**Growth Retardation and Mortality**

Since the first report (47), a constant association between growth retardation in weight for age and infant (0–11 months) and childhood (1–4 years) mortality has been reported. In poor populations, moderate to severe malnutrition usually is associated with death at preschool age in about one-half the cases (48). In Brazil, for example, it is common to find that one-third to one-half of the children born in malnourished populations do not reach the age of 5 years. Data in Table 2 indicate that in 1980, developing countries contributed 99% of all children with moderate to severe deficit in weight for age and 93% of all deaths below 5 years of age. Being born in a developing country increases 40 times the risk of growth retardation and 12 times the risk of death during the first 5 years of age when compared with developed countries. Mechanisms of association between early malnutrition and mortality are depression of cell-mediated immunity as well as high duration and intensity of exposure to infection. Higher infant mortality is also mediated through increased incidence of LBW babies and, in poor populations with early weaning, the marasmic type of malnutrition.

Unexpectedly, no consistent association has been found between the provision of supplements and duration of diarrhea in Bogota and Guatemala. Given the high validity and reliability of the measures used to estimate supplemental intake and the duration of diarrhea, it was concluded that diarrhea was not affected by the improvement in nutritional status produced by the food supplement.

The association between growth retardation and risk of death is influenced by age (49), degree of wasting measured by the adequacy of weight for height (50), and availability of health care services and nutritional programs (45). As expected, the younger, more wasted, and neglected the malnourished child, the higher the risk of dying (51).

Data on the potential impact of nutritional programs on mortality come from studies in Bogota and Guatemala. In Bogota, the food supplementation program was associated with a 50% decrease in perinatal mortality. In Guatemala, food supplementation during pregnancy and lactation and simplified health care at the primary level were associated with a marked reduction in infant and child mortality. Similar effects on infant and preschool child mortality have been reported in other studies, and the rate of decrease in mortality was notably more rapid than in similar areas where there was no intervention (52). Although in these studies there was no clear indication about the most effective component of each intervention,
the following features were particularly effective: an integrated approach that included elements of nutrition and health care, maternal nutrition, maternal immunization against tetanus, monitoring of growth, nutrition, and health, immunization of children against common contagious diseases, early treatment and referral of acute respiratory infections and diarrhea, widespread coverage, greater use of paramedical personnel, and effective training programs.

In Guatemala, infant mortality was negatively associated with length of lactation independent of age of death. Furthermore, weight at birth, actual weight, height, and head and arm circumference at 15 days and 3 months of age were also negatively related to risk of death during the first year of life. Later, these anthropometric variables proved to be useful risk indicators for primary health care programs (53). Because of the consistency of the association between growth and mortality, anthropometric measurements have become simple and useful tools, not only for somatic classification but also for gross prognosis of the child's capacity to survive during infancy and preschool age. This selection allows concentration on public health programs for those children who are in greatest need.

Early Malnutrition, Growth Retardation, and Suboptimal Mental Development

Effects During Infancy

In developed countries, an association between birthweight, head circumference at birth, and subsequent cognitive function has been reported (54). Some studies also have reported effects of the nutritional intervention on behavioral and cognitive variables independent of birthweight (6,55). In Bogota, visual habituation at 15 days of age was faster in the group receiving prenatal supplementation than in the control infants. High-protein supplementation during pregnancy was similarly associated with better scores in habituation, dishabituation, and length of play episodes measured at 1 year of age in New York. Thus the two studies exploring habituation (New York and Bogota) reported faster habituation processes in the infants of the supplemented groups.

The Mexican study revealed significantly improved psychomotor development throughout the first years of life in the group supplemented during pregnancy. Results of the Taiwan study indicated no effect of the supplement on the Bayley mental scale scores at 8 months of age; however, there was an impact on the motor scores.

Data in Table 5 from the Guatemalan study indicate that food supplementation during pregnancy and mother's third trimester weight, head circumference, and birth interval were positively associated with psychomotor development of the baby at 6 months of age. Other important maternal variables were negatively associated with psychomotor development: duration of breastfeeding, parity, morbidity, and immunoglobulin levels in cord blood. These associations were not due to colinearity with birthweight. Furthermore, in these populations, retardation in psychomotor
TABLE 5. Variables significantly related to sixth-month composite infant score performance*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Subscales (correlation coefficient)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caloric supplementation during pregnancy (N = 351)</td>
<td>0.11&lt;sup&gt;b&lt;/sup&gt; 0.12&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mother's third trimester weight (N = 205)</td>
<td>0.18&lt;sup&gt;b&lt;/sup&gt; 0.06</td>
</tr>
<tr>
<td>Mother's head circumference (N = 351)</td>
<td>0.13&lt;sup&gt;b&lt;/sup&gt; 0.13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Parity (N = 351)</td>
<td>0.05 0.13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Birth interval (9–37 mo) (N = 256)</td>
<td>0.18&lt;sup&gt;b&lt;/sup&gt; 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Months lactating during pregnancy (N = 141)</td>
<td>0.22&lt;sup&gt;b&lt;/sup&gt; 0.02</td>
</tr>
<tr>
<td>IgM level (N = 155)</td>
<td>0.15 0.17&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Morbidity of mother during pregnancy (N = 214)</td>
<td>0.12 0.14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Adapted from Lasky et al. (56).

