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Chronic undernutrition in pregnancy and lactation

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Based on the dietary energy supply per person per d and a minimum energy requirement of 1·4 × basal metabolic rate (BMR), it is estimated that 11–32% of adults in developing countries were undernourished (Food and Agriculture Organization, 1990). Even if adequate amounts of food are available, unequal food distribution favouring men over women and cultural taboos may restrict food intake of women. Since they are usually engaged in productive activities which entail a substantial energy expenditure (McGuire & Popkin, 1989), it is likely that the majority of undernourished adults in developing countries are women. Indeed, most publications from developing countries report low energy intakes of women, particularly during pregnancy and lactation. The high incidence of low birth weight and growth faltering at an early age have been attributed to maternal undernutrition. While there is no disagreement about the adverse effects of acute and severe energy deficits on the outcome of pregnancy and lactation (Stein *et al.* 1975; Prentice, 1980), no consensus has yet been reached on the relationship between maternal nutrition and reproductive performance in communities having marginal energy intakes either seasonally or chronically (Rush, 1983; National Academy of Sciences, 1990, 1991). Maternal depletion over the course of numerous reproduction cycles is an often hypothesized but little measured phenomenon (Merchant *et al.* 1990*a*,*b*).

Results of recent studies indicate that, in industrialized countries, healthy pregnant and lactating women who can eat to appetite do not increase their dietary energy intake to the degree recommended (World Health Organization, 1985), with no resulting impairment of their reproductive function (Whitehead *et al.* 1981; Durnin, 1987; National Academy of Sciences, 1990; van Raaij *et al.* 1991). The longitudinal study on energy requirements of apparently healthy pregnant women which included three developing countries (The Philippines, Thailand, The Gambia) did not show a consistent pattern of reproductive physiology (Durnin, 1987). The main problem lies in the concept of 'apparently healthy'. On the other hand, the extra energy requirement during lactation in developing countries may approach the dietary recommendation (Frigerio *et al.* 1991; Madhavapeddi & Rao, 1992).

The calculated energy requirements in pregnancy and lactation (World Health Organization, 1985) or observed energy intakes of apparently healthy women in industrialized countries bear little relationship to the needs of many Third World women who are poorly nourished to start with. For practical purposes it is more relevant to assess at which level of maternal energy status, child and maternal outcomes of reproduction are compromised.

Studies in The Gambia show that seasonal fluctuations in energy intake were reflected in concomitant weight changes of pregnant and lactating women, mean birth weight and the quantity and quality of breast milk were reduced, the incidence of low birth weight increased (Prentice, 1980). The improvement of energy intake and the replenishment of body fat during the period of abundance was not sufficient to subsidize the whole of a

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reproductive cycle in the lean period. Subsequent studies have produced evidence of a remarkable mechanism for coping with the extreme seasonal fluctuations in energy intake by an overall mobilization of body fat, a reduction of BMR and a reduction in physical activity towards the end of pregnancy (Prentice, 1984; Prentice & Whitehead, 1987).

In most areas with rain-dependent agriculture, seasonal fluctuations in energy balance may be less profound than in areas like The Gambia. To my knowledge, no published information is available of the repercussions of such seasonal stress on maternal nutrition during pregnancy and lactation. In a study of non-pregnant women the energy deficit *during* the lean season was compensated by losing weight and/or a reduction of BMR and/or a reduction of physical activities (Durnin, 1990: Ferro-Luzzi, 1990).

Some distinguished researchers claim that energy requirements for reproduction are relatively low and can be compensated by protective mechanisms such as lower BMR and reduced physical activity (Naismith, 1981; Prentice & Whitehead, 1987). Shetty (1990) in his review of energy metabolism in adults with low body weight and low body mass index (weight/height^2; BMI) concluded, however, that meaningful adaptive responses in energy expenditure could not be demonstrated. Increased metabolic efficiency in the BMR component of energy expenditure in such subjects may just be an illustration of decreased active tissue due to a change in body composition in response to chronic energy deficiency. Gopalan (1990) rightly states that a reduction in physical activity only maintains the low productivity and quality of life among populations in energy balance with their present poor diets.

The functional meaning of metabolic adjustments to seasonal hunger depends on whether or not such periods are superimposed on an already chronically-energy-deficient condition. Assuming that the degree of maternal undernutrition determines maternal response to reproductive stress, the recently introduced concept of chronic energy deficiency (CED) can be used in the analytical framework.

