Nutritional status of the Indian population

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High prevalence of low birth weight, high morbidity and mortality in children and poor maternal nutrition of the mother continue to be major nutritional concerns in India. Although nationwide intervention programmes are in operation over two decades, the situation has not changed greatly. In addition, the Indian population is passing through a nutritional transition and is expected to witness higher prevalences of adult non-communicable diseases such as diabetes, hypertension and coronary heart disease according to the theory of 'fetal origin of adult disease'. Clearly, there is a need for examining several issues of nutritional significance for effective planning of interventions. In particular, maternal nutrition and fetal growth relationship, long term effects of early life undernutrition, interactions of prenatal nutritional experiences and postnatal undernutrition are some of the major issues that have been discussed in the present paper with the help of prospective data from various community nutrition studies carried out in the department.

1. Introduction

Agricultural progress in the last decade has made India self-sufficient in major food grains. Yet undernutrition continues to be major nutritional problem especially in rural populations. While we are in the midst of combating these long-standing problems of undernutrition in children and women, a new situation has arisen. The World Bank has predicted that coronary heart disease will become the leading cause of premature death in India by 2015 and that the maximum number of diabetic patients in the world will be in India (Bulatao and Stephens 1992). Unlike undernutrition, these diseases are less recognized to be associated with poverty. Clearly, the Indian population is passing through a transition phase where subsistence conditions are being replaced by plentiful food but reduced physical work and therefore, an understanding of the changing nutritional scene is critical.

Recent studies (Law 1993; Fall *et al* 1995; Lithell *et al* 1996; Barker 1998) postulate a shift in the paradigm, that life style factors are not likely to explain risks of these adult diseases but are associated with a suboptimal inutero nutritional environment. As a result, several issues of nutritional significance arise. Firstly, it is essential to reduce prevalence of low birth weight. Secondly, it would be unwise to overlook the effect of postnatal undernutrition on adult health as it may amplify these risks determined inutero. Thirdly, the interactive effects of inutero undernutrition and postnatal undernutrition may even be more important than considering either factor in isolation. These issues are being discussed worldwide in view of their implications and have high relevance for us, especially for formulating effective interventions for improving the nutritional status of our populations. We have conducted longitudinal community nutrition studies on maternal nutrition and fetal growth, nutritional status of pre-school children and adolescent growth in rural populations around Pune and would like to report factual data and results from these studies in the light of the above issues and discuss strategies for achieving better health of our people.

2. Nutrition in early life

2.1 *Fetal growth*

One third of babies born in India are of low birth weight (LBW) (< 2·5 kg) and this continues to be a major public

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Abbreviations used: BMI, Body mass index; LBW, low birth weight.

health problem. In addition to short term consequences, such as high infant mortality and childhood growth failure among survivors (Pojda and Kelley 2000), LBW carries long term risk in the form of high rates of adult coronary heart disease and type II diabetes (Barker 1998). Known as the hypothesis of 'fetal origins of adult diseases' it states that fetal undernutrition at critical periods of development and during infancy leads to permanent metabolic and structural changes that increase risks for adult diseases.

In India, poor fetal growth has been attributed to widespread maternal undernutrition (Gopalan 1994). On the other hand, worldwide studies of energy and protein supplementation during pregnancy have produced variable results (Kramer 1993). Therefore understanding maternal nutrition and fetal growth relationship is critical. Dietary intakes of energy and protein of rural Indian mothers are known to be low (Bhatia *et al* 1981; Grover 1982; Hutter 1996; Rawatani and Varma 1989; Vijayalaxmi and Laxmi 1985; Vijayalaxmi *et al* 1988) and they are often engaged in high level of physical activity. Most of these studies have examined maternal diets in the form of quantity (macronutrients) using the 24 h recall method, but have rarely assessed quality (micronutrients).