<sup>b</sup>p < 0.05.

FIG. 3. Relationship between birthweight and performance on the Brazelton scale: (left) habituation, r = 0.273, p < 0.01, n = 141; (right) alertness, r = 0.116, N.S., n = 145.

**Development seemed to be indicative of extremely impaired functioning:** infants who died in the first 3 years of life had significantly lower scores in the mental and motor subscales at 6 months of age than did infants who survived (56).

Data in Figs. 3 and 4 indicate an association between birthweight and three of the four Brazelton psychomotor variables (habituation, motor fitness, tremors, and startles). Data in Fig. 5 show a similar association between birthweight and mental and motor variables at 6 months of age. Although the LBW category was consistently related to lower psychomotor test performance, this association seemed to
FIG. 4. Relationship between birthweight and performance on the Brazelton scale (B): (left) motor fitness, $r = 0.281, p < 0.01, n = 144$; (right) tremors and startles, $r = 0.174, p < 0.05, n = 145$. (Note: the lower the score, the more advanced the behavior.)

FIG. 5. Relationship between birthweight and performance in the composite infant score at 6 months of age: (left) mental, $r = 0.103$, N.S., $n = 352$; (right) motor, $r = 0.163, p < 0.01, n = 352$. 

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Persist among newborns weighing more than 2.5 kg. These associations between birthweight and psychomotor development held after controlling for measured potential confounding factors and were also observed within siblings of the same mother \( r = 0.266, \ n = 65 \) pairs, \( p < 0.5 \) (55). Thus the findings in Mexico, Taiwan, Bogota, and Guatemala are consistent in that nutritional effects during infancy were most evident on motor performance. In Guatemala, intermediate variables of fertility and indicators of maternal morbidity were also associated with psychomotor performance of the infant.

There was an association between early malnutrition, LBW, and low psychomotor test performance up to 1 year of age in the study populations. Overall, a miscellaneous set of positive effects on psychomotor development were associated with food supplementation during pregnancy and lactation, and the information available suggests that these effects are attributable to the nutrition intervention. The finding of effects primarily on the motor subscales should not be surprising; improvement in neuromotor and sensorimotor functions characterizes development at this age and therefore would be most affected by malnutrition.

There is a lack of information on the effects of maternal malnutrition on maternal function during the first year of life. Early bodily contacts, the quality of holding, and eye-to-eye communication are important components of the quality of early physical care, and most of these components may be affected by chronic maternal malnutrition, particularly energy deprivation. Some related data suggest lower levels of exploratory activity and attachment behavior, especially distance interaction and a heightened need for physical closeness to the mother. Lower psychomotor activity, a decrement of the overall time spent in play, and an increase in the time spent sucking at the breast have also been reported. These characteristics could interfere with other motivational determinants that lead to increased exploration and social contacts (57).

In Bogota, lower levels of irritability and higher levels of visual attention at 15 days of age were reported in infants from supplemented mothers. Lower levels of apathetic behavior were also reported at 4 and 8 months of age among infants from women supplemented during pregnancy. In the Bogota and Mexican studies, increased levels of activity and demand for attention on the part of the infants from supplemented mothers were also reported. Reports from these two studies also indicated higher levels of caretaker-infant interaction in the infants from mothers supplemented during pregnancy. Increased environmental stimulation and exploratory behavior may be mechanisms by which improved nutrition could affect intellectual and behavioral development. Functional isolation may be one of the most important steps mediating the causal relationship between early malnutrition and mental development.

Effects on Cognitive Development During Preschool Age

Most of the early studies on the effects on cognitive development during the preschool years indicated a clear effect of severe malnutrition. However, they
usually involved severely malnourished children recovering in the hospital and did not take into account the effects of hospitalization (58–61). Recent studies have reported similar improvements in psychological test performance in well-nourished children recovering in the hospital from other illnesses. This would suggest that at least part of the rise in developmental quotients observed in malnourished children during recovery may not be due to improved nutrition. Results of studies exploring this possibility indicate positive effects in malnourished children who underwent programs of structured psychosocial stimulation during hospitalization for recovery and later at home for at least 6 months. In Jamaica, severely malnourished children benefiting from similar programs made significant improvements in their developmental quotients in the hospital and at home and continued to do so after discharge. Six months after the intervention, they were significantly ahead of the malnourished group, who received standard hospital care only, and were no longer behind hospitalized, well-nourished children (62).

Impact of Nutritional Supplementation During the Perinatal Period on Cognitive Function 5 to 7 Years Later

A recent study (55) indicated that children supplemented during the perinatal period showed significant enhancement of most cognitive variables examined when compared with their siblings, who were supplemented after 1 year of age. The perinatal supplemented children showed better scores in IQ, attention span, visuo-motor synthesis, and school grade-point average at the first year of school in reading, writing, and arithmetic. They also were significantly taller for their age than their siblings, although no significant differences were observed in birthweight. The major problem in interpreting these data is the possibility that the above-mentioned differences could result from differences in variables correlated with the study design, namely, age at testing, parity, family size, and maternal age. Other factors, such as emotional stress, social deprivation, total amount of supplementation, health care, and nutritional counseling, could have operated systematically; thus results might not be due to the timing of nutritional supplementation.

