Low Nutrient Intakes among Infants in Rural Bangladesh Are Attributable to Low Intake and Micronutrient Density of Complementary Foods


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ABSTRACT We assessed the adequacy of nutrient intakes of 135 rural Bangladeshi breast-fed infants 6–12 mo of age and examined nutritional trade-offs due to possible displacement of breast milk by complementary foods. Observers completed 12-h daytime measurements of breast milk and complementary food intakes; data for the previous 12 h were obtained from maternal recall, yielding estimates of total 24-h intakes. On average, infants were mildly wasted (mean ± SD weight-for-length Z-score = −0.92 ± 0.88) and moderately stunted (length-for-age Z-score = −1.49 ± 0.96). Total energy intakes at 6–8 and 9–12 mo were 88 and 86% of absolute energy requirements (kJ/d), 106 and 105% of requirements per kg body weight, and 97 and 94% of requirements per kg median weight-for-length, respectively. Breast milk contributed 78% of energy intake at 6–8 mo and 75% at 9–12 mo. Mean meal frequency and energy density of complementary foods were generally consistent with recommendations, but only small amounts of food were offered. Nevertheless, only 72% of the food energy offered was consumed. Total energy intake was positively correlated with meal frequency, quantity consumed per meal, and energy intake from breast milk, but not with energy density of complementary foods. Energy intake from complementary foods was inversely related to energy intake from breast milk. The diets fell short of recommended intakes for numerous vitamins and minerals. We conclude that although greater intakes of complementary foods were associated with higher total energy intake, micronutrient intake remained low due to the low micronutrient density of the complementary foods consumed and the partial displacement of breast milk.


KEY WORDS: • infant dietary intake • Bangladesh • breast-feeding • complementary food • malnutrition

The rates of childhood malnutrition in rural Bangladesh are among the highest in the world: ~55% of children < 5 y old are stunted and 18% have low weight-for-height (1). Among children 6–11 mo and 12–23 mo old, the prevalence of anemia (hemoglobin < 110 g/L) is 78 and 64%, respectively (2); ~11% of children die before reaching the age of 5 y (1). Poverty is a major contributor to these problems, with per capita GNP averaging US$240 (1,3).

High rates of nutritional stunting of young Bangladeshi children can be attributed to both intrauterine growth retardation and postnatal growth faltering (4–6). The latter is caused by limited household food availability and poor infant feeding practices, leading to inadequate energy and nutrient intakes and high rates of infection. Alleviation of low birth weight will require improvements in women’s nutrition and health, and one or more generations to overcome the intergenerational sequelae of maternal malnutrition. On the other hand, mitigation of postnatal growth faltering and specific micronutrient deficiencies should be possible through improved complementary feeding practices and reduced morbidity.

Technical guidelines on optimal complementary feeding practices have been published (7,8). Critical components include: 1) introduction of foods other than breast milk at 6 mo of age, 2) adequate energy density and frequency of feeding of complementary foods, and 3) satisfactory nutrient density of these foods. Before implementing these guidelines, it is essential to understand current child feeding practices, the factors that influence these practices, and possible constraints to improving them. We therefore completed a series of studies using quantitative and qualitative techniques to evaluate complementary feeding practices among rural Bangladeshi infants and identify ways to improve these practices. The studies included: 1) assessment of current dietary intakes, using direct observation of food preparation and consumption in the home, and 2) evaluation of the feasibility and acceptability of increasing the amount of food offered at each meal, increasing meal frequency, enhancing energy density using different recipes, and adding micronutrient supplements to existing foods at the time of preparation or serving, or providing liquid supplements directly to infants. The latter set of studies employed “behavior change trials” and is published elsewhere (9).

In this paper, we report the dietary intake results. Our objectives were as follows: 1) to evaluate the adequacy of energy intake, using various approaches to estimating requirements, 2) to examine the association of energy intake with...
meal frequency, quantities served and consumed per meal, and energy density of complementary foods, 3) to assess the adequacy of micronutrient intake, and 4) to examine the relation between intake of complementary foods and intake of breast milk, to assess nutritional trade-offs due to possible displacement of breast milk by complementary foods.

SUBJECTS AND METHODS

Study site. The study was conducted in 9 villages in Matlab thana, Comilla district, Bangladesh between June and September, 1999. A field research unit of the Centre for Health and Population Research (ICDDRB),¹ located in Matlab, served as the project’s central office. The research protocol was reviewed and approved by the human subjects committees at the University of California, Davis and ICDDR,B.

Village selection criteria, infant eligibility, and socioeconomic information. Observations were completed in villages located within an hour’s travel on a nonmotorized boat from ICDDR,B Matlab Center. The Matlab Health and Demographic Surveillance System supplied information on the number of infants per village and which households included infants of the appropriate age (10). In these villages, most infants in the 6- to 12-mo age range participated which households included infants of the appropriate age (10). In these villages, most infants in the 6- to 12-mo age range participated.

