Original Research Communications—surveys

Effect of maternal diet and body composition on lactational performance[1-3]

Nancy F Butte, PhD, Cutberto Garza, MD, PhD, Janice E Stuff, MS, RD, E O'Brian Smith, PhD, and Buford L Nichols, MD

ABSTRACT Milk production, dietary intake, and body composition of 45 lactating women were monitored for 4 months postpartum to examine the interrelationships of these maternal variables. A 3-day dietary record, 24-h test-weighing for determination of milk production, 24-h milk collection, anthropometric measurements, and water displacement for estimation of body fat were performed monthly. The overall mean (SD) energy intake was 2186 (463) kcal/day. Milk production (g/day) averaged 751 (130), 725 (131), 723 (114), and 740 (128) during the 4 sequential months. Weight postpartum was 64.6 (9.1) kg and was 59.3 (10.5) kg at 4 months. Body fat determined by water displacement averaged 28 (7)% at 1 month and 26 (8)% at 4 months. Estimations of body fat from skinfold thickness ranged from 28 (5)% postpartum to 27 (5)% at 4 months. Energy balance calculations based on the energy available from the diet plus the energy derived from tissue mobilization, minus the caloric equivalent of the milk, indicated sufficient energy available for maintenance and activity needs. Thus, it appears that successful lactation is compatible with gradual weight reduction and attainable with energy intakes less than current recommendations. *Am J Clin Nutr* 1984;39:296–306.

KEY WORDS Lactation, diet, body composition, milk volume, milk composition, nutrient requirements

Introduction

Lactational performance appears to be preserved over a wide range of maternal states. The gross composition of human milk is remarkably constant among women of varying nutritional status. The amount of milk produced by nutritionally depleted women is reduced, but only to a limited extent (1). The preservation of milk production results from the interplay of several maternal factors, specifically the synthetic capacity of the mammary gland, the metabolic and hormonal milieu, maternal diet, and the amount of mobilizable tissue reserves. The amount of milk required by infants during the first few months of life appears to be within the genetic potential of most women.

The energy needed for milk production is provided by the maternal diet and tissue reserves. The interactions of diet and maternal tissue reserves on the quantity and composition of milk have neither been examined simultaneously nor longitudinally in one study. The extent to which one energy source can compensate for a deficit in the other is unclear and the point at which milk

[1] Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, Texas Children's Hospital, Houston, TX 77030.

[2] Publication of the USDA/ARS, Children's Nutrition Research Center in the Department of Pediatrics at Baylor College of Medicine and Texas Children's Hospital.

[3] Address reprint request to: Nancy F Butte, PhD, Lactation Program, Department of Pediatrics, Baylor College of Medicine, Medical Towers Building, Suite 501, 6608 Fannin, Houston, TX 77030.

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production becomes compromised is undefined. Moreover, the limits of the adaptive mechanisms which preserve lactation have not been quantified.

This study was designed to examine the influence of maternal diet and body composition on lactational performance in a group of privileged, presumably well-nourished women. The information to be gained is fundamental for the establishment of energy recommendations during lactation. An evaluation of lactation in terms of growth performance of the infants in this study will be published elsewhere (2). Herein, we address the impact of maternal diet and body composition on lactational performance.

Materials and methods

A 4-month longitudinal study was designed which consisted of stages of screening, postpartum counseling, and observational studies at birth, 1, 2, 3, and 4 months postpartum. Potential subjects were identified in the prenatal period. Participants were required to meet the following selection criteria: healthy, nonsmoking, aged 18 to 36 yr, no chronic medications, parity one or two, and the intent to breast-feed exclusively for at least 4 months. Infants were required to be healthy, term, and appropriate size for gestational age. Informed consent to the study protocol, approved by the Institutional Human Experimentation Committees, was obtained after delivery.

Within 3 days postpartum, a breast-feeding consultant visited the mother to review basic breast-feeding skills and performed anthropometric measurements on the mother and infant. Whenever possible, the infant was observed nursing at the breast to ensure proper positioning. Throughout the study period, mothers had access to the consultants for advice on breast-feeding management. Pertinent information regarding maternal health, labor, and delivery, and infant status was extracted from the hospital records.