In the Bogota study, results indicated that children who were supplemented since the third trimester of pregnancy performed better than those who did not in the Griffith test of infant development and in the Cannon-Escalona scale up to 36 months of age. This association was particularly clear in motor skills in girls. It is important to note, however, that the effect on behavior seemed to be contemporaneous. The authors noted that although the intervention reduced the gap in cognitive performance between lower and upper socioeconomic classes, a disparity still remained by the end of the study at 3 years of age (63).

In the Guatemalan study, children in the high-protein-energy supplement group scored better than those in the energy supplement group in cognitive tests measuring vocabulary, motor control, memory, and visual ability at 3, 4, and 5 years of age. Results of multivariate analysis suggested that pregnancy and the first 2 years of age were critical periods for later mental development.
Data in Table 6 from the Guatemalan study indicate that the three supplement variables (supplement intake during pregnancy and lactation and supplementation of the child) were associated with cognitive performance. This association was independent and in addition to that observed for indicators of social environment. Mother’s supplementation during pregnancy and lactation was significantly associated with cognitive test performance in males and females up to 5 and 4 years of age, respectively. Child’s supplementation was associated with cognitive scores in males and females up to 6 and 7 years of age, respectively. Additional analysis indicated that supplement intake plus head circumference and height of the child statistically explained about 10% of the variance in cognitive composite scores at all study ages. These data, albeit limited, provide support for the causal nature of the association between early nutrition and cognition at preschool age. The data also indicate that both factors (maternal and early child nutrition) were important in contributing to the child’s cognitive competence (64).

**Long-Term Effects on Mental Development**

Does early malnutrition cause low cognitive test performance at school age? Different sets of data collected during the 1970s have helped to better understand this complex question. Birthweight has been found to correlate with subsequent cognitive function, particularly when large samples are studied. This relationship may not be linear, however, the impact of birthweight on IQ being clearer in infants with very LBW (below 1,500 g) (54,65).

Studies that have attempted to isolate early malnutrition from social environmental factors include prospective studies of middle class children who suffered early postnatal malnutrition because of specific medical conditions (66–68), retrospective studies of poor children with severe early malnutrition raised later in favorable social environments (59,69–71), and retrospective studies of army recruits

<table>
<thead>
<tr>
<th>Supplementary intake</th>
<th>Cognitive composite score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age (years)</td>
</tr>
<tr>
<td></td>
<td>Males</td>
</tr>
<tr>
<td>During pregnancy</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>During lactation</td>
<td></td>
</tr>
<tr>
<td>Of the child</td>
<td></td>
</tr>
</tbody>
</table>

*Adapted from Freeman et al. (64).
bp < 0.05.
cp < 0.01.
who experienced war-related famine as infants and were subsequently reared in middle class homes (72). All suggest that access to various social support systems could play an important role in compensating for low psychological test performance in children with early severe malnutrition.

Several reports indicate that children who suffered malnutrition during the first 6 months of age could gain considerable compensation in personal strength from their social surroundings. Most of the deficit in psychological test performance observed in children with early malnutrition during the first 5 years of life was no longer detectable in children from 6 to 12 years of age (66–68,73). Functioning in school and at home did not reveal higher difficulties in previously malnourished children when compared to controls, despite the fact that malnourished subjects showed early developmental retardation. Furthermore, no association has been reported between supplementation of school children and school achievement in developed countries (74).

In the Dutch study (9), psychological test performance was not associated with exposure to famine during pregnancy. There was a small excess of central nervous system defects in 19-year-old males born to mothers exposed to famine early in pregnancy but not in those born to mothers exposed to famine during the latter part of pregnancy. Although there the possibility exists that unmeasured mental functions were affected by exposure to famine, a more likely explanation is that the effect of prenatal nutritional deprivation was compensated by the favorable social stimulation conditions of postnatal life.

Few data are available concerning the implications for future competence in psychological test performance during the first 5 to 7 years of life in chronic malnourished populations. Data from the Guatemalan study reveal that performance in preschool tests is associated with how intelligent the children seemed to be to village adults and how they will eventually perform in primary school (75).

Data in Table 7 from the Guatemalan study present the results of multiple regression analysis computed for each of the 11 psychological tests composing the 7-year test battery. The independent variables in the regression model were sex, head circumference, and height at 7 years of age as indicators of nutritional status, as well as the quality of the house and maternal characteristics as indicators of family socioeconomic status. The maternal characteristics included indicators of vocabulary, modernity and school experience. In 7 of the 11 regressions, psychological test performance was predicted by the model at a statistically significant level (p<0.05). In 5 of these 7 tests, the child’s height and/or head circumference were related to psychological test performance at 7 years of age, after controlling for the family socioeconomic indicators. These results were observed in the fully longitudinal sample, followed from conception to 7 years of age. The amount of variance statistically explained by nutritional and socioeconomic indicators ranged between 3 and 11%, and their effect was about one-third to one-half of a standard deviation. The tests significantly associated to these factors are extremely varied and include measurements of verbal ability, memory, perceptual analytic capacity, and motor control.
TABLE 7. Relationship between 7-year psychological test performance and preschool nutritional and family socioeconomic status

