FREQUENT REPRODUCTIVE CYCLING: DOES IT LEAD TO NUTRITIONAL DEPLETION OF MOTHERS?

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ABSTRACT

Is frequent reproductive cycling (episodes of pregnancy and/or lactation) in poor women from developing countries a cause of poor maternal nutritional status? This review seeks to examine the evidence available to answer this question. The measurement of reproductive cycling, maternal nutritional status, and the energetic costs of pregnancy and lactation are reviewed. The data available on the anthropometric changes during pregnancy and lactation are described. Against this background, the evidence in support of the hypothesis that repeated reproductive cycling leads to a maternal depletion syndrome is examined. It is concluded that although the data are inadequate to unequivocally establish or rule out the existence of maternal nutritional depletion due to a demanding reproductive history, the data suggest this relationship does exist. Weaknesses of current measurement and study design methodologies are identified and priorities for future research aimed at clarifying the extent to which reproductive cycling affects maternal nutritional status are identified.

KEY WORDS: Maternal nutrition, Pregnancy, Lactation, Energy balance, Energy cost, Birth spacing

MATERNAL DEPLETION SYNDROME

The energetic and nutrient demands placed on women during pregnancy and lactation frequently have been identified as major nutritional stresses in the lives of women (1-3). How these stresses are accommodated has been an active area of research recently. The expectation has been that women cope with the increased demands arising out of the reproductive process through one or more of the following mechanisms: increased dietary intakes, reduced activity levels and catabolism of maternal tissues (4). More recently, some investigators suggest that metabolic adaptations during pregnancy and lactation also enable women to maintain energy balance (5-7).

Key questions remain unresolved including the following: To what degree do women need to increase dietary intakes and/or decrease activity levels to cope with reproductive stress without compromising maternal health? Are recovery periods between reproductive cycles necessary for women's health? How are women - who live under conditions where dietary intakes are marginal and where physical labor demands are high-- able to accommodate the nutritional stresses of reproduction? Is it by increasing intake, decreasing activity and/or spacing pregnancies? To what extent are metabolic adaptations complementary or alternative coping mechanisms? Although these questions clearly have relevance

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to all women and children, the focus of this article is on women of marginal nutritional status living in poverty in developing countries.

Reproductive cycling is the term used in this article to refer to both the frequency and duration of periods of gestation, as well as the frequency, duration and intensity of periods of lactation. The term maternal nutritional status can be used to encompass biochemical measures of levels and stores of vitamins and minerals, clinical signs of deficiency, as well as more general anthropometric measures of body tissue stores. The emphasis of this article is on the anthropometric measures of body tissue stores--because more data of this type are available and because anthropometric measures provide a useful summary indicator of long-term energy balance.

The extent to which reproductive cycling affects maternal nutritional status is the primary focus of this review. The impact of one pregnancy-lactation cycle or a portion of this cycle (short-term) as well as the cumulative impact of a number of cycles (long-term) on a woman's nutritional status is examined.

Unfortunately, little research has focused specifically on the relationship between reproductive history and maternal nutritional status. This review article begins by introducing in greater detail the concept of maternal depletion syndrome, followed by a review of recent work on energy balance during pregnancy and lactation. Next, methods of measuring maternal nutritional status during pregnancy and lactation are reviewed briefly and a detailed presentation of key studies of anthropometric changes during pregnancy and lactation is made, followed by an evaluation of current approaches to the measurement of reproductive cycling. Then, after drawing from these varied yet related topics, the limited evidence regarding the relationship between reproductive cycling and nutritional depletion is examined. Finally, the information reviewed is summarized and priorities for future research aimed at clarifying the extent to which reproductive cycling affects maternal nutritional status are identified.

Women in developing countries, are pregnant, lactating or both during large portions of the reproductive years (i.e., menarche to menopause) with--it is believed--detrimental effects on maternal nutritional status. Some researchers have used the term "maternal depletion syndrome" to refer to these repercussions on maternal health (8), but others question whether this characterization is appropriate (9-11). In the nutritionally-based model of maternal depletion syndrome, it is hypothesized that the greater energetic and nutrient demand on the mother during pregnancy and lactation results in a compromised nutritional status when many cycles of pregnancy and lactation occur within a short time-interval under conditions of relatively poor dietary intakes (12).

The increased biological stress may be accompanied by social/environmental stress for the mother due to the increase in family size which results from frequent reproductive cycling. Specifically, the increase in family size further limits resources of time and money, potentially reducing the quality of care of the children while increasing the burdens on the mother. In spite of the recognition that a larger context exists, the focus in this review is on the stress of reproductive cycling on maternal nutritional status.

Figure 1 provides a simple conceptual framework to describe the major factors related to reproductive behavior which deplete or benefit the nutritional status of women. It is not meant to provide an exhaustive description, but rather a scheme for organizing key concepts. Poverty directly (e.g., poor diets, heavier workloads, greater rates of infection) or indirectly (e.g., reduced access to and demand for family planning methods and therefore increased frequencies of conception) determines the negative demands on maternal nutritional status.
These challenges may be offset or prevented through various strategies such as nutritional supplementation, increased time intervals between births, improved environmental sanitation, greater access to health care and reduced activity levels. Maternal nutritional status leads to secondary outcomes affecting both mother (e.g., activity patterns, morbidity and mortality) and child (e.g., pregnancy outcome --birth size, gestational age--, lactation performance, the child's nutritional status, morbidity and ultimately mortality).

**ENERGY BALANCE**

It is important to consider the stress of reproductive cycling on maternal nutritional status in the wider context of energy balance because energy is such a fundamental component of metabolism. The various flows of energy of four physiological states are diagrammed in Figure 2. Two sources may contribute to the available energy pool, dietary intake (following ingestion, digestion, and absorption) and maternal tissue (following mobilization from storage). Use of the pool of circulating energy depends upon the physiological status of women. In a non-pregnant, non-lactating state, energy metabolism is regulated by homeostatic mechanisms; work and body tissue are the two potential targets of input energy (as shown in panel A).

The mechanisms regulating energy metabolism during pregnancy and lactation can be more accurately described as homeorhetic rather than homeostatic because
they coordinate a directed flow of energy. Homeorhesis is defined by Bauman and Currie (13) as "orchestrated changes in metabolism of body tissues necessary to support a physiological state." During pregnancy, an additional target for the available energy is fetal growth (panel B). Similarly, during lactation, the process of milk production claims a share of the available energy (panel C). When a woman is both pregnant and lactating, the potential use of the available energy is most diverse (panel D).

![Diagram A: Non-pregnant/Non-lactating](image)

![Diagram B: Pregnancy](image)

![Diagram C: Lactation](image)

![Diagram D: Pregnancy & Lactation](image)

**FIG. 2: Components of Energy Balance During Reproduction**

**Pregnancy**

Some of the commonly-held beliefs concerning the energetic needs of pregnancy are being challenged (5, 14-16). The theoretical estimate of the total energetic cost of pregnancy made by Hytten and Leitch (4) using a factorial approach (the cost of each component of use is estimated and summed) was 312 MJ (approx. 75,000 kcal). This estimate was later revised to 355 MJ (approx. 85,000 kcal, (17)). The FAO/WHO/UNU (18) use 335 MJ (80,000 kcal) as the theoretical estimate of the increased cost of pregnancy.