CED is defined as 'a steady state at which a person is in energy balance although at a cost, either in terms of risk to health or as an impairment of functions and health . . .' (James *et al.* 1988). Originally, the combined use of the physical activity level (PAL) as proxy for energy expenditure and BMI as proxy for energy reserves was suggested as criteria of CED. Later evidence showed that PAL was an unnecessary extra criterion, leaving BMI as the only indicator for CED (Ferro-Luzzi *et al.* 1992). Three grades of BMI were suggested to categorized CED as mild, moderate and severe, i.e. 17·0–18·4 (grade I), 16·0–16·9 (grade II) and less than 16·0 (grade III). Limited data from India suggest the same functional significance of BMI in adults as anthropometric indicators in young children. Among men lower BMI was related to higher mortality (Satyanaraya *et al.* 1991) and there was a remarkably close relationship between 24 h post-partum BMI categories and low birth weight (Naidu *et al.* 1991).

More information is needed to justify a definition of CED based on BMI for pregnant and lactating women. Data from a longitudinal study on maternal nutrition and reproduction in Madura, East Java will be used to address this issue.

CED IN PREGNANT AND LACTATING WOMEN IN EAST JAVA

The longitudinal study, known as the East Java Pregnancy Study (EJPS), was conducted in a rural community on the island of Madura, East Java province in the years 1981–89.

Details of the study population and methodology of data collection have been described in earlier publications (Kardjati *et al.* 1988, 1990; van Steenbergen *et al.* 1989; Kusin *et al.* 1990).

In summary, the study villages are located in a semi-arid zone along the coast. Mild seasonal fluctuations in energy intake of pregnant women were observed, the range between lean and harvest season being on average 6·3–7·1 MJ (1500–1700 kcal)/d.

As in any subsistence economy women are housewives and productive labourers. The activity records indicate that women were at most only moderately active. Irrespective of physiological state only 5–15% of the day (1–3 h) was spent on strenuous work, such as working in the fields, carrying large baskets of fish to the market, fetching water or collecting fodder. Thus, the level of physical activity would correspond to 1·5–1·7 × BMR (World Health Organization, 1985).

The framework of EJPS was a surveillance of all mothers with children aged 0–60 months and newly married couples. They were visited at home at four-weekly intervals to detect a pregnancy and to monitor growth of babies born in the study. On these occasions all women were weighed to provide prepregnant weight. Once a woman was found to be pregnant, she was asked to come to the antenatal clinic at four-weekly intervals for an obstetric examination. Birth weight was measured within 24 h after delivery. After delivery, the mother–infant pair was taken up in the surveillance system which ensured the measurement of mother's postpartum weight as well as infant's weight and length till the child was 12 months old.

In the first 3 years pregnant women were studied intensively. Anthropometric measurements were taken (height, weight, skinfold thickness at four sites, upper arm circumference). Their food consumption was measured, once in early pregnancy and monthly in the last trimester by the weighing technique over three consecutive days (Launer *et al.* 1991).

Data from women who had given birth to a single liveborn baby in the period September 1982–December 1989 in two study villages were analysed.

Prepregnant weight by height and BMI

A total of 972 women had given birth to 1782 single liveborn babies. Women were small (average height 1·50 m) and lean (average weight 42 kg). About 40% had a prepregnant weight of less than 42 kg. Mean BMI increases with weight and there was no relationship with height (Table 1). In fact, a very large percentage of women weighing less than 45 kg had a BMI below 18·5 and can be considered CED (Table 2). Of the total sample 2·6% can be categorized as severe CED, 10·3% as moderate CED and 28·4% as mild CED (not shown in Table).

The prevalence of CED was not related to parity and birth interval. The range was 51% for parity 1 to 28% for parity 7+ and 31% for birth interval less than 18 months to 28% for birth interval more than 27 months. There was no indication that women were not yet mature when they became pregnant for the first time.

These findings suggest that women of reproductive age were chronically undernourished initially. Thus, it is more likely that the degree of undernutrition will influence reproductive performance and probably fecundity rather than reproduction leading to maternal depletion.