<table>
<thead>
<tr>
<th>Dependent variable*</th>
<th>Nutritional status(^b)</th>
<th>Family socioeconomic status(^d)</th>
<th>(p)</th>
<th>(r^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vocabulary naming</td>
<td>×(^c)</td>
<td>×</td>
<td>0.0001</td>
<td>0.11</td>
</tr>
<tr>
<td>Verbal influences</td>
<td>×</td>
<td>×</td>
<td>0.0001</td>
<td>0.08</td>
</tr>
<tr>
<td>Digit memory</td>
<td>—</td>
<td>×</td>
<td>0.0562</td>
<td>0.03</td>
</tr>
<tr>
<td>Embedded figures</td>
<td>×</td>
<td>×</td>
<td>0.0069</td>
<td>0.05</td>
</tr>
<tr>
<td>Incomplete figures</td>
<td>—</td>
<td>×</td>
<td>0.0034</td>
<td>0.08</td>
</tr>
<tr>
<td>Block designs</td>
<td>×</td>
<td>—</td>
<td>0.0001</td>
<td>0.11</td>
</tr>
<tr>
<td>Draw-a-line slowly</td>
<td>×</td>
<td>—</td>
<td>0.0005</td>
<td>0.07</td>
</tr>
</tbody>
</table>

*Predicted variable. Tests with no significant association: discrimination learning, conservation of matter, conservation of area, and conservation of quantity.

\(^b\)As measured by head circumference and height at 7 years of age.

\(^c\)\(×\), \(p < 0.05\) for the partial \(F\) of corresponding independent variable.

\(^d\)As measured by quality of the house and maternal characteristics.

Data in Table 8 from the same study present the results of multiple regression analysis predicting intellectual ability at school age. The independent variables were child's age at the time of testing and sex, as well as preschool age nutritional status, socioeconomic status, and intellectual ability. These variables were entered in the order described, followed by the score measuring school performance. Nutritional indicators at 7 years of age were not associated with psychological test performance, and socioeconomic indicators at 7 years of age were consistently associated with school age cognitive test performance. In other words, in these rural villages, children with better cognitive test performance at school age were those who attended school for longer periods of time, performed better in school, came from higher socioeconomic strata, had higher psychological test performance at 7 years of age, but did not have better nutritional status at age 7. This was surprising given the general poverty and the high prevalence of chronic malnutrition and poor health conditions in these villages. In addition, no relationship was found between preschool nutritional status and school performance. The conclusion from this carefully controlled study was that if nutrition and growth play a role, it is through their relationship with the intellectual ability up to 7 years of age. Another important finding was the strong association between school performance and psychological test performance throughout a variety of psychological tests.

In summary, from this array of different study designs and populations, the available evidence suggests that children stunted because of early PEM show various indications of suboptimal mental development up to 7 years of age produced by the interaction between malnutrition and inadequate social environment, an interaction that entails deep implications for public health interventions. Psychological
TABLE 8. Relationship between school age cognitive test performance, preschool intellectual ability, nutritional and family socioeconomic status, and school experience

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Independent variables</th>
<th>School age intellectual ability</th>
<th>Preschool nutritional status</th>
<th>Preschool family socioeconomic status</th>
<th>School performance</th>
<th>p</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syllologism</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0.0001</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>Verbal rationale</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0.0001</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Correct responses</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0.0001</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Verbal Inferences</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0.0001</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Vocabulary naming</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0.0001</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Digit memory</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0.0001</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Block design</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0.0001</td>
<td>0.17</td>
<td></td>
</tr>
</tbody>
</table>


As measured by composite score of psychological test performance at 7 years of age.

As measured by head circumference and height at 7 years of age.

As measured by quality of the house and maternal characteristics when the child was 7 years of age.

As measured by composite score based on school performance at ages 9–15.

test performance at 7 years of age in turn is associated with intellectual performance and school performance up to 15 years of age. Thus the improved scores in psychological tests observed in preschool children with better nutrition up to 7 years of age may be associated with improved competence for the tasks of adult life. In contrast, a history of early malnutrition usually associated with unfavorable social environment and poor schooling will probably result in poor competence for adult tasks.

SUMMARY AND CONCLUSIONS

This chapter discusses the relationship between early malnutrition and survival, physical growth, and mental development, as well as the implications for action programs. Early malnutrition refers to PEM during intrauterine, breastfeeding, weaning, and postweaning periods up to 5 years of age. The main conclusions are as follows.

Children with early malnutrition have a higher probability of long-term physical growth retardation, suboptimal mental development, and early mortality than well-nourished children. Malnutrition results in physical growth retardation, which in turn is associated with a higher risk of mortality and low psychological test performance. To a large extent, the associations with growth retardation and mortality are due to complex interactions between early malnutrition and infection, while those involving mental development result from the interaction between malnutrition and inadequate social environment. These effects are greater when
malnutrition began earlier, lasted longer, and was more severe, and when social neglect and environmental deprivation continued to prevail. They appear to be of a long-term nature and are indicative of a continuing deleterious process that may be modified by improving nutrition, environmental sanitation, health care, and social environment.