Dietary intake. Trained observers completed one 12-h dietary record for each infant. The assistant remained in the child’s home for ≥12 h, from ~0600 until ~1800 h. Maternal recall of foods consumed during the previous 12 h (~1800 to ~0600 h) was used to estimate total 24-h intake of complementary foods. For the nighttime data, mothers were asked to demonstrate the amounts of food they fed their infants, which the field assistants converted to gram quantities. These nighttime recalls did not include water consumption or snacks, defined as a feeding episode in which <10 g was consumed. Nighttime snacks were excluded because both the field assistants and the mothers found it difficult to estimate such small quantities, people other than the mother often gave snacks, and the total quantities were expected to be extremely small. This final point was verified by the daytime weighed intake data, which demonstrated that the total amounts of all daytime snacks (all feedings <10 g) were summed, the mean (±SD) daily total was only 6.5 ± 5.0 g/d.

Breast milk nutrient intake determinations. Breast milk intake was determined by weighing the child before and after breast-feeds, as described previously (12), using electronic balances (Medela) with 2-g precision. Insensible water losses were measured twice daily (morning and afternoon) and averaged to correct the test-weighing values (12). For these latter measurements, the mean duration of each observation was ~4 ± 10 min, the mean weight lost during the observation period was ~9 ± 3 g, and the mean insensible loss correction was 0.059 ± 0.028 g/(kg body weight·min). Breast milk intake for each child was corrected by an amount equal to the product of the child’s own correction factor, total nursing duration, and body weight. The resulting child-specific underestimate of milk intake due to insensible losses (mean ± SD = 26 ± 16 g/12 h) was added to each child’s 12-h breast milk intake (mean 579 ± 117 g/12 h). This sum (mean 405 ± 122 g) was then converted to volume by dividing by the density of breast milk, which was previously measured to be 1037 g/L (12). Breast milk intake over 24 h was extrapolated by dividing by 0.53, the proportion represented by daytime intake, as determined previously (12).

Assumed values were used for breast milk composition. Breast milk fat (25.1 g/L), protein (9.4 g/L), and energy (2470 kJ/L or 0.59 kcal/mL) concentrations were adopted from Brown et al. (13), who examined the lactation performance of undernourished women from a semirural community of Dhaka. Breast milk micronutrient concentrations were taken from WHO/NUT/98.1 (7), except for vitamin A [226 µg retinol equivalents (RE)/L], which was based on data from Matlab, Bangladesh (14). Possible differences between the actual nutrient concentrations of breast milk and the imputed values are considered in the Discussion.

Measurement of complementary food intake. Using a scale accurate to 2 g, field assistants weighed all foods before and after serving the child. For mixed recipes, all foods included in the recipe were weighed before being added to the preparation, and the final weight of the prepared recipe was determined. The amount that the child consumed was recorded as a proportion of the total recipe, so that the intakes of each food ingredient could be calculated. During analysis of dietary data, a meal was considered to have taken place whenever a new ingredient (or combination of foods) was offered to the infant. It was very rare for more than 1 food or food combination to be served at the same time, i.e., within a 10-min period (this occurred for only 12 of the 636 feeding episodes observed).

The nutrient content of individual foods and recipes was estimated using the software package, The Food Processor (version 7.01), which incorporated USDA food composition data. Data from local food composition tables were added to the database as necessary. The mean energy density of the complementary food regimen was calculated by dividing the daily energy intake by the quantity consumed, not including noncaloric beverages.

The method of rice preparation commonly used in Bangladesh entails adding water to rice and boiling together until the rice is cooked, at which point the excess water is poured off. The discarded broth is commonly used as an animal feed. It is expected that this process increases vitamin and mineral loss, but empirical data are not available. USDA food composition values for parboiled, unenriched rice were used to approximate the nutrient content of rice. Many types of green leafy vegetables are used in Bangladesh. Nutrient values for spinach were used to approximate their nutrient composition. Standardized recipes were created by averaging the food amounts in similar recipes. The nutrient composition of the standardized recipe was used when information on a particular recipe could not be collected because the dish was prepared outside of the study home or before the observation period.

Assessment of adequacy of energy and nutrient intakes. Total nutrient intake from both breast milk and complementary foods was compared with the most recent values for average energy requirements and recommended nutrient intakes (RNIs). Energy requirements were based on energy expenditure and body composition data for breast-fed infants (8,15). RNIs were based on the U.S. Institute of Medicine Dietary Reference Intakes (DRIs) (16–19) or FAO/WHO values (20). Because the DRI and FAO/WHO RNIs differ substantially during infancy for several key nutrients (8), we chose to be conservative in making judgments about the likelihood of deficiency by using the lower value whenever there was a difference between them for a particular nutrient.