At approximately 2 wk postpartum, all subjects were interviewed and oriented to study procedures by one investigator (NFB) or a breast-feeding consultant. Explicit directions were given on the collection and freezing of human milk. Each subject received detailed instructions for the completion of 3-day dietary and monthly morbidity reports.

The measurements of milk production and composition, dietary intake, anthropometry, and body composition were performed at monthly intervals. Observations were made at 35.4 (4.6), 63.8 (3.4), 91.3 (3.8), and 119.0 (5.7) days postpartum, mean (SD). Study procedures were conducted in the homes with the exception of the anthropometric and body compositional measurements which were performed at laboratory facilities located in the Texas Medical Center.

Subjects

Forty-five women participated. Data are missing on two subjects at month 3 due to maternal illness and a scheduling oversight. Two subjects moved out of town and failed to complete the last month of the study. After 2 months, one mother stopped breast-feeding and another discontinued participation due to personal reasons unrelated to the study. Data of these six subjects were included in the analysis.

The women reflected middle-upper socioeconomic stratum. Mean maternal age was 28.0 (3.1) yr; the mean level of education attained was 15.4 (1.8) yr. Ethnic background was distributed as follows: 41 Caucasian, two Hispanic, one Asian, and one West Indian. Most (82%) of the women were employed in professional or technical positions before delivery.

Thirty-eight infants (84%) were delivered vaginally and seven (16%) by Caesarian section. The mean birthweight of the 45 infants was 3.58 (0.45) kg (range 2.56 to 4.57 kg). The mean gestational age according to Dubowitz was 39.2 (1.8) (range 37 to 42 wk). There were 27 males and 18 females. Apgar scores averaged 8.4 (0.7) and 9.2 (0.5) at 1 and 5 min, respectively. Forty-two percent of the infants were first born; the remainder were second born.

Human milk intake: test-weighing procedure

The amount of breast milk ingested over a 24-h period was determined by the test-weighing procedure in which the infant was weighed before and after each feeding on an automatic, electronic balance (Sartorius 3804 MP). Because of the relatively narrow intraindividual variation in daily milk production (2), a single 24-h estimate was considered to be representative. The mothers were asked to change the infants' diapers before each feeding, not to change the infants' clothing during a feeding, not to alter the frequency or duration of their usual lactation pattern, and to estimate any losses of milk, urine, and feces not retained on the infants.

Milk collection

Breast milk was collected for compositional studies within 3 days after the test-weighing procedure. Mothers were instructed not to alter their usual feeding routine. At each feeding throughout a 24-h period, the infant was offered one breast and the contents of the contralateral breast were expressed with the use of an Egnell electrical breast pump (Cary, IL). Breasts were alternated for feeding and pumping with successive feeds. If necessary, infants were supplemented with human milk which had been collected and frozen in advance.

Milk samples were refrigerated separately in sterile, acid-washed polypropylene bottles for a maximum of 24 h and transported on ice to the laboratory where volumes of each feeding were measured and a 24-h pooled milk sample was composed.

Biochemical analysis

The heats of combustion of the milks were determined in an adiabatic bomb calorimeter (Parr) (3). A weighed amount of milk (approximately 0.2 g) was combusted with a known amount of mineral oil. Nitrogen was analyzed by the Kjeldahl method before and after trichloroacetic acid (10%, 1:1 volume) precipitation, and nonprotein nitrogen was estimated from the difference between total and protein nitrogen (PN) (4). PN was converted to protein by the factor 6.25. Fat was determined gravimetrically after methylene chloride extraction, a modification of the Roese-Gottlieb method (5); lactose was determined using an automatic analyzer (YSI Model 27, Yellow Springs, OH) which detects the hydrogen peroxide produced during the oxidation of galactose.

Dietary analysis

Each subject completed a 3-consecutive day dietary record which included 1 weekend day. The subjects were instructed to continue normal eating patterns and to keep a complete and accurate record of all meals, snacks, and other foods eaten, including those consumed outside the home. Use of nutrient supplements was ascertained by interview. Subjects were instructed to express all food quantities in common household measures and to provide a complete description of the preparation and cooking of the food items. All food items listed in the record were converted into food and quantity codes according to the USDA handbook 456-3 (6) nutrient files, and a computer program applied the nutrient data files from Agriculture handbook 456-3 to calculate the daily intake of 22 nutrients and compute the percentage consumed of the recommended dietary allowances for lactation (7). Nutrient supplements were not included in the dietary analysis.

