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ENERGY AND PROTEIN REQUIREMENTS DURING LACTATION

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ABSTRACT

Additional energy needs for an exclusively breastfeeding woman are approximately 670 kcal/day. If one allows for gradual weight loss, the net increment needed is about 500 kcal/day. There is little evidence of energy-sparing adaptations in basal metabolic rate or dietary-induced thermogenesis during lactation, although physical activity may be reduced during the early postpartum period. In women with adequate fat reserves, moderately negative energy balance is not likely to affect lactation. The recommended increment in protein intake during lactation has been estimated to be about 15 g/day, based on a milk protein concentration of 11 g/liter. However, if one takes into account the protein cost of non-protein nitrogen in human milk, the recommended increment in protein is about 20 g/day. The latter value is consistent with data from nitrogen balance studies in lactating women. Low protein intakes are unlikely to affect milk volume but may alter certain fractions of milk nitrogen.

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ENERGY REQUIREMENTS

Introduction

The energy needs of lactating women have generally been calculated using a factorial method that takes into account breast milk volume, milk energy density, and the conversion efficiency from dietary energy to breast milk energy. This product is then added to the energy needs of nonpregnant, nonlactating (NPNL) women to derive the total energy requirements of lactating women. Adjustments can be made for changes in body fat (which, if negative, can be considered to "subsidize" the cost of lactation) and for differences in energy expenditure.

The resulting estimates have been a topic of considerable debate because observed energy intakes often fall short of estimated requirements. There are several possible reasons for this, among them the fact that energy intake is usually underestimated in affluent populations (2), but the discrepancy has spawned research to investigate whether there are energy-sparing mechanisms during lactation. The following four sections review each of the components included in the above factorial approach and briefly discuss the evidence regarding potential energy-sparing mechanisms [this topic has been discussed in detail by Prentice et al (38)]. The last section evaluates whether a negative energy balance is likely to affect lactation performance.

Energy Cost of Milk Production

MILK VOLUME Table 1 shows average values for breast milk intake of infants in developed countries. These estimates are based on data tabulated by Brown et al (5) from studies published since 1980. Average intakes of exclusively breastfed infants (defined as those who receive no other foods or fluids) range from 710 g/day at 0–2 months of age to 900 g/day at 9–11 months of age. For partially breastfed infants (defined as those who receive breast milk plus other foods or fluids), average intake decreases from 640–687 g/day at 0–5 months of age to 436–448 g/day after 9 months of age. During the first eight months of life, average intakes of infants in developing countries are generally quite similar to the values shown in Table 1 (5).

There is a wide range of variability in breast milk volume among individuals, as reflected by the relatively large standard deviations shown in Table 1. Even

Table 1 Breast milk intake (grams/day) of infants in developed countries[a]

	Age group (mo)				
Breastfed	0–2	3–5	6–8	9–11	12–23
Exclusively					
Mean	710	787	803	900	
SD	134	128	117	39	
Studies (N)	5	7	5	1	
Subjects (N)	333	399	139	26	
Partially					
Mean	640	687	592	436	448
SD	169	181	182	256	251
Studies (N)	4	5	6	4	1
Subjects (N)	175	416	351	108	40

[a]Data from Brown et al (5), based on studies since 1980. SD, Standard deviation; N, number.

among exclusively breastfed infants, a normal intake can range from about 550 to well over 1000 g/day. This is largely due to the fact that milk production is a function of infant demand (6, 7, 10). Both endocrine and autocrine control mechanisms operate to adjust milk volume in response to the infant's suckling behavior (i.e. nursing frequency and duration and degree of emptying of the breast) (6, 7). As a result, the energy needs of a lactating woman can vary considerably, depending on her infant's milk intake.

The amount of milk produced is generally not strongly associated with indices of maternal nutritional status such as body mass index (4, 35, 39). When adequate methods for measuring milk volume are used, there is remarkable similarity across populations with widely varying nutritional status (5, 37). By contrast, milk production is strongly affected by feeding other foods or fluids to the infant, because these usually reduce infant demand for breast milk (5). Thus, milk volume after the period of exclusive breastfeeding depends heavily on the infant feeding practices of the population. Breast milk intake after nine months of age is generally higher in infants from developing countries than in those from more affluent populations (5).