Anthropometry. A single field worker was trained to conduct all infant length measurements using standard procedures (21) and a length board accurate to the nearest mm. Weight was measured using balances accurate to 2 g (Medela). When total energy requirements were expressed per unit ideal body weight, ideal weights were calculated using the infant’s actual length and the median weight-for-length from pooled data on breast-fed infants from North America and Europe (22).

Statistical analyses. Statistical analyses were performed using SAS-PC for WINDOWS (version 6.10; SAS Institute). Pearson correlations were used to examine relations among breast-feeding frequency, breast milk intake, meal frequency, and complementary food intake and total energy intake, and multiple linear regression was used when more than one independent variable was included for a given outcome. Means were compared using Student’s t test. Dif-

¹ Abbreviations used: AI, Adequate Intakes; DRI, Dietary Reference Intakes; EAR, Estimated Average Requirement; GNP, Gross National Product; ICDDR,B, Centre for Health and Population Research; LAZ, length-for-age Z-score; RE, retinol equivalent; RNI, recommended nutrient intake; WAZ, weight-for-age Z-score; WLZ, weight-for-length Z-score.
RESULTS

Socioeconomic information. Typical houses in the study villages had mud floors, galvanized steel roofs, and walls constructed of metal (46%), bamboo (42%), thatch/jute (10%), or brick (2%). The education levels of the mothers and fathers were as follows: 36 and 31% with no education, 18 and 21% with 1–4 y, 34 and 32% with 4–8 y, and 12 and 16% with >8 y, respectively.

Characteristics of study children. Table 1 presents the mean weight-for-age (WAZ), length-for-age (LAZ), and weight-for-length (WLZ) Z-scores of the study infants. The infants were 6–12 mo of age and mildly wasted and moderately stunted compared with National Center for Health Statistics reference data (23). Z-scores declined as the age of the infants increased.

Dietary intake. All of the 135 infants were breast-fed and 94% received complementary food on the day of observation.

Breast milk consumption. The mean number of breast-feeds during the 12-h weighing intake period was 8.3 ± 2.0 with a mean total duration of 64 ± 22 min. Neither breast-feeding frequency nor total feeding duration changed significantly with age. Both frequency (r = 0.36, P < 0.0001) and total duration (r = 0.18, P < 0.04) of breast-feeds were significantly associated with 12-h breast milk intake.

Mean 12-h breast milk consumption was 0.379 ± 0.123 L at 6–8 mo and 0.400 ± 0.113 L at 9–12 mo. Using the daytime proportion of 0.53, estimated mean 24-h breast milk consumption was 0.715 ± 0.233 L at 6–8 mo and 0.754 ± 0.212 L at 9–12 mo. Assuming an energy density of 2470 kJ/L (0.59 kcal/mL), the mean estimated 24-h energy intake from breast milk was 1766 and 1862 kJ/d (422 and 443 kcal/d) at 6–8 mo and 9–12 mo, respectively (Table 2). Intake did not differ between boys and girls. Controlling for age, infant body weight was significantly associated with breast milk intake (r = 0.21, P < 0.05). Indicators of socioeconomic status (type of housing; parental education) were not associated with breast milk intake.

Complementary food consumption. In this analysis, “feeding episodes” include all feedings, “meals” include intakes 1 h before the observation, 38% of mothers reported feeding their infants meals (≥10 g); among these women, 1.8 ± 0.8 meals were offered during this period. The mean total number of meals per day was 2.6 ± 1.9 and the total number of feeding episodes, less nighttime snacks, was 3.5 ± 2.0. Meal frequency was higher by 0.2 meals/mo of age (r = 0.20, P = 0.02), although the total amount consumed (g/d) did not differ by age. Table 2 illustrates the amount of food and energy consumed by age group.

Foods commonly consumed during the observations included rice, wheat, legumes, vegetables (numerous local varieties of tubers, melons, and greens), fruits (guava, banana, mango, coconut), milk, eggs, and fish. Aside from rice and wheat, the quantities consumed were small. Rice was the major contributor of energy and was included in 53% of meals, either alone (20% of meals), mixed with water, milk, dhal, or vegetable or fish curry (24% of meals), or ground to make “luta,” a porridge (9% of meals). Wheat products represented 28% of meals and were usually served as suji (wheat porridge), flat bread, or crackers. Fruit accounted for 11% of meals, and 15% of all meals contained an animal source food, which was usually cow’s milk.