Anthropometry

Maternal weight was measured between 10:00 AM and 4:00 PM on a beam balance and height was measured with an upright extension meter. Mothers were dressed in bathing suits only. Skinfold thickness was measured using Lange calipers at the following sites: triceps, biceps, suprailiac, and subscapular (8). These measurements generally were made by one person with the exception of observations made in the hospital.

Body composition

Maternal body fat was calculated according to Siri (9) from water displacement measurements in a Whitmore volumeter (San Antonio, TX). Residual lung volume was estimated by a modification of the standard oxygen-dilution technique (10). Gastrointestinal gases were approximated to be 100 ml. Lean body mass (LBM) was calculated from the difference between body weight and body fat. Maternal body fat also was predicted from skinfold thickness based on the equation derived by Durnin and Womersley (11). LBM was determined by difference.

Maternal energy balance

Estimation of maternal energy balance was based on either body fat and LBM changes calculated from skinfold measurements, maternal weight changes, or water displacement methods. Energy balances were computed for individuals and then averaged for group means at each monthly interval. The energy equivalents applied to weight, fat, and LBM changes were assumed to be 6500, 9100, and 1200 kcal/kg, respectively. Conversion of dietary to milk energy was assumed to be 80% efficient. Residual energy for maintenance and activity needs was that which remained from dietary energy after accounting for the milk produced and changes in body weight and composition.

Statistical analysis

The Scientific Information Retrieval Data Base Management System (12) was utilized for quality control of data, update capability, and to interface with Minitab (13) for descriptive and statistical analysis, which included the Pearson correlation and regression. Trends over time were tested by fitting polynomial regressions to individuals.

Results

Milk production

Milk production averaged 733 (89) g/day overall and did not vary significantly over the four months of observation (**Table 1**). The mean coefficient of variation in milk production over the 4 months was 17%, which reflected the variability between individuals. The mean coefficient of variation in milk production within individuals over the four months was 12%. The number of feedings per day declined slightly over time. The correlation relating feeding frequency to the amount of milk produced was not statistically significant ($r = 0.10$ to 0.14). Corrections were not made for the amount of vomitus which was noted infrequently. There were no reported losses of urine or feces. The composition of the representative 24-h pooled milk samples is displayed in Table 1. The volume of milk expressed for analysis was equal to 49 (17)% of the 24-h milk production determined by test-weighing. The number of feedings included in the 24-h milk aliquots was equal to 90 (22)% of the number recorded during the test-weighing sessions.

Consecutive monthly values of total nitrogen, PN, fat, and calories were correlated significantly ($r = 0.42$ to 0.74, $p \leq 0.01$) to their subsequent monthly values indicating a degree of consistency in milk composition within mothers. Similarly, the quantities of milk produced were significantly correlated at months one and two ($r = 0.57$, $p \leq 0.01$) and at months three and four ($r = 0.49$, $p \leq 0.01$).

TABLE 1
Milk production over the first 4 months of lactation

	Mo 1 (n = 37)		Mo 2 (n = 40)		Mo 3 (n = 37)		Mo 4 (n = 41)	
Human milk* (g/day)	751	(130)†	725	(131)	723	(114)	740	(128)
Feedings (no/day)	8.3	(1.9)	7.2	(1.9)	6.8	(1.9)	6.7	(1.8)
Total nitrogen (mg/g)	2.17	(0.30)	1.94	(0.24)	1.84	(0.19)	1.80	(0.21)
Protein nitrogen (mg/g)	1.61	(0.24)	1.42	(0.17)	1.34	(0.15)	1.31	(0.17)
Nonprotein nitrogen (mg/g)	0.56	(0.28)	0.52	(0.20)	0.50	(0.13)	0.48	(0.14)
Fat (mg/g)	36.2	(7.5)	34.4	(6.8)	32.2	(7.8)	34.8	(10.8)
Energy (kcal/g)	0.68	(0.08)	0.64	(0.08)	0.62	(0.09)	0.64	(0.10)

* At the onset of the study, milk was estimated by deuterium dilution, a technique that was later determined to be inaccurate (14). For this reason, data are missing at 17 time points during the first 3 months.
† Mean (SD).