MILK ENERGY CONCENTRATION The energy density of human milk depends on the relative proportions of protein, fat, and the principal carbohydrate, lactose. In well-nourished populations, milk fat averages about 37–40 g/liter and contributes half or more of the total kilocalories, milk lactose averages about 70–74 g/liter and contributes 40–45% of the total energy, and milk protein averages about 9–10 g/liter and contributes only about 5–6% of the total energy

(21). There is little change in milk fat or lactose concentrations during lactation (21). Although milk protein concentration decreases with infant age, this has relatively little impact on milk energy density.

It is extraordinarily difficult to obtain an accurate estimate of the energy density of the milk consumed by a breastfed infant. This is because milk fat concentration (and, thus, energy density) varies both within a feed (hindmilk is higher in fat) and during the day (in different ways depending on the population). Most estimates of milk energy density are based on samples expressed by hand or by pumping. When care is taken to express samples throughout the day and night and to empty the breast completely, the milk obtained should be representative of the total amount produced, but it may not reflect the amount the infant consumed. Using such methods, the average gross energy content of human milk is generally reported to be about 0.68–0.74 kcal/g (38). The energy content of the milk consumed could be lower than this if the infant does not habitually take in all the hindmilk. Using doubly labeled water methods to estimate milk energy density indirectly, Lucas et al (25) calculated a value of about 0.61 kcal/g (after adjustment to be equivalent to gross energy), which they claim is closer to the true value of milk suckled by the infant. However, several debatable assumptions were required to arrive at this estimate. Therefore, it remains unclear what value to use when calculating milk energy output. Prentice et al (38) suggest using a value of 0.67 kcal/g, which is between the averages obtained using the two different methods described above.

Although milk energy density does not vary greatly by stage of lactation, it is affected by maternal body composition. Data from both affluent (31) and undernourished (3, 33, 34) populations indicate that milk fat concentration (and, thus, energy density) is positively correlated with measures of body fatness. However, this may not have a strong impact on total milk energy output, because infants who are allowed to nurse on demand generally compensate for a lower milk energy density by consuming a higher volume of milk (33).

EFFICIENCY OF CONVERSION OF DIETARY ENERGY TO MILK ENERGY Prentice et al (38) describe two alternative methods for estimating the efficiency with which a mother converts dietary energy: (*a*) computing the biochemical efficiency of synthesizing each of the energy-yielding constituents; and (*b*) performing metabolic balance studies of calorimetric efficiency. With the former method, the efficiency of synthesis for milk lactose, protein, and fat is about 91–94%; after taking into account the additional costs for digestion, absorption, interconversion, transport, and storage of these constituents, Prentice et al (38) estimate an overall efficiency of about 83%. The latter method, estimating calorimetric efficiency in lactating women, is fraught with numerous methodological difficulties, but if it is assumed that calorimetric efficiency is about 10–15% lower than biochemical efficiency, the resulting value would be 80–85%. Based on these calculations, Prentice et al (38) suggest retaining the estimate of 80% used in the 1985 FAO/WHO/UNU recommendations (14).

SUMMARY Given the above estimates, the average energy cost of the milk produced during the period of exclusive breastfeeding can be calculated as 710–800 g/day $\times$ 0.67 kcal/g, or approximately 500 kcal/day. Using an estimate of 80% efficiency for milk synthesis, the total average cost would be 625 kcal/day.

Energy Expenditure During Lactation

It has been suggested that lactating women may compensate for the energy demand discussed above by reducing energy expenditure. This could occur through decreases in basal metabolic rate, dietary-induced thermogenesis, or physical activity.

BASAL METABOLIC RATE Because milk synthesis is assumed to be a continuous process, its costs should be reflected in basal metabolic rate (BMR). Thus, one would expect BMR to be somewhat higher in the lactating than in the NPNL state. When this is not the case, it could indicate an energy-sparing adaptation.