The median energy density of the complementary food regimen was 4.79 kJ/g (1.2 kcal/g); the range was 0.9 to 18.7 kJ/g and the interquartile range was 2.9 kJ/g (0.2–4.5 kcal/g; interquartile range = 0.7 kcal/g) (Table 2). Energy density was inversely correlated with the amount of complementary food consumed (g/d) (r = −0.46, P < 0.0001) and with total daily energy intake from complementary foods (r = −0.32, 0.0002).

Complementary foods supplied 22 and 25% of total energy intake at 6–8 and 9–12 mo, respectively (Table 2). Energy intake (kJ/d) from complementary foods increased only slightly with age (r = 0.15, P = 0.08). Total daily energy intake from complementary foods ranged from 0 to >2092 kJ (500 kcal)/d, with 47% of infants consuming <415 kJ/d (100 kcal/d). Energy intake from complementary foods was positively correlated with the number of feeding episodes per 24 h (r = 0.67, P < 0.0001), the amount (g) consumed per 24 h (r = 0.82, P < 0.0001), and the amount (g) served per meal

### Table 1

<table>
<thead>
<tr>
<th>Characteristics of study children</th>
<th>6–8 mo</th>
<th>9–12 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>Male</td>
</tr>
<tr>
<td>n</td>
<td>61</td>
<td>29</td>
</tr>
<tr>
<td>Age, mo</td>
<td>7.4 ± 1.0</td>
<td>7.5 ± 1.0</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>6.6 ± 0.9</td>
<td>6.8 ± 0.8</td>
</tr>
<tr>
<td>Length, cm</td>
<td>68.7 ± 2.7</td>
<td>66.4 ± 2.5</td>
</tr>
<tr>
<td>WAZ</td>
<td>−1.7 ± 0.9</td>
<td>−1.8 ± 0.8</td>
</tr>
<tr>
<td>LAZ</td>
<td>−1.3 ± 0.9</td>
<td>−1.4 ± 0.9</td>
</tr>
<tr>
<td>WLZ</td>
<td>−0.8 ± 1.0</td>
<td>−0.9 ± 0.9</td>
</tr>
</tbody>
</table>

1 Values are means ± SD.
2 Compared with National Center for Health Statistics reference population (23).
during the 12-h weighed intake period ($r = 0.73, P < 0.0001$). Maternal educational level was positively related to energy intake from complementary foods ($r = 0.18, P < 0.04$).

The theoretical mean amount of energy needed from complementary foods, estimated as the difference between total energy requirements and the mean breast milk energy consumption in the current study, was 808 kJ (193 kcal) at 6–8 mo and 1008 kJ (241 kcal) at 9–12 mo. Energy intake from complementary foods, as a percentage of energy needed from complementary foods, averaged 63% at 6–8 mo and 61% at 9–12 mo (Table 2).

Total energy intake. Total energy intakes by 6–8 mo infants were 88% of estimated absolute energy requirements, 106% of requirements/kg body weight, and 97% of requirements/kg ideal body weight for length. The corresponding percentages for 9–12 mo infants were 86, 105, and 94% for these 3 estimates, respectively.

Total energy intake was positively correlated with energy intake from breast milk ($r = 0.69, P < 0.0001$), energy intake from complementary food ($r = 0.44, P < 0.0001$), complementary food meal frequency ($r = 0.31, P = 0.0003$), and quantity consumed (g) per meal ($r = 0.21, P = 0.02$), but not with energy density of complementary foods ($r = -0.09, P = 0.34$), maternal education ($r = 0.04, P = 0.65$), or type of housing ($r = -0.007, P = 0.93$). When both meal frequency and quantity per meal were included in the same model, the former was significantly associated with total energy intake ($P = 0.005$), but the latter was not ($P = 0.36$).

### Nutrient intake. Tables 3 and 4 compare total nutrient intakes with the RNIs at 6–8 and 9–12 mo, respectively, and illustrate the contribution of breast milk to total intakes. Breast milk was the major contributor of all nutrients except vitamin B-6 and iron. Protein intake exceeded the recommended amounts in both age groups. Nutrient intakes that fell short of the recommended amounts included vitamin A, folate, pantothenic acid, riboflavin, thiamin, vitamin B-6, vitamin D, calcium, iron, magnesium, phosphorus, potassium, and zinc. The mean nutrient density of the complementary food diet was below the desired nutrient density for vitamin A, folate, niacin, riboflavin, thiamin, vitamin B-6, vitamin C, calcium, iron, and zinc (data not shown) (8).

