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Volume and Frequency of Breastfeedings and Fat Content of Breast Milk Throughout the Day

Jacqueline C. Kent, PhD[a], Leon R. Mitoulas, PhD[a], Mark D. Cregan, PhD[a], Donna T. Ramsay, PhD[a], Dorota A. Doherty, PhD[b,c], Peter E. Hartmann, PhD[a]

[a]Department of Biochemistry and Molecular Biology, Faculty of Life and Physical Sciences, and [b]School of Women's and Infants' Health, The University of Western Australia, Crawley, Western Australia, Australia; [c]Women and Infants Research Foundation, Crawley, Western Australia, Australia

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ABSTRACT

OBJECTIVE. We aimed to provide information that can be used as a guide to clinicians when advising breastfeeding mothers on normal lactation with regard to the frequency and volume of breastfeedings and the fat content of breast milk.

METHODS. Mothers (71) of infants who were 1 to 6 months of age and exclusively breastfeeding on demand test-weighed their infants before and after every breastfeeding from each breast for 24 to 26 hours and collected small milk samples from each breast each time the infant was weighed.

RESULTS. Infants breastfed 11 ± 3 times in 24 hours (range: 6–18), and a breastfeeding was 76.0 ± 12.6 g (range: 0–240 g), which was 67.3 ± 7.8% (range: 0–100%) of the volume of milk that was available in the breast at the beginning of the breastfeeding. Left and right breasts rarely produced the same volume of milk. The volume of milk consumed by the infant at each breastfeeding depended on whether the breast that was being suckled was the more or less productive breast, whether the breastfeeding was unpaired, or whether it was the first or second breast of paired breastfeedings; the time of day; and whether the infant breastfed during the night or not. Night breastfeedings were common and made an important contribution to the total milk intake. The fat content of the milk was 41.1 ± 7.8 g/L (range: 22.3–61.6 g/L) and was independent of breastfeeding frequency. There was no relationship between the number of breastfeedings per day and the 24-hour milk production of the mothers.

CONCLUSIONS. Breastfed infants should be encouraged to feed on demand, day and night, rather than conform to an average that may not be appropriate for the mother-infant dyad.

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Key Words
breastfeeding, feeding behavior, feeding volumes, infant feeding, breast milk

Abbreviation
IQR—interquartile range

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Address correspondence to Jacqueline C. Kent, PhD, The University of Western Australia, Biochemistry and Molecular Biology, M310, 35 Stirling Hwy, Crawley, Western Australia 6009, Australia. E-mail: jkent@cyllene.uwa.edu.au

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Breastfeeding mothers should be made aware of the variability of milk volumes per breastfeeding, the frequencies of breastfeedings, and the distribution of milk intake by day and by night of healthy breastfed infants.[1]

Mothers among the !Kung hunter-gatherers have been observed to breastfeed 4 times every hour during the day and at least once at night.[2] In contrast, Cadogan,[3] in his essay to the Governors of the Foundling Hospital (London, United Kingdom) in 1748 recommended that infants be suckled only 4 times a day and not at night, because he considered the night feeding to result in breastfed infants' becoming "over fat and bloated." Relaxation of the concept of scheduled breastfeeding was first strongly promoted by Wickes[4] in 1953 and subsequently advocated by community support groups such as La Leche League and the Australian Breastfeeding Association that were at the vanguard of the movement back to breastfeeding in the early 1970s in Western societies. As a result, infants were breastfed more frequently both by day and by night. It now is recognized that breast milk provides the optimal nutrition for infants, and current recommendations to mothers are that infants be breastfed "on demand" (according to their appetite) exclusively for the first 6 months of life.[5,6]

Bangladeshi infants have been found to consume half their daily milk intake between 6 AM and 6 PM.[7] Matheny and Picciano[8] in the United States investigated whether measurement of milk production over a 12-hour period could be doubled to determine the 24-milk production. Studying 4-week-old infants, they found that more milk was consumed between 6 AM and 6 PM and less was consumed between 2 PM and 2 AM. Doubling of either of these 12-hour intakes resulted in significant inaccuracies in estimation of 24-hour milk consumption. The product of the volume of 1 or 2 consecutive breastfeedings and the number of breastfeedings in the period also has been found to be inaccurate.[9] The data of Cregan et al[10] showing variation in the volume and the frequency of breastfeedings over 24 hours for Australian infants also suggest that these calculations would be inaccurate. However, for accurate assessment of milk production, the necessity of a full 24-hour period of measurement of milk intake in our society for infants between 4 and 26 weeks has not been determined.