We conducted a prospective study on rural mothers ($n = 633$, full term singleton pregnancies) from six villages near Pune, to investigate the role of micronutrients in determining birth size. Rural mothers were thin (41·7 ± 5·1 kg), short (151·9 ± 5·1 cm) and many were chronically energy deficient [31·3% below 17 kg/m^2 body mass index (BMI)] before conception. Maternal intakes of energy and proteins were also low (7·40 ± 2·1 MJ, 45·4 ± 14·1 g at 18 wk; 7·0 ± 2·0 MJ, 43·5 ± 13·5 g at 28 wk) and were only 70 to 75% of the recommended intakes, throughout gestation. It was interesting to see that maternal intakes of these macronutrients were not related with birth size (Rao *et al* 2001). Among the macronutrients only fat intakes showed association with neonatal length ($P < 0·001$) and triceps skinfold thickness ($P < 0·01$).

Regression analysis carried out after adjusting for major confounding variables showed that birth size was strongly related to consumption of green leafy vegetables (GLV) and fruits at the 28th wk of gestation and milk at the 18th wk of gestation (table 1). The fact that the associations of these food groups with birth size were observed at different weeks of gestation is of significance in view of varying requirements of fetal growth at different stages. This is because it is known that fetal growth in early gestation is mainly muscle growth while that in late pregnancy mainly consists of deposition of fat tissue (Dugdale and Payne 1975). This was also reflected in our finding that consumption of milk in early gestation was not associated with neonatal measures of fat (triceps skinfold, biceps) and abdominal circumference while consumption of GLV was associated with all the neonatal

Table 1. Multiple regression analysis of the relationship of the frequency of maternal intakes of green leafy vegetables, fruits and milk products with birth weight among rural (R) and urban (U) Indian women.

Dependent variable	Area	Independent parameters	Green leafy vegetable intake at wk 28			Fruit intake at wk 28			Milk product intake at wk 18		
			R^2	*b*	*P*	R^2	*b*	*P*	R^2	*b*	*P*
Birth weight (g)	R	Sex, parity, gestation, pre-pregnant wt, energy intake, activity, social status+ weight gain up to 28 wk + micro/macro nutrients[a]	32·6 (1·8)	19·4	< 0·001	29·8 (0·34)	4·30	0·12	29·4 (0·4)	4·8	0·06
Birth length (cm)	U[b]	Sex, parity, gestation, pre-pregnant wt, energy intake, activity, weight gain up to 28 wk	–	–	–	25·2	0·58	0·05	–	–	–
Triceps (mm)	U[b]	Same as above	–	–	–	14·0	1·16	0·01	–	–	–

R, Rural; U, Urban; *P*, probability of significance.
Gestation, gestational age at delivery.
Figures in parentheses represent the contribution of dietary variables in the explained variation i.e. R^2.
[a]Indicates further adjustment for other variables including micro/macro nutrients: for green leafy vegetables – erythrocyte folate concentration; for fruit – serum vitamin C concentration, for milk products – fat intake.
[b]Relationship significant at 18th wk of gestation among urban affluent mothers.

measurements. All these relationships were strongest in lighter and thinner mothers (pre-pregnant weight < 40 kg). All the above food groups are rich in micronutrients and indicate the importance of micronutrients or their combinations for fetal growth.

A parallel study on urban affluent mothers ($n = 214$) was conducted to see whether similar food groups show association with birth size. The majority of urban mothers had low intakes of energy and protein (8·05 ± 2·44 MJ, 51·1 ± 17·2 g) in the 18th wk of gestation due to nausea, but were able to increase it significantly (9·10 ± 2·41 MJ, 58·6 ± 19·3 g) at the 28th wk, unlike rural women. In this population also, energy and protein intakes were not related to birth size but fat intakes at the 18th wk of gestation were related with birth weight ($P < 0.05$), birth length ($P < 0.05$) and triceps skinfolds ($P < 0.01$). Fruit consumption at the 18th wk of gestation also showed significant association (table 1) with birth length ($P < 0.05$) and triceps skinfold ($P < 0.01$).

The comparison of the results of studies on rural undernourished women and urban affluent mothers highlights two important issues. Firstly, the association of fat intake with birth size observed in rural as well as urban mothers begs the question whether fat is to be considered as a macro or micronutrient, in view of the recent studies showing importance of specific fatty acids (*n*3 fatty acids) in fetal growth (Elvevoll and James 2001). Secondly, we observed that consumption of fruits with birth size was significant when maternal intakes were low in rural mothers (throughout gestation) as well as urban mothers (in early gestation) despite large differences in pre-pregnant nutritional status of rural and urban mothers. Fruits are rich in micronutrients, especially vitamin C and other antioxidants. Therefore, the observation highlights the importance of micronutrients for fetal growth when macronutrients are limiting in the maternal diet.