Maternal dietary intake

Maternal energy intake (**Table 2**) decreased significantly over the 4 months of lactation ($p \leq 0.01$). Nutrient analysis of the 3-day dietary records revealed an overall mean energy intake of 2186 (463) kcal/day or 37 (10) kcal/kg/day. The range of reported mean 3-day energy intakes varied widely from 1099 to 4398 kcal/day. The mean coefficient of variation in energy intake for the 4 months was 26% which represented the variability between individuals. The monthly variation in energy intake within individuals was 17% (mean coefficient of variation). The daily variation in energy intake calculated from 3-day records was 19% (mean coefficient of variation). The group mean for energy intake was 7, 15, 13, and 16% below the recommended allowance for energy (NRC) at the 4 respective months. Overall, 17% of the energy was derived from protein, 37% from fat, and 46% from carbohydrate.

The ingested amounts of protein, phosphorus, vitamin A, thiamin, riboflavin, niacin, and ascorbic acid provided between 96 to 155% of the recommended dietary allowances for lactation. Calcium intake provided between 84 to 102% of the recommended dietary allowances. The diets provided 80% of the iron recommended for nonpregnant, nonlactating women.

Most mothers (94%) continued the use of their prenatal multivitamin-mineral supplements during lactation. Additional iron and calcium supplements were taken by 33 and 23% of the women, respectively.

Anthropometry

Maternal weights displayed a gradual, steady decline over the 4 postpartum months ($p \leq 0.001$) (**Table 3**). The overall rate of weight loss was 48 g/day. A mean weight loss of 3.8 (2.3) kg occurred during the 1st month, followed thereafter by a modest decline of 0.67 (0.11) kg/month. A wide range of maternal weights was represented in this study (41 to 91 kg); maternal weights were 16 (6) (range 0 to 29%) above prepregnancy weights at the onset of lactation and 5 (7)% (range −10 to 21%) above after 4 months of lactation. There was considerable variability in the rate of weight change among the women. Excluding the first month which was associated with postpartum diuresis, weight changes ranged from −5.6 to 5.5 kg/month.

The skinfold measurements are presented in Table 3. Triceps and biceps skinfold thicknesses did not change significantly during the study period. Measurements of the suprailiac and subscapular skinfolds ($p \leq 0.001$) and the sum of all sites ($p \leq 0.002$) decreased significantly over time.

Body composition

Maternal body fat calculated from the water displacement method decreased from 28 (7)% at 1 month postpartum to 26 (8)% at 4 months postpartum ($p \leq 0.001$) (**Table 4**). Maternal body fat predicted from skinfold thickness decreased from 28 (5)% postpartum to 27 (5)% by the 4th month of lactation ($p \leq 0.001$). The estimations of maternal body fat by these two methods did not differ significantly. Overall, LBM aver-

TABLE 2
Maternal dietary intake during lactation

	Mo 1 (n = 43)		Mo 2 (n = 44)		Mo 3 (n = 40)		Mo 4 (n = 40)	
Energy (kcal/day)	2334	(536)*	2125	(582)	2170	(629)	2092	(498)
% recommended dietary allowances (RDA)	93	(21)	85	(23)	87	(25)	84	(20)
Protein (g/day)	98	(28)	91	(27)	89	(25)	87	(20)
% (RDA)	153	(44)	143	(42)	140	(39)	136	(31)
% Energy	17	(4)	17	(3)	17	(4)	17	(3)
Fat (g/day)	93	(29)	88	(28)	90	(39)	87	(25)
% Energy	36	(5)	37	(6)	37	(6)	37	(4)
CHO (g/day)	277	(69)	289	(72)	249	(76)	241	(72)
% Energy	48	(7)	45	(7)	46	(7)	46	(6)
Calcium (mg/day)	1219	(543)	1030	(466)	1024	(478)	1009	(460)
% (RDA)	102	(45)	86	(39)	85	(40)	84	(38)
Phosphorus (mg/day)	1722	(553)	1496	(456)	1467	(459)	1465	(434)
% (RDA)	144	(46)	125	(38)	122	(38)	122	(36)
Iron (mg/day)†	16.2	(4.8)	14.1	(3.7)	13.9	(4.0)	13.5	(2.7)
Vitamin A (IU/day)	9070	(5920)	8532	(5341)	7598	(4807)	7126	(3775)
% (RDA)	151	(99)	142	(89)	127	(80)	119	(63)
Thiamin (mg/day)	1.9	(0.9)	1.5	(0.6)	1.5	(0.5)	1.5	(0.7)
% (RDA)	124	(61)	96	(40)	99	(31)	102	(46)
Riboflavin (mg/day)	2.6	(1.1)	2.1	(0.7)	2.1	(0.8)	2.1	(0.8)
% (RDA)	155	(64)	121	(47)	124	(49)	125	(50)
Niacin (mg/day)	23.6	(8.4)	20.3	(5.8)	20.5	(7.2)	20.2	(5.9)
% (RDA)	131	(47)	110	(36)	114	(40)	112	(33)
Ascorbic acid (mg/day)	150	(90)	124	(78)	114	(81)	115	(56)
% (RDA)	150	(90)	124	(79)	114	(81)	115	(56)