In populations with PEM, either acute or chronic, appropriate food supplementation of pregnant and lactating mothers and of their weaning children decreased the incidence of intrauterine and postnatal growth retardation in weight, height, and head circumference. The effect on growth was greater in populations with severe malnutrition and in those where the intervention was applied earlier, during pregnancy and lactation, and continued in the weaned children. However, improvements in postnatal growth rates were not proportional to the increments in total nutrient intake produced by food supplementation, probably because of the high prevalence of diarrhea.

Food supplementation programs, integrated with primary health care services, improved indicators of mental development and the probability of survival of the offspring. Primary health care programs carried out by auxiliary personnel contributed to reduce infant and child mortality and to decrease the duration of common child diseases, including severe malnutrition. Cost-effectiveness estimations for these integrated interventions are lower the earlier in life the intervention is implemented. Furthermore, access to appropriate school and social support systems in part compensates for long-term deficits in intellectual development of children with early malnutrition.

In summary, the distribution of physical growth retardation and mortality in children under 5 years of age is associated with food availability at country and social stratum level. Planned changes in dietary intake of pregnant and lactating women and their children, integrated with primary health care services, were followed by improvement in growth rates, mortality, and psychological test performance up to school age. There was a clear time sequence between the dietary modification and the observed improvement in growth rate and functional outcomes. These associations were consistent across different populations and study designs. There was a defined dose-response relationship between additional intake and pre- and postnatal growth. Causal mechanisms for these associations between malnutrition and growth retardation and low psychological test performance have been identified. They include not only metabolic processes related to nutrition and growth but also complex interactions of nutrition with infection and inadequate social environment. Finally, there is no evidence for noncausal explanations of these associations. Thus stunting and suboptimal mental development may represent part of the price to be paid for adaptation and survival when dietary intake is chronically restricted through generations. This adaptative capacity of the reproductive process should not serve as an excuse for inaction.

Food supplementation alone may not be the most effective way to deal with these complex interactions between malnutrition, infection, and inadequate social environment. Improvements in nutrition usually follow positive changes in educa-
tion, purchasing power, health care services, food availability at the family level, and environmental sanitation. Isolated vertical programs exclusively aimed at distributing food may have little impact on growth and functional outcomes. A greater impact is expected from integrated nutritional programs, including: (a) immunizations, environmental sanitation, and oral rehydration for diarrhea; (b) effective promotion of breastfeeding and appropriate weaning practices; (c) nutrition and health promotion, including monitoring of physical growth to decrease home diet replacement and improve food utilization and intrafamily food distribution; (d) development of adequate social environment and improved schooling programs; and (e) improvement of self-sufficiency in food availability at the family level.

Investments in these integrated nutritional programs would alleviate the heavy burden on development programs incurred by malnutrition and would produce economic returns important enough to stimulate social and economic development.

In these integrated nutritional programs, the nutrient content of the food supplements should be tailored to provide the most limiting nutrients in the home diet. When information on the main limiting nutrients is missing, the mean protein/energy ratio of the supplements should be close to 11%. Food supplementation programs should also be designed to meet the desired and self-perceived needs of the target group by involving participants and program workers in program planning, implementation, and evaluation.

No evidence has been detected of harmful effects of protein-energy supplementation provided through regular foods within the recommended dietary allowances. However, economic and social dependency on the program, inhibition of breastfeeding, stimulation of early and inappropriate weaning, inhibition of self-sufficiency on the part of the population being served, adverse changes in eating habits, and inhibition of the local food industry may counteract program impacts, particularly in long-term operations. For these reasons, food supplementation programs should be implemented as short-term interventions to deal mostly with acute, urgent components of the nutritional problem. They should be gradually replaced by community development interventions aimed at increasing self-sufficiency in food availability at the family level.

REFERENCES

61. Stoch MB, Smythe PM. Undernutrition during infancy and subsequent brain growth in intellectual


DISCUSSION

Dr. Briend: It does not seem possible to derive from your data the conclusion that food supplementation during pregnancy results in a lower rate of LBW babies. One would have to know the birthweight rate before intervention, and this is not available. The correlation that was observed between maternal food supplementation during pregnancy and birthweight is fairly low and explains only 1% of the variance of birthweight. The fetus and the placenta themselves are oxygen consumers; they may consume as much as 8 or 10% of maternal oxygen. One may assume, therefore, that women who are giving birth to babies with a higher birthweight are bound to consume more food. Since the amount of food consumed by women is determined by self-selection, there could be a bias in this study. Women who took more food during pregnancy had babies with higher birthweights, but a causal relationship could not be derived from this observation. This kind of correlation between maternal food intake and birthweight was observed in many other circumstances, first by Thompson in 1959. He derived no cause-effect relationship from this observation. We should be as cautious as he was.

