The energy cost of human lactation

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1. The energy values of the diets of twenty-three women who were breast-feeding and thirty-two who were bottle-feeding their babies were determined by 7 d weighed surveys. All the subjects were healthy and living at home, and their babies were thriving. The lactating mothers took, on average, 591 kcal (2·5 MJ)/d more than those who were not lactating.

2. Both groups were losing weight, on average. The estimated contribution of such losses to the total energy supply was added to and the amounts expended on basal metabolism deducted from the dietary energy intakes. Since the activity of each group was fairly similar, it was possible to conclude that the average amount of energy available to support lactation was 618 kcal (2·6 MJ) daily. The average energy value of the milk produced was estimated from the weights of the babies to be 597 kcal (2·5 MJ) daily.

3. Critical evaluation of those averages, and of the assumptions on which they were based, led to the conclusion that the energy exchanges in human lactation have an efficiency of 90% or more, with a lower limit of about 80%.

4. The additional supply of 600 kcal (2·5 MJ) in the daily diet should suffice to support lactation and a 'round figure' of 500 kcal (2·1 MJ) daily may be regarded as reasonable in official recommended allowances.

Many national and international authorities have estimated that a lactating woman requires 1000 kcal daily in addition to ordinary requirements. That figure appears to have been first proposed by the FAO (1950) Committee on Calorie Requirements. A second FAO (1957) report, while confirming the estimate, noted that 'some women find that an increase of 1000 Calories daily is not easily achieved and an increase of 800 Calories may be a more reasonable estimate'.

The daily allowance of 1000 kcal was based on an assumed production of 850 ml milk with an energy value of 600 kcal. The efficiency with which dietary energy is converted into energy in milk was therefore taken to be 60%, an estimate which was briefly explained in an appendix to the 1950 report. It was derived from sixty-nine published records of the milk yields of nineteen women, all of whom were said to be taking diets of about 3000 kcal daily. An arbitrary base-line of energy expenditure, representing a constant level of maintenance and activity, was deducted from the intake, and the excess over this base-line was related to the energy value of the milk produced. No details of the calculations were given.

In 1960, we reviewed the published evidence available to the FAO Committee, together with some scanty additional material, and concluded that a production efficiency of about 80% fitted the data better than 60% (Hytten & Thomson, 1961). It was noted, however, that most of the evidence came from exceptional subjects, such as high-yielding wet-nurses, or had been collected under special experimental conditions. 'What seems to be needed now is a study of "typical" lactating women living under ordinary dietetic and social conditions.'

A comprehensive study of the energy cost of lactation would be difficult to conduct, especially in a society where sustained lactation has become exceptional. But during the past 15 years, in connexion with a variety of research projects, we have measured the dietary intakes of many women who were fully breast-feeding or fully bottle-feeding their babies. This material, though incomplete, permits a fresh approach to the estimation of the energy exchanges involved in human lactation.

EXPERIMENTAL

Subjects. A total of fifty-five diet surveys was made on forty-nine women living in Aberdeen, Scotland, mostly about 2 months after parturition (range 6–17 weeks). Twenty-three of the mothers were fully breast-feeding their babies. Although eight of them had started to give cereal supplements, the amounts involved were trivial and did not contribute significantly to the energy supply of the babies. In twenty-one of the other thirty-two subjects, breast-feeding had not been attempted, and in the remainder it had been abandoned within 6 weeks and usually within 1 month of parturition. Except for one subject where the diet survey was made 2 weeks after the start of bottle-feeding and two where the gap was 3 weeks a period of at least 4 weeks had elapsed between the cessation of lactation and the start of the diet survey.

The mothers concerned were selected (usually during pregnancy) from patients with good educational and home backgrounds in order to secure effective co-operation. All were physically well although some, particularly in the breast-feeding group, complained of feeling more tired than usual. All were living at home and eating to appetite on self-chosen diets. All the babies were gaining weight normally and thriving.