Newer evidence from a variety of countries suggests that the current estimates of the energetic cost of pregnancy are inflated. The results of a five country study were published recently in a series of articles coordinated by Durnin (5, 19). Studies were conducted of pregnant women from Scotland (20), the Netherlands (21), Thailand (22), the Gambia (23), and the Philippines (24); it was concluded that the energy cost of pregnancy is more likely to be about 250 MJ (60,000 kcal).

Major discrepancies between theoretical estimates and experimental results from Durnin's multicenter study occur in the case of two components of energetic cost: maternal fat gain and basal metabolism during pregnancy. Hytten and Leitch (4) estimated that 148 MJ (approx. 35,500 kcal) were needed for increased maternal fat tissue and that 121 MJ (29,000 kcal) were required for increased oxygen
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consumption during pregnancy. These are 47% and 39%, respectively, of the total estimated energy cost. The value for increased oxygen consumption later was revised to 164 MJ (approx. 39,500 kcal) (17), making the increased maternal fat and increased oxygen consumption cost 42% and 46% of the total estimate, respectively.

A summary table (Table 1) of the results from the five-country study demonstrates that in no case was the mean fat gain more than 2.3 kg, or 38% of the total observed/calculated energetic cost. An interesting aspect of these data is that in spite of tremendous diversity of conditions, varying techniques to estimate fat and differing absolute mean fat gains among the study populations, there is remarkable consistency in the percentage (31 to 38%) of the total energy cost that was used for maternal fat deposition. In order to demonstrate the importance of the magnitude of the maternal fat gain component in the estimation of the energetic cost of pregnancy, the cost has been calculated (Table 1) for each sample as if the mean gain had been 4.0 kg (C4).

Note that the energy gap between the expected theoretical cost (Ct = 312 MJ) and the C4 estimate is much smaller (particularly in the case of Thailand, the Philippines and the Gambia) than the gap between the theoretical cost (Ct) and the measured cost (Cm). It appears that the theoretical cost is overestimated mainly due to the assumption of a 4 kg gain in fat during pregnancy.

TABLE 1
Fat Gain, Relative Energy Cost of Fat, Total Energy Cost and Total Energy Gap during Pregnancy from a Five-Country Study

<table>
<thead>
<tr>
<th>sample size</th>
<th>fat gain (kg)</th>
<th>energy cost of fat</th>
<th>total energy cost (MJ)</th>
<th>total energy gap (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SE</td>
<td></td>
<td>Ct C4 C4 - Ct</td>
<td></td>
</tr>
<tr>
<td>Scotland</td>
<td>2.3 (0.3)</td>
<td>37.7</td>
<td>281 327</td>
<td>31 -15</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2.0 (0.3)</td>
<td>32.2</td>
<td>286 346</td>
<td>26 -34</td>
</tr>
<tr>
<td>Gambia</td>
<td>0.6 (0.3)</td>
<td>35.4</td>
<td>78 202</td>
<td>234 110</td>
</tr>
<tr>
<td>Thailand</td>
<td>1.4 (1.1)</td>
<td>31.0</td>
<td>208 296</td>
<td>104 16</td>
</tr>
<tr>
<td>Philippines</td>
<td>1.3 (0.3)</td>
<td>33.0</td>
<td>181 273</td>
<td>131 39</td>
</tr>
<tr>
<td>Theoretical</td>
<td>4.0</td>
<td>48.7</td>
<td>C4 = 312</td>
<td></td>
</tr>
</tbody>
</table>

Ct = theoretical estimate of total energy cost (4)
Cm = measured total energy cost (5)
C4 = Five-country estimates of total energy cost if 4.0 kg of fat had been gained rather than what was actually gained.

The Gambian absolute mean fat gain is strikingly low compared to the mean fat gain in each of the other four samples. Seasonality and food availability are important determining factors of patterns of fat gain and loss in the Gambian population. Although the mean fat gain of the Gambian women in this sample was 0.6 kg, those who received an energy-rich supplement had a mean fat gain of 2.0 kg after adjustment for seasonality. This is similar to the mean fat gain of the Scottish and the Dutch women (Table 1).

The results of this five-country study challenge the commonly-accepted estimation that a "normal" pregnancy results in a mean storage of 4 kilograms of fat. Rather, there appears to be tremendous variation between women and across cultures and socioeconomic strata and there is no evidence of adverse functional outcomes associated with fat gains in the range of 2 to 2.5 kg.

The other major component of the energetic cost of pregnancy is the basal metabolic or resting metabolic rate. The "normal or average" range of this
component is also controversial. Results from two (the Gambia and Scotland) of the five countries studied suggest that women have lower metabolic rates early in pregnancy (6, 25) than originally expected (4). These investigators suggested that the lower resting metabolic rate may be an adaptation to the high energy cost of pregnancy. In the case of the Gambia, it has been suggested that adaptation (or accommodation to adverse circumstances) of a population that experiences chronic, cyclic and severe food shortages has occurred. Illingworth and coworkers (15) recently reported a 28% reduction in postprandial energy expenditure during the middle trimester of pregnancy in seven healthy women relative to the values obtained post-lactationally in the same women. The specific physiological mechanisms for proposed adaptations or accommodations have not been delineated.

Women completing "successful, normal" pregnancies do not appear to be increasing their dietary intake to the degree that currently is being recommended (6, 14, 16, 20, 21, 23, 24). This discrepancy may be largely a result of the fact that energy requirements allow for an unrealistic increase of 4 kg of maternal fat during pregnancy.

The energetic cost of physical activity during pregnancy is the component of energy balance remaining to be explored in the effort to explain the apparent discrepancy between measured intakes and estimations of the total energetic cost of pregnancy. Most studies of activity patterns indicate that major alterations do not occur during pregnancy and the postpartum period in most societies (16, 26). Yet, minor changes may play an important role in determining requirements if sustained over several months. McNeill and Payne (27) reported that patterns of physical activity from 115 rural south Indian women (using 24 hr recall) suggest that pregnant and lactating women spend more time in personal activities (mainly resting) and less time in social activities, working in the fields, and travel than do non-pregnant, non-lactating women." The degree to which energy spent on physical activity can be reduced is dependent on the level of activity normally engaged in. McNeill and Payne (27) suggested that "where the normal level of physical activity is high, significant changes (15-20% lower than non-pregnant, non-lactating)" in activity may occur. The problem however, is that current methods lack the necessary precision for recording such changes.

Not only can women's use of time change during pregnancy but also the cost associated with a particular activity can change. The increase in maternal body weight which occurs during pregnancy will increase the cost proportionately of weight bearing activities (28). Banerjee and coworkers (29) showed no significant differences between 42 pregnant and 37 non-pregnant women in the energetic cost per unit of body weight of eight common daily activities.

Several investigations indicate that the energetic cost of non-weight bearing activity (pedaling on a bicycle ergometer) does not differ for women between pregnancy and the postpartum period (30, 31). In contrast, Pernoll and coworkers (32) reported a significant increase in oxygen consumption and in the length of the recovery period (or oxygen debt) for women pedaling a bicycle ergometer during pregnancy compared to the postpartum period.