### Relations between breast-feeding and complementary feeding. Breast-feeding frequency was inversely related to meal frequency. For 6–8 mo and 9–12 mo old infants, each additional complementary food meal (≥10 g) was associated with a decrease of 1.0 ($r = -0.59, P < 0.0001$) and 0.5 ($r = -0.39, P < 0.0005$) breast-feeds respectively, over the 12-h observation period. Using recall data to approximate 24-h values, each additional meal corresponded to a decrease of 0.9 ($r = -0.55, P < 0.0001$) and 0.3 ($r = -0.22, P < 0.06$) breast-feeds for 6–8 mo and 9–12 mo old infants, respectively.

Similarly, energy intake from complementary foods was inversely associated with energy intake from breast milk. Over the 12-h observation period, each additional 4.2 kJ (1 kcal) from complementary food was associated with a decrease of 0.9
TABLE 3
Mean nutrient intakes from complementary foods and breast milk compared with recommended nutrient intakes for 6- to 8-mo-old infants

<table>
<thead>
<tr>
<th>Complementary foods</th>
<th>Breast milk</th>
<th>Total intake</th>
<th>Recommended2,3</th>
<th>% Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein, g/d</td>
<td>2.7 ± 2.9</td>
<td>6.7 ± 2.2</td>
<td>9.4 ± 2.9</td>
<td>9.1</td>
</tr>
<tr>
<td>Protein, g/(kg BW - d)</td>
<td>0.4 ± 0.4</td>
<td>1.0 ± 0.3</td>
<td>1.4 ± 0.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Vitamin A, µg RE/d</td>
<td>12 ± 31</td>
<td>161 ± 53</td>
<td>174 ± 52</td>
<td>400</td>
</tr>
<tr>
<td>Folate, µg/d</td>
<td>10 ± 12</td>
<td>61 ± 20</td>
<td>71 ± 20</td>
<td>80</td>
</tr>
<tr>
<td>Folic acid, µg/d</td>
<td>0.92 ± 0.99</td>
<td>1.07 ± 0.35</td>
<td>2.00 ± 1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Other micronutrients</td>
<td>1.52</td>
<td>3.18</td>
<td>4.69 ± 1.66</td>
<td>4.0</td>
</tr>
</tbody>
</table>

1 Values are means ± SD.
2 All recommended values are AIs, except for iron and zinc, which are RDAs.
3 Protein and potassium values are based on WHO/NUT/98.1 (7). All vitamin and mineral values based on WHO, 2002 (20) except calcium, copper, phosphorus, and zinc, which are based on Institute of Medicine, Dietary Reference Intakes (17,18).
4 Breast milk vitamin A estimated at 226 ¿g/L; range in developing countries 170–640 ¿g/L (7,14,25).
5 Using the conversion that 60 mg of tryptophan is equivalent to 1 mg of niacin (26).
6 Breast milk riboflavin concentration estimated at 0.35 mg/L; range in developing countries 0.16–0.2 mg/L (27,28).
7 Breast milk thiamin concentration estimated at 0.21 mg/L; range in developing countries 0.11–0.27 mg/L (27).
8 Breast milk vitamin B-6 concentration estimated at 93 µg/L; range in developing countries 68–120 µg/L (27,29).
9 Breast milk B-12 concentration estimated at 0.97 µg/L; range 0.33–3.32 µg/L (30).
10 Assuming a medium bioavailability of 10%.
11 Breast milk selenium concentration estimated at 20 µg/L, range 10–30 µg/L (31).

kJ (0.22 kcal) from breast milk at 6–8 mo (r = -0.29, P < 0.02) and 1.3 kJ (0.30 kcal) (r = -0.42, P < 0.002) at 9–12 mo. Approximating 24-h intake by using recall data for complementary food and estimates of nighttime breast milk consumption, each additional 4.2 kJ (1 kcal) from complementary food was associated with a decrease of 1.7 (0.41 kcal) from breast milk at 6–8 mo (r = -0.32, P < 0.01) and 2.1 kJ (0.51 kcal) (r = -0.42, P < 0.002) at 9–12 mo.

We calculated the theoretical changes in intake of selected nutrients if an infant consumed an additional 418 kJ (100 kcal) of complementary food, leading to a displacement from the diet of 184 kJ (44 kcal) of breast milk, the mean estimated displacement for infants in both age groups (Table 5). This increase in complementary food intake would result in a 17% increase in protein intake, but only small increases (<10% of the RNI) in the intakes of iron, zinc, calcium, and riboflavin, and a small decrease in the intakes of vitamins A and C. The estimates for iron, zinc, and calcium do not take into account the potential differences in bioavailability from complementary foods vs. breast milk.

