Effects of energy density and feeding frequency of complementary foods on total daily energy intakes and consumption of breast milk by healthy breastfed Bangladeshi children


ABSTRACT

Background: Information is needed on the minimum energy density and feeding frequency of complementary foods that can provide adequate energy intakes (EIs) for healthy breastfed children.

Objectives: The objectives of the study were to evaluate the effects of various energy densities and feeding frequencies of complementary foods on EI from these foods, breast milk consumption, and total EI from both sources.

Design: During 9 separate, randomly ordered dietary periods lasting 3–6 d each, we measured intakes of food and breast milk by 18 healthy breastfed children 8–11 mo of age who, 3, 4, or 5 times/d, were fed porridge with a coded energy density of 0.5, 1.0, or 1.5 kcal/g. Food intake was measured by weighing the feeding bowl before and after meals, and breast milk intake was measured by test weighing.

Results: The mean amounts of complementary foods consumed were inversely related to their energy density and positively related to the number of meals/d (P < 0.001 for both); EIs from foods were positively related to both factors. Breast milk intake decreased slightly but progressively, with greater energy density and feeding frequency of complementary foods; total EIs (kcal/d) increased in relation to both factors (P < 0.001 for both).

Conclusions: The energy density and feeding frequency of complementary foods affect infants’ total daily EI and breast milk consumption. Recommendations can be developed for the appropriate combinations of these dietary factors that are compatible with adequate EI, although longer-term effects of complementary feeding practices on breast milk intake and breastfeeding duration need further community-based studies. Am J Clin Nutr 2008;88:84–94.

INTRODUCTION

In lower-income countries, children’s weight gain commonly falters in relation to international reference data between ≈3 and 15 mo of age (1), the span during which complementary foods are usually introduced into their diets. The primary explanations for children’s restricted growth during this period include insufficient or inappropriate dietary intake, frequent infections, and, possibly, intrauterine programming of postnatal growth. To meet their physiologic requirements, infants >6 mo old require, in addition to breast milk, complementary foods of appropriate energy and nutrient densities (2). The relatively high energy requirements of young children, together with their limited stomach capacity, challenge their ability to meet physiologic energy needs, particularly if the energy density of the diet is low or if only a few meals are offered each day (2–4). Dietary energy density and feeding frequency are independently related to total daily energy intake (EI) in weaned children; thus, both factors should be considered in developing recommendations for infant feeding (2). When the energy density of complementary foods is greater, fewer meals can be provided; conversely, when more meals are offered, energy requirements can be met with diets of lower energy density.

The effects of dietary energy density and feeding frequency on total daily EIs have been studied in fully weaned children recovering from malnutrition (2); however, comprehensive studies that include quantitative assessment of breast milk intake are still lacking. To develop appropriate recommendations for breastfed children, the potentially adverse effects on breast milk intake that may be imposed by feeding diets with excessively high energy density or feeding frequency also must be considered. It is conceivable that unnecessarily high intakes of complementary food could suppress a child’s desire to nurse at the breast, thereby influencing the amount of breast milk consumed and the overall quality of the diet and possibly hastening discontinuation of breastfeeding and the mother’s return to fertility (5, 6).

Our group recently completed a preliminary study to determine the number of days required for stabilization of breast milk intake after the introduction of 3 daily servings of high-energy-density complementary foods (1.5 kcal/g) to the diets of children who had been receiving low-energy-density complementary foods (0.4 kcal/g) and after a similar switch from a high-energy-density food to a lower-energy-density food (7). We found that total daily EI was greater from the high-energy-density complementary food, but breast milk intake decreased slightly. Neither

1 From the Program in International and Community Nutrition, University of California, Davis, CA (MMM, JMP, KGD, and KHB); the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B), Dhaka, Bangladesh (MMI, MK, and TA); and the Department of Pediatrics, Dhaka Medical College Hospital, Dhaka, Bangladesh (MAHM).
2 Supported by the Government of Bangladesh through the Improved Health for the Poor: Health, Nutrition and Population Research Project.
3 Reprints not available. Address correspondence to KH Brown, Program in International and Community Nutrition, University of California, Davis, One Shields Avenue, Davis, CA 95616. E-mail: khbrown@ucdavis.edu. Received October 30, 2007. Accepted for publication March 20, 2008.
breast milk intakes nor intakes of the high-energy-density complementary food varied by day of observation during either of the 7-d diet periods. However, intakes of the low-energy-density complementary foods increased progressively for 5 d before stabilization occurred. These data were used to design the current study, which was carried out to provide information on the effects of a greater number of combinations of energy density and feeding frequency of complementary foods on total daily EIs and consumption of breast milk. We hypothesized that increasing the energy density and feeding frequency of complementary foods would positively affect EIs from these foods and total daily EI but would negatively affect breast milk intake.