The conflicting results may be due to the fact that the timing of the measurement in the postpartum period differed between the studies, 6 wk (30), 3 mo (31) and 6 mo (32) following birth. Another problem is that it is extremely difficult to standardize exercise conditions for even a carefully controlled oxygen consumption measurement. As Illingworth and coworkers (15) point out "any changes in posture act as a potent stimulus for the release of noradrenaline which will itself promote a significant increase in metabolic rate" (33). In addition, the energetic cost and therefore oxygen consumption is affected by mechanical efficiency (which varies as a function of posture) and by training.
These difficulties prevent a conclusive statement on the contribution of physical activity to the energy-balance equation. The measurement of energy expenditure using doubly labelled water appears to be a promising technique for the clarification of pregnancy-related changes (34-36). Davies and coworkers (37) used this method for making serial measurements at 6-week intervals in 7 well-nourished pregnant British women (following prepregnant baseline measurements). Prentice (36) summarized the major finding as "the metabolic and behavioral responses to pregnancy are extremely variable"; and also stated that "none of the subjects showed any energy-sparing decreases in the cost of physical activity."

**Lactation**

Investigations addressing the energetic costs of lactation have been reviewed thoroughly by Prentice and Prentice (38) and is dealt with only briefly here. As in the case of pregnancy, the recommended dietary intake for this period seems to be substantially higher than observed values (16). This discrepancy occurs in spite of the fact that recommendations for dietary intake during lactation assume that some of the energetic need will be supplied by maternal fat mobilization, as demonstrated by Thomson and coworkers (39).

The recommended energy intake during lactation of 2092 kJ/d (500 kcal/d) is based on the expectation that 150 MJ (36,000 kcal) will be available from the 4 kg of fat deposited during pregnancy. This energy store is expected to provide 837 kJ/d (200 kcal/d) for 6 months, reducing the additional energy required to sustain lactation from 2929 kJ (700 kcal/d) to 2092 kJ/d (500 kcal/d). Of course, if the average fat gain during pregnancy is 2 kg and not 4 kg, the net energy contribution of fat losses would be reduced from 200 kcal/d during the first six months. The total energetic cost of lactation is estimated using data derived from the results of the WHO Collaborative Study on Breastfeeding (40) which are summarized in Table 2 (18). This estimate is consistent with the estimate reported by Gopalan and Belavady (41) of an increased energetic requirement for a sample of lactating Indian women on "the order of 500 to 700 calories per day".

<table>
<thead>
<tr>
<th>Month of Lactation</th>
<th>Median volume of milk (ml/d)</th>
<th>Energy content of milk (kcal/d)</th>
<th>Energy cost of lactation (kJ/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>719</td>
<td>503</td>
<td>2105</td>
</tr>
<tr>
<td>1-2</td>
<td>795</td>
<td>556</td>
<td>2326</td>
</tr>
<tr>
<td>2-3</td>
<td>848</td>
<td>594</td>
<td>2485</td>
</tr>
<tr>
<td>3-6</td>
<td>822</td>
<td>575</td>
<td>2405</td>
</tr>
<tr>
<td>6-12</td>
<td>600</td>
<td>420</td>
<td>1757</td>
</tr>
<tr>
<td>12-24</td>
<td>550</td>
<td>385</td>
<td>1610</td>
</tr>
</tbody>
</table>

*Data from the results of WHO Collaborative Study on Breastfeeding (40).*

b *Taken as 0.7 kcal (2.9 kJ)/ml.*

c *Assumed efficiency of conversion = 80%.*

These calculations are highly dependent on the amount of milk produced. Measurement of the amount of milk produced daily is a challenge. Traditional methods such as weighing the infant before and after each suckling period are notoriously difficult to carry out and are obtrusive in such a way as to change patterns of breastfeeding and even milk output on the measurement day. New techniques using deuterium oxide show promise but require further development (42, 43). Also, the measurement of dietary intake and energy expenditure due to physical activity remain problematic during lactation as in pregnancy.
As with pregnancy, investigators have looked for evidence of energy-sparing adaptations to lactation. The evidence regarding changes in basal metabolic rates during lactation is inconsistent. Although an increase in basal metabolic rates would be expected (due to milk synthesis), some studies have not only shown no evidence of an increase but rather a decrease (38). In addition, Illingworth and colleagues have observed lower postprandial thermogenesis in lactating women compared with women who are not lactating (44).

Generally lactation is recognized to lead to weight loss and some of these data will be presented in the following section. Data from Gambian women (45) however, suggest that fat loss during lactation does not always occur and that it is dependent on other components of energy balance (particularly, dietary intake). As previously mentioned, seasonality affects food availability and physical activity in Gambian women. Weight loss (shown to be highly correlated with fat changes) was observed in lactating women in this population during the wet season (the season in which food availability is decreased and physical demands are increased) and weight gain was observed in lactating women during the dry season. There are also data of postpartum weight changes from women in affluent societies demonstrating that weight loss in lactating women was not greater than that of non-lactating women (38). Prentice and Prentice (38) suggest that "it is probably more realistic to view women's large adipose tissue stores as an emergency buffer against acute restriction of food intake."

In a small sample (n=18) of Guatemalan women it appears that the energetic cost of lactation was supplied almost entirely by fat tissue mobilization (rather than by increased dietary intakes) (46). A comparison with 6 non-lactating Guatemalan women of similar size from the same communities showed no significant differences from the lactating women "in terms of daily energy intake, daily energy expenditure, the energy cost of specific activities, or the pattern of activities throughout the day." However, it is possible the sample sizes were inadequate to show actual differences between the groups.

MATERNAL NUTRITIONAL STATUS DURING PREGNANCY AND LACTATION

This section begins with a discussion of various approaches and difficulties encountered in the assessment of maternal nutritional status during pregnancy and lactation. Problems associated with the use of anthropometry are considered and reference is made as well to measurement difficulties related to more direct measurements of body composition. Next, studies of body fat changes during pregnancy and/or lactation are reviewed.

Measurement Techniques

Generally, attained weight and height are considered to be the minimal measures necessary to assess a person's nutritional status. However, the assessment of a woman's nutritional status using weight measurements during pregnancy is complicated by the fact that a measure of weight is a composite measure of maternal and fetal tissue. Weight gain during pregnancy has generally been studied in relation to (as a predictor of) fetal growth or birthweight, not as an indicator of maternal nutritional status, and many attempts have been made to develop weight gain charts that are appropriate for pregnant women (4, 47-52).

Measures of limb circumferences and fatfolds at various sites on the body avoid the problem of including fetal components and give information regarding a person's body composition, but have not been used extensively in investigations of maternal nutritional status. Fatfold thicknesses are not easy to measure reliably and therefore it is crucial to standardize measurement techniques and
to train anthropometrists carefully. Because the magnitude of changes in the measures are small, imprecisions easily can obscure meaningful relationships.

Reference data for fatfold measurement sites are not available for pregnant women, nor have methods for estimating total body fat from fatfolds been developed for pregnant women. Because of the lack of data, reference data and methods of body fat estimation for non-pregnant, non-lactating women (53, 54) have been applied to pregnant women (55, 56), in spite of indications that body fat distribution is altered during pregnancy (57).