Diet survey procedure. Food taken during 7 consecutive days was weighed and measured at home by the subjects themselves, with frequent supervision by a dietitian. Accurate balances and other measuring equipment were provided. Of the forty-nine subjects, thirty-one had participated in similar surveys on several previous occasions and were therefore experienced in the method. All the records were well-kept and seemed to be complete and accurate. The energy values of the diets were calculated from their protein, fat and carbohydrate (monosaccharide) contents, using the factors 4, 9 and 3·75 kcal/g respectively (Thomson, 1958).

Body measurements and estimates derived from them. Rate of weight change was averaged from weight at the time of discharge from the maternity hospital (usually about 1 week *post partum*) and that at the time of the diet survey. The energy equivalent of weight gained or lost was taken as 6500 kcal/kg (Best, 1954; Keys, Anderson & Brozek, 1955; Wishnofsky, 1958).

Basal metabolism was estimated from weight and height at the time of the survey, using the tables of Quenouille, Boyne, Fisher & Leitch (1951).

The food intake of the babies was not measured directly. Their energy intakes were estimated as 127 kcal/kg for those aged between 31 and 60 d, and 117 kcal/kg for those aged 61 to 90 d (Fomon, Owen & Thomas, 1964).

Activity. The field workers concerned allocated each subject to a four-category grading from 'very active' (A) to 'very inactive' (D) using agreed definitions. The gradings were, inevitably, subjective and imprecise but subjects in grades C and D were almost certainly less active (and did have diets of a lower average energy value) than those in grades A and B. Eleven lactating and twenty-six bottle-feeding women kept diaries from which it was possible to calculate the average number of hours per day during the survey week spent in bed, sitting and in light or more strenuous activities. Attempts to convert such data into energy expenditure (kcal) were too approximate to be useful.

RESULTS

Tables 1 and 2 give detailed results and averages for the lactating and bottle-feeding groups, respectively. Table 3 gives some calculations of differences between the averages for the groups. The lactating and bottle-feeding mothers took, on average, 2716 and 2125 kcal/d respectively. Adding the assumed energy equivalents of body-weight being lost, the total energies available were 2977 and 2364 kcal/d. Deducting from those totals the average expenditures on basal metabolism, we obtain, as residual available energy, 1547 kcal/d for the lactating and 929 kcal/d for the bottle-feeding groups, respectively. If it can be assumed that the expenditure on activity was similar in each group (a question which is discussed below), it appears that 618 kcal, on average, was available for milk production. Since the estimated energy value of the milk supplied was 597 kcal, an average production efficiency of 97% is implied. This estimate, and the values from which it has been derived, will now be evaluated.

Dietary intakes. The diet survey data are believed to be as accurate as can be obtained from housewives living at home. The results for individuals show a degree of variability similar to that reported in a review by Harries, Hobson & Hollingsworth (1962) and it is recognized that intake during 7 d can be only broadly representative of the intake over a longer period. Given such limitations, we believe that the averages indicate reliably the intakes of the two groups. They might be altered slightly by using different food analysis tables, or different factors for converting nutrients into energy, but this would have little effect on the difference between the two groups. The difference indicated—just over 600 kcal/d—is likely to be a fair estimate of the additional dietary energy taken by lactating women under British domestic conditions. In Australia, English & Hitchcock (1968) found that sixteen lactating women were taking 580 kcal/d, on average, more than ten women who were bottle-feeding.

Energy equivalent of weight lost. Changes of weight during the survey week itself were not observed; they would be small and difficult to measure accurately (Khosla & Billewicz, 1964). The average rate of loss during the much longer period covered by our measurements is probably reliable, since the rate during the first 2 or 3 months *post partum*, excluding the first 10 d, is approximately linear (Dennis & Bytheway, 1965). The slightly greater rate of loss among lactating as compared with non-lactating women is in accord with the findings of Dennis & Bytheway, and also some of our own (Hytten & Thomson, 1961).