A wide variation in the frequency of breastfeeding has been recorded in the United States and Sweden in exclusively breastfed infants.[11,12] These authors collected longitudinal records of the number, time of day, and duration of breastfeedings of infants between 2 and 26 weeks of age, but no information was provided on the volume of milk consumed at each breastfeeding by these infants. Previously, interest has focused on the nutrient intake of the infant, and the total consumption has been quoted with no information provided on the volume of milk consumed from each breast.[13,14] Therefore, it was not possible to assess how the infant feeds to appetite in relation to the volume of milk available in the mother's breasts. Furthermore, the literature on the frequency of breastfeeding generally fails to define what constitutes a breastfeeding. Although Hörnell et al[11] defined "one breastfeeding episode" as the "duration of suckling 2 minutes or longer and separated from previous breastfeed by at least 30 minutes," this does not consider whether the infant fed from 1 breast or both during that episode.

In this article, we investigate the volume and the pattern of milk intake in a cross-sectional study of 1- to 6-month-old infants who were being exclusively breastfed on demand, and we examine the contribution of each breast. This is the first article to describe the variation in the volume of milk consumed from each breast at each breastfeeding, the degree of fullness of each breast before and after each breastfeeding, and the fat content of the milk consumed from each breast throughout the day and night. This will provide a normal reference range to enhance clinicians' support for breastfeeding mothers.

METHODS

Data were collected from 71 mothers who were exclusively breastfeeding on demand healthy, term infants who were aged between 1 and 6 months. These mothers were participants in studies that were conducted in this laboratory from 2000 to 2004.[15–17] These studies were approved by the Human Research Ethics Committee of The University of Western Australia.

The mothers test-weighed their infants before and after each breastfeeding from each breast on a Medela electronic Baby Weigh Scale (Medela AG, Baar, Switzerland) for a period of 24 hours plus 1 breastfeeding. A corrected 24-hour production for each breast then was determined using these data, but no correction for infant insensible water loss was made; therefore, milk production may be underestimated by 3% to 10%.[18–20] All measurements of breastfeed amounts, storage capacity, and milk production are expressed in grams that can be considered to be nearly equivalent to mL because the density of milk is 1.03 g mL^{-1}.[21] For each mother, the breast that had the higher 24-hour production was termed "more productive" and the breast that had the lower 24-hour production was termed "less productive." In addition, milk samples (≤1 mL) were collected by hand expression into 5-mL polypropylene plastic vials (Disposable Products, Adelaide, Australia), immediately before and after each breastfeeding from each breast. Samples were frozen as soon as possible and kept at −15°C for analysis. The cream content of the milk samples was measured by the creamatocrit method,[22] and the fat content of each sample, in grams per liter, was calculated as 5.37 × creamatocrit + 5.28.[15]

The original estimation of fat content as a function of degree of breast emptying was introduced by Daly et al,[23] whereby fat content was best predicted using a quadratic function with degree of emptying as a predictor. Although time since last breastfeeding and individual breast had a small effect, the best predictor of fat content was degree of emptying. This accounted for 68% of variation, which was deemed satisfactory given the physiologic process being measured. Degree of fullness was calculated as 1 − degree of emptying, and it was obtained via inverse calculation of degree of emptying using the equation fat = 21.50 + 9.38 × (degree of emptying) + 70.99 × (degree of emptying)^2.[23] This relationship between degree of emptying and fat content was individualized, whereby for each woman, minimal, median, and maximal fat content over 24 hours was set to correspond to degree of fullness of 1, 0.6892, and 0, respectively, that protected against physiologically impossible estimates (ie, degree of fullness exceeding 1 or becoming negative). The storage capacity (the amount of milk available to the infant when the breast is full) was determined using a regression line relating change in degree of fullness at each feeding to the amount of milk removed from the breast at that feeding. Assuming that a change in degree of fullness of 0 corresponds to a feeding amount of 0, the regression line was forced to pass through the origin. Storage capacity then could be calculated as the amount of milk that corresponds to a change in degree of fullness of 1. The volume of available milk in the breast before each breastfeeding was calculated as the degree of fullness multiplied by the storage capacity of the breast.

We defined a breastfeeding as an infant's taking milk from 1 breast. When the next breastfeeding was >30 minutes after the end of the first, the breastfeeding was considered to be unpaired. When the infant took milk from the other breast within 30 minutes of finishing on the first breast, the breastfeedings were considered to be paired. When the infant fed again from the first breast within 30 minutes of finishing on the second breast, the breastfeedings were considered to be clustered. A meal was defined as an unpaired breastfeeding, or 2 paired breastfeedings, or 3 clustered breastfeedings. This definition of a "meal" is equivalent to "1 breastfeeding episode" as defined by Hörnell et al.[11] Four breastfeedings were 0 g when the infant went to the breast and apparently suckled but there was no difference between the infant's weight from before to after the breastfeeding.

For this study, the day was divided into 4 intervals. Morning was considered to be from 4:01 AM to 10:00 AM, day was 10:01 AM to 4:00 PM, evening was 4:01 PM to 10:00 PM, and night was 10:01 PM to 4:00 AM.