Dr. Lechtig: As mentioned before, the magnitude of this effect is low when expressed in terms of the proportion of the birthweight variance statistically explained by ingestion of food supplements: 1 to 2%, depending on the groups analyzed. On the other hand, when this effect is estimated in terms of proportion of LBW babies, the results are impressive. In the Guatemalan study, the proportion of LBW babies decreased from 33% in a small sample at the beginning of the study in 1969 to 13% at the end of the intervention in 1977. The
proportion of LBW babies decreased from 19% in the low supplementation group to 10% in the group with high supplementation. Thompson's data were based on measurements of home diet, while the Guatemalan study was based on direct recording of daily supplement intake throughout pregnancy.

The problem with self-selection in the design of the Guatemalan study was pointed out more than a decade ago (Lechtig A, Arroyave G, Habicht JP, Béhar M. Nutricion materna y crecimiento fetal. Arch Latinoam Nutr 1971;21:505), but it was not possible to change the design. Because of this "inborn" design problem, the analytical approach indicated for longitudinal quasiexperimental cohort studies was carried out as follows: (a) reliability and validity of the two main variables (daily supplement intake during pregnancy and birthweight) proved to be very high: about 0.99; (b) extensive statistical analysis failed to identify maternal characteristics that could "confound" the relationship observed between food supplement ingestion and birthweight; (c) since the relationship was also observed within pairs of consecutive siblings of the same mother, we discounted the possibility that maternal factors constant to the mother (e.g., maternal height) could be responsible for the observed association; (d) obviously, there still remained the possibility of confounding factors not related to the mother but to each pregnancy within the same mother. Of those factors that could change from one pregnancy to the other, several were measured: parity; changes in home diet; diseases, including diarrhea; changes in socioeconomic status; and indicators of subclinical intrauterine infection. None of these variables was shown to be responsible for the observed association between food supplementation and birthweight. Moreover, anthropological and time-activity surveys showed no evidence of significant changes in patterns of physical activity of the study mothers. Thus we concluded that, because of the observed replication of similar findings across different types of analysis, the most suitable interpretation of this association was one of a cause-effect relationship between food supplementation and birthweight.

In well populations, where food availability is not a problem, regulators of fetal growth may influence maternal intake; therefore, the size of the baby may be the cause and not the effect. The reverse is expected to occur in poor populations where nutrient availability limits dietary intake and socioeconomic factors regulate nutrient availability. As observed in many poor populations, socioeconomic characteristics not directly caused by fetal growth are the main limiting factors of nutrient availability and, in turn, the main determinants of nutrient intake. The observation that in malnourished populations food supplementation during pregnancy is associated with higher birthweight contributes additional support to this cause-effect hypothesis. Thus dietary intake may operate as both cause and effect of fetal growth, depending on the nutritional characteristics of the population studied. In poor populations, such as those of Northeast Brazil, intense physical work increases energy expenditure but not dietary intake; therefore it will decrease fetal growth more than expected from the low dietary intake alone. A high incidence of diarrhea usually increases energy expenditure and decreases dietary intake. This double action decreases fetal growth further than expected from "usual" intake alone. Thus these two variables, intense physical work and high incidence of diarrhea, contribute to a greater magnitude of the apparent relationship between low dietary intake and high incidence of LBW babies. It is clear that in these two examples, neither physical work nor incidence of diarrhea are acting as effects but as important contributing causes of fetal growth retardation in addition to low dietary intake per se.

If we provide food supplements alone to such a population without decreasing physical activity and incidence of diarrhea, the effect on birthweight, important as it may be, would not fill the gap observed between poor and well-nourished populations. This does not mean
that it is not important to improve dietary intake in malnourished populations, but that other factors limit fetal growth in these populations, in addition to dietary intake.

One must be careful in reviewing some data. Dr. Lechtig mentioned that the experiment in India had a high effectiveness, attributable to the low food intake of these women before supplementation. As far as I know, however, this effect was measured by comparing birthweights among mothers admitted to the hospital a few weeks before delivery to receive the food supplement and among outpatients. In one of the first studies carried out on birthweight and published in Paris in 1898, it was shown that admitting a woman to a hospital a few weeks before delivery, without any other intervention, was enough to observe a birthweight 200 g heavier than among outpatients. I am reluctant to ascribe the effects observed in the quoted study in India to the nutritional intervention by itself and suggest that maternal rest may have played a role.

The dose-response relationship in the Indian study was notably higher than that observed in Guatemala or Colombia (71 versus 41 g/10,000 kcal). This increased impact suggests an effect of resting on birthweight in addition to the effect of improved dietary energy intake. The effect of resting would be equivalent to saving about 125 kcal/day. In other words, in this specific case, the effect contributed by resting to birthweight (in addition to the effect of dietary improvement) could be explained by the amount of energy saved. Of course, this inference does not discount other mechanisms of action.

Dr. Mata: Birthweight as an indicator of fetal growth is a variable that exhibits secular changes. This has been obvious in the Japanese population, where there has been a tremendous increase in mean birthweight and a marked increase in the incidence of LBW over the last three decades. In Costa Rica, a country where we have been able to obtain reliable data over a long period of time, we also can compare changes. Considering the frequency of birthweight distribution, which is the most obvious way to measure changes over time, and the data of 1970 and 1975 for Costa Rica, we find a bell-shaped distribution. This is different from that of Guatemala, where the distribution is skewed to the left, denoting the common fetal growth retardation. The only way to deal with Dr. Lechtig's design would be to compare two villages that have supplements with two other villages that do not have supplements and present the results graphically. With a large number of babies, it is possible to see several LBWs at the beginning and at end of the period.