The calorie equivalent used, 6500 kcal/kg, is based on values obtained for obese persons losing weight and may not apply to normal women during the late puerperium.

Table 1. *Characteristics, energy intake and estimated energy expenditure of twenty-three lactating women, together with the weights and estimated energy intakes of their babies*

Subject	No. of previous children	Weeks *post partum*	Age (years)	Height (cm)	Wt (kg)	Dietary energy (kcal/d)	Wt change (kg/week)	Energy equivalent (kcal/d)	Total energy available (kcal/d)	Basal energy expenditure (kcal/d)	Energy available less basal (kcal/d)	Wt of baby (g)	Estimated energy intake of baby (kcal/d)
1	0	6	24	157	54·4	2640	−0·44	+409	3049	1383	1666	4595	584
3	0	5	19	158	58·5	3380	−0·69	+641	4021	1448	2573	3883	493
5	2	7	31	165	66·5	3500	+0·04	−37	3463	1490	1973	5216	662
6	0	8	29	166	72·8	2910	+0·02	−19	2891	1560	1331	NS	—
10	0	8	26	157	54·7	3200	+0·02	−19	3181	1380	1801	4563	580
14	1	8	28	166	66·9	2530	−0·37	+344	2874	1512	1362	4536	576
15	0	7	22	150	46·3	2330	−0·38	+353	2683	1303	1380	4649	590
18	0	6	22	160	55·3	2320	−0·33	+306	2626	1413	1213	3742	475
20	0	11	27	154	50·6	2250	−0·28	+260	2510	1330	1180	5443	637
25	0	8	24	159	60·8	2260	−0·34	+316	2576	1551	1025	5398	686
26	0	6	20	154	56·3	2330	−0·10	+93	2423	1410	1013	3969	504
28	1	6	27	161	63·3	3070	−0·14	+130	3200	1470	1730	4423	562
29	0	7	29	149	52·6	2800	+0·58	−539	2261	1316	945	4423	562
33	0	9	22	160	57·5	2270	−0·42	+390	2660	1434	1226	4822	564
35	1	8	26	161	49·9	3290	−0·62	+576	3866	1348	2518	5443	691
37	0	13	20	151	57·2	2830	−0·59	+548	3378	1408	1970	5579	653
30	0	9	28	161	50·8	2990	−0·23	+214	3204	1350	1854	4717	552
40	0	9	24	163	49·9	2900	−0·14	+130	3030	1367	1663	5783	677
41	0	9	23	152	55·8	1690	−0·51	+474	2164	1390	774	5048	591
41	1	9	26	152	60·3	2020	−0·72	+669	2689	1413	1276	4876	570
42	0	6	20	156	71·0	2610	−0·34	+316	2926	1550	1376	4082	518
46	0	10	28	157	55·0	2550	−0·50	+464	3014	1375	1639	4989	584
49	2	8	30	173	86·1	3810	+0·02	−19	3791	1696	2095	6423	816
Mean		8·0	25·0	158	58·8	2716	−0·28	+261	2977	1430	1547	4846	597
Standard error		—	0·7	1·2	1·9	107	0·06	58	103	20	99	138	17

Table 2. *Characteristics, energy intake and estimated energy expenditure of thirty-two women who were not lactating*