SUBJECTS AND METHODS

Study site and subjects

The research was conducted in a periurban community of Dhaka, Bangladesh, and in the Advanced Biomedical Research Ward of the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR.B; also in Dhaka, Bangladesh) between November 2005 and September 2006. Eighteen healthy infants (8 boys and 10 girls) aged 8–11 mo who were reportedly being breastfed ≥6 times/d and receiving complementary foods ≥2 times/d were invited to participate in preliminary dietary studies to confirm the reported feeding practices. Trained dietitians remained in the homes for the preliminary dietary studies to confirm the reported feeding frequency and food and breast milk intakes. The dietitians weighed the children before and after breastfeeding with a balance sensitive to 0.1 g (TE 4101; Sartorius, Hamburg, Germany). The energy value of the breast milk was estimated by using information obtained from previous studies (10), and the 12-h data were extrapolated to estimate the 24-h milk intakes (11).

Recruitment of study participants

Initial identification and dietary intake studies

A survey was completed in the study community to identify children who were potentially eligible to participate. Those who reportedly satisfied the eligibility criteria were then included in the preliminary dietary studies to confirm the reported feeding practices. Trained dietitians remained in the homes for ≈12 h (from 0700 to 1900) on 2 consecutive days to record the infants’ feeding frequency and food and breast milk intakes. The dietitians weighed all ingredients used in the preparation of complementary foods before cooking and the amounts of all items consumed by using a balance sensitive to 0.1 g (TE 4101; Sartorius, Goettingen, Germany). The energy values of the complementary foods were calculated from food composition tables of the International MiniList (9). Breast milk intake was measured by weighing the children before and after breastfeeding with the use of a balance sensitive to 2 g (#7281321009; SECA, Hamburg, Germany). The energy value of the breast milk was estimated by using information obtained from previous studies (10), and the 12-h data were extrapolated to estimate the 24-h milk intakes (11).

Selection criteria for intervention phase

The children’s eligibility for the intervention phase of the study was based on the observed intake of complementary foods and breast milk during the home observations, according to the following criteria: 1) consumption of complementary foods ≥ 2 times/d, 2) EI from complementary foods ≥ 85 kcal/d, 3) breastfeeding ≥ 6 times/d, and 4) breast milk intake ≥ 262 g/d (≥ 157 kcal/d). The rationale for the required minimum intake of energy from complementary foods was based on the current recommendations for total EI by infants aged 9–11 mo (686–601 kcal/d). The rationale for the minimum intake of breast milk was based on the lower range of the 95% CI for previously observed breast milk EI (601 kcal/d) (10). Thus, the minimum energy required from complementary food was set at 85 kcal/d (686–601 kcal/d). The rationale for the minimum intake of breast milk was based on the lower range of the 95% CI for previously observed breast milk EIs (157 kcal/d) (10). Thus, we would expect low breast milk consumers (mean: −2 SD) to receive ≥157 kcal/d from breast milk, which is equivalent to ≈262 g/d, assuming breast milk’s energy density to be 0.6 kcal/g, as has been reported for developing countries (10).

Study protocol

The eligible infants and their mothers were admitted to the ICDDR.B research unit for a period of 42 d. During the initial 3-d acclimation period, the study children were provided 3 daily servings of a diet containing 1.0 kcal/g. By starting with this acclimation period, we were able to confirm that all of the children accepted the study diets and that their mothers were able to adhere to the study procedures. During the subsequent 13-d study periods, complementary foods were offered 3, 4, or 5 times/d at previously determined intervals. The sequence of the study periods was randomly ordered with regard to the feeding frequency, and, within each permutation of feeding frequency, the order of the energy densities also was randomly allocated. An example of one dietary sequence is shown in Figure 1.

According to our group’s previous study (7), EIs from a diet containing 0.4 kcal/g stabilized by the 5th day of exposure, and EIs from diets containing 1.5 kcal/g stabilized by the 2nd day. In a previous study (13), EIs from a diet containing 1.0 kcal/g also stabilized within 2 d. Thus, in the current study, we offered the lower-energy-density diet (0.5 kcal/g) for 6 d and the 2 higher-energy-density diets (1.0 and 1.5 kcal/g) for 3 d each. Data collected during the last 2 d of each dietary period were included in the analyses. At the beginning and end of each sequence of feeding frequency (ie, study days 3, 16, 29, and 42), breast milk was expressed for laboratory analysis to determine the milk energy contents. On these days, children were offered 3 daily servings of a diet containing 1.0 kcal/g.

During each dietary period, the mothers were asked to spoonfeed the respective diet to their infant ad libitum under the supervision of study personnel. Each meal was continued until the infant refused the food on 3 occasions separated by a 1-min “rest period,” as described previously (7). The total duration of the feeding excluding these rest periods was recorded.

Any child who developed an acute illness during the course of the study was removed from the protocol on that day and was provided 3 times/d with the intermediate-energy-density diet (1.0 kcal/g) for as long as the symptoms persisted. After 2 symptom-free days, the study protocol was resumed, beginning with the first day of the same preillness dietary period. Children...
who became ill during the study were treated according to standardized ICDDR,B disease management protocols. The infants’ body weights were measured at admission and each subsequent morning of the study period, before the first meal was served, by using a balance sensitive to 2 g (SECA). Length was measured according to standard procedures (14) at admission, weekly thereafter, and at the time of discharge by using a locally constructed length board with 0.1-cm increments.