In theory this should be a simple hypothesis to test, but in reality there are many methodological pitfalls. The preferred study design is a longitudinal study of BMR in the same women during lactation and in the NPNL period. Even with a longitudinal design, the potentially confounding effects of changes in body composition should be taken into consideration. Table 2 summarizes the results of six studies in which a longitudinal design was used. The comparison period was postlactation in two studies, pre-pregnancy in three studies, and both pregnancy and weaning periods in one study. The results are mixed: Three studies showed no meaningful change in BMR during lactation, two showed a slight ($\leq$5%) increase, and one showed a decrease of about 8%. The latter study (22) was the only one conducted in a developing country population. The decrease in BMR in this setting might be interpreted as an energy-sparing mechanism, but cross-sectional data from the same population did not confirm these findings (42). Thus, most of the evidence indicates that BMR is unchanged or slightly increased during lactation.

DIETARY-INDUCED THERMOGENESIS Only two longitudinal studies have examined whether there are changes in dietary-induced thermogenesis (DIT) during lactation (also shown in Table 2). Illingworth et al (20) found a significant 30% reduction during lactation relative to postlactation, but Spaaij et al (44) did not observe any difference in DIT between lactation and the pre-pregnancy period. Cross-sectional studies (27, 17) also show mixed results and are further complicated by the confounding effects of differences in the energy content of

Table 2 Changes in basal metabolic rate or dietary-induced thermogenesis during lactation[a]

Outcome	Study	Location	Δ during lactation?	Comparison period
Basal metabolic rate	Illingworth et al (20)	UK	No	Postlactation
	Goldberg et al (18)	UK	No	Postlactation
	van Raaij et al (48)	Netherlands	No	Prelactation and during weaning
	Spaaij et al (44)	Netherlands	Slight ↑ (<5%)	Prepregnancy
	Sadurskis et al (41)	Sweden	Slight ↑ (~5%)	Prepregnancy
	Lawrence et al (22)	Gambia	↓ ~8%	Prepregnancy
Dietary-induced thermogenesis	Illingworth et al (20)	UK	↓ 30%	Postlactation
	Spaaij et al (44)	Netherlands	No	Prepregnancy

[a]Based on longitudinal studies of the same subjects when lactating and nonlactating. UK, United Kingdom.

the test meal and body composition of the lactating and NPNL control groups. Even if there are changes in DIT during lactation, the magnitude of this effect on overall energy balance would be minimal given that DIT is only about 10% of total energy expenditure.

PHYSICAL ACTIVITY LEVEL Several studies have examined patterns of physical activity among lactating women. Table 3 summarizes the findings of those for which physical activity level (PAL) ratios (total daily energy expenditure/BMR) could be calculated. In some studies, data for the NPNL period are also available for comparison. In developed countries, PALs are generally low during the first 4–6 weeks postpartum (1.47–1.50), which reflects a relatively sedentary lifestyle during the first few weeks after childbirth. In some of these studies (in the United Kingdom and the United States), the PALs increased with time postpartum (to about 1.60) as women resumed greater activity, but in others (e.g. the Netherlands) they remained low. Lactating women who reported regular physical activity had PALs that were somewhat higher (1.65–1.82). In the three studies conducted in developing countries, average PALs during lactation were generally higher (1.61–1.97) than were the values reported for developed countries, reflecting the greater workloads experienced by women in the former.

These data demonstrate that physical activity during lactation varies greatly, depending on cultural and economic influences. In general, PALs are somewhat lower during lactation, especially during the early postpartum period, than during the NPNL period. However, when calculating energy needs it is risky to assume that women can cut back on energy expenditure during lactation—there are circumstances when this is not feasible.

Table 3 Physical activity levels (TDEE/BMR) during lactation[a]

Authors	Location	Stage of lactation (wk postpartum) 4–6	8–9	12–13	18–20	26–27	NPNL comparison
Developed countries							
van Raaij et al (47)	Netherlands	1.47	1.50	1.42		1.50	1.53
Goldberg et al (18)	UK	1.50	1.56	1.59			1.66
Sadurskis et al (41)	Sweden		1.59				1.60
Forsum et al (15)	Sweden		1.82			1.79	1.94
Dewey et al (11)	US						
	Sedentary	1.48		1.60	1.58		
	Exercisers			1.74	1.65		
Developing countries		Lactation				NPNL	
Panter-Brick (32)	Nepal	1.80				1.92	
Singh et al (43)	Gambia	1.97				1.98	
Tuazon et al (46)	Philippines	1.61 (6 wk); 1.80 (12 wk)					

[a]TDEE, Total daily energy expenditure; BMR, basal metabolic rate; UK, United Kingdom; US, United States.