More-sophisticated approaches to body composition determination can be used: techniques which estimate body composition based on the water content of the body, such as, densitometry, hydrometry, gamma ray spectrometry, and new methods such as neutron activation, dual-photon absorptiometry, ultrasound, infrared interactance, bioelectrical impedance, and total body electrical conductivity. (See Lukaski (58) for a review of these techniques.)

There are problems of applicability with each of these techniques (given considerations of safety, convenience and/or practical limitations of expense and availability of equipment) for women who are pregnant. Questions can be raised as to the biological validity of the required assumptions in a physiological state such as pregnancy for most of these techniques. The implications of the inherent assumptions that are least likely to be valid during pregnancy are discussed below. The newer methods have the additional problem that they are still in the development stage and require further study before general application can be recommended.

Another problem associated with the measurement of maternal nutritional status is created by the unidentified or unknown sources of variation in body water which occur during pregnancy. This will lead to inaccuracy and imprecision, particularly in the measurement of weight but also in the most common techniques for estimating body composition (densitometry, fatfolds, hydrometry and gamma ray spectrometry).

Because assessment of body composition is crucial to understanding the nutritional status of both mother and fetus, investigators have attempted to measure total body water. The most common method used is a deuterium dilution technique. Using this technique, Hytten and coworkers (67) demonstrated (in 93 Scottish women with normal pregnancies) that the mean total body water of women with no clinical edema rose by 6.8 kg (15 lb) from 10 to 38 weeks of pregnancy compared to a mean 9.8 kg (22 lb) increase for women with generalized edema. Forty-six of the ninety-three women showed clinical signs of edema (20 leg edema and 26 generalized edema). All 93 women "whether or not they had edema, were perfectly well throughout pregnancy and had normal healthy babies" (59). In order to confirm this surprisingly high incidence of edema during pregnancy, Thomson and coworkers (60) conducted an epidemiological study and found a similar incidence in women who also were categorized as normotensive (showing neither hypertensive nor pre-eclamptic signs).

It is not clear where the additional water of pregnancy is stored. It has been estimated that 5,800 ml of additional water are associated with the various tissue changes of pregnancy, but an average of 1,700 ml, 2,100 ml and 2,700 ml remain unaccounted for in women with no clinical signs of edema, leg edema and generalized edema, respectively (59). Robertson (61) examined the changes in compressibility of tissue in 39 clinically-normal primigravid women and postulated that "generalized edema may occur because of a hormonally activated change in the extracellular ground substance" of connective tissue.

Given the magnitude of variation in "normal" pregnancies and the poor understanding of the changes in total body water and tissue hydration during
pregnancy, determination of total body fat during pregnancy using current techniques is shaky at best. Although no assumptions are made regarding the constant level of hydration of fat free mass using fatfold measurements (unlike densitometric, gamma-ray spectrometric and hydrometric techniques of total body fat estimation) these measurements may be affected by water retained subcutaneously, but this should be minimal. Robertson (61) reported that "edema of the lower limbs is easily displaced by pressure" and Taggart and coworkers (57) found that the presence of edema had no consistent effects on the pattern of change in fatfold measures.

A problem of greater concern (than edema) when using fatfold measures to predict total body fat is the assumption that subcutaneous fat storage is representative of internal fat storage. Although there are no data for women, in a study of fat partitioning in dairy cows during pregnant, lactating and "dry" periods, it was concluded that subcutaneous fat measures should be good indicators of body fat reserves and that "the distribution of subcutaneous fat between seven defined regions of the carcass was not affected by differences in total fatness in different physiological states" (62).

Probably the most difficult problem is how to combine measures from different sites in a biologically meaningful way. Durnin and Wormersley (54) developed prediction equations for total body fat of adult men and adult non-pregnant women from fatfolds using densitometry as the "gold standard". Direct measurement of body fat has been done on only a limited number of cadavers, none of which were pregnant (63). Some investigators have avoided the problems of predicting total body fat from fatfolds by using the measures at the various sites to describe changes for each measured site (not attempting to combine the measures in order to predict total body fat) (45, 57, 64, 65).

One of the two major complications in the assessment of nutritional status of pregnant women is clearly not a problem for lactating women. Since the women have given birth, all of the tissue is maternal tissue and measures such as mass are no longer composite measures of maternal and feto-placental tissue. The other major complication in pregnancy -tissue hydration-- still may apply, though. Although, body water balance was reported to have returned to prepregnant status by two weeks postpartum by Durnin (66), earlier work suggests that altered body water balance may persist in women with generalized edema even 6 to 8 wk postpartum (67). Since specific data are not reported in one case (66), it is not possible to explain the conflicting conclusions (although one possibility is that none of the women had generalized edema in the investigation to which Durnin refers).

Anthropometric Changes

Reference is made in this review only to those studies with more-complete information (known length of gestation at time of measurement, longitudinal measurements, and an emphasis on studying changes in maternal nutritional status, body composition and/or fat during pregnancy and/or lactation.

Longitudinal measurement is essential in the study of these changes because variation in patterns of change among women is high. Investigators examining anthropometric measures longitudinally frequently have identified subgroups of women with respect to patterns of change.

The first comprehensive study of maternal fat changes during pregnancy was conducted by Taggart and coworkers (57). Measurements were made on 84 healthy British women at four points during pregnancy and at two points postpartum. The investigators chose seven sites (triceps, biceps, scapula, costal, suprailiac, mid-thigh, and knee-cap) determined (in preliminary trials) to be appropriate for use during pregnancy. In addition, these investigators measured both body...
weight and total body water in 48 of the subjects using the deuterium dilution technique.

Two differentiating characteristics created the following subgroups: 1) overweight/underweight and 2) primiparous/multiparous women. A greater increase in fatfold measures of the underweight and primiparous groups was reported. As mentioned previously, no differentiating patterns of change were observed with respect to the presence or absence of edema.

Increases in fat occurred between 10 and 30 wk of gestation at all sites (Figure 3). Most measures either decreased slightly or remained unchanged from 30 to 38 wk. All the measurements at all sites declined between 38 wk of gestation and 6 wk postpartum; later the changes were variable. The proportional change (relative to values at 10 weeks of pregnancy) was greatest at the supra-iliac site (Figure 4).

FIG. 3: Absolute changes (from initial measurement at 10 weeks) in fatfold thicknesses during and after pregnancy. (Adapted from Taggart, et al. (57), p. 444)

No study provides as much information on site-specific changes in fat during pregnancy as that of Taggart and coworkers (57). But, other studies have expanded our knowledge of the diversity of patterns of changes among populations and of relationships with levels of intake, season of the year, and activity patterns. In some cases, information is available across longer periods of time, including lactation and even through the subsequent pregnancy and lactation period. It appears that due to the varying nature of factors influencing body composition changes, there is great heterogeneity in patterns of fat deposition among populations (although comparisons are often made difficult because of variation in methods).