Descriptive summaries of continuous data used means and SDs or medians and interquartile ranges (IQRs), depending on data normality. Inference was based on summary data averaged over 24 hours (n = 71), overall summaries for individual breasts (n = 142), and all individual breastfeedings recorded over 24 hours (n = 775). Analyses of individual breastfeedings were weighted according to the number of breastfeedings recorded per woman. Paired and unpaired univariate comparisons of summary data were performed using t tests or their nonparametric equivalents depending on data normality. Multivariate analysis was based on analysis of variance with repeated measures performed using Proc GLM (SAS 8.02; SAS Institute Inc, Cary, NC), and goodness of fit was assessed via analysis of residuals. Linear and polynomial regression analyses were used to assess relationships. Two-sided P values are quoted, and $P < .05$ was regarded as statistically significant.

RESULTS

The characteristics of the mothers are presented in Table 1. There were 41 male and 30 female infants. There was no significant difference either between the mean age of the male and female infants or in the age and parity of their mothers.

Frequency and Volume of Breastfeedings

A total of 775 breastfeedings were monitored. Each infant had 11 ± 3 breastfeedings per day (range: 6–18). The interval between breastfeedings was 2 hours 18 minutes ± 43 minutes (range: 4 minutes to 10 hours 58 minutes). Of these breastfeedings, 345 (44.5%) were unpaired (182 from the more productive breast and 163 from the less productive breast), with an interval of >1 hour until the next breastfeeding for 90% of these breastfeedings. A total of 412 (53.2%) breastfeedings were paired, and 18 (2.3%) were clustered. That is, there were 7.9 ± 1.8 meals per day (range: 4–13), and the interval between meals was 3 hours 2 minutes ± 41

TABLE 1 Subject Characteristics

	Mean ± SD	Range
Mother		
Age, y	31.8 ± 4.3	23–42
Parity	1.7 ± 0.8	1–4
Infant		
Age, wk	15.3 ± 5.9	4–26
24-h breast milk intake, g		
Total	788 ± 169	478–1356
More productive breast	459 ± 106	253–769
Less productive breast	339 ± 90	161–553
Breast storage capacity, g		
More productive breast	193 ± 60	76–382
Less productive breast	164 ± 53	74–320
Average breastfeed volume, g		
More productive breast	84 ± 28	32–131
Less productive breast	67 ± 26	27–147
Breastfeed frequency, feeds per day		
More productive breast	5.6 ± 1.6	3–9
Less productive breast	5.4 ± 1.5	3–9
Fat content of milk, g/L		
More productive breast	41.3 ± 8.4	22.5–60.8
Less productive breast	40.9 ± 8.4	22.3–61.6

minutes (range: 40 minutes to 10 hours 58 minutes). Thirteen percent of infants always had paired breastfeedings ($n = 9$), 30% of infants always had unpaired breastfeedings ($n = 21$), and the remaining 57% of infants had a mixture of paired and unpaired breastfeedings ($n = 41$).

There were no changes in the breastfeeding frequency with age of the infant and no significant difference in breastfeeding frequency between girls and boys. The more productive breast was fed from as frequently as the less productive breast, and when the breastfeedings were paired, the more productive breast was offered first as frequently as the less productive breast. There was no relationship between the number of breastfeedings per day and the 24-hour milk production of the mothers.

The infants took 76.0 ± 12.6 g (range: 0–240 g) at each breastfeeding. There was an inverse relationship between the number of breastfeedings per day and the average breastfeeding volume ($r^2 = 0.442$; $P < .001$; $n = 142$ breasts). The average meal was 101.4 ± 15.6 g (range: 0–350 g). The average breastfeeding volume was unrelated to the age of the infant ($P = .421$), but there was an increase in the maximum breastfeeding volume with advancing age between 4 and 26 weeks ($r^2 = 0.09$; $P < .010$). The maximum breastfeeding volume of boys was greater than that of girls (154.6 ± 54.8 g for boys vs 129.8 ± 29.0 g for girls; $P = .029$), but there was no significant difference in the average breastfeeding (79.3 ± 26.9 g for boys vs 73.0 ± 22.4 g for girls; $P = .299$). The average breastfeeding from the more productive breast was higher than that from the less productive breast ($P < .001$; Table 1), and individual breastfeedings from the more productive breast were larger than from the less productive breast ($P < .001$; Fig 1).

Breastfeeding volumes were significantly associated with breastfeedings' being unpaired, paired, or clustered. For an unpaired breastfeeding, the infants consumed 90 ± 26 g (range: 0–240 g). When the breastfeedings were paired, the infants consumed 73 ± 11 g (range: 5–185 g) for the first breast and 54 ± 9 g (range: 0–176 g) from the second. For the clustered breastfeedings, the infant took a median of 42 g (IQR: 31–103 g) from the first breast, a median of 20 g (IQR: 8–44 g) from the second breast, and a median of 31 g (IQR: 6–73 g) from the third breast. For the paired breastfeedings, when the more productive breast was fed from first, the infant took more ($P < .0001$) from the first breast than from the second breast (Fig 1). When the less productive breast was fed from first, the infant took similar volumes from each breast (Fig 1).