TOTAL DAILY ENERGY EXPENDITURE Table 4 summarizes data on total daily energy expenditure (TDEE) (not including milk energy output) of lactating women from four studies that used the doubly labeled water method. Sample sizes for such studies are generally small because of the expense of this method, but the results are very useful for assessing energy needs during lactation. In three of the studies (from Sweden, the United States, and the Gambia) the results are remarkably similar: an average of 2400–2600 kcal/day at 2–6 months postpartum. These samples all included women who took part in regular physical activity. In the other study (from the United Kingdom) the average TDEE was 2100–2200 kcal/day at 4–12 weeks postpartum. These lower values are consistent with the lower PALs reported for the United Kingdom sample (see previous section) and are similar to the average expected energy expenditure for NPNL women in affluent populations (30).

Energy Available from Mobilization of Body Reserves

In affluent populations, gradual weight loss is common during lactation. In calculating energy needs, it is sometimes assumed that the fat stored during pregnancy can be mobilized to support lactation. Prentice et al (38) recently summarized data on changes in body weight and fatness during lactation. As might be expected, there is great variability in the rate of weight change, with some women losing more than 2 kg/month and others gaining an equivalent amount. Thus, it is not valid to assume that all women can subsidize lactation

Table 4 Estimates of total daily energy expenditure during lactation, not including milk energy output, based on doubly labeled water studies[a]

Authors	Location	N	Stage of lactation	TDEE (kcal/day) Mean	SD
Goldberg et al (18)	UK	10	4 wk	2119	462
			8 wk	2181	228
			12 wk	2148	343
Forsum et al (15)	Sweden[b]	23	2 mo	2544	480
			6 mo	2592	648
Lovelady et al (24)	US[c]	9	12–26 wk	2424	238
Singh et al (43)	Gambia	14	20 ± 8 wk	2592	499

[a]N, Number; TDEE, total daily energy expenditure; SD, standard deviation; UK, United Kingdom; US, United States.

[b]The women were described as professionally active.

[c]Half of the subjects exercised regularly.

by mobilizing fat from tissue stores. Nonetheless, on average, lactating women lose about 500 g/month (16.7 g/day), which represents about 155 kcal/day. Depending on the population, this can be taken into account when estimating energy requirements.

Summary of Energy Needs During Lactation

Table 5 summarizes the additional energy needs during lactation. For a woman who is exclusively breastfeeding, the average energy costs for milk production are 595 kcal/day at 0–2 months postpartum and 670 kcal/day at 3–8 months postpartum. If one allows for 500 g of fat loss per month, the energy needs to support this would be 440–515 kcal/day. For a partially breastfeeding woman, energy needs are lower, depending on the extent to which non–breast milk foods are consumed by her infant.

Total energy needs are the sum of the additional energy for milk production plus TDEE during lactation. As shown in Table 3, TDEE may be slightly lower in lactating than in NPNL women because of lower activity levels of the former, but this is highly variable. TDEE also depends on the woman's weight and body composition. According to the data shown in Tables 4 and 5, total energy needs of exclusively breastfeeding women range from about 2500 kcal/day (low PAL; allowing for fat loss) to 3300 kcal/day (higher PAL; no allowance for fat loss).

When reported energy intakes during lactation are lower than 2500 kcal/day, this generally implies one of the following: (*a*) the women are not exclusively breastfeeding; (*b*) the women are losing weight more rapidly than 500

Table 5 Summary of additional energy needs during lactation

Breastfeeding (mo)	Milk volume[a] (ml/day)	Energy cost of milk[b] (kcal/day)	Energy cost of milk synthesis[c] (kcal/day)	Total energy cost	
				Full costs (kcal/day)	Allowing for fat loss[d] (kcal/day)
Exclusively					
0–2	710	476	119	595	440
3–8	800	536	134	670	515
Partially					
0–5	660	442	111	553	398
6–8	590	395	99	494	339
9+	440	295	74	369	369

[a]Values rounded from those in Table 1.
[b]Using 0.67 kcal/g.
[c]Assuming 80% efficiency.
[d]Assuming about 500 g/mo (16.7 g/day) up to 8 months (none thereafter) at 9.3 kcal/g.

g/month; and/or (*c*) usual dietary intake has been underestimated. In most cases, energy-sparing alterations in BMR or DIT are not likely to be of sufficient magnitude to explain large discrepancies with the above figures.