Clearly, there is a need for reappraisal of nutrition intervention programmes for pregnant women in India. Improving supplementation qualitatively (micronutrients) will improve birth weight but subsequently is likely to reduce risks of adult diseases.

2.2 *Nutritional status in pre-school age*

Even though the problem of fetal growth may be taken care off, rural conditions are such that poor growth is a characteristic phenomenon among pre-school children and it may be interesting to examine postnatal effects of chronic undernutrition on adult size and health.

In a longitudinal growth study on rural pre-school children ($n = 376$) *Z*-score (observed weight/height expressed as standard deviation units of distribution of expected weight/height) values for weight as well as height, were negative at all ages indicating poor growth throughout pre-school age. The maximum negative value was however, observed in the age class of 18–24 months, which then improved and stabilized beyond 3·5 yrs age, for both the sexes (figure 1). The implication is that there is no evidence for catch-up beyond the third year of life. This was also true when we examined annual velocity (gain in weight/height over a period of one year) data (figure 1) on urban slum children (Rao *et al* 2000a). The rural preschool children were also observed at 10 + yr and 15 + yr age subsequently in an another growth study on adolescents. Heights attained by these children at these ages are given by their nutritional status in early life in table 2. It was observed that the difference in attained heights at 10 + yr for normal and stunted children was minimum (around 4 cm) if stunting had occurred in the first two yrs of life and increased (to 8 cm), if stunting had occurred beyond 3 yrs of life. These deficits remained similar even at 15 + yr which is the age at spurt for rural children. This indicates that the first three years of life are critical and rural children may miss the ‘second opportunity’ for catch-up growth during adolescence due to stunting in early life. The observations thus indicate that supplementation beyond age of 3 yrs may not be beneficial and that existing intervention programmes for pre-schoolers need to concentrate their efforts on covering children below 3 yrs of age.

Thus, the critical window of the first 3 yrs of life highlights the importance of appropriate feeding and weaning practices in infants and toddlers. This can be better achieved by creating nutritional awareness among rural mothers, than by distributing food supplements. Reallocation of priorities for covering children in this critical age window will not only result in optimum utilization of limited resources but more importantly ensure better adolescent growth and better adult size as well.

3. Nutritional status in adolescence

3.1 *Growth*

Adolescence is known to be a “second opportunity” for growth as it facilitates catch-up growth for children experiencing nutritional deficits in their early life. However, as discussed above, stunting appeared to be a persistent phenomenon beyond the 3rd year of life among rural children and it had significant impact at 10 + yrs of age. Thus, the majority of rural children enter adolescence with poor nutritional status. We therefore, examined various issues (Joshi *et al* 1998; Rao *et al* 1998a, b, 2000b; Kanade *et al* 1999) related to adolescent growth of rural children from six villages near Pune in the longitudinal study carried out during 1992–1998. It was observed that children who were underweight as well as stunted near take-off, have significantly lower attained values of weight and height as compared to their normal counterpart throughout adolescence (figure 2). In fact, the differences at the start (11 yrs age) in weight (4 kg) and height (8 cm) almost increased to 12 kg and 10 cm by adulthood. Entering adolescence with poor nutritional status thus hampers the capacity for catch-up growth and affects final adult size.

3.2 *Velocity*

The longitudinal data on growth enabled us to investigate the velocity curves for normal and undernourished boys (figure 3). It was observed that the differences in the maximum velocity for weight or height were not prominent but were significant for ages at which maximum velocity occurs. Thus, more than growth rates, the timing of peak height/weight velocity was more sensitive to undernutrition. As a result of undernutrition the velocity curve shifts to the right showing significant gains at later ages both in girls and boys. Despite this, it was worth-