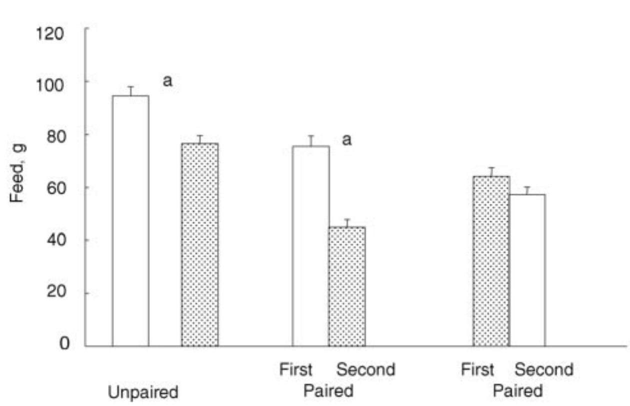

FIGURE 1
Volume of milk consumed at a breastfeeding from the more productive breast (□) and the less productive breast (▤) when the breastfeedings were unpaired or paired. Values are means with SEM represented by vertical bars. [a] More productive and less productive breasts are different ($P < .0001$).

Storage Capacity, Degree of Fullness, and Available Milk

The storage capacity of each breast was 179 ± 59 g (range: 74–382 g). There was no association between the storage capacity and time after birth ($r^2 = 0.015$; $P = .155$; $n = 142$ breasts). There was a positive relationship between the storage capacity and the 24-hour milk production ($r^2 = 0.393$; $P < .001$; $n = 142$ breasts), the maximum breastfeeding ($r^2 = 0.460$; $P < .001$; $n = 142$ breasts), and the average breastfeeding ($r^2 = 0.297$; $P < .001$; $n = 142$ breasts) from each breast. There was a significant difference ($P = .013$) between the total breast storage capacity for mothers who were breastfeeding boys (394 ± 126 g) compared with those who were breastfeeding girls (333 ± 71 g). There was a significant difference ($P = .003$; Table 1) between the storage capacity of the more productive breast (193 ± 60 g; range: 76–382 g) and the less productive breast (164 ± 53 g; range: 74–320 g).

For unpaired breastfeedings, there was no significant difference between the more and less productive breasts in the degree of fullness of the breast at the beginning of the feed (prefeed; 0.69 ± 0.10). This was significantly higher ($P = .032$) than the prefeed degree of fullness of the first breast of a paired breastfeeding. For paired breastfeedings, there was a significant difference ($P = .001$) between the prefeed degree of fullness for the breasts (0.63 ± 0.08 and 0.52 ± 0.07 for the first and second breasts, respectively) regardless of whether the breast was the more or less productive. When the breastfeedings were clustered, the "third" breast had a prefeed degree of fullness of 0.26 ± 0.07. For the 0-g feeds, the mean difference in the cream content of the samples that were collected before and after the breastfeeding was 1.4%, and the prefeed degree of fullness ranged from 0.21 to 0.58. There was a significant relationship between the volume of milk available in the breast and the volume of milk consumed at each breastfeeding ($r^2 = 0.358$; $P < .001$; $n = 775$ breastfeedings).

For unpaired breastfeedings, the available milk was different between the more productive breast and the less productive breast ($P = .003$; Fig 2), but a similar percentage of the available milk was removed (72 ± 7%

and 69 ± 8% from the more and less productive breasts, respectively). The degree of fullness of the breast at the end of the breastfeeding (postfeed) was 0.19 ± 0.06 for both the more and the less productive breasts.

When the breastfeedings were paired and the more productive breast was fed from first, there was a significant difference in the available milk (118 ± 19 g and 80 ± 14 g for the more and less productive breasts, respectively; $P < .0001$; Fig 2), whereas when the less productive breast was fed from first, there was no significant difference between the breasts in the available milk (Fig 2). The percentage of available milk that was removed during paired breastfeedings was significantly less than during an unpaired breastfeeding ($P < .0001$), but a similar percentage of the available milk was removed (63 ± 8%), regardless of the order from which the breasts were fed. There was a significant difference ($P = .003$) between the postfeeding degree of fullness for the breasts (0.20 ± 0.05 and 0.26 ± 0.05 for the first and second breasts, respectively) regardless of whether the more or less productive breast was first. For the clustered breastfeedings, 47 ± 13 g was available in the "third" breast, 47% of the available milk was removed, and the postfeeding degree of fullness was 0.19 ± 0.05 ($n = 4$).