**DISCUSSION**

Although mean energy intake of the infants observed in this study was close to the required level (depending on how intake is expressed), and mean protein intake exceeded the recommended level, mean intakes of several micronutrients were far below recommended amounts, particularly for iron, zinc, vitamin A, and vitamin B-6. The mean intake of breast milk was relatively high compared with the mean values reported by the WHO (7), but energy intake from complementary foods was relatively low, and the micronutrient quality of the diet was poor. The results were similar to those from a study conducted in 1978 in villages near Matlab (11), indicating that infant dietary intake has changed very little in the past 2 decades. The low nutrient density of complementary foods is not unique to Bangladesh, but has been observed in many developing countries (32).

**Adequacy of energy intake.** There are several possible approaches to assessing the adequacy of infant energy intake. Comparing energy intakes to absolute requirements has the advantage of allowing extra energy per kilogram for catch-up growth of children with low body weight due to previous nutritional growth retardation. Low body weight may be due to intrauterine growth retardation, postnatal nutritional deficiencies, and/or repeated illnesses. Normal birth weight infants are usually born with adequate reserves of nutrients, such as iron and zinc, for the first 6 mo of life, but infants born with low birth weight may exhaust those stores and begin experiencing growth retardation very early in life (7). Although a portion of intrauterine, infantile, and multigenerational growth stunting can be overcome (33), absolute energy requirements probably overestimate the true needs of this population because even with optimal postnatal nutrition and care, it is unlikely that these infants will achieve their full genetic potential in height.
TABLE 4
Mean nutrient intakes from complementary foods and breast milk compared with recommended nutrient intakes
for 9- to 12-mo-old infants1

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Complementary</th>
<th>Breast milk foods</th>
<th>Total intake</th>
<th>Recommended2,3</th>
<th>% Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein, g/d</td>
<td>3.6 ± 2.7</td>
<td>7.1 ± 2.0</td>
<td>10.6 ± 2.6</td>
<td>9.6</td>
<td>110</td>
</tr>
<tr>
<td>Protein, g/(kg BW · d)</td>
<td>0.5 ± 0.4</td>
<td>1.0 ± 0.3</td>
<td>1.5 ± 0.4</td>
<td>1.0</td>
<td>150</td>
</tr>
<tr>
<td>Iron, mg/d</td>
<td>170 ± 48</td>
<td>191 ± 60</td>
<td>200 ± 40</td>
<td>400</td>
<td>48</td>
</tr>
<tr>
<td>Folate, μg/d</td>
<td>16 ± 17</td>
<td>64 ± 18</td>
<td>80 ± 22</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Niacin, mg/d</td>
<td>1.22 ± 0.91</td>
<td>1.13 ± 0.32</td>
<td>2.36 ± 0.88</td>
<td>4</td>
<td>59</td>
</tr>
<tr>
<td>Zn, mg/d</td>
<td>0.49 ± 0.23</td>
<td>0.73 ± 0.21</td>
<td>0.82 ± 0.27</td>
<td>0.5</td>
<td>164</td>
</tr>
<tr>
<td>Vitamin C, mg/d</td>
<td>4 ± 9</td>
<td>30 ± 9</td>
<td>34 ± 10</td>
<td>30</td>
<td>113</td>
</tr>
<tr>
<td>Vitamin D, μg/d</td>
<td>0.22 ± 0.44</td>
<td>0.42 ± 0.12</td>
<td>0.63 ± 0.40</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Calcium, mg/d</td>
<td>43 ± 46</td>
<td>211 ± 60</td>
<td>254 ± 54</td>
<td>270</td>
<td>94</td>
</tr>
<tr>
<td>Copper, mg/d</td>
<td>0.10 ± 0.07</td>
<td>0.19 ± 0.05</td>
<td>0.29 ± 0.08</td>
<td>0.3</td>
<td>145</td>
</tr>
<tr>
<td>Magnesium, mg/d</td>
<td>18 ± 13</td>
<td>26 ± 7</td>
<td>44 ± 12</td>
<td>54</td>
<td>81</td>
</tr>
<tr>
<td>Phosphorus, mg/d</td>
<td>63 ± 49</td>
<td>106 ± 30</td>
<td>169 ± 42</td>
<td>400</td>
<td>61</td>
</tr>
<tr>
<td>Potassium, mg/d</td>
<td>120 ± 109</td>
<td>396 ± 112</td>
<td>516 ± 115</td>
<td>700</td>
<td>74</td>
</tr>
<tr>
<td>Selenium, μg/d</td>
<td>11 ± 8</td>
<td>15 ± 5</td>
<td>25 ± 10</td>
<td>10</td>
<td>250</td>
</tr>
<tr>
<td>Zinc, mg/d</td>
<td>0.44 ± 0.30</td>
<td>0.91 ± 0.26</td>
<td>1.34 ± 0.30</td>
<td>2.8</td>
<td>45</td>
</tr>
</tbody>
</table>

1 Values are means ± SD. See Table 3 for footnotes 2–11.

Using requirements based on energy per kilogram body weight has the advantage of accounting for the small size of these infants, but does not provide energy for catch-up growth nor does it account for low body weight due to wasting. Accordingly, because the infants in this study were both stunted and thin, requirements based on energy per kilogram body weight probably underestimate desirable energy intake.