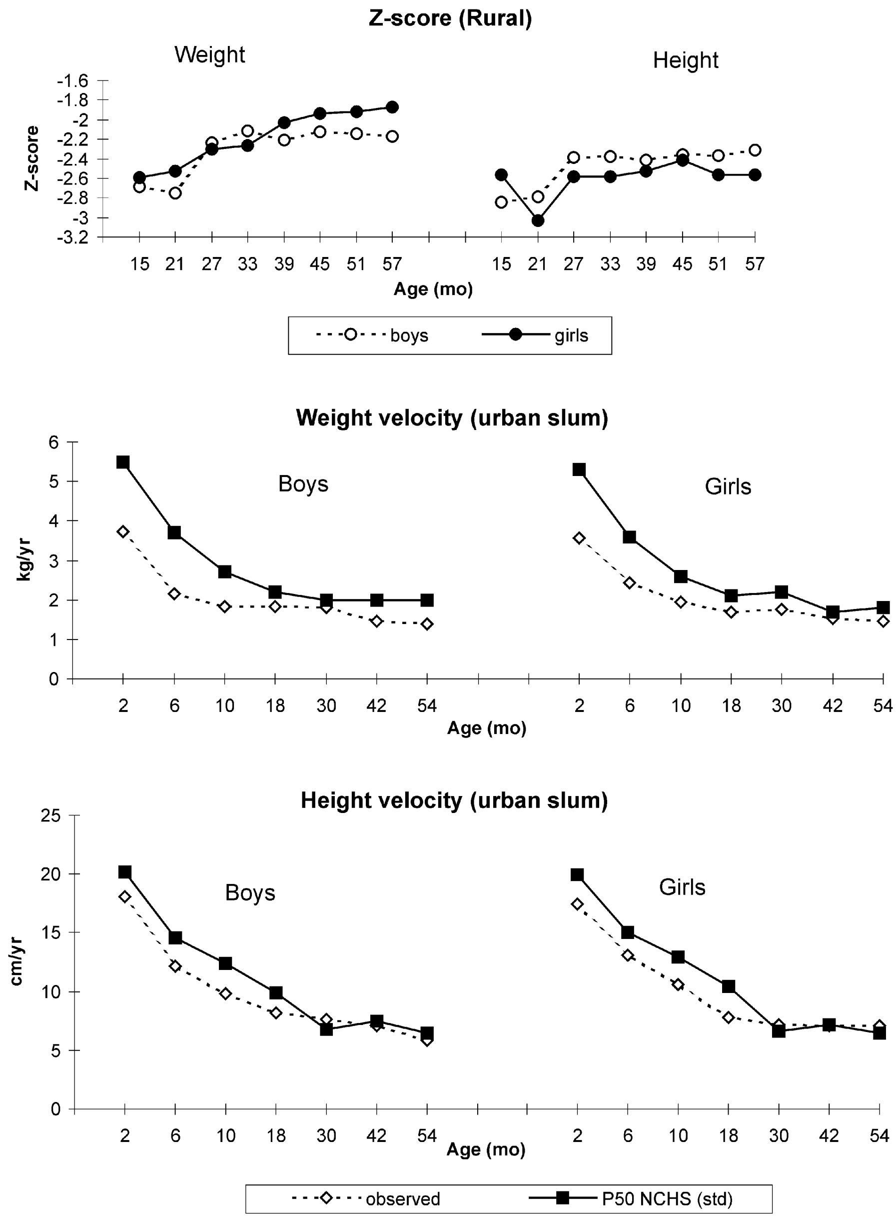

Figure 1. Mean *Z*-scores for weight and height by age for rural children and velocities for urban slum children in India.

while to note that the final adult size remained significantly smaller compared to normal.

3.3 *Adolescent pregnancy*

The continuation of growth at later ages, i.e. beyond 18 yrs especially among girls, is a matter of concern as they get married at an early age. We followed rural girls (*n* = 388) dropping out of our growth study due to early marriage for the period of 3 yrs. It was observed that adolescent pregnancy wastage was considerably higher (15–20%) if age at marriage was below 18 yrs, or if age at delivery was below 18 yrs, or if age at menarche was delayed (> 15 yrs) or when gynaecological age (duration between age at menarche and age at first conception) was less than 2 yrs. Thus delayed adolescent growth resulting in slow but significant stature growth at later ages coupled with poor nutritional status of rural girls and early marriage was responsible for significant adolescent pregnancy wastage in this community. While it is easy to advocate that age at marriage should be above the legal age, in reality it may be difficult to see it happening in the near future. Parents often feared that leaving young girls alone at home while they were at work was risky due to sexual abuse even by close relatives. As a result, majority of rural girls will continue to get married at an early age for a considerable time in the future. The alternative therefore, is to motivate them to postpone their first pregnancy (at least beyond 20 yrs) so as to reduce pregnancy wastage as well as maternal mortality. This will require untiring efforts through government programmes or NGOs to disseminate the necessary information through non-formal mass educational programmes for young rural girls.