Table 1. *Prepregnant body mass index (weight/height²; BMI) in relation to prepregnant weight and height categories for East Javanese women giving birth to single liveborn babies**

(Mean values and standard deviations; *n* 1089 single live births)

Prepregnant wt (kg)	Height (m)										BMI total	
	<1·45		1·45–1·49		1·50–1·54		1·55–1·59		≥1·60			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<42	18·7	1·2	17·8	1·1	17·0	0·9	16·4	0·6	16·2	–†	17·7	1·2
42–44·9	21·0	0·8	19·8	0·5	18·6	0·5	17·6	0·5	16·8	–†	19·1	1·1
45–48·9	22·3	0·6	21·2	0·6	19·8	0·6	18·8	0·5	18·2	0·5	20·0	1·2
≥49‡	–	–	23·0	0·5	21·4	0·5	20·4	0·6	19·7	0·5	22·2	2·0
BMI total	19·4	1·7	19·2	2·0	19·0	2·0	18·7	1·9	19·3	2·0	19·1	1·9

* East Java Pregnancy Study (Kardjati *et al.* 1988, 1990; van Steenbergen *et al.* 1989; Kusin *et al.* 1990).
† One subject only.
‡ 49–53 kg.

Table 2. *Percentage of chronic energy deficiency* relative to categories of prepregnant weight and height (percentages of total) for East Javanese women giving birth to single liveborn babies†*

Prepregnant wt (kg)	Height (m)					Percentage of wt category
	<1·45	1·45–1·49	1·50–1·54	1·55–1·59	≥1·60	
<42	4·0	13·0	10·1	1·8	0·1	73
42–44·9	—	—	3·9	3·5	0·1	29
45–48·9	—	—	—	1·1	0·6	7
≥49	—	—	—	—	—	—
Percentage of height category	30	36	41	48	35	38

* Body mass index (weight/height²) <18·5.
† East Java Pregnancy Study (Kardjati *et al.* 1988, 1990; van Steenbergen *et al.* 1989; Kusin *et al.* 1990).

The period of pregnancy

On average home diets contributed 6·7 MJ and 42 g protein/d (Launer *et al.* 1991). Energy intake would correspond to 1·6 × BMR for non-pregnant, non-lactating women of 42 kg weight.

Total weight gain in pregnancy was on average 6·6 kg. Compared with well-nourished British women (Taggart *et al.* 1967) skinfold thicknesses of Madurese women were much lower, about 50% lower at the triceps and biceps sites and 15–20% lower at the subscapula and suprailiac sites (Kardjati *et al.* 1990). The difference in BMI before pregnancy and at 4–7 weeks post partum illustrates the net weight gain in pregnancy (Table 3). There was a clear and differential response to reproductive stress by BMI

Table 3. *Changes in body mass index (weight/height²; BMI) over pregnancy in relation to categories of prepregnant BMI for East Javanese women giving birth to single liveborn babies**

(Mean values and standard deviations)

Prepregnant BMI	*n*	BMI: Prepregnant Mean	SD	BMI: 4 weeks post partum Mean	SD	Change in BMI 4 weeks post partum minus prepregnant Mean	SD
<16	23	15·3	0·7	16·6	1·6	+1·3[a]	1·6
16–16·9	64	16·6	0·3	17·7	1·1	+1·1[a]	1·0
17–18·4	192	17·2	0·4	18·6	1·0	+0·8[b]	1·0
≥18·5	429	20·2	1·6	20·2	1·7	0·0[c]	1·4
All	708	19·1	1·9	19·4	1·8	+0·3	1·3

[a,b,c] Mean values with unlike superscript letters were significantly different: [a,b] $P<0·001$, [b,c] $P<0·01$.

* East Java Pregnancy Study (Kardjati *et al.* 1988, 1990; van Steenbergen *et al.* 1989; Kusin *et al.* 1990).

categories. CED mothers (BMI less than 18·5 and prepregnant weight less than 42 kg) gained weight during pregnancy. Non-CED mothers did not lose weight but they also did not build up fat reserves.