Total 24-Hour Milk Production

The overall 24-hour milk production for both breasts combined was 788 ± 169 g (range: 478–1356 g; Table 1). A significant difference in the 24-hour milk production between the more productive and less productive breasts was evident ($P < .001$; Table 1), with an absolute median difference between the breasts of 106 g (IQR: 39–173 g; range: 5–441 g). For the majority of the mothers (76%), the right breast was the more productive, resulting in a significant difference between the right and the left breasts (426 ± 116 g [range: 161–769 g] and 372 ± 109 g [range: 177–601 g], respectively; $P = .003$).

There was a significant difference in milk production ($P = .036$) between mothers of boys (831 ± 187 g) and those of girls (755 ± 151 g). No significant effects on milk production were associated with time after birth ($r^2 = 0.037$, $n = 71$), parity ($r^2 = 0.051$, $n = 71$), or maternal age ($r^2 = 0.028$, $n = 71$). There was no relationship between the "cold" and "warm" months of the year and the 24-hour milk production ($r^2 = 0.010$; $P = .413$).

Overall, infants consumed 64% of their 24-hour intake (497 ± 17 g) in 6.8 ± 0.3 feedings between 6 AM and 6 PM and 275 ± 13 g in 4.0 ± 0.2 feedings between 6 PM and 6 AM. Between 2 PM and 2 AM, they consumed 322 ± 12 g (42% of their 24-hour intake) in 5.1 ± 0.2 feedings and 450 ± 16 g in 5.7 ± 0.2 feedings between 2 AM and 2 PM. Younger infants, up to 9 weeks of age, consumed 443 ± 32 g (61% of their 24-h intake) in 7.0 ± 0.7 feedings between 6 AM and 6 PM and 275 ± 15 g in 4.7 ± 0.4 feedings between 6 PM and 6 AM. Between 2 PM and 2 AM, they consumed 328 ± 15 g (45% of their 24-hour intake) in 5.8 ± 0.6 feedings and 390 ± 29 g in 5.6 ± 0.7 feedings between 2 AM and 2 PM.

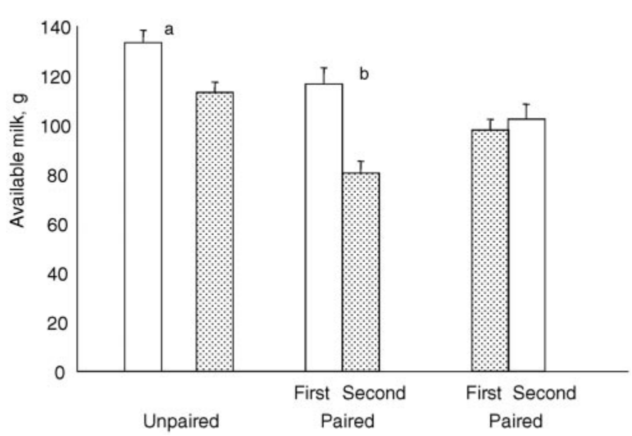

FIGURE 2
Volume of milk available before each breastfeeding from the more productive (□) and the less productive (▦) breasts when the breastfeedings were unpaired or paired. Values are means with SEM represented by vertical bars. More productive and less productive breasts are different ([a] $P = .003$; [b] $P < .0001$).

Night Feedings

The majority (64%) of infants breastfed between 1 and 3 times at night (10 PM to 4 AM), and the number of nighttime breastfeedings did not change between 4 and 26 weeks. Only 36% of infants did not feed during the night.

There was no significant difference in the total 24-hour milk production for infants who did and did not breastfeed at night. Mothers of infants who breastfed at night had a total breast storage capacity of 342 ± 95 g, which was not significantly different ($P = .078$) from that of mothers of infants who did not breastfeed at night (386 ± 108 g). There was no significant difference in the total number of breastfeedings per 24 hours between infants who did and did not breastfeed at night, with the median numbers of 11 breastfeedings (IQR: 8–13; range: 6–18) and 10 breastfeedings (IQR: 10–12; range: 6–17), respectively ($P = .890$). Infants who breastfed at night had fewer breastfeedings at night (median: 1; IQR: 1–2) than during any other interval ($P < .001$). There was a median of 3 breastfeedings (IQR: 3–4; range: 1–6) during all other intervals, irrespective of whether the infants breastfed at night.