* Mean (SD).
† Thirty to 60 mg iron are recommended for 2 to 3 months after parturition in order to replenish stores depleted during pregnancy. This quantity is not readily attainable from typical American diets, therefore, supplemental iron is recommended.

aged 43.6 (4.9)% based on water displacement measurements and 44.1 (5.0)% estimated from skinfold thickness.

Maternal energy balance

The residual energy for maintenance and activity averaged 1912 (398) kcal/day based on the weight changes over the four months of lactation (**Table 5**). It may be misleading to assume that the weight loss in the 1st month of lactation represented adipose tissue since approximately 2 kg of water is lost in the puerperium; therefore, the overall mean residual energy was calculated for months 2, 3, and 4 and was found to be 1741 (380) kcal/day.

Energy balance based on skinfold measurements indicated a mean residual energy of 1801 (378) kcal/day over the entire 4 months. Exclusion of the 1st month reduces the mean residual energy to 1714 (364) kcal/day. The estimations from water displacement averaged 1729 (430) kcal/day overall. Water displacement measurements were not made in the postpartum period.

Relationships between energy intake and anthropometric changes

As energy intake increased, weight change became progressively less negative or more

TABLE 3
Anthropometric changes during lactation

Parameter	Postpartum	Mo 1	Mo 2	Mo 3	Mo 4
Wt (kg)	64.6 (9.1)*	61.3 (9.5)	60.7 (10.0)	60.2 (10.4)	59.3 (10.5)
Wt/ht (kg/cm)†	0.40 (0.04)	0.37 (0.05)	0.37 (0.05)	0.37 (0.05)	0.36 (0.06)
Wt/prepregnancy wt‡	1.16 (0.06)	1.08 (0.05)	1.07 (0.05)	1.06 (0.05)	1.05 (0.07)
Wt change (kg/mo)		−3.83 (2.26)	−0.59 (1.20)	−0.62 (1.12)	−0.80 (1.86)
Triceps (mm)	16.3 (5.1)	16.9 (4.6)	17.0 (4.7)	17.3 (5.3)	17.2 (5.2)
Subscapular (mm)	18.2 (7.1)	16.8 (6.4)	16.4 (7.4)	15.7 (7.2)	15.1 (7.3)
Biceps (mm)	7.8 (3.9)	6.9 (3.2)	6.9 (3.3)	7.3 (4.6)	6.8 (3.4)
Suprailiac (mm)	26.1 (8.5)	25.7 (6.9)	25.2 (7.6)	23.1 (8.1)	22.2 (8.0)
Sum skinfolds (mm)	68.4 (20.2)	66.3 (18.9)	65.5 (20.6)	63.4 (22.9)	61.7 (21.8)
Midarm circumference (cm)	26.9 (3.5)	26.7 (2.6)	26.8 (3.2)	26.6 (2.9)	26.7 (3.6)

* Mean (SD).
† Maternal ht = 163.0 (6.3 cm).
‡ Prepregnancy wt gain = 14.4 (3.3 kg).

positive. Significant correlations were demonstrated between maternal weight change and energy intake during months 3 and 4 (r = 0.50, p ≤ 0.01). The summary regression of these two months was Y = −3.68 + 0.0014 X, where Y represented maternal weight change (kg/month) and X represented maternal energy intake (kcal/day). Similar patterns were observed in the relationships between energy intake and change in body fat predicted by water displacement throughout the 4 months of lactation. As dietary energy increased, the change in body fat became less negative [Y = −2.75 + 0.0010 X, where Y represented the change in body fat (kg/month) and X signified maternal energy intake (kcal/day)], (r = 0.37 to 0.61, p = 0.05 to 0.01).