Impact of Negative Energy Balance on Lactation

It is useful to consider whether lactation performance of women who do not meet their energy needs might be compromised. As discussed in detail by Brown & Dewey (4) and by Rasmussen (39), testing this hypothesis poses methodological challenges. The question can be approached in several different ways. First, one can examine whether there is any association between weight change postpartum and either milk volume or milk energy output. In affluent populations these relationships are generally not statistically significant (4, 10, 21). However, in developing countries where chronic undernutrition is common (such as Bangladesh), some researchers have reported an association between postpartum weight loss and lower milk energy transfer (3). In observational studies of this nature, it is difficult to disentangle the potentially confounding effects of seasonal differences in maternal activity patterns, time devoted to breastfeeding, and illness, as well as of infant factors such as birthweight (which has a strong impact on infant demand for milk) (10, 33).

An alternative approach, and one that has been attempted numerous times, is to supplement women who are considered to be undernourished. The evidence from dietary supplementation trials with lactating women is conflicting, partly because most of the studies have had serious methodological limitations. To date, no study has met all the necessary conditions, which include:

(*a*) selection of a truly undernourished population; (*b*) random assignment to supplementation and control groups; (*c*) measurement of breast milk energy output, including analysis of energy density based on representative samples of milk; and (*d*) maintenance of exclusive breastfeeding throughout the study period. Despite these limitations, most of the evidence suggests that increasing maternal energy intake has little or no impact on milk energy transfer, except perhaps in women whose fat reserves are very low initially (4, 39).

A third approach is to study the effects of caloric restriction directly. The most relevant animal model for human lactation is other primates, because the energetic demand of lactation relative to TDEE in species such as rats is much higher than in humans (36). In lactating baboons, milk volume was unchanged when energy intake was restricted to 80% of ad libitum consumption, but there was a significant decrease when intake was limited to 60% of ad libitum consumption (40). This implies a threshold effect, i.e. that caloric restriction does not have a significant impact on lactation until intake is below some critical level. It is obviously much more difficult to study this in humans. Strode et al compared lactation performance of 14 exclusively breastfeeding women who voluntarily reduced their energy intakes by an average of 32% for one week with that of a control group of eight women who did not change their intake (45). Among mothers in the former group who consumed $>$1500 kcal/day during the diet week, there was no reduction in milk volume, but in six women who consumed $<$1500 kcal/day during the diet week, milk volume decreased by an average of 15% during the week after restriction. These results are consistent with the hypothesis that there is a threshold effect. However, the limitations of the study design (study groups were not randomly assigned; milk energy density was calculated from samples taken only once per day) make it difficult to draw definitive conclusions.

Dusdieker et al (12) evaluated milk production of 33 breastfeeding women who enrolled in a weight-loss program. They observed no decrease in milk volume or concentrations of fat or protein, despite an average weight loss of 4.8 kg during the 10-week study period. These results suggest that modest weight loss (about 0.5 kg/week) is safe during lactation, but the lack of a control group in this study limits the inferences that can be made. Moreover, of the 33 women who enrolled, 11 dropped out before completing the study. Those who dropped out tended to have lower fat reserves (as measured by skinfold thickness), energy intake, and milk production at baseline, all of which might have put them at greater risk during caloric restriction.

The question of energy balance has also been approached by examining lactation outcomes in women with high energy expenditure. No adverse effects of regular aerobic exercise have been observed in either cross-sectional comparisons (23) or randomized intervention studies of previously sedentary