Arroyo and coworkers (64) compared patterns of change between the well-nourished Scottish women of Taggart's study and a sample of potentially undernourished Mexican women. These investigators measured the same seven fatfold sites on 57 pregnant women at 24, 30 and 35 wk of gestation and divided the sample into two groups: overweight (n=26) and low weight (based on weight-for-height
values at 24 weeks of gestation). Within both the overweight and the low weight groups they observed three additional subgroups of women: those who increased, those who decreased and those who showed no change in the sum of their fatfold measures between the 24th and the 35th week of gestation.

The average pattern of change of the sum of the seven fatfold measures for both of the weight groups is illustrated in Figure 5 with the corresponding
measures from Taggart's study shown for comparison. In addition, using the data reported by Arroyo and coworkers, the average of the entire sample (n=57) has been calculated and plotted in Figure 5. Although Taggart's data are over a longer time span, the values fall between the overweight and the low weight groups and are surprisingly similar to those from the women in Arroyo's study.

Pipe et al. (55) and Dibblee and Graham (56) made estimates of fat and fatfree (lean body) mass for samples of women from the United States (n=27 and n=16, respectively). Both sets of investigators used the formulas developed by Durnin and Wormersley (54) to estimate total body fat of women (non-pregnant) based on four fatfold measures (triceps, biceps, subscapular and suprailiac). The ranges and magnitudes of change are surprisingly similar across the two studies (Figure 6).

Pipe (n=27)

Dibblee (n=16)

![FIG. 6: Changes in total maternal fat mass during pregnancy. (Data from Pipe et al. (55) and Dibblee and Graham (56)).](image)

Taggart and coworkers (57) report the measurements at each site, therefore it is possible to sum values for the four sites (used by Pipe) and to compare these to the data reported by Pipe and coworkers (55). As can be seen in Figure 7, the sums of the 4 fatfold measurements in the women in Taggart's study appear to be lower than the measures in Pipe's study but the pattern of change is similar in both studies.

Prentice and coworkers (45) and Adair and coworkers (7) investigated anthropometric changes over pregnancy and lactation in Gambian and Taiwanese samples, respectively. In the study conducted by Prentice and coworkers, patterns of change were clearly different between the two major Gambian seasons (the dry and the wet season), as shown in Figure 8. The wet season is characterized by low food availability and heavy physical work demands and hence the marked fat losses observed in women who were pregnant or breastfeeding during this season. The dry season is less demanding from a nutritional point of view and fat changes are positive for women who were pregnant or breastfeeding during this season. The investigators note that "the lactating women appeared to have a raised mobility of their fat stores compared with non-pregnant, non-lactating women" (greater fat deposition during the dry season and, greater fat utilization during the wet season). This result is very interesting and worthy of further study.
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Adair and coworkers (7) used data from the Bacon Chow supplementation trial conducted in Taiwan to investigate maternal anthropometric changes during pregnancy and lactation. Although there were supplemented and unsupplemented women in the study sample, other analyses had demonstrated no significant difference in fatfolds between treatment groups (65), so the two groups were combined for this analysis. A unique feature of these data is that the final trimester of one pregnancy and the following lactation period as well as the complete subsequent pregnancy and lactation period were studied for each of the women. Longitudinal changes in maternal triceps and subscapular measures across pregnancy and lactation periods are shown in Figure 9. The pattern of change during pregnancy follows the general pattern (a gain during the first two trimesters followed by a loss during the third trimester) demonstrated by Taggart et al. (57) and Arroyo et al. (64).

Adair and coworkers were able to provide data for two successive lactation periods in the same women. Fatfold measures increased from birth to one month postpartum but decreased subsequently in lactation. Even though mean fatfold measures decreased over lactation, increases occurred in a substantial proportion (generally over half) of women. Individual women generally maintained the same pattern of fat change during the second postpartum period as they had during the first postpartum period. In addition, women who had gained more fat during pregnancy seemed to lose more fat during the postpartum period compared to women who had gained less fat during pregnancy.

The investigators divided the sample into net-gain and net-loss groups (based on fatfold changes) during the first twelve months of the first and second lactation periods (Figure 10). Dramatic increases in fatfold thicknesses occur immediately following birth; Adair and colleagues provide this explanation, "mothers no longer need to meet the metabolic demands of the placenta, early milk production is low and total energy intake is higher than in the third trimester of pregnancy. These factors, along with dramatic hormonal shifts could favor rapid fat deposition in the first postpartum month." A possible explanation for the greater intakes following birth is that the fetus and placenta cease to limit gastric capacity, allowing the mother to eat more.

FIG. 7: Changes in total fatfold measures at 4 sites. (Data from Taggart et al. (57) and Pipe et al. (55)).
FIG. 8: Rate of change in sum-of-fatfold (triceps, subscapular, and suprailliac sites) of pregnant and lactating women. Values are means ± SE, and no. of subjects. (Adapted from Prentice, A.M., et al. (45), p. 2795.)

FIG. 9: Mean maternal triceps and subscapular fatfold thicknesses during pregnancy and lactation. (Adapted from Adair, L.S., et al. (7), p. 777.)
An immediate postpartum increase in fat stores also seems to occur in Gambian women (45) during the dry season and even though fat is lost during the wet season, rates of loss are markedly reduced for the period immediately following birth (Figure 8). On the other hand, this phenomenon is not observed in several studies (57, 68, 69). Clearly, the early postpartum changes in fat deposition or mobilization require more-thorough investigation.
Quandt examined postpartum anthropometric changes in relation to feeding patterns and found that women who lost fat in the postpartum period breastfed their infants more frequently compared to women who gained fat during the postpartum period. She postulated that the increased prolactin levels caused by frequent suckling probably influence the activity of lipoprotein lipase in various tissues as has been seen in studies of pregnant rats (70). A measure of prolactin levels would be the first step in testing this hypothesis. In addition, it would be of interest to compare other components of energy balance between these two groups of women such as dietary intake, energy expenditure and the growth rates of the infants (controlling for the caloric intake from foods other than breast milk if they are not being exclusively breastfed).

It is clear from this survey of studies that there is tremendous variability in patterns of change of fat (energy stores) during pregnancy and lactation among women and yet there is surprising consistency in the general trends among studies. The functional significance (in terms of maternal health, pregnancy outcome and lactation performance) of the differing levels of maternal nutritional status must be identified.

**Parity, Interval Measures and Reproductive Cycling**

Virtually all investigations of interest characterize reproductive stress using birth interval (or interpregnancy interval) and/or parity. Parity is used to indicate the number of pregnancies, but actually only captures information about the number of live births because miscarriages, abortions and stillbirths are not counted. Another problem with parity is that it does not provide information on the timing or spacing between births.

A single birth interval is not a satisfactory measure of reproductive cycling since it is only the time interval between two successive births and does not take into account the spacing of previous births. In previous studies, the focus of research is usually the child, and the variables of interest frequently are the previous or subsequent interval relative to the index child. However in this review, we are concerned with the mother and hence, each birth interval she experiences is relevant, especially when the investigation addresses her cumulative reproductive experience.

Other time interval measures combining various components of the reproductive cycle have been constructed in order to refine the information being characterized. For example, interpregnancy interval, the time span between the previous birth and the successive conception, has been used as a measure of the non-pregnant interval of the cycle. Another problem with interval measures is that the length of pregnancy is variable with consequences of its own on fetal growth and ultimately child health.