Statistically different volumes were measured at different intervals of the day ($P = .019$; Fig 3), with the night breastfeedings being the largest and increasing with both age and degree of fullness of the breast ($r^2 = 0.255$; $P < .001$; $n = 81$). Infants who breastfed at night had significantly larger breastfeedings during the night compared with the morning ($P = .012$), the day ($P = .002$), and the evening ($r^2 = 0.294$; $P = .001$; $n = 496$

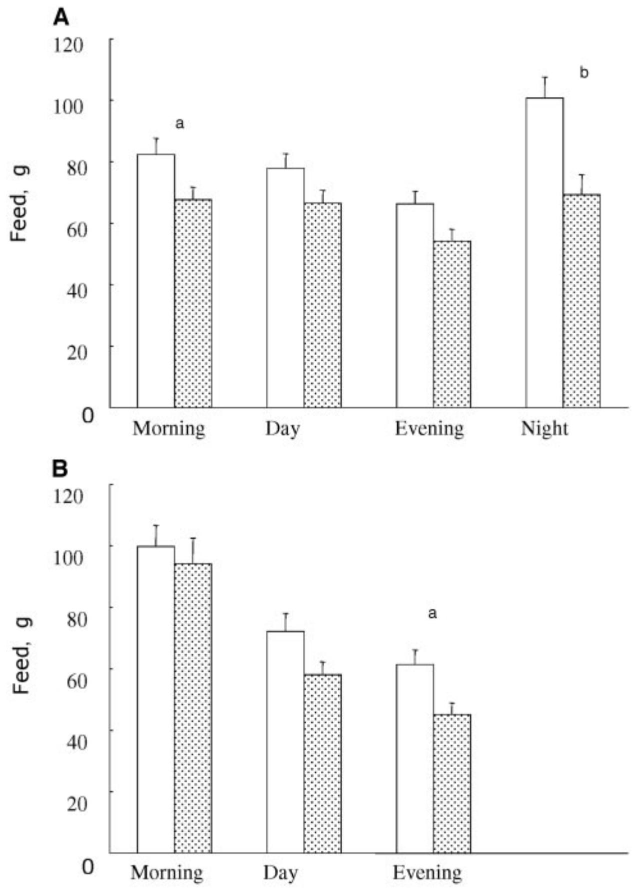

FIGURE 3
Volume of milk consumed at a breastfeeding from the more productive breast (□) and the less productive breast (▤) during the morning (4:01 AM to 10:00 AM), day (10:01 AM to 4:00 PM), evening (4:01 PM to 10:00 PM), and night (10:01 PM to 4:00 AM) by infants who breastfed at night (A) or did not breastfeed at night (B). Values are means with SEM represented by vertical bars. More productive and less productive breasts are different ([a] $P < .05$; [b] $P < .0001$).

breastfeedings; Fig 3A). From the less productive breast, the infants had smaller breastfeedings in the evening than during the night and the morning ($P < .05$). Although the night breastfeedings were larger from the more productive breast, because the night breastfeedings were less frequent than during the rest of the day, 20 ± 7% of the total 24-hour milk production was consumed at night, which was significantly less ($P < .008$) than that taken during the morning (28 ± 9%), the afternoon (28 ± 8%), and the evening (24 ± 8%).

Infants who did not breastfeed at night had significantly larger breastfeedings during the morning than during the day and the evening ($P < .001$) from both the more and the less productive breasts (Fig 3B). These infants took more of the 24-hour milk production (40 ± 12%) during the morning than during the day (29 ± 10%) and during the evening (25 ± 9%; $P < .001$).

The volume of milk that was available at the beginning of a breastfeeding in the breasts of mothers who breastfed at night ranged from 88.9 g for the less productive breast in the evening to 125.8 g for the more productive breast at night. For mothers who breastfed only during the day, the volume of milk that was available at the beginning of a breastfeeding ranged from 83.7 g in the evening for the less productive breast to 156.0 g in the morning for the more productive breast.

For mothers who breastfed at night, more milk remained in the breast at the end of breastfeedings in the morning and the night (degree of fullness: 0.27 and 0.24, respectively) than during the day or the evening (degree of fullness: 0.17 and 0.18, respectively; $P < .001$). For mothers who breastfed only during the day, more milk remained in the breast at the end of breastfeedings in the morning (degree of fullness: 0.31) than during the day or the evening (degree of fullness: 0.18 and 0.20, respectively; $P < .001$).

Fat Content of Breast Milk

The average fat content of the milk was 41.1 ± 7.8 g/L and ranged from 22.3 to 61.6 g/L. The average fat content was not associated with either the time after birth ($r^2 = 0.036$, $n = 71$) or the number of breastfeedings during the day ($r^2 = 0.013$, $n = 775$). There was an inverse relationship between the mean fat content of the milk and the 24-hour milk intake from that breast ($P = .007$, $r^2 = 0.089$, $n = 142$). The average 24-hour fat intake of the infants was 32.0 ± 7.7 g (range: 15.4–49.5 g) and was not related to the frequency of breastfeedings.