Study diets

Semisolid study diets of varied energy density were prepared from rice powder (Whole-grain Brown Rice Solids, RiceLife Solids; Creative Research Management, Stockton, CA), previously gelatinized rice starch (Remy Industries NV, Leuven-Wijgmaal, Belgium), rice maltodextrin (Rice Syrup Solids; California Natural Products, Lathrop, CA), sucralose (Splenda sucralose; Tate & Lyle PLC, Decatur, IL), thickening gum (Dairyblend 366-THK; TIC Gums Inc, Belcamp, MD), nonfat milk powder, soybean oil, and cocoa powder. The composition of the study diets is shown in Table 1. The amounts of water and the relative proportions of rice powder, previously gelatinized rice starch, rice maltodextrin, and gum were varied to achieve different levels of energy density while maintaining a similar consistency of the diets. Other sensory characteristics of the diets were matched by varying the amounts of sucralose, cocoa powder, and flavoring agents. Adult volunteers who participated in preliminary taste trials could not detect any differences in the general appearance, color, flavor, consistency, or sweetness of the diets, although they could identify minor differences in mouthfeel between the lowest-energy-density (0.5 kcal/g) and the 2 higher-energy-density (1.0 and 1.5 kcal/g) diets.

The kitchen staff prepared the diets separately for each child and delivered the respective diets to the study unit in coded containers. The diets were refrigerated until the time of serving, at which time they were warmed to ≈40 °C in a microwave oven. Neither the mothers nor the clinical personnel responsible for supervising the feedings were aware of the identity of the study diets.

The children also received a daily vitamin-mineral supplement (1/2-tablet, Centrum Kids; Wyeth Laboratories, Madison, NJ) to provide 2500 IU vitamin A (20% as β-carotene), 30 mg vitamin C, 200 IU vitamin D, 15 IU vitamin E, 5 μg vitamin K.

### Table 1

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>0.5 kcal/g</th>
<th>1.0 kcal/g</th>
<th>1.5 kcal/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice powder</td>
<td>2.695</td>
<td>6.930</td>
<td>10.500</td>
</tr>
<tr>
<td>Pregelatinized rice starch</td>
<td>2.079</td>
<td>3.366</td>
<td>—</td>
</tr>
<tr>
<td>Rice maltodextrin</td>
<td>0.770</td>
<td>3.168</td>
<td>10.500</td>
</tr>
<tr>
<td>Nonfat milk powder</td>
<td>2.213</td>
<td>4.455</td>
<td>6.750</td>
</tr>
<tr>
<td>Sucralose, dry</td>
<td>0.003</td>
<td>0.003</td>
<td>—</td>
</tr>
<tr>
<td>Salt</td>
<td>0.069</td>
<td>0.089</td>
<td>—</td>
</tr>
<tr>
<td>Cocoa powder</td>
<td>0.154</td>
<td>0.248</td>
<td>0.300</td>
</tr>
<tr>
<td>Thickening gum</td>
<td>1.800</td>
<td>1.000</td>
<td>0.350</td>
</tr>
<tr>
<td>Soybean oil</td>
<td>1.510</td>
<td>2.990</td>
<td>4.500</td>
</tr>
<tr>
<td>Water</td>
<td>88.746</td>
<td>78.567</td>
<td>67.450</td>
</tr>
<tr>
<td>Energy (kcal/100 g prepared diet)</td>
<td>50.28</td>
<td>100.49</td>
<td>150.48</td>
</tr>
</tbody>
</table>

1 All diets contained 11.5% of energy as protein, 29.8% of energy as fat, and 58.7% of energy as carbohydrate.
0.75 mg thiamine, 0.85 mg riboflavin, 10 mg niacin, 1 mg vitamin B-6, 200 µg folic acid, 3 µg vitamin B-12, 22 µg biotin, 5 mg pantothenic acid, 54 mg Ca, 9 mg Fe, 25 mg P, 75 µg I, 20 mg Mg, 7.5 mg Zn, 1 mg Cu, 0.5 mg Mg, 10 µg Cr, and 10 µg Mo. The half-tablet was crushed and added to the first 1–2 spoonfuls of the breakfast meal each day throughout the study period.

Measurement of complementary food intake

All feeding episodes took place under the supervision of clinical staff. An electronic balance with 0.1 g precision (#TE 4101; Sartorius) was used to weigh food portions before and after they were served, and the actual amount consumed was calculated by subtracting the amount of the leftover food from the amount offered. Previously weighed napkins were provided to swab any food that was spilled or vomited, and any such losses were subtracted from the amount offered.