The total amount of energy available from the diet and tissue reserves was fairly constant throughout the 4 months postpartum. Based on water displacement measurements, the overall mean energy available was 2282 (315) kcal/day: 2140 (386) kcal/day provided by the diet and 156 (224) kcal/day mobilized from tissue reserves. An inverse relationship was demonstrated between energy intake and the amount of energy mobilized from LBM and body fat over the 4 months (r = 0.51, p ≤ 0.01). Milk production was not significantly correlated to the total amount of energy available from the diet and tissues.

The effect of maternal factors on milk production

Maternal age did not influence the amount of milk produced. By study design, parity was limited to a maximum of two children. Although virtually all the multiparous women had breast-fed their first child, there was no significant difference between their milk production and that of the primiparous mothers. By the 4th month of lactation, seven of the women had resumed menses, however, they did not differ from the rest of the group with respect to the amount of milk produced, the number of feedings per day, or the percentage of body fat.

Dietary energy intake was significantly correlated with milk production (g/day) at months 2 and 3 (r = 0.32; .38; p ≤ 0.05). A summary regression equation describes the

TABLE 4
Body compositional changes during lactation predicted from measurements of water displacement and skinfold thickness

Mo postpartum	Water displacement			Skinfold thickness*		
	Body density	Body fat (%)	LBM (%)	Body density	Body fat (%)†	LBM (%)
0				1.036 (0.011)‡	28.1 (5.0)	46.3 (4.8)
1	1.036 (0.016)	28.0 (7.4)	43.7 (4.8)	1.036 (0.010)	27.6 (4.6)	44.1 (5.0)
2	1.038 (0.014)	27.2 (6.3)	44.0 (5.5)	1.037 (0.011)	27.3 (5.0)	43.7 (5.3)
3	1.039 (0.016)	26.3 (6.8)	43.8 (5.4)	1.037 (0.011)	27.2 (5.3)	43.4 (5.1)
4	1.040 (0.016)	26.3 (7.6)	43.2 (5.2)	1.038 (0.011)	27.0 (5.1)	42.9 (5.4)

* Body fat (%) calculation based on triceps, biceps, and subscapular skinfold thickness. Due to measuring difficulties, the suprailiac site was not used in the calculation.
† No statistically significant differences between methods (paired *t* test).
‡ Mean (SD).

TABLE 5
Maternal energy balance during lactation

Interval (n)	Energy intake	Energy equivalent wt change*		Energy equivalent milk produced†	Residual energy‡
Calculated from weight change (kcal/day):					
Mo 0–1 (32)	2390 (539)	−726 (409)		652 (171)	2463 (656)
Mo 1–2 (39)	2098 (536)	−141 (275)		586 (146)	1653 (470)
Mo 2–3 (35)	2232 (594)	−147 (287)		581 (154)	1798 (489)
Mo 3–4 (37)	2089 (496)	−251 (432)		590 (137)	1750 (473)
Mo 1–4 (45)	2182 (453)	−154 (243)		595 (111)	1741 (380)
		Energy equivalent body fat change§	Energy equivalent LBM change‖		Residual energy¶
Calculated from skinfold thickness (kcal/day):					
Mo 0–1 (32)	2390 (539)	−353 (344)	−88 (69)	652 (171)	2179 (593)
Mo 1–2 (39)	2098 (536)	−82 (335)	−15 (48)	586 (146)	1610 (470)
Mo 2–3 (35)	2232 (594)	−22 (423)	−24 (43)	581 (154)	1697 (531)
Mo 3–4 (37)	2089 (496)	−193 (322)	−21 (62)	590 (136)	1713 (424)
Mo 1–4 (45)	2182 (453)	−110 (216)	−18 (28)	595 (111)	1714 (364)
Calculated from water displacement values (kcal/day):					
Mo 1–2 (35)	2054 (513)	−268 (691)	11 (103)	584 (146)	1727 (645)
Mo 2–3 (34)	2221 (599)	−119 (738)	−12 (100)	585 (155)	1766 (788)
Mo 3–4 (37)	2089 (496)	−126 (801)	−30 (102)	590 (136)	1655 (678)
Mo 1–4 (45)	2182 (453)	−137 (316)	−6 (39)	595 (111)	1729 (430)