3.4 *Linear components*

Undernutrition during adolescence not only delayed growth spurt but affected all the linear components of growth. Data on sitting height and leg length of rural boys was compared (figure 4) with reported Indian studies (Agarwal *et al* 1992; Dasgupta and Das 1997) and British data (Eleveth and Tanner 1976). This shows that rural boys have significantly smaller leg length compared to British children. However, this difference is reduced in case of middle class Bengali boys, and Indian well-off children have infact larger leg length than British children. Sitting height too showed a similar socio-economic gradient but unlike leg length, it was lower throughout adolescence when compared with British children even for well-off Indian boys (Rao *et al* 2000b). In fact, the difference in final adult size for leg length of rural boys when compared with British children was only 3 cm but was 8·4 cm in case of sitting height. It thus appeared that growth in leg length is influenced by postnatal environmental influences while growth in sitting height had probably intra-uterine nutritional influence apart from genetic influence. The possibility cannot be ruled out that in the event of maternal undernutrition during pregnancy,

Table 2. Attained heights (cm) of children at 10 + and 15 + yr according to nutritional status in early life.

Initial age (yr)	Nutritional status	Height (cm) at 10 + yr[a]		Height (cm) at 15 + yr[b]	
		n	Mean ± SD	*n*	Mean ± SD
1 +	Normal	32	130·4 ± 5·09*	18	157·4 ± 7·85
	Stunted	29	127·4 ± 4·33	19	153·7 ± 6·54
	Difference		3·0		3·7
2 +	Normal	60	131·0 ± 4·48**	40	157·3 ± 7·94*
	Stunted	57	126·7 ± 4·24	38	154·1 ± 6·29
	Difference		4·3		3·2
3 +	Normal	103	131·0 ± 4·50**	66	157·3 ± 7·82**
	Stunted	78	125·6 ± 4·53	58	152·8 ± 6·81
	Difference		5·4		4·5
4 +	Normal	102	131·5 ± 4·74**	66	158·5 ± 7·20**
	Stunted	117	125·0 ± 4·43	82	151·2 ± 7·65
	Difference		6·5		7·3
5 +	Normal	65	132·0 ± 4·33**	48	158·6 ± 6·36**
	Stunted	77	124·5 ± 4·25	52	150·1 ± 7·43
	Difference		7·5		8·5

*$P < 0·05$; **$P < 0·01$.
[a]Children available in early life and 10 + yr were considered.
[b]Children available in early life and 15 + yr were considered.

an attempt to protect the growth of vital organs, viz. brain and heart, affects trunk growth. Our hypothesis that sitting height is influenced by prenatal nutritional environment while leg height is influenced by postnatal nutritional influence is rendered some support from the observations on Japanese children (Tanner *et al* 1982). It was observed that although there was a significant increase in stature of Japanese children after the second World War, it was almost entirely due to increase in leg length.

The above observations have significant implications for nutrition intervention programmes for pre-school children. The resulting catch-up growth due to intervention may solely be due to growth in leg length bringing in some kind of disproportionate growth. In that case it may be necessary to develop an index of disproportionate growth and examine whether it shows any association with adult health risks.