Measurement of breast milk intake

Mothers were requested to breastfeed day and night, according to their usual feeding pattern before the study, or more frequently if the child demanded. At each nursing, breast milk was offered ad libitum, and the amount consumed was measured by test-weighing before and after nursing (15), as described above. The feed-related weight changes were adjusted for child-specific insensible losses, which were measured on the same balance for ≥30 min/d. For these adjustments, the total number of minutes of nursing and the body weight on that particular day were multiplied by the child’s mean insensible losses in g·kg body wt⁻¹·min⁻¹ for a particular month, and the amount of insensible losses was added to the feed-related weight changes. The duration of each episode of breastfeeding was measured by using a stopwatch, and the frequencies of nursing and total duration per 24 h were recorded.

Collection of breast milk for laboratory assay

To obtain representative samples of breast milk for analysis of energy content, breast milk was expressed with an electric breast pump (Elite Electric Breast Pump, Ameda; Hollister Inc, Libertyville, IL) for 24 h on days 3, 16, 29, and 42 (at baseline and after each sequence of feeding frequency) by using the alternate-breast expression method (16). Aliquots of milk representing 10% of each expressed sample were saved, pooled over 24 h, and then stored in a freezer at −20 °C until subsequent analysis. The remaining milk was fed to the child by cup and spoon shortly after each expression. Milk samples were analyzed for energy content at the Nutritional Biochemistry Laboratory at ICDDR,B by using automatic adiabatic bomb calorimetry (Gallenkamp Autobomb; Gallenkamp, Loughborough, United Kingdom).

Sample size estimation and statistical analysis

The sample size was estimated based on the observed mean (±SD) of EIs from complementary foods and breast milk during the previous study by our group (7). For these estimates, we considered the overall mean intakes of each energy source on days 2–3 of the high-energy-density diet period and days 5–6 of the low-energy-density diet period. (Intakes of complementary food were 618 ± 111 g/d and 525 ± 109 kcal/d, respectively; intake of breast milk was 225 ± 78 g/d, and total EI was 660 ± 108 kcal/d.) A sample size of 18 children was estimated to be sufficient to permit detection of a 15% within-subject difference in mean daily EI from breast milk, a 9% difference in mean daily EI from complementary food, an 8% difference in mean daily amount of complementary food intake, and a 7% difference in mean total daily EI in relation to any permutation of energy density or feeding frequency, at a 5% level of significance and 80% power. This sample size of 18 also permitted a balanced study design in which 3 infants were allocated to each of the possible permutations of feeding frequency. The subject recruitment continued until we were able to collect data from 18 mother-infant pairs. In other words, if any mother-infant pair was unable to complete the study, another pair was recruited to replace the one that departed. During the course of the study, 2 mother-infant pairs departed for personal reasons.

Data were entered into the computer with OFFICE EXCEL software (version 2003; Microsoft, Redmond, WA), and all statistical analyses were completed with SAS for WINDOWS software (version 9.1; SAS Inc, Cary, NC). The primary response variables were EI from complementary foods, EI from breast milk, and total EI (all: in kcal·kg body wt⁻¹·d⁻¹) from both sources. The total time required for feeding episodes and the frequency and duration of breastfeeding also were examined. Data from days 5 and 6 for the lowest-energy-density diet (0.5 kcal/g) and days 2 and 3 for the 2 higher-energy-density diets (1.0 and 1.5 kcal/g, respectively) were included in the analyses. Descriptive statistics (x, SD, minimum, maximum, and median) were calculated for all continuous variables, and any data not conforming to the normal distribution were transformed appropriately. The data were analyzed with the SAS MIXED MODEL procedure, and the main effects were dietary energy density (3 levels), frequency of feeding (3 levels), diet periods (3 levels), individual (random) effects, weight-for-length levels, frequency of feeding (3 levels), diet periods (3 levels), individual (random) effects, weight-for-length z score [previously found to be associated with the EI from complementary foods (17)], and energy density × feeding frequency interactions. An autoregressive covariance structure was assumed for the within-individual error term. When any of the independent variables was found to be significant (P < 0.05), Tukey’s test was performed to examine the pairwise levels of significance.

RESULTS

Study subjects

The general characteristics of the infants and their mothers at the time of the initial screening examination are shown in Table 2. The infants’ mean age was 9 mo, and all were reportedly breastfeeding ≥6 times/d and receiving complementary foods ≥2 times/d at home. The infants’ mean length-for-age and weight-for-length z scores were less than the reference population medians (8), but all values were within the normal range, as per the study entry criteria. Maternal body mass index ranged from 18.7 to 25.8, and thus none of the mothers was considered to be chronically energy deficient or overweight.

A summary of the home dietary intake data for the 18 infants selected to participate in the feeding trial is shown in Table 3. When at home, they consumed less energy from complementary foods than is recommended for their age (12), but they consumed more energy from breast milk than published age-specific means. Thus, they were able to meet their theoretical energy requirements.

During the course of the 42-d clinical study, the children’s median weight gain was 734 g (interquartile range: 146–1828 g),
and their weight-for-length z score increased by 0.16 ± 0.70. Four children developed illnesses during the course of the study, and they were treated according to standardized management guidelines before they resumed the dietary protocol. Two children developed pneumonia, one had acute watery diarrhea, and one had an acute upper respiratory tract infection.