Subject	No. of previous children	Weeks *post partum*	Age (years)	Height (cm)	Wt (kg)	Dietary energy (kcal/d)	Wt change (kg/week)	Energy equivalent (kcal/d)	Total energy available (kcal/d)	Basal energy expenditure (kcal/d)	Energy available less basal (kcal/d)
2	0	8	23	157	50·8	1900	−0·23	+214	2114	1353	761
2	1	10	26	157	51·8	1840	−0·34	+316	2156	1350	806
4	0	12	27	164	57·5	1950	−0·44	+409	2359	1428	931
7	0	6	25	154	64·9	2020	−0·22	+204	2224	1468	756
8	0	8	27	171	63·0	1940	−0·39	+362	2302	1498	804
9	1	14	34	157	62·3	2050	+0·30	−279	1771	1416	355
11	2	9	37	168	64·9	2020	−0·27	+251	2271	1478	793
12	0	7	24	157	52·6	760	−1·20	+1114	1874	1370	504
13	1	6	25	173	69·2	2570	−0·86	+799	3369	1568	1801
16	0	7	27	166	64·3	3010	−0·04	+37	3047	1493	1554
17	0	10	22	164	50·8	2000	−0·15	+139	2139	1385	754
19	1	8	24	164	64·2	2980	−0·03	+28	3008	1500	1508
21	0	8	24	164	54·9	1800	−0·28	+260	2060	1366	694
22	1	13	27	168	61·9	1610	+0·05	−46	1564	1480	84
23	1	8	31	164	60·0	2240	−0·36	+334	2574	1432	1142
24	0	7	24	159	49·0	2080	0	+46	2080	1344	736
27	0	10	31	160	49·9	1970	−0·24	+223	2193	1327	866
28	0	8	24	161	60·7	2700	−0·45	+418	3118	1458	1660
30	1	8	32	161	62·1	2270	+0·34	−316	1954	1434	520
31	0	17	27	171	63·2	2300	−0·06	+56	2356	1501	855
31	1	8	29	171	66·1	2440	−0·41	+381	2821	1522	1299
32	0	7	27	175	61·5	2350	−0·19	+176	2526	1470	1056
34	0	7	23	150	48·9	2210	−0·41	+381	2591	1251	1340
36	2	8	24	171	68·4	1670	−0·63	+585	2255	1558	697
38	0	7	24	165	61·6	2160	−0·35	+325	2485	1480	1005
38	1	8	26	165	60·9	2260	−0·16	+149	2409	1470	939
43	0	8	22	164	52·3	1640	−0·86	+799	2439	1395	1044
44	0	9	26	156	50·3	1820	−0·03	+28	1848	1335	513
44	1	8	27	156	51·5	2360	+0·10	−93	2267	1344	923
45	0	8	26	168	68·9	2170	−0·29	+269	2439	1545	894
47	0	8	23	168	63·5	2230	−0·08	+74	2304	1510	794
48	0	7	24	163	53·5	2670	−0·06	+56	2726	1400	1326
Mean		8·9	26·3	163·5	58·9	2125	−0·26	+239	2364	1435	929
Standard error		—	0·6	1·1	1·1	76	0·06	53	71	14	67

The weight gained during pregnancy and not lost rapidly during and after parturition is believed to consist mainly of fat (Hytten & Leitch, 1964) and it may be reasonable to assume that the weight lost by these subjects also consisted mainly of fat, with an energy value of 9300 kcal/kg. If so, the total amounts of available energy in Table 3 would be increased to 3088 and 2470 kcal, and the energy available for activity (and lactation) to 1658 and 1035 kcal, for the lactating and bottle-feeding groups, respectively. However, the estimate of energy available for lactation would be raised from 618 to 632 kcal only, a trivial change.

Basal metabolism. Similarly, the difference beween the two groups would be little affected by estimating expenditure on basal metabolism from other reference tables.

Table 3. *Average energy intakes and estimated energy expenditure of twenty-three lactating and thirty-two non-lactating women (from Tables* 1 *and* 2) *and the difference between them*

	Lactating (A) (kcal/d)	Bottle-feeding (B) (kcal/d)	Difference (A–B) (kcal/d)
Dietary energy	2716	2125	591
Subsidy from weight lost	261	239	22
Total energy available	2977	2364	613
Basal energy expenditure	1430	1435	5
Energy available, less basal	1547	929	618
Estimated energy value of breast milk	597	—	597

Activity. The two groups of mothers were living under similar domestic circumstances and gave the impression of having fairly similar average levels of physical activity. Though 26% of the lactating subjects had one or more other children to look after compared to 37·5% of the bottle-feeding subjects, there is no evidence in the results that energy intakes were influenced by the number of dependent children.