A shortcoming of both parity and intervals as measures of the "energetic challenges" of reproductive cycling is that lactation is disregarded. In actuality, full breastfeeding on demand has a higher energetic cost than pregnancy (18). The use of birth or interpregnancy interval as a measure of the duration of a replenishment period for the mother contains the implicit assumption that lactation behavior has either no effect or a beneficial effect on nutritional status. Parity as a gross measure of reproductive stress also can be misleading because lengthy lactation periods between births may (depending on the amount of milk produced) have a more depleting effect on nutritional status than frequent pregnancies. If replenishment is the crucial factor, then the lactation behavior of the mother during birth intervals must be taken into account.
There is great variation and complexity in the reproductive patterns (number of births, spacing, and the length and intensity of each lactation period) between women. A woman can be viewed as potentially cycling through four states (Figure 11): 1) initially, neither pregnant nor lactating (N), 2) a woman may become pregnant, 3) at the end of pregnancy, a woman may begin lactation (L) or not (N) and 4) a woman may become pregnant again while breastfeeding the previous child ($L_1 + P_2$), or may wean the child and return to the non-pregnant/non-lactating state (N).

![Reproductive Cycling Diagram]

**FIG. 11: Reproductive Cycling**

**REPRODUCTIVE CYCLING AND NUTRITIONAL DEPLETION**

The evidence that nutritional depletion of mothers occurs from frequent reproductive cycling within short intervals of time will be addressed in this section.

The assertion that continual reproductive cycling depletes a mother nutritionally, even under conditions of poverty in developing countries, is being challenged by several investigators (9-11, 71). These authors have called attention to the fact that very little evidence exists in the published literature either for or against the existence of these deleterious effects.
Jelliffe and Maddocks (B) are credited with advancing the "maternal depletion syndrome" hypothesis. They postulated that a state of impairment results "from the increasing and cumulative nutritional stresses of successive pregnancies and lactation." This was based on observations of the harsh lifestyle and very poor physical condition of women living in a remote mountainous region of New Guinea.

The term "maternal depletion" has been quite popular since its introduction. It is frequently used (particularly in the demographic literature but also in the nutrition literature) both as a descriptor of the consequences of frequent childbearing under difficult living conditions and as an explanation for other relationships. For example, short birth intervals have been associated with increased child mortality in several populations (72-76) and maternal nutritional depletion has been postulated as a possible mechanism. Maternal depletion could operate to decrease nutrient availability to the fetus (thereby leading to low birthweight and increased risk of death) or it could reduce nutrient availability for milk production. Also, poor maternal nutritional status could restrict maternal activity and affect adversely the quality of child care.

Not only infant mortality, but also low birthweight, poor infant and child growth and increased morbidity are in some cases attributed to the effects of nutritional depletion of mothers (1). These adverse conditions are more-commonly investigated than the malnutrition of women, which is the direct effect of the state of depletion. (Figure 1.)

Given the frequent use of the concept of the nutritional depletion of women due to the stress of reproduction and lactation, it is important first to review the existing evidence carefully, to develop the concept further and finally to test it more thoroughly.

Thirty years of investigations provide information regarding reproductive cycling and maternal nutritional depletion. In 1958, Gopalan (77) published a report of a series of studies on lactation in poor Indian communities. In the first two studies of this series, it was determined that lactational performance was fairly satisfactory as evidenced by breast milk output and resulting infant growth at various stages of lactation. But given the low protein intake of these women and the adequate protein content of the milk, Gopalan postulated that "if the needed protein is not forthcoming from the diet, the maternal tissues are raided to meet the protein requirement." To investigate this possibility, he studied the nitrogen balance of 6 of the women over the final 3 days of consuming a protein supplement for a total of 10 days. Gopalan reported "that nitrogen retention increased as protein intake was raised. This might not be a specific attribute of the lactating state but could be the result of relative tissue-protein depletion of the subjects investigated."

Initially the most common method for assessing the nutritional status of women was the observation of the prevalence of clinical signs of malnutrition in women and their relationship to reproductive histories and/or performance (1, 8, 78, 79). Jelliffe and Maddocks gave a fairly general and descriptive account of what they observed and learned from other investigators during a visit to the New Guinea Highlands. Using an ecological framework, they linked the severe living conditions and demanding reproductive histories to the very poor nutritional status and physical condition of these women and provided the first description of the maternal depletion syndrome.

A technical group was convened to consider critically the different aspects of maternal nutrition and its relationship to patterns of reproduction (1). After reviewing data available (such as "the incidence of three signs related to malnutrition in seven Latin American and Caribbean countries, in relatively small samples of pregnant, lactating and other women"); they concluded that "facial
lesions may be more common in pregnant and lactating women. Similarly, the incidence of thyroid enlargement appears to increase during pregnancy.

On the other hand, Rajalakshmi (78) concluded that "the clinical status of the subjects was no different at 6 months of lactation and two years after its cessation without an intervening pregnancy." In addition he reported that "the bone status of women as judged by cortical thickness and width of the second metacarpal bone as well as femur also did not seem to be affected by lactation performance although there was a distinct difference between poor and upper class women." Other investigators have had a similar lack of evidence of depletion through bone demineralization (80-84).

In another study of the nutritional status of women from rural India, 501 subjects were randomly sampled from a group of similar villages (79). A clinical assessment of nutritional status was made based on an examination focusing on 13 signs of malnutrition. A relatively sophisticated conceptual model was proposed and tested. Multivariate techniques were used to analyze the effects of socio-economic status, family structure, demographic characteristics, subsocial norms of food consumption habits, and fertility behavior. Fertility behavior, measured by total number of pregnancies, explained 10% of the variation in nutritional status. In addition, "it was seen that nutritional deficiency was higher among older women than among younger women. In each of the age categories, the higher the parity was, the higher was the nutritional deficiency."

The most common simple method to examine a study sample of women for evidence of maternal depletion has been to test for an association between the body weight of the women and the number of live births (parity) they have had. Some investigators have observed a significant negative relationship between these two characteristics (3, 85) and others have not (45, 78, 86).

When a relationship is found between maternal body weight and parity, the question can be raised -- is this in actuality a relationship between body weight and maternal age? In the study reported by Rizvi (85) two parity groups were contrasted, those with parity less than or equal to 2 and those with parity greater than or equal to 3. It would be useful to compare the age distribution between these two groups. Chowdhury (3) demonstrates a negative relationship between parity and maternal weight within two age groups of women, those younger than thirty and those thirty and older.

In investigations where evidence for a simple relationship between parity and maternal body weight has not been found, questions regarding appropriateness of measures, sample sizes and the assumption of a linear relationship between the two have been raised. The issue of appropriateness of measures has been addressed in previous sections. Regarding sample size, in the case of Rajalakshmi's investigation (78) the sample size is relatively large (829 women of low socioeconomic status and 81 women of upper socio-economic status), although the Gambian sample (45) was smaller (143 women total, approx. 10 women per parity group).