**Complementary food intake**

The mean amounts of complementary foods consumed by the children were decreased in relation to the dietary energy density and increased in relation to the feeding frequency (P < 0.001 for both; Figure 2A). EIs from complementary foods increased in relation to both factors (P < 0.001 for both; Figure 2B). The interactions between dietary energy density and feeding frequency for either of the outcomes were not significant (P = 0.33 for amount consumed and P = 0.29 for energy consumed).

After control for feeding frequency, the mean amounts consumed decreased by 18% when the dietary energy density was increased from 0.5 to 1.5 kcal/g (63.6 ± 3.2 and 51.7 ± 3.2 g·kg body wt⁻¹·d⁻¹, respectively; P < 0.001), although EIs from complementary foods increased by 143% after this change in dietary energy density (32 ± 3.2 and 78 ± 3.2 kcal·kg body wt⁻¹·d⁻¹, respectively; P < 0.001). In contrast, after control for energy density, the mean amounts of complementary foods increased by 42% when the feeding frequency was raised from 3 to 5 meals/d (47.7 ± 3.4 and 67.8 ± 3.5 g·kg body wt⁻¹·d⁻¹, respectively; P < 0.001), and EI from these foods increased by 38% (46.7 ± 3.3 and 64.8 ± 3.4 kcal·kg body wt⁻¹·d⁻¹, respectively; P < 0.001).

After control for the effects of dietary energy density and feeding frequency, the children’s intakes of complementary foods did not change significantly during the 42-d study period when expressed as either daily amounts (P = 0.14 for g/d; P = 0.36 for kcal/d) or amounts per unit of body weight (g·kg body wt⁻¹·d⁻¹ (P = 0.44) and kcal·kg body wt⁻¹·d⁻¹ (P = 0.79)) (Table 4). The maximum intake of complementary food from a single meal for any combination of dietary energy density and feeding frequency ranged from 16.5 to 37.0 g/kg body wt (± SD: 25.0 ± 6.0 g/kg body wt).

There was no significant relation between dietary energy density and feeding time (min/d) at any level of feeding frequency (P = 0.87; Figure 3A). However, after control for dietary energy density (Figure 3B), the total time required for complementary food consumption (min/d) was higher in relation to the feeding frequency (P < 0.001).

**Breast milk intake**

After control for feeding frequency, breast milk consumption decreased significantly (by 11%) when dietary energy density was increased from 0.5 to 1.5 kcal/g (P < 0.001; Figure 4A), and, after control for dietary energy density, breast milk intake fell by 8% when feeding frequency was increased from 3 to 5 times/d (P = 0.04; Figure 4B). There was no significant interaction between the effects of dietary energy density and feeding frequency for breast milk intake (P = 0.29).

There were no significant intraindividual differences in mean energy contents of breast milk on any of the 4 d when milk was expressed for laboratory analyses (ie, study days 3, 16, 29, and 42; P = 0.11). Thus, the energy content of milk was averaged for each child to calculate his or her EI from breast milk. The overall energy content of milk was 0.66 ± 0.03 kcal/g (range: 0.59–0.71 kcal/g for individual mothers). Changes in breast milk EIs by dietary energy density and feeding frequency of complementary foods were similar to those reported above for the breast milk amounts (Figure 5). After control for complementary feeding characteristics, breast milk intakes decreased gradually during the course of the study (P < 0.001; Table 4).

**Nursing frequency and total time spent nursing**

The overall nursing frequency was 8±8 times/d. Nursing frequency decreased 7% from study period 1 to study period 3 (from 8.8 ± 0.27 to 8.1 ± 0.27 times/d; P = 0.003). After control for complementary feeding frequency, there was no significant relation between dietary energy density of complementary foods and nursing frequency (P = 0.61), but, after control for dietary energy density, there was a marginally significant negative relation between complementary feeding frequency and nursing frequency (P = 0.08).

**TABLE 3**

Mean intakes of breast milk and complementary foods during home observation studies

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of breastfeeding (times/d)</td>
<td>12.0 ± 1.6 (9.0, 14.5)</td>
</tr>
<tr>
<td>Breast milk intake (g/d)</td>
<td>828.6 ± 195.0 (397.4, 1151.5)</td>
</tr>
<tr>
<td>Estimated energy intake from breast milk (kcal/d)</td>
<td>497.2 ± 117.0 (238.4, 690.9)</td>
</tr>
<tr>
<td>Frequency of feeding complementary foods (times/d)</td>
<td>3.2 ± 0.5 (2.5, 5.0)</td>
</tr>
<tr>
<td>Energy intake from complementary foods (kcal/d)</td>
<td>197.7 ± 48.6 (113.9, 318.9)</td>
</tr>
<tr>
<td>Energy density of complementary foods (kcal/g)</td>
<td>0.7 (0.6–0.9)</td>
</tr>
<tr>
<td>Total energy intake from both breast milk and complementary food (kcal/d)</td>
<td>694.8 ± 109.4 (422.4, 869.0)</td>
</tr>
<tr>
<td>Total energy intake as percentage of absolute requirement (%)</td>
<td>101 ± 16 (62, 127)</td>
</tr>
</tbody>
</table>