Prepregnant BMI and fetal growth

In view of the weight changes during pregnancy, one can reasonably assume that the habitual dietary energy intake was not sufficient to support adequate fetal growth, and maternal energy reserves before pregnancy would be crucial. Table 4 shows that the relationship between prepregnant BMI and fetal growth. There was an upward gradient in mean birth weight with increasing prepregnant BMI and a corresponding decrease in

Table 4. *Birth weight and incidence of low birth weight (LBW) in relation to categories of prepregnant body mass index (weight/height²; BMI) in East Javanese women giving birth to single liveborn babies**

(Mean values and standard deviations)

Prepregnant BMI	*n*	Birth wt Mean	SD	Percentage LBW (<2500 g)
<16	28	2729[a]	332	21[d]
16–16·9	94	2859[a]	343	10[d]
17–18·4	266	2941[b]	380	8[e]
≥18·5	608	3025[c]	358	5[e]
All	996	2978	368	7

[a,b,c,d,e] Mean values in vertical columns with unlike superscript letters were significantly different: [a,b] $P<0·001$, [b,c] $P<0·01$, [d,e] $P<0·003$.

* East Java Pregnancy Study (Kardjati *et al.* 1988, 1990; van Steenbergen *et al.* 1989; Kusin *et al.* 1990).

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Table 5. *Body mass index (weight/height^2; BMI) in the first year post partum in relation to categories of weight at 4 weeks post partum for East Javanese women giving birth to single liveborn babies*‡

(Mean values and standard deviations)

Mother's wt (kg) 4–7 weeks post partum . . .	BMI											
	<36		36–37·9		38–41·9		42–49·9		≥50		All	
Period post partum (months)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	16·3*†	1·4	17·4	0·9	18·3	1·0	19·8	1·3	22·6	1·8	19·4	1·9
3	16·5*†	1·4	17·6	1·0	18·3	1·1	19·8	1·3	22·5	1·9	19·4	1·9
6	16·8*†	1·7	17·6	1·1	18·2	1·2	19·6	1·4	22·2	2·2	19·3	1·9
12	17·5*†	2·1	17·8	1·2	18·3	1·4	19·5	1·5	21·8	2·1	19·2	1·9

Mean values for <36 kg group were significantly different from those for 36–37·9 kg: $^*P<0·05$.
Mean values for <36 kg group were significantly different from those for all other groups (≥36 kg): †$P<0·001$.
‡ East Java Pregnancy Study (Kardjati *et al.* 1988, 1990; van Steenbergen *et al.* 1989; Kusin *et al.* 1990).

the incidence of low birth weight. A very high incidence of low birth weight (21%) was only observed in the severe CED group, but the incidence in the other CED groups was still two times higher than that in the non-CED group.

Mothers' weight changes in the first 12 months post partum

Breast feeding is a natural process in the Madurese community and the median duration of lactation is 18–24 months. Daily energy intake during lactation was about 0·8 MJ/d higher than that during pregnancy, while activity levels were similar across physiological states (J. A. Kusin, Sri Kardjati and U. H. Renqvist, unpublished results). The average weight loss in the first 12 months post partum was 0·7 kg, but the variation was large. The pattern of weight changes in the first year after birth by categories of 4–7 weeks postpartum weight was similar to that over pregnancy (Table 5). The severe CED women gained weight (2·5 kg), so did the moderate CED group, but much less (0·8 kg), and the non-CED group lost weight (0·8 kg).

Infant growth in the first year

If weight gain in CED women during lactation reflects a repletion of her own energy stores, one may expect reduced breast milk production and poor growth of their infants. Unfortunately it is customary to force-feed infants from as early as the first week after birth, although the semi-solid additional food (mashed rice and banana) does not influence milk production (van Steenbergen *et al.* 1991). Thus, infants' growth may be a crude proxy of breast milk intake. To adjust for birth weight, infant growth is presented in two categories with the mean birth weight (2800 g) of infants of the severe and moderate CED women as the cut-off point. Table 6 illustrates the expected upward gradient in weight increment with increasing BMI of mothers. The differences between the groups whose maternal prepregnant BMI were below 17 and the groups with higher maternal prepregnant BMI was significant only for the higher birth weight category. The

Table 6. *Postnatal growth of infants according to mother's prepregnant body mass index (weight/height²; BMI) for East Javanese women giving birth to single liveborn babies*†

(Mean values and standard deviations; nos. at birth adapted to nos. at 3 months)

Mothers' BMI . . .	<17		17–18·4		≥18·5		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Birth wt <2800								
n	16		64		93		173	
Birth wt	2577	185	2483	218	2553	176	2519	203
Wt gain 0–12 months	5100	585	5325	1043	5412	928	5345	928
Birth wt ≥2800								
n	27		125		378		517	
Birth wt	2981	168	3104	225	3142	260	3131	256
Wt gain 0–12 months	4558*	803	4909	861	4932	930	4896	909