* Assumption: energy equivalent of wt changes = 6500 kcal/kg.
† Assumption: 80% energetic efficiency for converting dietary to milk energy.
‡ Residual energy = energy intake − energy equivalent wt change − energy equivalent of milk produced.
§ Assumption: energy equivalent of body fat change = 9100 kcal/kg
‖ Assumption: energy equivalent of LBM change = 1200 kcal/kg
¶ Residual energy = energy intake − energy equivalent body fat change − energy equivalent LBM change − energy equivalent of milk produced.

relationship as Y = 556 + 0.077 X where Y represents milk production (g/day) and X signifies energy intake (kcal/day). Approximately 13% of the variability in milk production was accountable by dietary energy intake. The dietary components, protein, carbohydrate, and fat, had no detectable impact on milk quantity or quality.

There were no significant interactions between milk quantity/quality and the battery of maternal anthropometric indices. The variables explored were maternal weight, height, metabolic size (weight $^{3/4}$), body surface area, change in body fat, prepregnancy weight, and weight gain during pregnancy.

There were a total of 68 reported incidences of maternal illness, among which colds, mastitis, headaches, and influenza predominated. Because study procedures were postponed in the event of illness, the direct effect of morbidity on milk production could not be evaluated.

Discussion

The intent of this study was to examine the influence of maternal diet and body composition on lactational performance among well-nourished women. Anthropometric, dietary, and socioeconomic data suggest that these women were well nourished. Their educational level and income bracket would suggest, although not insure, that access to an adequate diet was not limited by lack of knowledge or funds. Adequate weight gains during pregnancy, 14.4 (3.3) kg, and satisfactory infant birthweights, 3.58 (0.45) kg, are indirect indicators of good nutritional status during pregnancy. These mothers entered lactation with ample energy reserves. Although their diets contained somewhat less than the recommended allowance for energy, they provided sufficient quantities of protein, vitamin A, thiamin, niacin, and ascorbic acid, which indicates a judicious selection of nutrient-dense foods. It should be noted that the computerized dietary program did not analyze the diets for several nutrients which tend to be marginal in diets of reproductive women, eg, vitamin B_6, zinc, folic acid, and magnesium. However, the conscientious ingestion of vitamin-mineral supplements probably safeguarded against dietary insufficiencies.

The adequacy of lactational performance may be evaluated by the quantity and quality of milk produced and by the growth of the recipient infant. The levels of milk production recorded in this study conformed to the classic observations of Wallgren (15) and to more recent reports in the literature (4, 16–19). Typical milk production rates ranged from 600 to 900 g/day. Although exceptionally high milk outputs have been cited for Australian women (20), it is unclear whether or not their performance is typical of most lactating women.

The milk composition in this study was within expected norms. The concentration of TN and its partition between PN and nonprotein nitrogen were similar to those of other studies (4, 21). The fat concentrations agreed with some reports (22, 23), but were at variance with others (24, 25). The energy density, 0.65 (0.09) kcal/day, was slightly less than the generally accepted norm of 0.67 kcal/day and can be attributed to the slightly lower fat concentration, 34.3 (6.9) mg/g. The 24-h milk aliquot obtained in this study accounted for diurnal variation in fat concentrations and changes throughout a single feed, and therefore may be more representative of an infant's average intake than alternative sampling techniques.

Infant growth compared favorably with NCHS reference standards (26). The mean weights of these infants were consistently greater than the mean weights of NCHS study populations. There was a slight tendency for weight for age percentiles to decrease after the first month of life at a rate of 2.6 percentile/month. However, none of the infants displayed clinically significant deviations from growth percentiles defined at birth.

It may be concluded that the lactational performance of these women was adequate by most standards. Difficulties arise, however, in the attempt to compare the performance of the women in this study with that of women in various studies performed under different experimental conditions or procedures. Nevertheless, the milk production and resultant infant growth encountered in the present study were consistent with reports from well-nourished populations.