Analysis of the individual breastfeedings showed that there was no effect on the average milk fat content as a result of the gender of the infant ($P = .160$); more or less productive breast ($P = .332$); unpaired, paired, or clustered breastfeedings ($P = .339$); or whether the infant breastfed at night or not ($P = .830$). The mean fat content of the milk was significantly related to time of day ($P < .001$) and was higher ($P < .008$) during the day and the evening (42.8 ± 9.1 and 43.2 ± 9.1 g/L, respectively) compared with the morning and the night (37.1 ± 10.1 and 37.2 ± 10.3 g/L, respectively).

The interval between meals was independent of the volume of the previous meal (paired or unpaired breastfeeding). The interval was also independent of the average fat content of the milk consumed in that meal or the amount of fat in the meal.

DISCUSSION

Frequency and Volume of Breastfeedings

The spectrum of breastfeeding behavior of normal infants who were exclusively breastfed ranged between having a few large breastfeedings and having frequent small breastfeedings during 24-hour periods, and the infants distributed the number of breastfeedings evenly when comparing morning with afternoon and evening, with fewer breastfeedings at night. The wide range in frequency of "meals" that we observed was very similar to that described by Butte et al,[24] Cregan et al,[10] and Hörnell et al.[11] The inverse relationship between the number of breastfeedings per day and the average breastfeeding volume is consistent with the lack of a relationship between the number of breastfeedings per day and the 24-hour milk production of the mothers. The volume of milk consumed during a breastfeeding depended on (1) whether the breast was the more or less productive breast, (2) whether the breastfeeding was unpaired or paired, (3) whether it was the first or the second breast of paired breastfeedings, and (4) the time of day (Figs 1 and 3).

For 53% of the meals, 1 breast was sufficient to satisfy the infant for at least 1 hour. This is consistent with the unpaired breastfeedings, particularly from the more productive breast, being larger than the average breastfeeding (Fig 1) and supports the advice of Riordan and Aurbach[25(p247)] that after breastfeeding becomes established, it may not be necessary to use both breasts at each meal, and also the recommendation of the National Health and Medical Research Council[6] that both breasts be offered at each meal, but the infant may or may not feed from the second breast. For the 44% of the breastfeedings that were paired, if the second breast was the less productive breast, then the breastfeeding volume could be considered to be a "top up." However, if the second breast was the more productive breast, then the infant took an equal volume to the first breast. Therefore, the milk yield from the second breast, when the infant chooses to feed from it, may provide a significant volume of milk.

The larger breastfeedings in the morning compared with the evening were also observed by Butte et al.[24] For infants who breastfed at night, although there were fewer breastfeedings during this time, those from the more productive breast were the largest of the 24-hour period, and the nighttime intake composed 20% of the total 24-hour intake. For the infants who did not breastfeed at night, the morning breastfeedings were the largest (Fig 3B).

Some mothers are concerned about the frequency of breastfeeding and wish to extend the interval between breastfeedings. We found that some infants would breastfeed again within 1 hour after breastfeedings of up to 175 g, and others would not breastfeed for >8 hours after a breastfeeding of as little as 35 g. In fact, the interval after the largest meal of 350 g was only 3 hours 35 minutes. Infants of the 5 mothers with total storage capacity of <235 mL all breastfed at night. However, most of the infants of mothers with larger storage capacities chose to breastfeed at night. Infants may need to feed at night if they have a relatively small stomach capacity and/or a rapid gastric emptying time.

Storage Capacity, Degree of Fullness, and Available Milk

The storage capacity that was calculated in this study is similar to that calculated by Kent et al[26] for the first 6 months of lactation (196 ± 57 g). It is smaller than that measured by Daly et al[27] (242 mL; SD: 129) by Computerized Breast Measurement; however, that study included 1 breast with an unusually large storage capacity of 606 mL. The relationship between storage capacity of the breast and the 24-hour milk production is similar to that found by Kent et al.[26] In the current cross-sectional study, there was no relationship between the storage capacity of the breast and the age of the infant. However, in a longitudinal study, the mean storage capacity at 1 month (179.9 ± 20.2 g) increased to 234.6 ± 17.5 g at 6 months (mean ± SEM), indicating that the storage capacity of the breast can change during lactation.[26] Because the maximum breastfeeding increased between 4 and 26 weeks and there was a relationship between the storage capacity and the maximum breastfeeding, it is likely that the storage capacity of the breast is able to change to meet an increase in demand for milk.

Anecdotally, mothers usually first offer the breast that feels more full. The data on the prefeeding degree of fullness of the breast confirm this subjective choice of the mothers. The prefeeding degree of fullness and the storage capacity allow calculation of the volume of available milk in the breast. The volume of milk that is available accounted for most of the differences in volume of milk consumed at each breastfeeding (Figs 1 and 2). For unpaired breastfeedings, not only was there more milk available in the more productive breast, but also the infants took a higher percentage of that available milk than during a paired breastfeeding.