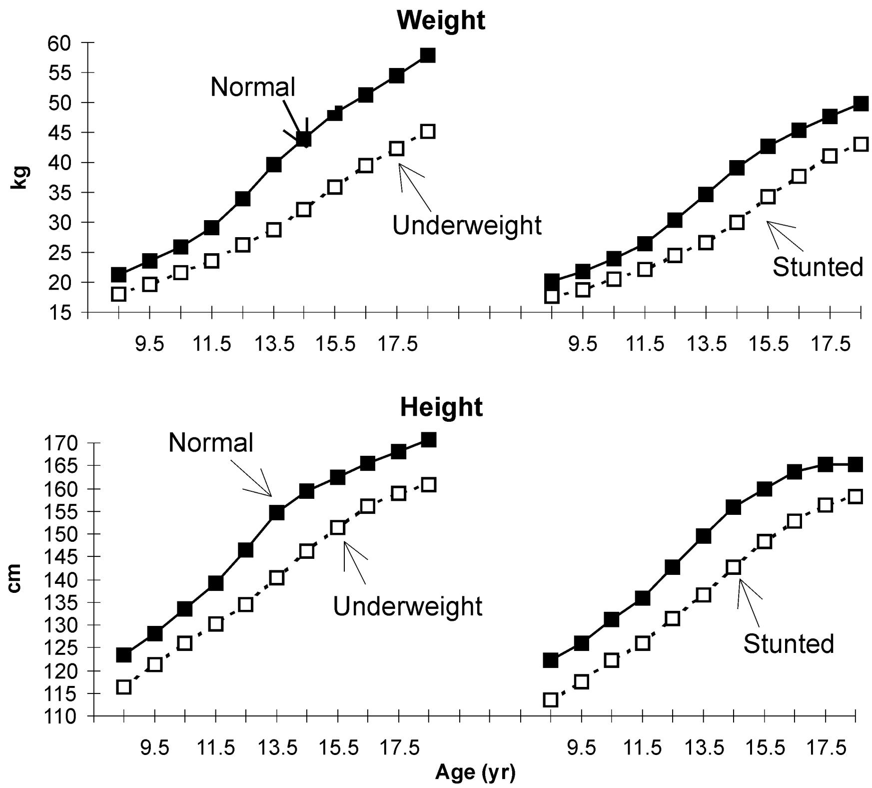

Figure 2. Mean attained weights and heights during adolescence for children who were underweight, stunted or normal at take-off.

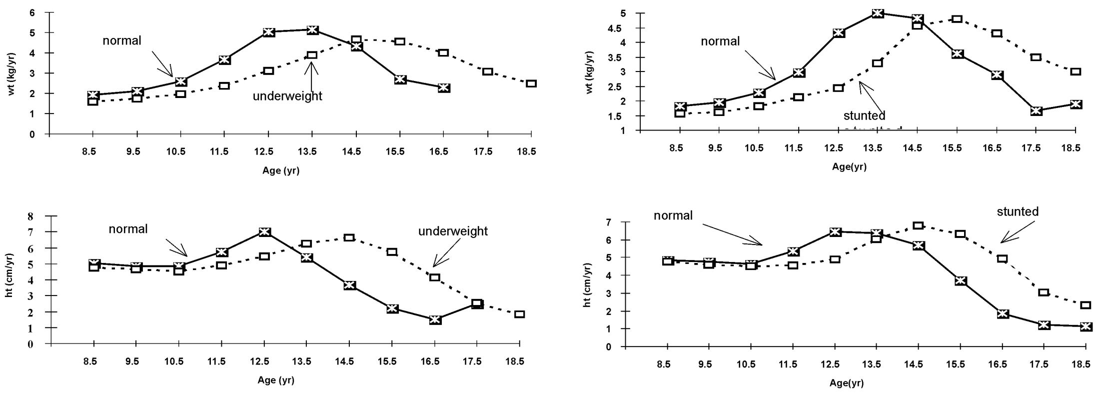

Figure 3. Weight and height velocities during adolescence for normal and undernourished rural Indian children.

4. Implications for adult health

The retrospective nature of observations based on which the fetal origins theory is proposed, overlooks the confounding effect of life style and environmental factors in determining the risks for adult diseases. Continuous exposure to poor environmental conditions, morbidity and undernutrition in rural India, need investigation of post-natal influences in determining the risks associated with adult diseases.

The results discussed in earlier sections clearly indicate that the majority of rural children continue to grow on a lower growth trajectory with low attained weights and heights as compared to their normal counterpart, and end up as small adults. But there may be some who have the opportunity for catch-up growth in postnatal life and may end up as tall or even fat adults. These situations reflect different interactions of prenatal and postnatal nutritional experiences and will certainly pose different risks for adult diseases. How it is possible to model these interactions for predicting risks of adult diseases is a major area left unanswered by the theory of fetal origins.