A third approach, using energy requirements based on ideal body weight for length, accounts for wasting by substituting expected weight for length based on values from a well-nourished population, but does not provide for catch-up from stunting. These values may result in an overestimate of requirements if Bangladeshi infants are genetically destined to be thinner than children in the reference population. Anthropometric data from a 7-country study of breast-fed infants of well-educated mothers indicate that Indian infants are significantly lower in weight for length than infants from other regions of the world (34). On the other hand, basing energy needs on ideal weight for length may underestimate requirements by not allowing sufficient extra energy for catch-up growth in length. Of the 3 approaches, the 3rd one probably provides the best estimate of the children's true energy needs.

In these infants, total energy intake was low compared with absolute energy requirements, whereas intake per kilogram was at or above requirements. Using the 3rd approach, based on energy needs per kilogram ideal weight for length, intakes were 94–97% of requirements. There are several potential errors when estimating energy intakes of breast-fed infants. For example, we assumed a breast milk energy density of 2470 kJ/L (0.59 kcal/mL), based on the value reported by Brown et al. (24) for Bangladeshi women with a mean BMI of 17.8 kg/m². However, if the women in the current study had a higher BMI than in the study by Brown et al., we may have underestimated the energy density of breast milk because it is correlated with maternal fatness (13). Rice et al. (14) recently reported a BMI of 18.9 from women in the Matlab area. Other possible sources

TABLE 5
Theoretical percentage change in nutrient intake due to an additional 418 kJ (100 kcal) of complementary foods1

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Energy (kJ)</th>
<th>Protein, g</th>
<th>Iron, mg</th>
<th>Zinc, mg</th>
<th>Calcium, μg RE</th>
<th>Vitamin A</th>
<th>Riboflavin, mg</th>
<th>Vitamin C, mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount lost from displacement of 184 kJ (44 kcal) of breast milk</td>
<td>184 (44)</td>
<td>0.7</td>
<td>0.02</td>
<td>0.09</td>
<td>20.4</td>
<td>20.8</td>
<td>0.026</td>
<td>2.9</td>
</tr>
<tr>
<td>Amount added from complementary foods2</td>
<td>418 (100)</td>
<td>2.3</td>
<td>0.45</td>
<td>0.31</td>
<td>31.3</td>
<td>13.3</td>
<td>0.060</td>
<td>1.8</td>
</tr>
<tr>
<td>Difference</td>
<td>+234 (56)</td>
<td>+1.6</td>
<td>+0.42</td>
<td>+0.22</td>
<td>+10.9</td>
<td>−7.5</td>
<td>+0.034</td>
<td>−1.1</td>
</tr>
<tr>
<td>Recommended intake3</td>
<td>2724 (651)</td>
<td>9.4</td>
<td>9.34</td>
<td>3</td>
<td>270</td>
<td>400</td>
<td>0.4</td>
<td>30</td>
</tr>
<tr>
<td>Change in intake as a % of recommended intake</td>
<td>8.6</td>
<td>17</td>
<td>3.9</td>
<td>4.5</td>
<td>4.0</td>
<td>−2.2</td>
<td>8.6</td>
<td>−4.4</td>
</tr>
</tbody>
</table>

1 Based on the 24-h regression coefficient for all infants of 0.44, representing the association between decreasing breast milk energy as energy from complementary food increases.

2 Nutrient density based on the complementary feeding regimen observed in this study.

3 Based on recommended intakes for 6- to 11-mo-old infants (7).

4 Assuming medium bioavailability (7).
of error include the assumptions about the amount of breast milk consumed at night, the inability to collect information on snacks of complementary foods consumed at night (although these amounts were likely to be quite small), and the estimate of the energy density of rice.

The low WLZ of infants in this study (mean, –0.9) suggests inadequate energy intake. The mean WLZ of Indian infants of well-educated mothers at this age was similar (approximately –0.7) (34), making it unclear how to interpret this finding. Frequent illness is a likely contributor to the low mean WLZ. However, morbidity data were not collected and dietary data were not collected on days when infants were overtly ill; thus, it is not possible to estimate the effect of morbidity in the present study.