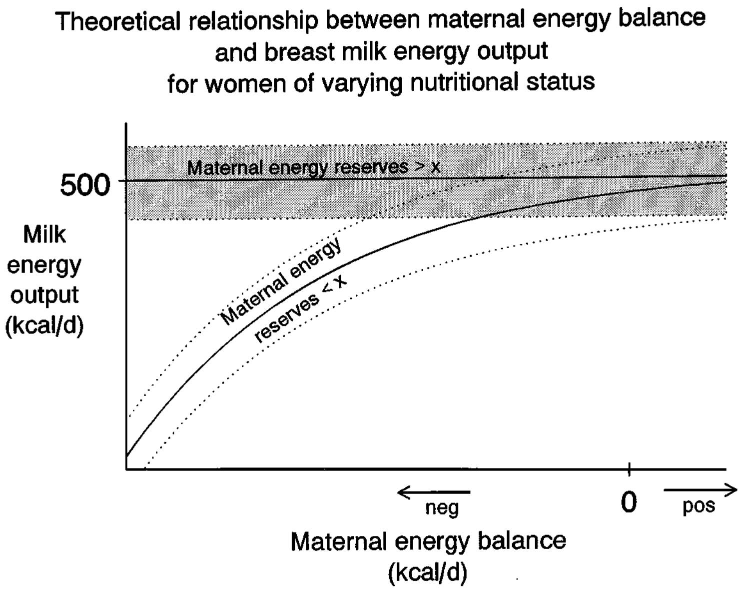

Figure 1 Theoretical relationship between maternal energy balance and breast milk energy output for women of varying nutritional status. (From 4, p. 93, copyright © 1992 Wiley-Liss, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

lactating women (11). However, in both studies, the energy deficit was similar between exercise and control groups because the former consumed more calories in response to their elevated energy expenditure. No published data are yet available on the impact of a combination of caloric restriction and exercise.

To summarize, the evidence to date indicates that, in women with adequate fat reserves, gradual weight loss (up to 0.5 kg/week) is not likely to have any adverse consequences on lactation. There is less information regarding the potential effects of weight loss among underweight women, or of very rapid weight loss among normal weight or overweight women. Figure 1 illustrates the theoretical relationship between maternal energy balance and breast milk energy output (4). It is hypothesized that milk energy output will be maintained within the expected range in women with "adequate" (as yet undefined) energy reserves, regardless of energy balance, and also in women with low energy reserves who are not losing weight. It is only under the combined circumstances of low maternal energy reserves and negative energy balance that milk energy output is predicted to decrease. The threshold at which this might occur in humans has not yet been identified.

PROTEIN REQUIREMENTS

Introduction

Protein requirements during lactation have typically been calculated using a factorial approach, i.e. by estimating the amount of dietary protein needed to support production of a given amount of protein in milk. However, metabolic studies of lactating women have sometimes yielded different estimates of protein needs. The following five sections discuss the protein content of human milk, factorial estimates of protein needs during lactation, the results of metabolic studies, recommended protein intakes, and the influence of maternal protein intake on lactation. Specific requirements for individual amino acids are not discussed.

Protein Content of Human Milk

The concentration of protein in human milk varies with the stage of lactation. Values decline from about 20–30 g/liter for colostrum (approximately 1–5 days of lactation) to about 13–15 g/liter at day 10, 10–12 g/liter at one month, and 8–9 g/liter thereafter (9). These values are concentrations of "true protein" ([total nitrogen minus non-protein nitrogen] X 6.25), which is equivalent to protein as determined by amino acid analysis. Non-protein nitrogen (NPN) is approximately 26% of total nitrogen in human milk (9). About half of the NPN fraction is urea, with the remainder being choline, carnitine, creatine, creatinine, nucleotides, nitrogen-containing carbohydrates, and oligosaccharides (1).

Factorial Approach to Estimating Protein Needs During Lactation

In the factorial approach used by both FAO/WHO/UNU (14) and the US National Research Council (NRC) (30), the protein concentration of human milk was assumed to be about 11 g/liter. As mentioned above, this value is a good estimate of the true protein content of human milk at about one month postpartum. However, it does not take into account the protein cost of the NPN fraction of human milk. In addition, it does not reflect the change in milk protein concentration later in lactation.