4.1 *Homeostatic view of adult health*

The homeostatic concept of adult health is based on the evidence of biological individuality witnessed by almost all physiological processes. For example, an individual is perfectly normal as long as his blood glucose is within the homeostatic range. Similar examples are of blood pressure and body temperature. However, these vital processes are finely regulated and operate within the narrow range of

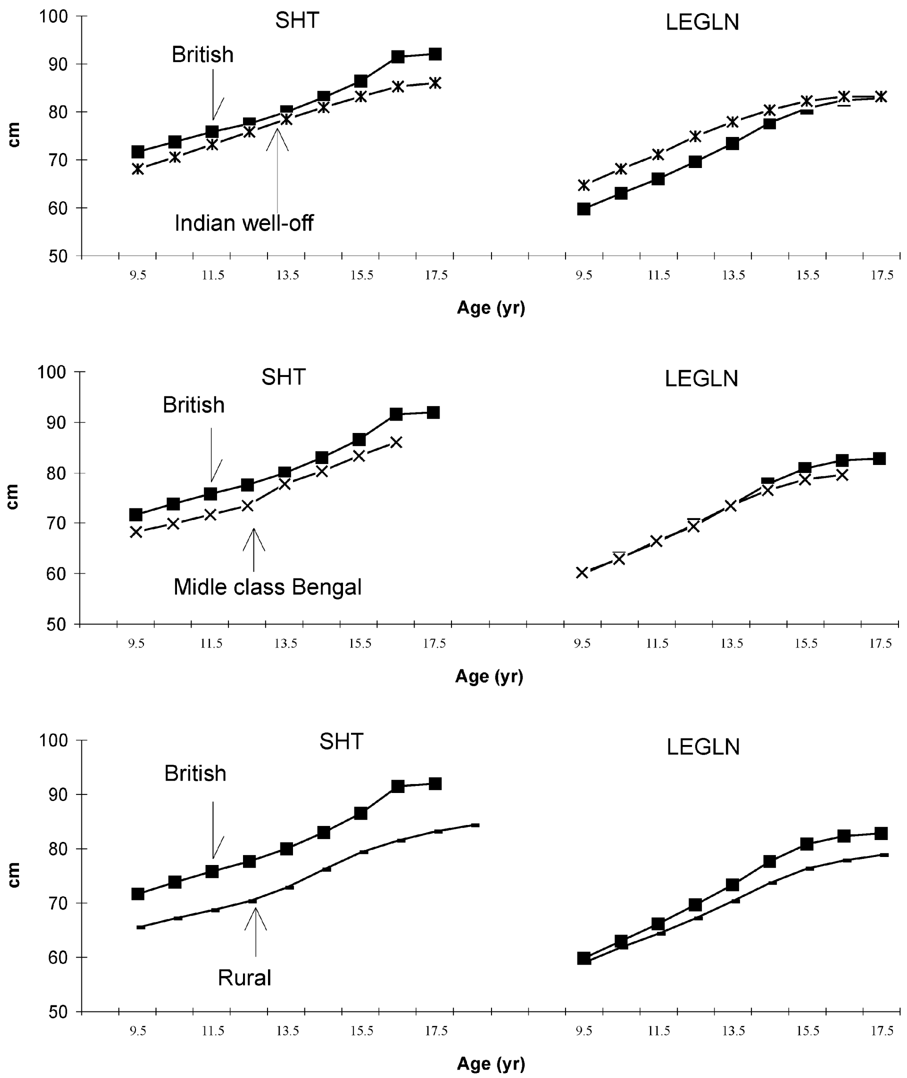

Figure 4. Comparison of sitting height (SHT) and leg-length (LEGLN) of Indian rural and well-off boys with British boys.

biological variability. The individual is under stress only when its homeostatic limits are crossed. For example, a normal healthy individual shifting to a high fat diet and lower physical activity is liable to disturb his homeostasis, encountering a risk of obesity and related adult diseases subsequently.