Dr. Lechtig: As we have mentioned repeatedly, the demonstration in the Guatemalan study of an effect of dietary intake on birthweight does not mean that other maternal and environmental factors are not important. In poor populations of developing countries, a high prevalence of LBW babies is the outcome of stunted and wasted mothers because of malnutrition through generations, current low dietary intake, short birth intervals, frequent episodes of diarrhea, bacteriuria, malaria, and hard physical work during pregnancy. Thus dietary improvement plus interventions focused on malaria in Africa, or plus oral rehydration, diarrhea prevention, and birth spacing in Bangladesh, or plus actions aimed at decreasing physical work in the hilly slums of Rio de Janeiro will have a stronger effect than food supplementation in the Harlem population in New York City, for example, where dietary intake and anthropometry do not suggest a high prevalence of malnutrition. A far more effective intervention in this population to decrease prevalence of LBW babies would be one focused on birth spacing, cigarette smoking, and drug control. Obviously, effectiveness of these interventions will vary across populations, depending on epidemiological and nutritional profiles as well as their economic and social feasibility.

Secular trends in fetal growth usually are associated with improved socioeconomic status, dietary intake, sanitation, hygiene, and maternal education, as well as with decreased
incidence of diarrhea, short birth interval, and physical activity during pregnancy. However, developing countries require faster and less expensive ways to solve their problems. Today, there are many more babies with LBW than 20 years ago. Thus the issue, from a public health point of view, is not whether secular trends exist but what are their main causal mechanisms. Further knowledge of these mechanisms may help to improve new interventions aimed at avoiding fetal growth retardation in developing countries.

Dr. Barness: Please explain the adverse effects of supplementation.

Dr. Lechtig: The New York study reported an excess of premature babies and of neonatal deaths in the group with high-protein supplementation (estimated protein/energy ratio: 34%). This finding, observed particularly in the group of women with prior LBW infants, led the authors to conclude that high-protein supplements could be toxic for those women. I do not see any nutritional reason to provide protein in such high concentration to this population. I cannot see why protein could be toxic for adult women or for mothers with a prior LBW baby.

Before arriving at such a conclusion, one must discard other alternatives that require careful consideration: the presence of contaminants (toxic agents per se) in the canned beverages provided as food supplements, differential use of available health services by these mothers, and changes in home intake due to high-protein supplementation, among several other alternatives. As far as I know, the authors have not published any data on these possibilities.

Dr. Whitehead: I have commented on our experience with a maternal supplementation program in the Gambia and its effect on birthweight. It is relevant to make a more general comment about other changes that have occurred in the village of Keneba in the Gambia. Twenty years ago, Sir Ian McGregor showed that in that village, 50% of children died before the age of 5 years. Furthermore, by 2 years, two-thirds of surviving children would be judged undernourished by international standards. Initially, our program involved the introduction of medical service provided by a doctor and a nurse. This resulted in a profound improvement in mortality rates, but morbidity rates and growth patterns were virtually unaffected. We then introduced a baby supplementation program. Although this did result in a somewhat improved growth rate, the differences were only marginal when considered in relation to the magnitude of our input. We did not begin to see any dramatic improvement in the growth rates of babies during the first 12 months of life until we introduced the maternal supplementation program during pregnancy. Exactly why our children are on the average 750 g larger by 1 year is not clear. Perhaps the greater weight at birth creates a better start in life for the children. We are currently looking at morbidity patterns to see whether or not there is any evidence that the children are now less ill during infancy than they used to be. Nevertheless, it seems that increased maternal dietary intake during pregnancy is a cost-effective way of subsequently improving the health of babies.

Dr. Lechtig: I agree that the evidence of the effect of maternal dietary intake on fetal growth is clearer in famine situations, such as Leningrad or Holland, than in populations with chronic moderate malnutrition. At first glance, the distinction between acute and chronic malnutrition appears obvious. In the two extreme situations, there are clear differences in onset (abrupt versus gradual), duration (short versus long), and severity (severe versus moderate). The limit becomes less clear when they are analyzed closely. The current world economic recession is slowly producing decreased dietary intake in many poor areas of the world. In Brazil, for example, the rate of LBW babies has increased in São Paulo and the northeast during 1982–1983, compared with 1978–1979. Does the 5-year drought of northeast Brazil result in a long episode of acute malnutrition or the gradual deterioration
of a previously chronically malnourished population? How could we classify the lactating mothers of Guatemala who lose an average of 369 g of weight per month compared to their prepregnancy weight? The results of our energy expenditure studies in this population indicate that they were “compensating” for the greater energy expenditure through weight loss more than through higher energy intake.

Is seasonal variation an acute episode of malnutrition or a chronic situation of intermittent cycles of food deprivation? Each episode of diarrhea during pregnancy could also be considered acute malnutrition. However, we describe the whole picture as endemic diarrhea associated with chronic moderate malnutrition.