Mean meal frequency and energy density were generally consistent with recommendations. However, the relatively high energy density observed may reflect foods and preparation techniques that do not result in the consistency needed to facilitate infant feeding. This may have constrained the amount of complementary foods consumed per meal, which was low. This is supported by the observation that energy intake from complementary foods was positively correlated with meal frequency and quantities offered and consumed, but negatively correlated with the energy density of the diet. Despite the fact that the amount of energy from complementary foods offered to the infants was only ~74% of the recommended amounts, only 72% of the amount of food offered was consumed. Thus, the infants were apparently unwilling or unable to consume the amounts offered. There are several possible explanations. First, the small size of the infants and limited potential for catch-up growth may explain their low energy intakes. Second, the caregivers may have offered inappropriate foods (e.g., improper consistency) or used feeding methods that made it difficult for the infants to consume adequate amounts. Third, the infants’ appetites may have been depressed due to chronic subclinical infections or micronutrient deficiencies.

**Adequacy of micronutrient intake.** For several micronutrients, the mean total intake (from both breast milk and complementary food) was far below the RNI. Conclusions about the adequacy of micronutrient intakes depend on assumptions made about breast milk composition and infant nutrient requirements. Breast milk micronutrient values potentially affected by maternal status include vitamin A, riboflavin, thiamin, vitamin B-6, vitamin B-12, and selenium (value ranges are presented in Table 3 footnotes). Those that are not likely to be affected by maternal status include folic acid, vitamin D, calcium, iron, copper, and zinc (7). In this study, mean intakes of protein, niacin, folate (9–12 mg), vitamin B-12, vitamin C, selenium, and copper equaled or exceeded the RNI, regardless of the assumptions regarding breast milk nutrient concentration. By contrast, mean intakes of folate (6–8 mg), pantothenic acid, riboflavin, thiamin, vitamin B-6, vitamin D, calcium, copper, magnesium, phosphorus, potassium, and zinc intakes were less than the RNI, regardless of the assumptions employed. Mean intakes were particularly low for iron (8–9% of the RNI), vitamin D (12–13% of the RNI), zinc (40–45% of the RNI), and vitamin B-6 (50% of the RNI), although it should be noted that vitamin D requirements can be met by adequate exposure to sunlight (35). The adequacy of vitamin A intake depends on which assumptions are used for breast milk concentrations. Using an estimate of 226 μg/L (14), mean vitamin A intakes were only 44–48% of the RNI.

The nutrient recommendations used in this study were based on recently published DRIs (16–19) or RNIs (20). The proportion of a group that is at risk of nutrient inadequacy can be estimated by using the Estimated Average Requirement (EAR) Cut Point Method (36). This is not yet possible for infants because EARs for infants are presently available only for iron and zinc. All other vitamin and mineral intake recommendations are Adequate Intakes (AI), which during infancy are based on observed intakes of infants in the United States (8,15). By definition, the AI should be greater than the EAR and possibly the RDA. Thus, the proportion of a population with intakes below the AI is likely to be an overestimate of the prevalence of nutrient inadequacy. For this reason, there is uncertainty about the percentage of infants with inadequate micronutrient intakes in our study population.

**Programmatic implications.** Assuming that total energy intake is indeed lower than desirable, one possible recommendation would be to increase the amount of complementary food offered without decreasing meal frequency or energy density. However, this might not be successful considering that not all of the food currently offered was consumed. Moreover, increased intake of complementary foods is associated with some decrease in intake of breast milk, although the net effect on total energy intake is positive. The magnitude of the inverse relation between breast milk and complementary food intake observed in this study is in agreement with values reported by Drewett et al. (37) from an observational study in Thailand [a displacement of 1.3–1.7 kcal (0.3–0.4 kcal) of breast milk for each additional 4.18 kcal (1 kcal) from complementary food among similarly aged infants]. Even if the Bangladeshi infants consumed more energy, however, the effect on total micronutrient intakes might be negligible due to poor nutrient density of the complementary foods, or there might even be adverse effects because of poor microbiological quality and displacement of breast milk. Our estimates indicate that an increase in energy intake from the currently consumed complementary foods would not substantially improve micronutrient intake (Table 5).

Increasing the variety and amount of the foods consumed could reduce deficits in vitamin A, folate, pantothenic acid, thiamin, riboflavin, vitamin B-6, magnesium, phosphorus, and potassium. However, major changes in the diet, probably necessitating a large increase in the consumption of animal source foods, would be required to achieve adequate intakes of iron and zinc. Fortification or supplementation may be the most efficient way to achieve adequate intakes of these nutrients. Recommendations have to focus concomitantly on increasing the nutrient density of the diet, improving palatability of foods, and educating caregivers on appropriate feeding practices. In addition, the microbiological safety of complementary foods should be emphasized. Because microbiologically contaminated complementary foods are a common cause of diarrhea, recommendations to increase the quantity, frequency, or variety of foods offered should be accompanied by appropriate food safety guidelines.

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**LITERATURE CITED**