While variations between individuals, in any measurement can be attributed to extrinsic factors, variations within an individuals often arise due to interactions of an individual with environmental stimuli. We know that an individual grows from birth to adulthood along his growth trajectory and witnesses large variations around it, owing to his continuous interactions with the environment. Variations within individuals thus reflect the capacity to regulate the growth process. Interesting observations emerged when we analysed longitudinal data on weight and height velocities of children. It was observed that in successive periods of equal time interval, higher weight velocity in one period is followed by higher height velocity in the second period and showed systematic fluctuations indicating regulatory patterns in growth (Rao and Joshi 1992). It was clearly seen that even normal children do not grow with uniform growth rates and exhibit wide variations (Joshi 1996).

More importantly, it was observed that the range of systematic fluctuations was significantly smaller in case of undernourished children as compared to normal children. This suggests that the homeostatic limits of systematic fluctuations around the growth trajectory are narrower in undernourished children, compared to normal ones. It is commonly observed that a sickness of similar severity causes much more harm to an undernourished child than a normal child.

Undernourished people exhibiting lower capacity to interact with the environment would have a narrow range of homeostasis. It would therefore, be easier to understand why Asian population or persons of Asian ancestry living in western countries have elevated health risks at low levels of BMI, or waist circumference (Seidell *et al* 2001) and why the cut-off points based on conventional classifications of BMI are not applicable to them. A homeostatic view of adult health would thus give a new research focus.

The homeostatic view of adult health visualizes the dynamic equilibrium of physiological processes that maintain health. Short term perturbations such as an illness or changes in diet may temporarily disturb homeostasis, but there is always a movement towards attaining a balance through built-in autoregulatory mechanisms. But long term changes in lifestyle, i.e. increased inactivity or increased consumption of energy-dense foods will gradually disturb the homeostasis to result in health risks associated with increased body fat. Similarly, any imbalance between prenatal (programmed inutero) and postnatal nutritional experiences is likely to result in disturbing the homeostatic limits and thus in increasing the health risks. For example, recent studies (Lithell *et al* 1996; Philips 1996) bring out the fact that babies born with low birth weight but acquiring higher body fat postnatally have higher risks for insulin resistance and blood pressure.

The above discussion thus indicates that undernourished people in many developing countries including India, are exposed to the risks of adult diseases owing to current nutritional transition. With increase in income and growing affluence, shift in diet patterns and activity is becoming more and more obvious in urban areas. In contrast, drastic changes in diet, activity or other life style factors are not so obvious in the rural Indian population, and may explain why prevalences of adult diseases are still significantly lower in rural populations than urban populations in India. The risks of adult diseases can only be minimized by conscious efforts to avoide drastic shifts in diet and activity patterns.

5. Strategies for improving nutritional status

In the light of the above discussion, it is necessary to discuss some strategies required for improving the nutritional status of our people. The current research highlights the need for re-examining the existing programmes, identifying their limitations, ensuring logistics and feasibility rather than proposing new programmes. Some of the important considerations are the following:

- Maternal nutrition intervention programmes need to examine the role of micronutrient rich foods. Interventions to improve preconceptional maternal nutritional status of rural young girls may be more beneficial than those during pregnancy.
- In view of the increasing importance of micronutrients identifying functional or protective foods consumed in different rural communities of India is essential.
- Most problems related to maternal and child health will need awareness in rural mothers as supplementation cannot be a permanent solution.
- While it may be difficult to increase age at marriage in rural areas, postponement of first pregnancy appears to be a feasible and achievable goal to ensure better reproductive health.
- Policy for free education to girls implemented in some states of India has long term health benefits, as it will automatically delay the age at marriage and conception.
- It is highly essential that children below 3 yrs are covered in the on-going nationwide intervention programme so that they can have better adolescent growth and adult size.
- Drastic shifts in diet pattern and activity occurring in urban populations owing to nutritional transitions are

partly responsible for increased prevalences of adult diseases. The rural population may experience similar risks even at a relatively lower level of shift in diet pattern.

Finally, it cannot be denied that formulating appropriate programmes and strategies are essential but effective implementation is the key to success. Efforts are necessary for exploring non-nutritional avenues such as imparting knowledge about nutritional needs during pregnancy, lactation and infancy, and creating nutritional and health awareness among young rural girls to ensure a better quality of life for the next generation.

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