1 n = 18.
2 ± SD; minimum and maximum in parentheses (all such values).
3 Based on extrapolation of 12-h milk intakes and assumed milk energy density of 0.6 kcal/g. Each child was studied for 12 h during 2 consecutive days.
4 Median; interquartile range in parentheses.
The total time spent nursing was inversely related to both dietary energy density ($P < 0.001$) and feeding frequency ($P = 0.024$). After control for feeding frequency, the infants nursed 13% less time when dietary energy density was increased from 0.5 to 1.5 kcal/g ($P < 0.001$; Figure 5A). After control for dietary energy density (Figure 5B), the infants nursed 9% less time when meal frequency was increased from 3 to 5 times/d ($P = 0.018$). There was a significant within-subject correlation between EI from breast milk and total time spent nursing ($P < 0.001$); EI from breast milk increased by 2.2 kcal with each additional 1 min of nursing.

### Total energy intake

Despite the slight decreases in breast milk consumption that occurred with greater energy density and greater feeding frequency of complementary foods, the total EI from both sources combined (kcal/d) was positively related to each of these characteristics of the complementary feeding regimen ($P < 0.001$ for both; Figure 6). After control for dietary energy density and feeding frequency, total EI expressed as kcal/d did not change significantly over the course of the study ($P = 0.73$). However, when analyzed in relation to body weight (kcal · kg body

### TABLE 4

Complementary food and breast milk intakes by dietary period

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study period 1</th>
<th>Study period 2</th>
<th>Study period 3</th>
<th>$P^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complementary food</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount (g/d)</td>
<td>447.2 ± 152.6(^i)</td>
<td>463.1 ± 151.2</td>
<td>497.1 ± 193.7</td>
<td>0.14</td>
</tr>
<tr>
<td>(g · kg body (w^{-1} \cdot d^{-1}))</td>
<td>56.9 ± 19.2</td>
<td>57.3 ± 18.0</td>
<td>60.4 ± 23.7</td>
<td>0.44</td>
</tr>
<tr>
<td>Energy (kcal/d)</td>
<td>434.8 ± 225.6</td>
<td>453.3 ± 239.4</td>
<td>475.5 ± 218.8</td>
<td>0.36</td>
</tr>
<tr>
<td>(kcal · kg body (w^{-1} \cdot d^{-1}))</td>
<td>55.2 ± 27.9</td>
<td>56 ± 27.6</td>
<td>57.5 ± 26.1</td>
<td>0.79</td>
</tr>
<tr>
<td>Breast milk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount (g/d)</td>
<td>594.2 ± 164.7(^a)</td>
<td>548.0 ± 168.8(^b)</td>
<td>504.1 ± 176.4(^c)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(g · kg body (w^{-1} \cdot d^{-1}))</td>
<td>76.0 ± 21.1</td>
<td>68.0 ± 20.7</td>
<td>61.0 ± 19.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Energy (kcal/d)</td>
<td>393.9 ± 110.4(^a)</td>
<td>364.4 ± 116.4(^b)</td>
<td>334.4 ± 118.5(^c)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(kcal · kg body (w^{-1} \cdot d^{-1}))</td>
<td>50.4 ± 14.1(^a)</td>
<td>45.3 ± 14.2(^b)</td>
<td>40.4 ± 13.2(^c)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total energy intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kcal/d)</td>
<td>828.6 ± 217.1</td>
<td>819.7 ± 219.2</td>
<td>809.9 ± 197.2</td>
<td>0.73</td>
</tr>
<tr>
<td>(kcal · kg body (w^{-1} \cdot d^{-1}))</td>
<td>105.5 ± 26.3(^a)</td>
<td>101.3 ± 24.0(^b)</td>
<td>98.0 ± 22.6(^b)</td>
<td>0.05</td>
</tr>
</tbody>
</table>

\(^i\) SD (all such values).
wt$^{-1}$·d$^{-1}$), there was marginally significant gradual reduction in total EI over the course of the study ($P = 0.05$; Table 4).

There was a significant negative relation between EI from complementary foods and EI from breast milk ($P < 0.001$; Figure 7). Regardless of the energy density and feeding frequency of complementary foods, for each additional 1 kcal/d intake of complementary food, EI from breast milk was diminished by 0.18 kcal/d.

**DISCUSSION**

The results of the present study indicate that total daily EI from complementary foods by healthy, 8–11-mo-old infants increases in relation to the energy density and feeding frequency of these foods. In contrast, breast milk consumption decreases slightly in relation to these 2 characteristics of the complementary feeding regimen, mainly because of a shorter time spent nursing, which probably occurs in response to the infants’ greater meal-related satiety. Thus, in developing complementary feeding recommendations for young children, the effect on breastfeeding also must be considered.

The current study was restricted to infants whose weight and length fell within the normal range, according to international reference data (8). The infants were further screened during home dietary observations to ensure that they conformed to expected feeding practices and dietary intakes. Thus, the results of the study should be applicable to a broad range of children with adequate nutritional status who are both breastfeeding and consuming complementary foods.