Mean value was significantly different from those for all other groups: $*P<0\cdot05$.
† East Java Pregnancy Study (Kardjati *et al.* 1988, 1990; van Steenbergen *et al.* 1989; Kusin *et al.* 1990).

lower weight increments in this category are difficult to explain; it is tempting to attribute them to substrate limitation of milk production to a level insufficient for the bigger babies. One can at least conclude that infants born to CED women are not 'in the driving seat' with respect to determining energy intake according to their needs.

FOOD FOR THOUGHT

Maternal nutrition has been studied in relation to fetal growth, lactation and infant growth but the effect of reproduction on women's nutritional status has received limited attention (Krasovec & Anderson, 1991). There is evidence that pregnant and lactating women can be in energy balance on surprisingly low energy intakes, admittedly 'not always compatible with an optimum quality of life' (Prentice, 1984). An understanding of the limits of the maternal body to support fetal and infant growth without depleting her own energy reserves is a condition for any intervention programme to promote the well-being of mother and infant.

In the population for our study the cut-off point in BMI of 18·5 did differentiate women in terms of maternal and infant outcomes of reproduction. The high prevalence of CED before the first pregnancy suggests that undernutrition among women of reproductive age is primarily a result of low energy intakes. In such a situation it is more likely that undernutrition will influence reproductive performance rather than reproduction having an adverse effect on maternal energy status.

Prepregnant weight and BMI was found to determine maternal response to reproductive stress in such a way that pregnancy and lactation appear to promote weight gain in chronically undernourished women to the detriment of fetal and infant growth. Contrary to conventional wisdom, maternal weight gain during pregnancy and lactation among Madurese women was an indication of a poor maternal energy status and predictive of a poor reproductive outcome!

There are very few studies for comparison. In The Gambia there was evidence of a competition between repletion of maternal subcutaneous fat and milk production in

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undernourished lactating women (Paul *et al.* 1979) and being pregnant appears to benefit a woman's own energy balance (Durnin, 1987). Most comparable to our study is that of Winkvist (1992). She examined weight changes over two consecutive pregnancies among Pakistani women and did a secondary analysis of data from the well-known supplementation study in Guatemala. The net weight change during one reproductive cycle was defined as the difference in 1–3 months postpartum weight of two consecutive pregnancies. The largest positive maternal weight gain and the highest negative difference in mean birth weight between two consecutive births was observed in the low initial weight group. In a comparable study in the Philippines weight changes during lactation did not differ across the range of postpartum weight and BMI, although maternal weight and height distribution was similar to that in East Java (Adair *et al.* 1990).

Through which processes would CED women replete their energy stores at the expense of the fetus and infant? The homeostatic mechanism that regulates the partitioning of dietary energy during reproduction and growth in the human are poorly understood. Quantitative aspects of the partitioning of nutrients between mother and offspring have been extensively studied in animal sciences. Compartmentalization to protect maternal health seems to depend on previous maternal nutritional status (Glore & Layman, 1985; Young & Rasmussen, 1985; Sadurskis *et al.* 1991). Work still remains to be done on the relationship between maternal nutrition and weight gain and the outcome at birth in humans. Path models, used to analyse the effect of the famine of the 1944–5 winter in The Netherlands suggest that under famine conditions there may be a shift in the role of the placenta in the passage of nutrients from the mother to the fetus to the advantage of the mother (Susser, 1991).

Whatever the mechanisms underlying the preferential partitioning of energy to the CED mother, they may explain the modest effect or absence of an effect of energy supplementation to undernourished pregnant and lactating mothers. Additional criteria for selection of beneficiaries (level of maternal BMI) and maternal indicators for evaluation of impact are needed.

Communities in developing countries are not homogenous and the observations in one area will certainly not have a universal validity. Nevertheless one can conclude that weight monitoring of mothers is as essential as growth monitoring of young children. Indeed, by concentrating entirely on child malnutrition, one has distorted the picture of food needs in developing countries (Ferro-Luzzi *et al.* 1992). The Safe Motherhood Initiative, designed to reduce maternal mortality, is too limited to address the problem of maternal ill health and undernutrition.

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