Parity may not show a simple linear relationship with maternal weight. Some investigators have suggested that if a woman's nutritional status deteriorates, her fecundity is reduced, resulting in a lower parity. Therefore a subgroup of women with lower parities may be of poorer nutritional status. This could have the effect of reducing the overall mean and increasing variation at lower parities. As discussed previously, parity is a poor measure of reproductive cycling and may not be complex enough to capture subtleties such as these. Alternatively, it may be that the inconsistency in reports of a negative relationship between parity and maternal body weight represents true differences between the sample groups.
Although Chowdhury (3) concluded that there were long-term negative effects of reproductive cycling on nutritional status (a negative relationship between maternal weight and parity). This study did not contain clear evidence of nutritional stress during the first year of lactation when triceps fatfold measures and maternal body weights were measured monthly.

Another method of investigating short-term effects has been to examine the relationship between maternal nutritional status at one birth and the duration of the previous birth interval. This method treats the time following birth as a time of replenishment (regardless of lactation status). In a Taiwanese (7) and in a Bolivian (87) sample a significant positive relationship has been observed between birth interval and the maternal measures of fat taken at the birth which closes the interval.

Although the concept of maternal nutritional depletion originated in the field of public health and nutrition, it has been most carefully investigated in recent years by demographers. The two most recent, thorough conceptualizations and systematic investigations for evidence of maternal depletion have been conducted by Costello (71) within a sample of Ugandan women and by Pebley and DaVanzo (88) within a sample of Guatemalan women. In both cases, these investigators postulated that maternal depletion may partially explain poor child health and/or survival.

Costello (71) used data from the 1970 Ugandan Demographic Research Project. The sample was composed of rural Ugandan women from two different regions (Ankole, n=228 and Teso, n=173). Information was collected from a household survey, a series of fertility histories, and medical exams conducted on a sub-sample of women. The medical exams provided some anthropometric measures and hemoglobin levels. In the initial analyses, the relationships of parity and age to the ponderal index (wt/ht^2), triceps fatfold, mid-upper arm muscle circumference and hemoglobin were examined in each of the two districts.

Within broad age-groupings (15-29, 30-44, and 45-59 years), a U-shaped relationship between parity and some of the measures of nutritional status was seen but the results were inconsistent between districts, age groups and measures of nutritional status. Costello suggested that this U-shaped relationship could be interpreted as evidence of the selectivity of higher parities for women of better health until a point where increased parity becomes a liability. For example, the women past reproductive age (46-60) of Ankole, "the healthiest group tends to be those of parity 4 to 6, the least healthy of parity 1 to 3".

Costello concluded the results of the initial analyses with the following statement, "overall, from these results there is little support for the simple hypothesis that nutritional status deteriorates with increasing parity, or that cumulative maternal depletion occurs in these populations. The frequent observance of U-shaped patterns in both districts indicates that there may be other influential factors intervening in the relationship that are not controlled by this type of analysis."

Next Costello conceptualized a multivariate model of maternal depletion. She improved the measure of reproductive cycling by dividing the reproductive years into periods of pregnancy, lactation and "a resting state" (when the woman is not pregnant or lactating), reasoning that the nutritional stress of reproduction is absent during this period. A weakness of her conceptualization is the assumption that pregnancy and lactation are mutually exclusive when it is known that these two states can and do occur simultaneously, particularly in populations where depletion is likely to occur. She measured the short-term component of reproductive cycling as "the time elapsed since last leaving a depletion state, or the current presence in that state."
The multivariate analyses "reveal that there are significant factors related to maternal nutritional status in these rural populations, but cumulative depletion due to extensive periods of pregnancy and lactation is not of major importance. There is no predominant long-term depletion effect associated with the parity-related measure of pregnancy months evident in most cases, nor with the spacing effect of the pregnancy proportion, nor with the lactation variables. However, the short-term depletion status variables do show some significant association with a deterioration of nutritional status."

Short-term nutritional depletion of mothers is one of the main postulated explanations for the observed relationship between short birth spacing and increased child morbidity and mortality. Previously, birth interval has been the major measure used to demonstrate the presence of short-term depletion. Pebley and DaVanzo (88) refined the approach to investigations of short-term maternal depletion by considering the role of lactation in the birth interval. In addition to the interpregnancy interval, two "recuperative" intervals were defined, the "non-breastfeeding" and the "non-full breastfeeding" recuperative intervals.

Using data from the longitudinal supplementation trial conducted by INCAP in four Guatemalan communities, they examined the relationship between the intervals described above (and illustrated in Figure 12) and indices of maternal nutritional status (weight at time of conception and maternal weight gain during pregnancy) as well as two pregnancy outcome indicators, birthweight and length of gestation.

![FIG. 12: Recuperative Intervals](image)

Their investigation "suggests that only weight gain during pregnancy is affected by the length of the previous pregnancy interval." Contrary to their expectations, they found "that women with shorter previous intervals tend to weigh more at conception, to gain less weight during pregnancy, and to have babies who weigh the same as women with longer previous intervals." In addition, they found "that women with shorter previous intervals have longer lengths of gestation, as do women with shorter recuperative intervals."

Pembley and DaVanzo (88) suggest that these results may indicate that a selection for healthier women is occurring in the process of becoming pregnant. "In other words, women who are better off nutritionally or in better health may both become pregnant more quickly and are more able to bring the pregnancy to term than women in poorer nutritional status or health." In an attempt to further clarify the relationship between postpartum maternal weight changes and
lactation status, the investigators find "strong evidence of an important role of the duration of full breastfeeding in determining a woman's weight." They further conclude that this evidence "suggests full breastfeeding may be an important factor bringing about depletion (or preventing repletion) of maternal nutritional resources during the interpregnancy interval."

It is crucial to determine when the next conception occurs in relation to weaning or the nadir of weight change. Generally there is a pattern of maternal weight loss following birth as was shown previously. This is illustrated in Figure 13. If two women (woman 1 and woman 2 in Figure 13) are following a normal course of weight loss following birth and during lactation, it is not surprising that the weight at conception would be higher when the interval following the previous birth is shorter (see Figure 13, $W_{t1} > W_{t2}$). If a woman (woman 3 in Figure 13) has stopped breastfeeding and has started to replenish her nutritional stores and gain weight, it is still possible that at the time of the next conception her weight is not yet higher than a woman (woman 1 in Figure 13) who is breastfeeding and has a shorter interpregnancy interval (see Figure 13, $W_{t1} = W_{t3}$). (For the sake of illustration the example is very simple and only one curve of weight change is shown and all three hypothetical women fall at some point on this curve. Initial nutritional status could be expected to influence the position and shape of this curve, for example, under-nourished women may begin and end at a lower weight relative to well-nourished women.)

![Diagram](image)

**FIG. 13**: Hypothetical example of pre-conception measures of 3 women

The potential for bidirectional causality between maternal nutritional status and 1) the likelihood of conception and 2) the duration of lactation, as well as the tremendous variation in patterns of weight and fat change make it clear that the relationships are complex and require a careful consideration of the time sequence of events. Therefore, conceptualizations must not be simplistic (for example, direct parity-to-maternal weight relationships) and conclusions drawn from them must not be accepted without further study.
The description of reproductive cycling and the relative costs have not been adequate, although progress in this area is being made. There is a need to distinguish short-term and long-term depletion within investigations and discussions of maternal nutritional depletion and to clarify the expected outcomes. Whereas nutritional depletion originally meant visible or clinical signs of ill-health, premature aging or malnutrition, later it was measured by maternal weight or changes in maternal weight. Measures of changes in maternal fat stores have not been used in the study of this topic but should be. In spite of these severe weaknesses of the current literature, it is still possible to conclude that there is some indication that under some conditions the nutritional demands of reproductive cycling negatively affect maternal nutritional status.