The study was conducted in a research ward, where it was possible to prepare well-defined, masked diets and to measure precisely the individual infants’ food and breast milk intakes around the clock. The mothers were requested to nurse day and night, according to their usual home feeding patterns before the study, or more frequently if the child demanded. The mothers fed their infants under supervision according to a specified protocol, which allowed the infants to determine the level of consumption. The diets were carefully formulated to eliminate any differences in sensory characteristics that could have confounded the effects of the specific dietary factors of interest—namely, energy density and feeding frequency. This step was crucial, because earlier studies found that sweetness (18) and viscosity of the diet (19, 20) may independently affect children’s energy consumption. The macronutrient profiles also were matched for all of the diets.

The current study was designed to provide the desired information within the shortest time, according to the results of previous observations by our group (2, 7, 13). In particular, our group previously found that the number of days required for dietary intakes to stabilize varies according to the energy density of the diets, and so the current protocol was designed accordingly. Only the last 2 d of each dietary period were included in the

**FIGURE 3.** A: Mean (±SE) complementary feeding time (min/d) by dietary energy density of complementary foods, after control for feeding frequency ($n = 18$ infants). There were no significant significant differences, $P = 0.87$ (Tukey’s test). B: Mean (±SE) complementary feeding time (min/d) by feeding frequency of complementary foods, after control for dietary energy density ($n = 18$ infants). Bars with different letters are significantly different, $P < 0.001$ (Tukey’s test).

**FIGURE 4.** A: Mean (±SE) breast milk intake (g/d) by dietary energy density of complementary foods, after control for feeding frequency ($n = 18$ infants). Bars with different letters are significantly different, $P = 0.05$ (Tukey’s test). B: Mean (±SE) breast milk intake (g/d) by feeding frequency of complementary foods, after control for dietary energy density ($n = 18$ infants). Bars with different letters are significantly different, $P < 0.001$ (Tukey’s test).
analyses to eliminate variability attributable to adaptation to the diets.

The results of the current study are consistent with earlier observations, which indicated that children consumed less food when the energy density was increased (2, 7, 13), although this adaptation does not fully compensate for the higher energy density. In other words, EI from these foods also rises with greater energy density, despite the smaller amount consumed. The present study augments the earlier results by providing concurrent information on breast milk intakes. Notably, there was a negative linear relation between EI from complementary foods and EI from breast milk (Figure 7). That is, any feeding recommendations that result in greater EI from complementary food are likely to reduce breast milk consumption, and, thus, such recommendations should be calculated to provide adequate but not excessive intakes of energy from complementary foods. It is important to note that the children’s breast milk intakes while they resided in the study ward were approximately two-thirds of those during the home dietary studies, when they received ∼3 times/d complementary foods with an average energy density of ∼0.70 kcal/g. In contrast, the children consumed approximately twice as much energy from complementary food while residing in the study ward, where they had access to unlimited amounts of food, often with greater energy density than the foods they received at home. Under these latter conditions, their total EIs were ∼20% greater than their theoretical requirements, and breastfeeding frequency declined from ∼12 to ∼8 times/d, despite the advice to their mothers to maintain their usual nursing frequency. Thus, it appears that, when the complementary feeding regimen provides for average total EIs that are greater than average energy requirements, breast milk intake will decline, as was observed during the course of the present study, when daily breast milk intake fell by ∼3 g/d.

Three other studies have examined the relation between different complementary feeding regimens and breast milk intake. Two studies of Indian infants examined the effects on breast milk consumption of adding oil to cereal-legume mixture–based complementary foods (21) or of increasing the feeding frequency of complementary foods (22). In the first study, the energy density of a cereal-legume mixture was boosted by 0.20–0.35 kcal/g, and consumption of the oil-fortified food for 1 d was accompanied by a significant 24% reduction in breast milk intake but no change in total energy consumption. In the second study, the same cereal-legume mixture with an energy density of 0.35 kcal/g was offered either 3 or 4 times/d on consecutive days.

**FIGURE 5.** A: Mean (±SE) breastfeeding time (min/d) by dietary energy density of complementary food, after control for feeding frequency (n = 18 infants). Bars with different letters are significantly different, P < 0.001 (Tukey’s test). B: Mean (±SE) breastfeeding time (min/d) by feeding frequency of complementary foods, after control for dietary energy density (n = 18 children). Bars with different letters are significantly different, P = 0.024 (Tukey’s test).