The energy intakes, 2186 (463) kcal/day or 37 (10) kcal/kg/day, recorded in this study were consistent with recent reports in the literature of well-nourished, lactating women (27–30), although not invariably so (31–34). Recent reports from the US indicate a mean energy intake of approximately 2027 kcal/day, or 32.5 kcal/kg/day in those studies where maternal weight was measured. In contrast, investigations conducted in the UK, Scotland, and Australia found higher energy intakes among lactating women, which averaged 2708 kcal/day or 45.2 kcal/kg/day in those studies stipulating maternal weight. Regression analysis indicated that a caloric intake of approximately 2600 kcal/day was associated with no weight loss which would be undesirable for most women in the present study.

In the foregoing dietary studies, milk production was not measured, but was assumed to be adequate. In this study, milk production was dependent partially on maternal energy intake. In the 2nd and the 3rd months postpartum, a significant correlation was found between milk production and maternal energy intake, although energy intake accounted for only 13% of the variability in production. Consumption of a diet that is constantly low in energy may result in a diminution in milk production of clinical significance to the infant.

Clearly, mobilization of maternal tissue reserves can subsidize the energy cost of lactation. The inverse relationship between energy intake and the amount of energy mobilized from LBM and body fat substantiates the adaptive interaction of diet and body reserves. Irrespective of the methodological approach, the estimated energy mobilized from the tissues was less than the 200 to 300 kcal/day assumed in the calculation of the recommended dietary allowances for energy during lactation. On the average, 2300 kcal/day derived from diet and tissue reserves seemed to be required for adequate milk production among these women. Milk production was not dependent, however, on the amount of tissue reserves. Mothers whose body fat content was less than 20% did not produce less milk; they did, however, tend to consume more energy, 2369 (364) kcal/day. It would be misleading to propose a critical energy level required for milk production for all women. A recommended range of energy intakes would be more appropriate since a woman's total dietary energy requirement is highly dependent upon her metabolic and activity needs, as well as her tissue reserves.

Energy expenditure was not measured in this study, but was deduced from maternal energy balance calculations. Regardless of the methodological approach, approximately 1730 kcal/day were available for maintenance and activity needs after accounting for the energy cost of lactation. The basal metabolic requirement (BMR) of these lactating women would be 1389 (132) based on body surface area calculated according to Fleish (35). Subtracting this from the residual energy, approximately 340 kcal/day would remain for activity.

Blackburn and Calloway (27) measured total and basal energy expenditure in a group of mature, lactating women. The BMR of 12 lactating women 8 to 12 wk postpartum averaged 1157 (164) kcal/day or 18.2 kcal/kg/day. The BMR calculated for the women in this study may be an overestimation, because of the increased adiposity postpartum. Total energy expenditure among the lactating women described by Blackburn as sedentary, averaged 1852 (166) kcal/day, which is comparable to the residual energy calculated for the women in this study. The partition of residual energy between maintenance and activity needs is somewhat arbitrary, but nevertheless informative. The approach used in this study derived estimates of BMR which appeared slightly elevated and estimates of activity needs which seemed slightly low, even for sedentary lifestyles.

The level of energy balance attained by these lactating women was physiologically sound. The energy available from the diet and tissue reserves adequately supported milk production and normal metabolic and activity needs. The majority of women was in negative weight balance, but not to their detriment. Most mothers were still above their prepregnancy weights at 4 months postpartum.

It would appear, therefore, that the recommended energy allowance of 2500 kcal/day is in excess of the needs of these lactating women. It should be noted that this recommendation is based on a milk production of 850 g/day which is greater than that observed in this study. The overall mean intake of 2186 kcal/day supported adequate lactation and permitted a gradual reduction in maternal weight. This conclusion is contingent on the reliability of the dietary records. The 3-day records were verified against 7-day records in a previous study and found to be in agreement (36), nevertheless, the relative uncertainty of dietary intake is fully acknowledged.

Human milk production and composition are recognized to vary considerably among individuals. Within the ranges encountered in this study, maternal characteristics explained only a small portion of the variability in milk production. Besides the moderate influence of maternal energy intake on milk production already discussed, dietary components were not related to milk quantity or quality. Neither body size nor composition influenced milk production. Although there appeared to be some consistency of milk quantity and quality within individuals, the determinant maternal characteristics were not identified.

Summary

Successful lactational performance was documented in 45 well-nourished mothers. Milk production, in terms of quantity and quality, and infant growth were satisfactory by current standards. Maternal energy intakes were less than current recommended allowances, but compatible with adequate milk production and a gradual reduction in maternal weight.

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