**SUMMARY AND RESEARCH NEEDS**

The relationship between maternal nutritional intake and the health outcome for the child, particularly birthweight, growth and mortality has been explored extensively (through the major nutritional supplementation trials as well as other investigations). It generally is postulated or assumed that a mother's nutritional status is the biological link between the positive impact of increased dietary intake (nutritional supplementation) of the mother or the negative impact of short birth intervals on various child outcomes such as birthweight or child mortality. But maternal nutritional status is rarely treated as an important outcome in and of itself.

Because women are seen mainly as vehicles for child health rather than as primary health care beneficiaries in their own right, long term effects on women's health have been ignored. Not only are maternal/child health (MCH) resources limited, when MCH does research the puerperium, it addresses outcomes for the fetus, not for the mother. As an illustration of this bias, an extensive review of MCH literature found that out of 22,080 articles, only four percent dealt with maternal health issues. (Howard (89))

This biased emphasis alone could be considered a major weakness in the literature, and more importantly, in health services and nutritional planning programs that affect women, but in addition, attempts rarely are made to establish that the actual effects of increased dietary intake and short birth intervals truly are operating through the postulated pathway of improving or impairing maternal nutritional status.

The neglect on the part of the scientific community is not due entirely to oversight, it is partially a reflection of the difficulty of measuring maternal nutritional status (and particularly during changing physiological states such as pregnancy and lactation) versus the relative ease of measuring birthweight or child mortality. A more compelling and important reason for this biased emphasis is the recognition that the early years of life are a period of particular susceptibility to those factors threatening survival. Clearly, the well-being of mother and child are linked and the relevant research issues are interrelated.

Investigators now should begin to take a broader view of adverse outcomes that may result from maternal depletion besides low birthweight and child mortality. There are more immediate adverse outcomes such as poor maternal nutritional status and morbidity. In the general conceptual model presented in Figure 1, maternal nutritional status is the central and primary outcome of sources of nutritional stress such as frequent reproductive cycling, morbidity, high activity patterns and low dietary intakes. In this conceptualization the adverse consequences to the child are outcomes secondary to the maternal nutritional status.
This review has examined evidence regarding the existence of maternal nutritional depletion by considering 1) the energetic cost of pregnancy and lactation and various explanations for how this cost is met; 2) the issues of measurement of both reproductive cycling and maternal nutritional status; 3) the various patterns of change in anthropometric measures and estimation of body fat during pregnancy and the postpartum period, and finally 4) by examining the conceptualization and evidence of the more direct attempts to establish the presence or absence of maternal nutritional depletion.

It is concluded that:

- The characterization of reproductive cycling (and its corresponding demand) using parity and time intervals between pregnancies or births is too simplistic. These measures miss the great variation and complexity of reproductive cycling (particularly because neither considers the lactation behavior of the mother). The most promising improvements that have been introduced recently are the use of proportions of time spent pregnant or lactating within a specified period of time, and the definition of recuperative intervals based on lactation status.

- Not enough effort has been devoted to the characterization of maternal nutritional status during pregnancy and lactation. The physiological alterations of water balance and tissue hydration during pregnancy and the early postpartum period as well as the presence of feto-placental tissue during pregnancy create the most difficult technical problems. Weight is the least useful and fatfold thicknesses and limb circumferences are the most useful measurements for characterizing maternal nutritional status during pregnancy. Reference data for these measures are needed for pregnancy, the postpartum period and various stages of lactation in healthy populations living in a variety of contexts.

- The patterns of change in fatfold thicknesses are highly variable. In attempting to characterize anthropometric changes during pregnancy and lactation it is crucial to distinguish various patterns and to identify maternal and environmental characteristics associated with the different patterns. Some data indicate that a large increase in fatfold measures occurs during the early postpartum period in some populations; this should be examined further. Some data indicate an increased mobility of fat stores of lactating women relative to non-pregnant, non-lactating women, another result worthy of further investigation. In addition, prepregnant measures rarely have been obtained. A greater effort should be made to extend the time frame of measurement (to collect more measures before conception and following birth).

- Information on the relative energetic demand imposed by pregnancy, lactation, both and neither will provide a more accurate picture of the nutritional stress imposed by reproductive cycling. Estimating the energetic costs of pregnancy and lactation has been a topic of interest for many, although success has been limited. Recent evidence suggests that the estimated cost has been inflated (although it is not clear which components have been overestimated).

Fat gain and resting or basal metabolic rate are the two largest components of the energetic cost of pregnancy; there is some evidence that both have been overestimated in the past. The average fat gain in healthy women originally estimated to be 4 kg may be closer to 2.5 kg. With respect to the basal or resting metabolic rate, some unexpected trends (reductions) during pregnancy have been observed (particularly in the Gambian population) and are worthy of further investigation to determine the range of adjustment that is common and under what circumstances the adjustments occur. Further understanding of the hormonal influence on energy balance and the metabolic changes during periods of pregnancy and lactation is needed.
Data regarding fat changes and metabolic rates during lactation are particularly lacking. It is crucial for the determination of the energetic cost of lactation, that the fat gain during the corresponding pregnancy be well characterized because it is expected that these additional fat stores are accumulated during pregnancy in order to offset the energetic cost of lactation (reducing the amount of energy required from the diet during lactation). The contribution of physical activity to the energy balance equation has been virtually impossible to measure, but new methods using doubly-labelled water may change this situation.

The cumulative effect on the mother of multiple pregnancies and lactations within short periods of time has not been examined adequately. The short-term effect of pregnancy and/or lactation on maternal nutritional status has not been clarified adequately, either. The evidence reviewed here clearly demonstrates that the relationships of cumulative maternal nutritional depletion due to the high demands of reproductive cycling are too complex to be established merely by a relationship (or lack thereof) between parity and maternal weight. Longitudinal anthropometric measures and information on lactation status (in addition to birth and pregnancy intervals) should be used. Patterns of anthropometric change must be examined in relation to the changing reproductive status (physiological states) of the women.

A thorough investigation of the effect of reproductive cycling on maternal nutritional status therefore should include: longitudinal maternal anthropometric measurements during pregnancy, lactation and intervening periods across successive reproductive cycles; information on maternal dietary intake and work patterns; infant growth measures; and functional outcomes (such as incidence of morbidity and mortality) of maternal health status. This is a demanding list of requirements for a single investigation, particularly for the time span over which the information is desired (although specific areas of the research agenda can be addressed separately).

Thorough study of the topics reviewed can call attention to the unique health and nutrition problems of women, more specifically it can help a) define what are appropriate “repletion” periods between births and lactation periods, b) identify when in the cycle it is most appropriate to intervene nutritionally, c) identify mothers at risk who require special attention in primary health care and public health programs and d) formulate reasonable recommendations for weight gain during pregnancy, and for levels of dietary intake and physical activity during pregnancy and lactation.

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Maternal Nutritional Depletion