Table 6 shows estimated protein needs for milk production using a factorial approach. Two options are shown: Option 1 considers only the true protein content of human milk, whereas Option 2 includes the additional cost in protein of the NPN fraction. Estimated milk volumes are from Table 1. The efficiency of conversion from dietary protein to milk protein is assumed to be 70% (14). The resulting estimates of average additional protein requirement for Option 1 range from 11.1 g/day for exclusively breastfeeding women at 0–2 months postpartum to 5.7 g/day for partially breastfeeding women at ≥9

Table 6 Additional protein needs during lactation

Breastfeeding (mo)	Milk volume[a] (ml/day)	Protein content (g/liter)	Protein output (g/day)	Average dietary need[b] (g/day)	CV milk volume[c] (%)	Safe level[d] (g/day)
Option 1: Considering only the true protein content of human milk						
Exclusively						
0–2	710	11	7.8	11.1	19	15.3
3–8	800	9	7.2	10.3	15	13.4
Partially						
0–5	660	10	6.6	9.4	26	14.3
6–8	590	9	5.3	7.6	31	12.3
9+	440	9	4.0	5.7	58	12.3
Option 2: Considering the total nitrogen content of human milk						
Exclusively						
0–2	710	14.9	10.6	15.1	19	20.8
3–8	800	12.2	9.8	13.9	15	18.1
Partially						
0–5	660	13.5	8.9	12.7	26	19.3
6–8	590	12.2	7.2	10.3	31	16.7
9+	440	12.2	5.4	7.7	58	16.6

[a]Values rounded from those in Table 1.
[b]Assuming 70% efficiency from dietary protein to milk protein.
[c]From Table 1.
[d]Average plus two standard deviations.

months postpartum. The values for Option 2 are 35% higher (total nitrogen in milk = protein nitrogen/0.74, assuming that NPN is 26% of total nitrogen).

To derive safe levels, or recommended protein intakes intended to cover the needs of 97.5% of the population, the usual convention is to add two standard deviations (SD) to the mean requirement. In both the FAO/WHO/UNU (14) and US NRC (30) reports, the coefficient of variation (CV) for milk volume was assumed to be 12.5%. However, the actual SDs shown in Table 1 indicate CVs that are considerably greater than this, especially among partially breastfeeding women. If these values are used to derive safe levels, the resulting estimates for Option 1 range from 15.3 g/day for exclusively breastfeeding women at 0–2 months postpartum to 12.3 g/day for partially breastfeeding women at ≥6 months postpartum. Again, the values for Option 2 are 35% higher.

Protein Metabolism of Lactating Women

Nitrogen balance and other parameters of protein status have been examined in several metabolic studies of lactating women consuming varying levels of protein. In 1990, Motil et al (28) reported that negative nitrogen balance was observed in all 12 of their lactating subjects when they consumed 1.0 g of protein/kg/day and in 50% of these subjects when they consumed 1.5 g of protein/kg/day. The lower level (1.0 g/kg/day) approximates the 1989 Recommended Dietary Allowance (50 g/day for NPNL women plus about 15 g/day for lactating women, assuming an average weight of about 65 kg). This level of intake was associated with reductions in urinary 3-methylhistidine excretion, reflective of decreased skeletal muscle protein breakdown, which the authors interpreted as a compensatory response. Their conclusion was that current recommendations for protein intake during lactation may be insufficient.

In a later study with five lactating women, four nonlactating postpartum women, and four nulliparous women, the same group of investigators found somewhat different results (26): Apparent nitrogen balance was positive in lactating women at habitual (1.5 g/kg/day) and recommended (1.0 g/kg/day) protein intakes but negative at very low protein intakes (0.4 g/kg/day). Nitrogen flux and rates of protein degradation and synthesis in the fed state were lower and net protein retention was higher in the lactating women than in the nonlactating postpartum women at intakes of 1.0 g/kg/day (though not at the other two levels of intake). The authors concluded that lactating women can adapt rapidly to protein restriction by down-regulating protein metabolism, but the metabolic cost for this is unknown. Although nitrogen balance was positive in this study at 1.0 g/kg/day, a decrease in body protein turnover might be viewed as an unfavorable condition that could compromise certain physiological functions (49). The authors speculated that the more positive nitrogen balance in the later study was due to a shorter experimental diet interval, and that a longer interval at 1.0 g/kg/day would result in a negative nitrogen balance.