The observation that the breasts are rarely drained at the end of a breastfeeding was also noted by Dewey et al,[20] who found that an extra 12% of milk could be expressed after a breastfeeding. Because breast expression is not always effective in removing all of the available milk,[15] this finding is consistent with the infants' removing 63% to 72% of the available milk during a breastfeeding. This suggests that the breasts do not need to be drained at every feeding to maintain adequate milk production.

Total 24-Hour Milk Production

The 24-hour milk production was within the normal range of 440 to 1220 g,[26] except for 2 mothers, who produced 1298 g and 1356 g. The average of 798 g is similar to the data presented by Dewey and Lönnerdal.[14] It is important to note the wide SD and bear in mind that the variation in milk production is related to the variation in the growth rates of the infants.[12,26,28] In addition, the higher milk intake of male infants was also noted by Butte et al[29] and is consistent with their higher growth rate.[30] The lack of effect of either maternal age or parity on milk production is in agreement with the findings of Dewey and Lönnerdal.[14]

Consistent milk intake from 1 to 6 months supports previous findings.[26] This is not surprising considering 2 factors. First, younger infants (1–3 months of age) grow more rapidly than older infants (4–6 months of age).[30] Second, smaller infants have a larger surface area to volume ratio and therefore have a relatively higher metabolic rate per kilogram of body weight[31] and use relatively more of their nutrient intake for maintenance of body temperature than do older, heavier infants.

Differences in milk production of right and left breasts have been noted previously. Mitoulas et al[32] found a significant difference between breasts, with the right breast being more productive (443 vs 356 g/24 hours). In addition, Cox et al[33] showed that the right breast was often more productive than the left. In this context, it is interesting to note that when we measured the milk production of 4 mothers who were exclusively expressing their milk for their infants (>660 g/day), there was a significant difference ($P = .03$) between the left and the right breasts (unpublished results). Three of these mothers, who were double pumping and therefore submitting both of their breasts to equivalent vacuums and times of expression, had the largest differences between the breasts. This leads us to suggest that the difference in milk production between the breasts may be attributable to differences in intrinsic milk production rather than the infant's preference. The 24-hour milk production of mothers of infants who breastfed at night was the same as for those who did not breastfeed at night, similar to the observations of Butte et al.[24]

The current data for infants up to 26 weeks of age confirm the findings of Matheny and Picciano[8] for 4-week-old infants that more milk is consumed between 6 AM and 6 PM and less is consumed between 2 PM and 2 AM. The uneven distribution of the volumes of breastfeedings of both infants who breastfeed at night and those who do not breastfeed at night (Fig 3) explains why doubling of either of these 12-hour intakes will result in significant inaccuracies in estimation of 24-hour milk consumption. Therefore, our measurements confirm that in our society, a full 24-hour period of measurement of milk intake is necessary for accuracy.

Fat Content of Breast Milk

The fat content of the milk that we measured was similar to that measured by Dewey and Lönnerdal,[14] and the 24-hour fat intake of the infants was similar to that measured previously.[12,14] Fat content of the milk at different times of day reflects the higher degree of milk removal during the day and evening and the higher degree of fullness in the morning and night. The changes in fat content of milk from the beginning to the end of the first and second breasts of a paired breastfeeding described by Woodward et al[34] can be explained by the degrees of fullness that we have calculated. The lower fat content of milk from the first breast at the beginning of the breastfeeding that they measured reflects the mother's starting to feed her infant on the fuller breast, and the higher fat content of milk from the first breast at the end of the breastfeeding reflects the higher degree of milk removal from the first breast.

Because the breast was not full at the beginning of each breastfeeding for the whole day, the fat content of the fore-milk was not always low. Because the fat intake of the infants was not related to the frequency of breastfeedings, mothers can be reassured that infants who take frequent small breastfeedings have the same daily fat intake as infants who take infrequent large breastfeedings.

An understanding of the patterns of milk intake by the breastfed infant has implications for mothers who need to express their milk either fully for a preterm infant or when they return to the paid workforce. Given the variability in breastfeeding patterns, it may be unreasonable to expect all breasts to yield the same volume of milk at the same rate when the mother is using an electric breast pump, and the breast may not need to be totally drained at every expression to maintain an adequate supply of milk. Breast pump settings and regimens may need to be customized for each mother.

CONCLUSIONS

Healthy, exclusively breastfed 1- to 6-month-old infants consume 0 to 240 g of milk between 6 and 18 times during 24 hours, with 64% of infants breastfeeding 1 to 3 times at night. The right breast usually produces significantly more milk than the left, and the volume of milk consumed at each breastfeeding is related to the volume of milk available in the breast, whether the breastfeeding is unpaired or paired, and the time of day. On average, 67% of the available milk is consumed at each breastfeeding. The fat content of breast milk varies between mothers (22.3–61.6 g/L) and within and between breastfeedings, but the amount of fat consumed by the infant is independent of the frequency of breastfeeding.

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