The problem for most poor populations in developing countries may be related to thresholds. Whenever dietary intake during pregnancy is below the threshold required to support fetal growth, there will be an effect on birthweight. These thresholds probably vary across and within populations. They may represent points of “dynamic” equilibrium influenced by nutrient expenditure, maternal nutrient reserves, and time for adaptation, among other variables. In the famines of Holland and Leningrad, where most mothers were previously well nourished, this threshold could be located around 1,500 kcal/day. In many poor populations of developing countries, this threshold oscillates around higher levels: about 1,800 kcal/day. This difference could be explained by the smaller maternal nutrient reserves in these populations. Thus the conclusions from this hypothesis are as follows: (a) in malnourished populations, appropriate nutritional programs during pregnancy can decrease the incidence of LBW babies; (b) this effect will be greater the lower the level of nutrition in that population (acute, severe) and the higher the magnitude of the nutritional treatment; and (c) in poor populations, there are other important factors of fetal growth retardation (e.g., diarrhea, intense physical work, bacteriuria, smoking) which should be controlled through specific interventions.

Dr. Whitehead: It is unlikely that one could ever force, or indeed persuade, people to eat something they do not like or do not see the need for. Our understanding was based on a biscuit of high caloric and nutrient density produced for us by the village baker using local techniques. We claim that it is because we introduced such a biscuit as a snack food that the consumption of traditional foods was so little reduced despite the supplement. Interestingly, in parallel studies carried out in Cambridge, there too we found that women increased their food intake during pregnancy and lactation largely by consuming energy dense foods, such as cake and biscuits.

Dr. Lechtig: In the Guatemalan study, we provided two beverages of different caloric density: Atole (0.9 kcal/ml) and Fresco (0.3 kcal/ml). The two supplements were freely available for each village, and attendance and intake were voluntary. No significant differences were found between Atole and Fresco intake in terms of net energy supplementation (106 and 82; pooled SD; 87 kcal/day) or in total energy intake (1,588 and 1,526; pooled SD; 453 kcal/day). Mothers drank more than twice as much Fresco as Atole. As a result, supplement energy intakes overlapped considerably in the Atole and Fresco villages. The situation in children was very different, those in the Atole group ingesting more supplemental energy than those in the Fresco group.

Dr. Guesry: I draw your attention to the danger of concluding too rapidly on any medical or nutritional intervention done on pregnant women, especially at the end of pregnancy. Every additional week at the end of pregnancy increases the birthweight of the baby by about 150 g.

Dr. Lechtig: In the Guatemalan study, food supplement intake was associated with an average increment of 5 days in length of gestation. This effect amounted to 71% of the
difference in length of gestation between poor rural populations from Guatemala and middle class groups from the United States. The proportion of preterm babies decreased from 16.8 to 6.6%. In the Dutch study, length of gestation decreased 2 days during famine and increased 4 days afterwards. These findings are consistent with prior reports of decreased duration of gestation in mothers from poor populations and in mothers with low prepregnancy weight.

In the Guatemalan and Dutch studies, the changes in length of gestation explained partially, but not totally, the effects of dietary intake on birthweight. Two conclusions arise: (a) there is an effect of maternal nutrition on duration of gestation; and (b) changes in birthweight associated with dietary intake are a consequence of both increased length of gestation and increased fetal growth rate per se.

Dr. Pierson: With respect to the role of the sex of the fetus in the effect of supplementation, males seem to be benefiting more than females from the prenatal supplementation. It may be an anabolic effect due to the male gonads which occurs in the last week of gestation and continues after birth.

Dr. Lechtig: As mentioned, the effect of dietary intake was greater in males than in females in Bogota, Taiwan, and Guatemala. During the last weeks of pregnancy, the male fetus has greater potential for growth and therefore is more likely to benefit from dietary improvements.

Dr. Waterlow: What happens to these calories? I assume that your 10,000 kcal was a net supplement after allowing for any displacement of food in the family. It is difficult to understand what is happening to these calories unless there is an increase in the mother's physical activity, or unless she is simply "burning them off." The effect cannot be accounted for by the gain in either mother's or fetus' weight.

Dr. Lechtig: In Guatemala, about 1 kg of maternal weight was gained per 10,000 net supplemented calories, or about 55 additional calories per day. Of that 1 kg of weight gain, 41 g corresponded to an increase in birthweight per se. Thus the efficiency of supplemented calories to build maternofetal tissues was high: about 60%. The other 40% (about 22 kcal/day) was spent in physical activity and increased resting metabolic rate. The computed relationship between maternal weight gain and birthweight was also close to the maximum expected values. A similar effect of food supplementation on maternal weight gain during pregnancy was also reported in Bogota, India, Mexico, Montreal, New York, and the Dutch famine study. Therefore, the dose-response relationships presented in my chapter are compatible with current nutritional theory. The main problem is that our expectations for a nutritional effect on birthweight were excessively high 15 years ago when most of these longitudinal studies were designed. At that time, it was assumed that food supplementation would solve all differences in physical growth related to poverty.

On one hand, we have learned that the picture is more complicated than simple, linear, aristotelic logic suggested. On the other hand, we also learned that nutritional supplementation may indeed be important when appropriately implemented in malnourished populations.