De Santiago et al (8) conducted a nitrogen balance study with seven lactating Otomi Indian women in Mexico who for 10 days were given diets with 0.8, 1.0, or 1.2 g of protein/kg/day, 70% of which came from vegetable sources. The reference diet contained 1.2 g of protein/kg/day, 80% of which came from animal sources. Equilibrium nitrogen balance was attained at an average of 1.1 g of protein/kg/day, and the safe level was estimated to be 1.4 g/kg/day. Nitrogen digestibility was higher with the reference diet, but because urinary nitrogen excretion was also higher, there was no significant difference in nitrogen balance at 1.2 g/kg/day between the predominantly vegetable-source versus the animal-source diets.

It is somewhat difficult to interpret the results of the studies cited above because of the limitations of the nitrogen balance approach. If subjects are in negative energy balance, this can affect nitrogen balance. In the 1990 study by Motil et al (28), the lactating subjects lost an average of 0.3 kg during the 10-day diet period, which could partly explain why nitrogen balance was negative in a large percentage of the women. Allowing sufficient time for adaptation to an experimental diet can also be a challenge in metabolic studies. Nonetheless, all three studies imply that average protein needs during lactation are greater than 1.0 g/kg/day.

Recommended Protein Intakes During Lactation

The US NRC (30) currently recommends an additional 14.7 g of protein/day during the first six months of lactation, and a value 20% less than this thereafter (to take into account lower milk outputs). The safe levels recommended by FAO/WHO/UNU (14) are similar: 16–17 g/day for 0–6 months of lactation, 12.3 g/day for 6–12 months of lactation, and 11.3 g/day for 12–24 months of lactation. These estimates are close to those shown in Option 1 of Table 6. However, as described above, metabolic studies suggest that these values may be too low and that safe intakes may be 20–50% higher than current recommendations. This discrepancy could be at least partially explained by the fact that the recommendations do not take into consideration the NPN fraction of human milk. If this fraction is included (Option 2 of Table 6), the safe levels for exclusively breastfeeding women would be 23–36% higher than the current US NRC recommendations.

Influence of Maternal Protein Intake on Lactation

If maternal protein intake is lower than is recommended, can this potentially affect milk volume or composition? In animals such as rats and swine, milk volume is increased with greater protein intake, but in humans the evidence is much less clear (21). Research conducted 20–40 years ago in India (19) and Nigeria (13) suggested that women given extra protein produce more milk, but the studies lacked control groups and their designs may have biased the results (21). Since that time, two small-scale, short-term experimental studies in humans failed to find any significant effect of variations in maternal protein intake on milk volume (16, 29).

With regard to milk composition, the evidence is also somewhat mixed. Most cross-sectional studies of populations that differ in protein intake do not indicate much difference in milk protein concentration (21). However, two experimental studies in well-nourished women demonstrated that reduced protein intake resulted in changes in milk composition (16, 29). In the first (16), a change from 20% to 8% of energy intake from protein was associated with decreases in total nitrogen, protein, and NPN concentrations in milk. In the second (29), the impact of a lower protein diet (1.0 vs 1.5 g of protein intake/kg) was apparent only in reductions in milk concentrations of NPN and certain amino acids. Because both of these studies were short-term (5–10 days), it is unknown whether these effects are sustained with prolonged marginal protein diets.

CONCLUSIONS

The nutritional demands of lactation are substantial for both energy and protein. The estimates shown in Tables 5 and 6 (Option 2) for exclusively breastfeeding women represent an increase of about 30% for energy and 40% for protein compared with the needs of NPNL women (30). When dietary intake is inadequate, this can have a major impact on the mother's nutritional status over the long-term. For example, it has been estimated that protein output in milk during six months of exclusive breastfeeding is about 1.5 kg, and that if a lactating woman consumes only the amount of protein recommended for a NPNL woman it would represent a loss of about 19% of her lean tissue (21).

What is less clear is how much of an impact marginal energy and protein intakes have on lactation performance. As described in the first part of this review, lactating women in negative energy balance are likely to mobilize their own body reserves before there is a major impact on total milk energy transfer to the infant. This assumes, however, that maternal breastfeeding behavior is responsive to the demands of the infant, thereby allowing endocrine and autocrine mechanisms to govern the rate of milk synthesis. With respect to low maternal protein intake, there is no clear evidence that this compromises milk volume, but short-term studies suggest an impact on at least some fractions of milk nitrogen concentration. Further research is needed to understand whether this has any long-term impact on infant protein status or growth.

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