According to the activity grading, 22% (5) of the lactating and 9% (3) of the bottle-feeding mothers were in groups C and D (relatively low levels of activity). In the eleven lactating and twenty-six bottle-feeding subects who kept diaries, the average numbers of hours recorded in bed and sitting were closely similar. The average amounts of time up and about were therefore also similar, though the lactating group spent 1·1 h/d in 'more strenuous' activities compared with 1·4 h/d for the bottle-feeding group.

In our opinion, therefore, the hypothesis that activity levels in the two groups were similar is not unreasonable. But if it is assumed that the bottle-feeding group spent about 10% more energy on physical activity—say 100 kcal/d—recalculation of the values in Table 3 suggests that about 700 kcal/d were available to support lactation.

Energy output in breast milk. The values of Fomon *et al.* (1964) which we used to estimate the energy intakes of the babies were derived from babies which were being fed to appetite. Some of the babies in this series may have been taking slightly less, if the available breast-milk or other food was limited. On the other hand, all the babies were gaining weight satisfactorily and appeared to be healthy; the average rate of gain of the breast-fed babies was 233 (SD 49) g/week.

The mean daily energy intake of the breast-fed babies, calculated from Fomon's results, was 123 kcal/kg. The use of lower values widely accepted in the paediatric literature, 120 or 115 kcal/kg, would give mean daily intakes of 582 or 557 kcal for the energy value of the milk output.

DISCUSSION

As already noted, the values in Table 3 indicate that the average efficiency of human milk production is 97%. Calculating from the statistics in Tables 1 and 2, the 99% confidence limits of the estimate are from 64 to 129%. These are, of course, the limits specified by sampling variation, the underlying biological assumptions being unchanged.

We think it is more reasonable to assess the probable limits by determining the effect on the average of adopting the most extreme biological assumptions that can be regarded as plausible. If the energy value of the milk supply was as low as 557 kcal/d, and the energy available to sustain it was as high as 700 kcal/d, the efficiency of production would be about 80%. On the other hand, more moderate assumptions lead to an estimate of efficiency that is close to 100%. A tentative conclusion that energy in human milk is produced with an efficiency of about 90% agrees reasonably well with the evidence we reviewed a decade ago (Hytten & Thomson, 1961). It also agrees with the much earlier comment—and results—of Shukers, Macy, Nims, Donelson & Hunscher (1932) that three wet-nurses 'exhibited a high degree of efficiency in the transformation of food energy into milk'.

For a woman producing 500–600 kcal/d in milk, the provision of about 600 kcal/d (2·5 MJ) as available dietary energy should be adequate. If it can be assumed that mothers who are breast-feeding exhibit a reduced level of physical activity, the practical allowance (additional to that of a non-pregnant, non-lactating woman) may be a little lower.

There seems to be little doubt that the milk supply is usually subsidized to some extent from extra body fat which has been laid down during pregnancy. The loss of this extra fat—in most women after parturition, whether lactating or not—seems to be part of the natural cycle of adaptation to pregnancy, since parity has remarkably little additional influence on the usual tendency of body-weight to increase with age (Thomson & Billewicz, 1965).

The suggestion of the (USA) National Research Council: Food and Nutrition Board (1968), that lactation should involve the provision of an extra 1000 kcal (4·2 MJ) daily, 'or that amount compatible with maintenance of weight', seems to be excessive in practice and dubious in theory. The recent proposal of the Ministry of Health: Department of Health and Social Security (1969), that 'an additional daily intake of 500 kcal (2·1 MJ) seems adequate, both in relation to the physiological needs and to the food habits of lactating women', is more realistic.

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