**FIGURE 6.** Mean (±SE) total energy intake from both complementary food and breast milk, by dietary energy density and feeding frequency (n = 18 infants). Data were analyzed with mixed-models ANOVA. Main effects of dietary energy density and feeding frequency were significant (P < 0.001 for both); the interaction was not significant (P = 0.76). All dietary energy densities were different from each other; feeding frequency of 3 meals/d was significantly different from that of 4 and 5 meals/d (P = 0.01 and P < 0.001, respectively; Tukey’s test).
There was no difference in mean total EI when the feeding frequency was increased from 3 to 4 meals/d, but there was a significant 10% decrease in breast milk intake. Although both of these studies found a negative effect of increased energy density and feeding frequency of complementary foods on breast milk intake, the short study durations limited the strength of these conclusions, because dietary intakes may not have stabilized during the observation period. The third study, which was conducted among 6-mo-old infants in rural Malawi, evaluated the effect of different types or amounts of complementary foods on breast milk intake (23). The infants’ caregivers were given either a dry porridge (corn-soy blend) for preparation with an energy density of 1.1 kcal/g to provide a total of 285 kcal/d or 1 of 2 amounts of a fortified fat-based spread with an energy density of 5.3 kcal/g to provide either 255 or 127 kcal/d. Unlike the previous reports, this study found no differences in the effect of the 2 interventions on the infants’ breast milk intakes. However, the investigators did not measure consumption of the complementary foods, so it is uncertain whether the foods were actually consumed as instructed. Moreover, the caregivers were told that the corn-soy blend, but not the fat-based spread, could be fed more than once a day, and, therefore, the results could be confounded by differences in feeding frequency. Finally, the young age of the study subjects and the relatively high energy density of the corn-soy blend control diet in the study by Galpin et al (23) complicate any comparison with the present study.

To examine the practical implications of the results of the present study, we calculated the amount of complementary food intake that would result in total EIs (from both complementary food and breast milk) equal to the mean theoretical requirements for age (686 kcal/d) or the mean requirement + 2 SD (858 kcal/d) (12). This latter amount is the level of intake at which nearly all children in this age range would be expected to meet their individual energy needs. As shown in Figure 8, the children would need to consume ≈227–322 kcal/d from complementary foods, depending on the energy density of these foods, to achieve a total EI of 686 kcal/d and to consume ≈421–515 kcal/d from complementary foods to reach a total intake of 858 kcal/d.

We then examined the possible combinations of dietary energy density and feeding frequency of complementary foods that...
of total EI. For this purpose, we developed a regression model with total EI as the dependent variable and energy density, energy density squared (to account for nonlinearity), feeding frequency, and dietary period as the independent variables (along with their interactions), by using the SAS MIXED procedure to account for within-subject correlation. We then solved the resulting equation for the energy densities that would be necessary to permit the indicated levels of EI. The resulting energy densities are shown in Table 5, along with the calculated amounts of complementary food intake that would be consumed at each meal. As indicated in Table 5, the energy densities that would result in total energy consumption of 686 kcal/d range from 0.47 to 0.70 kcal/g, depending on whether 3, 4, or 5 meals are offered per day. The corresponding energy densities that would result in a total EI of 858 kcal/d range from 0.84 to 1.19 kcal/g. Table 5 also shows the likely short-term changes in breast milk intake affect the total duration of breastfeeding and the ultimate quality of the diet and child health.

We appreciate the advice and support of Cheryl Mitchell of Creative Research Management Corporation, who assisted with the design and supply of the study diets. The authors’ responsibilities were as follows: MMI, KGD, and KHB: conceptualization and design of the study and analysis and interpretation of data; MAHM: assistance in planning the study; MMI, MK, and TA: implementation of clinical procedures and supervision of data collection; JMP: assistance with data analysis and statistical modeling procedures; MMI and KHB: draft of the manuscript; and all authors: review of the manuscript. None of the authors had a personal or financial conflict of interest.

REFERENCES

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### TABLE 5

Estimated combinations of energy density and feeding frequency of complementary food that would permit total energy consumption of 686 or 858 kcal/d by breastfed infants 9-11 mo old

<table>
<thead>
<tr>
<th>Desired total energy intake and feeding frequency</th>
<th>Complementary food</th>
<th>Energy intake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy density</td>
<td>Required amount</td>
</tr>
<tr>
<td></td>
<td>kcal/g</td>
<td>g/d</td>
</tr>
<tr>
<td>686 kcal/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 meals/d</td>
<td>0.70</td>
<td>370</td>
</tr>
<tr>
<td>4 meals/d</td>
<td>0.56</td>
<td>482</td>
</tr>
<tr>
<td>5 meals/d</td>
<td>0.47</td>
<td>617</td>
</tr>
<tr>
<td>858 kcal/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 meals/d</td>
<td>1.19</td>
<td>380</td>
</tr>
<tr>
<td>4 meals/d</td>
<td>0.97</td>
<td>465</td>
</tr>
<tr>
<td>5 meals/d</td>
<td>0.84</td>
<td>554</td>
</tr>
</tbody>
</table>

\(^1\) Based on empirical data from 18 infants. Relation between complementary food intake, feeding frequency (meals/d), and dietary energy density (kcal/g) was estimated by using a mixed-model procedure. Required dietary energy density was calculated from the estimated regression equation: CF = \(-193.5 \times \text{density}^2 + 719 \times \text{density} + c\), where \(c = 277.7\) for 3 meals/d, 342.0 for 4 meals/d, or 391.8 for 5 meals/d, and CF = 686 or 858 kcal/d.

\(^2\) Estimated intake.